FGDC-STD-018-2012

Coastal and Marine Ecological Classification Standard

Marine and Coastal Spatial Data Subcommittee
Federal Geographic Data Committee

June, 2012

CONTENTS

PAGE

FIGURE PAGE

TABLE PAGE

1. Introduction

The past 150 years have witnessed the steady improvement in society's ability to access and monitor the environment, observe systems in great detail over long periods of time, compile and analyze the resulting data, and display findings with great sophistication. In step with these developments, numerous approaches have been proposed for describing and classifying ecosystems and biological communities. In the United States, noteworthy strides have been made in establishing standards for terrestrial systems, *National Vegetation Classification Standard*, FGDC-STD-005-2008 (FGDC 2008), ecological systems (Comer et al. 2003), freshwater systems (Higgins et al. 2005), and wetlands, *Classification of Wetlands and Deepwater Habitats in the United States*, FGDC-STD-004 (FGDC 1996b), and formal or informal classification strategies have gained wide acceptance for each. No analogous consensus has emerged for estuarine, coastal, or open-ocean settings. This document is submitted to the U.S. Federal Geographic Data Committee (FGDC) to provide a key for translating between the myriad marine ecosystem and community classifications available today and offer a common path to unambiguous identifications in the future.

1.1 Objectives

The Coastal and Marine Ecological Classification Standard (CMECS)
is a catalog of terms that provides a means for classifying ecological units using a simple, standard format and common terminology (CMECS uses the term "unit" to refer to any defined entity in the standard at any level of the hierarchy; "units" include seagrass bed, sand, lagoon, and water mass). CMECS offers a way to organize and interpret data about the marine environment, and it provides a common platform for inter-relating data. It builds upon approaches from published national, regional, and local habitat classification procedures, and it offers an umbrella under which a national coastal and marine ecological classification can grow and evolve.

CMECS allows investigators to determine the types of data to be collected. Its structure accommodates data from multiple disciplines, and its use is not limited to specific gear types or to observations made at specific spatial or temporal resolutions.

Significant attention has been paid to assure that CMECS is compatible with relevant FGDC-endorsed national standards—FGDC-STD-004 (FGDC 1996b), FGDC-STD-005-2008 (FGDC 2008), and the *Metadata Profile for Shoreline Data*, FGDC-STD-001.2-2001 (FGDC 2001). This compatibility is intended to facilitate studies across the transition between terrestrial and coastal aquatic ecosystems. Section 1.5 of this document provides further discussion of the relationships between existing FGDC standards and CMECS.

The ultimate goal of CMECS is to facilitate assessment, monitoring, protection, restoration, and management of biotic assemblages, harvested and protected species, vital habitats, and important ecosystem components. Thus, CMECS enhances scientific understanding, advances ecosystem-based and place-based resource management, and safeguards coastal communities.

1.2 Need

The purpose of habitat classification is "to provide a language through which data and information regarding habitats can be communicated and managed" (McDougall, Janowicz, and Taylor 2007). At a time when the complexity and significance of marine resource issues are mounting, the need for additional habitat observations is growing, but the fiscal resources to address these needs are diminishing. Under such circumstances, it is imperative that existing and new data be used to their fullest extent. As a first step, there must be agreement on the identities of the ecosystems under study. Adoption of a national classification standard for coastal and marine ecosystems would be a major step toward this goal.

Many marine habitat classifications are available in the literature. Table 1.1 lists several representative, widely applied approaches. Unfortunately, none of these provide universal coverage and none are universally accepted. Classifications tend to focus on specific geographic regions, distinct biotic groups, characteristic environmental features, or limited portions of the seascape. The veracity or utility of these classifications for the purposes for which they were developed is not at issue, but their application for wider use has been problematical. Parks (2002) calls for a *lingua franca* for marine habitat classification in the face of this fractionation; CMECS aspires to meet this need.

1.3 Scope

The domain of CMECS encompasses waters from the head of tide or inland incursion of ocean salinity to the splash zone of the coasts to the deepest portions of the oceans and the deep waters of the Great Lakes. This domain includes all marine and coastal waters under U.S. jurisdiction for which no FGDC-endorsed classification standard currently exists.

CMECS addresses attached or suspended biota in the water column and on or in bottom sediments. Scale size ranges from colonies or aggregations of microscopic organisms to megafauna and megaflora. CMECS addresses the grain size and composition of marine substrates and major structural features of the environment (geoforms and hydroforms) to characterize coastal and marine ecosystems. These are discussed and presented in the context of the major marine Biogeographic Settings.

CMECS was developed primarily for application in the territorial waters of the United States (including the Exclusive Economic Zone); however, its architecture and underlying approach do not preclude application of the standard in other parts of the marine world.

Development of the units in this document has been focused on estuarine and marine systems. Many of the concepts and units are applicable to the Great Lakes but additional work is needed to develop a comprehensive list of units for this area.

Table 1.1. Modern Coastal, Marine, and Great Lakes Habitat Classifications. This list is not exhaustive; it references some of the more widely used approaches.

Reference	Name	Location
FGDC 1996b	*Classification of Wetlands and Deepwater Habitats in the United States*	U.S.
Dethier 1990	*A Marine and Estuarine Habitat Classification System for Washington State*	Washington
Madley, Sargent, and Sargent 2002	*Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida*	Florida
Resource Information Standards Committee 2002	*British Columbia Marine Ecological Classification: Marine Ecosections and Ecounits*, Version 2.0	British Columbia, Canada
Connor et al. 2004	*The National Marine Habitat Classification for Britain and Ireland*	Britain and Ireland
Davies et al. 2004	*EUNIS Habitat Classification*	Europe
Ministry of Fisheries and Department of Conservation 2008	*Marine Protected Areas: Classification, Protection Standard and Implementation Guidelines*	New Zealand
Commonwealth of Australia 2010	*National Marine Bioregionalization of Australia*	Australia

1.4 Application

Among the most fundamental questions asked by resource managers are:

- What resources are out there?
- Where are they located?
- How abundant are they?
- How are they doing?

The first question can be addressed using well-defined taxonomies (for species) or classifications (for communities and ecosystems), which provide comprehensive lists with definitions of potential resource units. The second and third questions can be answered by applying inventory, observation, and mapping techniques that enumerate and place the resource on the seascape. The fourth question requires condition assessment studies as well as status and trend monitoring.

While CMECS is relevant to all four questions, it speaks specifically to the first question. The remaining questions all require that a standard classification be in place before they can be answered efficiently. Section 12 of this document touches on aspects of the second and third questions in regards to using CMECS in data development and mapping. Specific implementation and mapping guidance will be offered in a companion document, which will be produced after the publication of CMECS. The companion document will include standards for sampling, inventorying, and mapping the ecological units described in CMECS. It also will address issues such as appropriate remote sensing technologies, map scales and minimum mapping units, recommended technology, timing and frequency of sampling, mapping conventions for "split" map classes, and best practices for addressing spatially and temporally variable units.

Issues pertaining to the fourth question (on habitat and resource quality) will be addressed in one or more subsequent documents. These will discuss methods for assessing and monitoring the ecological integrity and condition of the units defined in CMECS.

1.5 Relationship to Previous FGDC Standards

CMECS strives to accommodate all relevant data, to facilitate the use of historical data in combination with data from ongoing or future activities, and to be compatible with or complementary to applicable FGDC standards. Many refinements (discussed below) were made to align CMECS in this fashion.

At the highest level of the organization, CMECS adopts the terms *Marine System*, *Estuarine System*, and *Lacustrine System*; these corresponds to terms found in FGDC-STD-004 (FGDC 1996b), although some modifications were made the Estuarine System's boundaries. The CMECS Estuarine System extends upstream to the *head of tide* or to waters of salinity lower than 0.5, whichever is most inland. Downstream, the Estuarine System extends to an imaginary line closing the mouth of the river, bay, or sound at the seaward end of the estuary. *Head of tide* is identified in accordance with FGDC-STD-001.2-2001 (FGDC 2001):

> "The inland or upstream limit of water affected by the tide. For practical application in the tabulation for computation of tidal datums, head of tide is the inland or upstream point where the mean range becomes less than 0.2 foot. . ."

CMECS subsystems provide more delineation than those proposed in FGDC-STD-004 (FGDC 1996b), which permits the capture of significant ecological distinctions. For example, in FGDC-STD-004, *Tidal Riverine* is a subsystem of the Riverine System (non-tidal freshwater). However, since CMECS does not address Riverine System environments, *Tidal Riverine* is adopted to delineate subsystems of the CMECS Estuarine System. Tidal Riverine portions of an estuary include those areas where ocean-derived salts measure less than 0.5 during the period of average annual low flow, upriver to the head of tide, where the mean tidal range becomes less than 0.2 foot or 0.06 meters (FGDC 2001).

The CMECS Substrate Component (SC) is compatible with sediment-related elements of FGDC-STD-004 (FGDC 1996b). The *Soil Geographic Data Standard*, FGDC-STD-006 (FGDC 1997) is referenced in the SC for the benefit of investigators concerned with marine soils. Marine sediments traditionally have not been considered soils; hence, the SC follows the approaches of Wentworth (1922) to define sediment particle sizes and Folk (1954) to describe mixes.

Classes and subclasses of the Biotic Component (BC) are determined by the dominant biota (defined as most abundant in terms of percent cover) of the substrate. These closely track units identified in FGDC-STD-004 (FGDC 1996b), where the classifications coincide in domain, but refer to Appendix G for a comparison of departures from the earlier standard.

Some BC subclasses are equivalent to and provide good linkages with the formation, group, and association levels of FGDC-STD-005-2008 (FGDC 2008). A protocol for the addition of new biotic groups and biotopes is included in CMECS (Section 13). This protocol is modeled on the one proposed in FGDC-STD-005-008, and it also draws from the approach outlined in *Marine Habitat Classification for Britain and Ireland* (Connor et al. 2004).

1.6 Development Procedures

CMECS was developed based on literature review, expert opinion, field testing, and peer review. To date, CMECS is not based on quantitative analysis of new data, although analysis of field-collected, quantitative data across the range of coastal and marine environments is a long-term goal.

Development of the standard began in the late 1990s. Previous versions of CMECS (Madden and Grossman 2004; Madden, Grossman, and Goodin 2005; FGDC 2010) and a precursor classification framework (Allee et al. 2000) were developed with the assistance of over 100 coastal and marine habitat experts, who represented agencies of federal, state and local governments, academia, non-governmental organizations, and industry. Contributors included scientists from the United States, Canada, Australia, and several European countries. Expert input was collected via four major workshops and via extensive reviews by internal and external experts.

As CMECS matured, efforts were made to encourage pilot applications and comparisons (or crosswalks) with other classifications. Tests by scientists who were not directly involved in developing CMECS were of special interest. To date, applications across a variety of habitats in various parts of the United States have been undertaken. These applications confirmed the utility of CMECS and the basic soundness of the logic behind the standard. Outside the U.S., comparisons and trials of CMECS relative to local classifications have been done in Argentina, Australia, Canada, Chile, Denmark, Germany, Iran, Mexico, Norway, and Uruguay.

In mid-August 2010, a Federal Register announcement opened CMECS for a 120-day public comment period. Subsequently, the standard was peer reviewed by over a dozen scientists representing a broad range of geographic and technical expertise.

Revisions to CMECS, including evaluating and responding to comments from the public and peer reviews, were the work of over thirty scientists and managers drawn from federal and state governments, academia, and non-governmental organizations. Organizations represented in this group are listed in Table 1.2. The names and affiliations individuals who commented on or assisted with the final development of CMECS appear in Appendix J.

Table 1.2. Organizations Whose Personnel were Involved in Development of CMECS.

Type of Organization	Organization Name
U.S. Government	National Oceanic and Atmospheric Administration Environmental Protection Agency U.S. Geological Survey U.S. Fish and Wildlife Service National Park Service U.S. Army Corps of Engineers
State Government	Massachusetts Division of Marine Fisheries Texas Parks and Wildlife Department Oregon Coastal Management Program
Academia	Florida International University Texas A&M University University of Miami University of Rhode Island University of Southern Mississippi Virginia Institute of Marine Science

Type of Organization	Organization Name
Nongovernmental Organizations	NatureServe The Nature Conservancy

1.7 Guiding Principles

Five central premises directed the development and testing of CMECS.

1.7.1 Build a Scientifically Sound Ecological Classification

CMECS is based on the best available scientific knowledge about the relationships between the environment and the biota. Distinctions between units in CMECS were chosen specifically to reflect factors believed to shape biological communities. This is true for the Biotic Component (BC) as well as for the abiotic components.

Many of the common, pre-existing classification schemes were used to inform CMECS units. This process included drawing upon local or regional scientific studies to illustrate the specific environmental patterning of groups of units (e.g., local studies on lichen zonation [Fletcher 1973]), as well as considering comprehensive classifications developed for individual states and countries (see examples in Table 1.1). The intent of this effort was to take advantage of existing information and arrange it into a consistent, more broadly applicable framework. A common framework allows legacy datasets and new data to be incorporated into a single structure, which will ensure that existing scientific data and knowledge are preserved and available for future use.

1.7.2 Meet the Needs of a Wide Range of Users

The audience for CMECS includes coastal managers and planners, academic scientists, and educated lay users. Such users are drawn from a broad variety of backgrounds, including biology, geology, oceanography, applied mathematics, engineering, and mapping. CMECS is designed to meet the varied needs of this broad audience. It provides detailed units for those who require specific knowledge of the components, as well as more general units for those who need less specificity.

CMECS also is developed to address applications whose scales range from local to national to global. Most classification systems are keyed to regional or local applications. Their operational scales (meters to kilometers) reflect the scales at which state and local governments monitor and manage resources. Local and regional approaches do not readily support national comparisons across ecosystems, methods of observation, or analytical techniques. CMECS is designed to provide the specificity needed by local applications, while at the same time allowing aggregation and assessment across diverse systems at regional, national or global scales—without loss of utility at local levels.

CMECS is designed to operate at multiple spatial scales in order to allow users to address different objectives. For example, a federal management agency seeking to identify and catalog the benthic ecosystems of the large estuaries in North America may restrict its analysis to the upper three levels of the Biotic Component (BC). On the other hand, a local agency classifying ecosystems within a single estuary may want to use the lower two or three levels of the BC hierarchy. Using CMECS as a common standard, both agencies will be able to organize and compare results by applying a unified vocabulary within a common and interoperable data framework. The framework provides the end-user with the tools to build the bottom levels of ecosystems and biology into the larger conceptual framework.

1.7.3 Create a Comprehensive Internally Consistent Classification

CMECS provides a comprehensive approach to classify all recognized marine ecological units—similar to the Linnaean goal of classifying and describing all species on Earth (but without the aim of inferring evolutionary relationships). CMECS attempts to answer the question: What is out there? At the upper levels of each component, the lists of units—when completely elaborated—are intended to provide complete coverage of the biota, substrate features, geomorphic structures, aquatic features, and biogeographic influences that shape biological communities.

CMECS is not technology-constrained; units (especially lower-level units on the scale of meters) are not defined solely on what is identifiable from remote imagery or other currently available sensing technology. Likewise, CMECS is a classification of existing units—that is, those documented to exist in a given place at a given time. Therefore, CMECS is not constrained to units that are spatially or temporally static. Units that vary in time and space (such as phytoplankton blooms) provide a mapping challenge. However, they are classified and described in CMECS because they represent recognizable, consistently repeating ecological units that are of conservation and management value.

CMECS also strives to be internally consistent. As a rule, CMECS employs comparable concepts and classifiers at analogous levels within a component to the extent practical.

CMECS units are intended to be unique and non-duplicative. Every effort was made to define thresholds between units to avoid conceptual overlap and so that units can be unambiguously applied.

Clearly documented terminology is essential to a comprehensive and internally consistent standard. Each CMECS unit is defined in the sections for the individual components, and boundaries and thresholds between are identified.

1.7.4 Meet Mapping Needs

Although CMECS units are not defined on the basis of "map-ability," mapping is a primary application of the system. Each classification unit represents a measurable space, and it can be ascribed to a specific place with defined geographic boundaries. The ability to map each classification unit has been considered in the process of defining the unit, and ease of mapping application was accommodated wherever possible. Because current mapping technology is limited in the details that can be interpreted, ground-based data collection will be required for identifying and mapping many lower-level features.

1.7.5 Create a Flexible Classification

Having a broad audience of users requires that CMECS be flexible enough to meet a variety of needs. CMECS is designed with multiple components to allow users to select the components that most effectively describe the ecological units under observation. Within individual components, users apply CMECS at the level of specificity that best meets their circumstances.

Users specializing in one aspect of CMECS or in or local applications of the standard may be interested in tracking a finer level of detail than is offered by the standard catalogue of types. Two options are available, one or both of which may be used. CMECS includes a standard list of modifiers that allow users to further parse standard features according to qualities such as energy, turbidity, or characteristic structural components. This provides flexibility to local and specialized users. Modifiers are intended for broad application and add detail at all levels of the classification. The second option is to introduce finer, non-standard levels of classification beyond the lowest tiers of the CMECS components.

Though CMECS provides clear thresholds for the boundaries between the units, some users applying CMECS may be interested in capturing information on additional characteristics of a unit that fall outside of the threshold. For example, a given area on the bottom might be classified according to CMECS as a seagrass bed, because of the area is dominated by a given seagrass species. However, that same area also may contain a moderate (but not dominant) cover of soft corals that are of interest to the user. CMECS enables users to classify the unit as a seagrass bed, while also cataloging the soft corals as a Co-occurring Element. This flexibility allows consistent application of the standard, while meeting the individual needs of the practitioner. See Section 10 for a discussion of this methodology.

The nature of scientific inquiry is that understanding improves over time. CMECS is a dynamic content standard and offers the flexibility to add or refine units based on new information through a moderated, peer-reviewed, transparent process. See Section 13 for a discussion of CMECS as a dynamic content standard.

1.8 Maintenance Authority

The National Oceanic and Atmospheric Administration (NOAA) was assigned responsibility to coordinate, manage, and disseminate marine and coastal spatial data under the policy guidance and oversight of the FGDC. CMECS was developed under the authority of the Office of Management and Budget Circular A-16 (OMB 2002). Through the Marine and Coastal Spatial Data Subcommittee, NOAA will oversee the maintenance and updating of the Standard through periodic review. In addition, NOAA will oversee the maintenance, updating, dissemination, and implementation of CMECS, based on this Standard, in collaboration with member agencies, professional societies, and other organizations. Future revision of this Standard shall follow the standards development process described in the FGDC Standards Reference Model (FGDC 1996a). The dynamic content of the CMECS shall be updated under the direction of a national review board authorized by NOAA through the Subcommittee. For more information about the Marine and Coastal Spatial Data Subcommittee or the review board, please contact:

NOAA Coastal Services Center
Attn: FGDC Marine and Coastal Spatial Data Subcommittee
2234 South Hobson Avenue
Charleston, SC 29405-2413

2. Overall Structure

CMECS characterizes marine and coastal environments in terms of two settings and four components (Figure 2.1). Settings offer alternate but complementary approaches for partitioning the marine and coastal world. Components provide specific tools for describing observation (sampling) sites. Settings are applicable to all components.

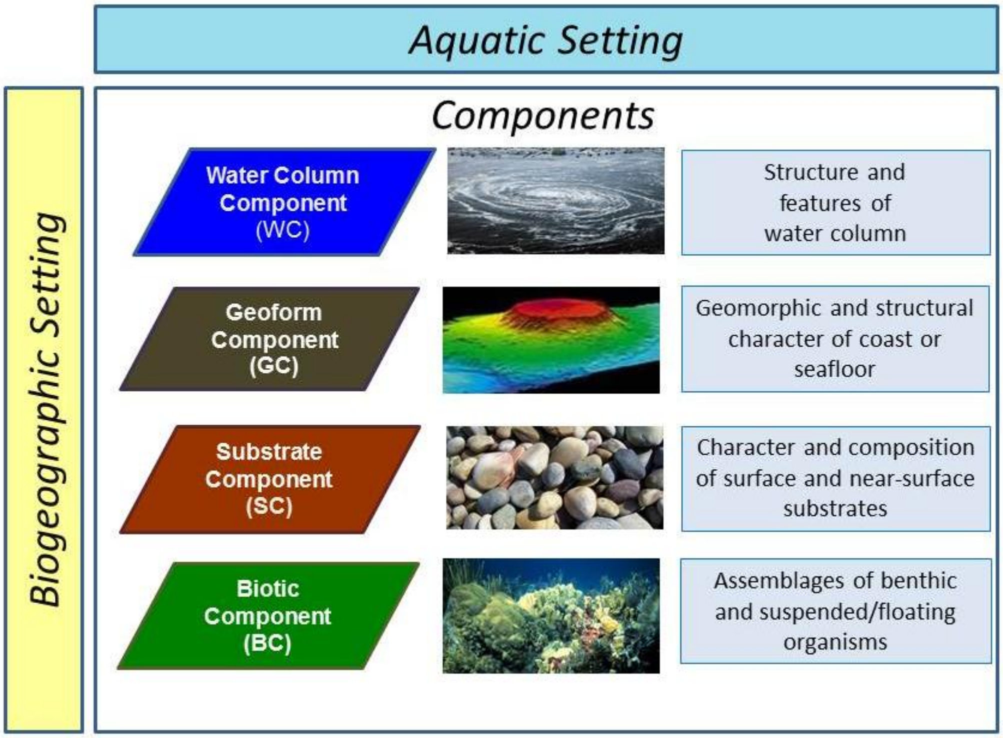

Figure 2.1. CMECS Settings and Components.

CMECS users may employ one or both settings and one or more components to classify environmental units, depending on their interests, observation methods, and objectives. Introductory overviews of CMECS settings and components are provided below.

2.1 Settings

CMECS provides two broad based, complementary settings within which to partition the coastal and marine world—the Biogeographic Setting (BS) and the Aquatic Setting (AS). These may be used independently or together. Each setting is described briefly below; more complete accounts are presented in Sections 3 and 4.

2.1.1 Biogeographic Setting (BS)

The BS identifies ecological units based on species aggregations and features influencing the distribution of organisms. Coastal and marine waters are organized into regional hierarchies composed of realms (largest), provinces and ecoregions (smallest).

CMECS adopts the approach described by Spalding et al. (2007) in *Marine Ecosystems of the World* (MEOW) to characterize Biogeographic Settings occurring in the Estuarine System and in the Marine Nearshore and Marine Offshore Subsystems. MEOW is worldwide in coverage and identifies five realms, eight provinces, and 24 ecoregions in U.S. waters (Appendix A). Representative units include the Gulf of Maine/Bay of Fundy, Carolinian, and Southern California Bight ecoregions.

Biogeographic Settings for the CMECS Oceanic Subsystem are defined in the *Global Open Ocean and Deep Seabed (GOODS) Biogeographic Classification* (UNESCO 2009). As in MEOW, hierarchies composed of regions, provinces, and ecoregions are identified, but separate suites of terms are applied to benthic and water column habitats. Additional information about the BS is provided in Section 3.

2.1.2 Aquatic Setting (AS)

CMECS also divides the coastal and marine environment into three Systems: Marine, Estuarine, and Lacustrine. These conform to those described in the *Classification of Wetlands and Deepwater Habitats in the United States*, FGDC-STD-004 (FGDC 1996b). Secondary and tertiary layers of the Aquatic Setting describe Subsystems (e.g., Nearshore, Offshore, and Oceanic within the Marine System) and Tidal Zones within the Estuarine System and Marine Nearshore Subsystem. See Section 4 for a more comprehensive treatment of the aquatic setting.

2.2 Components

CMECS is organized into four components to record and define the attributes of environmental units and biota within each setting--the Water Column Component (WC), the Geoform Component (GC), the Substrate Component (SC), and the Biotic Component (BC) (Figure 2.1). Each component is a stand-alone construct that can be used on its own or in combination with other components or settings. CMECS components include a variety of modifiers to enhance the specificity and detail of resulting descriptions and classifications.

Units within the BC and SC are organized into traditional hierarchical frameworks; however, this is not the case for the WC and the GC. Units within each of the latter overlap significantly in nature and do not lend themselves to hierarchies. CMECS organizes the WC and GC into subcomponents that may be used on their own or in combination (Table 2.1)

In-depth descriptions of CMECS components are provided in Sections 5-8. Brief synopses of each, with examples, are presented below as an introduction.

Table 2.1. CMECS Settings and Components. AS, BS, BC, and SC are internally hierarchical**.** WC and GC include non-hierarchical subcomponents.

Biogeographic Setting (BS)	Aquatic Setting (AS)	Water Column Component (WC)	Geoform Component (GC)	Substrate Component (SC)	Biotic Component (BC)
		Layer Subcomponent	**Tectonic Setting Subcomponent**	*Substrate Origin* *Substrate Class* *Substrate Subclass* *Substrate Group* *Substrate Subgroup*	*Biotic Setting* *Biotic Class* *Biotic Subclass* *Biotic Group* *Biotic Community*
		Salinity Subcomponent	**Physiographic Setting Subcomponent**		
Realm *Province* *Ecoregion*	*System* *Subsystem* *Tidal Zone*	**Temperature Subcomponent**	**Level 1 Geoform Subcomponent** *Geoform Origin* *Level 1 Geoform* *Level 1 Geoform Type*		
		Hydroform Subcomponent *Hydroform Class* *Hydroform* *Hydroform Type*	**Level 2 Geoform Subcomponent** *Geoform Origin* *Level 2 Geoform* *Level 2 Geoform Type*		
		Biogeochemical Feature Subcomponent			

2.2.1 Water Column Component (WC)

The WC represents a new approach to the ecological classification of open water settings. The component describes the water column in terms of vertical layering, water temperature and salinity conditions, hydroforms, and biogeochemical features. Modifiers allow users to further subdivide water column units. Representative units include “cold, oligohaline estuarine open water surface layer” and “warm marine offshore western boundary current oceanic epipelagic upper layer.” See Section 5 for more details.

2.2.2 Geoform Component (GC)

The GC describes the major geomorphic and structural characteristics of the coast and seafloor. This component is divided into four subcomponents that describe tectonic and physiographic settings and two levels of geoform elements that include geological, biogenic, and anthropogenic geoform features. Representative units include lagoon, ledge, tidal channel/creek, and moraine. See Section 6 for more details.

2.2.3 Substrate Component (SC)

The SC describes the composition and size of estuary bottom and sea bed materials in all CMECS systems. This component is hierarchical and encompasses substrates of geologic, biogenic, and anthropogenic origin. Particle size classes conform to those developed by Wentworth (1922) and substrate mixes conform to the standard described by Folk (1954). Representative units include sandy mud, coral sand, and construction rubble. See Section 7 for more details.

2.2.4 Biotic Component (BC)

The BC is a hierarchical classification that identifies (a) the composition of floating and suspended biota and (b) the biological composition of coastal and marine benthos. Representative units include *Sargassum* raft, jellyfish aggregation, *Oculina* reef, *Crassostrea* bed, and *Rhizophora mangle* fringe forest. Units are compatible with terms used in FGDC-STD-004 (FGDC 1996b) and FGDC-STD-005-2008 (FGDC 2008). See Section 8 for more details.

2.3 Biotopes

A biotope is defined as the combination of abiotic features and associated species (Connor et al., 2003). Using CMECS, biotopes can be derived by identifying repeating BC biotic communities that are consistently associated with combinations of environmental units from any of the other CMECS settings or components (Figure 2.2). While individual biotope units have not been defined yet, users can begin to define and describe biotopes as they apply CMECS. As knowledge of biotopes increases, biotope units and descriptions will be added to CMECS. See Section 9 for more details.

2.4 Modifiers

CMECS incorporates a list of standard modifiers—a consistent set of characteristics and definitions— as part of each component to describe the nature and extent of observed variability within ecological units (Figure 2.2). Modifiers allow users to customize the application of the classification in a standardized manner. See Section 10 for more details.

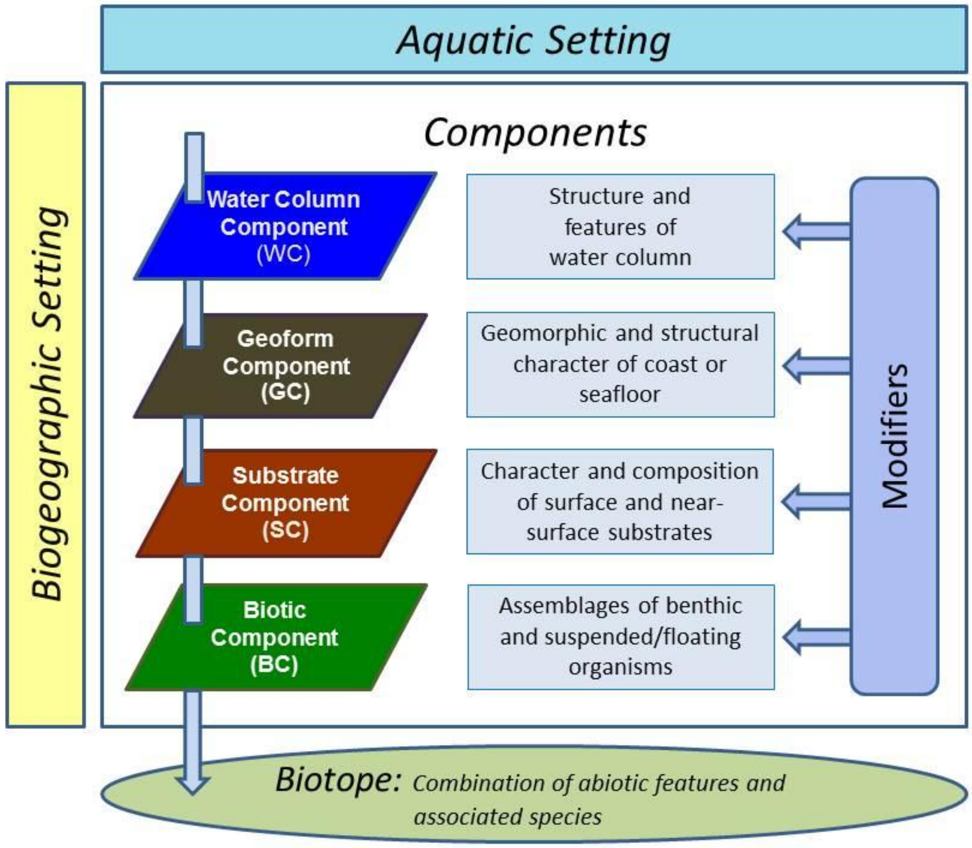

Figure 2.2. Relationship between CMECS Settings, Components, Modifiers and Biotopes.

2.5 Using the Components

Each CMECS component is autonomous (i.e., designed to be classified and mapped independently of the others), but components can be combined as necessary, depending on application. This is analogous to combining information from independent land cover, landform, and soil classifications (in terrestrial classifications) to describe specific locations on land.

For example, a CMECS user requiring an inventory of seagrass distribution might categorize and map biological units using the BC to arrive at estimates of total seagrass acreage or coverage by a single species. Users interested in mapping benthic cover by conventional means (i.e., via downward-looking sensors) would use the SC and the BC together. However, users concerned with the global distribution of seamounts would focus on the GC instead. Those users with interest in the zonation of biotic communities on seamounts might overlay the BC on the GC, to provide insight into how patterns in the biology vary with geologic structure.

CMECS allows users to examine relationships between biotic and abiotic features and processes in different ecological units at comparable scales. This can be done qualitatively (using the scales implied within the components) and quantitatively (either by creating maps of ecological units or by using spatial and temporal modifiers).

The aim of modifiers is to better characterize relationships among multi-scale quantitative ecological data, natural variability, and human influence in order to provide the best information for effective management and assessment of these ecosystems (Guarinello, Shumchenia, and King 2010). For example, spatial modifiers help relate the geographic extent of features to one another—especially when mapping or geographic information system (GIS) tools are not a part of the classification effort. Temporal modifiers help distinguish features based on expected temporal persistence or variability.

While the natural inclination of many users may be to apply CMECS from the "top-down"—from the broadest elements of the classification to increasingly narrow (i.e., more precise) elements—the system works equally well when applied from the "bottom-up." Such analyses may involve one or more components and permit examinations such as those evaluating factors influencing the occurrence or success/failure of biotic assemblages in space and time.

The CMECS components enable the development of sophisticated analyses of physical, chemical, and biological information—and they permit users to explore complex ecological interactions. The application and combination of components is further discussed in Section 12.

2.6 Ecological Foundation

The goal of CMECS is matching specific aspects of the physical environment—defined in ecological units—to organisms and biological associations that use the environment. Physical, geological, and chemical characteristics of the environment interact with the requirements and behaviors of organisms to create the patterns of life observed in benthic and water column settings. In turn, patterns of environmental stresses and drivers, resource utilization, nutrient transformation, reproduction, population dynamics, and community structure reflect the availability of habitat in time and space (Cushing 1990). Many of these processes are not uniformly applicable across all aspects of CMECS, and some may conflict at different scales. The multiple-component structure of CMECS is designed to accommodate for both of these concerns.

CMECS addresses the full range of natural processes—from short to long timescales. Drivers of ecological interactions operate at specific frequencies to which the biota is matched (Ulanowicz 1996), and life cycles and behavior are tuned to temporal and resource patterns to optimize resource use, survival, and recruitment. Multiple scales of energy, temperature, light, and resource sufficiency are captured in the CMECS structure. Many processes are hierarchical, in that a larger-scale process drives or influences smaller-scale, internal processes. Identifying those drivers that organize the geo-physical environment (and the organisms that inhabit it) is a significant challenge facing CMECS (Pahl-Wostl and Ulanowicz 1993).

2.6.1 Temporal and Spatial Variation

Units that experience change over time can be described by repeated assessment. Individual CMECS characterizations represent snapshots of the state of ecosystem units at given points in time. Temporal variability or change may be examined by comparing time series of individual characterizations. In the same way that animation achieves a sense of movement by juxtaposing a succession of individual illustrations, studying multiple, successive characterizations of CMECS ecological units demonstrates the nature and rate of changes occurring on (or within) a unit of substrate or the water column. Because analytical contexts are determined by the observer—and are dictated in part by the scope of the available data and the nature of analytical techniques at hand, CMECS may be considered temporally neutral, accommodating with equal facility variation ranging from short term (fractions of seconds to hours) to long term (years to centuries).

The wide range of spatial and temporal scales in marine and coastal systems is a challenge for ecological classification, because measuring tools capture only portions of the space-time continuum. CMECS integrates components of large- and small-scale geologic, biotic, water column, and sediment-related processes within a common hierarchical framework. Analyses of species-environment relationships can be structured to use time, spatial replication, or spatial contrast as the basis for experimentation and hypothesis testing (Murawski et al. 2010). Because spatial and temporal scales are linked, complex ecosystems can be deconstructed and understood in space and time simultaneously (Wu 1999). A further discussion of time and space considerations in the context of CMECS is presented in Section 11.

2.6.2 Nature of CMECS Units

CMECS provides a standardized framework for naming ecological units in coastal and marine settings. Units are conceptual and circumscribed by defined conceptual boundaries based on consensus best professional judgment and observations by the community of practice. Unit definitions include a limited degree of variation consistent with what is observed in nature across the range of occurrence. Ideally, over time, the conceptual boundaries that delimit CMECS units will be based on analysis of data collected across the range of each unit.

Assemblages classified by CMECS as ecological units occur multiple times in nature. Contrary to animal and plant taxonomy where a species may be described on the basis of a single specimen, CMECS units reflect recurring observations in space and time. Similarly, the occurrence of a single specimen with a unit of the ecosystem is insufficient to characterize that unit. Evidence of an aggregation or assemblage that repeats on the seafloor (or in the water column), the presence of dominant or representative species, or the occurrence of characteristic geological, chemical, or physical attributes is required before units can be classified. A photo of a single sea cucumber is insufficient to characterize a holothurian biotic community.

CMECS provides a systematic approach for classifying continuously-varying, multidimensional assemblages. Ecological units often span physical, chemical, or geological gradients in space or time; the units may transition gradually or sharply, depending on the abruptness of the determining feature (Gleason 1926; Curtis 1959; Whittaker 1962). Classification frameworks impose boundaries across gradients to define units, under the assumption it is reasonable and useful to separate a continuum into meaningful units (Whittaker 1975; McIntosh 1993). Units based on “natural breaks” generally are more easily applied and are of greater utility.

In cases where no discontinuities occur and there is strong reason to favor differentiation, boundaries may reflect consensus professional opinion about meaningful breakpoints or non-environmental realities such as analytical or measurement limitations. CMECS provides a systematic approach for classifying continuously-varying, multi-dimensional assemblages. As a result, CMECS units are largely homogeneous in composition or structure, recognizing limited natural variability or a limitation in an analytical approach’s ability to discern differences within a unit.

CMECS units are spatial tessellations, defined on the basis of attributes observed in specific areas of the seafloor (as viewed from above) or specific segments of the water column (in three-dimensional space). As such, definitions of benthic BC units generally note that the area is dominated by a particular organism, to indicate the units are representations of the organisms on a specific area of the bottom. For each component, one patch of seafloor (or one segment of the water column) corresponds to one CMECS unit.

CMECS units are not constrained to specific observational approaches (e.g., satellite imagery, benthic grab samples) or specific sample areas or volumes (e.g., 1- meter square quadrats). CMECS units are scale-independent; they can be fitted to the requirements of individual studies.

CMECS encompasses both natural and anthropogenic features. Humans impact the seascape for good and for bad; these influences shape the seafloor and affect conditions in the water column. The inclusion of anthropogenic features within CMECS allows the classification of all environmental components presently found in nature.

3. Biogeographic Setting

The composition and characteristics of biological communities vary with latitude and longitude and are functions of factors including climate, geological setting and evolutionary history. Variation across time and space of elements such as temperature, insulation, water and food availability, degree of isolation, and presence of suitable habitat affect the abundance, activity, reproductive capacity, and ecological competitiveness of individual species. This, in turn, produces changes in species dominance, food-web complexity, and the functioning of regional and local ecosystems.

Over the past century and a half, considerable effort has been invested in describing and deciphering the factors responsible for observed geographic patterns in animal and plant community distributions. Notable successes have been achieved for terrestrial and freshwater settings (Bailey et al. 1994, Omernik 1995, Keys et al. 1995, EPA 2001, Cleland et al. 2005, Abell et al. 2008), and valuable regional and local characterizations have been produced for estuarine and nearshore coastal settings. However, comprehensive national and international biogeographic assessments for marine systems have been lacking until recently (e.g., see Wilkinson et al. 2009, pp. 5-7). CMECS draws from some of the most recent publications and divides the Biogeographic Setting into three hierarchical categories (Table 3.1).

Table 3.1. Biogeographic Setting Classification Structure.

Biogeographic Setting
Realm
Province
Ecoregion

3.1 Biogeographic Units--Estuarine System and Marine Nearshore and Offshore Subsystems

In 2007, Spalding et al. proposed a new approach for characterizing bioregions of marine coastal and shelf environments. The *Marine Ecoregions of the World* (MEOW) technique affords global coverage and creates a nested, three-tiered system of realms, provinces, and ecoregions (moving from larger-scale to smaller-scale units). The classification builds upon existing global and regional literature, and the classification has achieved significant acceptance—especially within the international community. Water column and benthic environments are addressed in the classification, and it deals with all waters under U.S. jurisdiction, including those adjacent to U.S. commonwealths and territories. CMECS proposes to use the MEOW realms, provinces, and ecoregions for describing biogeographic elements of the Estuarine System and the Marine Nearshore and Offshore Subsystems. The following definitions of these descriptors are from page 575 (Spalding et al. 2007):

- **Realms:** "Very large regions of coastal, benthic, or pelagic ocean across which biota are internally coherent at higher taxonomic levels, as a result of a shared and unique evolutionary history. Realms have high levels of endemism, including unique taxa at generic and family levels in some groups. Driving factors behind the development of such unique biota include water temperature, historical and broad scale isolation, and the proximity of the benthos." Examples include Arctic, Temperate Northern Pacific, and Tropical Atlantic.

- **Provinces:** "Large areas defined by the presence of distinct biota that have at least some cohesion over evolutionary time frames. Provinces will hold some level of endemism, principally at the level of species. Although historical isolation will play a role, many of these distinct biota have arisen as a result of distinctive abiotic features that circumscribe their boundaries. These may include geomorphological features (isolated island and shelf systems, semi-enclosed seas); hydrographic features (currents, upwellings, ice dynamics); or geochemical influences (broadest-scale elements of nutrient supply and salinity)." Examples include Cold Temperate Northeast Pacific, Tropical Northwestern Atlantic, and Cold Temperate Northeast Pacific.

- **Ecoregions:** "Areas of relatively homogeneous species composition, clearly distinct from adjacent systems. The species composition is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the eco-regions vary from location to location but may include isolation, upwelling, nutrient inputs, freshwater influx, temperature regimes, ice regimes, exposure, sediments, currents, and bathymetric or coastal complexity." Examples include Virginian, Northern Californian, and Eastern Caribbean.

Figure 3.1 illustrates the global distribution of MEOW realms, provinces, and ecoregions. Appendix B lists the MEOW units impinging upon U.S. waters.

3.2 Biogeographic Units--Marine Oceanic Subsystem

MEOW coverage does not extend much beyond the edge of the U.S. Exclusive Economic Zone (Spalding et al. 1997). However, the principles guiding the MEOW approach were applied to oceanic benthic and water column settings and published as the *Global Open Oceans and Deep Seabed Biogeographic Classification* (GOODS) by scientists working under the aegis of UNESCO (United Nations Educational, Scientific and Cultural Organization)(UNESCO 2009).

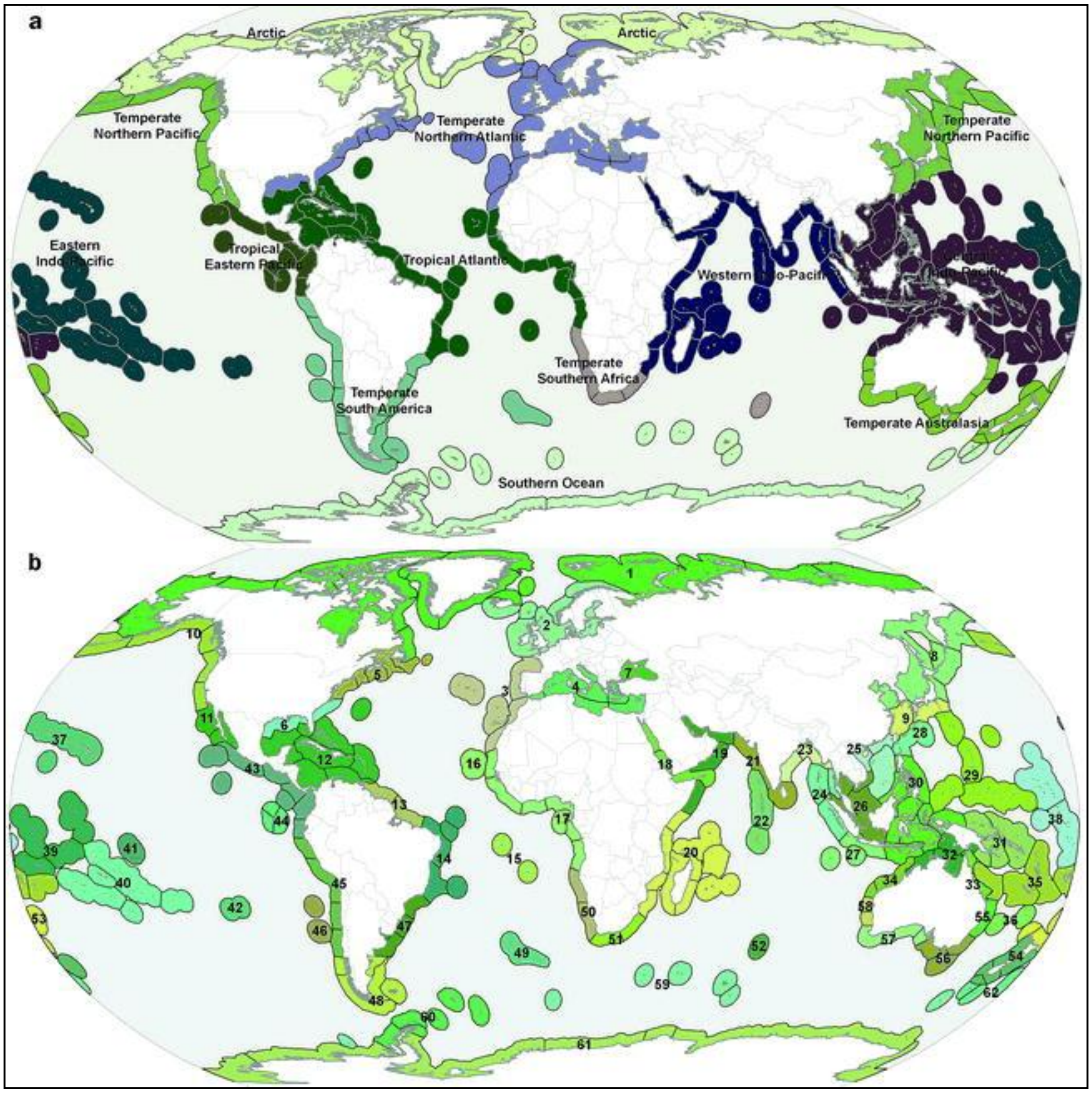

Figure 3.1. MEOW Realms, Provinces, and Ecoregions.
At top (a), biogeographic realms with ecoregion boundaries outlined; *at bottom (b)*, provinces with ecoregions outlined (from Spalding et al. 2007, 577).

As in MEOW, GOODS partitions the marine system into realms, provinces, and ecoregions; however, separate units are defined for benthic and water column settings. Figure 3.2 illustrates the pelagic provinces proposed in GOODS, and Figures 3.3 and 3.4 depict the lower bathyl and abyssal provinces identified in GOODS. GOODS remains under development and refinements are expected over time. However, the biogeographic units are sufficiently well-defined for application as part of the CMECS Biogeographic Settings.

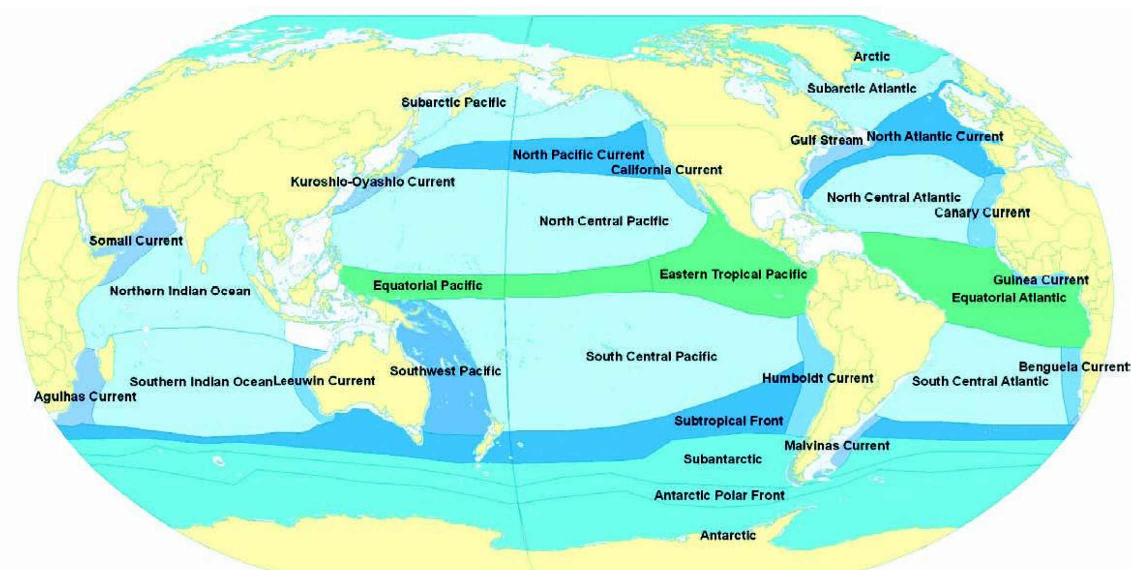

Figure 3.2. Pelagic Biogeographic Provinces Identified in GOODS
(UNESCO 2009).

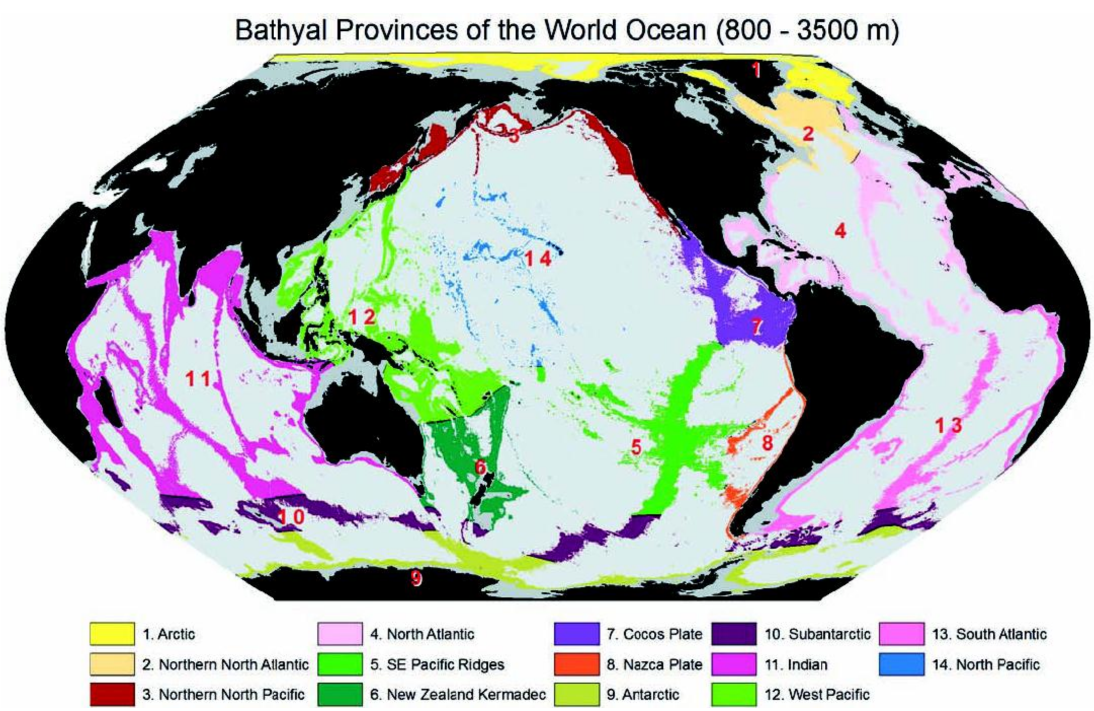

Figure 3.3. Lower Bathyl Benthic Biogeographic Provinces Proposed in GOODS
(UNESCO 2009).

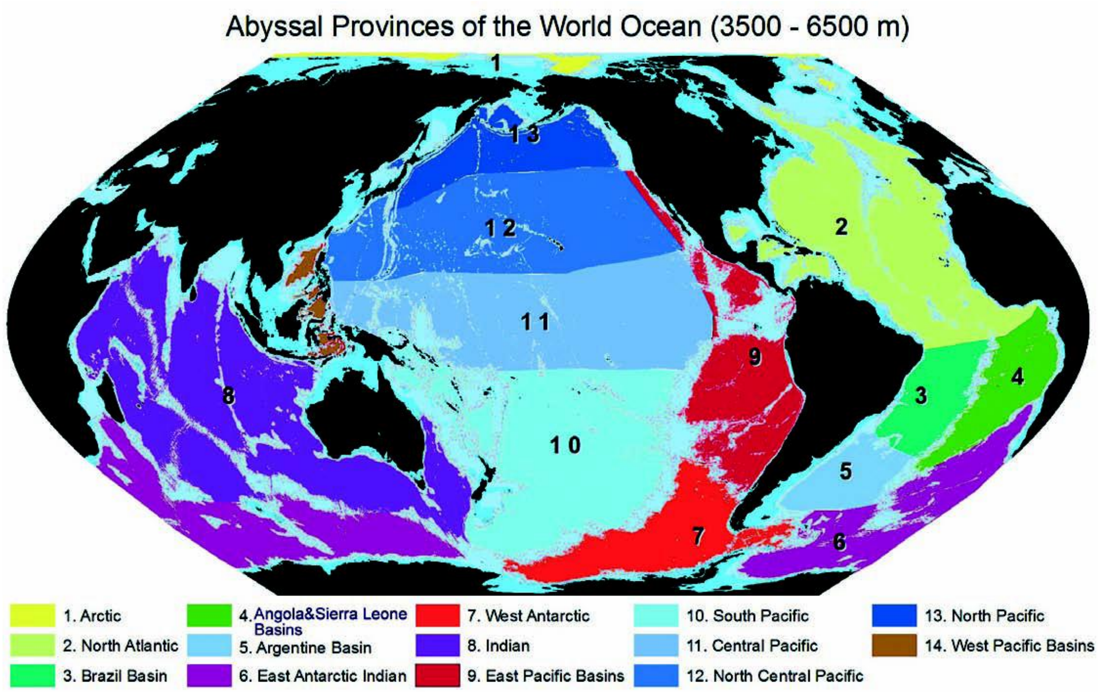

Figure 3.4. Abyssal Benthic Biogeographic Provinces Proposed in GOODS (UNESCO 2009).

3.3 Biogeographic Units--Lacustrine System (Great Lakes)

MEOW does not extend inland to include freshwater systems; however, a rich heritage of biogeographic study exists for the Great Lakes. CMECS proposes the approach taken by Abell et al. (2008) as an interim means for defining biogeographic units in the Great Lakes. A more definitive treatment of biogeographic units for the Great Lakes will be developed under the dynamic standard provisions of CMECS.

4. Aquatic Setting

The Aquatic Setting (AS) is comprised of three hierarchical levels (System, Subsystem and Tidal Zone) and provides the context for all CMECS components. It distinguishes oceans, estuaries and lakes, deep and shallow waters and submerged and intertidal environments within which more refined classification of geological, physicochemical, and biological information can be organized.

Table 4.1. Aquatic Setting Classification Structure.

Aquatic Setting
System
Subsystem
Tidal Zone

4.1 Aquatic Setting Hierarchical Structure

4.1.1 System

The CMECS Systems—Lacustrine, Estuarine, and Marine—are based on salinity and geomorphological characteristics of the setting. System (as defined in CMECS) is equivalent in concept to system as defined in *Classification of Wetlands and Deepwater Habitats in the United States*, FGDC-STD-004 (FGDC 1996b). The definition and units of the Lacustrine System are similar to the analogous system of FGDC-STD-004. The Great Lakes are classified as a Lacustrine System in CMECS and coincide with the definitions and concepts of FGDC-STD-004. The Estuarine System has basic similarity with FGDC-STD-004, but includes the tidal freshwater portion of the Riverine System as defined in FGDC-STD-004. This is done to unify the tidal fresh and low-salinity portions of estuaries within the CMECS Estuarine System umbrella. The Marine System has been elaborated significantly in CMECS, to include the ocean environments and habitats.

4.1.2 Subsystem

Each system is divided into subsystems based on depth and position relative to the shoreline. Lacustrine Systems include the Subsystems Littoral and Limnetic, conforming, respectively to shoreline and deepwater habitats. The Estuarine System has four Subsystems: Coastal, Open Water, Tidal Riverine Coastal and Tidal Riverine Open Water. The Marine System is comprised of three Subsystems: Nearshore, Offshore, and Oceanic, distinguished by total water depth.

4.1.3 Tidal Zone

Tidal zone is an important determinant of biological and abiotic processes in the environment. Habitats in the littoral zone support life forms that can tolerate the sometimes highly energetic physical processes of tide, wave and current action. Biota in these areas are also subjected to alternate submergence and drying/desiccation. Temperatures in littoral and intertidal habitats are more extreme than in the buffered subaqueous environment, and excessive light and radiant energy can present a challenge for some biota. Evaporation, drying and concentration of salts creates sometimes harsh conditions for vegetation and fauna at the land-sea margin and the high energy of coastal situations increases erosional depositional forces.

Subtidal environments are presented with a different set of challenges in that oxygen, light, nutrients and temperature are often reduced with respect to biological requirements and species and communities have developed characteristic strategies to optimize access to resources in these environments. In CMECS each Subsystem in the Estuarine and Marine System is distinguished by tidal zone (Figure 4.1).

4.2 Aquatic Setting Units

4.2.1 Lacustrine System

The CMECS Lacustrine System includes (a) all deepwater areas of the Great Lakes and (b) shoreline areas of the Great Lakes with less than 30 percent areal coverage by trees, shrubs, and persistent emergents. In areas with a greater percentage of vegetative cover, the appropriate Palustrine FGDC-STD-004 should be used for classification. Where a river enters or leaves a lake, the extension of the lacustrine shoreline forms the riverine-lacustrine boundary.

- **Subsystem: Lacustrine Littoral –** The Littoral Subsystem includes shallow habitats in the Lacustrine System. The shoreward boundary of this subsystem extends to the landward limit of non-persistent emergents. The lakeward boundary includes all waters to a depth of 2 meters below Mean Lower Low Water (MLLW), or to the maximum extent of non-persistent emergents, whichever depth is greater.

- **Subsystem: Lacustrine Limnetic –** The Limnetic Subsystem includes all deepwater habitats within the Lacustrine System. “Deepwater habitats” are those that occur at depths greater than 2 meters below MLLW—unless there are non-persistent emergents in those areas. In which case, “deepwater habits” are those beyond the limit of occurrence of non-persistent emergents.

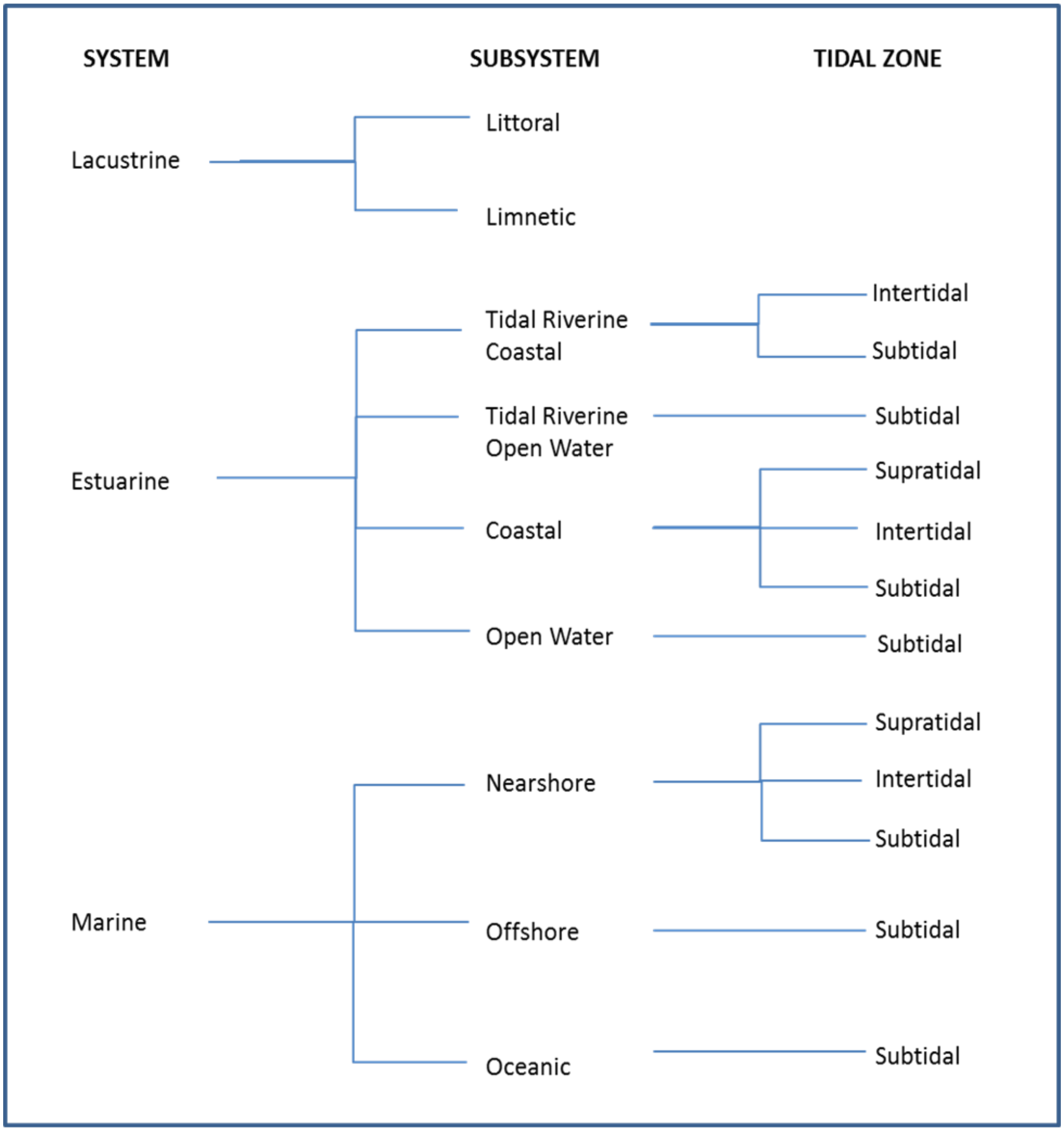

Figure 4.1. Aquatic Setting Hierarchy Showing System, Subsystem and Tidal Zone.

4.2.2 Estuarine System

The Estuarine System is defined by salinity and geomorphology. This System includes tidally influenced waters that (a) have an open-surface connection to the sea, (b) are regularly diluted by freshwater runoff from land, and (c) exhibit some degree of land enclosure.

The Estuarine System extends upstream to the head of tide and seaward to the mouth of the estuary. Head of tide is identified in accordance with the *Metadata Profile for Shoreline Data*, FGDC-STD-001.2-2001 (FGDC 2001) as the inland or upstream limit of water affected by a tide of at least 0.2 foot (0.06 meter) amplitude. The mouth of the estuary is defined by an imaginary line connecting the seaward-most points of land that enclose the estuarine water mass at MLLW. Islands are included as headlands if they contribute significantly to the enclosure.

Estuaries occur on continents or on islands and include waters of any depth. In CMECS they are defined as waters bounded by significant enclosure by land, having a direct connection to the sea and receiving measurable freshwater input to some part of the enclosed system during an average year. Salinity, a dimensionless conductivity ratio as measured on the practical salinity scale (PSS), was established by the IAPSO (International Association for the Physical Sciences of the Oceans) in 1978 (UNESCO 1981), and is of prime importance in distinguishing freshwater from saline estuarine environments and differentiating among estuarine and marine environments of differing salinity. The range of salinity considered in the CMECS classification extends from zero to hyperhaline (>40). Oceanic salinities normally encountered throughout the world range from 30-40 on the PSS scale. Highly saline negative estuaries such as Laguna Madre and Florida Bay may experience salinity as high as 70-80. Extreme environments like the Dead Sea have salinity near 300.

The tidally influenced part of the estuary may occur in a fresh reach where salinity is <0.5. According to FGDC-STD-004, this area would be classified within the Riverine System. However in CMECS, the Tidal Riverine area is considered to be an integral part of the ecology of the estuarine ecosystem, so it is classified within the Estuarine System instead.

The Estuarine System has four subsystems: Coastal, Open Water, Tidal Riverine Coastal, and Tidal Riverine Open Water.

- **Subsystem: Estuarine Coastal –** The Estuarine Coastal Subsystem extends from the supratidal zone at the land margin up to the 4 meter depth contour in waters that have salinity greater than 0.5 (during the period of average annual low flow). The Estuarine Coastal Subsystem would be considered the shallow perimeter in a deeper estuary, although many estuaries may be entirely less than 4 meters deep and be classified as completely in the Coastal Subsystem. The 4 meter contour was selected as a cutoff between "coastal" and "offshore" estuarine waters because it identifies (somewhat arbitrarily) a region that is both shallow and generally in close proximity to the shore, making the substrate-to-water volume ratio here the highest in the entire estuary. A convening of experts delineated this 4 meter contour as described in Reilly, Spagnolo, and Ambrogio (1999) as important in both an ecological and a regulatory sense in estuarine systems and CMECS has adopted it to emphasize the significant human and natural processes that occur there.

The high wetland-water ration and pelagic-benthic connectivity makes the Estuarine Coastal Subsystem an extremely dynamic and active area in terms of hydrodynamics, geology, and biology. It is this area in shallow coastal waters where maximum interaction between estuarine waters, and adjacent wetlands or developed shoreline occurs and often where intense juxtaposition of human activity and the natural system occurs. Watershed, point and non-point inputs to the estuary are often maximal in this shallow zone.

Because the Coastal Subsystem tends to receive an abundance of light, these waters and bottom areas are usually sites of high primary production. In water columns, shallow waters typically support high phytoplankton productivity while shallow water bottoms are covered in highly productive microphytobenthos, macroalgae and/or rooted macrophytes and their attached epiphytic communities. As regions of high primary production, shallow waters attract an abundance of higher trophic level organisms that feed on plants and on their grazer communities. Strong physical subsidies from flowing waters and wind stresses create waves and currents that generally maintain the shallow waters in a well-oxidized state. Surface waters of the Coastal Subsystem tend to be well-mixed and are affected by strong physical processes that impact the bottom: resuspending sediments, reducing light and altering spectral characteristics of the light climate. The estuarine bottom in shallow waters is also subject to frequent wind-induced reworking and transport of sediments and dynamic bedforms.

The Estuarine Coastal Subsystem is divided in three zones based on tidal action:

- **Tidal Zone: Estuarine Coastal Subtidal –** The substrate is generally continuously submerged in this zone and includes those areas below MLLW.

- **Tidal Zone: Estuarine Coastal Intertidal –** The substrate in this zone is regularly and periodically exposed and flooded by tides. This zone extends from MLLW to Mean Higher High Water (MHHW). The Coastal Intertidal is exposed regularly to the air by tidal action.

- **Tidal Zone: Estuarine Coastal Supratidal –** This zone includes areas above MHHW; areas in this zone are affected by wave splash and overwash. It does not include areas affected only by wind-driven spray, which may extend further inland.

- **Subsystem: Estuarine Open Water –** The Estuarine Open Water Subsystem includes all waters of the Estuarine System with a total depth greater than 4 meters, exclusive of those waters designated Tidal Riverine Open Water.

The Open Water Subsystem is subject to a number of physical factors that make it distinct from the Coastal Subsystem, including reduced air-water exchange, potentially reduced light at depth, reduced physical impact from waves and surface currents and reduced interaction between the water column and the bottom. Moreover, because of the formation of stratified layers in the Estuarine System, the Open Water Subsystem is often “capped” by a relatively strong density or stability gradient that distinctly separates the lower water column from the upper water column, separated by a zone of transition (such as a pycnocline, halocline, or thermocline).

The Open Water Subsystem may be heterotrophic, because it often acts as a receiving basin for organic material settling from the shallower, better lit surface waters, especially when the waters are stratified and form shallow flanks of the water body. At times, this role as a heterotrophic zone may support high rates of respiration (relative to production) and therefore consume much of the available oxygen and lead to the formation of hypoxic or anoxic zones, generally in the deeper parts of these waters. Additionally, stratification and the mechanics of estuarine circulation often promote the formation of a salt wedge intrusion (from the marine environment) that renders the bottom waters more saline than waters in the surface layer above.

  - **Tidal Zone: Estuarine Open Water Subtidal –** The substrate is generally continuously submerged in this zone and includes those areas below MLLW.

- **Subsystem: Estuarine Tidal Riverine Coastal –** The Estuarine Tidal Riverine Coastal Subsystem includes the most upstream region of the estuary, in those areas between MHHW to the 4 meter depth contour below MLLW in waters that (a) can be regularly influenced by tides and (b) where salinity is below 0.5 during the period of annual low flow. The areas with this salinity may extend upriver to the head of tide, which is identified as the point where the mean tidal range becomes less than 0.2 feet (0.06 meters) (FGDC 2001).

  The Tidal Riverine Coastal Subsystem includes upstream areas that are influenced by ocean tides, but do not experience significant salinity. The hydraulic gradient is low and water stage and velocity fluctuate under tidal influence. Water is always present and is confined within a channel, and is usually flowing. The Tidal Riverine Coastal Subsystem is a critical part of the ecology and habitat of the estuary. This area is the site of significant ecological activity and a number of estuarine and coastal species depend on Tidal Riverine Coastal areas for breeding habitats, nursery habitats, and migratory pathways (e.g., striped bass, wading birds, and anadromous fishes). The Tidal Riverine Coastal Subsystem also supports unique hydrological features, for example the Estuarine Turbidity Maximum, tidal bores and Coriolis deflections.

  - **Tidal Zone: Estuarine Tidal Riverine Coastal Subtidal –** The substrate is generally continuously submerged in this zone and includes those areas below MLLW.

  - **Tidal Zone: Estuarine Tidal Riverine Coastal Intertidal –** The substrate in this zone is regularly and periodically exposed and flooded by tides. This zone extends from MLLW to the extent of tidal inundation, i.e., the extreme high water of spring tides. The Coastal Intertidal is exposed regularly to the air by tidal action.

- **Subsystem: Estuarine Tidal Riverine Open Water –** The Estuarine Tidal Riverine Open Water Subsystem includes tidal freshwater areas with a salinity of <0.5 and a depth of greater than 4 meters at MLLW.

  The Estuarine Tidal Riverine Open Water Subsystem is the most upstream portion of the estuary and subject to river and watershed influences, including high nutrient and sediment loads and low salinity. Similar to the Estuarine Open Water Subsystem, physical impact from waves and surface currents is reduced interaction at depth. This zone may be the site of the upper limit of the salt wedge and of a turbidity maximum zone, important as feeding and aggregation sites for plankton and benthic species. This zone is also potentially subject to high organic loading and formation of hypoxic waters. Primary production is often low, due to high turbidity and deep, dimly lighted water columns, especially in the river channel. For this reason, the Tidal Riverine Open Water Subsystem may be heterotrophic with net negative metabolic rates.

  - **Tidal Zone: Estuarine Tidal Riverine Open Water Subtidal –** The substrate is generally continuously submerged in this zone and includes those areas below MLLW.

4.2.3 Marine System

The Marine System is defined by salinity, which is typically about 35, although salinity can measure as low as 0.5 during the period of average annual low flow near fresh outflows. This system has little or no significant dilution from fresh water except near the mouths of estuaries and rivers. The Marine System includes all non-estuarine waters from the coastline to the central oceans. The landward boundary of this system is either the linear boundary across the mouth of an estuary or the limit of the supratidal splash zone affected by breaking waves. Seaward, the Marine System includes all ocean waters.

The Marine System is typified by waves, currents and coastal water regimes determined by oceanic tides. Coastal indentations and bays that do not receive appreciable and regular freshwater inflow are part of the Marine System. Areas where river plumes discharge directly into marine waters without geomorphological enclosure are also part of the Marine System. In such areas, (e.g., Mississippi River plume, Chesapeake Bay plume), low salinity water and fresh plumes may discharge from the seaward boundary of the estuary, extending far into the Marine System beyond the enclosed part of the estuary. These freshwater features are considered to be Hydroforms within the Marine System (see Section 5).

The Marine System has three subsystems (which are defined by depth): Nearshore, Offshore, and Oceanic.

- **Subsystem: Marine Nearshore –** The Marine Nearshore Subsystem extends from the landward limit of the Marine System to the 30 meter depth contour. The 30 meter depth contour was selected as a useful cutoff between shallower nearshore and deeper offshore waters. It is intended to represent an ecologically significant depth to which water column and benthic processes are strongly coupled in the Nearshore Subsystem. Surface currents and waves impinge the bottom at the storm wave base (Keen and Holland 2010) and vertical circulation generally distributes nutrients and sediments throughout the water column. The photic zone extends through the entire water column except in extreme cases (Kleypas, McManus and Menez 1999). The presence of nutrients and light support the growth of vegetation on the bottom including seagrass and macroalgal beds and 30 meters generally represents the depth to which most living coral is found.

    - **Tidal Zone: Marine Nearshore Subtidal –** The substrate is generally continuously submerged in this zone and includes those areas below MLLW.

    - **Tidal Zone: Marine Nearshore Intertidal** – The substrate is regularly and periodically exposed and flooded by tidal action. This zone extends from MLLW to MHHW.

    - **Tidal Zone: Marine Nearshore Supratidal** – This zone includes areas above MHHW that are affected by wave splash and overwash but does not include areas affected only by wind-driven spray. This zone is subjected to periodic high wave energy, exposure to air, and often to variable salinity.

- **Subsystem: Marine Offshore –** The Marine Offshore Subsystem extends from the 30 meter depth contour to the continental shelf break, as defined by the maximum slope discontinuity with a rapid change in gradient of 3° or greater at the outer edge of the continental shelf. This shelf break boundary generally occurs between 100 - 200 meters depth. In the case of steep-sided, oceanic islands, where a continental shelf is not present, the offshore boundary of the Offshore Subsystem is defined at a bottom slope discontinuity occurring between 100-200 meters, or at 200 meters if no such discontinuity exists.

The waters and benthos of the Offshore Subsystem are less coupled to each other and typically less influenced by terrigenous processes than in the Nearshore Subsystem. Distance from shore can vary greatly, depending on shelf morphology, and waters at the 30 meter isobath can be quite distant from the shore or may lie relatively close to land.

The Offshore Subsystem may be strongly influenced by open-ocean biogeochemistry and physical processes. Often distinct water layers at the surface and bottom may be present. Because Offshore Subsystem waters are less influenced by coastal inputs, they generally are less turbid than those of the Nearshore Subsystem. Light penetration in the Offshore Subsystem can extend to significant depths and often reach the ocean bottom.

- **Tidal Zone: Marine Offshore Subtidal –** The substrate is subtidal and continuously submerged in this zone and includes those areas below MLLW.

- **Subsystem: Marine Oceanic –** The Marine Oceanic Subsystem represents the open ocean, extending from the continental shelf break to the deep ocean. Oceanic waters typically have salinity levels of ≥ 36. Water depths typically range from 100 - 200 meters at their shallowest at the shelf break to over 11,000 meters at the deepest point in the ocean.

  The great depth of the Oceanic Subsystem is responsible for many of its characteristics. The oceanic water column tends to be more stable physicochemically; undergoing changes in temperature and salinity relatively slowly. Greater depth also diminishes the influence of the sea bottom on the overlying water column. Surface and bottom processes generally are poorly coupled and separated by great distances and thermocline layers. The waters of the Oceanic Subsystem receive little direct terrigenous input; the inputs from land typically occur indirectly, after passage through the substantial coastal water masses or atmospheric deposition.

  Conditions in the Oceanic Subsystem are a function of the properties of the water column. For example, light penetration diminishes with depth (as sea water absorbs component wavelengths); thus, the quality and intensity of ambient light changes with depth. Little surface light penetrates below the photic zone (~200 meters). At greater depths, light is limited to that produced locally by bioluminescence. Water pressure also increases directly with depth because of the weight of the overlying water column, and water temperatures diminish with depth.

  - **Tidal Zone: Marine Oceanic Subtidal –** The substrate is subtidal and continuously submerged in this zone.

`

5. Water Column Component

The Water Column Component (WC) describes the water column environment of estuaries and oceans.The water column presents unique challenges to classification and characterization—due to its three-dimensional structure; a high degree of temporal variability; a wide, dynamic range in environmental characteristics (across multiple spatial scales); and the inherent challenges of measuring the various parameters. The WC identifies the structures, patterns, properties, and processes, of the water column relevant to ecological relationships and habitat-organism interactions. This component extends from the land-sea margin to the deep oceans and vertically from the surface of the water to the benthic interface. The WC encompasses the Lacustrine, Estuarine, and Marine Systems. The water column component of the Lacustrine System will be fully addressed in a later document, while the latter two systems are described here.

Because the water column is highly variable in both time and space, it is difficult to assign structures or properties to a specific location or depth with certainty. The characteristics of the water continuously change over time. For example, in the clear waters of the open ocean, the well-lit zone of photosynthesis generally extends throughout the upper 200 meters of the water column. In estuaries and coastal waters, surface conditions and water constituents reduce the depth of the photic zone by orders of magnitude. Nearshore photic depths can be quite shallow and variable from place to place or over short time periods. In shallow waters, optical dynamics are compressed in the vertical dimension and their effects are amplified—strongly influencing biota in the water column and in the benthos.

The WC is designed to accommodate the high degree of spatio-temporal variability of the water column with a simple and flexible structure and a comprehensive array of units and modifiers. The WC provides a way to define and organize key information most commonly required to characterize the water column. Spatially, the WC can be applied to points or profiles within the water column, as well as to water masses, regions, entire water bodies and entire oceans.

The WC contains five subcomponents that can be used alone or in combination (Table 5.1): Layer, Salinity, Temperature, Hydroform and Biogeochemical Feature. The Layer subcomponent indicates vertical position within the water column, using a set of defined layers associated with each subsystem and gives information about relative proximity to the atmosphere, mid-depth or benthos. Units in the Salinity and Temperature subcomponents describe the salinity and temperature characteristics of a water parcel within standard ranges. Hydroform Classes, their hydroforms, and hydroform types describe physical hydrographic features such as currents, waves, water masses, gyres, upwellings and fronts. The Biogeochemical Features subcomponent describes such phenomena as biofilm, thermocline and turbidity maximum—features of the water column that include properties and constituents beyond simple hydrodynamics. Modifiers can be selected from a comprehensive list and applied to any component to define additional characteristics such as trophic status, oxygen status, tide regime and energy regime.

Table 5.1. Water Column Classification Structure.

Water Column Component				
Layer Subcomponent	**Salinity Subcomponent**	**Temperature Subcomponent**	**Hydroform Subcomponent**	**Biogeochemical Feature Subcomponent**
List of layers	List of salinity ranges	List of temperature ranges	*Hydroform Class* *Hydroform* *Hydroform Type*	List of biogeochemical features

5.1 Water Column Layers

The Water Column Layer Subcomponent resolves the water column vertically into its major coherent layers based on position relative to the surface and to the pycnocline or mid-depth. These layers reflect ecologically important characteristics of the water column structure. The layers for all cross-shelf waters include Surface Layer, Upper Water Column, Pycnocline and Lower Water Column. In the Marine Oceanic Subsystem, additional divisions (described below) are based on depth in the water column. The Layer subcomponent works with the Subsystem of the Aquatic Setting described in Section 4 to define the estuarine and marine water column as a grid. The grid framework is composed of horizontal regions (x-y axes) divided on the basis of position relative to land and total water depth, and vertical layers (z-axis) defined by depth below the surface. This structural arrangement provides a fixed frame of reference for describing position within the water column and accommodates the variability in water column features, conditions and movements by applying additional subcomponents (Figure 5.1).

One set of Water Column Layers is defined for application to all Estuarine Subsystems and the two Marine Subsystems (Nearshore and Offshore) in cross shelf waters where the total water depth is relatively shallow.

For all subsystems (except the Marine Oceanic) the following Water Column Layers are defined:

- **Surface Layer:** The interface between the water column and the atmosphere, extending to a depth of several centimeters, represents the surface of maximum exchange of atmospheric gases, heat and light. Surface films, floating vegetation and aggregations of materials or biota accumulate at this interface.

- **Upper Water Column:** The area from just below the surface to the boundary of the pycnocline, if present. (If a pycnocline is not present or is not detected, the region above mid-depth in the water column is defined as the Upper Water Column.) The upper water column layer is in close contact with the atmosphere; usually oxygenated, well-mixed and well-lighted; and is generally marked by high rates of photosynthesis and net autotrophic production.

- **Pycnocline:** The zone of maximum change of density of a particular physicochemical variable—normally salinity or temperature—that segregates two distinct layers, which are of relatively homogeneous density. The presence of a pycnocline provides a barrier to vertical mixing between the upper and lower water columns, and this layer enhances the stability of the water column.

- **Lower Water Column:** The area below the pycnocline (or, if absent, below mid-depth in the water column), the lower portion of the water column is often dimly or negligibly illuminated (particularly in estuaries) and can be heterotrophic. These deeper waters have limited contact with the atmosphere, may be reduced in oxygen content, and can have a high degree of interaction with bottom sediments. This layer receives organic and mineral material from upper waters and is frequently the site of anoxia. In estuaries, the salt wedge and counter current flow occur in this layer.

For shallow subsystems, the Water Column Layers are:

- **Estuarine Coastal:**
    - **Estuarine Coastal Surface Layer:** Estuarine waters between the shore and the 4 meter depth contour at the surface of the water column to a depth of a few centimeters.
    - **Estuarine Coastal Upper Water Column:** Estuarine waters above the pycnocline (or the mid-depth) between the shore and the 4 meter depth contour.
    - **Estuarine Coastal Pycnocline:** Estuarine waters within the pycnocline, between the shore and the 4 meter depth contour.
    - **Estuarine Coastal Lower Water Column:** Estuarine waters below the pycnocline (or mid-depth) and between the shore and the 4 meter depth contour.

- **Estuarine Open Water:**
    - **Estuarine Open Water Surface Layer:** Estuarine waters at the surface, at or beyond the 4 meter depth contour.
    - **Estuarine Open Water Upper Water Column:** Estuarine waters above the pycnocline (or mid-depth), at or beyond the 4 meter depth contour.
    - **Estuarine Open Water Pycnocline:** Estuarine waters within the pycnocline, at or beyond the 4 meter depth contour.

    - **Estuarine Open Water Lower Water Column:** Estuarine waters below the pycnocline (or mid-depth), at or beyond the 4 meter depth contour.

- **Estuarine Tidal Riverine Coastal:**
    - **Estuarine Tidal Riverine Coastal Surface Layer:** Tidal fresh waters at the surface, from the land-water interface up to the 4 meter depth contour.
    - **Estuarine Tidal Riverine Coastal Upper Water Column:** Tidal fresh waters above the pycnocline (or mid-depth), from the land-water interface up to the 4 meter depth contour.
    - **Estuarine Tidal Riverine Coastal Pycnocline:** Tidal fresh waters within the pycnocline, from the land-water interface up to the 4 meter depth contour.
    - **Estuarine Tidal Riverine Coastal Lower Water Column:** Tidal fresh waters below the pycnocline (or mid-depth), from the land-water interface up to the 4 meter depth contour.

- **Estuarine Tidal Riverine Open Water:**
    - **Estuarine Tidal Riverine Open Water Surface Layer:** Tidal fresh waters at the surface, at or beyond the 4 meter depth contour.
    - **Estuarine Tidal Riverine Open Water Upper Water Column:** Tidal fresh waters above the pycnocline (or mid-depth), at or beyond the 4 meter depth contour.
    - **Estuarine Tidal Riverine Open Water Pycnocline:** Tidal fresh waters within the pycnocline, at or beyond the 4 meter depth contour.
    - **Estuarine Tidal Riverine Open Water Lower Water Column:** Tidal fresh waters below the pycnocline (or mid-depth), at or beyond the 4 meter depth contour.

- **Marine Nearshore:**
    - **Marine Nearshore Surface Layer:** Marine waters at the surface, from the land-water interface up to the 30 meter depth contour.
    - **Marine Nearshore Upper Water Column:** Marine waters above the pycnocline (or mid-depth), from the land-water interface up to the 30 meter depth contour.
    - **Marine Nearshore Pycnocline:** Marine waters within the pycnocline, from the land-water interface up to the 30 meter depth contour.
    - **Marine Nearshore Lower Water Column:** Marine waters below the pycnocline (or mid-depth), from the land-water interface up to the 30 meter depth contour.

- **Marine Offshore:**
  - **Marine Offshore Surface Layer:** Marine waters at the surface, between the 30 meter depth contour and the shelf break.
  - **Marine Offshore Upper Water Column:** Marine waters above the pycnocline (or mid-depth), between the 30 meter depth contour and the shelf break.
  - **Marine Offshore Pycnocline:** Marine waters within the pycnocline, between the 30 meter depth contour and the shelf break.
  - **Marine Offshore Lower Water Column:** Marine waters below the pycnocline (or mid-depth), between the 30 meter depth contour and the shelf break.

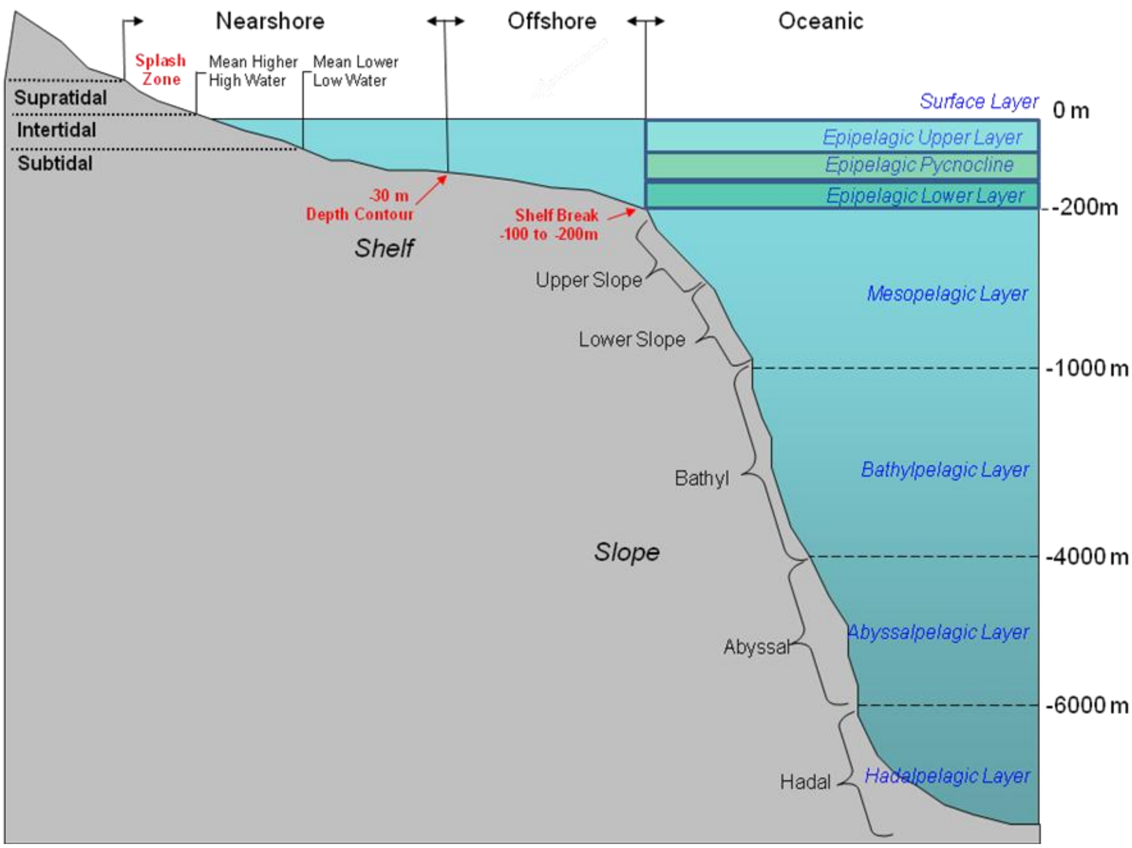

Figure 5.1. Marine Subsystems, Oceanic Water Column Layers, and Oceanic Benthic Depth Zones.

The Marine Oceanic Subsystem lies beyond the shelf break, extending to waters of great depth in the central ocean. The shelf break is defined as the point of maximum change in slope, a grade of up to 3˚ at the outer Continental Shelf, generally occurring between 100-200 meters. The water column layers for this subsystem are scaled differently from those of the other subsystems, because of the large spatial scale and the complexity and depth of the oceanic water column. Eight Marine Oceanic layers are defined using what are considered traditional oceanographic ecological and depth criteria and terminology:

- **Marine Oceanic Surface Layer:** The interface between the atmosphere and the water column, extending to a depth of several centimeters. Surface films, floating vegetation, and aggregations of materials or biota accumulate at the surface, which also represents the surface of maximum exchange of atmospheric gases, heat, and light.

- **Marine Oceanic Epipelagic Upper Layer:** The Epipelagic Layer is the upper 200 meters of the oceanic water column. Within the Epipelagic, the Marine Oceanic Epipelagic Upper Layer is the region between the sea surface and the Epipelagic Pycnocline, if present, or mid-depth in the Epipelagic zone at 100 meters. This layer is generally well-mixed, well-lighted, and highly oxygenated, and supports photosynthesis largely throughout, although weakly in the lower depths. It has no contact with, and very minimal influence from land, and is very clear compared to coastal water masses. It is the zone of maximal productivity in the Oceanic Subsystem.

- **Marine Oceanic Epipelagic Pycnocline:** Within the Epipelagic Layer, the Marine Oceanic Epipelagic Pycnocline is the zone of maximum vertical change in density of the water normally due to a salinity or temperature gradient, which segregates the water column into two distinct layers that are of relatively homogeneous density. The presence of a pycnocline provides a barrier to mixing between the upper and lower water columns, and this layer enhances the stability of the water column preventing mixing to the bottom.

- **Marine Oceanic Epipelagic Lower Layer:** Within the Epipelagic Layer, the region below the Epipelagic pycnocline if present (or below mid-depth [100 meters]). Photosynthesis can generally occur through this layer although diminishing with depth to the critical depth for phytoplankton, which represents the point where production and respiration are in balance and no net productivity occurs. The lower bound of the Epipelagic Lower Layer is the bottom of the Epipelagic Layer at 200 meters.

- **Marine Oceanic Mesopelagic Layer:** The region where light is vertically attenuated to below the level required for photosynthesis, generally between 200 meters and 1,000 meters in depth. Oxygen declines rapidly to a minimum, corresponding with the lower limit of the Mesopelagic Zone—due to high bacterial respiration from settling organic material.

- **Marine Oceanic Bathypelagic Layer:** The region where light does not penetrate, rendering the water column totally dark except for bioluminescence, generally from 1,000 meters to 4,000 meters depth. Organisms at these depths are subjected to immense pressure; food webs depend on organic detritus rather than active photosynthetic production. Waters in this layer generally are composed of cold, bottom currents (from sinking water masses descending from polar latitudes).

- **Marine Oceanic Abyssopelagic Layer:** The region of the water column that is generally in contact with the abyssal seafloor, except in deep basins and trenches and represents the bottom layer of the ocean, generally from 4,000 meters to 6,000 meters depth. This layer is aphotic; it receives biogenic, detrital and mineral material descending from above and this layer acts as an accumulation zone. Oozes from tests of planktonic organisms form on the seafloor and fans of sedimentary material accumulate here. There are diverse and specialized faunal communities at these depths. Trophic webs are based on chemoautotrophic processes, hydrothermal vents, decomposition of organic matter and bacterial production.

- **Marine Oceanic Hadalpelagic Layer:** The deepest waters of the globe occur in trenches and deep basins generally at depths greater than 6,000 meters. There is a high degree of tectonic and thermal activity in these areas. Waters in this layer have unique characteristics of immense pressure, strong currents, accumulation of sediments and organic material; macrofauna that occur at these extreme depths have special feeding strategies and adaptations to intense pressure and total darkness.

5.2 Salinity Subcomponent

Salinity in seawater results from a concentration of salts including bromine, iodine, and (principally) sodium chloride. Salinity is measured as a dimensionless conductivity ratio on the practical salinity scale (PSS), which was established by the IAPSO (International Association for the Physical Sciences of the Oceans) in 1978 (UNESCO 1981). Most marine waters have salinities between 34 and 35, while in estuaries and coastal waters salinity can vary considerably from zero to hyperhaline ($\geq$ 40). In estuaries, the salinity distribution is a function of direct precipitation, the influx of freshwater supplied by rivers, groundwater sources and runoff from the land and marine water supplied by exchange with the ocean as a function of tidal regime. Salinity is an indicator of the dynamic or conservative nature of mixing within the water body, and is one of the defining features of the structure of coastal waters. Most aquatic organisms function optimally within a narrow range of salinities, which has impact on the ecological balance and trophic structure of communities. Salinity categories and ranges for CMECS are provided in Table 5.2.

Table 5.2. Categories and Ranges for the Salinity Subcomponent.

Salinity Regime	Salinity (Practical Salinity Scale)
Oligohaline Water	< 5
Mesohaline Water	5 to < 18
Lower Polyhaline Water	18 to < 25
Upper Polyhaline Water	25 to < 30
Euhaline Water	30 to < 40
Hyperhaline Water	≥ 40

5.3 Temperature Subcomponent

Temperature is a measure of kinetic energy, and in most cases decreases with depth in the water column. The mean temperature of oceanic seawater, which by volume is principally at depth, is generally low, 0 – 5^{o} C, but higher in the water column temperatures tend to converge toward air temperature at the surface. Marine waters are structured vertically with a mixed surface layer having little gradient in temperature, a thermocline with a highly variable gradient, and underlying waters with little stratification. A thermocline is established between an upper layer of one temperature and a lower layer of another and can be seasonal or permanent depending on the circulation and weather patterns. Pronounced thermoclines occur in the tropics, and essentially none occur in Polar Regions. In estuaries, temperatures are more variable because waters are shallower and under more influence of the temperature of inflowing freshwaters or of tidal marine waters. Temperature has a considerable impact on ecosystem functioning, affecting photosynthesis, growth, metabolism, and mobility of organisms. Rates of microbial processes of decomposition, nitrogen fixation and denitrification generally double with each increase of 10^{o} C. Organisms tolerate a particular temperature range, and the temperature optimum range may span only a few degrees. The solubility of gases and pH are dependent on temperature, and temperature influences the ability of water to hold oxygen or oxic status.

Temperature categories are established in intervals of sufficient range and resolution to provide meaningful ecological differences yet yield a parsimonious number of categories. Temperature categories are based on the *British Columbia Marine Ecological Classification for Canada* (Howes, Harper, and Owens 1994, Zacharias et al. 1998, Resource Information Standards Committee 2002), modified to add the higher temperature ranges typical of the subtropics and tropics. Categories for water mass temperature are established in Table 5.3.

Table 5.3. Categories for Water Temperature.

Temperature Category	Degrees (°C)
Frozen/Superchilled Water	0 and below
Very Cold Water	0 to < 5 (liquid)
Cold Water	5 to < 10
Cool Water	10 to < 15
Moderate Water	15 to < 20
Warm Water	20 to < 25
Very Warm Water	25 to < 30
Hot Water	30 to < 35
Very Hot Water	≥ 35

5.4 Application of Water Column Layer (L), Salinity (S) and Temperature (T) Subcomponent Units

Many applications of classification may be satisfied by characterizing the water column using any of the subcomponents singly. However, more powerful information can be developed by combining subcomponents. Salinity (S) and/or Temperature (T) can be combined with Layer (L) to produce unique S-L, T-L or T-S-L combinations as needed. It is highly recommended that the Layer information always be applied to the other subcomponents when data are available. All possible combinations of units are too numerous to practically display; however, below are examples of how the Water Column Layers can be combined to create combinations pertinent to several subsystems. The order of subcomponents is: Temperature, Salinity, and Layer.

Layer: Estuarine Coastal Surface Layer

Example SL: Upper Polyhaline Estuarine Tidal Riverine Coastal Surface Layer
Example TL: Warm Estuarine Tidal Riverine Coastal Surface Layer
Example TSL: Warm Upper Polyhaline Estuarine Tidal Riverine Coastal Surface Layer

Layer: Estuarine Coastal Upper Water Column

Example SL: Mesohaline Estuarine Coastal Upper Water Column
Example TL: Cool Estuarine Coastal Upper Water Column
Example TSL: Cool Mesohaline Estuarine Coastal Upper Water Column

Layer: Estuarine Coastal Pycnocline
Example SL: Euhaline Estuarine Coastal Pycnocline
Example TL: Cold Estuarine Coastal Pycnocline
Example TSL: Cold Euhaline Estuarine Coastal Pycnocline

Layer: Marine Nearshore Lower Water Column
Example SL: Upper Polyhaline Marine Nearshore Lower Water Column
Example TL: Moderately Warm Marine Nearshore Lower Water Column
Example TSL: Moderately Warm Upper Polyhaline Marine Nearshore Lower Water Column

Layer: Marine Offshore Upper Water Column
Example SL: Euhaline Marine Offshore Upper Water Column
Example TL: Warm Marine Offshore Upper Water Column
Example TSL: Warm Euhaline Marine Offshore Upper Water Column

Layer: Marine Oceanic Mesopelagic Layer
Example SL: Euhaline Marine Oceanic Mesopelagic Layer
Example TL: Cool Marine Oceanic Mesopelagic Layer
Example TSL: Cool Euhaline Marine Oceanic Mesopelagic Layer

5.5 Hydroform Subcomponent Hierarchical Structure

Hydroforms are physical entities that have a coherent, definable structure with identifiable boundaries and characteristic physical properties. The Hydroform Subcomponent is a hierarchy of three levels consisting of Hydroform Classes, Hydroforms and Hydroform Types. Hydroforms are ecologically important because they shape their environment by creating gradients, surfaces, barriers, compartments and energy vectors. They strongly influence the distribution and condition of biota and often act as habitat by creating a complex environmental structure, by facilitating and enhancing transport of materials and energy, cycling nutrients, providing refugia, aggregating food resources, and providing migration paths. They influence the transfer of heat, salts, oxygen, carbon dioxide, trace elements, momentum, predicted trajectory, temporal persistence and associated fauna. Hydroforms vary extensively in size, volume, areal extent, persistence, and ecological significance.

In this standard hydroforms are represented conceptually as the average expression of their defining characteristics. The boundaries of the hydroforms are to be determined by methodology, technology limits, user objectives and application and lie along a continuum. Implementation guidance will be developed to assist in determining quantitative cutoffs that define their boundaries.

5.5.1 Hydroform Classes

Hydroform Classes are major groups of oceanic and coastal water column forms: Currents, Water Masses, Fronts, and Waves. Currents represent the advective movement of a mass of water, important in transport and circulation. Water masses are large, coherent parcels of water that reflect homogeneous properties and are distinct from surrounding waters. They may be moving or stationary. Fronts form at the interface between waters of two different masses or types with distinctly different characteristics. The frontal boundary represents the intense gradient between them. Waves are the propagation of energy through the water column and impact water column mixing, movement of biota, shoreline impact, and oxygenation and represent an input disturbance. These basic units are found throughout the world's estuaries and oceans across multiple temporal and spatial scales and each major Hydroform Class can be broken into many more specific forms as described below.

5.5.2 Hydroforms and Hydroform Types

Hydroforms are nested within Hydroform Classes and are distinguished by scale, system, location or other attributes of the Hydroform Class. Examples include Langmuir circulation (Current), Mesoscale Lens (Water Mass), Tidal Front (Front), and Internal Wave (Wave). Hydroforms can be broken down further into Types based on distinguishing characteristics such as temperature, energy level, circulation patterns, and geography.

5.6 Hydroform Subcomponent Units

Hydroform Class: Current

Water that is undergoing coherent mass movement, either as laminar or turbulent flow, relative to surrounding waters and fixed structural, landform or geologic features. A directional, coherently flowing water mass. Currents operate on a wide range of temporal and spatial scales from huge ocean gyres and major surface and deepwater currents of the ocean operating on annual timescales to tidal currents that operate on sub daily timescales. However, all currents have features in common: the advective movement and transport of water, constituents (such as particulates and dissolved compounds), qualities (such as temperature and salinity) and biota (such as plankton, nekton, and megafauna). Currents are driven by gravity flow, geostrophic flow, density differences, hydraulic differential or energy input. They may be isolated from land and freely flowing in the water column as is the Gulf Stream, or they may be in channelized flow or long-shore flow. Currents that impact land also shape the littoral zone or sea bottom by winnowing sediments, physically mixing or shearing substrates and biota and creating geoforms such as sand ripples and bars.

- **Hydroform: Boundary Current –** The portion of an ocean gyre that moves along the continental boundary.

    - **Hydroform Type*:* Eastern Boundary Current (EBC)** – The eastern portion of the great ocean gyres circulating in the ocean basins against west continental coasts. They may be broad or narrow and meandering; they transport colder water into the tropics. EBCs are typically shallow and slow-flowing compared to the Western boundary currents. EBCs may be associated with upwellings and nutrient rich seas that can support very productive fisheries, such as in the Peruvian Upwelling.

    - **Hydroform Type*:* Western Boundary Current (WBC)** – The western portion of the great ocean gyre circulation, which moves along the eastern coasts of the continents. These currents are deeper (up to 1,000 meters) and faster moving than eastern counterparts. The western intensification, due to Coriolis forces being stronger in the latitudes of the Westerlies that steer Western boundary currents, is responsible for the great speed and intensity of these currents. WBCs transport warmer tropical waters into the cold higher latitudes and have a great effect on both oceanic and terrestrial climate, water temperatures and distribution of biota.

- **Hydroform: Buoyancy Flow –** Current flow created by discontinuity in buoyancy of two juxtaposed water masses of different density, causing one to flow relative to the other toward buoyancy equilibrium.

    - **Hydroform Type: Downwelling** – Downwardly-directed current caused by convergence of water masses.

    - **Hydroform Type: Upwelling** – Upwardly-directed current caused by divergence of water masses

- **Hydroform: Current Meander –** A current that deviates from a straight line flow, which is often the result of incursion by lateral currents or the presence of a physical or density barrier. Meanders can pinch off from the main current flow and form rings.

- **Hydroform: Deep Boundary Current –** A current that connects high-latitude ocean waters (where deep water is formed) with upwelling regions. The core depths of these currents are between 1,500 meters and 4,000 meters. Western-located Deep Boundary Currents lie adjacent to continental slopes in all ocean basins.

- **Hydroform: Deep Circulation** – The mass circulation of the oceans that carries cold polar surface water to depth, sinking due to higher density and wind forcing. The mass transport also carries salt, oxygen, and other properties. Deep circulation is wind driven, with a tidal mixing component. It cools the surface and evaporates water, which determines where deep convection occurs. Wind-driven turbulence in the deep ocean mixes cold water upward at lower latitudes. Deep circulation has relative slow current movements but transport of water is comparable to surface transport and is responsible for closing the Earth's heat budget and determining climate.

    - **Hydroform Type: Abyssal Deep Circulation** – Deep, slow circulation in the abyssal zone driven by horizontal differences in density of water masses. The vast majority of ocean circulation is of this type, initiating by the sinking of cold water in the high latitudes to the ocean bottom, and spreading throughout the abyssal plains of the ocean basins.

    - **Hydroform Type: Bathyl Deep Circulation** – Deep, slow circulation in the bathyl zone driven by horizontal differences in density of water masses. Water sinks down the continental slope and through the bathyl zone as part of thermohaline ocean circulation.

- **Hydroform: Deep Convection –** Large mass flows of water in the deep ocean that form critical parts (and return paths) of the great ocean circulation.

- **Hydroform: Density Flow –** Flow caused by differential density between two convergent water masses—or by a parcel of denser water flowing along a sloping bottom under a column of less-dense water.

- **Hydroform: Ekman Flow** – The flow of water at 90˚ to the direction of the wind, at steady state, due to Earth's rotational effect.

    - **Hydroform Type*:* Ekman Upwelling –** Upwardly-directed current resulting from either the divergence of water masses or from movement of surface water away from the coast. At the divergence of two water masses (or the wind-driven movement of water away from a coastline), continuity of mass flow will move water from depth to the surface as replacement. In the nearshore, the circulation will bring the water from the shallow bottom. In deeper waters, the upwelling will carry water from a variety of depths—from near the surface to depths to as great as 500 meters (below the pycnocline). Because the upwelled water is working against gravity, its maximum influence is not as great as downwelled water (which is aided by gravity); however, the upwelling can reach into the mesopelagic zone.

- **Hydroform Type*:* Ekman Downwelling** – Downwardly-directed current, resulting from either the convergence of water masses or from the convergence of a water mass with a coastline. At this convergence, gravity will force water into a downwelling, which will carry surface water to greater depths. In the nearshore, the circulation will take the water to the shallow bottom and then move seaward. In deeper waters, the downwelling will carry water to a depth determined by energy dissipation and relative density considerations; the maximum downwelling depth can be into the abyssalpelagic zone.

- **Hydroform: Inertial Current** – Currents that continue motion through inertia. Due to the rotation of the Earth, inertial currents tend to form circular gyres.

- **Hydroform: Langmuir Circulation** – Rotational oscillatory motion of surface waters induced by wind and Coriolis deflection. This circulation is caused by the transport of a parcel of water obliquely to the direction of wind transport due to the apparent Coriolis force imparted by the rotation of the Earth. In the Northern Hemisphere this vector is to the right of the wind direction, in the Southern Hemisphere, it is to the left. This causes a piling of water in cells lateral to the direction of travel. The piled water sinks to balance forces, and it also circulates to create elongated tubular circulations of water at the surface. Langmuir cells are important to productivity by circulating water through the water column, and form fronts at the junction of two Langmuir cells that are important points of aggregation and feeding of plankton and higher trophic levels (Wetzel 2001).

- **Hydroform: Mean Surface Current** – The time-averaged steady state ocean surface current pattern responsible for mean oceanic water motions.

  - **Hydroform Type: North Equatorial Surface Current** – The southern portion of the northern ocean gyres. This current flows westward, is maintained by the trade winds, and entrains some water from southern oceans into the northern oceans. It is accompanied by a weaker easterly-flowing counter current.

  - **Hydroform Type: South Equatorial Surface Current** – The counterpart to the North Equatorial current, also flows east to west, forming the northern limb of the southern ocean gyres.

- **Hydroform: Mesoscale Eddy** – A rotational feature that (a) breaks off of an ocean gyre or large current (such as the Gulf Stream) and (b) persist autonomously for some period (from days to months) at sizes of 20 kilometers to 500 kilometers. These eddies play an important role in ocean mixing—and in sheltering and acting as nursery waters for biota. The most energetic eddies are at the smaller end of the spatial scale. The larger eddies (called mesoscale eddies) are slower moving, but they persist for many months and are ubiquitous in the global oceans. Mesoscale Eddies are most prevalent in the North Atlantic and North Pacific, but they can occur in all oceans.

  - **Hydroform Type: Cold Core Ring** – An eddy that forms when a boundary current meander pinches off and closes, trapping a parcel of colder water in a surrounding ring of warmer water. The ring measures up to 300 kilometers and extends to 4,000 meters depth or the ocean bottom. The colder water in the core tends to be higher in nutrients and more productive than that in the surrounding ring, so they become islands of biological activity as they move through the ocean. Rings form in all oceans and can persist for months to years.

  - **Hydroform Type: Warm Core Ring** – An eddy that forms when a boundary current pinches off a parcel of warmer water. The ring measures 100-200 kilometers and extends to 1,500 meters depth. The warm water in the core tends to be less productive than the colder, nutrient rich waters in the ring.

- **Hydroform: Residual Current** – Current movement resulting from asymmetry in tidal flow—notably within a partially enclosed estuary or embayment—that results in characteristic estuarine circulation patterns.

  - **Hydroform Type: Fjord Circulation** – Circulation in estuaries that possess a sill at the seaward end, inhibiting inflow of seawater into the bottom waters. Seawater flows over the sill mixing into the intermediate water of the estuary, and sinking to the bottom. The estuary receives freshwater input in excess of evaporation and the resulting brackish mixture is exported across the sill into the ocean end-member. The limited exchange of bottom waters can promote hypoxic conditions in some fjord estuaries.

  - **Hydroform Type: Partially Mixed Domain** – An estuarine circulation with an intermediate level of advective and tidal energy that can disrupt the density barrier between the fresher upper and salty lower water column of an estuary, entraining water in both directions. This results in a gradient of increasing salinity from top to bottom, with no barrier to mixing.

- **Hydroform Type: Reverse Estuarine Flow** – An estuarine circulation where evaporation greatly exceeds freshwater input, as in hot dry climes, salinity is concentrated within the estuarine basin. This results in a salinity maximum in the estuary that can far exceed seawater salinity.

- **Hydroform Type: Salt Wedge Domain** – Portions of estuaries that have an unimpeded connection of bottom waters to the sea develop a wedge-shaped formation of high-salinity water in the bottom, with lower salinity water from upstream freshwater loading in the upper water column. The wedge form is developed as hydrostatic pressure of river water pushes against the incoming seawater and, being less dense, rides over it. The difference in salinity and density is important in estuarine chemistry and biology as the density barrier between upper and lower water columns restrains mixing and transport across the transitional gradient, called the pycnocline. This leads to an upper, autotrophic and lower, generally heterotrophic portion of the water column.

- **Hydroform Type: Well-mixed Domain** – Reaches of estuaries where the tidal flux and/or the river discharge is sufficient to overcome the salt-wedge structure, the water column becomes well-mixed and vertical homogeneous.

- **Hydroform: Sub-mesoscale Eddy** – A reverse current with rotational movement created when fluid flows past an obstacle. Sub-mesoscale eddies are of size scale smaller than 20 kilometers.

- **Hydroform: Thermohaline Eddy** – Eddy formation due to the interaction of temperature and salinity differences between two water masses initiating convective flow.

- **Hydroform: Tidal Flow** – Advective flow resulting from of tidal movement, often amplified in velocity when moving through an inlet, pass or channel. Tides are important in mixing the water column and transporting water, salt, nutrients and biota, particularly weak-swimming larval or non-motile planktonic forms. The life cycles of many organisms depend on tidal transport for survival.

  - **Hydroform Type: Diurnal Tidal Flow** – Tidal ocean waters where, due to the geometry of the ocean basin and obstructions presented by land, a second daily tide is suppressed, resulting in a single or diurnal tide regime with one high and one low tide per day, as in the Gulf of Mexico.

- **Hydroform Type: Mixed Semi-diurnal Tidal Flow** – Tidal ocean waters where the amplitudes of two semi-diurnal tides are unequal, resulting in a stronger and a weaker high and low tide each day.

- **Hydroform Type: Semi-diurnal Tidal Flow** – Tidal ocean waters where the gravitational action of the sun and moon on Earth's oceans create two high and two low tides per day of relatively equal amplitude.

- **Hydroform: Turbidity Flow** – A flow of water down slope carrying a dense suspension of fluid mud or unconsolidated material.

- **Hydroform: Wave-driven Current** – Residual current caused by asymmetrical force created by wave motion.

  - **Hydroform Type: Longshore Current** – A current that moves parallel to or at an oblique angle to the shoreline, carrying water and often transporting soft sediments downstream. Prevailing wind and wave directions can persist in a longshore direction for long periods, and are commonly responsible for the formation of spits, bars and many barrier islands.

  - **Hydroform Type: Rip Current** – A formation of water flow in a seaward direction generated by wave action and local topography nearshore. Shallow depressions in the sea floor or breaks in a bar will channel receding water at high velocity away from shore and through the surf zone after onshore wave action.

  - **Hydroform Type: Undertow** – Seaward-directed current generated by water that is receding from the shoreline after wave run up.

- **Hydroform: Wind-driven Current** – Current caused by wind shear as distinguished by those caused by density differences, which result in thermohaline circulation. Though only a portion of the oceans are exposed to wind energy, winds are responsible for the great ocean gyres, dominant features of ocean circulation.

Hydroform Class: Front

Front Hydroforms are linear features formed at the conjunction of two or more water masses with different properties. Fronts are formed in many different ways when two water masses juxtapose. The front itself becomes a third water feature, and it has several distinctive properties of its own, including current speed and direction, physicochemical properties derived from the two merging water masses, sharp gradients in properties (such as salinity, temperature, nutrients and water clarity) and an accumulation of matter and biota. In estuaries, fronts can occur at the boundaries of horizontal layers between fresher upper layers and saltier bottom waters; in the ocean, fronts can occur between the upper mixed layer and lower layers.

- **Hydroform: Coastal Upwelling Front** – A frontal interface where a nearshore upwelling occurs due to local turbulent mixing. The upwelling front develops between the upwelling water and the coastal water mass.

- **Hydroform: Shelf-break Front** – Frontal formations where cross-shelf waters encounter slope waters from the deeper oceans, often associated with upwelling. The seasonally transitional features are sites of high temperature, salinity and density gradients and often of high productivity where deep upwelled water contributes high nutrients.

- **Hydroform: Tidal Front** – A front created by the linear convergence of two water masses brought into juxtaposition by tidal action. Generally the two masses will have differential characteristics such as temperature, density, and often of color and productivity. Fronts can be maintained as distinct due to these differences, which inhibit mixing across a density barrier. There is often strong vertical mixing on either side of the front, producing upwelling and aggregations of biota feeding on the material grown in situ or accumulated at the front.

Hydroform Class: Water Mass

The Water Mass Hydroform Class refers to a parcel of water with homogeneous properties (e.g., chemical, physical). If no other hydroform applies (or sufficient information is not available to classify the hydroform), the default would be a water mass that describes the general properties of the parcel. Any physicochemical property (or properties) can define a water mass. Common water mass types are those of homogeneous salinity, temperature or density—or a combination of those properties. The properties of a water mass generally change relatively slowly, because the factors that created and constrain the homogeneity tend to be buffered by the inertial properties of water itself. Thermal mass of water, for example, means that the water temperature will change much more slowly than air temperature. Non-conservative properties (such as nutrient concentration or pH) can change much more quickly, because biological processes can alter them.

- **Hydroform: Background Mesoscale Field** – A water mass characterized by organized ocean-surface currents formed by coupled eddies (at the mesoscale length scale); responsible for much of water movement on the ocean surface.

- **Hydroform: Fumerole Plume** – A plume of hot gases venting from the sea bottom associated with volcanic or tectonic activity from cracks in the Earth's crust; often a site of significant chemoautotrophic activity.

- **Hydroform: Hydrothermal Plume** – A discharge of hot fluids from sea-bottom vents associated with volcanic or tectonic activity. The fluids are often laden with high concentrations of minerals, which impart either a dark—even black—color or a white color. These minerals precipitate readily out of supersaturation.

    - **Hydroform Type: Detached Hydrothermal Plume** – A parcel of hot, mineral rich water that has become detached from its source and forms a persistent lens within the water column.

- **Hydroform: Ice** – Frozen form of water, which is less dense than liquid water; ice floats on the surface of liquid water, sometimes extending into deep water zones. This property drives a number of important biological and physical processes in the ocean, including preventing freezing of the ocean to the bottom. Ice either floats on—or forms a solid cover on—the underlying water, which isolates atmospheric input for the duration of cover. Nonetheless, strong circulation and water motion occurs in the aquatic system under the ice (driven by advection of adjacent water masses or thermal convection). Because freshwater freezes at a higher temperature than salt water, surface freezing of the ocean concentrates salt brine in the liquid water below the ice. Ice formation and ice cover maintenance is relatively stable in both spatial and temporal terms, determined by relative air and water temperatures, velocity of water movements, and geomorphology of the setting.

    - **Hydroform Type: Drift Ice** – Ice that floats freely on the sea surface.

    - **Hydroform Type: Fast Ice** – Ice that is attached to a land mass such as the coast or, in shallow water, the sea floor.

    - **Hydroform Type: Frazil or Grease Ice** – Ice formation that develops when super-cooled water is turbulently mixed, permitting development of small ice crystals which continually fragment and break up without forming ice cover. Over time a slushy suspension of increasing density forms on the surface of the water. In quiet conditions frazil crystals can freeze together to form a continuous thin sheet of young ice.

    - **Hydroform Type: Ice Field** – Expanse of ice greater in size than an ice floe (≥10 kilometers in any dimension).

- **Hydroform Type: Ice Floe** – Large floating ice chunk less than 10 kilometers on its longest axis.

- **Hydroform Type: Pack Ice** – Accumulation of drift ice into a large floating mass, often against a continental shoreline.

- **Hydroform Type: Pancake Ice** – Thin plaques of compressed ice particles formed by wave action into plates several meters in diameter that float on the sea surface.

- **Hydroform Type: Polnya** – An area of open, liquid seawater surrounded by ice.

- **Hydroform: Mesoscale Lens** – A trapped, homogeneous parcel of water lying within (or atop) larger ocean fields due to density differences. These hydroforms are 30 - 300 kilometers in size.

  - **Hydroform Type: River/Estuary Plume** – Formation of water resulting from the discharge of low-salinity water into marine waters of the ocean, forming a distinct layer of water on top of the seawater due to its lower density. The plume can extend for many kilometers and persist for months after the freshwater flow has stopped before being entrained into the seawater. These plumes are typically higher in nutrients, turbidity and productivity than the surrounding seawater and can gradually deliver those water quality characteristics to the adjacent ocean water.

  - **Hydroform Type: Meddy** – A lens of water that enters the eastern Atlantic from the Mediterranean Sea, flows down the Continental slope and pinches off at the depth of neutral buoyancy, about 1,000 meters. The salty warm water rotates clockwise and travels slowly westward in the Atlantic, persisting for many months.

- **Hydroform: Microscale Lens** – A homogeneous parcel of water on the order of meters to a few kilometers positioned within (or atop) a larger ocean fields of different density.

  - **Hydroform Type: Small Freshwater Plume** – Similar to a river plume but on smaller scale and can be initiated from variety of sources such as a groundwater seep, a non-point source or a transient discharge.

- **Hydroform: Winter Water Mass** – The mass of water produced—and introduced to oceans—as a result of melting winter ice formations. These water masses tend to be fresher than surrounding waters, and they often flow over the denser salt water.

Hydroform Class: Wave

The Wave Hydroform Class is a propagation of energy that moves through the water, causing a vertical, oscillatory motion with characteristic wavelength, amplitude, and celerity. Waves are of several types: internal, standing, and surface. Each type of wave propagates energy and impacts the waters, substrate, and biota that it contacts. Waves are initiated by an energy source (such as wind, landslides, Earthquakes, or volcanic eruptions), and they can occur at any depth in the water column. Wave energy varies depending on type and intensity of energy input; the wave regime can change on hourly timescales.

- **Hydroform: Anthropogenic Wave** – Boat wake or other wave caused by energy resulting from human activity.

- **Hydroform: Coastally Trapped Wave** – A wave that moves along the coastal margin, which forms a trapping barrier.

    - **Hydroform Type: Internal Kelvin Wave** – Subsurface gravity wave with a rotational component propagated along a density interface against a vertical barrier such as a coast or the wall of a basin.

    - **Hydroform Type: External Kelvin Wave** – Surface gravity wave with a rotational component propagated along the sea surface against a vertical barrier such as a coast or the wall of a basin. Such Kelvin waves are important at the Equator in determining the presence and strength of El Niño/ENSO events.

    - **Hydroform Type: Shelf Wave** – A wind-induced wave guided by continental shelf topography.

    - **Hydroform Type: Topographic Wave** – A sub-basin scale wave that is driven by wind-stress from the passage of cyclones across or along the shelf, with long period (~ 5 days) and to which a vorticity is imparted by the apparent Coriolis Effect.

- **Hydroform: Edge Wave –** A wave that moves along a trapping barrier, such as the continental shelf, the continental margin or an inertial water mass.

- **Hydroform: Equatorial Wave –** A wave that is trapped by and moves along the Equatorial water mass, which forms a density barrier.

- **Hydroform: Non-Equatorial Wave –** A wave that is propagated along an edge or barrier, such as a continental margin, and that is not associated with an equatorial water mass.

- **Hydroform: Internal Wave –** A wave that propagates along a density surface within the water column, below the water's surface.

- **Hydroform: Seiche** – A long-period, standing wave that creates an oscillatory sloshing of water within an enclosed water body. This is due to wind or pressure effects that cause water motions that resonate with the length scale of the water body.

- **Hydroform: Storm Surge –** A propagation of water associated with intense meteorological and wind activity such as a tropical storm. The surge of water from deep into shallow waters and onto land is caused by wind forcing in the forward, shoreward direction and by pressure differential within a cyclonic storm that positions extreme low pressure over a section of ocean, permitting tides to rise above normal range.

- **Hydroform: Surf Zone** – Zone with incipient wave breaks, which are the result of an increase in the steepness of the wave as the water depth decreases. The surf zone is the region extending from the seaward boundary of wave breaking to the limit of wave uprush. The surf zone is the specific subset of the wave hydroform where waves are breaking against a shoreline. This relatively narrow area occurs when waves encounter bottom friction and break, forming a region of high turbulence, mixing, and intense energy. This occurrence affects biota in the water column, as well as bottom and shore substrates and biota. The surf zone is highly variable temporally and spatially in extent, energy characteristics, and physicochemical properties; this variability is due to the tight coupling between the water column and the substrate it impacts. In areas of soft sediments, high turbidity can result. Benthic biota (such as diatom mats) can be mixed into the water column, imparting its photosynthetic parameters to the water column and elevating water-column productivity. Nutrients can also be mixed from disturbed sediments into the water column, elevating concentrations there.

- **Hydroform: Surface Wave –** A wave generated by energy input from sources such as wind, landslides, tidal action, or current action, and that moves along the surface of the ocean.

- **Hydroform: Surface Wind Wave –** A surface wave generated by direct wind action on the water's surface producing shear, piling up water in the direction of the wind and generating a wave.

- **Hydroform: Surface Swell –** A surface gravity wave propagating into an area from a distant source of energy/disturbance and that is not caused by direct local action of the wind.

- **Hydroform: Tsunami** – A large long-wavelength (tens or hundreds of kilometers) ocean wave that is generated by a powerful undersea disturbance such as a landslide, Earthquake, or volcano. The wave is nearly imperceptible in the open ocean but as it approaches land, it can reach heights of many tens of meters. They can have enormous destructive impact on the coast (and inland), as well as the biology of the nearshore zone.

5.7 Biogeochemical Feature Subcomponent

The Biogeochemical Feature more specifically defines the water column by identifying factors including constituent composition (e.g., chlorophyll maximum, turbidity maximum), physical energy (e.g., light, surface mixed layer,), and gradients (halocline, thermocline). The Biogeochemical Feature subcomponent provides information that conveys the structure and the processes that form and sustain the feature—as well as its potential relationship with the biota. The feature integrates specific information, which may include ecoregion, climate zone, position in the water column, position relative to land and spatial scale that is ecologically relevant. The Biogeochemical Feature also conveys information about properties of the other water column subcomponents.

5.7.1 Biogeochemical Feature Subcomponent Units

- **Benthic Boundary Layer –** The layer formed at the interface between the lower water column and the benthic substrate.

- **Boundary Layer** – Layer formed at the interface between water and another water mass (or solid interface) where frictional shear forces on water motion cause exponential damping of movement with proximity to the interface.

- **Chlorophyll Maximum** – A feature in deeper water columns (often in the ocean), where phytoplankton production is locally high at depths along a surface of nutrient (nitrate) entrainment from lower-water layers.

- **Chlorophyll Minimum –** A layer of low chlorophyll—and hence phytoplankton—concentration (relative to adjacent waters) due to highly concentrated grazing activity.

- **Drifting Fine Woody Debris –** Aggregations of floating or suspended fine woody material such as small tree branches, husks or fibrous seeds, with a median particle size < 64 millimeters.

- **Drifting Herbaceous Debris –** Floating or suspended detached, decaying herbaceous plant matter such as leaves, forbs or grasses, including deciduous leaves or needles, palm leaves, seagrass debris, *Spartina* debris.

- **Drifting Trees** – Floating or suspended large dead trees or very large branches, with a median particle size of greater than 4,096 millimeters**.**

- **Drifting Woody Debris –** Floating or suspended detached large branches with a median particle size of 64 millimeters to < 256 millimeters such as Mangrove branches, coconut rafts.

- **Euphotic Zone –** The zone of the water column that is sufficiently illuminated for photosynthesis to occur.

- **Halocline –** The zone of rapid salinity change with depth in the water column, often separating two layers of different, homogeneous salinity. As the density of water changes with salinity, the halocline presents a barrier to vertical circulation and enhances water column stability

- **Lens** – A homogeneous parcel of water that—by composition—maintains coherence within water of different properties. Often a freshwater lens will sit perched atop saline ocean waters for long periods.

- **Lysocline** – The depth in the ocean at which calcium dissolution increases due to increased pressure. This depth is around 4,000 meters in the Pacific Ocean and 5,000 meters in the Atlantic Ocean, owing to differences in temperature and chemistry. Below this depth, the precipitation of calcium carbonate decreases rapidly to the point where no calcite is deposited.

- **Marine Snow Aggregation** – A concentration of organic material in the ocean water column. Composed of a mix of mineral, dead organic materials, and—sometimes—a rich microbial community. In this feature small particles aggregate through attractive ionic forces and then begin to fall through the water column.

- **Microlayer** – Any extremely thin layer of material, nutrients, organisms or specific properties that exists on or in the water column. The microlayer can be a surface film or at depth and often refers to a microbial film.

- **Nepheloid Layer** – Layer of water that contains a high concentration of silt and sediment—usually at the benthic-water column interface. This layer can be nearly a fluid mud. In the deep oceans, the layer can be hundreds of meters thick; in shallower waters with less fine sediments, it can be much thinner (only a few centimeters in places) or absent. Thickness is determined by substrate composition and current shear.

- **Neustonic Layer** – Layer of biota that lives at the surface of the water. These organisms are either positively buoyant, maintain position by taking advantage of surface tension, or live on other biotic or abiotic material. Epineuston floats atop the water, hyponeuston lives just under the surface.

- **Nutrient Maximum** – A layer or region in the water column that has high concentrations of a particular nutrient or nutrients due either to biological transformation or to abiotic factors such as advection or entrainment from adjacent water masses.

- **Nutrient Minimum** – A layer in the ocean where net nutrient accumulation is at a minimum, often due to a locus of high biological activity drawing down nutrient stocks.

- **Nutricline** – The zone of rapid nutrient change with depth in the water column, often as a result of entrainment of water from a lower depth that is higher in concentration of a particular nutrient. The nutricline can be a rich source of a limiting nutrient and hence, the site of intense microbial or photosynthetic activity.

- **Oxygen Maximum** – A layer in the ocean where oxygen concentration is at a minimum, often due to a locus of high respiratory activity, notably microbial.

- **Oxygen Minimum** – Region in the water column where oxygen is reduced (relative to surrounding waters) due to high respiration rates, usually associated with high concentrations of organic matter.

- **Oxycline** – Zone in the water column where oxygen concentration changes rapidly with depth, often as a result of biological or abiotic processes that consume oxygen. Deep, bottom water that contains no photosynthetic organisms—yet receives much deposited organic matter—can generate both high respiration rates and extremely low oxygen concentrations. The transition layer between hypoxic bottom water and oxygenated surface water is the oxycline.

- **Sea Foam** – Sea foam is produced by turbulent mixing and agitation of surface waters, enhanced by high concentrations of dissolved organic matter (DOM).

- **Seep** – Area on the ocean bottom where fluid slowly emerges. Cold seeps are usually at the continental margins; waters in these seeps are often highly concentrated in minerals and dissolved gases, such as hydrogen sulfide, methane, and hydrogen. Cold-fluid seeps and oil seeps are sources of energy for chemoautotrophic communities of bacteria and archaea, which in turn support communities of clams, mussels and vestimentiferan tubeworms.

- **Surface Film** – Thin layer of materials and biota that exist on the surface of the water, often only a few microns thick. The surface film can contain a rich microbial community that consumes the material that concentrated in the film. Dissolved Organic Carbon (DOC) is concentrated up to five times in the surface microlayer. These films are often aggregated and concentrated at frontal convergences of two water masses and can lead to formation of a rich community that feeds on the material.

- **Surface Mixed Layer** – The layer of water at the ocean surface that is mixed by wind. Water of homogeneous density is easily mixed to a depth determined by the intensity of wind shear and density of the water. Often wind mixing of the surface occurs to the pycnocline depth where density increases rapidly. The mixed layer depth is an important determinant of the extent and intensity of photosynthetic production as plankton cells are mixed through the vertical light gradient.

- **Thermocline** – The zone of rapid temperature change with depth in the water column, often separating two layers of different, homogeneous temperature. As the density of water changes with temperature, the thermocline presents a barrier to vertical circulation and enhances water column stability.

- **Turbidity Maximum** – Region in an estuary where turbidity is high, due to concentration of particulates in the water column. This occurs as a result of the increasing ionic strength of the water from the introduction of salt in the downstream direction (generally at around areas with a salinity of 5), which causes particle aggregation. This process is enhanced by the mixing regime particular to this upper estuary region, in which countercurrent flows from the salt wedge are entrained into the seaward-flowing, upper-water layer. As particles settle out of the upper layer, they are carried upstream in the lower layer and so circulate within a zone of maximum turbidity.

5.8 Water Column Component Modifiers

A wide range of modifiers that can be used to further define the water column are described in Section 10. Modifiers that are particularly important and widely applied to the water column are listed below and further defined in Section 10.

- Physical
  - Tidal Regime (amplitude)
  - Wave Regime (amplitude)
- Physicochemical
  - Oxygen
  - Photic Quality
  - Turbidity
  - Turbidity Type
  - Turbidity Provenance

- Water Column Stability

- Temporal
  - Temporal Persistence

6. Geoform Component

The geomorphology of an area has a determinative influence on the character and stability of soil and sediment, and local topography has a powerful influence on plant and animal communities. In CMECS, the geological context—and associated features of the landscape and seascape—are captured in the Geoform Component (GC), which describes the physical structure of the environment across multiple scales. Geoform units provide structure, channel energy flows, and regulate bioenergetics. They also control such processes as water exchange rates and water turnover times; hydrologic and energy cycling; shelter and exposure to energy inputs; and migration and spawning. Because of these diverse interactions, it is impossible to fully understand a biotic community without also considering the geological context in which the organisms are found. The GC addresses five aspects of the coastal and seafloor morphology: tectonic setting, physiographic setting, geoform origin, geoform, and geoform type. The framework for the GC adopts most of the structures described by Greene et al. (2007) and the estuary types outlined in Madden et al. (2008), but expands the options to include a larger number of coastal and nearshore features.

The GC is not intended to be a geological classification *per se*. Rather, it provides a way to present the structural aspects of the physical environment that are relevant to—and drivers of—biological community distribution. This component does not include surface geology attributes [such as hardbottom, softbottom, sand, gravel, and cobble as in Greene et al. (2007)], because these attributes are included in the Substrate Component that describes the character and composition of the seafloor. Used together, geoform and substrate component units reflect the physical environment in which benthic/attached biota occurs.

The GC is organized into four subcomponents that occur along a spatial continuum (Table 6.1): tectonic setting and physiographic setting describe large, global features, while the level 1 and level 2 geoform subcomponents describe meso- and microscale units (extending down to features at the meter scale). Each subcomponent has a general scale range associated with it, but features within these categories will naturally overlap one another—because of the natural gradients and transitions between geologic units and processes. Similarly, regional differences in processes will cause units to respond differently on spatial and temporal scales (Harris et al. 2005).

There are no mapping scales explicitly associated with the geoform levels. Users should determine a spatial scale for their work based on (a) project objectives and (b) the observational technologies to be employed. Users should then apply the appropriate GC units based on that scale; they are free to use any subcomponent singly or in combination. Modifiers are available to further describe geoform features.

The GC features listed in this document are meant to be an initial list; they are subject to modification as the standard is applied over time. See Appendix D for a table of the GC units and Section 10 for more details on CMECS modifiers.

Table 6.1. Geoform Component Classification Structure.

Geoform Component			
Tectonic Setting Subcomponent	**Physiographic Setting Subcomponent**	**Level 1 Geoform Subcomponent**	**Level 2 Geoform Subcomponent**
List of tectonic settings	List of physiographic settings	*Geoform Origin* *Level 1 Geoform* *Level 1 Geoform Type*	*Geoform Origin* *Level 2 Geoform* *Level 2 Geoform Type*

6.1 Tectonic Setting Subcomponent

At the largest scales, the GC is divided into eight planetary features that reflect global tectonic processes (both past and present). Generally, these features are thousands of square kilometers or larger in size. They include both continental and oceanic crustal units, and the tectonic setting features form the context for all of the smaller-scale geoforms.

- **Abyssal Plain** – A flat region of the deep ocean floor (with a slope less than 1:1,000) that was formed by the deposition of pelagic and gravity-current sediments, which obscure the pre-existing topography. Vast areas of the ocean floor fall within this setting, which can be subdivided into smaller basins based on regional topography.

- **Convergent Active Continental Margin** – Intense areas of active magmatism, where the oceanic lithosphere is subducted beneath the continental lithosphere. This results in chains of volcanoes near the continental margin; the leading edge of the continental plate is usually studded with steep mountain ranges.

- **Divergent Active Continental Margin** – Areas where tensional tectonic forces result in the crustal rocks being stretched and–ultimately—split apart or rifted. These areas are marked by subsidence and a continental rise.

- **Fracture Zone –** An elongate zone of unusually irregular topography (on the deep seafloor) that often separates basins and regions of different depths; fracture zones commonly follow (and extend beyond) offsets of the mid-ocean ridge.

- **Spreading Center** – Spreading centers are areas where tectonic plates are moving apart, allowing new oceanic crust to reach the surface of the sea floor.

- **Mid-Ocean Ridge** – An extremely large, global spreading center. The mid-ocean ridge is a continuous, seismically active, median mountain range extending through the North Atlantic, South Atlantic, Indian, and South Pacific Oceans. It is a broad, fractured swell with a central rift valley and usually extremely rugged topography. The ridge is 1–3 kilometers in height, about 1,500 kilometers in width, and over 84,000 kilometers in length. Sections of this feature are sometimes named based on the ocean region in which this feature occur (for example, Mid-Atlantic Ridge).

- **Passive Continental Margin** – The transition between oceanic and continental crust that is not an active plate margin. This feature was constructed by sedimentation above an ancient rift, now marked by transitional crust. Major tectonic movement is broad, whereas regional vertical adjustment, Earthquakes, and volcanic activity are minor and local.

- **Transform Continental Margin** – A feature defined by the transform fault that develops during continental rifting. These margins differ from rifted or passive margins in two key ways; they have a narrow continental shelf (less than 30 kilometers) and a steep ocean-continent transition zone (Keary et al. 2009).

- **Tectonic Trench** – A narrow, elongate depression of the deep seafloor associated with a subduction zone. These can be oriented parallel to a volcanic arc and are commonly aligned with the edge of the adjacent continent, between the continental margin and the abyssal hills. Trenches are commonly greater than 2 kilometers deeper than the surrounding ocean floor, and they may be thousands of kilometers long.

6.2 Physiographic Setting Subcomponent

Spatially nested within the tectonic settings, physiographic settings describe landscape-level geomorphological features from the coast to mid-ocean spreading centers. These large features—generally on the scale of hundreds of square kilometers—can cross tectonic settings, and they can be delineated at a scale of 1:1,000,000 (or greater) using bathymetric maps and other remote sensing data. Each setting will normally contain a wide variety of the smaller geoform features.

- **Abyssal/Submarine Fan** – A low, outspread, relatively flat–to-gently sloping mass of loose material—shaped like an open fan or a segment of a cone—deposited by a flow of water at the place where it issues from a narrower or steeper-gradient area into a broader area, valley, flat, or other feature. Abyssal fans form at the mouths of submarine canyons, and fans are also the result of turbidities (that is, gravity-driven, underwater avalanches).

- **Barrier Reef** – A long, narrow coral reef, roughly parallel to the shore and separated from it by a lagoon of considerable depth and width. This reef may enclose a volcanic island (either wholly or in part), or it may lie a great distance from a continental coast (such as the Great Barrier Reef). Generally, barrier reefs follow the coasts for long distances—often with short interruptions that are called passes or channels. Three principle examples of this type of feature are

Australia's Great Barrier Reef, the New Caledonia Barrier Reef, and the Meso-American Barrier Reef system—although similar features exist elsewhere.

- **Bight** – A broad bend or curve in a generally open coast. Examples include the South Atlantic Bight and the Southern California Bight. These are distinguished from Embayment/Bays by the shallower angle between the apex of the bight and the adjacent coasts, although the term *Bay* has been used to name these features (e.g., Bay of Campeche).

- **Borderland** – An area of the continental margin (between the shoreline and the continental slope) that is topographically more complex than the continental shelf. This feature is characterized by ridges and basins, some of which are below the depth of the continental shelf.

- **Continental/Island Rise** – An area that lies at the deepest part of a continental or island margin between the continental slope and the abyssal plain. The rise is a gentle incline (with slopes of 0.5° to 1°) and it has generally smooth topography—although it may bear submarine canyons.

- **Continental/Island Shelf** – That part of the continental margin that is between the shoreline and the continental slope (or a depth or 200 meters when there is no noticeable continental slope); it is characterized by its very gentle slope of 0.1°. Island shelves are analogous to the continental shelves, but surround islands.

- **Continental/Island Shore Complex** – This feature includes the land-water interface zone and contains geoforms across a diversity of scales. For CMECS, the supratidal zone forms the landward limit of geoforms found within the shore complex setting. This setting does not include the land-water interface along tidal rivers that may extend a considerable distance inland.

- **Continental/Island Slope** – That part of the continental margin that is between the continental shelf and the continental rise (if there is one); it is characterized by its relatively steep slope of 1.5 - 6°. Island slopes are analogous to the continental slopes, but occur around islands.

- **Embayment/Bay** – A water body with some level of enclosure by land at different spatial scales. These can be wide, curving indentations in the coast, arms of the sea, or bodies of water almost surrounded by land. These features can be small—with considerable freshwater and terrestrial influence—or large and generally oceanic in character.

- **Fjord** – A long, narrow, glacially eroded inlet or arm of the sea. They are often U-shaped, steep-walled, and deep. Because of their depth, they tend to have low surface-area-to-volume ratios. They have moderate watershed-to-water-area ratios and low-to-moderate riverine inputs. Fjords often have a geologic sill formation at the seaward end caused by glacial action. This morphology—combined with a low exchange of bottom waters with the ocean—can result in formation of hypoxic bottom waters.

- **Inland/Enclosed Sea** – A large, water body almost completely surrounded by land. Salinities range from fresh through marine. The term *inland* is used to describe situations where the water body is connected to an adjacent large water body by a narrow strait, channel, canal, or river. Examples of this type of setting are the Mediterranean and Black Seas. The Great Lakes, due to their connectivity to the Atlantic Ocean via the St. Lawrence River also fall into this category.

- **Lagoonal Estuary** – This class of estuary tends to be shallow, highly enclosed, and have reduced exchange with the ocean. They often experience high evaporation, and they tend to be quiescent in terms of wind, current, and wave energy. Lagoonal estuaries usually have a very high surface-to-volume ratio, a low-to-moderate watershed-to-water-area ratio, and can have a high wetland-to-water ratio. The flushing times tend to be long relative to riverine estuaries and embayments because the restricted exchange with the marine-end member and the reduced river input lengthen residence times. As such, there tends to be more benthic-pelagic interaction, enhanced by generally shallow bathymetry. Additionally, exchange with surrounding landscapes (often riparian wetland and palustrine systems) tends to be enhanced and more highly coupled than in other types of estuaries.

  Occasionally, a lagoon may be produced by the temporary sealing of a river estuary by a barrier. Such lagoons are usually seasonal and exist until the river breaches the barrier; these lagoons occur in regions of low or sporadic rainfall.

- **Major River Delta** – The nearly flat, alluvial tract of land at the mouth of a river, which commonly forms a triangular or fan-shaped plain. It is crossed by many distributaries, and the delta is the result of sediment accumulation from the river. Deltas are distinguished from alluvial fans by their flatter slope. Examples of this feature include the Mississippi Delta, the Nile Delta, and the Ganges Delta. All deltas are dynamic areas of mixed-water flow and salinity.

- **Marine Basin Floor** – Basin floors refer broadly to the areas of the seafloor between the base of the continental margin (usually the foot of the continental rise) and the mid-ocean ridge. Occasionally, this large region is subdivided into smaller basins based on local bathymetry.

- **Ocean Bank/Plateau** – A mound-like or ridge-like elevated area on the seafloor; it may have a modest-to-substantial extent. Although submerged, this feature can reach close to sea level (e.g., Bahama Banks).

- **Riverine Estuary** – This class of estuary tends to be linear and seasonally turbid (especially in upper reaches), and it can be subjected to high current speeds. These estuaries are sedimentary and depositional, so they may be associated with a delta, bar, barrier island, and other depositional features. These estuaries also tend to be highly flushed (with a wide and variable salinity range) and seasonally stratified. Riverine estuaries have moderate surface-to-volume ratios with a high watershed-to-water-area ratio—and they can have very high wetland-to-water-area ratios as well. These estuaries are often characterized by a V-shaped channel configuration and a salt wedge.

High inputs of land drainage can promote increased primary productivity, which may be confined to the water column in the upper reach, due to low transparency in the water column. Surrounding wetlands may be extensive and healthy, given the sediment supply and nutrient input. This marsh perimeter may be important in taking up the excess nutrients that are introduced to the system. Physically, the system may tend to be stratified during periods of high riverine input, and the input of marine waters may be enhanced by countercurrent flow.

- **Shelf Basin** – Basins occurring on the continental shelf formed by offshore faulting activity.
- **Shelf Break** – The slope discontinuity (rapid change in gradient) of 3° or greater that occurs at the outer edge of the continental shelf. This boundary generally occurs at a depth between 100–200 meters and forms the boundary between the Marine Offshore and Oceanic Subsystems.
- **Sound** – (a) A relatively long, narrow waterway connecting two larger bodies of water (or two parts of the same water body), or an arm of the sea forming a channel between the mainland and an island (e.g., Puget Sound, WA). A sound is generally wider and more extensive than a strait. (b) A long, large, rather broad inlet of the ocean, which generally extends parallel to the coast (e.g., Long Island Sound, NY).
- **Submarine Canyon** – A general term for all linear, steep-sided valleys on the seafloor. These canyons can be associated with terrestrial or nearshore river inputs, such as in the Hudson or Mississippi canyons.
- **Trench** – Trenches in the physiographic setting subcomponent occur at a smaller spatial scale than the hemispheric-sized trenches in the tectonic setting. Both types of trenches share similar morphology, but physiographic setting Trenches are not necessarily associated with plate subduction.

6.3 Level 1 and Level 2 Geoform Subcomponent Hierarchical Structure

The Level 1 and Level 2 geoform subcomponents have the same structure and are composed of three hierarchical levels that describe the origin of the geoform (Geoform Origin), the geoform structure (Geoforms), and specific types of geoforms (Geoform Type).

Geoform Origin
With the exception of major barrier reef complexes (e.g., the Great Barrier Reef), the tectonic and physiographic setting units are the result of geologic activity and physical processes. Geoforms, on the other hand, are spatially smaller and can be created by a variety of means, which are important to understanding their history and ecology. In CMECS, the three major geoform origin types—geologic, biogenic, and anthropogenic—are based on the processes that created the physical features reflected in the geoform units. Note that (a) a designation of biologic geoform does not infer the presence of living biota (which is captured in the Biotic Component) and (b) anthropogenic geoforms do not imply any particular human use at the time of observation.

6.3.1 Level 1 and Level 2 Geoforms

Geoforms are physical, coastal and seafloor structures that are generally no larger than hundreds of square kilometers in size. This size determination may be an areal extent or a linear distance. Larger geoforms (Level 1) are generally larger than one square kilometer, and correspond to Megahabitats in the Greene et al. classification system (2007). These features can be defined using geologic or geomorphic maps and bathymetric images of the seafloor at map scales of 1:250,000 or less. Smaller geoforms (Level 2) are generally less than one square kilometer in size (or less than 1 kilometer in distance); and correspond to Meso- and Macro-habitats in the Greene et al. system. Level 2 geoforms (such as individual coral reefs, tide pools, and sand wave fields) can be identified through *in-situ* observational methods (such as underwater videography) or through low-altitude, high-resolution optical or acoustic remote sensing.

Level 1 and Level 2 geoforms are arranged as two separate subcomponents so that they can be used in tandem to describe complex spatial patterns of geoform structures. Level 2 geoforms normally occur as portions of—or smaller features contained (nesting) within—Level 1 geoforms, but are not hierarchically constrained by the Level 1 geoforms. It is possible for geoforms at either level to nest within other units within their same level (for example, a Level 2 pockmark may occur within a Level 2 shoal/bar as in Figure 6.1 below).

6.3.2 Geoform Types

Geoform types are varieties of geoforms that provide further information on morphology and physical processes underway at any individual geoform. Users are encouraged to apply the Type designations where applicable—but they are not required to use it if their data do not support this level of detail. Users are also encouraged to provide the full nesting (recording of upper-level attributes) for any geoforms they identify, although there will be many instances where this is not practical.

Figure 6.1. Level 2 Pockmarks Occurring on a Small, Level 2 Tidal Flat.

6.4 Level 1 and Level 2 Geoform Units

Although Level 1 and Level 2 geoforms are considered different subcomponents because of their scale differences, they share the same hierarchical structure and some units are found in both levels (if they occur over a broad range of sizes). For brevity, we have combined the definitions of these units into one listing and have indicated the subcomponent(s) in which they reside.

Geoform Origin: Geologic

Geologic geoforms are formed by the abiotic processes of uplift, erosion, volcanism, deposition, fluid seepage, and material movement. Uplift may be a result of local and regional seismic and tectonic processes. Waves, currents, wind, chemical dissolution, seismic motion, and chemical precipitation all contribute to these geoforms and give them their distinctive qualities.

- **Geoform: Apron (Level 1)** – An extensive, subaqueous, blanket-like deposit of alluvial, unconsolidated material that is derived from an identifiable source and deposited at the base of a mountain or seamount.

- **Geoform: Bank (Level 1)** – An elevated area above the surrounding seafloor that rises near the surface. Banks generally are low-relief features, of modest-to-substantial extent, that normally remain submerged. They may have a variety of shapes and may show signs of erosion resulting from exposure during periods of lower sea level. Banks tend to occur on the continental shelf. Banks differ from shoals in having greater size and temporal persistence. The Geoform Bank differs from the Coral Reef Zone modifier Bank based on its geologic origin.

- **Geoform: Bar (Levels 1 & 2)** – A relatively shallow place (in a stream, lake, sea, or other body of water) that is typically a submerged ridge, or bank consisting of (or covered) by sand or other unconsolidated material—but may also be composed of rock or other material (modified from Jackson 1997).

    - **Geoform Type: Bay Mouth Bar (Level 1 only)** – A bar of sand or gravel extending partially or entirely across the mouth of a bay. It usually connects two headlands, thus straightening the coast.

    - **Geoform Type: Longshore Bar (Level 1 only) –** A low sand ridge, built chiefly by wave action, occurring at some distance from and generally parallel with the shoreline, being submerged at least by high tides, and typically separated from the beach by an intervening trough.

    - **Geoform Type: Point Bar (Level 2 only) –** Low, arcuate, subaerial ridges of sand developed adjacent to an inlet and formed by the lateral accretion or movement of the channel.

    - **Geoform Type: Relict Longshore Bar (Level 2 only) –** A narrow, elongate, coarse-textured ridge that once rose near to, or barely above, a pluvial or glacial lake or other body of water and extended generally parallel to the shore but was separated from it by an intervening trough or lagoon; both the bar and lagoon are now relict features (Jackson 1997).

- **Geoform: Basin (Level 1)** – General term for an area of the seafloor or land surface that lies below the surrounding bottom or terrain elevation. They are normally areas of low relief.

- **Geoform: Beach (Levels 1 & 2)** – A gently sloping zone formed by unconsolidated material at the shoreline, typically with a concave profile. This zone extends landward from the low-water line to either (a) the place where there is a definite change in material or physiographic form (such as a cliff) or (b) the line of permanent vegetation. Only those portions of the beach within the splash zone would be within the CMECS system; areas of the beach further inland are terrestrial systems.

    - **Geoform Type: Barrier Beach (Levels 1 & 2)** – A narrow, elongate, coarse-textured, intertidal, sloping landform that is generally parallel with the beach ridge component of the barrier island (or a spit), and which is adjacent to the ocean (Jackson 1997; Peterson 1981).

    - **Geoform Type: Mainland Beach (Levels 1 & 2)** –Any beach that is connected to the mainland, whether fronting bluffs, dunes, or extensive marshes.

- **Geoform Type: Pocket Beach (Level 2 only)** – A small beach between two headlands. Because of this isolation, there is very little—or no—exchange of sediment between the pocket beach and the adjacent shorelines.

- **Geoform Type: Tide-Modified Beach (Levels 1 & 2)** – Beaches that occur in areas of high tide range (3–15 times the wave height) and usually lower waves (less than 0.3 meter). Tide-modified beaches include reflective beaches with a low-tide terrace, reflective beaches with bars and rips, and ultra dissipative beaches.

- **Geoform Type: Tide-Dominated Beach (Levels 1 & 2)** – Beaches that occur in areas of high tide range (10–15 times the wave height) and usually lower waves; wave height is very low. Tide-dominated beaches include reflective beaches with sand ridges, reflective beaches with sand flats, reflective beaches with tidal sand flats, reflective beaches with tidal mud flats, and reflective beaches with rock flats.

- **Geoform Type: Wave-Dominated Beach (Levels 1 & 2)** – Beaches that are exposed to persistent ocean swell, waves, and low tides (range of less than 2 meters). Wave-dominated beaches include reflective beaches, intermediate beaches, and dissipative beaches (Short 2006).

- **Geoform: Beach Berm (Levels 1 & 2)** – The natural bench or platform lying below the main beach slope and above the foreshore.

- **Geoform: Boulder Field (Level 1)** – An area dominated by large, boulder-sized (256 millimeters – 4,096 millimeters) stones or pieces of rock. These can occur below cliffs or at the foot of steep slopes or canyons, where they are the result of depositional processes. These fields can also occur as the result of currents that have removed the finer sediments.

- **Geoform: Cave (Level 2)** – A natural passage extending beneath the Earth's surface.

- **Geoform: Channel (Levels 1 & 2)** – A general term for a linear or sinuous depression on an otherwise more flat area (for example, a valley- or groove-like feature through which water flows). This is a very broad term that is often used in connection with other terms to provide more meaning.

    - **Geoform Type: Pass/Lagoon Channel (Level 2 only)** – A generally narrow passage way, open on both ends, through a shoal. In coral reef settings this feature connects the lagoon with the open ocean or bay.

    - **Geoform Type: Sand Channel (Level 2 only)** –These are narrow passages between, and in association with, pavement formations commonly oriented perpendicular to the shore. The bottoms of these channels normally consist of sand or other unconsolidated mineral substrates. They occur in areas of moderate wave surge and have low vertical relief as compared to spur-and-groove formations.

- **Geoform Type: Slough (Level 1)** – (a) A sluggish body of water in a tidal flat, bottomland, or coastal marshland; may also be called bayous or oxbows. (b) A sluggish channel of water (such as a side channel of a river) in which water flows slowly through either low, swampy ground (such as along the Columbia River) or a section of an abandoned river channel (which may contain stagnant water) that occurs in a flood plain or delta.
- **Geoform Type: Tidal Channel/Creek (Levels 1 & 2)** – Linear or sinuous body of water through which ebb-and-flood tidal movement takes place. Smaller tidal creeks often branch off of these features. Portions of tidal channels may be intertidal or completely subtidal.

- **Geoform: Cone (Levels 1 & 2)** – (a) A type of submarine, fan-shaped deposit—especially a deep-sea fan associated with a major active delta (such as deltas of the Mississippi, Nile, and Ganges Rivers). (b) A formation resulting from the extrusion of material onto the surrounding seabed (e.g., a volcanic cone).

- **Geoform: Cove (Levels 1 & 2)** – A small, narrow, sheltered bay or recess in an estuary; often found inside a larger embayment (modified from Jackson 1997).

  - **Geoform Type: Barrier Cove (Levels 1 & 2)** – A subaqueous area adjacent to a barrier island (or submerged barrier beach) that forms a minor embayment or cove within the larger basin.
  - **Geoform Type: Mainland Cove (Levels 1 & 2)** – Small embayment or narrow indentation in a mainland coast. These coves usually have narrow entrances and are circular or oval in shape.

- **Geoform: Delta (Levels 1 & 2)** – The low, nearly flat, alluvial tract of land at (or near) the mouth of a river. Deltas commonly form a triangular or fan-shaped plain of considerable area, which is crossed by many distributaries of the main river; deltas may extend beyond the general trend of the coast, and occur as a result of the accumulation of river sediment supplied in such quantities that it is not removed by tides, waves, and currents.

  - **Geoform Type: Glacial (Kame) Delta (Level 1 only)** – A landform made by a stream flowing through glacial ice and then depositing material as it enters a lake or pond at the end (or terminus) of the glacier. This delta is distinctive because it has been sorted by the action of the stream. This landform may often be observed after the glacier has melted. As the glacier melts, the edges of the delta may subside (as ice under it melts); additionally, glacial till may be deposited in the lateral or side area of the delta from the melting glacier.

- **Geoform Type: Ebb Tidal Delta (Level 2 only)** – A largely subaqueous (although sometimes intertidal), crudely fan-shaped delta with sand-sized sediment, which has been formed on the seaward side of a tidal inlet (modified from Boothroyd et al. 1985; Davis 1994; Ritter, Kochel, and Miller 1995).
- **Geoform Type: Flood Tidal Delta (Level 2)** – Equivalent to an Ebb Tidal Delta, except that this delta occurs on the landward side of a tidal inlet (modified from Boothroyd et al. 1985; Davis 1994; Ritter et al. 1995). Flood tides transport sediment through the tidal inlet, over a flood ramp where currents slow and dissipate before entering the lagoon (Davis 1994). Generally, flood tidal deltas along microtidal coasts are multi-lobate and unaffected by ebbing currents (modified from Davis 1994).
- **Geoform Type: Flood Tidal Delta Slope (Level 2 only)** – The sloping surfaces found at the edge of the tidal delta.
- **Geoform Type: Levee Delta (Levels 1 & 2)** – A delta having the form of a long, narrow ridge that resembles a natural levee.

- **Geoform: Delta Plain (Level 1 only)** – The level (or nearly level) surface that makes up the landward part of a large delta; strictly, a flood plain characterized by repeated channel bifurcation and divergence, multiple distributary channels, and interdistributary flood basins.

- **Geoform: Depression (Level 2)** – General term for any relatively sunken part of the Earth’s surface—especially a low-lying area surrounded by higher ground. Depressions often have no natural outlet for surface drainage (such as an interior basin or a karstic sinkhole) (Jackson 1997).

  - **Geoform Type: Scour Depression (Level 2 only)** – Depression formed by the abrasive action of sand or sediment driven by the movement of water or ice.

- **Geoform: Diapir (Levels 1 & 2)** – A dome or anticlinal fold in which the overlying rocks or sediments have been ruptured when the plastic core material was squeezed out. Diapirs in sedimentary strata usually contain cores of salt or shale; igneous intrusions may also show diapiric structure.

  - **Geoform Type: Salt Dome (Levels 1 and 2)** – A diaper formed by the intrusion of salt into surrounding rocks.

- **Geoform: Dike (Level 2)** – A tabular, igneous intrusion that cuts across the bedding or foliation of the country rock. Dikes are often more resistant to erosion than the surrounding country rock, and dikes can form long ridges.

- **Geoform: Drumlin Field (Level 1)** – Groups or clusters of closely spaced drumlins or drumlinoid ridges, distributed more or less en echelon, and commonly separated by small, marshy tracts or depressions (interdrumlins).

- **Geoform: Drumlin (Level 2)** – Drumlins are products of the streamline (laminar) flow of glaciers, which molded the subglacial floor through a combination of erosion and deposition. A drumlin is a low, smooth, elongated-oval hill, mound, or ridge of compact till, which has a core of bedrock or drift. A drumlin usually has a blunt nose facing the direction from which the ice approached, and a gentler slope tapering in the other direction. The longest axis is parallel to the general direction of glacier flow.

- **Geoform: Dune Field (Level 1)** – An assemblage of moving and/or stabilized dunes; sand plains; interdune areas; and the ponds, lakes, or swamps produced by the blocking of waterways by migrating dunes (U.S. Department of Agriculture 2008).

- **Geoform: Dune (Level 2)** – An active accumulation of sand (formed by wind action) with some elevation; dunes occur on a beach or further inland.

- **Geoform: Fan (Levels 1 & 2)** – A low, outspread gently to steeply sloping mass of loose material, which is shaped like an open fan or a segment of a cone. Fans are made of material deposited by a flow of water at the place where it issues from a narrower or steeper gradient area into a broader area, valley, flat, or other feature.

    - **Geoform Type: Alluvial Fan (Level 1 only)** – A low, outspread, relatively flat (or gently sloping) mass of loose rock material, shaped like an open fan or a segment of a cone. The rock material was deposited by flowing water where it issues from a narrow valley or where the gradient abruptly changes. Alluvial fans are usually steeper than the surrounding surface.
    - **Geoform Type: Basin Floor Fan (Level 1 only)** – Deposition of submarine fans on the lower slope or basin floor; fan formation is associated with the erosion of canyons into the slope and the incision of fluvial valleys into the shelf. Siliciclastic sediment bypasses the shelf and slope through the valleys and canyons to feed the basin floor fan; sediment may be deposited at the mouth of a canyon or in an area widely separated from the canyon mouth—or a canyon may not be evident.

    - **Geoform Type: Shoreline Fan (Level 1 only)** – A prograding shoreline formed where an alluvial fan is built out into a lake or sea.
    - **Geoform Type: Washover Fan (Levels 1 & 2)** – A fan-like landform of sand that washed over a barrier island or spit during a storm, and then deposited sand on the landward side. Washover fans can be small

and completely subaerial—or they can be quite large and include subaqueous margins that extend into adjacent lagoons or estuaries. Large fans can composed of ephemeral washover channels (micro feature) cut through dunes or beach ridges, back barrier flats, (subaqueous) washover fan flats, and (subaqueous) washover fan slopes. Subaerial or intertidal portions can range from barren to completely vegetated (U.S. Department of Agriculture 2008).

- **Geoform: Flat (Levels 1 & 2)** – A general term for a level (or nearly level) surface or area of land marked by little or no relief; flats are often composed of unconsolidated sediments (such as mud or sand). These forms are more commonly encountered in the intertidal or in the shallow subtidal zones (see Figure 6.2).
    - **Geoform Type: Back Barrier Flat (Level 1 only)** – A subaerial, gently sloping landform on the lagoon side of the barrier beach ridge. These flats are composed predominantly of sand washed over (or through) the beach ridge during tidal surges (modified from Jackson 1997).
    - **Geoform Type: Barrier Flat (Level 1 only)** – A relatively flat, low-lying area that is separating the exposed (or seaward) edge of a barrier beach or barrier island from the lagoon behind it. Barrier flats commonly include pools of water, and may be barren or vegetated. These flats are an assemblage of both deflation flats left behind migrating dunes and/or storm washover sediments.
    - **Geoform Type: Ebb Tidal Delta Flat (Level 2 only) –** The relatively flat, dominant component of the ebb tidal delta. At extreme low tide, this landform may be exposed for a relatively short period (U.S. Department of Agriculture 2008).
    - **Geoform Type: Flood Tidal Delta Flat (Level 2 only)** – The relatively flat, dominant component of the flood tidal delta. At extreme low tide, this landform may be exposed for a relatively short period (U.S. Department of Agriculture 2008).
    - **Geoform Type: Tidal Flat (Levels 1 & 2)** – An extensive, nearly horizontal, barren (or sparsely vegetated) tract of land that is alternately covered and uncovered by the tide. Tidal flats consist of unconsolidated sediment (mostly clays, silts and/or sand, and organic materials).
    - **Geoform Type: Washover Fan Flat (Level 1 only)** – A gently sloping, fan-like, subaqueous landform created by overwash from storm surges that transports sediment from the seaward side to the landward side of a barrier island (Jackson 1997). Sediment is carried through temporary overwash channels that cut through the dune complex on the barrier spit (Fisher and Simpson 1979; Boothroyd et

al. 1985; Davis 1994) and spill out onto the lagoon-side platform, where they coalesce to form a broad belt. Also called Storm-Surge Platform Flat (Boothroyd et al. 1985) and Washover Fan Apron (Jackson 1997).

- **Geoform Type: Wind Tidal Flat (Level 1 only)** – A broad, low-lying, nearly level sand flat that is alternately flooded by ponded rainwater or inundated by wind-driven marine and estuarine waters. Salinity fluctuations and prolonged periods of exposure preclude establishment of most types of vegetation (except for mats of filamentous blue-green algae).

Figure 6.2. Wind Tidal Flat: Lower Laguna Madre, Texas.

- **Geoform: Fluvio-Marine Deposit (Levels 1 & 2)** – Stratified materials (clay, silt, sand, or gravel) formed by both marine and fluvial processes, resulting from non-tidal sea-level fluctuations, subsidence, and/or stream migration (e.g., materials originally deposited in a nearshore environment and subsequently reworked by fluvial processes as the sea level fell).

- **Geoform: Fracture (Levels 1 & 2)** – A crack or split formed in a rock or bedrock as a result of local erosion or rock stress; they are not due to tectonic actions (which form larger faults and fracture zones).

- **Geoform: Hole/Pit (Level 2)** – A generally more steep- sided indentation or depression that is lower than the surrounding surface formed through a variety of processes.

- **Geoform Type: Scour Hole (Level 2 only)** – A hole formed by the powerful and concentrated clearing and digging action of flowing air, water, or ice—especially the downward erosion by stream water (in sweeping away mud and silt on the outside curve of a bend) or during the time of a flood.
- **Geoform Type: Solution Hole/Pit (Level 2 only)** – An indentation formed on a rock surface by a solution.

- **Geoform: Hydrothermal Vent Field (Levels 1 & 2)** – An area where several hydrothermal vents, either active or inactive, are present.

- **Geoform: Hydrothermal Vent (Level 2)** – Structures on the seafloor through which materials related to volcanic activity are extruded. These often form tall, chimney-like structures and can support diverse chemosynthetic biota and associated communities.

- **Geoform: Inlet (Levels 1 & 2)** – Inlets are narrow constrictions through which water flows. The term is commonly used to describe gaps between barrier islands that allow tidal exchange with the adjacent—more enclosed—bays, lagoons, or marshes.

  - **Geoform Type: Tidal Inlet (Level 1 only)** – Any inlet through which water alternately floods landward, with the rising tide, and ebbs seaward, with the falling tide (Jackson 1997).
  - **Geoform Type: Relict Tidal Inlet (Level 1 only)** – A channel remnant that is left from a former tidal inlet. The channel was cut off or abandoned by infilling from migrating shore sediments.

- **Geoform: Island (Levels 1 & 2)** – An area of land completely surrounded by water—or an elevated area of land surrounded by swamp or marsh, which is isolated at high water or during floods.

  - **Geoform Type: Barrier Island (Levels 1 & 2)** – A long, narrow, sandy island that is above high tide and parallel to the shore. Barrier islands commonly have dunes, vegetated zones, and swampy or marshy terrains extending lagoon-ward from the beach.

- **Geoform: Karren (Level 2)** – Repeating, surficial solution channels, grooves, or other forms that are etched onto massive, bare limestone surfaces; types range in depth from a few millimeters up to one meter, and they are separated by ridges May also refer to the total complex (all varieties) of surficial solution forms found on compact, pure limestone (U.S. Department of Agriculture 2008).

- **Geoform: Knob (Level 2)** – A rounded protuberance, usually prominent or isolated with steep sides; also including peaks or other projections from seamounts, or a groups of boulders, or other protruding areas of resistant rocks

- **Geoform: Lagoon (Levels 1 & 2)** – Lagoons tend to be shallow, highly enclosed, with reduced exchange with the ocean, often experiencing high evaporation, and quiescent in terms of wind, current, and wave energy. They tend to have a very high surface to volume ratio, low to moderate watershed to water area ratio and can have a high wetland to water ratio. The flushing times tend to be long relative to riverine estuaries and even embayments, as the restricted exchange with the marine end member and reduced river input lengthen residence times.

- **Geoform: Lava Field/Plain (Level 1)** – A relatively well-defined area that is covered by lava flows. These can be found either along the coast or in deeper water. Terrain in lava fields can be rough and broken or it can be relatively smooth; the terrain can also include vent structures (e.g., small cinder cones or spatter cones), surface flow structures (e.g., pressure ridges or tumuli), and small, intermittent areas covered with pyroclastics.

- **Geoform: Ledge (Levels 1 & 2)** – Bedding planes that are exposed (either on the surface or at depth) often form ledges that have a high habitat value and support colonizing plants and animals. Ledges often provide a more level surface than the bounding slopes. Ledges in the intertidal zone can form shelves or projections of rock (that are much longer than they are wide) on a rock wall or cliff face. They are formed along a coast by differential wave action on softer rocks and may be eroded by biological and chemical weathering.

- **Geoform: Marine Lake (Level 1)** – An inland body of permanently standing brackish or saline water whose water level is commonly influenced by ocean tides through subterranean cavities connecting to nearby lagoons. The lake is generally of appreciable size (larger than a pond) and too deep to permit emergent vegetation to take root completely across the expanse of water. Such water bodies can have unique biota (e.g., the stingless jellyfish of Palau).

- **Geoform: Marsh Platform (Levels 1 & 2)** – The flat, often thick, accumulation of peat that supports emergent marsh vegetation. It is commonly dissected by tidal creeks, and it is occasionally buried and re-exposed through the action of beach erosion and new inlet development.

- **Geoform: Megaripples (Level 1)** – Large, sand waves or ripple-like features having wavelengths greater than 1 meter or a ripple height greater than 10 centimeters; Megaripples are formed in a subaqueous environment, and they are also known as subaqueous dunes. They may be superimposed with smaller bedforms (Bates and Jackson 1984).

- **Geoform: Moraine (Level 1)** – A mound, ridge, or other distinct accumulation of unsorted, unstratified, glacial drift (predominantly till) that is deposited chiefly by direct action of glacier ice.

- **Geoform Type: Disintegration Moraine (Level 1)** – A drift topography characterized by chaotic mounds and pits (generally randomly oriented) developed in supraglacial drift by collapse and flow as the underlying stagnant ice melted. Slopes may be steep and unstable, and there will be used and unused stream courses and lake depressions interspersed with the morainic ridges. Characteristically, there are numerous abrupt changes (lateral and vertical) between unconsolidated materials of differing lithology.
- **Geoform Type: End Moraine (Level 1)** – A ridge-like accumulation that is being (or was) produced at the outer margin of an actively flowing glacier at any given time; a moraine that has been deposited at the outer or lower end of a valley glacier.
- **Geoform Type: Ground Moraine (Level 1)** – An extensive, low-relief area of till, that has an uneven or undulating surface and is commonly bounded on the distal end by a recessional or end moraine. Ground moraines usually consist of poorly sorted rock and mineral debris (till), which has been dragged along, in, on, or beneath a glacier, and then deposited by basal lodgment and release from downwasting stagnant ice by ablation.
- **Geoform Type: Kame Moraine (Level 1)** – An end moraine that contains numerous kames, commonly comprising the slumped or erosional remnants of a formerly continuous outwash plain that built up over the foot of rapidly wasting or stagnant ice.
- **Geoform Type: Lateral Moraine (Level 1)** – A ridge-like moraine carried on (and deposited at) the side margin of a valley glacier. It is composed chiefly of rock fragments derived from valley walls by either glacial abrasion and plucking or colluvial accumulation from adjacent slopes.
- **Geoform Type: Recessional Moraine (Level 1)** – An end or lateral moraine, built during a temporary—but significant—halt in the final retreat of a glacier. May also refer to a moraine built during a minor re-advance of the ice front during a period of general recession.
- **Geoform Type: Terminal Moraine (Level 1)** – An end moraine that marks the farthest advance of a glacier; usually has the form of a massive arcuate or concentric ridge (or complex of ridges) underlain by till and other drift types.

- **Geoform: Mound/Hummock (Levels 1 & 2)** – A low, rounded, natural hill of unspecified origin, which is generally less than 3 meters high and composed of Earthy material.

    - **Geoform Type: Tar Mound (Level 2 only)** – A mound of extruded tar (or other viscous hydrocarbons) on the seafloor that has some relief above the surrounding bottom. Tar mounds in southern California are typically 10 - 100 meters in diameter and can coalesce to form tar reefs. Over time, tar mounds can come to support a diversity of colonizing organisms (Lorenson et al. 2009).

- **Geoform: Mud Volcano (Level 2)** – An accumulation (usually conical in shape) of mud and rock formed by volcanic gases; may also refer to a similar accumulation formed by escaping petroliferous gases (Bates and Jackson 1984) (see Figure 6.3).

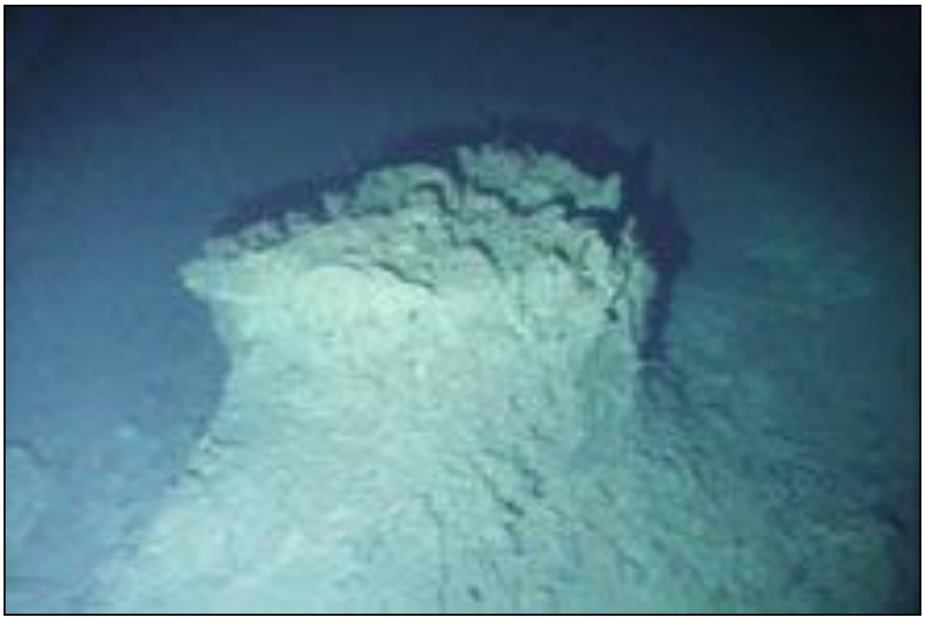

Figure 6.3. Mud Volcano.

- **Geoform: Natural Levee (Level 1)** – An embankment of sediment, bordering one or both sides of a submarine canyon, fan valley, deep-sea channel, river, or other feature. A natural levee has a long, broad, low shape and is composed of sand and coarse silt, which was built by a stream on its flood plain and along both sides of its channel—especially in time of flood when water overflowing the normal banks is forced to deposit the coarsest part of its load. It has a gentle slope away from the river and toward the surrounding floodplain, and its highest elevation is closest to the river bank.
    - **Geoform Type: Lava Levee (Level 1)** – The scoriaceous sheets of lava that overflowed their natural channels and solidified to form a levee, similar to levees formed by an overflowing stream of water.
- **Geoform: Overhang (Cliff) (Levels 1 & 2)** – A rock mass jutting out from a slope, especially the upper part or edge of an eroded cliff projecting out over the lower, undercut part (as above a wave-cut notch). Generally these are characterized as having a slope greater than 90 degrees.

- **Geoform: Panne (Level 2)** – Shallow depressions or flats, often occurring in and adjacent to marshes in the high intertidal that zone that receive saltwater inflow on an infrequent basis. They often are unvegetated and can have encrustations of salt left by evaporation.

- **Geoform: Pavement Area (Levels 1 & 2)** – Flat (or gently sloping), low-relief, solid, carbonate rock with little or no fine-scale rugosity. These areas can be covered with algae, hard coral, gorgonians, zooanthids, or other sessile vertebrates; the coverage may be dense enough to partially obscure the underlying surface. On less colonized pavement features, rock may be covered by a thin sand veneer (Kendall et al. 2001).

- **Geoform: Platform (Levels 1 & 2)** – Any level or nearly level surface, ranging in size from a terrace or bench to a plateau defined by slopes around its edges.

    - **Geoform Type: Wave-Cut Platform (Level 1 only)** – A gently sloping surface produced by wave erosion, which extends into the sea or lake from the base of the wave-cut cliff. When subaqueous, they are relict, erosional landforms that originally formed as a wave-cut bench and abrasion platform (from coastal wave erosion), which were later submerged by rising sea level or subsiding land surface (modified from Jackson 1997).

- **Geoform: Pockmark Field (Level 1)** – An area of the seafloor dominated by many pockmarks.

- **Geoform: Pockmark (Level 2)** – Small craters in the seabed caused by fluids (gas and liquids) erupting and streaming through the sediments. Some pockmarks discovered off Nova Scotia have been up to 150 meters in diameter and 10 meters deep.

- **Geoform: Ridge (Levels 1 & 2)** – A long, narrow elevation, usually sharp crested with steep sides. Larger ridges can form an extended upland between valleys.

    - **Geoform Type: Beach Ridge (Levels 1 & 2)** – A low, essentially continuous mound of beach (or beach-and-dune material) heaped up by the action of waves and currents on the backshore of a beach, beyond the present limit of storm waves or the reach of ordinary tides. The ridge can occur singly or as one of a series of approximately parallel deposits. The ridges are roughly parallel to the shoreline and represent successive positions of an advancing shoreline.

    - **Geoform Type: Esker (Levels 1 & 2)** – A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified sand and gravel that was deposited as the bed of a stream flowing in a subglacial ice tunnel (within or below the ice) or between ice walls on top of the ice of a wasting glacier. Eskers remain behind as high ground when the glacier melts. Eskers range in length from less than a kilometer to more than 160 kilometers, and the height range is 3 - 30 meters.

- **Geoform: Ripples (Level 2)** – Small, linear structures that form as a result of water movement over unconsolidated sediments. The shape and pattern of the ripples provide indications of the general water movement regime in the area. Ripples can be straight, sinuous, catenary, or linguoid.

- **Geoform: Rock Outcrop (Levels 1 & 2)** – An area where bedrock is exposed at the Earth's surface.

    - **Geoform Type: Authigenic Carbonate Outcrop (Level 2 only)** – These outcrops result from the slow seepage of fluid containing dissolved carbon. They form pavements, chimneys, and rings, donuts, or slabs (Stakes et al. 1999).

- **Geoform: Rubble Field (Level 1)** – A loose mass of angular rock fragments. These can occur both on land and underwater.

- **Geoform: Runnel/Rill (Level 2)** – A small, transient channel carrying the water of a wave after it breaks on a beach. They can also be formed by tidal ebb or runoff (following moderate rains or ice/snow melts). Larger runnels can have steep sides.

- **Geoform: Sediment Wave Field (Levels 1 & 2)** – An area of wave-like bedforms in sand or other unconsolidated material which are formed by the action of tides, currents, or waves. These bedforms range from centimeters to meters in size and may be superimposed on larger features. Sand waves lack the deep scour associated with dunes or megaripples (Bates and Jackson 1984).

- **Geoform: Scarp/Wall (Levels 1 & 2)** – A relatively straight, cliff-like face or slope of considerable linear extent, which breaks up the general continuity of the land by separating surfaces lying at different levels (as along the margin of a plateau or mesa).

  The term wall can be applied to steep or vertical areas on the seaward or exposed side of a reef. Although hard corals may be present, walls in this setting are formed by geologic processes and are not the result of reef-building activities by corals. A wall may be vertical or terraced, and is often referred to as the "drop-off."

    - **Geoform Type: Fault Scarp (Levels 1 & 2)** – A feature caused by the rapid erosion of soft rock on the side of a fault (as compared to that of more resistant rock on the other side), for example, the east face of the Sierra Nevada in California.

  - **Geoform Type: Erosion Scarp (Levels 1 & 2)** – A long, steep slope or line of cliffs at the edge of a plateau or ridge formed by erosion.
  - **Geoform Type: Beach Scarp (Levels 1 & 2)** – An almost vertical slope (caused by wave erosion) that fronts a berm on a beach. Scarps may range in height from several centimeters to a few meters, depending on the character of the wave action and the nature and composition of the beach.

- **Geoform: Scar (Levels 1 & 2)** – A scar can be either a gouge or deformation of the bottom, or an area where the surface of the substrate, vegetation, or other colonizing organisms have been removed by abrasion or impact. These may be temporary or permanent features.
  - **Geoform Type: Iceberg Scour Scar/Furrow (Levels 1 & 2)** – A scar formed by an iceberg dragging across the substrate. These can occur in shallow water and extend for long distances.
  - **Geoform Type: Slump Scar (Levels 1 & 2)** – A scar formed by the removal of surface sediment as a result of mass wasting. These scars have the appearance of fresh, unweathered, or colonized sediment.

- **Geoform: Seamount (Level 1)** – An elevation of the seafloor, which is 1,000 meters or higher. Seamounts may be discrete, arranged in a linear or random grouping, or connected at their bases and aligned along a ridge or rise.
  - **Geoform Type: Guyot (Level 1)** – A type of seamount that has a flat top.
  - **Geoform Type: Knoll Seamount (Level 1)** – A submerged elevation of rounded shape that rises from the ocean floor, but is less prominent than a seamount.
  - **Geoform Type: Pinnacle Seamount (Level 1)** – A steep-sided, often isolated peak that can occur at depth or reach close to the surface. They are often important aggregation points for fish and other marine life.

- **Geoform: Sediment Sheet (Level 2)** – A thin, widespread, sedimentary deposit, formed by a transgressive sea advancing for a considerable distance over a stable shelf area; may also be called a blanket deposit (Bates and Jackson 1984).

- **Geoform: Shelf Valley (Level 1)** – A valley crossing the continental shelf, often forming an extension of an existing terrestrial river and terminating in a canyon as the valley reaches the shelf break. Shelf valleys were formed during periods of lower sea level, and continental, glacial melt water contributed to their genesis.

- **Geoform: Shoal (Levels 1 & 2)** – A relatively shallow area in a body of water that rises very close to, or reaches, the surface. Shoals have a variety of shapes that are influenced by tidal and river currents. They tend to consist of (or be covered by) sand or other unconsolidated sediments, but may also be composed of rock or other materials. Unlike banks, shoals can be exposed during low tide or periods of low water flow in rivers or streams (modified from Jackson 1997).

- **Geoform Type: Moraine Shoal (Levels 1 & 2)** – The submerged portion of a glacial moraine that reaches close to the surface. These often occur where sea-level rise has drowned former terrestrial glacial features.

- **Geoform: Shore Complex (Level 1)** – Generally a narrow, elongate area that parallels a coastline—commonly cutting across diverse inland landforms. Shore complexes are dominated by landforms derived from active coastal processes that give rise to beach ridges, washover fans, beaches, dunes, wave-cut platforms, barrier islands, cliffs, etc. (Schoeneberger and Wysocki 2005).

- **Geoform: Shore (Levels 1 & 2)** – The intersection of a specified plane of water with the beach that migrates with changes of the tide or of the water level.

  - **Geoform Type: Foreshore (Levels 1 & 2)** – The zone of the shore or beach that is regularly covered and uncovered by the rise and fall of the tide.
  - **Geoform Type: Backshore (Levels 1 & 2)** – The upper or inner zone of the shore or beach that is above the high-water line of mean spring tides and below the upper limit of shore-zone processes. The backshore is usually dry or moistened by spray, and is acted upon by waves (or covered by water) only during exceptionally severe storms or unusually high tides. It is essentially horizontal or slopes gently landward, and it is divided from the foreshore by the crest of the most seaward berm.

- **Geoform: Slope (Levels 1 & 2)** – An inclined area of ground or substrate with a change in depth or elevation between its upper and lower limits. Slopes occur at all scales and can refer to broad areas of inclined topography to the flanks of small mounds or depressions in the Earth's surface.

  - **Geoform Type: Washover Fan Slope (Level 1 only)** – A subaqueous extension of a washover fan flat, which slopes toward deeper water of a lagoon or estuary and away from the washover fan flat.

- **Geoform: Spit (Level 1)** – (a) A small point, low tongue, or narrow embankment of land, which commonly consists of sand or gravel deposited by longshore transport. One end of the spit is attached to the mainland, and the other terminates in open water (usually the sea); a spit is a finger-like extension of the beach. (b) A relatively long, narrow shoal or reef extending from the shore into a body of water (Jackson 1997).

- **Geoform: Stack (Level 2) –** A rocky subaerial landform consisting of a steep (and often vertical) column or columns of rock in the sea near a coast which have been isolated from the mainland by wave erosion.

- **Geoform: Submarine Slide Deposit (Level 1)** – This form includes a wide variety of mass-movement landforms and processes involving the down slope transport (under gravitational influence) of soil and rock material *en masse*. Geoforms that could occur within (or as a result of) landslides are Rubble Field**.**

- **Geoform: Swale/Slack (Level 2)** – A long, narrow, generally shallow trough-like depression between two beach ridges and aligned roughly parallel to the coastline. These typically will be found in the intertidal or supratidal zones.

- **Geoform: Terrace (Level 1)** – Any long, narrow, relatively level or gently inclined surface, generally less broad than a plain, but broader than a ledge and bounded along one edge by a steeper descending slope and along the other by a steeper ascending slope. Terraces may border a valley floor or shoreline, and they can represent the former position of a flood plain, lake, or sea shore. Terraces may be created by erosion, wave action, uplift, currents, or any other process.

    - **Geoform Type: Fluviomarine Terrace (Level 1)** – A constructional, coastal strip, which slopes gently seaward and/or down valley and is veneered by (or completely composed of) unconsolidated fluviomarine deposits—typically silt, sand, and fine gravel (Schoeneberger and Wysocki 2005).
    - **Geoform Type: Wave-Built Terrace (Level 1)** – A subaqueous, relict, depositional landform originally constructed by river or longshore, sediment deposits along the outer edge of a wave-cut platform, and then later submerged by rising sea level or subsiding land surface (modified from Jackson 1997).
    - **Geoform Type: Marine Terrace (Level 1)** – (a) A narrow, coastal strip, formed of deposited material, that slopes gently seaward. (b) An elevated marine-cut bench or a wave-cut platform that has been exposed by uplift along a seacoast (or by lowering of sea level). Marine Terrace may also refer to a wave-cut platform that merges into a wave-built terrace (Bates and Jackson 1984).

- **Geoform: Tidepool (Level 2)** – A pool of salt water left by an ebbing tide that generally persists until the next flood tide. These normally occur in rock substrates and support diverse animal and plant communities (see Figure 6.4).

Figure 6.4. Pacific Coast Tidepool, one of the Smallest Features to be Found in the Geoform Category.
(courtesy U.S. Fish and Wildlife Service)

- **Geoform: Till Surface (Levels 1 & 2)** – An area of substrate (predominantly unsorted and unstratified drift) that is generally unconsolidated, because it was deposited directly by a glacier without subsequent reworking by melt water. The surface consists of a heterogeneous mixture of clay, silt, sand, gravel, stones, and boulders; rock fragments of various lithologies are imbedded within a finer matrix that can range from clay to sandy loam.

- **Geoform: Tombolo (Level 1)** – A sand or gravel bar or barrier that connects an island with the mainland (or with another island).

Geoform Origin: Biogenic

Biogenic geoforms are physical features and landforms that were created by the action of living organisms (bioherms). These primarily consist of the different types of reefs. Examples of these generally hard, fixed structures include the incorporation of dissolved calcium carbonate into reef structure by corals, aggregations of mollusk shells into a fixed cohesive substrate, or the cementation of existing sediments into an aggregation of worm tubes. As with all geoforms the characteristic of concern in this component is the physical shape of these reef features, not the living biology that may have participated in their genesis. Any of the reef geoforms may or may not have living coral or other life present.

- **Geoform: Atoll (Level 1) –** A ring-like coral reef that nearly (or entirely) encloses a reef lagoon. The volcanic island normally associated with an atoll may or may not be present. Atolls appear in plain view as a roughly circular reef that is surmounted by a chain of closely spaced, low, coral islets that encircle (or nearly encircle) a shallow lagoon in which there is no land or islands of non-coral origin; the reef is surrounded by open sea.

  - **Geoform Type: Submerged Atoll/Atoll Reef (Level 1)** – Atoll structure in which new coral growth has not kept up with rising sea levels (or is overcome by the effects of subsidence such that it now lies below the surface). It may still support living coral communities.

- **Geoform: Burrows/Bioturbation (Level 2)** – Tubes, holes, furrows, and small mounds formed by the digging, feeding, and movement of benthic fauna. These can bring nutrients and other compounds to the surface—as well as destabilize the substrate.

  - **Geoform Type: Tilefish Burrow (Level 2)** – Burrows formed by the Tilefish (sp.). These can be up to 3 meters wide and 1 **-** 2 meters deep. In some areas, the density of these burrows can be over 1,000 per square kilometer, thus significantly altering the benthos.

- **Geoform: Coral Reef Island (Levels 1 & 2)** – A tropical island built of organic material derived from the skeletons of corals and other reef associates. Coral islands are usually low and may be several kilometers in size. Typically their structure is integrally part of a living or relatively recent coral reef.

- **Geoform: Mollusk Reef (Levels 1 & 2)** – An area of many shell reefs surrounded and intermixed with channels and unvegetated flats.

  - **Geoform Type: Fringing Mollusk Reef (Level 2 only)** – Narrow, linear reefs, which are usually lying below the marsh platform. These reefs form along the shore of tidal creeks, and they are typically intertidal (see Figure 6.5).
  - **Geoform Type**: **Linear Mollusk Reef (Level 2 only)** – Narrow straight or sinuous, ridge-like reefs formed primarily by oysters but also by other mollusks. These are also usually intertidal. Examples of this type of reef can be found in areas with small tidal ranges such as Apalachicola Bay and Nueces Bay, Texas (see Figure 6.6).
  - **Geoform Type: Patch Mollusk Reef (Level 2 only)** – Mounded, generally round or lobate reefs that have some vertical relief above the surrounding substrate. These are usually intertidal, but they can occur in subtidal settings (see Figure 6.7).
  - **Geoform Type: Washed Shell Mound (Level 2 only)** – Generally linear accumulations of dead shell that form high in the intertidal zone along tidal creeks and on the landward side of barrier islands. The

shells are loose, and they are usually bleached by the sun—giving them a bright appearance (see Figure 6.8).

Figure 6.5. Fringing Mollusk Reef (Made of Oysters) Below a Marsh Platform Edge.

Figure 6.6. Linear Mollusk Reef (Made of Oysters) in a Shallow Estuary, Nueces Bay, Texas.

Figure 6.7. Patch Mollusk Reefs (Made of Oysters) in Hamlin Sound, South Carolina.

Figure 6.8. Edge of Washed Shell Mound in Espiritu Santo Bay, Texas.

- **Geoform: Deep/Cold-Water Coral Reef (Levels 1 & 2)** – Reefs formed by deepwater azooxanthellate (i.e., lacking symbiotic algae), stony corals (Order Scleractinia). Aggregations of these colonial corals can form structures that range from small patch reefs that are several meters across, to large reefs and giant carbonate mounds up to 300 meters high and several kilometers in diameter; these reefs form over many thousands to millions of years (Roberts, Wheeler, and Freiwald 2006).

    - **Geoform Type: Biogenic Deep Coral Reef (Levels 1 & 2)** – Persistent structures, formed by deepwater corals, whose growth exceeds (bio) erosion. These reefs result in local topographic highs that alter hydrodynamic and sedimentary regimes. The actual reef structure remains, often with the growing reefs on their crest or side. The coral thickets and skeletal remains trap sediments, contributing to the accretion of the reef (Roberts et al. 2009).
    - **Geoform Type: Deep Coral Carbonate Mound (Levels 1 & 2)** – Topographic seafloor structures that are the result of previous periods of coral growth, often with successive periods of reef development, sedimentation, and erosion. These are elevated structures, composed of coral fossils and accumulated interstitial sediments. This type includes structures variously referred to as carbonate knolls, coral banks, bio-buildups, and lithoherms. Coral carbonate mounds can take on various shapes and sizes, reaching tens of meters in height and tens of kilometers in size. They may or may not currently include biogenic reefs (Roberts et al. 2009).

- **Geoform: Shallow/Mesophotic Coral Reef (Levels 1 & 2)** – Light-dependent coral reefs that occur within the photic zone (the mesophotic reefs occur in the lower part of this zone at depths of 30 - 150 meters). (http://www.mesophotic.org).

    - **Geoform Type: Aggregate Coral Reef (Levels 1 & 2)** – Continuous, high-relief coral formation that occurs in various shapes and lacks sand channels. This type includes linear coral formations that are oriented parallel to the shelf edge (Zitello et al. 2009).

    - **Geoform Type: Shallow/Mesophotic Coral Carbonate Mound (Levels 1 & 2)** – Topographic seafloor structures that are the result of previous periods of coral growth, often with successive periods of reef development, sedimentation, and erosion. These are elevated structures, composed of coral fossils and accumulated interstitial sediments. This type includes structures variously referred to as carbonate knolls, coral banks, bio-buildups, and lithoherms. Coral carbonate mounds can take on various shapes and sizes, reaching tens of meters in height and tens of kilometers in size. They may or may not currently include biogenic reefs (Roberts et al. 2009).

- **Geoform Type: Coral Head/Bomme (Level 2 only)** – Individual, massive coral colonies—usually with a boulder or mound-like shape.

- **Geoform Type: Coral Pinnacle (Level 2 only)** – A hard, columnar structure formed primarily by the growth of hard corals and other encrusting organisms. These can occur as isolated vertical structures or in association with other pinnacles.

- **Geoform Type: Fragile Mesophotic Coral Reef (Levels 1 & 2)** – Coral reef characterized by delicate branching corals and other reef organisms.

- **Geoform Type: Fringing Coral Reef (Levels 1 & 2)** – Fringing coral reefs are generally linear and generally aligned with the nearby coast. They have the same general morphology as the larger barrier reefs but occur at smaller scales.

- **Geoform Type: Halo (Levels 1 & 2) –** The zone of low-relief, generally bare, sand surrounding Patch Coral Reefs. Halos are often formed by the action of grazing herbivores in the adjacent patch reef itself.

- **Geoform Type: Linear Coral Reef (Levels 1 & 2)** – These are linear coral formations that are oriented parallel to shore or the shelf edge. They follow the contours of the shore/shelf edge. This category is used for such commonly used terms as forereef, fringing reef, and shelf edge reef.

- **Geoform Type: Patch Coral Reef (Levels 1 & 2) –** Individual patch coral reefs are coral formations with circular or oblong shapes and vertical reliefs of one meter or more in relation to the surrounding seafloor. These reefs are isolated from other coral reef formations by bare sand, seagrass, rhodoliths, or other habitats—and have no organized structural axis relative to the contours of the insular shelf edge (Zitello et al. 2009).

- **Geoform Type: Pinnacle Coral Reef (Levels 1 & 2)** – A reef structure formed by the aggregation of many individual pinnacles

- **Geoform Type: Spur and Groove Coral Reef (Levels 1 & 2)** – Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief (compared to pavement with sand channels), and they are separated from each other by 1 - 5 meters of sand or bare hardbottom (grooves)—although the height and width of these elements may vary considerably. This geoform type typically occurs in the forereef or bank/shelf escarpment zone.

- **Geoform: Tree Fall (Level 2)** – Tree falls are trees or woody parts that have sunk to the deep ocean floor (generally 2,000 meters or deeper) and may remain there for decades. They are colonized by a specialized group of wood-boring organisms such as xylophaga (a bivalve) and several crustaceans. Tree falls also support a suite of predators and scavengers.

- **Geoform: Whale Fall (Level 2)** – Whale carcasses that have fallen to the deep ocean floor (generally 2,000 meters or deeper), and which support a wide variety of arthropods and worms—and a limited number of fish. Whale falls can persist for decades (see Figure 6.9).

Figure 6.9. Whale Fall: Skeleton With Hagfish.

- **Geoform: Worm Reef (Level 2)** – Reefs that consist of the consolidated tubes of many individual tube worms, often of the sabellaria and serpulid genera. They may be calcareous or siliceous, and the outer surface of these reefs may support living worm communities.
    - **Geoform Type: Patch Worm Reef (Level 2)** – These reefs are often massive, boulder-like structures separated from each other by unconsolidated sediments.
    - **Geoform Type: Linear Worm Reef (Level 2)** – Linear or bench-like reefs formed by worms in the intertidal zone.

Geoform Origin: Anthropogenic

In many coastal and deep oceans, artificial structures (such as piers, breakwaters, bulkheads, berms, drilling rigs, and artificial reefs) are a significant part of the environment. The continually (or intermittently) submerged portions of features attract vagile fauna and provide attachment surfaces for plants and sessile animals. These features can also provide shelter from predators and prevailing current, and they can support niche communities that increase overall biodiversity. However, these structures can also have negative effects (such as altering natural hydrodynamic patterns, interfering with animal movement, and increasing contaminant loading into nearshore areas), and thus are often of interest to resource managers.

The same relationship between Level 1 and Level 2 geoforms prevails in this origin type as in the geologic and biogenic categories; however, due to the complexity of some of the anthropogenic structures, many more Level 2 units may be present in a single Level 1 geoform. Besides physical structures, features that are the result of human activity (such as scars and trawl marks) are included among the anthropogenic geoforms.

- **Geoform: Aquaculture Structure (Levels 1 & 2)** – These structures can take many forms: lines suspended over the sediment, floating wooden frameworks sub-tidal structures attached to the benthos such as wooden piers and platforms, and pens and enclosures (both at the surface and submerged). These structures are associated with the cultivation of fish, crustaceans, and shellfish for human use or consumption. They may be integrated into shallow water bays and ponds, or they may be deployed in deeper water. Due to their structural aspects, they can be attractive to fish and other animals. They are often sources of nutrients and, thus, have impacts on the surrounding ecology.

- **Geoform: Artificial Bar (Level 1)** – Shoal or bar constructed by human activity to influence the movement of water and tides—or reduce surface wave activity within an area.

    - **Geoform Type: Harbor Bar (Level 1)** – A bar built across the exit to a harbor, in some cases to reduce wave energy within the harbor itself.

- **Geoform: Artificial Dike (Level 1)** – A raised, linear barrier intended to contain or hold back water in order to prevent flooding of adjacent land. These may be concrete or fill structures.

    - **Geoform Type: Artificial Levee (Level 1)** – (a) A dike along the side of a river channel erected to prevent overflow during floods, usually running along the channel direction and near the natural levee crests of streams. (b) An artificial embankment constructed along the bank of a watercourse or an arm of the sea to protect land from inundation (or to confine stream flow to its channel).

- **Geoform: Artificial Reef (Level 2)** – An artificial structure placed on the ocean floor to provide a hard substrate for sea life to colonize. Artificial reefs are constructed by sinking dense materials (such as old ships and barges, concrete-ballasted tire units, concrete and steel demolition debris, and dredge rock) on the seafloor within designated reef sites.

- **Geoform: Artificial Scar (Level 2)** – A gouge or deformation of the bottom, or an area where the surface of the substrate, vegetation, or other colonizing organisms have been removed by abrasion or impact. These may be temporary or permanent features.

  - **Geoform Type: Prop Scar (Level 2)** – A scar that is the result of boat or ship propellers making contact with the bottom. Usually these are linear features occurring in shallow areas or shoals.
  - **Geoform Type: Trawling Scar (Level 2)** – A groove or cleared area of the substrate that is the result of dragging nets or weights across the seafloor. These scars can extend for a long distance and may overlap older scars. They are generally associated with damage to epibenthic organic communities.

- **Geoform: Buoy (Level 2)** – Anchored objects that float in a relatively fixed position at the water surface. Most buoys are used as navigational aids and markers for channels, but many buoys also contain scientific or other observational instruments.

- **Geoform: Breakwater/Jetty (Level 2)** – Structures extending more or less perpendicularly from the shore into a body of water, which are designed to direct and confine the current or tide, to protect a harbor, or to prevent shoaling of a navigable inlet by littoral materials.

  - **Geoform Type: Groin (Level 2)** – A small jetty extending perpendicular from the shore designed to reduce beach erosion. Groins provide hard substrate in what is often an area dominated by unconsolidated sediments.

- **Geoform: Breachway (Level 2)** – The shoreline that is created along the channel formed by jetties.

- **Geoform: Bulkhead (Level 2)** – An artificially reinforced section of the shoreline (or the structure itself). These can be composed of piles of natural material (such as rip-rap), or they may resemble walls of timbers or other substance. They may have many purposes but generally are not intended to prevent flooding of lower areas.

- **Geoform: Cable Area (Level 1)** – An area through which one or more cables have been placed in (or on) the substrate. These areas can be navigation hazards, so they are commonly noted on nautical charts. Scarring, debris, and other features associated with cable installation or maintenance may be present.

- **Geoform: Cable (Level 2)** – Structures that serve as linear conduits for electricity or as supporting lines for other in-water or above-water infrastructure.

- **Geoform: Canal (Levels 1 & 2)** – (a) Man-made channels produced to facilitate navigation between water bodies. (b) Generally linear, dredged, closed-ended ditches that have been dug between housing units along the coast.

- **Geoform: Dam (Levels 1 & 2)** – An obstruction across a flow that produces a lake, pond, or other widening.

- **Geoform: Dock/Pier (Level 2)** – A landing place for vessels normally oriented perpendicular to the shore with a flat surface for off-loading materials. Docks may be fixed in position through anchors or piles, or be supported by pilings or other structures.

- **Geoform: Dredged/Excavated Channel (Levels 1 & 2)** – A roughly linear, deep area within an existing water body formed by a dredging operation for navigation purposes (after Wells et al. 1994).

- **Geoform: Dredge Deposit (Levels 1 & 2)** – An accumulation on the seafloor (or land surface) where spoil materials from a dredging operation are placed. They often exhibit some topographical expression and can support biological communities that are different than the surrounding area. These deposits are often unconsolidated in character, but they can also be relatively stable.

    - **Geoform Type: Dredge Deposit Shoal (Levels 1 & 2)** – A subaqueous area that is substantially shallower than the surrounding area, which resulted from the deposition of materials from dredging and dumping.
    - **Geoform Type: Dredge Deposit Bank (Levels 1 & 2)** – A subaerial mound or ridge (which permanently stands above the water) composed of randomly mixed sediments deposited during dredging and dumping.

- **Geoform: Dredge Disturbance (Level 2)** – An area of the seafloor impacted by dredging activities. In this instance, the term is meant to apply to secondary scarring, smothering, or destruction of epibenthic and near-surface infaunal communities by dredging activity (rather than the direct removal of material by dredging which would be characterized under the Dredged Channel or other geoforms).

- **Geoform: Drilling (Oil and Gas) Rig (Level 2)** – Large structures built to house workers and machinery needed to drill wells in the ocean bed in order to extract oil or other natural resources. They may be attached to the ocean floor, consist of an artificial island, or be floating; rigs often provide important structure and attachment points for marine animals.

- **Geoform: Fill Area (Level 2)** – A topographically low area into which unconsolidated material has been placed in order to raise the ground level as part of development or expansion of coastal infrastructure.
    - **Geoform Type: Landfill (Level 2)** – A fill area where some form of solid waste is being used as the fill material.
- **Geoform: Fish Pond (Level 2)** – These are mostly enclosed basins, usually along the shore used to trap fish. During high tide they are open to the sea but as the tide recedes they become cut off to allow capture of the trapped fish. These features may be very old and have strong cultural and archaeological significance.
- **Geoform: Harbor (Level 1)** – A small bay or a sheltered part of a sea, lake, or other large body of water. A harbor is usually well protected (either naturally or artificially) against high waves and strong currents and serves as a safe anchorage for ships and where port facilities are present. Many smaller anthropogenic geoforms may be encountered within a harbor.
- **Geoform: Lock (Level 2)** – A chamber designed to lift vessels—from one water body to another—by adjusting the level of water in the chamber.
- **Geoform: Lost/Discarded Fishing Gear (Level 2)** – This consists of nets, floats, weights and cabling associated with fishing activities, usually at a commercial level. This type of debris forms a serious hazard for marine life and can persist in the environment for long periods.
- **Geoform: Marina/Boat Ramp (Level 2)** – A series of docks, walkways, slips, and support infrastructure (such as cables and small pipelines) for in-water storage of yachts and boats. Marinas commonly include one or more boat ramps, which consist of a sloping driveway for launching small, trailered vessels.
- **Geoform: Mooring Field (Level 1)** – These are anchorages with many small, fixed buoys in place for securing yachts and other vessels.
- **Geoform: Mosquito Ditch (Level 2)** – Straight, narrow channels that were dug to drain the upper reaches of salt marshes in order to control the populations of mosquitoes that breed there. However, draining the standing water also impacts populations of mosquito-eating fish that live in those waters (http://www.edc.uri.edu/restoration/html/intro/salt.htm).
- **Geoform: Outfall/Intake (Level 2)** – Outfalls are pipelines or tunnels that discharge municipal or industrial wastewater, storm water, combined sewer overflows, cooling water, or brine effluents to a receiving water body. Intakes are

pipes designed (and placed) to draw lake or seawater into a man-made pond or other facility.

Figure 6.10. Pilings Supporting an Abandoned Trestle in Humboldt Bay, California.

- **Geoform: Pilings (Level 2)** – A structure formed by piles that are long, slender columns—usually made of timber, steel, or reinforced concrete (see Figure 6.10).
- **Geoform: Pipeline Area (Level 1)** – A corridor through which one or more pipelines have been placed.
- **Geoform: Rip Rap Deposit (Level 2)** – An accumulation of rock or boulders placed along a waterway or shoreline to reduce erosion.
- **Geoform: Salt Pond Complex (Level 1)** – A series of shallow ponds separated by berms or levels, designed to produce salt from marine water or other brines through the process of evapotranspiration. The ponds are periodically drained to harvest salts. These can support various microalgal communities while water is present.
- **Geoform: Salt Pond (Level 2)** – Usually enclosed areas just landward of the shoreline with a permanent-to-intermittent flooding regime of saline-to-hypersaline waters.
- **Geoform: Seawall (Level 1)** – A man-made wall or embankment of stone, reinforced concrete, or other material along a shore that was built to prevent wave

erosion. These are similar to jetties, but seawalls are more commonly oriented along the water's edge (instead of perpendicular to the shore).

- **Geoform: Tidal/Wave Energy Structure (Level 2)** – Structures that consist of long booms deployed at the surface or turbines placed on the seafloor or other structures. Some portions of these structures may form attachment surfaces for sessile fauna.

- **Geoform: Trash Aggregation (Levels 1 and l 2) –** Aggregations of submerged, floating or suspended trash. These may be loose and mobile as when floating at the water's surface or consolidated by sediment on the bottom or along shore. Trash aggregations may be the result of local storm or seismic events such as floods or tsunamis. Trash aggregations can also form over long periods due to the action of large gyres and currents as in the mid-Pacific Ocean.

- **Geoform: Wharf (Level 2)** – A structure on the shore of a harbor where ships may dock to load and unload cargo or passengers. A wharf is usually a fixed platform, often on pilings. Smaller and more modern wharves are sometimes built on flotation devices (pontoons) to keep them at the same level as the ship—even during changing tides. Wharves form attachment surfaces for shellfish and sessile epifauna, and they are common aggregation points for fish. Also, wharves are often locations where contaminants are introduced into the environment (through spills or waste disposal).

- **Geoform: Wind Energy Structure (Level 2)** – Structures deployed in the marine environment in order to produce energy from the wind. These structures often consist of piling, cabling supports, and associated anchoring devices.

- **Geoform: Wreck (Level 2)** – Any of a variety of man-made structures (such as sunken ships or collapsed drilling rigs) that have fallen to the seafloor. They may be either completely or partially submerged. Wrecks often provide valuable habitat for attaching organisms or fish, but they may also leach contaminants into the environment.

6.5 Status of Geoform Component Units

Compiling a comprehensive list of geoforms can be a challenge—given the broad geography addressed by the CMECS, the range of scales across which these features can occur, and the subtle differences between them. The geoforms presented in Section 6 should be considered an initial—not final—list, which focuses on those features that exert an influence on biological communities and generally surround (or encompass) biological units in the Biotic Component.

In addition, it is recognized that there are many colloquial terms for geoform units. These terms often reflect local conditions and can have historical meaning. CMECS geoform units are not intended to include all the local variations in terminology but rather to focus on unit names that reflect the shape, morphology, and aspect of landform features. Users are encouraged to use the CMECS units as the primary attribute for a feature but are not prohibited from providing additional attribution using a colloquial term when this will enhance usability of the data. Generally the process which resulted in a geoform is not included in the geoform type name, although some exceptions to this approach have been made when the process results in a unique variant of the geoform (e.g., ebb tidal delta).

6.6 Geoform Component Modifiers

The following is a list of modifiers relevant to the GC. Users are free to apply these as appropriate for project goals and as data supports their use. Users are not obligated nor limited to the list below.

- Anthropogenic
    - Anthropogenic Impact
- Biogeographic
    - Primary Water Source
- Physical
    - Energy Intensity
    - Energy Type
    - Induration
    - Seafloor Rugosity
    - Small-scale Slope
    - Surface Pattern
    - Tidal Regime (Amplitude)
- Spatial
    - Benthic Depth Zones
    - Coral Reef Zone
    - Enclosure
    - Profile
- Temporal
    - Temporal Persistence

7. Substrate Component

Substrate is defined in CMECS as the non-living materials that form an aquatic bottom or seafloor, or that provide a surface (e.g., floating objects, buoys) for growth of attached biota. Substrate may be composed of any substance, natural or manmade. Describing the composition of the substrate is a fundamental part of any ecological classification scheme. Substrate provides context and setting for many aquatic processes, and it provides living space for benthic and attached biota. The Substrate Component (SC) is a characterization of the composition and particle size of the surface layers of the substrate; this component is designed to be compatible with a range of sampling tools. The SC provides guidance to characterize the layers of substrate that support the majority of multicellular life – the upper layer of hard substrate, or (typically) the upper 15 centimeters of soft substrate – in a way that is consistent with a variety of past practices. The SC and the BC describe the non-living (SC) and living (BC) aspects of a plan-view perspective of the seafloor at comparable scales. SC observational unit scales range from sediment corers or grabs, to sediment profile or plan-view photographs of the seafloor, to defined quadrats or transects, to video clips, to high-resolution acoustic images. At larger scales, the structure, shape, and surface pattern of substrate features are described by the Geoform Component (GC).

7.1 Commonly Used Methods for Classifying Substrate Geology

Several approaches are now commonly used for describing substrate geology. In these approaches, the classification of sediment particle size is a basic element, which dictates the overall structure of the classification in many ways. Two approved FGDC standards, the *Classification of Wetlands and Deepwater Habitats in the United States* and the *National Vegetation Classification Standard* (FGDC-STD-004 and FGDC-STD-006, respectively) provide differing sets of definitions for classifying sediment grain size. A third set of definitions—based on Wentworth (1922)—is also in widespread use in the marine geological community and internationally (Shepard 1954; Folk 1974; Flemming 2000). An important goal of CMECS is to promote a single, consistent, and unified approach for classification—while at the same time maximizing compatibility with past practice and data.

Different grain size definitions present a significant complication in the unification of common substrate classification systems. For example, *sand* is defined differently under each system. All classifications specify 2 millimeters as the upper-end limit of sand particles, but the lower-end limit varies: FGDC-STD-004 specifies 0.074 millimeters, FGDC-STD-006 specifies 0.05 millimeters, and many of the other published methods that are based on Wentworth (1922) specify 0.0625 millimeters. For most sediment samples, these differences in sand definitions are not substantial; the "percent sand" calculated under each system will be quite comparable for the great majority of samples.

However, these definition differences are more problematic with regard to consistent classification, data analysis, quality control, and quality assurance.

Because there is no clear FGDC-approved option for classifying marine sediment grain size, CMECS adopts the Wentworth (1922) standard for mineral grain size definitions (Table 7.1). This scale reflects long-standing marine traditions and is used by a majority of marine scientists. The Wentworth standard is based on phi class sizes ($-\log_2$ of particle diameter in millimeters), and provides the foundation for particle size classifications in many published works and methods (Shepard 1954, Folk 1954, Flemming 2000, Valentine et al. 2005). Virtually all legacy datasets and recent measurements in marine waters use the Wentworth scale, including datasets from the Coastal and Marine Geology Program of the USGS.

Table 7.1. Mineral Grain Size Descriptors for CMECS (modified from Wentworth 1922). CMECS uses the term Mud to describe all particles smaller than sand (less than 0.0625 millimeters). The term Gravel is used to describe all rock fragment particles that are 2 millimeters or larger.

Descriptor	Grain Size (millimeters)	Class Sizes (phi)
Clay	< 0.004	> 8
Silt	0.004 to < 0.0625	> 4 to 8
Mud	< 0.0625	> 4
Sand	0.0625 to < 2	4 to < -1
(Very Fine Sand)	0.0625 to < 0.125	4 to < 3
(Fine Sand)	0.125 to < 0.25	3 to < 2
(Medium Sand)	0.25 to < 0.5	2 to < 1
(Coarse Sand)	0.5 to < 1	1 to < 0
(Very Coarse Sand)	1 to < 2	0 to < -1
Gravel	2 to < 4,096	-1 to < -12
Granule	2 to < 4	-1 to < -2
Pebble	4 to < 64	-1 to < -6
Cobble	64 to < 256	-6 to < -8
Boulder	256 to < 4,096	-8 to < -12

Figure 7.1 presents a grain-size translator to allow comparisons among the different systems in common use. As CMECS classifications are applied more widely, it is hoped that improved methods for translating data among approaches will continue to be developed (e.g., Poppe et al. 2003). This may enable graceful transitions between CMECS data and data processed using other systems.

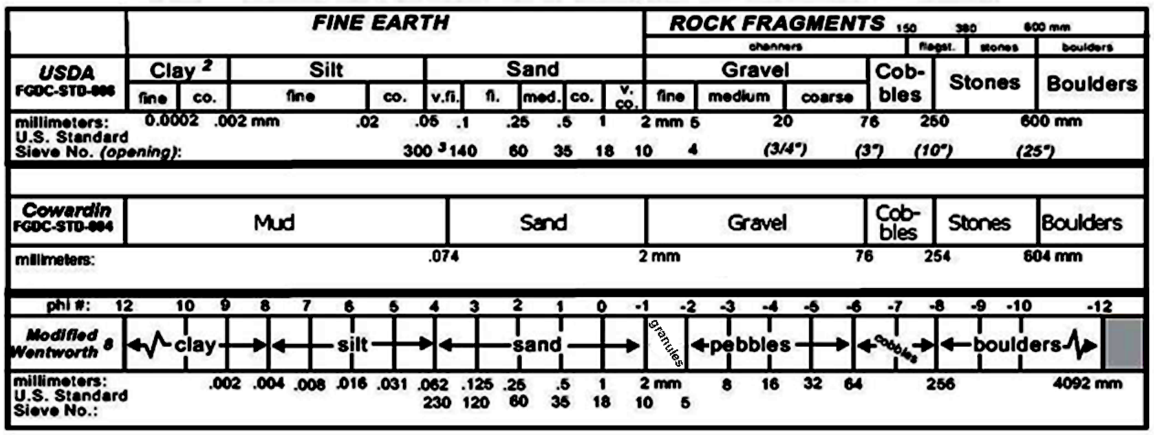

Figure 7.1. Sediment Grain Size Translator Diagram.
This diagram allows comparisons among three different grain size classification systems in common use (FGDC-STD-004, FGDC-STD-006, and Wentworth). Figure modified from Schoeneberger et al. (2002).

After a sample is assessed for the distribution of particle sizes, practitioners need a convenient and descriptive way to characterize the mixture and classify the sample. There are several classifications available for mineral sediment mixes, including Folk (1954), Shepard (1954), and Schlee (1973), which is a modification of Shepard. These are all based on the sedimentological approach of describing depositional environments with ternary diagrams.

In order to be consistent with commonly accepted marine classifications, the SC uses the Folk (1954) approach to classifying mineral sediment mixes. CMECS utilizes the original Folk ternary diagrams and Folk threshold values for Gravel-Sand-Mud combinations and for Sand-Silt-Clay combinations. This classification also provides good descriptive power since, by design, it incorporates all Wentworth grain size bins. The two Folk ternary diagrams are provided in Figure 7.2, which adds colors to show the hierarchical framework of the CMECS SC applied to the Folk diagrams. A few words are changed from the original work, to avoid duplication of terms in a single hierarchy (e.g. Muddy Sand becomes Silty-Clayey Sand in the Sand-Silt-Clay diagram).

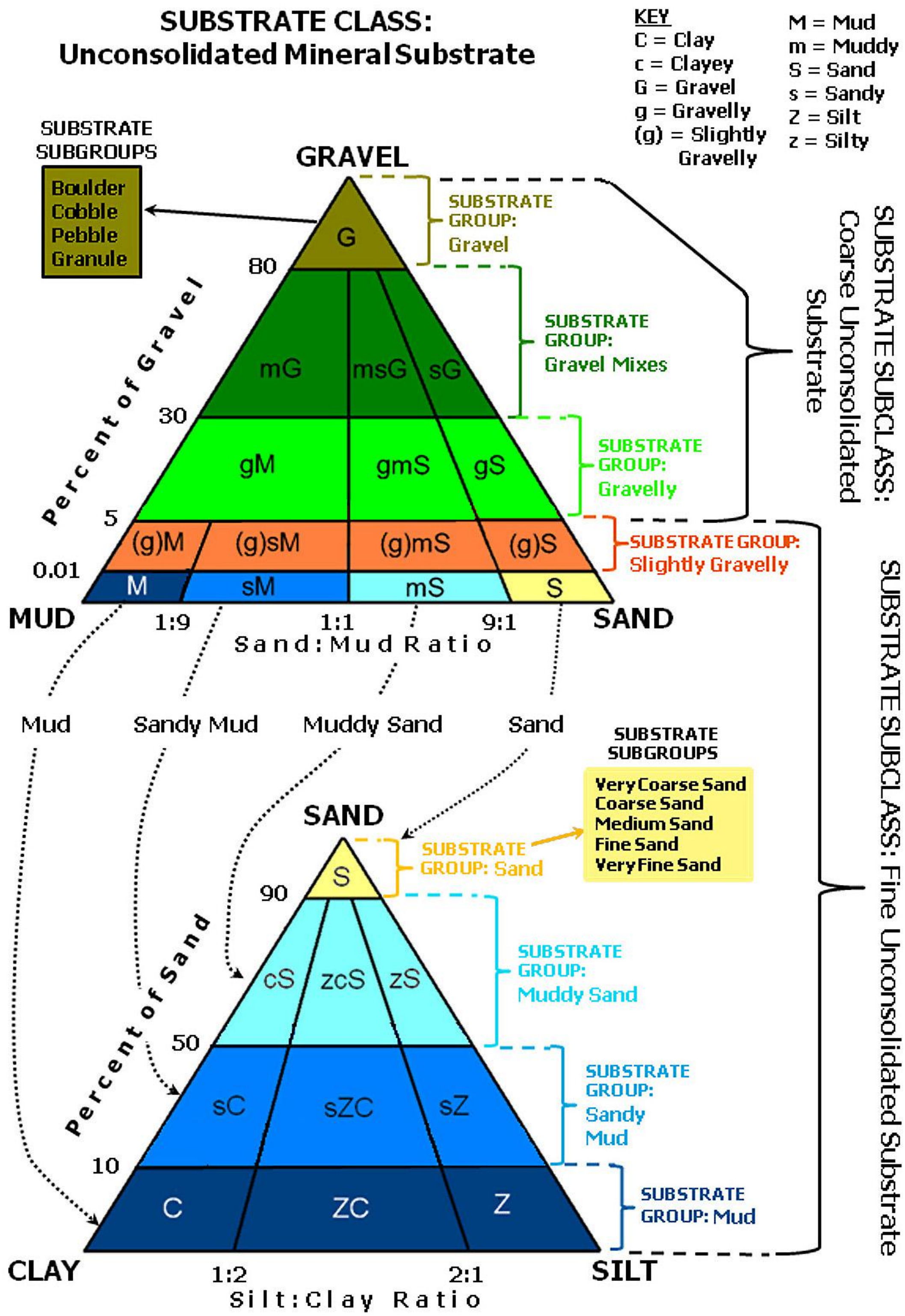

Figure 7.2. Ternary Diagrams for Gravel-Sand-Mud and Sand-Silt-Clay.
and for Sand-Silt-Clay, adapted from Folk (1954). Image: K. Ford.

CMECS adopted Folk (1954) due to the clear present-day preferences for it among public and invited reviewers of CMECS, its long-standing historical use in marine work, and its straight-forward approach to classification. In addition to Folk (1954), however, two existing FGDC classifications for substrate mixtures were considered for applications in CMECS. Of these, the *Classification of Wetlands and Deepwater Habitats in the United States*, FGDC-STD-004 (FGDC 1996b) addresses mostly aquatic substrate as sediment, and provides a fairly coarse method of classification into six major geology-based units. In contrast, the *Soil Geographic Data Standard*, FGDC-STD-006 (FGDC 1997) and Keys to Soil Taxonomy (Soil Survey Staff 2010) together provide more detailed classification options for classifying soils with many hundreds of descriptors that have been used in soil science for decades. A soils approach specifically recognizes and describes the biological, physical, and chemical processes that form (and alter) the substrate as part of classification. Through the National Cooperative Soil Survey, soil maps are available for all intertidal and supratidal areas of the United States. Users should consider these sources and approaches when classifying substrate in these areas.

Although soils approaches have in the past been used mostly for terrestrial work, some coastal scientists (and the USDA Natural Resources Conservation Service) are now applying soil taxonomies to shallow subtidal environments with good results (see Demas, Rabenhorst, and Stevenson 1996; Bradley and Stolt 2006; Stolt et al. 2011). Practitioners interested in soils approaches to classifying shallow subtidal (Estuarine Coastal Subsystem) substrate should consult *Keys to Soil Taxonomy* (Soil Survey Staff 2010), and Schoeneberger et al. (2002). It is recommended that a soils approach be used if a more detailed classification is needed for interpretations and management of shallow-water substrate.

7.2 Application of the Substrate Component

The SC attempts to characterize and classify the most ecologically significant geological features of the substrate surface according to composition and particle size. Shape, pattern, and structural features of the seabed are covered in the GC; living elements are covered in the BC.

To illustrate relationships among SC and BC classifications, SC units represent the non-living components that support, intersperse, or overlay the living components described in the BC—for example, SC's Fine Unconsolidated Substrate–Mud unit may support biological communities such as the BC's Faunal Bed unit describing Ophiuroids or brittle stars. Similarly, the physical structure and setting of an SC Coral Reef Substrate may be found underneath a living BC Coral Reef Biota Subclass. Here, the BC would further describe the living layer of corals or—if no live corals are present—whatever other organisms are colonizing the reef (e.g., macroalgae). This same logic applies to mollusk reefs; the SC describes only the physical substrate created by mollusks (e.g., an oyster reef), while the BC describes the biota currently living on that substrate. This biota may be live oysters—or it may be attached macroalgae or other colonizers, if the oysters have perished. When substrate builders are the dominant living component, classification terms may seem to be repeated in both SC and BC classes and subclasses. For instance, the Mussel Reef Substrate Group describes the structural and non-living substrate created by mollusks, while the BC Class Reef Biota and Subclass Mollusk Reef describe the living mollusks (if they are the dominant life form colonizing that substrate at the time of sampling or observation).

To enable maximum flexibility of methods, the percent cut-offs that define SC classifications (bins) may be used and reported in % weight (for retrieved samples), in % cover (for plan-view seafloor images), or in % composition (for large-scale approaches, sediment profile images, and other approaches), as directed for each classification type. While the SC and other CMECS components are intended to be scale-independent and method-independent, the reported scale of substrate "patchiness" is determined by the scale of observation, and so is somewhat method-dependent. To assist with comparability, practitioners should always report sampling gear, methods, units, scale of observation, and scale of reporting in project metadata. Data users should be aware of the methods that were used to collect and report data, and should make note of any data limitations that may exist.

Mixtures of all different substrate types are very common in nature, and the CMECS SC provides methods and descriptors for classifying various mixes of substrate. More detailed and descriptive Modifiers (to describe mixes, layers, and more) can also be incorporated into SC classifications. This is presented in Section 10 and Section 12.

7.3 Hierarchical Structure

The SC hierarchy is designed to be compatible with a wide variety of possible sampling tools. So, for instance, rapid tools (e.g., cameras and certain acoustic devices) may be used to identify the higher classification levels, while finer and more time-consuming tools (e.g., sediment retrieval and analysis) will be capable of resolving finer levels of the classification. The hierarchical structure of this component includes five levels: Substrate Origin, Substrate Class, Substrate Subclass, Substrate Group, and Substrate Subgroup. However, the last two levels are not used in every Substrate Origin.

Table 7.2. Substrate Component Classification Structure.

Substrate Component

Substrate Origin
  Substrate Class
    Substrate Subclass
      Substrate Group
        Substrate Subgroup

7.3.1 Substrate Origin

The first level of classification in the SC is substrate origin, which is subdivided into Geologic Substrate, Biogenic Substrate, and Anthropogenic Substrate. The substrate origin type is assigned based on dominance (greatest percent cover) of either the geologic, biogenic (but no longer living), or anthropogenic upper layer of substrate. Mixes of origins are addressed through Co-occurring Elements Modifiers (see Section 10).

7.3.2 Substrate Classes and Subclasses

Substrate classes and substrate subclasses are determined by the composition and particle size of the dominant substrate origin in the surface sediments. Class and subclass definitions represent a merging of approaches from Wentworth (1922), Folk (1954), and the FGDC-STD-004.

7.3.3 Substrate Groups and Subgroups

Substrate groups and substrate subgroups are determined by Folk (1954) mixes for Geologic Sediments and by taxa for the Biogenic Substrates. Groups and subgroups are not used for Anthropogenic Substrates.

7.4 Substrate Component Units

7.4.1 Substrate Origin: Geologic Substrate

Benthic substrates where percent cover of Rock and Unconsolidated Mineral Substrate exceeds percent cover of both Biogenic and Anthropogenic Substrates, considered separately. When Geologic Substrate is present, but does not constitute the dominant substrate origin, it may be included as a Co-occurring Element.

Substrate Class: Rock Substrate

Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 millimeters) in any dimension that cover 50% or greater of the Geologic Substrate surface.

- **Substrate Subclass: Bedrock** – Substrate with mostly continuous formations of bedrock that cover 50% or more of the Geologic Substrate surface.

- **Substrate Subclass: Megaclast** – Substrate where individual rocks—with particle sizes greater than or equal to 4.0 meters (4,096 millimeters) in any dimension—cover 50% or more of the Geologic Substrate surface.

Substrate Class: Unconsolidated Mineral Substrate

Geologic Substrates with less than 50% cover of Rock Substrate. This class uses Folk (1954) terminology to describe any mix of loose mineral substrate that occurs at any range of sizes—from Boulders to Clay. This hierarchy and the associated terms are shown in Figure 7.2. These classifications may be based on percent weight (e.g., for retrieved samples); percent cover (e.g., for plan-view images); or visual percent composition (for other approaches). Units with bracketed letters, e.g., [G], [mSG], correspond to the labeled polygons in Figure 7.2, using conventions from Folk (1954).

- **Substrate Subclass: Coarse Unconsolidated Substrate** – Geologic Substrate surface layer contains ≥ 5% Gravel (particles 2 millimeters to < 4,096 millimeters). These sediments are classified using the upper three rows of the Folk (1954) Gravel-Sand-Mud diagram.

    - **Substrate Group: Gravel** [G] - Geologic Substrate surface layer contains ≥ 80% Gravel (particles 2 millimeters to < 4,096 millimeters diameter).

        - **Substrate Subgroup: Boulder** – Geologic Substrate contains ≥ 80% Gravel, with a median Gravel size of 256 millimeters to < 4,096 millimeters.

        - **Substrate Subgroup: Cobble** – Geologic Substrate contains ≥ 80% Gravel, with a median Gravel size of 64 millimeters to < 256 millimeters.

        - **Substrate Subgroup: Pebble** – Geologic Substrate contains ≥ 80% Gravel, with a median Gravel size of 4 millimeters to < 64 millimeters.

        - **Substrate Subgroup: Granule** – Geologic Substrate contains ≥ 80% Gravel, with a median Gravel size of 2 millimeters to < 4 millimeters.

    - **Substrate Group: Gravel Mixes** – Geologic Substrate surface layer contains 30% to < 80% Gravel (particles 2 millimeters to < 4,096 millimeters in diameter). For more specificity in this group and in the following three substrate subgroups, the median size of "Gravel" may be substituted in, e.g., "Pebble Mixes", "Sandy Boulder", "Muddy Sandy Cobble", and "Muddy Granule".

        - **Substrate Subgroup: Sandy Gravel [sG]** – Geologic Substrate is 30% to < 80% Gravel, with Sand composing 90% or more of the remaining Sand-Mud mix.

        - **Substrate Subgroup: Muddy Sandy Gravel [msG]** – Geologic Substrate is 30% to < 80% Gravel, with Sand composing from 50% to < 90% of the remaining Sand-Mud mix.

- **Substrate Subgroup: Muddy Gravel [mG]** – Geologic Substrate is 30% to < 80% Gravel, with Mud composing 50% or more of the remaining Mud-Sand mix.

- **Substrate Group: Gravelly** – Geologic Substrate surface layer contains 5% to < 30% Gravel (particles 2 millimeters to < 4,096 millimeters in diameter). For more specificity in this group and in the following three substrate subgroups, the median size of "Gravelly" may be substituted in, e.g., "Bouldery", "Cobbley Sand", "Pebbly Muddy Sand", and "Granuley Mud".

  - **Substrate Subgroup: Gravelly Sand [gS] –** Geologic Substrate is 5% to < 30% Gravel, and the remaining Sand-Mud mix is 90% or more Sand.

  - **Substrate Subgroup: Gravelly Muddy Sand [gmS] –** Geologic Substrate is 5% to < 30% Gravel, and the remaining Sand-Mud mix is 50% to < 90% Sand.

  - **Substrate Subgroup: Gravelly Mud [gM]** – Geologic Substrate is 5% to < 30% Gravel, and the remaining Sand-Mud mix is 50% or more Mud.

- **Substrate Subclass: Fine Unconsolidated Substrate** – Geologic Substrate surface layer contains less than 5% gravel (particles 2 millimeters to < 4,096 millimeters in diameter). These sediments are classified using the bottom two rows of the Folk (1954) Gravel-Sand-Mud diagram, and the entire Folk (1954) Sand-Silt-Clay diagram.

  - **Substrate Group: Slightly Gravelly** – Geologic Substrate surface layer contains from a trace (0.01%) of Gravel to 5% Gravel (particles 2 millimeters to < 4,096 millimeters in diameter). For more specificity in this group and in the following four substrate subgroups, the median size of "Gravelly" may be substituted in, e.g., "Slightly Granuley", "Slightly Pebbly Sand", "Slightly Cobbley Muddy Sand", and "Slightly Bouldery Mud".

    - **Substrate Subgroup: Slightly Gravelly Sand [(g)S]** – Geologic Substrate is 0.01% to < 5% Gravel, and the remaining Sand-Mud mix is 90% or more Sand.

    - **Substrate Subgroup: Slightly Gravelly Muddy Sand [(g)mS]** – Geologic Substrate is 0.01% to < 5% Gravel, and the remaining Sand-Mud mix is 50% to < 90% Sand.

- **Substrate Subgroup: Slightly Gravelly Sandy Mud [(g)sM]** – Geologic Substrate is 0.01% to < 5% Gravel, and the remaining Sand-Mud mix is 50% to < 90% Mud.

- **Substrate Subgroup: Slightly Gravelly Mud [(g)M]** – Geologic Substrate is 0.01% to < 5% Gravel, and the remaining Sand-Mud mix is 90% or more Mud.

- **Substrate Group: Sand [S]** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand (particles 0.0625 millimeters to < 2 millimeters in diameter).

  - **Substrate Subgroup: Very Coarse Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand, with a median grain size of 1 millimeter to < 2 millimeters.

  - **Substrate Subgroup: Coarse Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand, with a median grain size of 0.5 millimeters to < 1 millimeter.

  - **Substrate Subgroup: Medium Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand, with a median grain size of 0.25 millimeters to < 0.5 millimeters.

  - **Substrate Subgroup: Fine Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand with a median grain size of 0.125 millimeters to < 0.25 millimeters.

  - **Substrate Subgroup: Very Fine Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of ≥ 90% Sand with a median grain size of 0.0625 millimeters to < 0.125 millimeters.

- **Substrate Group: Muddy Sand** – Geologic Substrate surface layer contains no trace of Gravel and is composed of 50% to < 90% Sand (particles 0.0625 millimeters to 2 millimeters in diameter); the remainder is composed of Mud (particles less than 0.0625 millimeters in diameter).

  - **Substrate Subgroup: Silty Sand [zS] –** Geologic Substrate surface layer shows no trace of Gravel and contains 50% to < 90% Sand; the remaining Silt-Clay mix is 67% or more Silt.

  - **Substrate Subgroup: Silty-Clayey Sand [zcS]** – Geologic Substrate surface layer shows no trace of Gravel and contains 50% to < 90% Sand; the remaining Silt-Clay mix is 33% to < 67% Silt.

- **Substrate Subgroup: Clayey Sand [cS]** – Geologic Substrate surface layer shows no trace of Gravel and contains 50% to < 90% Sand; the remaining Clay-Silt mix is 67% or more Clay.

- **Substrate Group: Sandy Mud [sM]** – Geologic Substrate surface layer contains no trace of Gravel and is composed of 10% to < 50% Sand; the remainder is composed of Mud (particles less than 0.0625 millimeters in diameter).

    - **Substrate Subgroup: Sandy Silt [sZ] –** Geologic Substrate surface layer shows no trace of Gravel and contains 10% to < 50% Sand; the remaining Silt-Clay mix is 67% or more Silt.

    - **Substrate Subgroup: Sandy Silt-Clay [sZC]** – Geologic Substrate surface layer shows no trace of Gravel and contains 10% to < 50% Sand; the remaining Silt-Clay mix is 33% to < 67% Silt.

    - **Substrate Subgroup: Sandy Clay [sC] –** Geologic Substrate surface layer shows no trace of Gravel and contains 10% to < 50% Sand; the remaining Clay-Silt mix is 67% or more Clay.

- **Substrate Group: Mud [M]** – Geologic Substrate surface layer contains no trace of Gravel and is composed of 90% or more Mud (particles less than 0.0625 millimeters in diameter); the remainder (< 10%) is composed of Sand (particles 0.0625 millimeters to < 2 millimeters in diameter).

    - **Substrate Subgroup: Silt [Z]** – Geologic Substrate surface layer shows no trace of Gravel and contains < 10% Sand; the remaining Silt-Clay mix is 67% or more Silt.

    - **Substrate Subgroup: Silt-Clay [ZC]** – Geologic Substrate surface layer shows no trace of Gravel and contains < 10% Sand; the remaining Silt-Clay mix is < 33% to 67% Silt.

    - **Substrate Subgroup: Clay [C]** – Geologic Substrate surface layer shows no trace of Gravel and contains < 10% Sand; the remaining Clay-Silt mix is 67% or more Clay.

7.4.2 Substrate Origin: Biogenic Substrate

Substrates where percent cover of non-living Biogenic Substrate exceeds percent cover of both Geologic Substrate and Anthropogenic Substrates, when all are considered separately. Biogenic substrates are classified at the higher levels by taxonomy, and at the lower levels by median particle size—using the units Reef Substrate (≥ 4,096 millimeters), Rubble (64 millimeters to < 4,096 millimeters), Hash (2 millimeters to < 64 millimeters), and Sand (0.0625 millimeters to < 2 millimeters). These units are derived from Wentworth (1922), and they can be broken down into Wentworth grain size classes for greater precision, if desired. Biogenic Substrate classifications may be based on percent weight (e.g., for retrieved samples); percent cover (e.g., for plan-view images); and visual percent composition (for other approaches). The terms “dominant” and “primarily” in the Biogenic Substrate Origin describe the substrate type that is present in the greatest percent cover, greatest percent weight, or greatest visual percent composition. When two Biogenic Substrate types are present, “dominant” and “primarily” are equivalent to “$\geq$ 50%”. When three or more types exist, the dominant type may occur at a lower percent-of-total value. Biogenic Substrate types that are present, but do not constitute the dominant feature, may be included as a Co-occurring Element modifier (see Section 10).

Substrate Class: Algal Substrate

Biogenic Substrate that is primarily composed of calcareous algae in various states of decomposition, including both crustose and coralline types.

- **Substrate Subclass: Algal Sand –** Biogenic Substrate that is primarily composed of broken down calcareous algae with a median particle size of 0.0625 millimeters to < 2 millimeters (Sand). This Sand may have a characteristic white color as it becomes bleached by the sun. However, when the composition and origin of Sand is unclear, it is assumed to be mineral Sand, and is classified as a Geologic Origin substrate.
  - **Substrate Group: *Halimeda* Sand –** Biogenic Substrate that is primarily composed of recognizable, broken segment-like fronds of *Halimeda*, a green coralline alga, and has a median particle size of 0.0625 millimeters to < 2 millimeters (Sand).
- **Substrate Subclass: Rhodolith Substrate –** Biogenic Substrate that is primarily composed of crustose algae that form rounded calcareous nodules (rhodoliths), often associated with coral reefs.
  - **Substrate Group: Rhodolith Rubble –** Substrate that is dominated by living or non-living Rhodolith Rubble, with a median particle size of 64 millimeters to < 4,096 millimeters (Cobbles and Boulders).
  - **Substrate Group: Rhodolith Hash** – Substrate that is dominated by living or non-living Rhodolith Hash, with a median particle size of 2 millimeters to < 64 millimeters (Granules and Pebbles).
  - **Substrate Group: Rhodolith Sand** – Substrate that is dominated by Rhodolith Sand, with a median particle size of 0.0625 millimeters to < 2 millimeters (Sand). When the composition and origin of Sand is unclear, it is assumed to be mineral Sand, and is classified as a Geologic Origin substrate.

Substrate Class: Coral Substrate

Non-living scleractinian coral reefs (or coral particles) constitute the dominant benthic substrate; this substrate may or may not be inhabited by live corals.

- **Substrate Subclass: Coral Reef Substrate** – Substrate that is dominated by living or non-living coral reefs with a median particle size of 4,096 millimeters or greater in any dimension.

- **Substrate Subclass: Coral Rubble** – Substrate that is dominated by living or non-living coral Rubble with a median particle size of 64 millimeters to < 4,096 millimeters (Cobbles and Boulders).

- **Substrate Subclass: Coral Hash** – Substrate that is dominated by coral Hash with a median particle size of 2 millimeters to < 64 millimeters (Granules and Pebbles).

- **Substrate Subclass: Coral Sand** – Substrate that is dominated by coral Sand with a median particle size of 0.0625 millimeters to < 2 millimeters (Sand). When the composition and origin of Sand is unclear, it is assumed to be mineral Sand, and is classified as a Geologic Origin substrate.

Substrate Class: Organic Substrate

Surface layers of substrate are primarily composed of non-living organic material, including fine or coarse organic particles up to 4,096 millimeters in any dimension. Substrates dominated by roots of live vegetation may be classified after removing the root material, and/or they may be classified by specialized methods considering, for example, below-ground biomass. Live fauna, and live flora together with their living root masses, are covered in the BC.

- **Substrate Subclass: Organic Debris** – Organic substrate is primarily composed of coarse organic material that is relatively intact, with a median particle size from 4 millimeters to < 4,096 millimeters (the size of Pebbles, Cobbles, and Boulders). Organic Debris that is larger than that (e.g., whale falls, tree falls) is covered in the Geoform Component.

    - **Substrate Group: Peat Debris** – Organic substrates that are primarily composed of non-living peat deposits—from modern or prehistoric times.

    - **Substrate Group: Woody Debris** – Organic substrates that are primarily composed of small trees, branches, wood, or wood fragments that are broken into particles with a median particle size from 4 millimeters to 4,096 millimeters.

        - **Substrate Subgroup: Fine Woody Debris** – Woody Debris with a median particle size from 4 millimeters to < 64 millimeters.

- **Substrate Subgroup: Coarse Woody Debris** – Woody Debris with a median particle size from 64 millimeters to < 256 millimeters.

- **Substrate Subgroup: Very Coarse Woody Debris –** Woody Debris with a median particle size from 256 millimeters to < 4,096 millimeters.

- **Substrate Subclass: Organic Detritus** – Unconsolidated organic substrate that is composed primarily of decomposing plant and animal tissues. Organic Detritus is mostly broken down—with a median particle size from 0.0625 millimeters to 4 millimeters (Sand and Granule)—and is often in an advanced state of utilization and decay. Organic Detritus may be produced *in-situ,* deposited from above, or transported horizontally, or may be remnant material.

- **Substrate Subclass: Organic Mud** – Unconsolidated organic substrate with a median particle size of less than 0.0625 millimeters (Silts, Clays, and Muds), and an organic carbon content of greater than 5%.

Substrate Class: Ooze Substrate

Deep sea substrates that are composed of ≥ 30% tests, shells, or frustules of small plankton, including diatoms, radiolarians, pteropods, foraminifera, and other marine plankters. Oozes are common in deeper waters far from shore, where terrestrial inputs to the bottom sediments are very low, and where surface productivity is reasonably high. Based on common practice in the field, definition of a substrate as "ooze" requires a 30% or greater (but not necessarily "dominant") ooze composition within the sediments. Once defined as an "ooze", type of ooze is determined by dominant percent composition.

- **Substrate Subclass: Carbonate Ooze** – Oozes that are formed primarily from the calcium carbonate-based shells of foraminifera, coccolithophores, pteropods, or other calcareous plankton. These oozes are limited to seafloors shallower than the carbonate compensation depth (4 - 5 kilometers); calcium carbonate dissolves in the cold acidic waters deeper than this.

  - **Substrate Group: Coccolithophore Ooze** – Oozes that are formed primarily from carbonate tests of phytoplanktonic coccolithophores.

  - **Substrate Group: Foraminiferan Ooze** – Oozes that are formed primarily from carbonate tests of foraminiferans.

    - **Substrate Subgroup: *Globigerina* Ooze –** Oozes that are formed primarily from multi-chambered carbonate tests of the foraminiferan Genus *Globigerina*.

  - **Substrate Group: Pteropod Ooze** – Oozes that are formed primarily from the shells of pteropods (a group of planktonic mollusks).

- **Substrate Subclass: Siliceous Ooze** – Oozes that are formed primarily from the silica-based tests, frustules, or shells of diatoms, radiolarians, or other siliceous plankton. Due to the chemistry of deep ocean waters, these are the most abundant oozes at ocean depths > 5 kilometers. Carbonate oozes dissolve in the colder, more acidic waters that are generally found deeper than 4 or 5 kilometers, but siliceous oozes do not dissolve in most ocean waters.

    - **Substrate Group: Diatomaceous Ooze** – Oozes that are formed primarily from the silica-based frustules or tests of phytoplanktonic diatoms.

    - **Substrate Group: Radiolarian Ooze** – Oozes that are formed primarily from the silica-based tests of amoeba-like radiolarians.

Substrate Class: Shell Substrate

Biogenic Substrate that is primarily composed of shells or shell particles. Most (but not all) shell-builders are mollusks.

- **Substrate Subclass: Shell Reef Substrate** – Substrate that is dominated by living or non-living cemented, conglomerated, or otherwise self-adhered shell reefs, with a median particle size of 4,096 millimeters or greater in any dimension. Live reef building fauna may or may not be present; this is described in the BC.

    - **Substrate Group: Clam Reef Substrate** – Shell Reef that is primarily composed of cemented or conglomerated clam shells.

        - **Substrate Subgroup: *Coquina* Reef Substrate –** Shell Reef that is primarily composed of cemented or conglomerated *Coquina* shells. Living clams may or may not be present: this is described in the BC. Note that *Coquina* shells are described in a separate substrate subgroup due to their distinctive features and special significance in many areas.

    - **Substrate Group: *Crepidula* Reef Substrate** – Shell Reef that is primarily composed of conglomerated *Crepidula* shells. While *Crepidula* are slowly mobile and do not cement their shells, the gregarious settlement of their larvae on conspecifics (Zhao and Qian 2002) can lead to very dense accumulations with a flat, reef-like texture as live shells build over dead shells.

    - **Substrate Group: Mussel Reef Substrate** – Shell Reef that is primarily composed of self-adhered or conglomerated mussel shells.

    - **Substrate Group: Oyster Reef Substrate** – Shell Reef that is primarily composed of cemented or conglomerated oyster shells.

- **Substrate Subclass: Shell Rubble** – Substrate that is dominated by living or non-living shells forming Rubble, with a median particle size of 64 millimeters to < 4,096 millimeters in any dimension (Cobbles and Boulders). Particles may be either loose, individual shells (whole or broken) or—particularly in the larger Rubble sizes—cemented, conglomerated, or otherwise attached so as to form Boulders of consolidated shell material. The presence of Shell Rubble is noted in this subclass (and in the following groups). The presence of living organisms is described in the BC.

    - **Substrate Group: Clam Rubble** – Shell Rubble (with a median particle size of 64 millimeters to < 4,096 millimeters) that is primarily composed of cemented or conglomerated clam shells.

        - **Substrate Subgroup: *Coquina* Rubble –** Clam Rubble (with a median particle size of 64 millimeters to < 4,096 millimeters) that is primarily composed of cemented or conglomerated *Coquina* shells.

    - **Substrate Group: *Crepidula* Rubble** – Shell Rubble (median particle sizes from 64 millimeters to < 4,096 millimeters) that is primarily composed of conglomerated *Crepidula* shells. While *Crepidula* are slowly mobile and do not cement their shells, the gregarious settlement of their larvae on conspecifics (Zhao and Qian 2002) can lead to very dense accumulations as live shells build over dead shells, and sediments fill in to bind these areas into flat shelly masses.

    - **Substrate Group: Mussel Rubble** – Shell Rubble (with a median particle size of 64 millimeters to < 4,096 millimeters) that is primarily composed of self-adhered or conglomerated mussel shells.

    - **Substrate Group: Oyster Rubble** – Shell Rubble (with a median particle size of 64 millimeters to < 4,096 millimeters) that is primarily composed of cemented or conglomerated oyster shells.

- **Substrate Subclass: Shell Hash** – Surface substrate layers are dominated by loose shell accumulations with a median particle size of 2 millimeters to < 64 millimeters (Granules and Pebbles). Shells may be broken or whole. The presence of Shell Hash is noted in this subclass (and in the following groups). The presence of living organisms is described in the BC.

    - **Substrate Group: Clam Hash** – Shell Hash (with a median particle size of 2 millimeters to < 64 millimeters) that is primarily composed of loose clam shells and shell bits.

        - **Substrate Subgroup: *Coquina* Hash** – Shell Hash (with a median particle size of 2 millimeters to < 64 millimeters) that is primarily composed of loose *Coquina* shells and shell bits.

- **Substrate Group: *Crepidula* Hash** – Shell Hash (with a median particle size of 2 millimeters to < 64 millimeters) that is primarily composed of loose *Crepidula* shells and shell bits.

- **Substrate Group: Mussel Hash** – Shell Hash (with a median particle size of 2 millimeters to < 64 millimeters) that is primarily composed of loose mussel shells and shell bits.

- **Substrate Group: Oyster Hash** – Shell Hash (with a median particle size of 2 millimeters to < 64 millimeters) that is primarily composed of loose oyster shells and shell bits.

- **Substrate Subclass: Shell Sand** – Biogenic Substrate layers that are dominated by Sand that is primarily composed of shell particles with a median particle size of 0.0625 millimeters to < 2 millimeters (Sand). Shells or remains are generally broken and difficult to identify. For this reason, only substrate-forming taxa that produce distinctive Sand types are listed as substrate groups. When the composition and origin of Sand is unclear, it is assumed to be mineral Sand and is classified as a Geologic Origin substrate.

  - **Substrate Group: *Coquina* Sand** – Shell Sand that is primarily composed of broken down C*oquina* shells; this Sand has a characteristic orange color. Living clams may or may not be present; this is described in the BC.

Substrate Class: Worm Substrate

Biogenic Substrates that are primarily composed of the cemented or conglomerated calcareous or sandy tubes of polychaetes or other worm-like fauna. Living or non-living worm-tube reefs or worm-tube particles constitute the dominant benthic substrate. The presence of Worm Substrate is noted in this class (and in the following subclasses and groups). The presence of living organisms is described in the BC.

- **Substrate Subclass: Sabellariid Substrate –** Biogenic substrate layers with conglomerated structures or smaller particles that are primarily composed of sand and shell bits cemented with adhesive proteins into cohesive, clustered tubes by sabellariid worms (e.g., *Sabellaria* or *Phragmatopoma*).

  - **Substrate Group: Sabellariid Reef Substrate –** Reef that is primarily composed of cemented mineral-based or shell-based sabellariid worm tubes, with a median particle size of 4,096 millimeters or greater in any dimension.

  - **Substrate Group: Sabellariid Rubble –** Substrate that is dominated by cemented mineral-based or shell-based sabellariid worm tube Rubble, with a median particle size of 64 millimeters to < 4,096 millimeters (size of Cobbles and Boulders).

- **Substrate Group: Sabellariid Hash –** Substrate that is dominated by the sand-shell-protein matrix and tubes constructed by sabellariid worms, with a median particle size of 2 millimeters to < 64 millimeters (size of Granules and Pebbles).

- **Substrate Subclass: Serpulid Substrate –** Biogenic substrate layers with conglomerated structures or broken particles that are primarily composed of cemented calcareous worm tubes produced by serpulid worms, e.g., *Serpula*.

  - **Substrate Group: Serpulid Reef Substrate –** Reef that is primarily composed of cemented or conglomerated calcareous worm tubes, with a median particle size of 4,096 millimeters or greater in any dimension.

  - **Substrate Group: Serpulid Rubble –** Substrate that is dominated by cemented or conglomerated calcareous worm tube Rubble, derived from serpulid worms, with a median particle size of 64 millimeters to < 4,096 millimeters (Cobbles and Boulders).

  - **Substrate Group: Serpulid Hash –** Substrate that is dominated by the calcareous tubes of serpulid worms, with a median particle size of 2 millimeters to < 64 millimeters (Granules and Pebbles).

7.4.3 Substrate Origin: Anthropogenic Substrate

Substrates where percent cover of Anthropogenic Substrate exceeds percent cover of both Geologic Substrate and Biogenic Substrates, considered separately. Anthropogenic Substrates are classified at the higher levels by composition, and at the lower levels by median particle size, using the units Reef Substrate (≥ 4,096 millimeters), Rubble (64 millimeters to < 4,096 millimeters), Hash (2 millimeters to < 64 millimeters), Sand (0.0625 millimeters to < 2 millimeters), and Mud (< 0.0625 millimeters). These units are derived from Wentworth (1922), and can be broken down into Wentworth grain size classes for greater precision if desired. Shape for this substrate origin is covered in the GC, but practitioners may choose to add further descriptors in a comment or notes field. Anthropogenic Substrate classifications may be based on percent weight (e.g., for retrieved samples); percent cover (e.g., for plan-view images); and visual percent composition (for other approaches). The terms "dominant" and "primarily" in the Anthropogenic Substrate Origin describe the substrate type that is present in the greatest percent cover, greatest percent weight, or greatest visual percent composition. When two Anthropogenic Substrate types are present, "dominant" and "primarily" are equivalent to "> 50%". When three or more types exist, the dominant type may occur at a lower percent-of-total value. When Anthropogenic Substrate is present, but does not constitute the dominant substrate, it should be included as a Co-occurring Element Modifier.

Substrate Class: Anthropogenic Rock

Anthropogenic Substrate that is primarily composed of natural mineral materials that were purposefully or accidentally deposited by humans. This includes breakwaters made of natural stone, dredge material, artificial reefs made of natural stone, as well as beach nourishment and beach fill. Shape for this substrate class is covered in the GC (e.g., Groin, Breakwater, and Dredge Deposit). If the origin of a feature cannot be determined, it is assumed to be of natural origin and classified in the Geologic or Biogenic Substrate Origin.

- **Substrate Subclass: Anthropogenic Rock Reef Substrate** – Substrate that is dominated by Anthropogenic Rock with a median particle size of 4,096 millimeters or greater in any dimension.

- **Substrate Subclass: Anthropogenic Rock Rubble** – Substrate that is dominated by Anthropogenic Rock with a median particle size of 64 millimeters to < 4,096 millimeters (Cobbles and Boulders).

- **Substrate Subclass: Anthropogenic Rock Hash** – Substrate that is dominated by Anthropogenic Rock with a median particle size of 2 millimeters to < 64 millimeters (Granules and Pebbles).

- **Substrate Subclass: Anthropogenic Rock Sand** – Substrate that is dominated by Anthropogenic Rock with a median particle size of 0.0625 millimeters to < 2 millimeters.

- **Substrate Subclass: Anthropogenic Rock Mud** – Substrate that is dominated by Anthropogenic Rock (mineral particles) with a median particle size of less than 0.0625 millimeters.

Substrate Class: Anthropogenic Wood

Anthropogenic Substrate that is primarily composed of woody materials that were processed or assembled by humans. Shape for this substrate class is covered in the GC (e.g., Jetty, Dolphin, Pilings, and Wreck).

- **Substrate Subclass: Anthropogenic Wood Reef Substrate** – Substrate that is dominated by Anthropogenic Wood with a median particle size of 4,096 millimeters or greater in any dimension.

- **Substrate Subclass: Anthropogenic Wood Rubble** – Substrate that is dominated by Anthropogenic Wood with a median particle size of 64 millimeters to < 4,096 millimeters.

- **Substrate Subclass: Anthropogenic Wood Hash** – Substrate that is dominated by Anthropogenic Wood with a median particle size of 2 millimeters to < 64 millimeters.

Substrate Class: Construction Materials

Anthropogenic Substrate that is composed of any single construction material or combination of construction materials (concrete, brick, rebar, pipe, porcelain, fiberglass, rubber, plastic, < 50% wood, < 50% metal, etc.) that were manufactured by humans. This substrate may be composed of one or many types of these materials. If anthropogenic wood or metal constitute a dominant fraction of the materials, the substrate is classified as Anthropogenic Wood or Metal, accordingly. Shape for this substrate class is covered in the GC (e.g., Breakwater, Wreck (if fiberglass, ferrocement, etc.).

- **Substrate Subclass: Construction Reef** – Substrate that is dominated by Construction Materials with a median particle size of 4,096 millimeters or greater in any dimension.

- **Substrate Subclass: Construction Rubble** – Substrate that is dominated by Construction Materials with a median particle size of 64 millimeters to < 4,096 millimeters.

- **Substrate Subclass: Construction Hash** – Substrate that is dominated by Construction Materials with a median particle size of 2 millimeters to < 64 millimeters.

Substrate Class: Metal

Anthropogenic Substrate that is dominantly composed of metal that was manufactured by humans. Shape for this substrate class is covered in the GC (e.g., Cable Area, Wreck [if metal]).

- **Substrate Subclass: Metal Reef** – Substrate that is dominated by Metal with a median particle size of 4,096 millimeters or greater in any dimension.

- **Substrate Subclass: Metal Rubble** – Substrate that is dominated by Metal with a median particle size of 64 millimeters to < 4,096 millimeters.

- **Substrate Subclass: Metal Hash** – Substrate that is dominated by Metal with a median particle size of 2 millimeters to < 64 millimeters.

Substrate Class: Trash

Anthropogenic Substrate that is usually composed primarily of plastics but may include other trash materials (waxed paper, paper, < 50% metal, rubber, glass, cardboard, tires) that were manufactured by humans.

- **Substrate Subclass: Trash Rubble** – Substrate that is dominated by plastics and/or other trash materials with a median particle size of 64 millimeters to < 4,096 millimeters.

- **Substrate Subclass: Trash Bits** – Substrate that is dominated by plastics and/or other trash materials with a median particle size of 2 millimeters to < 64 millimeters.

7.5 Status of Substrate Component Units

The SC units in the Geologic Substrate Origin have been well-tested and much-used over decades of application by the marine science community. CMECS modifications to these units are minor, and the Geologic Substrate Origin is considered to be robust. Units in the Biogenic Substrate Origin are an alignment of commonly used terms (Sand, Hash, Rubble, and Reef) with Wentworth size classes. These size/term definitions have not been extensively tested, and the Biogenic Substrate Origin terms are not as robust as the Geologic terms. The Anthropogenic units presented in this Section should be considered an initial attempt to classify Anthropogenic Substrates, focused on those substrates that are most common in coastal and oceanic waters.

7.6 Substrate Component Modifiers

The Substrate Component can be enhanced by a number of Modifier terms (see Section 10).

- Anthropogenic Modifiers
    - Anthropogenic Impacts
- Physical Modifiers
    - Energy Intensity
    - Seafloor Rugosity
    - Small-scale Slope
    - Tidal Range
    - Substrate Descriptors
    - Substrate Layering
    - Surface Pattern
- Physicochemical Modifiers
    - aRPD
    - RPD
- Spatial Modifiers
    - Benthic Depth Zones
    - Co-occurring Elements
    - Coral Reef Zone
    - Fine Percent Cover
    - Coarse Percent Cover
- Temporal Modifiers
    - Temporal Persistence

8. Biotic Component

The Biotic Component (BC) of CMECS is a classification of the living organisms of the seabed and water column together with their physical associations at a variety of spatial scales. The BC is organized into a branched hierarchy of five nested levels: biotic setting, biotic class, biotic subclass, biotic group, and biotic community (Table 8.1). The biotic setting indicates whether the biota are attached or closely associated with the benthos or are suspended or floating in the water column. Biotic classes and biotic subclasses describe major biological characteristics at a fairly coarse level. Biotic groups are descriptive terms based on finer distinctions of taxonomy, structure, position, environment, and salinity levels. Biotic communities are descriptions of repeatable, characteristic assemblages of organisms. In the absence of complete species association data, biotic communities can be approximated using dominant or diagnostic species and then refined once more information is available. When identified in the context of repeating environmental circumstances, biotic communities can be used as the basis for defining and fully describing biotopes. A biotope assigns a more complete description of the feature; involving all other applicable components of CMECS, listing the defining species and explaining the ecological and societal values of the biotope (see Section 9).

Unless otherwise noted, biotic classification units in the BC are defined by the dominance of life forms, taxa, or other classifiers in an observation. For collected observations (such as grab samples or cores), dominance is measured in terms of biomass or numbers of individuals, as specified by the user. In the case of images and visual estimates, dominance is assigned to the taxa with the greatest percent cover in the observational footprint. For example, an observation with 60% seagrass, 20% soft corals, and 20% sponges is classified as an Aquatic Vegetation Bed—whereas an observation with 60% soft corals, 20% seagrass, and 20% sponges is classified as a Faunal Bed. It may be important for some users to note the presence of the non-dominant biota, which can be achieved by using a Co-occurring Element in an observation. See Section 10 for information about how to note Co-occurring Elements and Associated Taxa.

Table 8.1. Biotic Component Classification Structure.

Biotic Component
Biotic Setting
Biotic Class
Biotic Subclass
Biotic Group
Biotic Community

8.1 Hierarchical Structure

8.1.1 Biotic Setting

The biotic setting separates organisms that live in or are closely associated with the bottom (Benthic Biota) from those organisms that are suspended in the water column or floating on the surface (Planktonic Biota). Benthic Biota units are defined by species that are fixed to the benthos and those that are slow moving (such that they cannot move beyond the unit boundary within one day). Planktonic Biota units are defined by organisms that passively float or drift through the water column (such as plankton, microbes, algae, and jellyfish). Free-swimming organisms (such as fishes, squids, or marine mammals that can actively move through the water column) are not used to define either biotic setting.

8.1.2 Biotic Class and Subclass

Biotic classes and subclasses are determined by the dominant percent cover based on the taxonomy and life forms of the living components of the sampled area. Biotic class definitions are based on the biologically defined classes of the *Classification of Wetlands and Deepwater Habitats in the United States,* FGDC-STD-004 (FGDC 1996b). CMECS Reef Biota, Emergent Wetland, Scrub-Shrub Wetland, and Forested Wetland definitions are equivalent to those in FGDC-STD-004, and the CMECS classes for Aquatic Vegetation Bed and Moss and Lichen Communities are nearly so (see Appendix G for a detailed comparison). These classes have stood the test of time, and they are ecologically meaningful and easily distinguishable units (FGDC-STD-004). However, CMECS BC also includes several classes that were not part of the FGDC-STD-004 (or were not treated at the class level): Zooplankton, Floating/Suspended Plants and Macroalgae, Phytoplankton, Floating/Suspended Microbes, Faunal Bed, and Microbial Communities.

In classifying reef-building biota, BC classes use similar terms as the Geoform Component (GC) and the Substrate Component (SC). The GC terms refer to the structures that are created by the reef-building organisms (which may or may not still be present), while the SC describes the composition of the reef substrate itself. BC terms describe the live organisms that are currently found on those structures. The GC term *reef* is used to refer to the structure. The SC term *reef substrate* is used to describe the nature of the substrate. The BC term *reef biota* is used to refer to the biotic characteristics of a given reef structure.

Biotic subclasses are based on finer distinctions of dominant life forms, taxa, and growth forms. For the classes noted above as the same (or nearly so) as those in FGDC-STD-004, CMECS subclasses have similarities. The CMECS subclasses for the Reef Biota and Aquatic Vegetation Bed classes are the same as those in FGDC-STD-004. However, for the three CMECS wetland biotic classes, the term *tidal* is used in the subclasses as the main classifier to explicitly exclude FGDC-STD-004 Palustrine, non-tidal riverine, and non-tidal wetlands—because they fall outside of the domain of CMECS.

8.1.3 Biotic Group

Biotic groups are observational, descriptive, or functional groupings of the characteristic biological types that occur as generalized patterns across their range. The biotic group level is designed for widespread use among different regions and for use with a variety of sampling methods. Biotic groups are designed as simple observational units, to be based upon regularly recurring biological features that are evident in the environment under observation. Biotic groups are intended to be identifiable using visual methods at appropriate scales. Identification of biology at this level does not require (a) written descriptions of ecoregion-specific biological and physical associations, (b) a statistical treatment of biotic relationships and co-occurrences, or (c) identification of diagnostic taxa to the species level.

The biotic group level is quite useful in many areas—and it is particularly applicable to many of the poorly described, soft-sediment habitats that constitute the major part of the seafloor. Biological classifications at this level are predictable, with regularly occurring physical and biological associations that are highly comparable among different studies and regions. Biotic groups can be used for research purposes and to set management goals. A significant portion of mapping surveys use optical imaging as one of the primary fine-scale sampling tools, and most biotic groups can be determined using visual methods (e.g., high-resolution, plan-view camera images, video camera images, sediment profile images, and diver surveys). Because the biotic classification is hierarchical, a broad imaging survey that identifies biotic groups can be accompanied by a more detailed, collection-based survey to (a) determine biotic communities (see below) and (b) improve understanding of biological and physical associations and interactions that will be important for defining biotopes (see Section 9).

8.1.4 Biotic Community

A biotic community is a repeatable grouping of species that is relatively uniform in structure, species composition, and habitat conditions (Olenin and Ducrotoy 2006, Hiscock and Tyler-Walters 2003). Biotic communities can be identified observationally, or (ideally) as statistically repeating species assemblages across their range of occurrence. The assemblage can be identified by diagnostic organisms that are dominant, highly constant, or otherwise distinctive. These diagnostic organisms are always fixed (or very slow moving), and they can include plants, algae, attached sessile fauna, unattached (but relatively non-motile or slowly moving) fauna, infauna, and bacterial colonies. Typically, one or two taxa are used to name a biotic community. For habitats dominated by vegetation (such as mangroves, coastal marshes and seagrass beds), the biotic community is equivalent to the association level of the *National Vegetation Classification Standard*, FGDC-STD-005-2008 (FGDC 2008). An association is defined by FGDC-STD-005-2008 as: “A vegetation classification unit… defined on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions and physiognomy (Jennings et al. 2006).

While the biotic community may be named by one (or a few) dominant or diagnostic species (or by genera where the taxonomy of the group is not well known), as an entity the community includes all of the associated, regularly occurring taxa that fill its many trophic and ecological niches. Biotic communities may be limited to specific geographic areas by the distributions of the associated species—some biotic communities may occur in only one ecological region, while others may occur across widespread geographic areas.

The process of defining biotic communities ideally relies upon rangewide analysis of field-collected specimens or species lists from areas that are relatively homogeneous in composition and structure. In practice, data on species assemblages across their range are currently largely unavailable for most biotic communities. In the absence of such data, practitioners may approximate biotic communities by identifying dominant or known diagnostic taxa (ideally genera or species). Most of the animal-dominated biotic communities currently listed in CMECS use the dominant taxa approach. Over time, as the knowledge of these assemblages increases, they will be refined, and replaced with biotic communities or biotopes.

To be classified as a given biotic community, observations in the field must verify aggregations or assemblages of dominant or characteristic species that are known to occur in other locations. An observation of a single individual of a species is not considered a biotic community unless there is some evidence that other individuals from the assemblage are present.

In many cases, specific mobile predators are associated with a certain biotic community (or a set of biotic communities). These predators may range from starfish (on coral reefs) to wolf eels (on mussel beds). These predatory organisms are not used to define the biotic community, which is characterized at the more stable, lower level of the trophic web (coral reef or mussel bed); however, common predators are considered as associates and they are included in the biotic community descriptions. The presence of distinctive organisms (such as larger, mobile predators) other than those used to define the biotic community may also be captured as a modifier (Co-occurring Elements or Associated Taxa) when describing an observational or reporting unit.

8.2 Biotic Component Units

The BC units are defined below. All faunal and non-vascular biotic communities listed below are examples of broad dominance types that are known to occur within a given Biotic Group. See Appendix E for a list of the units and Section 10 for relevant modifiers.

8.2.1 Biotic Setting: Planktonic Biota

Planktonic Biota includes biota that drift, float, or remain suspended in the water column in aggregations that are big enough to be (a) detected by the human eye (or with mild magnification) or (b) sampled with a fine-plankton net. Planktonic biota are not regularly associated with the seafloor. Water parcels may be examined for plankton using a dipnet, a water sampler, a towed plankton net, imagery (including "Plankton Cameras" that are moved through the water), or other means. In all cases, plankton are assigned classifications based on perceived dominance by the observer (either based on mass or numbers, as specified by the user/observer). Because most plankton communities are mixes of many types of zooplankton and phytoplankton, practitioners should consider the widespread use of the Co-occurring Elements modifier (when non-dominant taxa are covered in other parts of the CMECS classification) or the Associated Taxa modifier (when non-dominant taxa do not constitute a CMECS classification unit).

Biotic Class: Zooplankton

Water parcels or layers in which zooplankton are perceived to be the dominant feature. Zooplankton are heterotrophic biota of the water column; zooplankton drift with the currents, but may (or may not) be able to move through the water under their own power. Zooplankton may feed on phytoplankton, other zooplankton, or on detritus. CMECS classifies zooplankton that may range in size from gigantic salp chains (strings of gelatinous filter feeding tunicates that attain a length of 30 meters or more), to radiolarians (minute, shelled amoebas). CMECS was not designed to be used for the smallest planktonic forms (nanoplankton or picoplankton). CMECS Class Zooplankton includes both Holoplankton (that live out their entire life histories in the plankton) and Meroplankton (that are transient in the plankton). Meroplankton are typically larval stages that develop into nekton or benthos as they mature. Meroplankton in general are difficult to identify; specialized taxonomic knowledge and sets of regional keys are generally required. Both Holoplankton and Meroplankton are quite diverse and include members of most marine phyla.

Aggregations of specific types of zooplankton (or of mixed zooplankton/phytoplankton communities) may occur in many forms. In general, an "Aggregation" is a relatively dense and homogeneous group of plankton that may be produced by rapid reproduction in-place under favorable conditions (by phytoplankton and holoplankton), by hydrodynamic forcing, by a common mass origin, by plankton motility (e.g., diurnal vertical migrations), by barriers to movement (e.g., pycnoclines), or by other phenomena. A Spawning Aggregation forms after a mass spawning event when synchronous spawning by many individuals produces large pulses of gametes and larvae. Classification of a Spawning Aggregation requires some evidence of recent mass spawning. Aggregations of all types may occur as amorphously shaped packets of water, may occur in layers at various depths, and may occur as diurnal migrations, among other forms.

- **Biotic Subclass: Crustacean Holoplankton –** Water parcels in which crustacean holoplankton are the perceived dominant feature. Crustaceans constitute the vast bulk of zooplankton in many areas of the ocean.
    - **Biotic Group: Amphipod Aggregation –** Water parcels in which amphipods (laterally compressed or stick-like, elongated, generally small crustaceans) aggregate and are the dominant form of zooplankton.

    - **Biotic Communities:** e.g. *Hyperia* Aggregation, Caprellid Aggregation

  - **Biotic Group: Copepod Aggregation –** Water parcels in which copepods aggregate and are the dominant form of zooplankton. Planktonic copepods are thought to be among the most abundant multi-cellular animals on Earth. Most planktonic copepods use their large antennae to move in a series of jerky motions.

    - **Biotic Communities:** e.g. *Acartia* Aggregation, *Calanus* Aggregation

  - **Biotic Group: Krill Aggregation –** Water parcels in which shrimp-like krill constitute the dominant form of zooplankton. Most krill species are filter feeders, with a preference for diatoms. Biomass per square meter can be very high in krill aggregations, and they are a critical food source for many large consumers.

    - **Biotic Communities:** e.g., *Euphausia* Aggregation, *Thysanoessa* Aggregation

- **Biotic Subclass: Crustacean Meroplankton –** Water parcels in which crustacean meroplankton are the perceived dominant feature. These zooplankters typically go through several very different larval stages, and can be difficult to identify.

  - **Biotic Group: Decapod Larval Aggregation –** Water parcels in which crab, shrimp, and lobster larvae aggregate and are the dominant form of zooplankton.

    - **Biotic Communities:** e.g., Brachyuran Crab Larval Aggregation, Anomuran Crab Larval Aggregation, *Pandalus* Larval Aggregation

  - **Biotic Group: Mixed Crustacean Larvae –** Water parcels in which several forms of crustacean larvae are mixed, and together they constitute the dominant form of zooplankton. This biotic group is meant to be used for mixes where it is very difficult to identify a dominant Crustacean genus or species.

    - **(No Biotic Communities)**

- **Biotic Subclass: Coral Meroplankton –** Water parcels in which coral larval life-history stages are the perceived dominant feature. This generally occurs during and after synchronous spawning events in reef areas with high coral biomass.

  - **Biotic Group: Coral Spawning and Larval Aggregation –** Water parcels in which coral gametes and larvae are aggregated during and after simultaneous spawning (often in astronomical numbers). In events that involve synchronous spawning of multiple species of corals, the concept of species-specific or group-specific biotic communities (below) may not apply, and the feature is identified at the biotic group level.

- **Biotic Communities:** e.g., Acroporid Spawning Aggregation, *Montastraea* Spawning Aggregation

- **Biotic Group: Coral Larval Aggregation –** Water parcels in which coral larvae aggregate post-spawning, with no evidence of a recent spawning event, and they are the dominant form of zooplankton.

    - **Biotic Communities:** e.g., Acroporid Larval Aggregation, *Montastraea* Larval Aggregation

- **Biotic Subclass: Echinoderm Meroplankton –** Water parcels in which echinoderm larvae are the perceived dominant feature. Echinoderms go through distinctive larval stages, most of which are characterized by different series of ciliated bands that are arranged with bilateral symmetry. Each echinoderm group features different larval forms (e.g., pluteus larvae or bipinnaria larvae).

    - **Biotic Group: Mixed Echinoderm Larval Aggregation –** Water parcels in which these larval forms aggregate and are the dominant form of zooplankton.

        - **Biotic Communities:** Ophiuroid Larval Aggregation, Asteroidean Larval Aggregation, Holothurian Larval Aggregation

- **Biotic Subclass: Fish Meroplankton –** Water parcels in which fish meroplankton are the perceived dominant feature. Fish go through several larval stages as they progress from embryo to juvenile. Unlike many phyla, most of these stages do bear some resemblance to the adult (they are fish-like); nonetheless, the taxonomy of fish larvae is a specialized skill.

    - **Biotic Group: Fish Spawning and Larval Aggregation –** Water parcels in which fish gametes and larvae are aggregated (often in large numbers) after simultaneous spawning, and are the dominant form of zooplankton.

        - **Biotic Communities:** e.g., Damselfish Spawning and Larval Aggregation, Grouper Spawning and Larval Aggregation, Surgeonfish Spawning and Larval Aggregation

    - **Biotic Group: Fish Larval Aggregation –** Water parcels in which fish larvae aggregate and are the dominant form of zooplankton.

        - **Biotic Communities:** e.g., Clupeid Larval Aggregation, Engraulid Larval Aggregation, Sciaenid Larval Aggregation

- **Biotic Subclass: Gelatinous Zooplankton –** Water parcels in which gelatinous zooplankton (generally transparent, often quite large organisms, in which water constitutes a very high percentage of the body mass) are the perceived dominant feature. Most gelatinous zooplankton are predators on other zooplankton.

    - **Biotic Group: Ctenophore Aggregation –** Water parcels in which ctenophores aggregate so as to constitute the dominant form of zooplankton. Ctenophores are small, gelatinous, ciliated animals with a generally rounded or lobed form. Two retractable feeding tentacles may also be present.

        - **Biotic Communities:** e.g., *Beroe* Aggregation, *Mnemiopsis* Aggregation, *Pleurobrachia* Aggregation

    - **Biotic Group: Jellyfish Aggregation –** Water parcels in which jellyfish (free-swimming Medusozoan life-history stages) aggregate and are the dominant form of zooplankton. Most jellyfish are predators, and many have venomous nematocysts (stinging capsules in specialized cells).

        - **Biotic Communities:** e.g., *Aurelia* Aggregation, *Chrysaora* Aggregation

    - **Biotic Group: Salp Aggregation –** Water parcels in which salps (bag-like gelatinous filter-feeding tunicates) aggregate and are the dominant form of zooplankton. Many salps grow in a chain formation that can consist of 100 individuals or more, sometimes reaching 30 meters or greater in length, although much shorter chains are more common.

        - **Biotic Communities:** e.g., *Thalia* Aggregation, *Pegia* Aggregation

    - **Biotic Group: Siphonophore Aggregation –** Water parcels in which these jellyfish-like animals aggregate and are the dominant form of zooplankton. Siphonophores are colonies of many individual animals (polyps) that are each specialized for various roles (stinging tentacles, locomotion, and digestion) but appear and function as a single animal. Siphonophores are important predators on other zooplankton and small fishes. Most siphonophores are actively mobile, but the best-known siphonophore (the Portuguese man-of-war, *Physalia*) drifts with the wind using a gas-filled sac.

        - **Biotic Communities:** e.g., *Bargmannia* Aggregation, *Nanomia* Aggregation, *Physalia* Aggregation

Figure 8.1. Siphonophore, *Physalia sp*.
Dominican Republic (Image: G. Cicchetti).

- **Biotic Subclass: Mixed Zooplankton –** Water parcels in which complex mixes of zooplankton are the perceived dominant feature.
    - **Biotic Group: Mixed Zooplankton Aggregation –** Water parcels in which several phyla exist, with no clear dominant taxon. Biotic Communities are described by listing abundant or potentially dominant taxa.
        - **Biotic Communities:** e.g., Chaetognath, Salp, and Fish Larval Aggregation; Ctenophore, Worm and Copepod Aggregation
- **Biotic Subclass: Molluscan Holoplankton –** Water parcels in which mollusk holoplankton are the perceived dominant feature. Certain molluscan taxa with reduced shells exist entirely in the plankton.
    - **Biotic Group: Pteropod Aggregation –** Water parcels in which pteropod mollusks (characterized by a reduced shell and an expansive, wing-like foot) are the dominant form of zooplankton. They are sufficiently abundant in some areas of the ocean that their dead shells form ooze after sinking to the seafloor.
        - **Biotic Communities:** e.g., *Carolla* Aggregation, *Clione* Aggregation
- **Biotic Subclass: Molluscan Meroplankton –** Water parcels in which molluscan larvae are the perceived dominant feature.
    - **Biotic Group: Veliger Aggregation –** Water parcels in which veligers or pedi-veligers (the distinctive larvae of many mollusks) are the dominant form of zooplankton. Veligers are characterized by ciliated lobes attached to a formative shell and body.

    - **Biotic Communities:** e.g., Bivalve Veliger Aggregation, Gastropod Veliger Aggregation

- **Biotic Subclass: Protozoan Holoplankton –** Water parcels in which single-celled protozoans are the perceived dominant feature. CMECS considers only the larger, visible protozoans that form tests or shells.

  - **Biotic Group: Foraminiferan Aggregation –** Water parcels in which these numerous protists aggregate and are the dominant form of zooplankton. Most planktonic foraminifera are amoeboids that live in a 1 millimeter to 2 millimeters calcium carbonate test that is composed of several growth chambers. Amoeboid pseudopods extend through holes in the test.

    - **Biotic Communities:** e.g., *Globigerina* Aggregation Layer

  - **Biotic Group: Radiolarian Aggregation –** Water parcels in which radiolarians (amoeboid protists living in an intricate silica test) aggregate and are the dominant form of zooplankton. Radiolarians are particularly abundant in equatorial regions of the oceans.

    - **Biotic Communities:** e.g., *Acantharea* Aggregation, *Polycistina* Aggregation

- **Biotic Subclass: Worm Holoplankton –** Water parcels in which various holoplanktonic worm phyla are the perceived dominant feature.

  - **Biotic Group: Chaetognath Aggregation –** Water parcels in which chaetognaths aggregate and are the dominant form of zooplankton. Chaetognaths are small, fish-shaped worms with large "teeth," and they are ferocious predators. They are commonly known as Arrow Worms.

    - **Biotic Communities:** e.g., *Flaccisagitta* Aggregation, *Sagitta* Aggregation

  - **Biotic Group: Polychaete Aggregation –** Water parcels in which holoplanktonic polychaetes (distinctively segmented worms, generally with parapodia and setae modified into swimming appendages) are the dominant form of zooplankton.

    - **Biotic Communities:** e.g., Syllid Aggregation, *Tomopteris* Aggregation

- **Biotic Subclass: Worm Meroplankton –** Water parcels in which various meroplanktonic worm phyla are the perceived dominant feature. Many worm taxa spawn planktonic larvae, and identification can be difficult.

- **Biotic Group: Larval Worm Spawning Aggregation –** Water parcels in which gametes and larvae from various worm taxa are aggregated (often in very high abundance) after simultaneous spawning, and they are the dominant form of zooplankton. Epitokes may also be present. Epitokes are the detachable swimming gonad sections that form the posterior end of many species of polychaetes in their pre-breeding stage; these epitokes are released during spawning events, and appear as free-swimming worms.

  - **Biotic Communities:** e.g., *Neanthes* Spawning Aggregation, Nereid Spawning Aggregation, Palolo (*Eunice*) Spawning Aggregation

- **Biotic Group: Larval Worm Aggregation –** Water parcels in which larvae of various worm taxa aggregate and are the dominant form of zooplankton. Many worm larvae are difficult to identify. The initial larval stage of annelids (the rounded, ciliated trochophore stage) is very similar to the trochophore stage of larval mollusks. Annelid larvae will continue growth by adding segments, however, and become more worm-like.

  - **Biotic Communities:** e.g., Nereid Larval Aggregation, Nemeretean Larval Aggregation, Polychaete Larval Aggregation

Biotic Class: Floating/Suspended Plants and Macroalgae

This class includes areas dominated by vascular plants, detached plant parts, or macroalgae that are floating on the surface or are suspended in the water column—that is, plants and macroalgae that are not rooted or attached to the bottom.

- **Biotic Subclass: Floating/Suspended Macroalgae –** Areas dominated by macroalgae species that are floating on the surface or suspended freely in the water column.

  - **Biotic Group: Algal Rafts –** Thick mats composed of macroalgae that either float on the surface or are submerged in the water column. Some species primarily float (e.g., Kelp Rafts, Rockweed Rafts, and *Sargassum* Rafts), while others may both float and sink (e.g., *Gracilaria* Rafts and *Ulva* Rafts).

    - **Biotic Communities:** e.g., *Gracilaria* Rafts, Kelp Rafts, Rockweed Rafts, *Sargassum* Rafts, *Ulva* Rafts

  - **Biotic Group: Algal Particles –** Areas dominated by live drifting or floating macroalgae, or macroalgal pieces. They do not form rafts, but their distribution in the water column is at a density that can be clearly observed with the human eye.

        - **Biotic Communities:** e.g., *Gracilaria* Particles, Kelp Particles, Rockweed Particles, *Sargassum* Particles, *Ulva* Particles

- **Biotic Subclass: Floating/Suspended Vascular Vegetation –** Areas dominated by vascular vegetation that is floating on the surface or suspended freely in the water column. This subclass is limited to freshwater and brackish species. (There are no known marine, floating or suspended vascular, plant species.) Vascular vegetation that is floating on the surface, but rooted in the substrate is included in the Aquatic Vegetation Bed Class.

    - **Biotic Group: Floating/Suspended Freshwater and Brackish Vegetation –** Areas dominated by freshwater and brackish vascular vegetation that is floating on the surface or suspended in the water column.

        - **Biotic Communities:** e.g., *Eichornia* Mats, *Pistia* Mats

Biotic Class: Phytoplankton

This class includes areas of floating or suspended microscopic algae that are capable of photosynthesis. Although some species are motile, they are generally passively transported by water movements. Under certain conditions, they can form aggregations, large blooms or colonies.

The spatial and temporal expressions of phytoplankton are described as three types in CMECS. (1) Aggregations are detectable concentrations of one or more species within a defined volume or area. Aggregations form when conditions are sufficient for growth of phytoplankton and are typically represented as mixed aggregations, but often with a single species or group predominating. (2) Blooms are defined as rapid growth and multiplication of single species to high density in an area of surface waters within a short period of time (days), often to the exclusion of other species. Blooms are often considered to be harmful to the ecology of the system and may represent an imbalance of conditions. (3) Phytoplankton maxima layers are expressed as defined layers of one or more species, often with one group predominating, that form at depth within the water column, whose thickness is small relative to its areal extent. Maxima layers generally occur in response to presence of optimal conditions, such as salinity and temperature or the supply of a limiting resource, such as nutrients, for growth along an interface.

- **Subclass: Chlorophyte Phytoplankton –** Areas dominated by Chlorophytes (green algae that are unicellular, flagellated, and sometimes colonial phytoplankton), occurring more predominantly in the tropics.

    - **Biotic Group: Chlorophyte Aggregation –** Waters dominated by Chlorophytes. This group is known to aggregate at frontal zones and under ice pack.

        - **Biotic Communities:** e.g., *Chlorella* Aggregation

- **Biotic Group: Chlorophyte Bloom –** Surface waters where rapid growth and very high densities of chlorophytes occur, particularly under quiescent conditions when nutrients are in excess.
    - **Biotic Communities:** e.g., *Pyramimonas* Bloom

  Biotic Group: Chlorophyte Maximum Layer – Relatively thin layer dominated by chlorophytes at depth in the water column where nutrients are optimal. Chlorophytes are adapted to low light levels.
    - **Biotic Communities:** e.g., *Ostreococcus* Maximum Layer

- **Biotic Subclass: Chrysophyte Phytoplankton –** Waters dominated by Chrysophyte Phytoplankton, single-celled algae found mostly in freshwater (although several orders occur in brackish and salt water). The pigment fucoxanthin gives them a yellow or brown color, and there are a variety of forms of the so-called "golden algae," including plasmoid, amoeba-like, flagellated, naked, and silicious.
    - **Biotic Group: Chrysophyte Aggregation –** Waters dominated by chrysophytes; these cells can aggregate via mucus excretions that bind single cells into colonies, often combined with mineral particles and bacterial communities. Chrysophytes occur in coastal waters where nutrients and light are sufficient.
        - **Biotic Communities:** e.g., *Apindella* Aggregation
    - **Biotic Group: Chrysophyte Bloom –** Surface waters where rapid growth and very high densities of chrysophytes occur. These organisms form brown tide blooms that are common in coastal waters and estuaries and often damage seagrass beds (by shading).They also may exhibit toxicity to grazers and filter feeders.
        - **Biotic Communities:** e.g., *Aureococcus* Bloom
    - **Biotic Group: Chrysophyte Maximum Layer –** Relatively thin layer dominated by chrysophytes at depth in the water column; some chrysophytes are flagellated and can adjust their position in the water column. These and other plankton form maxima at depths where nutrients are in optimal concentrations.
        - **Biotic Communities:** e.g., *Dinobryon* Maximum Layer

- **Biotic Subclass Coccolithophore Phytoplankton –** Coccolithophores are small phytoplankters, predominantly marine, which produce plates of calcium carbonate as shells.

- **Biotic Group: Coccolithophore Aggregation –** Waters dominated by coccolithophores. This group is distributed throughout the oceans and tends to have high light requirements, often aggregating in the upper water column and surface layer.

  - **Biotic Communities:** e.g., *Coccolithus pelagicus* Aggregation

- **Biotic Group: Coccolithophore Bloom –** Surface waters where rapid growth and very high densities of coccolithophores occur. These organisms form enormous blooms in the coastal and offshore oceans. Blooms may be linked to upwelling events.

  - **Biotic Communities:** e.g., *Emiliania huxleyi* Bloom

- **Biotic Group: Coccolithophore Maximum Layer –** Relatively thin layer dominated by coccolithophores at depth in the water column where nutrients are optimal. Coccolithophores are not generally found at depth; however, when surface nutrients are depleted and the water column is clear, some instances of a deeper maximum in the epipelagic layer have been noted.

  - **Biotic Communities:** e.g., *Crenalithus* Maximum Layer

- **Biotic Subclass: Cryptophyte Phytoplankton –** Waters dominated by cryptophytes, a small—but diverse—group of unicellular algae that occur in fresh and salt water. Some species are mixotrophic and are able to thrive in low-nutrient environments.

  - **Biotic Group: Cryptophyte Aggregation –** Waters dominated by aggregations of cryptophytes. Cryptophytes aggregate in waters where nutrient concentrations are seasonally in low supply and nutritional needs can be met by consuming bacteria.

    - **Biotic Communities:** e.g., *Chrysophaeum* Aggregation

  - **Biotic Group: Cryptophyte Bloom –** Surface waters where rapid growth and very high densities of cryptophytes occur. Blooms are generally not toxic and can form in coastal and estuarine waters.

    - **Biotic Communities:** e.g., *Myrionecta* Bloom

  - **Biotic Group: Cryptophyte Maximum Layer –** Relatively thin layer dominated by cryptophytes at depth in the water column**.** Motility allows the group to avoid predation and to optimize their heterotrophic grazing.

    - **Biotic Communities:** e.g., *Teleaulax* Maximum Layer

- **Biotic Subclass: Cyanophyte Phytoplankton –** Areas dominated by cyanophytes, blue-green algae that are photosynthetic bacteria. Some of these are nitrogen fixing, some form resting cysts, and they can exist singly or in colonies.
  - **Biotic Group: Cyanophyte Aggregation –** Waters dominated by cyanophytes, which can aggregate under appropriate conditions in both coastal and open ocean environments. Those with nitrogen-fixing capability have a competitive advantage in nitrogen-poor environments, and coccoid cyanophytes are often dominant in oligotrophic tropical oceans.
    - **Biotic Communities:** e.g., *Nodularia* Aggregation
  - **Biotic Group: Cyanophyte Bloom –** Surface waters where rapid growth and very high densities of cyanophytes occur. Cyanophyte Blooms are increasingly common in coastal waters, and can be toxic.
    - **Biotic Communities:** e.g., *Synechococcus* Bloom
  - **Biotic Group: Cyanophyte Maximum Layer –** Relatively thin layer dominated by cyanophytes at depth in the water column**.** Cyanophytes can be found in a maximum layer where nutrients are sufficient (often at the base of the nutricline). They are often associated with an oxygen maximum layer due to their high rates of photosynthetic production.
    - **Biotic Communities:** e.g., *Trichodesmium* Maximum Layer
- **Biotic Subclass: Diatom Phytoplankton –** Waters dominated by Diatom Phytoplankton, single-cell algae that circulate passively or sink in the water column. This non-flagellated group possesses silica-based frustules that can form large and elaborate static appendages. They are considered desirable, high-quality food for grazers, supporting healthy food webs.
  - **Biotic Group: Diatom Aggregation –** Waters dominated by diatoms that aggregate passively during blooms or via exudation of sticky polymers that act as glue to bind cells together. (Bacteria may play an important role in the binding process.) Diatom aggregations play an important role in the marine carbon budget, and since aggregations sink more rapidly than single cells, they transport carbon to lower waters and the benthos.
    - **Biotic Communities:** e.g., *Thalassiosira* Aggregation
  - **Biotic Group: Diatom Bloom –** Surface waters where rapid growth and very high densities of diatoms occur. Diatoms are large cells and tend to have high nutrient requirements. Spring diatom blooms occur in many estuarine and coastal waters, as diatoms have low light requirements and are well adapted to the hydrologic period when turbid riverine inputs are

highest. They have higher nutrient requirements than other groups and require silica, needed to produce frustules. Land runoff contains silica making the spring period ideal for formation of coastal diatom blooms. The rise of the bloom is important in initiating food webs of zooplankton and other grazers and the decay of the bloom is important in nutrient cycling, and potentially contributes to the later formation of hypoxic bottom water as organic material accumulates in the lower water column.

  - **Biotic Communities:** e.g., *Skeletonema* Bloom

- **Biotic Group: Diatom Maximum Layer –** Relatively thin layer dominated by diatoms at depth in the water column**.** Layers of high diatom density generally form in the surface mixed layer and have also been found at deep subsurface maxima. These are associated with nutrient or temperature maxima.

  - **Biotic Communities:** e.g., *Asterionellopsis* Maximum Layer

- **Biotic Subclass: Dinoflagellate Phytoplankton –** Areas dominated by flagellated phytoplankton that have some motility and can control their position in the water column to a degree, diurnally migrating from surface to bottom to maximize conditions for growth. This group has both photosynthetic and heterotrophic species, which play a large role in coastal and estuarine trophic dynamics. These phytoplankton also can form noxious and harmful blooms, including red tides that may be toxic to higher consumers and to humans. Their complex life cycle goes through many stages, which can include resting cysts that spend prolonged periods in the benthic sediments.

  - **Biotic Group: Dinoflagellate Aggregation –** Waters dominated by dinoflagellates that aggregate in coastal and marine waters throughout the world. Some evidence suggests that both heterotrophic and mixotrophic feeding adaptations supplement autotrophy, giving dinoflagellates a competitive advantage over other groups—especially during periods of low nutrient availability. Aggregations are responsible for bioluminescence, which may reduce predation by disrupting grazers and by triggering secondary predators that consume dinoflagellate predators (Latz et al. 2004)

    - **Biotic Communities:** e.g., *Noctiluca* Aggregation

    - **Biotic Group: Dinoflagellate Bloom –** Surface waters where rapid growth and very high densities of dinoflagellates occur. These blooms have caused a number of problems in coastal waters because many species are toxic to consumers. Shellfish and fish can accumulate toxins and pass them on to higher trophic levels, including humans.

- **Biotic Communities*:*** e.g., *Karenia* Bloom

- **Biotic Group: Dinoflagellate Maximum Layer –** Relatively thin layer dominated by dinoflagellates at depth in the water column. Dinoflagellates migrate vertically through the water column to layers where nutrients and light are optimal for growth. Often the maxima can occur at the surface when nutrients are saturating throughout the water column. There is also evidence that migration is an adaptive strategy to avoid predation (Baek et al. 2011).

  - **Biotic Communities:** e.g., *Gymnodinium* Maximum Layer

Biotic Class: Floating/Suspended Microbes

Aggregations of microbes that are floating or suspended in the water column and not attached to the bottom or to any benthic substrate.

- **Biotic Subclass: Films and Strands –** Aggregations of microbes in a very thin layer (millimeters or less) on the water's surface or at a discontinuity layer within the water column. The air-water interface is a site of intense biological activity due to the abundance of light, oxygen and energy. The density gradients and discontinuity at the surface of the water column or at fronts and discontinuities within the water column are ideal for the aggregation of microbes in films covering large areas and strands that follow the movements of water currents (Cunliffe and Murrell 2009). The concentration of microbes creates numerous niches for feeding by higher trophic levels and for the processing of biogenic and inorganic compounds that are important to marine chemistry, including controlling carbon, nitrogen and sulfur redox processes (Hansel and Francis 2006). The film created by microbial concentration also creates a biological barrier that can either facilitate or impede transgression of materials across the air-water interface or other layer.

- **Biotic Subclass: Microbial Foam –** Aggregations of microbes within the foam matrix that forms on the water's surface. Sea foam is the foam the lies on the sea surface, in the surf zone and at times on intertidal areas, created from dissolved organic compounds when air is forcefully injected into the water column (Harden and Williams 1989). Foam formation is aided by properties of lignans, proteins and carbohydrates that act as surfactants or foaming agents. The large area presented by the micro-bubbles composing seafoam is an ideal surface for concentration and adherence of microbial communities including bacteria, viruses and microscopic plankton. The characteristics of the air-water interface, and particularly of sea foam are unique compared to the bulk water column (Lion and Leckie 1981) and possess unique physical and chemical properties. The foams are well-oxygenated, sites of photolytic processes and tend to support high levels of aerobic metabolism with high organic processing rates. Surface foam is the site of intense trophic activity at the microbial level because of the concentration of microbial biomass, sugars, lipids and other growth compounds and thus represents an important part of the marine microbial food web. Concentration and transformation of trace metals, nutrient compounds, contaminants and pollutants also occurs in sea foam and can enter the food web via microbial pathways. The properties of the foam have also been identified as delivering growth-promoting nutrients and organic material to seagrass and kelp communities.

- **Biotic Subclass: Microbial Aggregation** – Aggregations of microbes within the water column that have detectable, visible color. Microbial communities suspended in the water column can reach high concentrations and even be the dominant biota in an area, both numerically and in terms of biomass. Suspended free-floating microbes, as well as those adsorbed to suspended particulates are important in the marine food web. The concentration of bacterial communities has been linked to discoloration of the water column (Hansel and Francis 2006) via oxidation of molecular compounds in the water, such as manganese and iron.

8.2.2 Biotic Setting: Benthic/Attached Biota

This biotic setting describes areas where biota lives on, in, or in close association with the seafloor or other substrates (e.g., pilings, buoys), extending down to include the layers of sediment that contain multi-cellular life. As a rule, Benthic/Attached Biota units are characterized by the various life histories and taxonomic characteristics of the dominant life forms.

Biotic Class: Reef Biota

Areas dominated by reef-building fauna, including living corals, mollusks, polychaetes or glass sponges.

In order to be classified as Reef Biota, colonizing organisms must be judged to be sufficiently abundant to construct identifiable biogenic substrates. When not present in densities sufficient to construct reef substrate, the biota is classified in the Aquatic Vegetation Bed or Faunal Bed classes.

The Reef Biota Class refers to only the living component of reef structures. If referring to the reef structure, users should use the reef units in the Geoform Component. If referring to the composition of the reef substrate independent of the living cover, users should employ the Coral Substrate, Shell Substrate, or Worm Substrate Classes in the Substrate Component (SC).

- **Biotic Subclass: Deepwater/Coldwater Coral Reef Biota –** Areas dominated by biota closely associated with the structures and settings created by azooxanthellate (lacking symbiotic algae), deep-water, stony corals (Order Scleractinia) or stylasterid corals (Order Anthoathecatae; Family Stylasteridae). Biotic groups and communities for the Deepwater/Coldwater Coral Reef subclass recognize coral reef areas as structural settings that were constructed by the framework-forming corals. The living coral reef is characterized by the presence of live reef-forming corals, but may or may not be dominated by living corals; other fauna may in fact exceed the corals in percent cover.

The Deepwater/Coldwater Coral Reefs are separated into two Biotic Groups based on whether they are formed by stony corals or stylasterid corals. The growth forms of those corals and the reefs they create are structurally different. Biotic communities are characterized by the dominant species of framework-forming, deep-sea coral. For example, a Deepwater/Coldwater *Lophelia* Reef would be dominated by *Lophelia pertusa* coral, but may include other stony corals such as *Madrepora oculata*, *Enallopsammia rostrata*, or *Solenosmilia variabilis*.

- **Biotic Group: Deepwater/Coldwater Stony Coral Reef –** Areas dominated by deepwater stony corals. There are 17 known species of deepwater, azooxanthellate, stony corals (Class: Anthozoa; Order: Scleractinia) that form larger, branching colonies and contribute to reef frameworks. Six of these are particularly widespread or important, and these are major contributors to the framework of their respective habitats. These species form branching colonies (generally less than 1 - 2 meters in size), and aggregations of these living colonies—and their immediately adjacent dead framework and rubble—are important habitats for numerous other sedentary and mobile species.

    - **Biotic Communities:** e.g., *Enallopsammia* Reef, *Goniocorella* Reef, *Lophelia* Reef, *Madrepora* Reef, *Oculina* Reef, *Solenosmilia* Reef

- **Biotic Group: Deepwater/Coldwater Stylasterid Coral Reef –** Areas dominated by stylasterid corals. A number of stylasterid coral species (Class: Hydrozoa; Order: Anthoathecatae; Family: Stylasteridae) form smaller branching colonies that can dominate certain habitats, primarily in deeper, colder waters. Stylasterid coral reefs often predominate on oceanic islands, seamounts, and archipelagos (Cairns 1992).

    - **Biotic Communities:** e.g., Mixed Stylasterid Reef, *Stylaster* Reef

- **Biotic Group: Colonized Deepwater/Coldwater Reef –** Areas dominated by deepwater reefs where live reef building hard corals are present, but not clearly dominant. Cover is dominated by non-reef-forming biota, including black corals, gold corals, gorgonians, sponges, and other sedentary or attached macro-invertebrates. If no living reef-forming corals are present, then the biotic class is Faunal Bed.

    - **Biotic Communities:** e.g., Black Coral Colonized Deepwater/ Coldwater Reef, Gold Coral Colonized Deepwater/Coldwater Reef, Gorgonian Colonized Deepwater/Coldwater Reef, Mix

Colonized Deepwater/Coldwater Reef, Sponge Colonized Deepwater/Coldwater Reef

- **Biotic Subclass: Shallow/Mesophotic Coral Reef Biota –** Areas with ample light that are dominated by hermatypic (reef-building) hard corals or non-hermatypic reef colonizers.

  The Shallow/ Mesophotic Coral Reef Biota are largely based on the growth form of the dominant corals that (a) reflect differences in environmental conditions and (b) provide varied habitat circumstances (such as increased cover) for associated fish and invertebrate species. The same coral species can present different growth forms under different environmental circumstances. For example, *Acropora* sp. can have both branching and table growth forms, depending on the environment. To reflect the differences in the physical and biological environments, the same species may be used to define communities in more than one coral group.

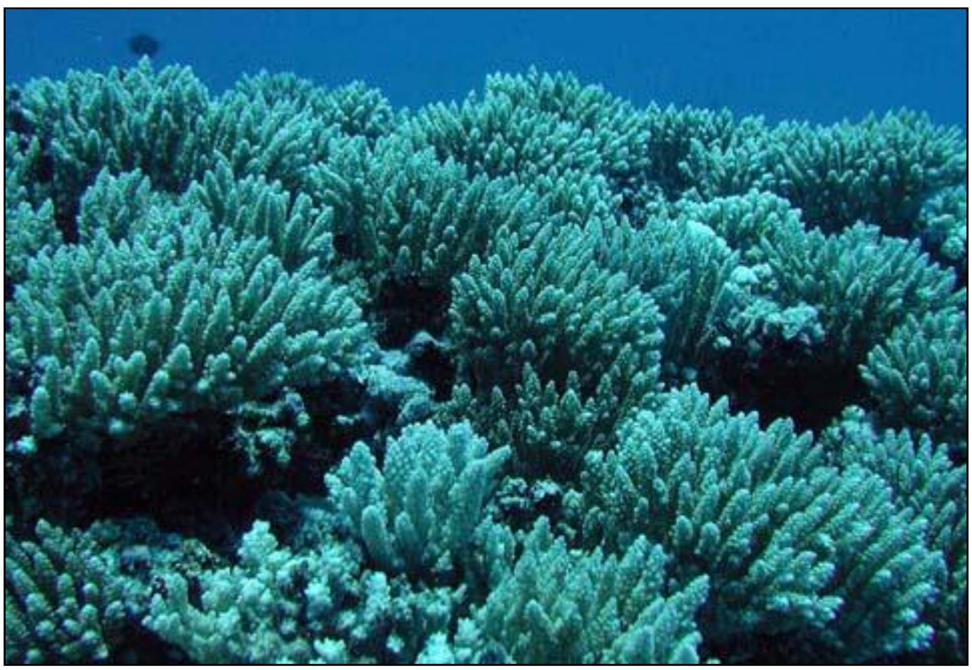

Figure 8.2. Branching Coral Growth Form.
Family Acroporidae, Northwestern Hawaiian Islands. Image: NOAA National Ocean Service Education.

  - **Biotic Group: Branching Coral Reef –** Reefs in shallow or mesophotic situations dominated by branching corals (includes arborescent, arboreal, digitate, corymbose, ramose, and elkhorn corals) that grow in a tree-like shape and have numerous branches, some with secondary branches. This group includes both fragile, branching corals and more robust, branching corals that have exceptionally thick and sturdy antler-like branches (such as elkhorn corals). See Figure 8.2 for an example of the branching coral growth form.

- **Biotic Communities:** e.g., Branching *Acropora* Reef, Branching *Madracis* Reef, Branching *Pocillopora* Reef, *Porites* Reef

- **Biotic Group: Columnar Coral Reef –** Areas dominated by columnar corals that emerge from a massive base in a pillar form and do not branch. They are commonly found in mild water flow at mid-depth water levels.

  - **Biotic Communities:** e.g., Columnar *Dendrogyra* Reef, Columnar *Psammocora* Reef

- **Biotic Group: Encrusting Coral Reef –** Reefs or reef-like, rocky structures dominated by encrusting corals (also called crustose corals) that (a) cover the substrate in a sheet and (b) expand in diameter rather than height. Encrusting corals are highly tolerant of strong water currents, and they are frequently found on rocky shorelines lacking a beach. See Figure 8.3 for an example of the encrusting coral growth form.

  - **Biotic Communities:** Encrusting *Millepora* Reef, Encrusting *Porites* Reef

- **Biotic Group: Foliose Coral Reef –** Areas dominated by foliose corals that have a vase-like structure and whorl-like growth pattern similar to the open petals of a flower. The structure of these corals provides shelter for fish and invertebrate species. See Figure 8.4 for an example of the foliose coral growth form.

  - **Biotic Communities**: Foliose *Agaricia* Reef, Foliose *Milipora* *R*eef

Figure 8.3. Encrusting Coral Growth Form.
Image: NOAA National Ocean Service Education.

Figure 8.4. Foliose Coral Growth Form.
Image: Linda Wade.

- **Biotic Group: Massive Coral Reef –** Reefs dominated by massive corals (also known as boulder or mound corals) that are characteristically ball- or boulder-shaped and relatively slow growing. This group includes reefs dominated by submassive corals, which are similar to massive corals, but have a lumpier structure. Brain corals are an example of massive coral.

  Massive and submassive corals are resistant to strong water currents, and are therefore commonly found in shallow and mid-depth waters. These forms are common on back-reef slopes. See Figure 8.5 for an example of the massive coral growth form.

  - **Biotic Communities:** Massive *Diploria* Reef, Massive *Montastraea* Reef, Massive *Porites* Reef

Figure 8.5. Massive Coral Growth Form.
Image: NOAA National Ocean Service Education.

- **Biotic Group: Plate Coral Reef –** Reefs dominated by plate corals that grow in a flattened plate, saucer-like, or thin sheet fashion—often in a terraced pattern. Plate corals (also known as laminar, leaf, or sheet corals) usually have thin, disc-shaped colonies with corallites growing only on one side. See Figure 8.6 for an example of a plate coral growth form.

- **Biotic Communities:** Plate *Agaricia* Reef, Plate *Leptoseris* Reef, Plate *Montastraea* Reef

Figure 8.6. Plate Coral Growth Form.
Image: www.freeimages.co.uk.

- **Biotic Group: Table Coral Reef –** Reefs dominated by table corals that form platforms that are made up of small, tightly packed branches. Table corals are usually found in shallow waters. See Figure 8.7 for an example of the table coral growth form.
    - **Biotic Communities:** e.g., Table *Acropora* Reef
- **Biotic Group: Turbinate Coral Reef –** Areas dominated by turbinate corals that are cone shaped. Turbinate corals are often found in calmer water at mid-depth levels, often on back reef-slopes.
    - **Biotic Communities:** e.g., Turbinate *Madracis* Reef.
- **Biotic Group: Mixed Shallow/Mesophotic Coral Reef –** Areas where multiple coral growth forms are present and none are clearly dominant.
    - **Biotic Communities:** To be determined.

Figure 8.7. Table Coral Growth Form.
Image: NOAA National Ocean Service Education.

- **Biotic Group: Colonized Shallow/Mesophotic Reef –** Tropical coral reef substrate where live reef building corals are present, but not clearly dominant. Cover is dominated by non-reef-forming corals (such as soft corals, gorgonians [e.g., sea fans and sea whips], and sea pansies), sponges, other sedentary or attached macro-invertebrates, occasional seagrasses, macroalgae, echinoderms, and other reef associates. Reef-building, hard corals are present, but not clearly dominant. If no living coral is present, then the biotic class if Faunal Bed.

  - **Biotic Communities:** e.g., Black Coral Colonized Shallow/ Mesophotic Reef, Gold Coral Colonized Shallow/Mesophotic Reef, Calcareous Algae Colonized Shallow/Mesophotic Reef, Coral Garden Reef, Coralline/ Crustose Algae Colonized Shallow/Mesophotic Reef, Gorgonian Colonized Shallow/ Mesophotic Reef, Soft Coral Colonized Shallow/Mesophotic Reef, Sponge Colonized Shallow/ Mesophotic Reef

- **Biotic Subclass: Glass Sponge Reef Biota –** Areas dominated by live, deep-water, glass sponges (Order: Hexactinosida) present in densities that are judged sufficient to form substrate. These sponges construct a complex siliceous skeleton that provides structure and relief on the seafloor, creating habitat for many other organisms.

- **Biotic Group: Glass Sponge Reef –** Areas dominated by one or more of the three species of glass sponges that appear to be the primary contributors to the framework of extant glass sponge reefs: *Heterochone calyx, Aphrocallistes vastus*, and *Farrea occa.* See Figure 8.8 for an example of a Glass Sponge Reef.
  - **Biotic Communities:** e.g., Hexactinosida Reef

Figure 8.8. Glass Sponge Reef: Hexactinosida Reef.
Hecate Strait, Canada. Image: Natural Resources Canada.

- **Biotic Subclass: Mollusk Reef Biota –** Areas dominated by consolidated aggregations of living and dead mollusks, usually bivalves (e.g., oysters or mussels or giant clams) or gastropods (e.g., vermetids) attached to their conspecifics and sufficiently abundant to create substrate.
  - **Biotic Group: Gastropod Reef –** Areas dominated by consolidated aggregations of living and dead gastropod mollusks, typically those of the Family Vermetidae or the Genus *Crepidula*. Shells in a “reef” must have consolidated or conglomerated into a reef structure with some relief and permanence; a reef is more that an accumulation of loose shells. Vermetids construct tubes that are cemented to hard substrates and to conspecifics, generally in intertidal habitats. *Crepidula* forms reefs through preferential settling of larvae on conspecifics (Zhao and Qian 2002) combined with very limited mobility, and sediment infilling. *Crepidula* reefs are generally flat features with little vertical relief.

    - **Biotic Communities:** e.g., *Crepidula* Reef, Vermetid Reef

  - **Biotic Group: Mussel Reef –** Areas dominated by the ridge- or mound-like structures formed by the colonization and growth of mussels that are attached to a substrate of live and dead conspecifics. Mussels use byssal threads and a powerful glue to tether their shells to a substrate, and their reefs also provide valuable habitat and filtration.

    - **Biotic Communities:** *e.g., Modiolus* Reef, *Mytilus* Reef

  - **Biotic Group: Oyster Reef –** Areas dominated by the ridge- or mound-like structures formed by the colonization and growth of oysters that are attached (cemented) to a substrate of live and dead conspecifics. Oyster reefs provide excellent structural habitat as well as effective water filtration.

    - **Biotic Communities:** e.g., *Crassostrea* Reef, *Ostrea* Reef

- **Biotic Subclass: Worm Reef Biota –** Areas dominated by relatively stable, ridge- or mound-like aggregations of living and non-living material formed by the colonization and growth of worm species (e.g., sabellariids).

  - **Biotic Group: Sabellariid Reef –** Areas dominated by ridge- or mound-like features formed by the colonization and growth of living sabellariid worm species that have cemented sediment grains into complex structures. Certain types of sabellariid reefs most often occur parallel to an ocean shoreline in shallow water, but many are also found in deeper waters where current energy is high.

    - **Biotic Communities:** e.g., *Phragmatopoma* Reef, *Sabellaria* Reef

  - **Biotic Group: Serpulid Reef** - Areas dominated by mound-like, bush-like, or patchy growths of living Serpulid worms that have secreted tubes of calcium carbonate to form complex aggregated structures. Serpulid worms can be distinguished from Sabellariid worms (see above) by the presence of a hard operculum that seals the hard, shell-like Serpulid tube. Living Serpulid reefs are extremely rare in U.S. coastal waters, but recently extinct Serpulid reef structures do occur, e.g., in certain Gulf of Mexico embayments. If no living Serpulid worms are present and the reef is extinct, it is classified in CMECS as Substrate (see Section 7.4.2). Living Serpulid reefs are, however, found in other parts of the world, and are considered valuable structure-forming habitat.

    - **Biotic Communities**: e.g., *Serpula vermicularis* Reef

Biotic Class: Faunal Bed

Seabeds dominated or characterized by a cover of animals that are closely associated with the bottom, including attached, clinging, sessile, infaunal, burrowing, laying, interstitial, and slow moving animals, but not animals that have created substrate (Reef Biota). Unlike Reef Biota, Faunal Bed biota cannot (or are not sufficiently abundant to) construct identifiable substrate. “Slow moving” animals included in the Faunal Bed class are defined as being incapable of moving outside the boundaries of the classification unit within one day. Faunal Bed organisms are aquatic, but they may be able to withstand periods of exposure to air.

Faunal Bed food webs may receive basic trophic inputs from benthic photosynthesis or chemosynthesis, plankton, allochthonous detritus and debris, or other sources. In nature, Faunal Bed habitats are often composed of complex mixes and associations of animals of different phyla, sizes, feeding strategies, and habits, and these areas can be difficult to classify. Faunal Bed classifications are determined in CMECS by greatest percent cover of fauna or faunal structures, or (particularly for infauna) by estimates of greatest biomass. The inherent complexity of these areas is addressed through Co-occurring Elements and Associated Taxa Modifiers (Sections 10.6.2 and 10.3.1)**.**

In the photic zone, primary producers often constitute the greatest biotic percent cover of substrate, and so define the biotic group of an area (e.g., Filamentous Algal Bed, Microphytobenthos). Faunal Bed organisms, when present in these areas, are classified in CMECS as Co-occurring Elements, for example: “Biotic Group: Coralline/Crustose Algal Bed with Co-occurring Element: Attached *Strongylocentrotus purpurata*”.

In waters deeper than the photic zone, however, most Faunal Bed biotic groups and communities are defined by immobile or slow-moving suspension-feeders and detritivores that dominate percent cover or biomass, and create a distinct living environment for other fauna. Other Faunal Bed biotic groups and communities are defined by slow-moving grazers or predators (e.g., urchins, starfish), when these are the clearly dominant fauna. However, practitioners should attempt to identify a biotic group that is providing “forage” for these predatory or herbivorous species. If a “forage” biotope is present, it will often dominate percent cover, and practitioners should characterize the area accordingly as (for example): “Biotic Community: Nassariid Bed with Co-occurring Element: *Pisaster*”. The Co-occurring Elements modifier (see Section 10.6.2) is used to describe areas where any two (or more) biotic groups, biotic communities, or other biotic classification units described in CMECS occur simultaneously. In these cases, the classification units exist together, as a mix, in a single location, and the non-dominant units are termed Co-occurring Elements. Further local research may indicate that the mix of biotic groups and co-occurring elements is, in fact, a repeatable unit that should be designated as a single defined biotic group or biotope.

Other common animals in seafloor environments include opportunistic predators or herbivores that are capable of moving outside the bounds of the classification unit within one day, such as portunid crabs, cancrid crabs, horseshoe crabs, cephalopods, other mobile benthic crustaceans, fishes, and other nekton. These animals actively move over the seafloor searching for prey, and are defined in CMECS as Associated Taxa (see Section 10.3.1).

As in other BC classes, practitioners may apply Genus and/or species names to define local biotic communities that are not listed in the current version of CMECS. In these cases, observations in the field must verify that these new biotic communities are predictable and repeating aggregations or assemblages of dominant or characteristic species. These names should be submitted as part of the CMECS Dynamic Content Standard (see Section 13).

Faunal Beds are highly dependent on substrate type. Individual species and entire biotic communities have adapted specialized anatomies and behaviors for survival on hard substrates; other species and communities have specialized and developed adaptations for life on soft substrates. Generalist fauna also occur (e.g., certain holothurians, crustaceans, and sponges) that can succeed on both substrate types. However, substrate type is such a defining aspect of the Faunal Bed class that CMECS Faunal Bed subclasses are assigned as physical-biological associations involving both biota and substrate.

The Faunal Bed class is arranged into two major subclasses: Attached Fauna, and Soft Sediment Fauna. Each subclass presents alphabetized biotic groups that are defined by ecological characteristics, followed by alphabetized biotic groups that are defined by taxonomic characteristics. Fauna that fit into two biotic groups are generally assigned to the group that provides the most ecological detail; e.g., *Serpulorbis* (an attached tube builder and a sessile gastropod) is placed in Attached Tube-Building Fauna, not Sessile Gastropods. Names of biotic communities from soft sediment faunal areas incorporate the term “Bed” to distinguish them from hard sediment (attached) faunal communities.

- **Biotic Subclass: Attached Fauna –** Areas characterized by rock substrates, gravel substrates, other hard substrates, or mixed substrates that are dominated by fauna which maintain contact with the substrate surface, including firmly attached, crawling, resting, interstitial, or clinging fauna. Fauna may be found on, between, or under rocks or other hard substrates or substrate mixes. These fauna use pedal discs, cement, byssal threads, feet, claws, appendages, spines, suction, negative density, or other means to stay in contact with the (generally) hard substrate, and may or may not be capable of slow movement over the substrate. However, these fauna are not able to achieve speeds sufficient to move beyond the unit boundary within one day. Many attached fauna are suspension feeders and feed from the water column. Other attached fauna are benthic feeders, including herbivores, predators, detritivores, deposit feeders, and omnivores. Within Attached Fauna, the Biotic Group is identified as the biota making up the greatest percent cover on the hard attachment surface within the classified area. Biota present at lesser percent cover values within the classified area may be identified as Co-occurring Elements (See Section 10.6.2) or (if not a CMECS Biotic Group) Associated Taxa (See Section 10.3.1).

- **Biotic Group: Mineral Boring Fauna –** Areas where specialized fauna have bored into hard mineral substrate (rock, shell, carbonate reef, peat, compacted stiff clay) and constitute the dominant biological feature by percent cover or biomass. Several taxa (including sponges, sipunculids, clams, mussels, gastropods, annelids and others) have developed mechanisms for boring into rock, shell and other mineral substrates.

    - **Biotic Communities:** e.g., Boring *Cliona celata***,** Boring *Penitella*, Boring *Lithophaga*

- **Biotic Group: Wood Boring Fauna –** Anthropogenic or natural wood substrate areas characterized or dominated by specialized fauna that have bored into the wood. Several taxa, including teredos or shipworms (bivalves), gribbles (crustaceans), and others have developed the ability to bore into wood so as to obtain food, protection, or both. Once wood-boring fauna have begun to break the wood apart, other fauna will move in to occupy spaces within the wood, feeding on detritus, wood-borers, plankton, and other fauna.

    - **Biotic Communities:** e.g., Boring *Bankia*, Boring *Limnoria*, Boring *Teredo*

- **Biotic Group: Diverse Colonizers –** Areas dominated by highly varied and diverse communities of mixed fauna that have attached to a biotic or abiotic hard substrate (which may be rock, cobble, oyster reef, non-living coral reefs, or other substrates). Common colonizing taxa include anemones, tunicates, barnacles, mollusks, hydroids, bryozoans, gorgonians, soft or leather corals, sponges, and/or other taxa. Diverse Colonizers on living coral reefs are included in the Colonized Shallow and Mesophotic Reef Biotic Group. Diverse Colonizers can be further described using the Invertebrate Community Organism Size Modifiers: Meiofauna (dominants $\leq$ 0.5 millimeter), Small Macrofauna (dominants > 0.5 millimeter to 2 millimeters), Large Macrofauna (dominants > 2 millimeters to 1 centimeter), Megafauna (dominants > 1 centimeter to 3 centimeters), Large Megafauna (dominants > 3 centimeters), with all measurements in the smallest dimension (e.g., width or height) and not including the length of slender lateral projections (e.g., arms or tentacles). As with all biotic groups, this unit may be used when communities cannot be identified, as in "Diverse Colonizers (Megafauna)", which provides important information despite limitations of data, e.g., video information.

    - **Biotic Communities:** e.g., Anemone/Mussel/Bryozoan Colonizers (Large Macrofauna), Mollusk/Sponge/Tunicate Colonizers (Large Megafauna), Sponge/Gorgonian Colonizers

- **Biotic Group: Attached Tube-Building Fauna –** Hard substrate areas with a percent cover dominated by tube builders, including annelids, phoronids, sipunculids, crustaceans, gastropods, pogonophorans, echiurans, priapulids, and other phyla. These animals construct chitinous, leathery, calcareous, sandy, mucus, or other types of tubes that are cemented or otherwise attached to hard substrate, and can occur in very high densities. If the tubes are built from a more permanent material (e.g., calcium carbonate) and occur in densities sufficient to construct substrate, these areas may be classified as Reef Biota.

  - **Biotic Communities**: *e.g.*, Attached Phoronids, Attached Pogonophorans, Attached *Sabellaria,* Attached *Serpula*, Attached *Serpulorbis*

- **Biotic Group: Vent/Seep Communities –** Areas near deep-sea vents and seeps, often dominated by very large fauna (e.g., bivalves, pogonophorans) which derive nutrition from chemoautotrophic bacteria that can utilize the chemicals present in the vent or seep as an energy source. Many Vent/Seep Communities are spectacular ecosystems with very high biomass and a diversity of unusual fauna. These areas are often characterized by hard substrates due to the active geologic processes that create vents and seeps.

  - **Biotic Communities:** e.g., *Calyptogena* Communities, *Riftia* Communities

- **Biotic Group: Attached Anemones –** Hard substrate areas dominated by attached anemones (coelenterates which secure themselves to a hard substrate with a pedal disc). These assemblages are common in certain rocky, coastal areas.

  - **Biotic Communities**: *e.g.,* Attached *Aiptasia,* Attached *Metridium*

- **Biotic Group: Barnacles –** Areas dominated by barnacles (small filter-feeding crustaceans in a protective shell that is attached to hard substrate) and associated fauna (e.g., the snail, *Littorina,* see Figure 8.9).

  - **Biotic Communities*:*** *e.g., Balanus* Communities, *Chthamalus* Communities

Figure 8.9. *Semibalanus balanoides* Communities with Co-occurring Element Mobile Mollusks on Hard or Mixed Substrates, *Littorina littorea*.
Massachusetts. Note also the recent set of small Semibalanus. Image: G. Cicchetti.

- **Biotic Group: Attached Basket Stars –** Hard or mixed substrate areas characterized by brushy, many-armed echinoderms known as basket stars. Basket stars and brittle stars (see below) are both members of the class Ophiuroidea, but the arms of basket stars bifurcate many times to form a large complex that is reminiscent of a basket. Basket stars are usually larger than brittle stars, and maintain an upright form, generally clinging to hard substrate or solid objects using their bifurcated arms, which also function in suspension feeding.

    - **Biotic Communities:** e.g., Attached *Astrophyton*, Attached *Gorgonocephalus*

- **Biotic Group: Attached Brachiopods –** Areas dominated by brachiopods, a phylum of animals with two shells, a stalk-like peduncle, and a tentacular, ciliated feeding organ. Brachiopods resemble clams, but are not mollusks. In some species, the peduncle is used to attach the animal to hard substrate, or one of the valves is cemented to the substrate. In other species, the peduncle and the valves are adapted to burrowing in soft sediment (see Burrowing Brachiopods, below). Brachiopods may occur in very high densities in some areas and are common on the U.S. west coast. Certain species can be identified by the wide gape between their shells when they are feeding, but not all species exhibit this wide gape. Most Brachiopods feed on plankton or on detritus.

    - **Biotic Communities:** e.g., Attached *Crania,* Attached *Laqueous*, Attached *Terebratalia*

- **Biotic Group: Brittle Stars on Hard or Mixed Substrates –** Assemblages dominated by crawling, epifaunal, crevice-dwelling brittle stars, often living on, between, or under rocks. Brittle stars (together with basket stars) are Ophiuroids, a relatively mobile class of echinoderms with long, slender arms and a distinct central disk. Some brittle star species are specialized for life on or among rocks and other hard substrates, others are specialized for infaunal burrowing, and some species may be generalists, found in a variety of substrates, and utilizing a variety of feeding methods.

- **Biotic Communities:** e.g., *Amphipholis* Communities, *Ophioderma* Communities, *Ophiothrix* Communities

- **Biotic Group: Attached Bryozoans –** Areas dominated by abundant or structurally complex, attached bryozoan communities that are may be habitat-forming. These colonial filter-feeding animals generally have a protective chinitous or calcareous covering that adds structural support. They may occur on hard substrates as flat encrusting growths, as feathery branched structures, as complex calcareous shapes, as fouling communities, and in other forms. Certain species of bryozoans may create extensive habitats.

  - **Biotic Communities:** e.g., Attached *Bugula,* Attached *Celleporaria,* Attached *Tubulipora*

- **Biotic Group: Chitons –** Areas dominated by attached chitons, gastropod-like mollusks with eight calcareous dorsal plates (valves), a broad foot for attachment to hard substrates, and a scraping radula for feeding. Several species can reach high abundances on intertidal or subtidal rocks. Some chitons will create a depression in rock substrate for improved protection; however, they are classified here as Chitons, rather than above as Mineral Boring Fauna.

  - **Biotic Communities:** e.g., Attached *Acanthopleura,* Attached *Katharina*, Attached *Nutallina*

- **Biotic Group: Attached Corals –** Subtidal (and deeper) substrates that are dominated by non-reef-forming corals. These include hexacorals such as black corals (Order Antipatheria) and gold corals (Order Zoanthidea, family Gerardiidae). All octocorals are non-reef forming, including soft corals and gorgonian sea fans and sea whips (Order Alcyonacea). Also in this group, bamboo corals are generally larger, erect, tree-shaped branching octocoral forms (with an articulated, bamboo-like skeleton) that are common in the deep sea. None of the octocorals produce the calcium carbonate structures associated with coral reefs, but octocorals can form important habitat areas, particularly in the deep sea, where large communities may cover significant area. Most species require a hard substrate for attachment, which may range from bedrock to a single pebble. Octocorals in the order Pennatulacea (sea pens, sea pansies, and sea feathers) are in general specialized for life on soft substrates, and are addressed in the Soft Sediment Fauna subclass.

  - **Biotic Communities:** e.g., Attached Black Corals, *Eugorgia* Communities, Attached Gold Corals, Attached Gorgonians, Isididae Communities, *Paragorgia* Communities, Attached Soft Corals

- **Biotic Group: Attached Crinoids –** Assemblages on hard or mixed substrates that are dominated by either attached, stalked crinoids (or "sea lilies") or motile (but often stationary, see Barnes 1980), comatulids (or "feather stars"). These animals are common in the deep sea and in other areas. Crinoids are a Class of echinoderm characterized (in general) by a stalk that supports the body, mouth, and arms of the animal. The branching arms are equipped with ciliated grooves that carry food items to the central, upward-facing mouth.

  - **Biotic Communities:** e.g., Attached *Comanthus*, Attached *Diplocrinus*

- **Biotic Group: Mobile Crustaceans on Hard or Mixed Substrates –** Areas where the epifaunal community is dominated by slow-moving crustaceans on hard or mixed substrates, often living on, between, or under rocks. Many of these animals feed on organic detritus, debris, or small fauna. This group is limited to the epifaunal crustacean taxa that are relatively non-motile (e.g., hermit crabs, xanthid crabs, grapsid crabs, mysids, palaemonids and other small shrimps, amphipods, isopods) and cannot move outside the boundaries of the classification unit within one day. This group does not include the larger, more mobile, usually predatory crustacean forms (e.g., swimming crabs, *Cancer* crabs, large spider crabs, penaied shrimps), which should be recorded as Associated Taxa with another Biotic Group (see Section 10.3.1) .

  - **Biotic Communities:** e.g., Caprellid Communities, *Crangon* Communities, *Pagurus* Communities

- **Biotic Group: Sessile Gastropods –** Hard substrate areas dominated by sessile (or mostly sessile) gastropods, often suspension feeders. Fauna in this biotic group may construct thick calcareous growths, but do not occur in abundance that is judged sufficient to construct substrate; where these species are sufficiently abundant that they do construct substrate, they are classified in the Reef Class as Mollusk Reef (see above).

  - **Biotic Communities:** Attached *Acmaea*, Attached *Crepidula*, Attached *Haliotis*, Attached Vermetids

- **Biotic Group: Attached Holothurians –** Areas where the epifaunal community is dominated by sessile or slow-moving holothurians (sea cucumbers) on hard or mixed substrates. Holothurians living on hard substrate may attach firmly, or may be capable of movement over the substrate. Many forms are adapted to deposit feeding by moving their sticky tentacles over the substrate; other forms are suspension-feeders.

    - **Biotic Communities:** e.g., Attached *Parastichopus*, Attached *Psolus*

- **Biotic Group: Attached Hydroids –** Areas dominated by mounds or mats of hydroids that are attached to a hard substrate. Hydroids are colonies of individual cylindrical polyps arranged in a branching structure, as a furry or brushy covering, or in other forms. Polyps are specialized for support, reproduction, and defense, and are armed with nematocysts (stinging capsules in specialized cells). Hydroids are the benthic life stage of planktonic jellyfish medusae, and most are predators on small life forms. Hydroid mounds or mats may form very dense assemblages.

    - **Biotic Communities:** e.g., Attached *Sertularia,* Attached *Tubularia*

- **Biotic Group: Mobile Mollusks on Hard or Mixed Substrates –** Areas dominated by slow-moving mollusks, most commonly gastropods. In general, the forms that reach densities sufficient to be defined as a Biotic Group are detritivores or suspension feeders. Slow moving predatory mollusks (e.g., whelks, drills, octopods) tend to be less abundant, and would more typically be classified in CMECS as Co-occurring Elements, together with another Biotic Group.

    - **Biotic Communities:** *Bittium* Communities, *Littorina* Communities, *Urosalpinx* Communities

- **Biotic Group: Attached Mussels –** Areas dominated by dense accumulations of mussels attached to a substrate other than conspecifics. This group includes associated faunal communities and predators on mussels (e.g., starfish), which may be highly conspicuous. Areas where mussels have constructed substrate are classified as Mussel Reef. Areas where mussels are not attached to a hard substrate are classified as Soft Sediment Fauna, Mussel Bed.

    - **Biotic Communities:** e.g., Attached *Modiolus*, Attached *Mytilus*

- **Biotic Group: Attached Oysters –** Areas dominated by accumulations of oysters attached to a substrate other than conspecifics. Areas where oysters have constructed substrate are classified as Oyster Reef (see above). Areas where oysters are not attached to the substrate are classified as Soft Sediment Fauna, Oyster Bed.

    - **Biotic Communities:** e.g., Attached *Crassostrea*, Attached *Ostrea*

- **Biotic Group: Attached Sponges –** Hard or mixed substrate areas that are dominated by sponges and their associated communities, e.g., where non-reef building sponge species grow attached to hard substrate or are nestled among hard substrate, or where reef-building sponges grow on hard substrates in densities that are not judged sufficient to constitute a reef. Most sponge species do not have fused silica spicules, and so do not create lasting skeletons that build reefs. Nonetheless, these more fibrous and ephemeral sponges provide seafloor relief and excellent habitat for other fauna, including many commensal species that live within the tissues of the sponge.

- **Biotic Communities:** *e.g.,* Attached *Cliona*, Attached *Halichondria*, Attached *Hyalonema*, Attached *Microciona*, Attached *Scypha*

- **Biotic Group: Attached Starfish –** Hard or mixed substrate areas in which starfish (sea stars) occur in large aggregations and clearly dominate the biota. Practitioners should note that, in most cases, starfish are predators on another Biotic Group (e.g., Attached Mussels) which (as the forage base) would normally constitute the dominant percent cover. In those cases, Starfish would be described as a Co-occurring Element, e.g., "Biotic Group: Attached *Mytilus edulis* with Co-occurring Element: Attached *Asterias rubens"*. The Attached Starfish biotic group is intended to describe areas where starfish constitute the dominant life form in percent cover, not areas with occasional or scattered starfish.

  - **Biotic Communities:** *e.g.,* Attached *Asterias,* Attached *Pisaster*

- **Biotic Group: Attached Tunicates –** Areas dominated by attached members of the subphylum Tunicata, known as tunicates, ascidians, or sea squirts. Tunicates are bag-like filter feeders with an incurrent and an excurrent siphon. In some areas they reach high abundances. One species (*Didemnum,* see Figure 8.10) is a rapid invasive that blankets large areas, excludes other fauna, and has invaded many countries around the world, including the United States, on both the East and West coasts.

  - **Biotic Communities:** *e.g.,* Attached *Didemnum*, Attached *Molgula*

Figure 8.10. Attached Tunicates, *Didemnum vexillum*, British Columbia.
Image: F. Poole, Search.USA.gov, USGS.

- **Biotic Group: Attached Sea Urchins –** Hard or mixed substrate areas dominated by mobile sea urchins. Many sea urchins are omnivorous, consuming algae, debris, sessile invertebrates, and other foods. In some situations, sea urchins will occur in great numbers, clearly constituting the dominant Biotic Group. These fauna may be associated with another Biotic Group (upon which they are feeding) and may be considered as Co-occurring Elements if the “forage” group occurs in greater percent cover, or dominates biomass.

  - **Biotic Communities:** e.g., Attached *Strongylocentrotus droebachiensis*, Attached *Strongylocentrotus purpurata*

- **Biotic Subclass: Soft Sediment Fauna –** Areas that are characterized by fine unconsolidated substrates (sand, mud) and that are dominated in percent cover or in estimated biomass by infauna, sessile epifauna, mobile epifauna, mobile fauna that create semi-permanent burrows as homes, or by structures or evidence associated with these fauna (e.g., tilefish burrows, lobster burrows). These animals may tunnel freely within the sediment or embed themselves wholly or partially in the sediment. In many cases, they will regularly leave their burrows, and may move rapidly or swim actively after doing so, but any animal that creates a semi-permanent home in the sediment can be classified as Soft Sediment Fauna.

These animals may also move slowly over the sediment surface, but are not capable of moving outside of the boundaries of the classification unit within one day. Most of these fauna possess specialized organs for burrowing, digging, embedding, tube-building, anchoring, or locomotory activities in soft substrates. Biotic communities in the Soft Sediment Fauna subclass are identified with the term “Bed”, to distinguish them from Attached Fauna biotic communities (which do not include the term “Bed”).

Within Soft Sediment Fauna, the Biotic Group is identified as the biota making up the greatest percent cover or the greatest estimated biomass within the classified area. Biota present at lesser percent cover or estimated biomass values within the classified area may be identified as Co-occurring Elements (See Section 10.6.2) or (if not a CMECS Biotic Group) as Associated Taxa (See Section 10.3.1). Associated Taxa include rapid epifaunal predators such as crustaceans, fishes, and other nekton that are capable of leaving the boundaries of the classification unit within one day. Associated Taxa may be capable of digging into the sediment surface to feed or hide (e.g., portunid crabs) but do not construct a semi-permanent burrow as would define Soft Sediment Fauna. For practitioners who wish to better characterize Soft Sediment Fauna, the Community Successional Stage Modifier (Section 10.3.2, including Figure 10.1 and Table 10.3) is a helpful addition to classifying soft sediment communities, and can be applied to almost every soft-sediment area. This modifier provides ecological and functional information, and adds an element of assessment.

- **Biotic Group: Larger Deep-Burrowing Fauna –** Assemblages dominated by the presence—or evidence—of larger, deep-burrowing, soft-bodied, generally worm-like infauna. Characteristic taxa include larger (body width > 2 millimeters) annelids (segmented worms), enteropneusts (acorn worms), sipunculids (peanut worms), priapulids (phallus worms), nemerteans (ribbon worms), echiuroids (spoon worms), and/or other worm-like fauna, typically living > 5 centimeters below the sediment-water interface. Diverse mixes of fauna are common, and biotic communities may or may not be identifiable with an abundant or distinctive dominant taxon. Large fecal casts, mounds, burrows, feeding voids, etc., may be taken as evidence of deep-burrowing fauna. However, areas characterized by larger, tube-building worms (that construct a significant tube structure rising above the sediment-water interface, but may live with a body position below the sediment surface) are classified as Larger Tube-Building Fauna. Burrowing fauna with shells (e.g., clams and crustaceans) are covered below in other biotic groups.

    - **Biotic Communities:** e.g., *Balanoglossus* Bed**,** *Boniella* Bed, *Glycera* Bed, *Nephtys* Bed, Sipunculid Bed

- **Biotic Group: Small Surface-Burrowing Fauna –** Areas dominated by small, burrowing, often worm-like fauna with a body width usually ≤ 2 millimeters; animals are typically found within 5 centimeters of the sediment-water interface. Common fauna include oligochetes, polychaetes, sipunculids, flatworms, nematodes, priapulids, small enteropneusts (acorn worms), and other phyla. Burrowing fauna other than worms may also be characteristic (e.g., small, surface-burrowing amphipods, mysids, copepods, or isopods). In many areas, surface fauna will be abundant, but individual animals generally associated with this group will be found living deeper than 5 centimeters into the sediment; these areas are still classified as Small Surface-Burrowing Fauna.

- **Biotic Communities:** e.g., Capitellid Bed, Harpacticoid Bed, *Leptocheirus* Bed, Lumbrinerid Bed, Nematode Bed, Oligochaete Bed, Turbellarian Bed

- **Biotic Group: Diverse Soft Sediment Epifauna –** Highly varied and diverse communities of mixed fauna that are present on the surface of soft unconsolidated substrates. Common taxa include annelids, holothurians, ophiuroids, anemones, tunicates, mollusks, sea pansies, hydroids, bryozoans, sea urchins, sponges, echiuroids, priapulids, and many others. Diverse Fine Sediment Epifauna can be further described using the Invertebrate Community Organism Size Modifiers: Meiofauna (dominants $\leq$ 0.5 millimeter), Small Macrofauna (dominants > 0.5 millimeter to 2 millimeters), Large Macrofauna (dominants > 2 millimeters to 1 centimeter), Megafauna (dominants > 1 centimeter to 3 centimeters), Large Megafauna (dominants > 3 centimeters), with all measurements in the smallest dimension (e.g., width or height) and not including the length of slender lateral projections (e.g., arms or tentacles). As with all Biotic Groups, this unit may be used when Communities cannot be identified, as in “Diverse Soft Sediment Epifauna (Large Macrofauna), which provides important information despite limitations of data, e.g., video information.

    - **Biotic Communities:** e.g., *Aphrodite* Bed, Bryozoan/Anemone Bed (Megafauna), Holothurian/Ophiuroid Bed, Sand Dollar/Sea Pansy/Mobile Mollusk Bed (Large Megafauna)

- **Biotic Group: Larger Tube-Building Fauna –** Soft sediment areas dominated by larger tube builders (tube width > 2 millimeters, or tube length > 30 millimeters), most commonly polychaetes, but including many other worm-like phyla (phoronids, sipunculids), crustaceans, and others. The tubes may be constructed in a variety of ways to produce calcareous, leathery, sandy, mucus-bound, chitinous, fibrous, papery, and other types of tubes. The animal itself may reside above or below the sediment surface, within the constructed tube. Some tube-building species (e.g., *Asabellides oculata*) may form extremely dense mounds of tubes that rise many centimeters above the seafloor. If colonization and growth of these fauna and their tubes results in the construction of substrate that is relatively stable, these faunal structures may be classified as Reef Biota.

- **Biotic Communities:** e.g., Robust *Ampelisca* Bed, *Asabellides* Bed, *Asychis* Bed, *Chaetopterus* Bed, *Diopatra* Bed, *Lagis* Bed, *Loimia* Bed, Phoronid Bed, *Phoronopsis* Bed

- **Biotic Group: Small Tube-Building Fauna –** Soft sediment areas dominated by tube-building annelids (e.g., spionids, sabellids), amphipods, small phoronids, or other small, surface-dwelling, tube-building fauna. These animals have a small tube width (≤ 2 millimeters), and the tubes often occur in dense mats. The animal itself may reside above or below the sediment surface within the constructed tube, which may be composed of a variety of materials (e.g., glued sediments, calcium carbonate, mucus, chitin, proteins).

  - **Biotic Communities:** e.g., Thin *Ampelisca* Bed, *Chone* Bed, *Paraprionospio* Bed, *Polydora* Bed, *Streblospio* Bed

- **Biotic Group: Tunneling Megafauna –** Intertidal or Subtidal areas dominated by burrowing or construction activities of larger (megafaunal) organisms that create a water-filled tunnel with a diameter of > 1 centimeter. Tunneling activities are often attributable to crustaceans (generally decapods), but fishes (e.g., tilefish) and other taxa may also create large tunnel features. An associated mound of sediment may also be constructed. This biotic group is usually identified by the presence of tunnels or structures; the actual animal may be difficult to locate.

  - **Biotic Communities:** e.g., *Callichirus* Bed, *Lepidophthalmus* Bed, *Lopholatilus* Bed, *Neotrypaea* Bed, *Nephrops* Bed, *Squilla* Bed, *Upogebia* Bed

- **Biotic Group: Oligozoic Biota –** Zones that are devoid of macrofauna, larger fauna, and microbial mats, i.e., where no evidence of larger multicellular life can be detected when a sufficient area of the substrate is sampled to deliver sub-millimeter resolution, and where microbial communities are not visible to the naked eye. Interstitial meiofauna, however, may be present or inferred. It is inappropriate to identify this biotic group with sampling methods that are not capable of sub-millimeter resolution and cannot detect infauna that may reside below the surface in soft sediments. Sampling methods which can resolve this biotic group include retrieval of substrate followed by sieving with ≤ 0.5 millimeter mesh size and stereoscopic examination, and sediment profile imaging with cameras that provide sub-millimeter resolution at the faceplate. This biotic group is found in areas of extremely high stress (e.g., anoxic zones, highly toxic areas, and high-energy pebble or cobble beaches) where conditions cannot support larger multicellular life. Oxic areas of subtidal mineral sands are generally sparsely colonized by multicellular organisms (e.g., haustoriid amphipods, syllids and other small polychaetes) and are not considered Oligozoic Biota.

- **Biotic Communities:** e.g., Anoxic Oligozoic Bed, Bacterial Bed, Meiofaunal Bed

- **Biotic Group: Burrowing Anemones –** Areas dominated by anemones (solitary coelenterates) that use their pedal disc to burrow in soft substrates. Many species are characterized by a whorl of tentacles at the sediment surface; when disturbed, the animal may very rapidly retract its tentacles into a burrow. These anemones occur at a range of densities, which requires sampling gear with an appropriate resolution and observational footprint (e.g., video transects or plan-view still photographs).

  - **Biotic Communities:** e.g., *Cerianthus* Bed, *Edwardsia* Bed

- **Biotic Group: Soft Sediment Basket Stars –** Sandy or muddy areas characterized by brushy, many-armed echinoderms known as basket stars. Basket stars and the more common brittle stars are members of the class Ophiuroidea, but the arms of basket stars bifurcate many times to form a large complex that is reminiscent of a basket. Basket stars are usually larger than brittle stars, and maintain an upright form, generally clinging to solid objects, conspecifics, or other fauna using their bifurcated arms. In some soft sediment locations, basket stars form large entangled aggregations consisting of many individuals and covering large areas. Most basket stars are suspension feeders, but some species are more omnivorous or predaceous.

  - **Biotic Communities:** e.g., *Asteronyx* Bed, *Gorgonocephalus arcticus* Bed

- **Biotic Group: Brachiopod Bed –** Soft-sediment areas dominated by burrowing, clam-like brachiopods, a phylum of animals with two shells, a stalk-like peduncle, and a tentacular, ciliated feeding organ. In soft sediment dwelling species, the peduncle and the valves are adapted to burrowing. In other brachiopod species, the animal is adapted to attach to hard substrate (see Attached Brachiopods, above). Most brachiopods feed on plankton or on detritus. Brachiopods may occur in very high densities in some soft sediment areas, including intertidal areas (particularly on the west coast of the United States).

  - **Biotic Communities:** e.g., *Glottidia* Bed, *Lingula* Bed

- **Biotic Group: Soft Sediment Brittle Stars –** Fine substrate assemblages dominated by crawling, burrowing or infaunal brittle stars, which are a relatively mobile class of echinoderms. Brittle stars may be either epifaunal or infaunal depending on the species and/or environmental conditions. In some situations, the central disc and several arms will be buried, but the remaining arm or arms will protrude typically ~ 1 centimeter to ~ 3 centimeters into the water column, where they may be mistaken for worms.

    - **Biotic Communities:** e.g., *Amphiura* Bed, *Ophiothrix* Bed, *Ophiura* Bed

- **Biotic Group: Soft Sediment Bryozoans –** Areas dominated by bryozoans (small colonial filter-feeding animals with a calcareous skeleton) that may grow in complex branched structures, bushy shapes, or other forms. Bryozoans may be partially embedded in fine substrates, or may be resting, unattached, on the sediment surface.

    - **Biotic Communities:** e.g., *Bugula* Bed, *Celleporaria* Bed, *Schizoporella* Bed

- **Biotic Group: Cephalochordates –** Soft-sediment areas (typically sandy) that are dominated by the rapidly burrowing, fish-like *Amphioxus*, or by other similar Genera of the subphylum Cephalochordata, a group of animals with characteristics of both vertebrates and invertebrates. These small (typically 2 - 15 centimeters in length) slender animals live buried just under the surface of sandy sediments. They feed on plankton or detritus that is strained from the water with a specialized feeding apparatus. *Amphioxus* and the related Genera have a worldwide distribution, and may occur in very high densities in some areas.

    - **Biotic Communities:** e.g., *Amphioxus* Bed, *Branchiostoma* Bed

- **Biotic Group: Clam Bed –** Areas where either: (a) living clams, siphons, or siphon holes are the dominant surface feature, or; (b) clams dominate the faunal biomass. Siphons or shells may (or may not) be visible from above the sediment surface. The Clam Bed biotic group includes clams of all sizes; clam size can be specified using the Invertebrate Community Organism Size Modifiers: Meiofauna (dominants $\leq$ 0.5 millimeter), Small Macrofauna (dominants > 0.5 millimeter to 2 millimeters), Large Macrofauna (dominants > 2 millimeters to 1 centimeter), Megafauna (dominants > 1 centimeter to 3 centimeters), Large Megafauna (dominants > 3 centimeters), with all measurements in the smallest dimension (e.g., the smallest shell width for most clams).

- **Biotic Communities:** e.g., *Arctica* Bed, *Donax* Bed, *Macoma* Bed, *Mercenaria* Bed, *Mulinia* Bed, *Mya* Bed, *Nucula* Bed, *Rangia* Bed, *Spisula* Bed, *Venus* Bed, *Yoldia* Bed

- **Biotic Group: Soft Sediment Crinoids –** Areas dominated by crinoid species that are not attached to a hard substrate. Stalked crinoids or "sea lilies" may fix themselves to the soft seafloor or may move along the bottom. These animals and the motile (but often stationary, see Barnes 1980) comatulid "feather stars" are common in the deep sea and in other areas. They may be resting on the sediment surface, or they may be partially embedded in the sediment. Both groups of crinoids (sea lilies and feather stars) are suspension-feeding echinoderms with many branched arms.

  - **Biotic Communities:** e.g., *Comanthus* Bed, *Diplocrinus* Bed, *Rhizocrinus* Bed

- **Biotic Group: Mobile Crustaceans on Soft Sediments –** Areas where the epifaunal or surface community is dominated by slow-moving crustaceans. This group is limited to the relatively non-motile, epifaunal, crustacean taxa (e.g., hermit crabs, mole crabs, amphipods, mysids, isopods) and does not include the more mobile arthropod forms (e.g., swimming crabs, horseshoe crabs, penaied shrimps) which can leave the classified area in less than one day and are defined as Associated Taxa. Larger mobile crustacean forms that construct a semi-permanent home (lobsters, burrowing shrimps, etc.) are classified as Tunneling Megafauna. Small burrowing crustaceans with a body measuring $\leq$ 2 mm in the smallest dimension are classified as Small Surface-Burrowing Fauna.

  - **Biotic Communities:** e.g., Caprellid Bed, *Emerita* Bed, Haustoriid Bed, Mysid Bed, *Pagurus* Bed

- **Biotic Group: Echiurid Bed –** Soft-sediment areas dominated by unsegmented echiurids or "spoon worms" which are abundant on the U.S. west coast in both intertidal and subtidal habitats. This group also includes communities where U-shaped echiurid burrows constitute the dominant or characteristic faunal feature, even if all animals have retracted into their burrows and cannot be seen.

  - **Biotic Communities:** *Echiurus* Bed, *Listriolobus* Bed, *Urechis* Bed

- **Biotic Group: Holothurian Bed –** Soft sediment assemblages dominated by holothurians or "sea cucumbers", which are common in both shallow and deep areas of the ocean. Holothurians common on sand or mud bottoms generally have features adapting them to life in soft sediment, and many species feed by ingesting sediment and associated organic matter as they burrow through the substrate. Tracks, trails, or feces left by these echinoderms may also be characteristic (see Fecal Mounds, also Tracks and Trails in the Inferred Fauna section below). The Holothurian Bed group is used only when the holothurians are present; use the Tracks and Trails or Fecal Mounds Biotic Groups when there is evidence of their presence, but living individuals are not seen.

- **Biotic Communities:** e.g., *Caudina* Bed, *Kolga* Bed, *Leptosynapta* Bed, *Stichopus* Bed

- **Biotic Group: Hydroid Bed –** Areas dominated by hydroid species that are not attached to a hard substrate. These animals may be resting on the sediment surface or may be partially embedded in the sediment. Hydroids are the benthic life stage of planktonic jellyfish medusae, and most are predators on small life forms. Hydroids are colonies of individual polyps usually arranged in a branching or bushy pattern. The polyps are specialized for various roles, and defensive/prey capture polyps are armed with nematocysts (stinging capsules in specialized cells). Hydroids may form large mounds or mats in some soft sediment areas.

  - **Biotic Communities:** *Sertularia* Bed, *Tubularia* Bed

- **Biotic Group: Mobile Mollusks on Soft Sediments –** Areas dominated by epifaunal, slow-moving, generally detritivorous, herbivorous, or omnivorous gastropods, scaphopods, or other mollusks foraging at the surface of unconsolidated sediments. These animals may be partly buried in the substrate. Predatory mobile mollusks such as moon snails, octopods, or whelks are generally preying on another Biotic Group (e.g., Clam Bed) which (as the forage base) would normally constitute the dominant percent cover. In those cases, Mobile Mollusks would be described as a Co-occurring Element, e.g., "Biotic Group: *Spisula* Bed with Co-occurring Element: *Polinices* Bed".

  - **Biotic Communities:** e.g., Nassariid Bed, *Olivella* Bed, *Polinices* Bed, Scaphopod Bed, Turritellid Bed

- **Biotic Group: Mussel Bed –** Soft-sediment areas dominated by mussel species that are not attached to a hard substrate. These animals may be resting on the sediment surface, partially embedded in the sediment, or attached to conspecifics (by using their byssal threads), or to a piece of gravel, e.g., in Slightly Gravelly Fine Sediments. Individuals in the Mussel Bed Group are not present in densities sufficient to construct substrate; in that case, they would be classified as Mussel Reef.

  - **Biotic Communities:** e.g., *Modiolus* Bed, *Mytilus* Bed

- **Biotic Group: Oyster Bed –** Soft-sediment areas dominated by oyster species that are not attached to a hard substrate and are not present in densities sufficient to construct substrate. These animals may be resting on the sediment surface, partially embedded in the sediment**,** or attached to conspecifics**.**

    - **Biotic Communities:** e.g., *Crassostrea* Bed, *Ostrea* Bed

- **Biotic Group: Pennatulid Bed –** Subtidal soft-bottom habitats that are dominated by sea pens or sea pansies (Phylum Cnidaria, Order Pennatulacea). These are colonial octocorals with a central stem-like support attached to a root-like peduncle, adapted for life in soft sediments. An arrangement of suspension-feeding polyps in a single plane on two sides of the central stem (which is a specialized polyp) gives some sea pens the overall appearance of a feather or quill pen. The root-like peduncle is embedded in soft sediments, but the sea pen can move to a new area if conditions are unfavorable. Sea pansies are more compact and fleshier than sea pens. Pennatulids are often common in deeper waters.

    - **Biotic Communities:** e.g., *Halipteris* Bed, *Pennatula* Bed, *Renilla* Bed, *Stylatula* Bed

Figure 8.11. Sea Pen Bed, *Stylatula elongata*, San Diego, California.
Image: G. Cicchetti.

- **Biotic Group: Sand Dollar Bed –** Assemblages dominated by surface-dwelling, “irregular” echinoids of the Phylum Echinodermata and Order Clypeasteroida (e.g., sand dollars, sea biscuits). Sand dollars typically move on top of the sediment surface or burrow in the top few centimeters of sediment. Sand dollars are characterized by a flat body and short spines, to visually distinguish them from Burrowing Urchins and Soft Sediment Sea Urchins (see biotic groups below). Most sand dollars are deposit feeders; some are suspension feeders.

- **Biotic Communities:** e.g., *Clypeaster* Bed, *Dendaster elongatus* Bed, *Mellita* Bed

- **Biotic Group: Scallop Bed –** Areas dominated by accumulations of scallops. Scallops have a series of small eyes and are mobile, clapping their shells together and pulsing through the water to escape predators such as starfish. Scallops may occur in high densities, but populations can be significantly affected by a number of factors, including larval recruitment, predation, and fishing pressure.

  - **Biotic Communities:** e.g., *Argopecten* Bed, *Placopecten* Bed

- **Biotic Group: Sponge Bed –** Sandy or muddy areas of the seafloor that are dominated by sponges and their associated communities, but do not create substrate such that they would be considered Reef Biota. Hexactinellid "glass sponges" that are capable of forming reefs may be classified as a Sponge Bed when occurring on sand or mud in densities not deemed adequate to compose a reef. Many sponge species have developed holdfast organs that adapt them to life in soft sediments, and can provide excellent structural habitat for other creatures, including the many commensal organisms that typically inhabit the tissues of living sponges.

  - **Biotic Communities:** *e.g., Monoraphis* Bed, *Tetilla mutabilis* Bed

- **Biotic Group: Starfish Bed –** Soft sediment areas in which starfish occur in large aggregations and clearly dominate the biota. Practitioners should note that, in most cases, starfish are predators on another Biotic Group (e.g., Clam Bed) which (as the forage base) would normally constitute the dominant percent cover or biomass. In those cases, Starfish would be described as a Co-occurring Element, e.g., "Biotic Group: Clam Bed with Co-occurring Element: *Astropecten"*.

  - **Biotic Communities:** *e.g., Asterias* Bed, *Astropecten* Bed

- **Biotic Group: Tunicate Bed –** Sandy or muddy areas dominated by members of the subphylum Urochordata, including ascidians, sea squirts, and other tunicates. Tunicates are bag-like organisms that use incurrent and excurrent siphons for filter feeding and respiration. These animals may be resting on the sediment surface, partially embedded in the sediment, or attached to conspecifics. On both East and West coasts of the U.S., and in many other areas worldwide, colonies of the invasive sea squirt *Didemnum* are rapidly invading and smothering local biotopes.

    - **Biotic Communities:** e.g., *Ciona* Bed, *Didemnum* Bed

  - **Biotic Group: Burrowing Urchins –** Assemblages dominated by burrowing, "irregular" echinoids (e.g., burrowing urchins, heart urchins). These flattened urchins typically live underneath the sediment surface and feed on mud or on particles of detritus.

    - **Biotic Communities:** e.g., *Echinocardium* Bed, *Lovenia cordiformis* Bed

  - **Biotic Group: Sea Urchin Bed –** Sandy or muddy areas dominated by "regular" echinoids (e.g., sea urchins). These rounded urchins typically live on top of the sediment surface, and several species are well adapted to life on soft sediments, occurring in great numbers in certain locations.

    - **Biotic Communities:** e.g., *Lytechinus anamesus* Bed, *Lytechinus pictus* Bed

- **Biotic Subclass: Inferred Fauna –** Areas dominated by evidence (real or inferred) of faunal activity, but where the fauna themselves are not currently present or evident, given the sampling methodology.

  - **Biotic Group: Egg Masses –** Areas distinguished by egg masses, egg cases, or other lasting evidence of gametes or reproduction. Many burrowing or tube-dwelling polychaetes will produce egg masses that look like bags of mucus attached to the soft sediment seafloor. Gastropods also often produce distinctive egg cases.

    - **Biotic Communities:** e.g., *Busycon* Egg Cases, Polychaete Mucus Cases, *Polynices* Egg Collars, Squid Egg Masses

  - **Biotic Group: Fecal Mounds –** Areas distinguished by large fecal mounds or castings. These features are characteristic of larger deposit-feeding polychaetes and other mud-ingesting fauna. Mounds or castings are not always present even when these fauna are abundant, particularly when water movements (currents, waves) are sufficient to remove the deposits.

    - **Biotic Communities:** e.g., *Arenicola* Castings, Balanoglossid castings, Holothurian Castings

  - **Biotic Group: Pelletized, Fluid Surface Layer –** Areas distinguished by a fluid, fecal-rich, pelletized surface layer, which is typically 5 - 15 millimeters thick (Rhoads and Young 1970). This layer is characteristic of deposit-feeding polychaetes, deposit-feeding clams, and/or other fauna. This layer is indicative of deposit feeders, but is not always present in deposit feeding communities, particularly when currents are sufficient to remove the layer.

- **Biotic Communities:** e.g., Fluidized Capitellid Layer, Fluidized Deposit Feeder Layer, Fluidized Maldanid Layer, Fluidized *Yoldia* Layer

- **Biotic Group: Tracks and Trails –** Areas where sediment surface patterns are dominated by tracks and trails left by locomotion of mobile epifauna (e.g., snails, holothurians, crustaceans), and other fauna that are no longer present. These are common in deeper waters, and in other areas where sediments are less disturbed by physical energy. The appropriate invertebrate size modifier (e.g., Megafaunal, Macrofaunal) may be used to describe the sizes of the organisms suspected of leaving the marks being evaluated.

  - **Biotic Communities:** e.g., Decapod Tracks, Gastropod Trails, Holothurian Trails

Biotic Class: Microbial Communities

Areas dominated by colonies of microscopic or single-celled organisms that form a hard structure, visible film, layer, or mat on or near the surface of the substrate. Colonies may be composed of benthic microalgae (e.g., diatoms), photosynthetic bacteria (e.g., cyanobacteria), archaea, saprotrophic bacteria (e.g., decomposers or decay organisms), chemoautotrophic bacteria, or other microbial groups. These features may exist on or near the surface of the sediment either subtidally or subaerially (Figure 8.12), or they may exist as extensive areas of decay associated with dead organisms that have fallen to the seafloor (Figure 8.13).

Note: There may be high levels of biotic diversity within microbial mats. Microbial mats are often encountered in extreme environments where grazing pressure from multi-cellular organisms is reduced; for example, they can be observed in the high intertidal zone, in areas of low dissolved oxygen, and in deep-sea areas around thermal vents.

- **Biotic Subclass: Structure Forming Microbes –** Areas dominated by microbes that form a hard structure, generally through secretions and entrapment of minerals and sediments.

  - **Biotic Group: Xenophyophores –** Areas (typically found in hadal zones and on the abyssal plains) dominated by tests of large, living, benthic foraminifera (“forams”), most of which are epifaunal, moving very slowly over the seabed. The tests of these single-celled organisms may be surprisingly large, several or many centimeters in size. The multi-nucleated single cell lives in the interlaced fine tubules that constitute the structure of the test. The tests are made of secretions, scavenged minerals, and small particles around the tubules, and may take many shapes -

rounded, globular, densely branching, or stick-like (protruding vertically from the sediment, with a portion that is buried). Evidence suggests that Xenophyophores exist in high densities over large areas of the abyssal and hadal seafloor.

  - **Biotic Communities:** e.g., *Occultammina* Communities, *Syringammina* Communities

- **Biotic Group: Stromatolites –** Areas dominated by large, mound-like formations built up in shallow marine areas by secretions of cyanobacteria, which further entrap minerals and sediment. They form Earth's oldest fossils and originated over 3 billion years ago.

  - **Biotic Communities:** e.g., Stromatolite Mound Communities

- **Biotic Subclass: Mat/Film Forming Microbes –** Areas dominated by microbes that form soft structures, generally through accumulations of conspecifics and other microbes into a matrix that appears as strands, a thin film, or a thicker mat.

  - **Biotic Group: Microphytobenthos –** Areas dominated by a visible accumulation of benthic diatoms, cyanobacteria, unicellular algae, and other single-celled organisms. These may appear at the surface of the substrate in the form of either (a) a thin film or stain or (b) a thicker crust or "felt." These forms may occur on rock or unconsolidated substrates in subtidal, intertidal, or supratidal areas.

    - **Biotic Communities**: e.g., Diatom Felt, Microbial Stain

  - **Biotic Group: Bacterial Mat/Film –** Areas dominated by colonies of bacterial decomposers and other decay organisms. These colonies can range in appearance from delicate and filamentous to a dense mass that may blanket the sediment surface. See Figure 8.12 for an example of a bacterial mat.

    - **Biotic Communities:** e.g., *Beggiatoa* Communities

  - **Biotic Group: Bacterial Decay –** Areas dominated by colonies of bacterial decomposers and other decay organisms that are observed covering and rotting larger organic matter (such as macroalgal debris, fish kills, or similar large organic inputs). See Figure 8.13 for an example of bacterial decay.

    - **Biotic Communities:** e.g., *Beggiatoa* Communities on Decaying Materials

Figure 8.12. Bacterial Mat: Tidal Flat in Humboldt Bay, California.
Image: Annie Eicher US Fish and Wildlife Service.

- **Biotic Group: Vent Microbes –** Areas dominated by chemoautotrophic bacteria living on or near hydrothermal vents. These bacteria can use the chemicals present around the vent as an energy source. The bacteria are present in the water column and on substrate near vents as bacterial mats, films, and strands. They form the primary food source (as symbionts or as free-living bacterial clusters) for the gigantic and diverse fauna that inhabit Vent Communities. Vent Microbes colonize new vents, making the area hospitable to other fauna.

    - **Biotic Communities:** e.g., *Thiobacillus* Communities, Thermoacidophiles Communities.

Biotic Class: Moss and Lichen Communities

Tidal areas dominated by submerged or emergent mosses or lichens. Communities dominated by mosses are limited to freshwater situations. Although some mosses have been reported in tidal salt marshes, they have not been reported as dominant (Garbary et al. 2008). Lichens, on the other hand, occur in both freshwater and marine environments in relatively recognizable zones based on, among other factors, the extent to which they are submerged or flooded (Hawksworth 2000; Fletcher 1973; Gilbert and Giavarini 1997). Lichens are generally recognized as a symbiotic association with a fungus and an alga (or cyanobacterium) living together and forming patches or a visible pattern on the surface of the substrate.

Figure 8.13. Bacterial Decay: White Clusters of Decay Bacteria on Dead Macroalgae in Narragansett Bay, Rhode Island.
Photograph is a sediment profile image, showing a cross-sectional slice into the substrate and the overlying water column. Image: G. Cicchetti.

- **Biotic Subclass: Freshwater Tidal Lichens –** Freshwater tidal areas dominated by salt-intolerant lichen species that form patches or visible patterns on the surface of the substrate. Freshwater lichen Biotic Groups are based on a modification of Gilbert and Giavarini (1997).

    - **Biotic Group: Freshwater Submerged and Regularly Flooded Tidal Lichen Zone –** Submerged or regularly flooded freshwater tidal areas dominated by lichens that can tolerate regular inundation**.** This zone includes the Submerged Zone described by Gilbert and Giavarini.

        - **Biotic Communities:** To be determined.

    - **Biotic Group: Freshwater Irregularly Flooded Tidal Lichen Zone –** Tidal areas that are irregularly flooded (less often than daily) by tidal or non-tidal floods. Areas are generally characterized by lichen species that require moist or damp substrates. This zone corresponds to the Fluvial Mesic and Fluvial Xeric Zones described by Gilbert and Giavarini, but the CMECS group only includes the parts related to the Tidal Lichen Zones.

- **Biotic Communities:** To be determined.

- **Biotic Subclass: Marine Lichens –** Marine tidal areas dominated by lichen species that form patches or visible patterns on the surface of the substrate. Marine Lichen Biotic Groups are based on a modification of Fletcher (1973).

  - **Biotic Group: Marine Intertidal Lichen Zone –** Zones dominated by patches of lichens that are regularly submerged by marine tides. This zone corresponds to the Littoral Zone described by Fletcher.

    - **Biotic Communities:** e.g., *Cocotrema* Communities, *Lecanora* Communities, Intertidal *Verrucaria* Communities

  - **Biotic Group: Marine Supratidal Lichen Zone –** Zones dominated by patches of lichens in association with the supratidal zone (splash zone). These areas are rarely submerged, but are regularly wetted by splash and sea spray. These lichen zones are most often associated with rocky shores with abundant sea spray. This zone corresponds to the Supralittoral Zone described by Fletcher.

    - **Biotic Communities:** e.g., *Anaptychia* Communities, *Caloplaca* Communities, *Ramalina* Communities, *Xanthoria* Communities, Supratidal *Verrucaria* Communities

- **Biotic Subclass: Freshwater Tidal Moss –** Freshwater tidal areas dominated by moss species.

  - **Biotic Group: Submerged Freshwater Tidal Moss –** Freshwater tidal areas dominated by submerged or regularly flooded moss species.

    - **Biotic Communities:** e.g., *Fontinalis antipyretica* Nonvascular Vegetation

  - **Biotic Group: Emergent Freshwater Tidal Moss –** Emergent freshwater tidal marshes dominated by mosses.

    - **Biotic Communities:** To be determined.

Biotic Class: Aquatic Vegetation Bed

This class includes subtidal or intertidal bottoms and any other areas characterized by a dominant cover of rooted vascular plants, attached macroalgae, or mosses, which are usually submersed in the water column or floating on the surface. They may be exposed during low tides. Non-rooted floating vegetation and free floating macroalgae are included with the Planktonic Biota Biotic Setting under the Floating/Suspended Plants and Macroalgae Subclass.

- **Biotic Subclass: Benthic Macroalgae –** Aquatic beds dominated by macroalgae attached to the substrate, such as kelp (Figure 8.14), intertidal fucoids, and calcareous algae. Macroalgal communities can exist at all depths within the photic zone, on diverse substrates, and across a range of energy and water chemistry regimes. In the CMECS framework, macroalgae that dominate the benthic environment and form a vegetated cover fall within this subclass. Macroalgal communities (typically coralline/crustose algae) that build substrate in a reef setting are categorized in the BC Reef Biota Class instead.

  Many macroalgal types and communities have low temporal persistence and can bloom and die-back within short periods. This aspect of macroalgae is reflected with the temporal persistence modifier, which allows further description of the units in this subclass.

  While many researchers organize macroalgae based on their pigmentation, CMECS takes a growth morphology approach to defining benthic algal biotic groups. This decision was driven by the fact that macroalgal assemblages often include a variety of co-existing algal species, making delineations of individual species difficult. This approach also captures the influence that the algal growth structure has in shaping the local environment—by providing shelter, shade, and detrital material to an area, which is important to associated fauna.

  The Biotic Group level of classification here is a modification of the “Littler functional-form model” for marine macroalgae, as described by Littler, Littler, and Taylor (1983) and promoted by Lobban and Harrison (1997). The Littler functional form groups are the sheet group, filamentous group, coarsely branched group, thick leathery group, jointed calcareous group, and crustose group. Littler, Littler, and Taylor (1983) discuss the morphological, metabolic, and ecological significance of each group, and they point out that these groups are best considered as recognizable points along a continuum (rather than as discrete bins). Biotic Groups and Communities defined by macroalgae generally also include a diversity of associated fauna, including many that consume macroalgae (e.g., sea urchins and mollusks); these may be characterized as Modifiers: Associated Taxa, or Co-occurring Elements.

  - **Biotic Group: Calcareous Algal Bed –** Areas dominated by calcareous algae that incorporate calcium carbonate into their tissues, support their own weight, and have an upright growth form. Calcareous algae can form carpets on the bottom, and—as they decay—the calcareous skeletons remain behind, occasionally forming loose accumulations on the bottom resembling chips. Calcareous algae that occur in a reef setting are included in the Colonized Shallow/ Mesophotic Reef biotic group.

- **Biotic Communities:** e.g., *Corallina* Communities, *Halimeda* Communities, *Jania* Communities, *Penicillus* Communities

Figure 8.14. Macroalgae: Canopy Forming Algae, Coastal California.

- **Biotic Group: Canopy-Forming Algal Bed –** Areas dominated by canopy-forming algae that have complex growth forms with holdfasts and well-defined stipes and blades. Canopy forming algae are distinguished from other types of macroalgae, in that they often reach heights of several meters or greater. Their presence alters water energy patterns and provides shelter for other marine organisms. Kelp beds are an example of canopy forming algal communities (Figure 8.14).

  - **Biotic Communities:** e.g., *Alaria* Communities, *Laminaria* Communities, *Macrocystis* Communities, Mixed Kelp Communities, *Nereocystis* Communities

- **Biotic Group: Coralline/Crustose Algal Bed –** Areas dominated by coralline or crustose algae that incorporate calcium carbonate into their tissues and form crusts on the substrate in many marine environments. Coralline algae can be attached or unattached (as in the rhodoliths that form nodules, which can occur in loose accumulations on the substrate). In the attached algae, the thalli are fixed to the substrate. Coralline/Crustose algae that occur in a reef setting are included in the Colonized Shallow /Mesophotic Reef biotic group.

- **Biotic Communities***:* e.g., *Hildenbrandia* Communities, *Lithothamnion* Communities, *Lithophyllum* Communities, *Peyssonnelia* Communities, *Porolithon* Communities, *Phymatolithon* Communities

- **Biotic Group: Filamentous Algal Bed –** Areas dominated by filamentous algae that have a growth form consisting of fine filaments or strands with no blades or stipes. Filaments may branch, but they lack complex structures. The strands are undifferentiated (with a growth axis in one direction). Filamentous algae can form dense mats.

    - **Biotic Communities:** e.g., Filamentous A*ghardiella* Communities, *Chaetomorpha* Communities, *Chordaria flagelliformis* Communities, *Cladophora sericea* Communities

- **Biotic Group: Leathery/Leafy Algal Bed –** Areas dominated by leathery/leafy algae have a variety of specialized tissues (including thalli) that resemble stems and leaf-like blades. They generally maintain their shape when removed from water, and they often possess air bladders (pneumatocysts) and other flotation bodies.

    - **Biotic Communities:** e.g., *Ascophyllum* Communities, *Caulerpa* Communities, *Chondrus* Communities, *Codium* Communities**,** *Fucus distichus* Communities, *Palmaria* Communities

- **Biotic Group: Mesh/Bubble Algal Bed –** Areas dominated by mesh or bubble algae that form small, generally spherical masses attached to the benthos. They may develop lobes as they grow, but they do not further differentiate at the macro level. These masses may be hard or leathery, and they can sometimes be hollow. Bubble algae can be fast growing, quickly colonizing exposed reef surfaces, overtaking new coral growth, and deterring other animals from attaching there.

    - **Biotic Communities***:* e.g., *Dictyosphaeria* Communities, *Valonia* Communities, *Ventricaria* Communities

- **Biotic Group: Sheet Algal Bed –** Areas dominated by sheet (thallose) algae that form thin, undifferentiated, membranous sheets with no stipe or blades. Growth in these algae occurs in two directions. The sheets can be as thin as a single cell.

    - **Biotic Communities:** e.g., *Agardhiella* Sheet Algae Communities, *Grinnella americana* Communities, *Monostroma grevillei* Communities, *Ulva lactuca* Communities

- **Biotic Group: Turf Algal Bed –** Areas dominated by turf algae that represent a multi-specific assemblage of diminutive, often filamentous, algae that attain a canopy height of only 1 - 10 millimeters (see Steneck 1988 for review). These microalgal species have a high diversity (more than 100 species in the western Atlantic), although only 30 - 50 species commonly occur at one time. There is a high turnover of individual turf algal species seasonally; only a few species are able to persist or remain abundant throughout the year. But turf algae—when observed as a functional group—remain relatively stable year round (Steneck and Dethier 1994), and they are often able to recover rapidly after being partially consumed by herbivores. Turfs are capable of trapping ambient sediment, and they kill corals by gradual encroachment.

- **Biotic Communities:** e.g., Mixed Algal Turf Communities

- **Biotic Subclass: Aquatic Vascular Vegetation –** Aquatic vascular vegetation beds dominated by submerged, rooted, vascular species (such as seagrasses, Figure 8.15) or submerged or rooted floating freshwater tidal vascular vegetation (such as hornworts [*Ceratophyllum* spp.] or naiads [*Najas* spp.]).

  Note: Nomenclatural standards and punctuation for vegetated biotic communities are taken directly from FGDC-STD-005-2008. Strata are separated by a "/" (i.e., tree/shrub/herbaceous). Hyphens between species names indicate that they are in the same strata. Parentheses indicate that the species is important in defining the association, but may not be in every observation of the association. The name of the FGDC-STD-005-2008 Class is always used at the end of the association name. The epithet, "[Provisional]" is used when the type has been identified, but not yet formally incorporated into FGDC-STD-005-2008.

  - **Biotic Group: Freshwater and Brackish Tidal Aquatic Vegetation –** Tidal aquatic vegetation beds dominated by submerged, rooted, vascular species that have limited (or no) salt tolerance. Some species, such as *Ruppia maritima,* can have a wide range of salt tolerance, and are included in this group when occurring in low salt environments or with other salt intolerant species that indicate low salt environments.

    - **Biotic Communities:** e.g., *Ceratophyllum demersum – Vallisneria americana – Najas* spp. Tidal Herbaceous Vegetation, *Ruppia maritima - Stuckenia pectinata* Herbaceous Vegetation

  - **Biotic Group: Seagrass Bed –** Tidal aquatic vegetation beds dominated by any number of seagrass or eelgrass species, including *Cymocedea* sp., *Halodule* sp., *Thalassia* sp., *Halophilla* sp., *Vallisnera* sp., *Ruppia* sp., *Phyllospadix* sp., and *Zostera* sp.. Seagrass beds (Figure 8.15) may occur in true marine salinities, and they may extend into the lower salinity zones of estuaries.

    Seagrass beds are complex structural habitats that provide refuge and foraging opportunities for abundant and diverse faunal communities in shallow waters. Seagrass beds require a specific set of ecological conditions for success, and they are generally perceived as areas of high environmental quality.

The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

- **Biotic Communities:** e.g., *Syringodium filiformis* – (*Thalassia testudinum*) Herbaceous Vegetation, *Halophila engelmannii* Herbaceous Vegetation, *Zostera marina* Herbaceous Vegetation

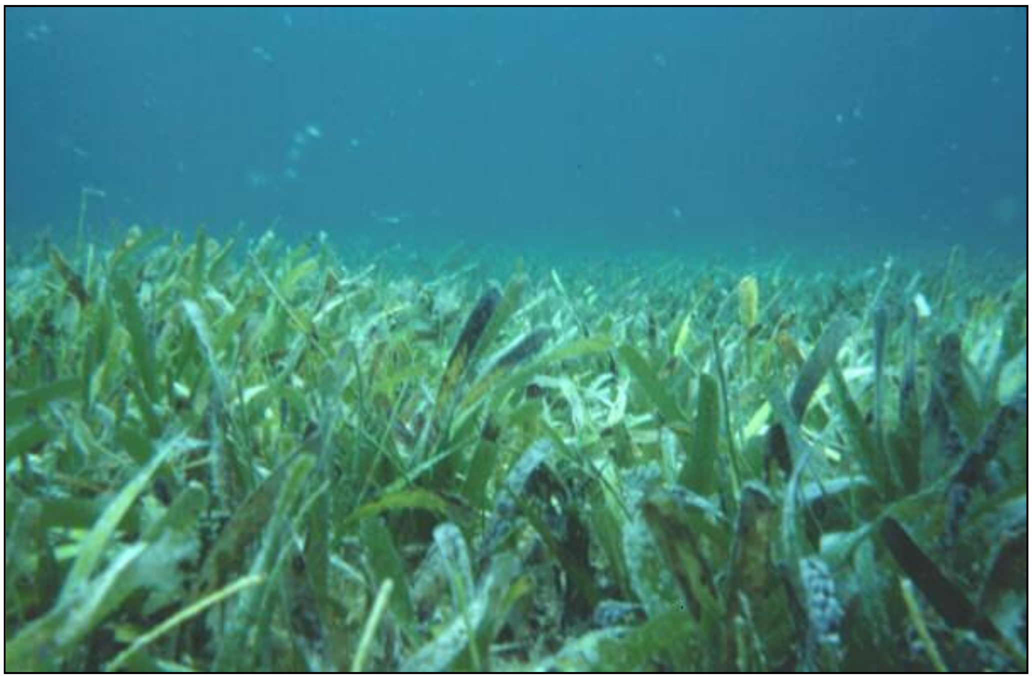

Figure 8.15. Seagrass Bed: Florida Keys National Marine Sanctuary.

Biotic Class: Emergent Wetland

Areas in this class are characterized by erect, rooted, herbaceous hydrophytes—excluding emergent mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants. This CMECS class is equivalent to the Emergent Wetland Class from FGDC-STD-004 (FGDC 1996b).

- **Biotic Subclass: Emergent Tidal Marsh** – Communities dominated by emergent, halophytic, herbaceous vegetation (with occasional woody forbs or shrubs) along low-wave-energy, intertidal areas of estuaries and rivers.

  Biotic communities in this subclass are equivalent to National Vegetation Classification Associations of FGDC-STD-005-2008, and follow their naming conventions (FGDC 2008). However, FGDC-STD-005-2008 does not split marshes into "herbaceous" or "scrub-shrub" at their Group level. As a result, some of the names of FGDC-STD-005-2008 types (which correspond to the CMECS Emergent Wetland class) indicate that the biotic community is a "Dwarf-shrubland." These specific communities are dominated by woody forbs, which—while technically dwarf-shrubs—function more like herbaceous vegetation. These types were included in Emergent Tidal Marsh, because their total floristics and physiognomy indicate an herbaceous marsh setting.

Vegetation in this subclass is composed of emergent aquatic macrophytes, especially halophytic species—chiefly graminoids (such as rushes, reeds, grasses and sedges), shrubs, and other herbaceous species (such as broad-leaved emergent macrophytes, rooted floating-leaved and submergent species [aquatic vegetation], and macroscopic algae). The vegetation is usually arranged in distinct zones of parallel patterns, which occur in response to gradients of tidal flooding frequency and duration, water chemistry, or other disturbances.

Tides may expose mudflats that contain a sparse mix of pioneering forb and graminoid species. Salinity levels (which control many aspects of salt-marsh chemistry) vary depending on a complexity of factors, including frequency of inundation, rainfall, soil texture, freshwater influence, fossil salt deposits, and more. Salt marshes often grade into (or are intermixed with) scrub-shrub wetlands in higher areas. See Figure 8.16 for an example of an emergent tidal marsh.

Figure 8.16. Emergent Tidal Marsh near Wilmington, North Carolina.
(Photo by Nancy Carter – www.nancycarterartist.com).

- **Biotic Group: Brackish Marsh –** Marshes dominated by species with a wide range of salinity tolerance. Depending on the salinity levels (0.5–30), more or less salt-intolerant species may be present. The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

  - **Biotic Communities:** e.g., *Amaranthus cannabinus* Tidal Herbaceous Vegetation, *Calamagrostis nutkaensis – Argentina egedii – Juncus balticus* Herbaceous Vegetation

- **Biotic Group: Freshwater Tidal Marsh –** Tidally influenced riverine marshes with salinity levels less than 0.5, which are dominated by salt–intolerant, herbaceous species (e.g., *Juncus* sp., *Eleocharis* sp., and *Zizania* sp.). Non-tidal, palustrine, freshwater marshes are beyond the scope of CMECS. The list of Biotic Communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

  - **Biotic Communities:** e.g., *Deschampsia caespitosa – Horkelia marinensis* Herbaceous Vegetation, *Eleocharis fallax – Eleocharis rostellata – Schoenoplectus americanus – Sagittaria lancifolia* Herbaceous Vegetation

- **Biotic Group: High Salt Marsh –** Salt marshes dominated by herbaceous, emergent vegetation and forb-like dwarf shrubs; areas are infrequently flooded by tides and characterized by distinctive patterns of halophytic vegetation (e.g., *Spartina patens*). Low shrubs may be present, but they are not dominant. Shrub-dominated portions of salt marshes are included in the Saltwater Tidal Scrub-Shrub Wetland Biotic Group. The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

  - **Biotic Communities:** e.g., *Spartina patens – Festuca rubra –* (*Spartina pectinata*) Herbaceous Vegetation, *Juncus roemerianus* Herbaceous Vegetation

- **Biotic Group: Low and Intermediate Salt Marsh –** Salt marshes that are regularly flooded by tides so as to support characteristic halophytic vegetation (e.g., *Spartina alterniflora*). In locations with appropriate topography and tidal exchange, extensive meadows may form. Shrubs are less common in these areas. The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

  - **Biotic Communities:** e.g., *Deschampsia caespitosa –* (*Carex lyngbyei, Distichlis spicata*) Herbaceous Vegetation, *Salicornia* *virginica* - *Distichlis spicata* - *Triglochin maritima* - (*Jaumea carnosa*) Herbaceous Vegetation

- **Biotic Subclass: Vegetated Tidal Flats –** Tidal Flats or Pannes (see GC for definition) colonized by herbaceous vegetation, usually with sparse cover. Cover is not sufficiently dense or raised to constitute a marsh.
  - **Biotic Group: Vegetated Freshwater Tidal Mudflat –** Tidal mudflats in freshwater riverine systems colonized by sparse, emergent, salt-intolerant vegetation.
    - **Biotic Communities:** To be determined.
  - **Biotic Group: Vegetated Salt Flat and Panne –** Tidal Salt Flats or Pannes (see GC for definition) colonized by sparse, emergent, halophytic, herbaceous or woody forb vegetation. The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.
    - **Biotic Communities:** e.g., *Sporobolus virginicus – Distichlis spicata* Herbaceous Vegetation, *Salicornia (virginica, bigelovii, maritima*) *– Spartina alterniflora* Herbaceous Vegetation

Biotic Class: Scrub-Shrub Wetland

Emergent wetland areas dominated by woody vegetation that is generally less than 6 meters tall. Characteristic species include true shrubs, young trees, and trees or shrubs that are small or stunted due to environmental conditions. Scrub-Shrub Wetland includes the shrub-dominated portions of high salt marshes—as well as stunted or low mangrove communities. This CMECS Class is equivalent to the Scrub-Shrub Wetland Class of FGDC-STD-004; however, the palustrine and non-tidal riverine portions of FGDC-STD-004 class are beyond the scope of CMECS.

- **Biotic Subclass: Tidal Scrub-Shrub Wetland –** Estuarine or tidal riverine areas dominated by shrub vegetation that has less than 10% tree cover. (The cutoff value is the standard employed by FGDC-STD-005-2008 for defining the Shrubland and Grassland Formation Class [FGDC 2008]).
  - **Biotic Group: Brackish Tidal Scrub-Shrub –** Tidal areas dominated by shrub or immature tree species that are less than 6 meters tall and have a range of salt tolerance. Salinity may range from 0.5–30 (PSS).
    - **Biotic Communities:** e.g., *Lonicera involucrata* / *Argentina egedii* Tidal Shrubland [Provisional]
  - **Biotic Group: Freshwater Tidal Scrub-Shrub –** Tidal areas dominated by shrub or immature tree species that are less than 6 meters tall and are salt intolerant. Salinity levels are less than 0.5. The list of biotic

communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

- **Biotic Communities:** e.g., *Alnus (incana ssp. rugosa, serrulata*) **–** *Cornus amomum* Shrubland, *Morella cerifera – Toxicodendron radicans* / *Spartina bakeri* Shrubland

- **Biotic Group: Saltwater Tidal Scrub-Shrub –** Tidal areas dominated by halophytic shrubs or immature trees that are less than 6 meters tall. Vegetation is composed of halophytic species, chiefly shrubs and other herbaceous species. The vegetation is usually arranged in distinct zones of parallel patterns in response to gradients of tidal flooding frequency and duration, water chemistry, or other disturbances. The list of Biotic Communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

  - **Biotic Communities:** e.g., *Borrichia frutescens* / *Spartina spartinae* Shrubland**,** *Baccharis halimifolia – Iva frutescens – Morella cerifera –* (*Ilex vomitoria*) Shrubland

Biotic Group: Tidal Mangrove Shrubland – Tidally influenced, dense, tropical or subtropical areas dominated by dwarf or short mangroves (and associates) that are generally less than 6 meters in height. Commonly found on intertidal mud flats along the shores of estuaries. Tidal mangrove shrublands may include immature stands or stunted mature trees that indicate a harsh growing environment. Areas characterized by tall mangroves (> 6 meters) are placed in the Tidal Mangrove Forest Biotic Group.

Where tidal amplitude is relatively low**,** the vegetation forms narrow bands along the coastal plains, and it rarely penetrates inland more than several kilometers along rivers. Where tidal amplitude is greater, mangroves extend further inland along river courses, forming extensive stands in the major river deltas. Also, mangrove cays may occur within the lagoon complex of barrier reefs.

The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

- **Biotic Communities:** e.g., *Rhizophora mangle – Avicennia germinans – Laguncularia racemosa* / *Batis maritima* Shrubland, *Avicennia germinans* / *Batis maritima* Shrubland

Biotic Class: Forested Wetland

Areas in this class are characterized by woody vegetation that is generally 6 meters or taller. This CMECS class is equivalent to the Forested Wetland Class of FGDC-STD-004 (FGDC 1996b and the Forest/Woodland Class of FGDC-STD-005-2008); however, the palustrine and non-tidal riverine portions of the FGDC-STD-004 class are beyond the scope of CMECS.

- **Biotic Subclass: Tidal Forest/Woodland –** Estuarine or tidal riverine areas with greater than 10% tree cover. This cutoff value is the standard employed by FGDC-STD-005-2008 for defining the Forest and Woodland Formation Class [FGDC 2008].

  - **Biotic Group: Brackish Tidal Forest/Woodland –** Tidal areas dominated by tree species that are greater than 6 meters tall and have a range of salt tolerance. Salinities may range from 0.5–30.

    - **Biotic Community:** e.g., *Picea sitchensis* / *Lonicera involucrata* – *Malus fusca* Tidal Woodland [Provisional]

  - **Biotic Group: Freshwater Tidal Forest/Woodland –** Tidal riverine areas dominated by salt-intolerant tree species that are greater than 6 meters tall. The list of Biotic Communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

    - **Biotic Communities:** e.g., *Pinus taeda – Nyssa biflora – Taxodium distichum* / *Morella cerifera* / *Osmunda regalis* var. *spectabilis* Forest, *Nyssa biflora* – (*Taxodium distichum, Nyssa aquatica*) / *Morella cerifera – Rosa palustris* Tidal Forest, *Taxodium distichum* / *Carex hyalinolepis* Woodland

  - **Biotic Group: Saltwater Tidal Forest/Woodland –** Tidal areas dominated by halophytic tree species that are greater than 6 meters tall.

    - **Biotic Communities:** e.g., *Tamarisk* Tidal Forest [Provisional], *Melaleuca* Tidal Forest [Provisional]

  Biotic Group: Tidal Mangrove Forest – Tidally influenced, dense, tropical or subtropical forest with a shore zone dominated by true mangroves (and associates) that generally are 6 meters or taller (Figure 8.17). Dwarf shrub and short mangroves are placed in the Tidal Mangrove Shrubland Biotic Group.

  Mangrove Forests (e.g., mangal or mangle) occur along the sheltered coasts of tropical latitudes of the Earth, and are commonly found on the intertidal mud flats along the shores of estuaries, usually in the region between the salt marshes and seagrass beds and may extend inland along river courses where tidal amplitude is high. Also, mangrove cays may occur within the lagoon complex of barrier reefs.

The list of biotic communities for this group is long: a few examples are provided below, and the complete list is available in Appendix F.

- **Biotic Communities:** e.g., *Avicennia germinans* Forest, *Conocarpus erectus* Forest, *Rhizophora mangle* – (*Avicennia germinans*, *Laguncularia racemosa*) Riverine Forest

Figure 8.17. *Rhizophora mangle* Fringe Forest Biotic Community.

8.3 Status of Biotic Community Units

For some biotic communities, detailed information now exists that could be compiled to fully describe them. However, for other biotic communities, more effort is needed in developing and analyzing large datasets to statistically categorize biotic communities, particularly for cryptic soft-sediment habitats that are characterized by infauna.

<u>*Status of Biotic Communities Defined by Vascular Vegetation*</u>
Biotic communities that are defined by vascular vegetation (i.e., emergent wetlands, shrub-scrub, and forests) are relatively well known and represent accepted FGDC-STD-05-2008 associations. Unless marked as “[Provisional]” the listed associations have been rigorously defined (over the last twenty years), described, and assigned at least a “moderate” level of confidence according to FGDC-STD-05-2008. Descriptions of these units are available online at www.natureserve.org/explorer. Those marked “[Provisional]” have been identified as potential FGDC-STD-05-2008 units, but have not

yet been through the review process to adopt them into the FGDC-STD-05-2008. Vegetated biotic communities currently in CMECS have been described for the United States only. Plant associations from other countries can be incorporated into the current framework for international application.

Status of Biotic Communities Defined by Fauna and Non-vascular Vegetation
All faunal and non-vascular biotic communities listed above are examples of broad-dominance types that are known to occur within a given biotic group. These biotic communities are considered provisional. The provisional biotic community names are presented here as examples of the diagnostic taxa that may provide the basis for more rigorously defined biotic communities in the future. These communities are not an exhaustive list, and—despite best efforts—these communities may be regionally skewed based on the current state of knowledge of these units (and the knowledge of the CMECS developers). The provisional, genus-level biotic community names given here can be applied for many project objectives (when these biotic communities are identifiable), and a significant amount of descriptive information for the listed biotic communities is available in the scientific literature.

Users are free to develop and use their own biotic communities as the classification is developed. Practitioners and other stakeholders are encouraged to suggest additions and refinements, and further communities will be developed through the process described in Section 13.

8.4 Biotic Component Modifiers

The following is a list of modifiers relevant to the Biotic Component. Users are free to apply these as appropriate for project goals and as supported by available data. Users are not obligated nor limited to the list below. These modifiers are fully described in Section 10.

- Anthropogenic
  - Anthropogenic Impact
- Biogeographic
  - Primary Water Source
- Biological
  - Associated Taxa
  - Community Successional Stage
  - Invertebrate Community Organism Size
  - Phytoplankton Productivity
  - Macrovegetation Productivity
- Physical
  - Energy Direction
  - Energy Intensity
  - Energy Type
  - Seafloor Rugosity

    - Small-scale Slope
    - Tidal Regime (Amplitude)
- Physicochemical
    - Oxygen
    - aRPD
    - RPD
    - Salinity (PSS)
    - Temperature
- Spatial
    - Co-occurring Elements
    - Coral Reef Zone
    - Fine Percent Cover
    - Coarse Percent Cover
    - Profile
- Temporal
    - Temporal Persistence

9. Biotopes

CMECS separates out the different aspects of the seascape in a flexible manner, which is helpful in satisfying a broad array of users. Components can be applied individually; however, when the components are combined, they provide an effective ecological tool that can help users understand how abiotic and biotic elements interact in nature. This approach is intended to advance understanding of the habitat requirements for biological communities and species. Currently our understanding of biotopes in U.S. coastal and marine waters is under development, and CMECS provides standards for identifying and describing these biotopes.

9.1 The Biotope Concept

A biotope is defined as the combination of abiotic habitat and associated species (Connor 1995, 1997; Connor et al. 2003). In this definition, the term *habitat* refers to a suite of environmental factors (such as sediment grain size, physiographic features, and specific physicochemical attributes) at a specific location; the term *associated species* refers to the biotic community or group of organisms that occur in that environment (Olenin and Ducrotoy 2006).

In CMECS "associated species" is equivalent to the concept of the biotic community defined in the Biotic Component (BC). Biotopes differ from biotic communities in that environmental features are explicitly used to classify and describe biotopes. It is the combination of the species assemblage and specific environmental circumstances that defines the biotope. While most species assemblages reflect repeating environmental patterns, their identification as biotic communities is not dependent on the co-occurrence of a common set of physical or geochemical features.

Connor et al. (2004) used this biotope concept to develop a comprehensive marine classification for Britain and Ireland, and the approach has been adopted for use in Europe (Davies et al. 2004). The result is a classification of biotopes defined by explicit biological and abiotic parameters—an approach that is quite effective in meeting a number of scientific and conservation needs. Example European biotopes include:

Mytilus edulis and barnacles on very exposed eulittoral rock
Mytilus edulis beds on sublittoral sediment
Nephtys cirrosa and *Macoma balthica* in variable salinity infralittoral mobile sand
Filamentous green seaweeds on low salinity infralittoral mixed sediment on rock

9.2 Using CMECS to Classify Biotopes

CMECS is ideally suited for the purpose of defining biotopes. CMECS units are the building blocks of biotopes. Combinations of features in the BS, AS, WC, GC, and SC may be used to characterize the abiotic environment of biotopes. Biotopes can be recognized when individual BC biotic communities are repeatedly associated with unique combinations of the abiotic features. Observational or statistical methods may be used to identify regularly occurring biological assemblages and the associated physical environments.

9.2.1 Classifying Biotopes with Quantitative Data

CMECS has been used to define and map biotopes in Narragansett Bay, Rhode Island using field-collected data and statistical clustering techniques. Shumchenia and King (2010) identified seven biotopes in Greenwich Bay (an embayment within Narragansett Bay) using the substrate, geoform, and biotic community features from CMECS (Figure 9.1). Although the spatial focus of the study was small, the methodology holds great promise for quantitatively identifying and describing biotopes across their entire range.

Identifying biotopes quantitatively across the U.S. is an enormous challenge, which can only be met by intensive, *in-situ* data collection and analysis within the range of marine environments. Once biotopes are identified, approaches (such as species suitability modeling (as described in Degraer et al. 2008) can be used to inventory species and forecast biotope occurrence across their range. Such an effort may take many years to achieve, but the output will provide the information that is needed to protect and maintain critical coastal and marine resources.

9.2.2 Classifying Biotopes with Observational Information

In the absence of range-wide data, CMECS can be used to qualitatively identify and describe biotopes. Information from the literature—and data collected from local and regional studies—can be placed in the CMECS framework to describe individual biotopes. The *Phragmatopoma lapidosa* Reefs on High Energy Sand Biotope (Figure 9.2) provides an example of how CMECS components can be combined to classify a biotope using qualitative information. As individual studies use the CMECS framework to identify the concurrence of biological communities and abiotic factors, the information can be coalesced to improve understanding of biotopes across their range.

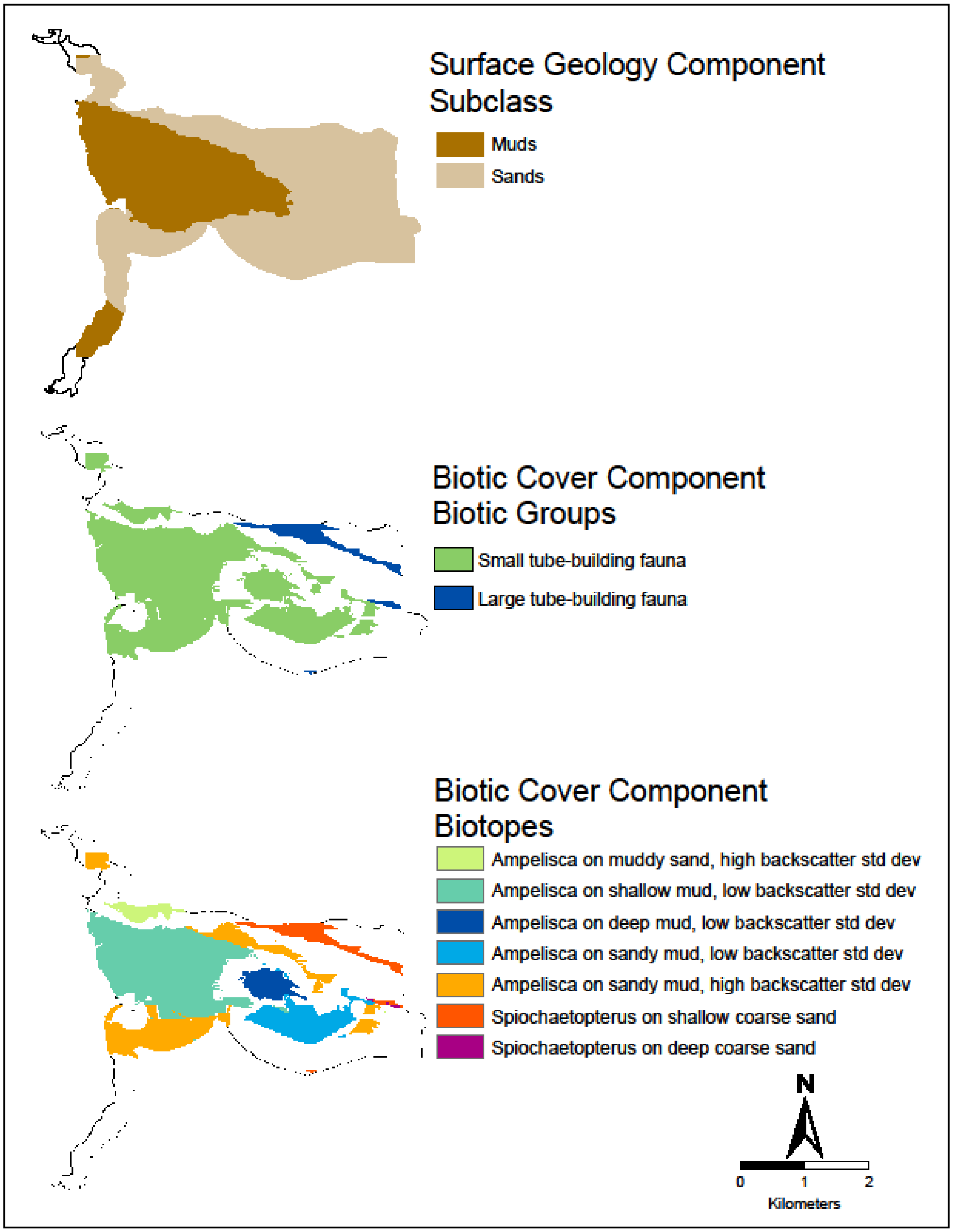

Figure 9.1. Illustration of how CMECS was used to define Biotopes.
The analysis for Figure 9.1 used CMECS Version 3.1. Changes to the standard in the current version (4.0) explain minor differences in terminology. Figure reprinted with permission from Elsevier.

9.3 Describing Biotopes

Biotope descriptions should be developed using the terms and concepts from each of the components, expanding on the defining biotic and abiotic features for the biotope. A formal biotope description includes information about the diagnostic and characteristics species and associated taxa, defining physical features, similar biotopes and how they can be distinguished, interactions with other biotopes, geographic range of occurrence, and the ecological and societal relevance or importance of the biotope. Repeatability, scales of time and space, and relative abundance of the biotopes should also be included in the descriptions as appropriate.

The following shaded area provides a sample biotope description.

Biotope: *Phragmatopoma lapidosa* Reefs on High Energy Sand
Biogeographic Component:
Realm: Tropical Atlantic
Province: Tropical Northwestern Atlantic
Ecoregion: Floridian

Aquatic Setting:
System: Marine
Subsystem: Nearshore
Tidal Zone: Intertidal, Subtidal

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Continental/Island Shore Complex
Geoform Origin: Geologic, Biologic
Level 1 Geoform: Beach
Level 1 Geoform Type: Wave Dominated Beach
Level 2 Geoform: Worm Reef
Level 2 Geoform Type: Linear Worm Reef, Patch Worm Reef

Substrate Component:
Substrate Origin: Geologic Substrate
Substrate Class: Unconsolidated Substrate
Substrate Subclass: Fine Unconsolidated Substrate
Substrate Group: Sand, Muddy Sand

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Reef Biota
Biotic Subclass: Worm Reef
Biotic Group: Sabellariid Reef
Biotic Community: *Phragmatopoma lapidosa* Reef

Description: The brownish mound-like or ridge-like worm reefs that characterize this biotope commonly occur in or just outside the surf zone running parallel to high-energy tropical or subtropical beaches, but may occur in other settings as well. In the United States, this biotope is most common on the Atlantic coast of southern Florida. These reefs have a honeycomb appearance, with a grainy texture that can be crumbled by hand. The diagnostic species *Phragmatopoma lapidosa* is commonly known as the "reef-building tubeworm" or "sand-tube worm." These 15 to 40 millimeter-sized animals cement sand-sized grains of substrate into 5 to 30 centimeter protective tubes that can form extensive reefs through successive colonization and growth of conspecifics. The reefs are important ecologically, providing refuge and hard substrate in an area of high wave energy. The reefs also play an important geological role by decreasing the effects of wave erosion on shores and by contributing to the formation and maintenance of barrier islands and beaches.

Physical Associations: This biotope is associated with turbulent, high-energy areas on sand substrates that provide appropriately sized suspended particles for tube construction and feeding. These conditions are most commonly found at high-energy beaches between the mid-tide level and a depth of 2 meters but can also occur at high-velocity tidal inlets and in other areas, and colonies have been reported at depths to 100 meters. Stable attachment sites are required for initial colonization, since larvae have a difficult time settling into unstable shifting sands. Living or dead conspecifics provide a preferred colonization site, but any stable solid object or feature can be used for initial settlement. Most reefs occur in tropical and subtropical areas at euhaline salinities.

Biological Associations: *P. lapidosa* reefs support a complex faunal assemblage with much higher diversity and abundance than can be found in adjacent sandy non-reef areas. A particularly high diversity of crustaceans generally dominates the associated macroinvertebrate community, and the crabs *Pachygrapsus transversus*, *Mennipe nodifrons*, *Pilumus dasypodus*, or *Panopeus bermudensis* are notable predators on the tube worms themselves. Many other taxa are abundant: barnacles (*Tetraclita squamosa),* sponges, bryozoans, coelenterates, and mollusks also colonize the reefs. Demersal and semi-demersal fishes (e.g., *Labrisomus nuchipinnis*, *Scartella cristata*, and *Diplodus holbrooki*) are also associated with this biotope. Pistol shrimps (*Synalphus fritzmuelleri*) may be common. Transient visitors foraging in this biotope include a variety of predatory fish, many of which are commercially or recreationally valuable.

Range: Western Atlantic from Florida to Brazil; present (but rare) in the Gulf of Mexico.

Related Biotopes: *Sabellaria vulgaris* reefs are found in the Western Atlantic north of Florida (generally in deeper waters) and constitute a common biotope in Delaware Bay and elsewhere. *Phragmatopoma californica* reefs are found from southern California into Mexico. *Sabellaria alveolata* reefs are found in the Eastern Atlantic (e.g., southwestern England, northern France).

Sources: Zale, A.V., and S.G. Merrifield. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida) – reef-building tube worm. U.S. Fish Wildlife Service. Biol. Rep. 82(11.115). U.S. Army Corps of Engineers, TR EL-82-4.

10. Modifiers

Modifiers are physicochemical, spatial, geological, biological, anthropogenic, and temporal variables with defined categorical values and ranges that are used to describe CMECS units. Modifiers can be applied when additional information is needed to further characterize an identified unit for individual applications. Modifiers provide additional environmental, structural, or biological information about the ecosystem; modifiers are useful for description and application—but they are not required for classification according to the CMECS schema. Modifiers are a dynamic component of the CMECS in the sense that users are free to apply additional local modifiers for their project needs as long as these are reported and do not conflict with modifiers outlined in this section.

The modifiers are organized by into general modifier types, and then listed alphabetically within the given type for easy reference. The general modifier types include Anthropogenic, Biogeographic, Biological, Geological, Physical, Physicochemical, Spatial, and Temporal. Modifiers within each type are as follows:

- Anthropogenic: Anthropogenic Impact
- Biogeographic: Primary Water Source
- Biological: Associated Taxa, Community Successional Stage, Invertebrate Community Organism Size, Productivity
- Physical: Energy (Direction, Intensity, Type), Induration, Seafloor Rugosity, Small-scale Slope, Substrate Descriptors, Surface Pattern, Tidal Regime (Amplitude), Wave Regime
- Physicochemical: Oxygen, Photic Quality, aRPD and RPD, Salinity, Temperature, Turbidity, Turbidity Type, Turbidity Provenance, Water Column Stability
- Spatial: Benthic Depth Zones, Co-occurring Elements, Coral Reef Zone, Enclosure, Percent Cover Range, Profile, Substrate Layering
- Temporal: Temporal Persistence

10.1 Anthropogenic Modifiers

10.1.1 Anthropogenic Impact

Table 10.1. Anthropogenic Impacts Modifier.

	Description
Aquaculture	Areas and structures where shellfish or finfish are being raised or confined for harvest. This may also include fish traps and ponds or enclosures.

Anthropogenic Impact Values	Description
Contaminated	Areas affected by past or present anthropogenic discharge of unnatural or excessive amounts of compounds (such as nutrients, sewage, metals, pesticides, or other materials) to waters or substrates, which results in concentrations significantly higher than those attributable to natural loading.
Developed	Coastal or marine areas that have been modified by durable and persistent human construction (e.g., artificial reef, pier, seawall, marina, residence, or drilling platform).
Dredged	Landscape that is mechanically altered by the removal of sediments or other materials (e.g., shell) in order to deepen or widen channels (e.g., for navigation or alteration to hydrology).
Exotic	Areas affected by human-mediated introduction of exotic species.
Filled	Areas where materials (such as sand or shell) have been placed on (or in) an area of coast or a water body.
Impounded/ Diverted	Areas where artificial construction impedes, redirects, or retains hydrological flow by building or placing barriers (e.g., dams, levees, dikes, berms, seawalls, or piers); these structures are designed to either retain water or to prevent inundation.
Restored	Areas where restoration activities have been conducted; may include planted areas.
Scarred	Areas of scarring by natural or anthropogenic activities other than trawling or harvesting. Examples include ice scouring, vessel grounding, prop scarring, or other industrial activities.
Trawled/Harvested	Areas affected by past or present trawling or shellfish harvesting.

10.2 Biogeographic Modifiers

10.2.1 Primary Water Source

The Primary Water Source Modifier refers to the provenance of water flowing through or into a location. This can range from freshwater inputs (from watersheds and sloughs) to seawater exchanges through tidal passes.

Table 10.2. Primary Water Source Modifier.

Primary Water Source Values	Provenance
Estuary	Plume flow that is from the estuary.
Local Estuary Exchange	Tidal exchange that is primarily estuarine water.
Local Ocean Exchange	Tidal exchange that is primarily marine water at the marine end member interface.
Marine	Unidirectional flow that is primarily marine water.
River	Tidal exchange or plume flow that is primarily river water.
Watershed	Flowing freshwater from the upstream watershed.

10.3 Biological Modifiers

10.3.1 Associated Taxa

The Associated Taxa Modifier is used in the Biotic Component to denote the presence of biota that are not a classification unit in CMECS; e.g., portunid crabs, groupers, gadids, barracuda, herring, all nekton, and other rapidly moving fauna. Further discussions on the use of Associated Taxa (as well as examples) are given under Co-occurring Elements, Section 10.6.2 below.

10.3.2 Community Successional Stage

The Community Successional Stage modifier is intended for use in the Biotic Component, Faunal Bed Class, Soft-sediment Fauna Subclass. In the ecological literature, successional stage is a concept used to characterize identifiable points along a continuum of sequential—and somewhat predictable—replacements of taxa following a major disturbance which opens up a relatively large space. These stages are based in part on the differing organism life-history strategies of biota, and in part on their resulting modifications to the physical environment (Odum 1969; Ritter, Montagna, and Applebaum 2005). Rosenberg (1976) pointed out that the same basic pattern of succession is seen in soft-sediment environments in many different parts of the world, in response to various stressors (e.g., organic input, temperature stress, or low oxygen), noting that species composition (but not the basic pattern) differs among settings. Early work on infaunal marine succession recognized that this process is a complex and continually varying response to a history of disturbance, and that "there is a complete spectrum in nature" (Johnson 1972). Nonetheless, there is (along this spectrum) a predictable pattern to benthic community structure that follows levels of stress and disturbance, and this is a very useful construct in understanding the environment

(Rosenberg 2001). CMECS provides four modifiers for Community Stage in soft-sediment areas; these have been described previously (Pearson and Rosenberg 1976, 1978; Rhoads and Germano 1982, 1986; Nilsson and Rosenberg 1997, 2000) and are shown in Figure 10.1.

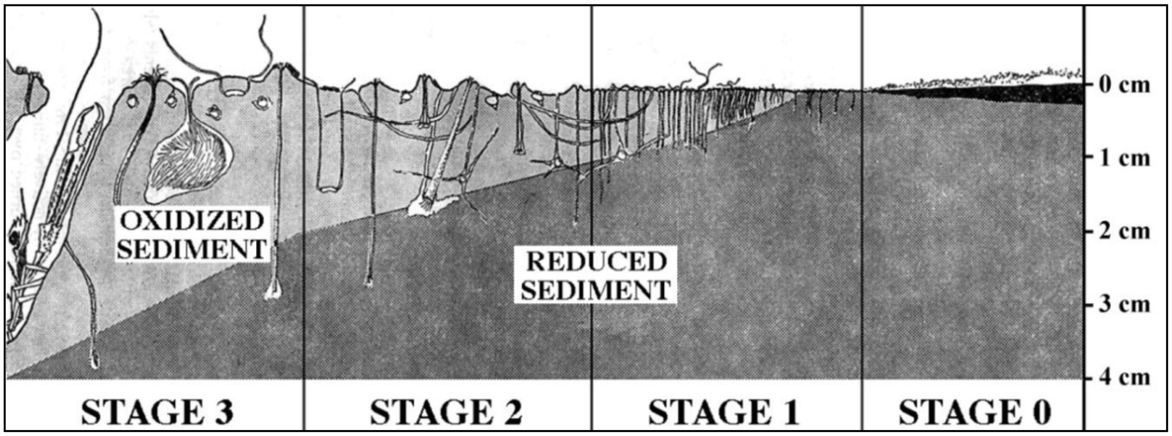

Figure 10.1. Distribution of Benthic Community Stages.
Stages in soft-sediment areas along a gradient of increasing environmental disturbance from left to right (figure modified from Nilsson and Rosenberg 1997).

Several methods have been developed to identify stages of soft sediment faunal status in relation to the concepts of succession. These methods include species identifications and comparisons to lists of fauna known to characterize successional stages (Pearson and Rosenberg 1976), as well as sediment-profile camera methods that use specific criteria to identify infaunal stage or status (Rhoads and Germano 1982, 1986; Nilsson and Rosenberg 1997, 2000). All of these approaches use different methods, and they are not identical in philosophy or in practical derivation. Further, the strict meaning of "successional stages" implies transitions from one group of species to another; this transition is difficult to determine based on a single snapshot (which does not provide information on these transitions over time). Imaging methods that cannot resolve species contribute to this difficulty as well. However, the basic meanings of the four stages described here—when interpreted as a snapshot of community stage in the sense of "infaunal status" (rather than as "successional stage" in a strict sense)—provide an informative perspective on infaunal communities that can be valuable for interpreting condition or habitat quality. Moreover, these stages are comparable over several identification methods for fine-grained sediments from temperate and (in some cases) sub-tropical climates. Practitioners may refer to regionally appropriate literature for further detail.

Table 10.3. Community Successional Stage Modifier.

Community Successional Stage Values	Description
Stage 3	These communities are identified by larger, long-lived, deep burrowing fauna or by evidence of the activities of those fauna; burrowing activities typically extend deeper than 5 centimeters. Characteristic species vary among localities and among environments; species can be identified through regionally appropriate literature. Common surface expression may include very large tube-building fauna (> 3 millimeters in diameter or > 30 mm in length), larger fecal mounds, burrowing urchins or ophiuroids, pits or tunnel openings (e.g., crustacean excavations with a lumen width of > 1 centimeter), or large digging spoils associated with pits or tunnels. Subsurface characteristics include oxygenated or active faunal feeding voids at 5 centimeters or deeper, active tunnels (subsurface excavations with a lumen width of > 1 centimeter) at depth, or presence of large polychaetes or other fauna. Frequently, evidence of smaller, opportunistic fauna will also be present in Stage 3 communities; these fauna are not necessarily eliminated by larger fauna. If evaluating sediment profile images, guidelines from Rhoads and Germano (1982, 1986) can be followed, or the Nilsson-Rosenberg Benthic Habitat Quality (BHQ) metric (Nilsson and Rosenberg 1997, 2000) can be used (Stage 3 will have BHQ > 10). Extensive bioturbation will be evidenced by deep RPD and aRPD depths.
Stage 2	Communities are characterized by fauna of intermediate sizes typically inhabiting the upper 2–4 centimeters of sediment. This stage is considered transitional and is often variable; in a percentage of samples it will be difficult to clearly distinguish Stage 2 from other stages within the continuous spectrum presented by natural environments. Regional literature identifying species typical of Stage 2 may be referenced. Surface evidence of Stage 2 communities includes openings to small burrows (defined as excavations with a lumen width ≤ 1 centimeter) and the presence of mid-sized tube dwelling fauna (e.g., robust *Ampelisca* tube mats; tubes > 2 millimeters in diameter; or tubes longer than 30 millimeters if very thin). Subsurface evidence includes burrows of polychaetes or other fauna in the upper 2–4 centimeters of sediment, small shallow-dwelling opportunistic bivalves, and small feeding voids in the upper 4 centimeters of sediment. If examining sediment profile images, guidelines from Rhoads and Germano (1982, 1986) can be followed or the Nilsson-Rosenberg BHQ metrics (Nilsson and Rosenberg 1997, 2000) can be used (BHQ for Stage 2 will range from 5 to 10).
Stage 1	These associations are inhabited by small opportunistic fauna (e.g., capitellids and spionids) in the upper centimeter of sediment. Larger fauna are not present, although juvenile individuals of larger species may occur. Names of small, opportunistic local species typical of Stage 1 are available in the regional literature. Surface expressions include small tubes (≤ 2 millimeters in diameter) of polychaetes or other fauna, or evidence of oligochaete burrowing activities. Subsurface evidence of either small worms or small burrow structures will primarily occur in the upper centimeter of sediment. If examining sediment profile images, guidelines from Rhoads and Germano (1982, 1986) can be followed or the Nilsson-Rosenberg BHQ metrics (Nilsson and Rosenberg 1997, 2000) can be used (Stage 1 BHQ values will range from 2 to < 5). Bioturbation depths will be shallow, with an aRPD depth typically > 2 millimeters to < 2 centimeters.
Stage 0	These oligozoic soft-sediment areas show little evidence of multi-cellular life; however, benthic samples that are retrieved and processed under magnification

Community Successional Stage Values	Description
	from Stage 0 stations will generally produce low numbers of small macrofauna or meiofauna. Multicellular fauna will not be obvious to the unassisted eye when examining sediment, and it will not be obvious in high-resolution images of the seafloor. Bacterial mats may be present. If examining sediment profile images, guidelines from Rhoads and Germano (1982, 1986) can be followed or the Nilsson-Rosenberg BHQ metrics (Nilsson and Rosenberg 1997, 2000) can be used (BHQ values for Stage 0 will range from 0 to 1.99). No evidence of active bioturbation exists, and aRPD depths are typically $\leq$ 2 millimeters.

10.3.3 Invertebrate Community Organism Size

The Invertebrate Community Organism Size modifier is intended for use in the Biotic Component, Faunal Bed Class. Ecological theory of community succession and disturbance posits that less frequently disturbed environments will provide the stability to support longer-lived communities of larger organisms, while frequently disturbed environments will be characterized by smaller and shorter-lived organisms. Faunal Bed communities are often complex, with a wide range of individual organisms and species occurring in many sizes to fill a variety of ecological niches. CMECS provides a coarse set of Organism Size Modifiers to describe Faunal Bed communities through sizes of the larger organisms that are evident in an observational unit. Many different methods have historically been proposed to distinguish macrofauna from megafauna—ranging from “visible to the unassisted eye,” to retention on various screen sizes, to inclusion only of much larger organisms. The CMECS criterion used to identify megafauna is a body size > 1 cm (in the smallest dimension). Importantly, this modifier describes the defining, significant, or dominant organisms that best characterize a community, recognizing that most communities include a variety of organisms that occur in both large and small individual sizes.

Table 10.4. Invertebrate Community Organism Size Modifier. Note that measurements of the smallest dimension of body size (e.g., height, width) will be misleading when the measured fauna are unusually flat or long, e.g., sand dollars, sea fans, nemerteans. Practitioners should consider this in assigning invertebrate community organism sizes, and should assign appropriately larger sizes in these cases.

Invertebrate Community Organism Size Values	Description
Large Megafauna	Benthic invertebrate communities that are dominated by organisms that typically reach a body size of greater than 3 centimeters in the smallest dimension (e.g., height, width), with this measurement not to include the length of slender, lateral protrusions (such as arms or tentacles).
Megafauna	Benthic invertebrate communities that are dominated by organisms that typically reach a body size of > 1 to 3 centimeters in the smallest dimension (e.g., height, width), with this measurement not to include the length of slender, lateral protrusions (such as arms or tentacles). These communities may be identified by evidence of these fauna (e.g., large mounds or pit or tunnel openings of > 1 to 3 centimeters).
Large Macrofauna	Benthic invertebrate communities that are dominated by organisms with a body width (smallest dimension) of > 2 millimeters to 1 centimeter; living organisms larger than this size range are rare in these infaunal or epifaunal associations.
Small Macrofauna	Benthic invertebrate communities that are dominated by organisms with a body width (smallest dimension) of > 0.5 to 2 millimeters; living organisms larger than this size range are rare in these infaunal or epifaunal associations.
Meiofauna	These benthic invertebrate communities are dominated by organisms with a body width (smallest dimension) of 0.5 mm or less, that would typically pass through an 0.5 mm sieve but be retained on an 0.25 mm sieve. Living organisms larger than this size range are rare in the infaunal or epifaunal association; the modifier may be applied to any classification unit within Faunal Bed.

10.3.4 Productivity

Productivity is a general categorization of the level of primary productivity—that is, the photosynthetic activity of autotrophs, including plankton, benthic microalgae, macroalgae, and vascular vegetation. The density of phytoplankton can be estimated by measuring the level of chlorophyll a in the water column, since all phytoplankton contain this fluorescent pigment enabling the harvesting of light. This measure also indirectly reflects the abundance of dissolved labile macronutrients (DIN and DIP), which phytoplankton use in photosynthetic processes. In broad terms, chlorophyll a content reflects net productivity, giving an indication of the trophic status of the system or the balance of primary production; secondary consumption by zooplankton, fish, and predators; and export from the system. Productivity is indicated by chlorophyll a concentration in water columns and by total biomass in macroalgal and rooted vascular plant communities. For water column phytoplankton communities, the modifier categories were derived, with modification, from the NOAA Estuarine Eutrophication Survey (NOAA 1997).

Table 10.5. Phytoplankton Productivity Modifier.

Phytoplankton Productivity Values	Chlorophyll a Level (µg/L)
Oligotrophic	< 5
Mesotrophic	5 to < 50
Eutrophic	≥ 50

Table 10.6. Macrovegetation Productivity Modifier.

Macrovegetation Productivity Values	Biomass (mg dry wt/m^2)
Oligotrophic	< 50
Mesotrophic	50 to < 1,000
Eutrophic	≥ 1,000

10.4 Physical Modifiers

10.4.1 Energy

To describe energy, CMECS follows a simplification of the concept introduced by Dethier (1990), which is also employed in several subsequent classifications (Howes, Harper, and Owens 1994; Holthus and Maragos 1995; Schoch 1999; Allee et al. 2000; Resource Information Standards Committee 2002). The ShoreZone classification work of Schoch (1999) provides the basis for a detailed nearshore classification of energy on land-sea margins, using a very simple energy classification related to the force of water movement (whether tidal, wave, or current).

Energy determines the kinds of animals and flora that can maintain attachment or position in a particular habitat. Energy level also determines the nature of the substrate by suspending, transporting, and sorting fractions of substrate particulates of specific grain sizes. Energy can shape bedforms (e.g., sand waves and sand ripples) and erode or accrete geoforms. Highly impacted areas are typified by the presence of erosive features, such as beach scarps or bare rock substrates.

The terminology of "degree of exposure" is common in many other classifications, but it is not used in CMECS—which favors the more accurate term *energy*. *Exposure* is a subjective term that includes qualification of both the direction of the feature (relative to hydrodynamic energetic) and the energy of the system (at a given point in time). An exposed and open coast may in fact be very quiescent, depending on the season or direction it is facing. *Energy*, along with a quantitative scale, is a more accurate indicator of the actual force that impacts a particular coastal or marine feature.

Energy Modifiers apply to the Substrate, Biotic, Geoform, and Water Column Components of the classification. Within the intertidal and subtidal benthic zones, energy acts to shape the geoforms. Within the water column, the energy is related to current speeds (in knots), wave intensity, and tidal motions. Energy Modifiers in CMECS are described by direction, intensity, and type.

Energy Direction

Energy can be classified according to its principal direction of travel or influence. In the case of tidal energy, this is generally an oscillation between onshore and offshore motions. In the case of currents and waves, the energy is usually directional.

Table 10.7. Energy Direction Modifier.

Energy Direction Values	Description
Baroclinic	Motion along lines of equal pressure within the water column.
Circular	Motion in a closed, circular form.
Downward	Descending and perpendicular to the sea surface or bottom.
Horizontal	Parallel to the sea surface or bottom.
Mixed	Combination of more than one of above directions.
Seaward	On land, water currents following a topographic gradient toward the sea.
Upward	Ascending and perpendicular to the sea surface or bottom.

Energy Intensity

Energy Intensity is classified into four categories as shown on Table 10.8.

Table 10.8. Energy Intensity (Current) Modifier.

Energy Intensity Values	Description
Very Low Current Energy	Area experiences little current motion under most conditions.
Low Current Energy	Area typically experiences very weak currents (0–1 knots).
Moderate Current Energy	Area regularly experiences moderate tidal currents (> 1–3 knots).
High Current Energy	Area regularly experiences strong currents (> 3 knots).

Energy Type

The Energy Type Modifier ia adapted from Dethier (1990) and Zacharias et al. (1998) with type categories as described in Table 10.9.

Table 10.9. Energy Type Modifier.

Energy Type Values	Description
Current	Coherent directional motion of the water.
Internal Wave	Vertical and transverse oscillating water motion—below the surface—due to seismic energy or a pressure differential.
Surface Wave	Vertical and transverse oscillating surface water motion due to wind or seismic energy.
Tide	Periodic, horizontally oscillating water motion.
Wind	Coherent directional motion of the atmosphere.

10.4.2 Induration

The stability of the substrate is a strong determinant of the suitability of an area for colonization by sessile organisms, and for feeding or burrowing activities by benthic epifauna and infauna. The Induration Modifier can be used to describe the hardness or amount of consolidation of bottom sediments (Substrate Component units). Induration is often measured with acoustic tools. The following categories are adopted from Greene et al. (2007).

Table 10.10. Substrate Induration Modifier.

Substrate Induration Values	Definition
Hard	Strongly consolidated fine sediment with low water content, or rock outcrop, or bedrock.
Mixed	A blend of hard and soft substrate materials.
Soft	Loose, fine, unconsolidated, or sediment-covered substrate with a high water content.

10.4.3 Seafloor Rugosity

Seafloor Rugosity, a measure of surface "roughness", is applicable at several scales using different measures (e.g., bathymetric x-y-z data, measured transect data, video data). Rugosity is derived as the ratio of surface area to planar (flat) area for a grid cell, or as the ratio of surface area to linear area along transects, and is calculated as follows:

$$f_r = A_r / A_g$$

where A_r is the real (true, actual) surface area and A_g is the geometric surface area (IUPAC 1997).

Values for Seafloor Rugosity are taken from Greene et al. 2007. The five rugosity types and their associated numeric values are given in Table 10.11.

Table 10.11. Rugosity Modifier.

Rugosity Values	Rugosity Range
Very Low	1.0 to < 1.25
Low	1.25 to < 1.50
Moderate	1.50 to < 1.75
High	1.75 to < 2.00
Very High	≥ 2.00

10.4.4 Small-scale Slope

The Slope Modifier refers to the angle of the substrate at a scale appropriate for the feature being described; Greene et al.'s (2007) geological classification is followed here to characterize slope.

Table 10.12. Slope Modifier.

Slope Values	Vertical Angle (Degrees)
Flat	0 to < 5
Sloping	5 to < 30
Steeply Sloping	30 to < 60
Vertical	60 to < 90
Overhang	≥ 90

10.4.5 Substrate Descriptors

The Substrate Component describes substrate size and composition, considering substrate origin as Geologic, Biogenic, and Anthropogenic. The Geologic classifications follow Wentworth (1922) and Folk (1954) to describe particle sizes and mixes, but do not consider geologic composition or several other important attributes. Substrate descriptors provide consistent terminology to meet these needs. Certain substrate descriptors may be used for other applications as well, e.g., Well-Mixed, Patchy, and Well-Sorted can be used to describe biotic communities or other units.

Table 10.13. Substrate Descriptor Modifier.

Substrate Descriptor Values	Description
Carbonate	Geologic Origin particles or substrates composed mainly of carbonate minerals, e.g., limestone, dolostone.
Compacted	Unconsolidated sediments with very little water content and a hard, packed form that resists penetration and resuspension. This is one of several terms that are used in CMECS to describe the fluid consistency of substrates.
Floc	A layer of very fine particles suspended in the water column just above firmer sediment. This is often most apparent with visual or imaging techniques, and may appear as a turbid or cloudy layer above a more defined sediment surface. This is one of several terms that are used in CMECS to describe the fluid consistency of substrates.
Fluid	Substrate with high water content. When a palmful of sediment is squeezed in the hand, most or all flows through the fingers after full pressure (Schoeneberger et al. 2002). This is one of several terms that are used to describe the fluid consistency of substrates in CMECS.
Gas	Subsurface bubbles of gas, possibly resulting from methanogenesis or other biogeochemical processes, are present. Escaping gas may or may not express at the sediment surface.
Mobile	Bedded sediments which regularly resuspend and/or move with local hydrodynamics due to the density, grain size, shape, and/or high water content of the sediment, or due to the higher hydrodynamic energy experienced in the local area. This term is used in CMECS to describe or predict behavior of substrates.
Non-mobile	Bedded sediments which do not regularly resuspend and/or move with local hydrodynamics due to the density, grain size, shape, and/or compaction (low water content) of the sediment particles, or due to the lower hydrodynamic energy experienced in the local area. This term is used in CMECS to describe or predict behavior of substrates.
Mud Clasts	Compacted or consolidated fragments (clumps, lumps, balls, shards, etc.) of mud or clay, typically occurring at the sediment surface, with diameters of millimeters to < 1 meter.
Patchy	Different elements within a sample, observational unit, or reporting unit are grouped into clusters or patches at the scale of the sample or unit. “Patchy” implies that clusters of elements or particles are arranged in a haphazard manner, as clusters of pebbles scattered on sand. This is one of several

Substrate Descriptor Values	Description
	terms used in CMECS to describe unit variability.
Pelagic Clay	Deep sea Geologic Substrates composed primarily of aeolian deposits, volcanic ash, and other non-biogenic materials that sink into the very deep oceans, or may be generated in the deep oceans. Pelagic Clays contain less than 30% ooze materials (tests, shells, and frustules of plankters) and are found in areas of low surface productivity.
Red Clay	A type of Pelagic Clay composed primarily of aeolian dust, with various marine-generated particles mixed in (fish bones, teeth, authigenic mineral deposits). Red clays are distinguished by their characteristic bright red or brown color and are found in the deepest and most remote ocean areas. Red Clay contains less than 30% ooze materials.
Siliciclastic	Geologic Substrate Origin particles or substrates composed primarily of silicate minerals e.g., quartz, sandstone, siltstone.
Sulfidic	Substrate in which bacterial sulfate reduction is an important biogeochemical process; this generally occurs in anaerobic environments and is often identifiable by a very low reflectance black or blue color, and a characteristic "rotten egg" odor when sediments are examined in air.
Volcaniclastic	Geologic Origin particles or substrates composed primarily of volcanic rock, crystals, glassy pumice, ash, or other volcanic products.
Volcanic Ash	A substrate or substrate layer composed primarily of volcanic dust and volcanic ash, often with various aeolian or marine-generated particles mixed in. In areas of the deep sea, where terrigenous input and bioturbation are limited, Volcanic Ash may be present in distinct layers at depth in the substrate matrix (see the "Layers" modifier).
Well-mixed	Different elements within a sample, observational unit, or reporting unit are well-mixed or poorly-sorted at the scale of the sample or unit. Well-mixed implies that elements or particles are completely and relatively evenly intermingled, e.g., Granule/Sand/Mud particles in an area with high bioturbation. This is one of several terms used in CMECS to describe unit variability. Note that CMECS does not use the equivalent geological term "Poorly-Sorted", because the descriptor may be used to describe distributions of non-geological features (such as biological communities or Geoform Component structures).
Well-sorted	Different elements within a sample, observational unit, or reporting unit are separated into different areas at the scale of the sample or unit. Well-sorted implies that elements or

Substrate Descriptor Values	Description
	particles are (or have been) separated and arranged in a non-haphazard manner, as an area of Coarse Sand adjacent to an area of Clay. This is one of several terms used in CMECS to describe unit variability.

10.4.6 Surface Pattern

The surface of the seafloor may be flat (on a scale of centimeters or meters), or it may be characterized by roughness or pattern. The Substrate Component describes substrate size and composition, while the Geoform Component describes texture or shape—including the Surface Pattern Modifier. These roughness patterns may have physical origins (e.g., caused by wave or current action) or biological origins (due to activities of life forms, e.g., mounds or tunnels). Physically influenced bedforms may appear as regularly spaced "sand ripples" (with a wavelength on the order of centimeters), which may be indicative of wave oscillations or of current flows. Physical energy in soft-sediment areas may occur through riverine flow or tidally driven flow, leading to erosion and deposition of mobile sediment layers.

Table 10.14. Surface Pattern Modifier.

Surface Pattern Values	Description
Biological	Roughness appears due to bioturbation, fecal mounds, tunneling, feeding or locomotory activities of megafauna, or other faunal activities. Further characterization of biological features is described in the Biotic Component.
Irregular	Sediment surface has a perceptible roughness or texture that is non-regular in either frequency, direction, or amplitude.
Physical	Roughness appears due to water motion, but the nature of the roughness is other than Rippled.
Rippled	Closely spaced, regular, repeating, vertical variations in the height of a sandy or muddy bottom, with a very short wavelength on the order of centimeters. A rippled substrate is generally caused by the physical processes of water motion.
Scarred	Roughness appears due to localized sediment disturbance resulting either from natural causes (e.g., slumps) or anthropogenic causes (e.g., anchor scars, propeller scars, trawl scars, or other fishing gear scars), but not as an artifact of camera or sampling gear deployment.

Surface Pattern Values	Description
Smooth	No perceptible roughness or texture to sediment surface at scales of less than 1 meter.

10.4.7 Tidal Regime (Amplitude)

The Tidal Regime Modifier refers to the height difference between mean high tide and mean low tide at the coast. The mean range gives a proxy for the energy and flow associated with tidal motions. Tidal Regime is shown in Table 10.15.

Table 10.15. Tidal Regime (Amplitude) Modifier.

Tidal Regime (Amplitude) Values	Tidal Range (amplitude in meters)
Atidal	< 0.1
Microtidal	0.1 to < 0.3
Minimally Tidal	0.3 to < 1
Moderately Tidal	1 to < 4
Macrotidal	4 to < 8
Megatidal	≥ 8

10.4.8 Wave Regime (Amplitude)

This modifier is intended to quantify intensity of wave energy by amplitude, and can be applied on any time scale, as specified by the user.

Table 10.16. Wave Regime (Amplitude) Modifier.

Wave Regime Values	Wave Height (amplitude in meters)
Quiescent	< 0.1
Very Low Wave Energy	0.1 to < 0.25
Low Wave Energy	0.25 to < 1.0
Moderate Wave Energy	1.0 to < 2.0
Moderately High Wave Energy	2.0 to < 4.0
High Wave Energy	4.0 to < 8.0
Very High Wave Energy	≥ 8.0

10.5 Physicochemical Modifiers

10.5.1 Oxygen

Oxygen concentration is an important water column modifier. Oxygen is critical to aerobic organisms and to aerobic processes (such as chemical oxidation and microbial respiration). Dissolved oxygen levels change daily in a dramatic way in systems such as estuaries, where they often go from hypoxic (at night) to saturated (during the day). The Oxygen Regime Modifier is intended for use in reporting persistent oxygen conditions, or can be used to explain variable regimes as described by the user. Oxygen levels are determined according to the following ranges, for the time scales and durations specified by the user; practitioners may specify, e.g., "oxygen varies from highly oxic during daylight hours to severely hypoxic at night". Furthermore, practitioners should note that oxygen saturation varies with temperature and pressure.

Table 10.17. Oxygen Regime Modifier.

Anoxic	0 to < 0.1
Severely Hypoxic	0.1 to < 2
Hypoxic	2 to < 4
Oxic	4 to < 8
Highly Oxic	8 to < 12
Very Oxic	≥ 12

10.5.2 Photic Quality

Photic quality is a highly variable parameter. In many cases, water is clear and downwelling light penetration extends the photic zone to the bottom of the water column. In cases of reduced water clarity, light is highly attenuated. Photic exposure depends on the depth, sun angle, cloud cover, time of year, and other factors. Moreover, the depth of the shift from photic to aphotic occurs at different points in the water column, depending on the ecosystem, watershed, and suspended substances reducing water clarity.

Vertical zones are evaluated relative to the penetration of light (photic and aphotic) for both water column and benthic components. The depth of the photic zone can also be calculated from ocean color imagery using satellite algorithms (Lee et al. 2007).

Table 10.18. Photic Quality Modifier.

	Condition
Aphotic	Region of the water column where no ambient light penetrates, no photosynthesis occurs, and animals cannot make use of visual cues based on even reduced levels of ambient light. In oceans, this zone typically lies below 500–1,000 meters of depth. In turbid estuaries, this zone may be very shallow.

Photic Quality Values	Condition
Dysphotic	Region of the water column, below the compensation depth, that receives less than 2% of the surface light; plants and algae cannot achieve positive photosynthetic production in this region, but some ambient light does penetrate such that animals can make use of visual cues based on reduced levels of ambient light.
Photic	Region of the water column where ambient light is > 2% of surface light and phototrophic organisms can photosynthesize.
Seasonally Photic	An area that regularly varies between photic and dysphotic/aphotic.

10.5.3 aRPD and RPD

The apparent Redox Potential Discontinuity (aRPD) is a measurement of the depth of the "color break," that is, the maximum color difference below the sediment-water interface at which lighter-colored (tan, brown, beige, yellow, or red), more-oxidized surface sediments transition into darker-colored (grey, black, or blue-black), more-reduced deeper sediments. The depth of the aRPD is easily measured, and it has been found to be an extremely useful parameter in characterizing certain biogeochemical aspects of the sedimentary environment. For instance, the aRPD represents the depth at which iron exists as colored, insoluble, ferric hydroxides, which dissolve into solution as iron monosulfides in a reducing environment, e.g., in the presence of sulfate reduction (Teal et al. 2009).

The aRPD is strongly correlated to the true RPD depth (Grizzle and Penniman 1991; Rosenberg et al. 2001), which is the depth where Eh (measured sediment reduction/oxidation potential) is zero. Both values are very useful as proxies for bioturbation (because the values are extended deeper by the effects of bioturbating fauna), and both are correlated to bottom-water dissolved-oxygen concentration (Rosenberg 1977; Diaz, Cutter, and Rhoads 1994; Cicchetti et al. 2006). The aRPD can be measured with a variety of techniques including retrieval of cores, sediment profile imaging, and direct observation. The RPD can be measured using microelectrodes, either in retrieved cores or *in situ*.

- **RPD (centimeters)** – The RPD is measured with electrodes, and is reported in centimeters.

- **aRPD depth (centimeters), muddy sediments** – The aRPD depth is measured at the color transition based on direct observation or from images, and it can be reported in centimeters or following the terms defined below (from Nilsson and Rosenberg 1997). These modifier terms apply only to sediments that contain some mud; aRPD depths manifest differently in sand sediments that are dominated by different diffusional processes and rates.

Table 10.19. aRPD Depth Modifier.

aRPD Depth Values	aRPD Depth (centimeters)
Zero	0.0
Diffusional	> 0.0 to 1.0
Shallow	> 1.0 to 2.0
Moderate	> 2.0 to 3.5
Deep	> 3.5 to 5.0
Very Deep	> 5

10.5.4 Salinity

Salinity is considered a classifier for the Water Column Component, i.e., it is an essential parameter for measurement in order to effectively classify the water column. However, users may wish to apply the CMECS terminology for salinity within other components when the water column itself is not being classified. The salinity ranges are repeated here in the modifier section to allow this convenience for users.

Table 10.20. Salinity Regime Modifier.

Salinity Regime Values	Salinity (Practical Salinity Scale)
Oligohaline	< 5
Mesohaline	5 to < 18
Lower Polyhaline	18 to < 25
Upper Polyhaline	25 to < 30
Euhaline	30 to < 40
Hyperhaline	≥ 40

10.5.5 Temperature

As with salinity, temperature is considered a classifier for the Water Column Component, i.e., it is an essential parameter for measurement in order to effectively classify the water column. Likewise, users may wish to apply the CMECS terminology for temperature within other components when the water column itself is not being classified. The temperature ranges are repeated here in the modifier section to allow this convenience for users.

Table 10.21. Temperature Range Modifier.

Temperature Range Values	Degrees (^oC)
Frozen/Superchilled	≤ 0
Very Cold	0 to < 5 (liquid)
Cold	5 to < 10
Cool	10 to < 15
Moderate	15 to < 20
Warm	20 to < 25
Very Warm	25 to < 30
Hot	30 to < 35
Very Hot	≥ 35

10.5.6 Turbidity

Turbidity is a factor of the suspended solids and color within the water column, and it affects light attenuation and the depth to which light penetrates in the water column. This is critically important for autotrophs that convert light to photosynthetic products. Turbidity also has important effects on visual hunting and predation avoidance. While turbidity is frequently reported in Nephelometric Turbidity Units (NTUs), CMECS establishes categories for turbidity based on Secchi disk depth; it would be difficult to standardize turbidity by NTUs due to regional variations in background measurements. Secchi disk observations are commonly used in the marine environment.

Table 10.22. Turbidity Modifier.
(as measured by Secchi depth)

Turbidity Values	Secchi Depth (meters)
Extremely Turbid	< 1
Highly Turbid	1 to < 2
Moderately Turbid	2 to < 5
Clear	5 to < 20
Extremely Clear	≥ 20

10.5.7 Turbidity Type and Provenance

There are two additional Turbidity Modifiers: Type and Provenance. The provenance of the attenuating substance—whether the reduced water clarity is derived from chlorophyll pigments (e.g., phytoplankton blooms), from color due to dissolved substances in the water (e.g., gelbstoff or tannins), from imported mineral terrigenous sediments, or from carbonate particulates in resuspension—is an important qualitative characteristic of turbidity. This qualitative assessment can be used in addition to a qualitative or quantitative evaluation of the degree of turbidity in the water column.

Table 10.23. Turbidity Type Modifier.

Turbidity Type Values	Definition
Carbonate Particulates	Attenuation produced by suspended precipitated $CaCO_3$ in the water column, generally creating an opaque “milky” appearance.
Chlorophyll	Attenuation produced by chlorophyll a, b, c, or d as constituents of live phytoplankton in the water column.
Colloidal Precipitates	Dispersed particulates that precipitate out of the water to form aggregations such as marine snow.
Mineral Particulates	Attenuation produced by suspended inorganic sediments derived from soil and rock weathering.
Detritus	Attenuation due to larger particles of organic detritus in suspension.
Dissolved Color	Substances dissolved in water that have color.
Mixed	Attenuation due to a variety of the above sources and substances.

Table 10.24. Turbidity Provenance Modifier.

Turbidity Provenance Values	Definition
Allochthonous	Originating outside of the system and transported into the system.
Autochthonous	Generated *in situ* by biogenic processes (e.g., phytoplankton bloom).
Marine Origin	Materials, water, or energy originating in the ocean.
Precipitated	Solutes such as calcium carbonate that precipitate out of solution.
Resuspended	Deposited materials mixed into the water column by currents (e.g., bottom sediments).
Terrigenous Origin	Materials, water, or energy in a water body resulting from land drainage or wind deposits.

10.5.8 Water Column Stability

Water column stability can be characterized as stratified, partially mixed, and well-mixed. This structure is defined by density differentials from bottom to surface, as shown in the table below. Water Column Stability is assessed using the more universally applied delta Sigma-t to calculate stability, which incorporates salinity, temperature into the calculation of density and adjusts for adiabatic effects (Pond and Pickard 1983). The Stability Regime modifier compares the calculated δ Sigma-t, or the relative density of two water parcels by subtraction of the density of the surface layer from the density of the deeper layer. If the density difference equals or exceeds 0.125, the water column is considered to be vertically stable; if it differs by less than 0.125, and density is homogeneous between the upper and lower layers, the water column is classified as well-mixed. If the density difference is less than 0.125 and variable between the two layers, the water column is classified as partially mixed.

Table 10.25. Water Column Stability Regime Modifier.

Water Column Stability Regime Values	δ Sigma-t relative to surface density
Partially stratified	< 0.125 and variable
Stratified	≥ 0.125
Well-mixed	< 0.125 and homogeneous

10.6 Spatial Modifiers

10.6.1 Benthic Depth Zones

The depths of benthic zones vary depending on regional geology and turbidity. It is often useful to describe a specific depth or range of depths for the bottom, and the CMECS Benthic Depth Zone Modifiers represent the major divisions in a gradient from land to the deep ocean bottom. They are generally based on the zones in which surf or ocean swell influences bottom communities, lower limits of vegetation (such as kelp), overall photic availability, and temperature. The zones within this category are drawn or adapted from Greene et al. (2007) and Connor (1997). The following definitions are intended as guidance for adaptation of depth ranges to regional environmental conditions:

- **Littoral** – All areas that are episodically exposed to air; intertidal.
- **Infralittoral** – Subtidal areas within the photic zone, often characterized by macroalgae or rooted vascular plants. Divided into shallow and deep zones.

- **Circalittoral** – Subtidal areas below the photic zone, generally characterized by animal communities (although very sparse algae may be present).

Table 10.26. Benthic Depth Zone Modifier.

Benthic Depth Zone Values	Approximate Depth Range (meters)
Littoral	Intertidal
Shallow Infralittoral	0 to < 5
Deep Infralittoral	5 to < 30
Circalittoral	30 to < 200
Mesobenthic	200 to < 1,000
Bathybenthic	1,000 to < 4,000
Abyssalbenthic	4,000 to < 6,000
Hadalbenthic	≥ 6,000

10.6.2 Co-occurring Elements

Nature is inherently a mixture or a continuum. CMECS provides an ecologically meaningful methodology to classify nature into discrete environmental types using consistent threshold values that define primary classification units. However, in natural coastal and marine settings, less abundant, co-occurring (or secondary) features are frequently mixed into these primary classification types at some level beneath a classification threshold. Therefore, these co-occurring features are not recognized in the syntax of the primary classification. In some situations, project goals may require identification of these co-occurring features and associated taxa. In other situations, identification of co-occurring materials, taxa, or mixes may detract from project goals.

CMECS provides a modifier, Co-occurring Elements, for identification of secondary CMECS classification units that are mixed into a primary classification unit at a level below the classification threshold. Co-occurring Elements are used in the hierarchical Biotic and Substrate Components when the primary feature and the co-occurring feature are both units in that same Component. Examples of Co-occurring Elements may include mixes such as:

- An observational unit where Geological Substrate Origin and Anthropogenic Substrate Origin coexist (e.g., a 5% cover of large Plastic/Trash on top of a dominant Fine Sand Substrate):
    - <u>Classification</u> – Geologic Substrate, Substrate Subgroup Fine Sand

  - Co-occurring Element Modifier – Anthropogenic Substrate, Substrate Subclass Plastic/Trash Rubble 5% cover

- An observational unit where two Biotic Groups are present. Consider a seafloor image with dominant Larger Deep-Burrowing Fauna, but also containing a cluster of sponges:
  - Classification – Benthic Biota, Faunal Bed, Soft Sediment Fauna, Larger Deep-Burrowing Fauna
  - Co-occurring Element Modifier – Biotic Group, Sponge Bed

CMECS also provides another modifier, Associated Taxa (see Section 10.3.1 above), to identify biota that are present in an observational unit, but do not constitute a CMECS classification unit. Associated Taxa may be predators, rapidly-moving fauna, or other biota that are not identifiable as Biotopes or Biotic Groups.

Examples of Associated Taxa may include mixes such as:

- An observational unit where Mussel Beds on mud are the dominant Fauna, and where fish and crab predators are common:
  Classification – Benthic Biota, Faunal Bed, Soft Sediment Fauna, Mussel Bed
  Associated Taxa Modifier – fish (*Tautoga*) and crabs (*Callinectes*)

Co-occurring Elements and Associated Taxa follow the conventions adopted for all modifiers. This convention allows any CMECS classification unit to be used within its appropriate component as a Co-occurring Element modifier to indicate a mixture, and allows any type of organism to be included in the Biotic Component as Associated Taxa. When evaluating mixes, the spatial scale of the variability of the mixture (the "patch size") becomes an important concept. Consider a sand seafloor spotted in a seemingly haphazard pattern with a scattered mosaic of patches of broken shell material that average 1 meter x 1 meter in size. Different observational methods—for example, a 10 centimeters x 10 centimeters grab, a 150 centimeters x 200 centimeters still image, or a 500 meters acoustic swath—will view these shell patch sizes differently. Also, the reporting unit for the project may differ from the observational unit, further complicating the description of mixes. Below the minimum mapping unit size, these shell patches could be considered Co-occurring Elements. However, at the point where the patches exceed the minimum mapping unit the shell patches would be large enough to be classified as separate reporting units with a new label—and not as a "mix" or Co-occurring Element within an observational or reporting unit.

In many projects, Co-occurring Element Modifiers (and Associated Taxa Modifiers) will be used extensively for classifications at the Biotic Group level. This is because biological assemblages have not been well characterized for many ecosystems and regions, and reporting multiple Biotic Groups as Co-occurring Elements provides a flexible tool to consistently characterize the biota that are present within an observational unit. As biological assemblages become better characterized and lists of detailed biotope descriptions are developed, the use of Co-occurring Elements to describe multiple Biotic Groups at each location should be replaced by identification of a single biotope at each location—a single, well-characterized, repeating assemblage that inherently and predictably consists of multiple Biotic Groups and Associated Taxa.

10.6.3 Coral Reef Zone

All coral reef environments contain distinct horizontal and vertical zones created by differences in depth, morphology, wave and current energy, temperature, and light. The following zones are commonly present on shallow and mesophotic reefs (Zitello et al. 2009).

Table 10.27. Coral Reef Zone Modifier.

Coral Reef Zone Values	Description
Back Reef	Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is present only when a reef crest exists.
Bank/Shelf	Deeper water area (usually > 30 meters) extending offshore from the seaward edge of the fore reef (or shoreline) to the beginning of the bank/shelf escarpment where the insular shelf drops off into deep, oceanic water.
Bank/Shelf Escarpment	The edge of the bank/shelf where depth increases rapidly into deep oceanic water. This zone begins at approximately 20–30 meters depth, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photos, and this zone is intended to capture the transition from the bank/shelf to deep waters of the open ocean.
Fore Reef	Area from the seaward edge of the reef crests (which slopes into deeper water) to the landward edge of the bank/shelf platform. Features not forming an emergent reef crest—but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf—are also designated as forereef.
Lagoon	Shallow area (relative to the deeper water of the bank/shelf) between the shoreline intertidal zone and a back reef or barrier island. This zone is protected from the high-energy waves commonly experienced on the bank/shelf and reef crest. If no reef crest is present, there is no lagoon zone.

Coral Reef Zone Values	Description
Reef Crest	The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone lies between the back reef and fore reef zones. In aerial images, breaking waves will often be visible at the seaward edge of this zone.
Reef Flat	Shallow (semi-exposed) area between the shoreline intertidal zone and the reef crest of a fringing reef. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest. Reef flat is typically not present if there is a lagoon zone.
Ridges and Swales	An area of numerous thin, narrow, discontinuous bands of coral ridges and leeward sand- and sediment-filled swales. Debris and reef-rubble fields behind many of the reefs may obscure these margin-parallel seabed features. In Florida, for example, this zone extends for an estimated 200 kilometers along the Florida shelf (from Key Largo to Halfmoon Shoal), and it is discontinuous due to (a) topography, (b) inconsistent responses of coral reefs to changing sea levels, and (c) varying effects of the physical environment on reefs and sediments.
Shoreline/Intertidal	Area between the mean high water line (or the landward edge of emergent vegetation—such as Red Mangrove—when present) and the lowest spring tide level (excluding emergent segments of barrier reefs).
Vertical Wall	Area with near-vertical slope from the shore to the shelf (or shelf escarpment). This zone is typically narrow and may not be distinguishable in remotely gathered imagery; however, it is included because it is recognized as a biologically important feature.

10.6.4 Enclosure

Enclosure represents the degree of isolation of a water body from other waters because of enclosure by a land mass. In estuaries, enclosure determines the degree of exchange of water, materials, energy, and biota between the estuary and the sea. More enclosed water bodies have longer water residence times, can tend to be more evaporative and hypersaline, and can more readily trap and retain materials within them.

Table 10.28. Enclosure Modifier.

Enclosure Values	Angular Gap
Unenclosed	≥ 150° angular gap from landward end of water body to seaward opening; no confining land masses (e.g., islands) within or just outside water body.
Partially Enclosed	90° to < 150° angular gap from landward end of water body to seaward opening.
Significantly Enclosed	45° to < 90° angular gap from landward end of water body to seaward opening.
Very Enclosed	10° to < 45° angular gap from landward end of water body to seaward opening.
Enclosed	Essentially separated from the ocean; waters are completely surrounded by land or with a narrow channel connection to the sea. This category includes perched estuaries and lagoonal estuaries.
Intermittent	Class of water bodies that regularly close due to low flow, opening seasonally during high flow. Also called ICOLL (Intermittently Closed and Open Lake or Lagoon).

10.6.5 Percent Cover Range

To classify a unit to the class and subclass level of the Biotic Component, a user needs to know the relative percent cover of each of the components of the substrate. The degree of substrate cover for each biotic feature is assessed using the following ranges. These categories can also be used as a modifier to describe the density of vegetation (such as seagrasses) or other substrate components, and are useful in the Substrate component as well. Coarse Percent Cover can be described using one of five coarse descriptors, e.g., "Sparse", or, if greater detail is needed, Fine Percent Cover can be described using one of eleven range categories, e.g., "10 to < 20%".

Table 10.29. Percent Cover Modifiers.

Coarse Percent Cover Values	Fine Percent Cover Values
Trace	< 1%
Sparse (1 to < 30%)	1 to < 10%
	10 to < 20%
	20 to < 30 %
Moderate (30 to < 70%)	30 to < 40 %
	40 to < 50 %
	50 to < 60 %
	60 to < 70 %
Dense (70 to < 90%)	70 to < 80 %
	80 to < 90%
Complete	90 to 100%

10.6.6 Elevation Profile

The Profile Modifier refers to the elevation of a feature relative to the surrounding level of the water or bed.

Table 10.30. Elevation Profile Modifier.

Elevation Profile Values	Relative Height (meters)
None	0
Low	0.1 to < 2
Medium	2 to < 5
High	≥ 5

10.6.7 Substrate Layering

Substrate in CMECS conceptually extends to the greatest depth that supports multicellular life. Although certain large fauna may penetrate several meters below the surface in soft sediments, CMECS generally considers the uppermost 15 centimeters of fine substrates, recognizing that evidence of very-deep burrowing fauna will also be present in the top 15 centimeters. The upper 15 centimeters of substrate may present as a set of horizontal layers constituting a three-dimensional matrix. A basic identification of horizontal substrate layers can be accomplished by describing the characteristics of these layers and recording the mean thickness in centimeters together with the ordering of each layer below the sediment surface. The process of identifying and describing substrate layers can provide ecological insights and practical value for users interested in substrate structure and process, as well as in ecological history.

The structuring of distinctly layered sediments is captured in CMECS as a modifier using any SC classifiers, modifiers, or descriptors in the following format, with measurements indicating thickness or depth of the examined layers (as specified). The term “veneer” may be used to describe a thin (< 1 centimeter thick) covering of one sediment type over another sediment type. Examples:

Modifier: Layering – 4 centimeters (thick) Coarse Sand Layer over > 11 centimeters (thick) Sandy Silt-Clay Layer
Modifier: Layering – Mud veneer over Cobbles
Modifier: Layering – 2 centimeters (thick) Shell Hash Layer over 6 centimeters (thick) Sand Layer over > 7 centimeters (thick) Mud Layer
Modifier: Layering – 0 to 5 centimeters (deep) Anthropogenic Woody Debris Layer over 5 to > 20 centimeters (deep) Geologic Clay Layer
Modifier: Layering – Sand Layer over Muddy Sand Layer

More advanced sediment dating techniques, which benefit from special coring equipment to recover several meters of sediment, can also provide identification of layers by age in years. These more detailed descriptions of layering may require different approaches.

10.7 Temporal Modifiers

10.7.1 Temporal Persistence

The Temporal Persistence Modifier describes the permanency or variability of a hydromorphic, geomorphic, or biological feature. Though qualitative and relative, it is useful is distinguishing between features that are similar in morphology—but are temporally diverse in terms of stability. An example is a mud shoal versus a mudbank; the former tends to be moved by changing currents or storms, while the latter is more stable and persistent.

Table 10.31. Persistence Modifier.

Persistence Values
Stochastic
Hours
Days
Weeks
Months
Years
Seasons
Inter-annual
Decades
Centuries

11. A Spatial-Temporal Framework for CMECS Components

Each CMECS component encompasses a unique expanse of space and time. As such, each component may be arrayed within a relative spatial-temporal context to illustrate its place within the global marine ecosystem (Figure 11.1). CMECS uses spatial and temporal gradients as the basis of the classification standard, because much of what is understood about species-environment relationships is structured within a spatial-temporal framework. This framework is intended to provide ecological context for the entire classification standard, maximize usability for scientists and managers, and—eventually—guide habitat data collection and mapping efforts.

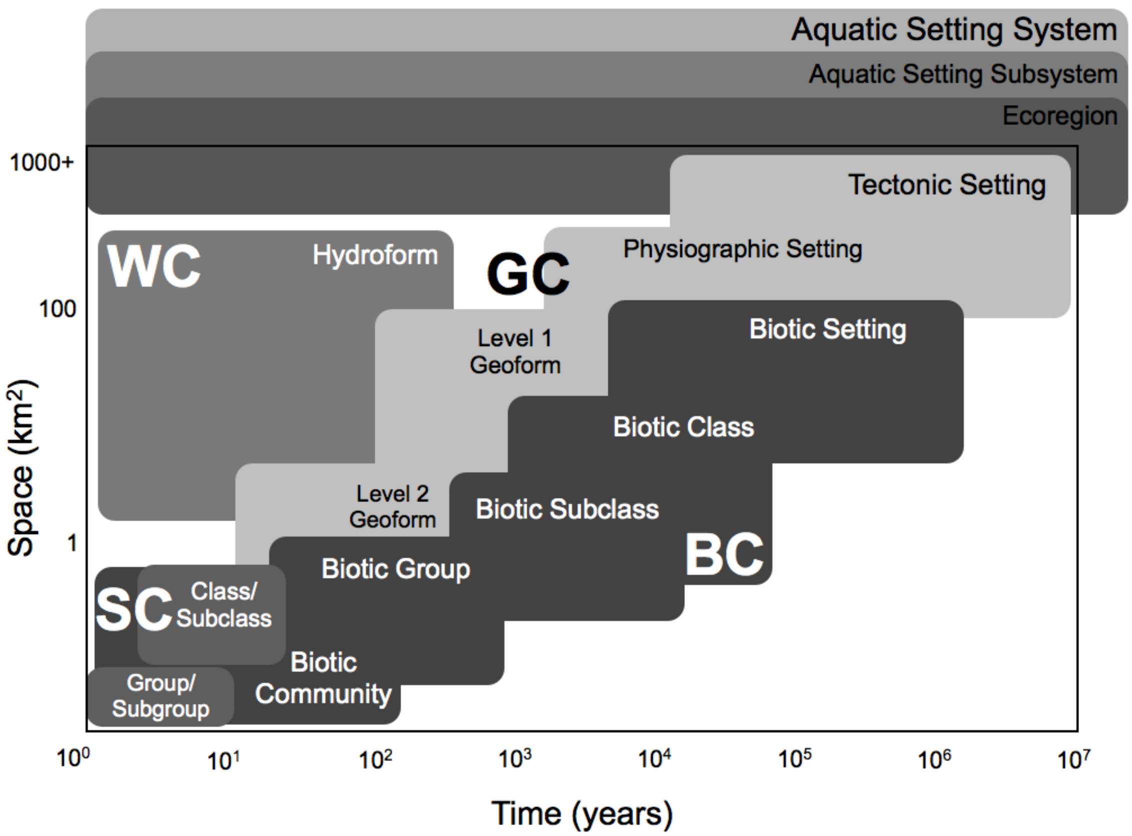

Figure 11.1. CMECS Components in a Spatial-Temporal Framework.
Bounding boxes for units are clipped spatially and temporally (on the bottom left) to avoid overlap and confusion between units. See figures below for a more accurate spatial-temporal treatment of each component.

11.1 Why use a spatial-temporal framework?

The first goal of CMECS is to identify the resources that are present (i.e., "What resources are out there?"); however, this document also seeks to frame other ecologically important questions (such as "Where are the resources located?" and "How are they doing?") and position CMECS to answer them. In order to address these questions, it must be acknowledged that ecosystems are dynamic in space and time. By building a spatial-temporal framework into the classification standard, the examination of landscape patterns, organization, and change—at multiple spatial and temporal scales—is encouraged (Guarinello, Shumchenia, and King 2010).

The CMECS nomenclature serves as a common language for marine ecosystems, and adding the spatial-temporal framework makes this nomenclature process oriented. Associations and coupling mechanisms among components can be suggested, because the framework aligns ecosystem elements on a common scale. Also, structural and functional relationships between components can be visualized and form the basis for hypothesis testing. Other ecological processes (such as natural and human disturbances, succession, invasion, and evolution) can be conceptualized within the same framework and then overlaid onto CMECS components, which aids users in understanding which processes might be most relevant to particular ecological units (Figure 11.2).

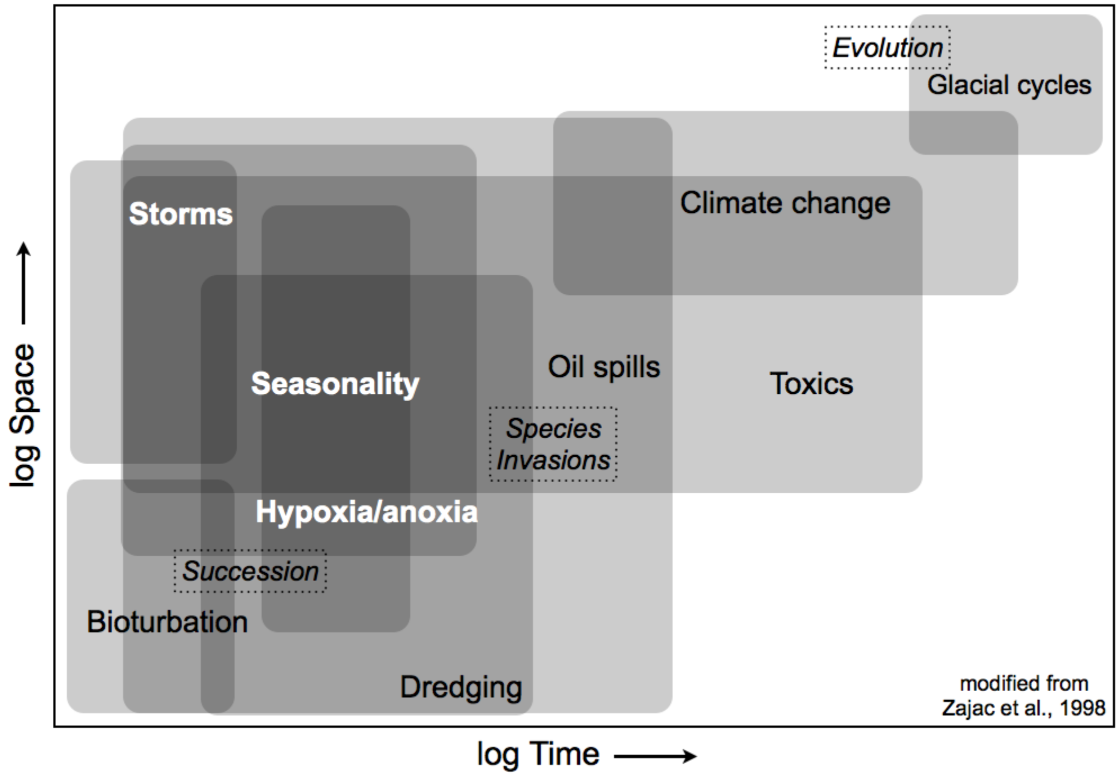

Figure 11.2. The Spatial and Temporal Scale of Ecological Processes (Including Natural and Human Disturbances).

These processes can be overlain with CMECS units in order to determine which processes are most influential at the scales of interest.

11.2 Applications

From a practical standpoint, the spatial-temporal framework puts the ecological unit of interest into perspective. Various researchers have shown that the classification does not need to be applied in a particular direction; examples can be found in Hewitt et al. (2004) and Shumchenia and King (2010). Complex ecosystems can be decomposed and understood in space and time simultaneously, because spatial and temporal scales are often linked (Wu 1999). Spatial and temporal gradients are valuable for evaluating ecosystem interactions, and the analysis of ecosystems can be structured to use time, spatial replication, or spatial contrast as the basis for experimentation and hypothesis-testing (Murawski et al. 2010). The sampling tools and sampling effort necessary to capture patterns and processes at a particular scale are related to spatial-temporal gradients (Figure 11.3). In this way, the spatial-temporal framework can guide sample collection and inform monitoring plans.

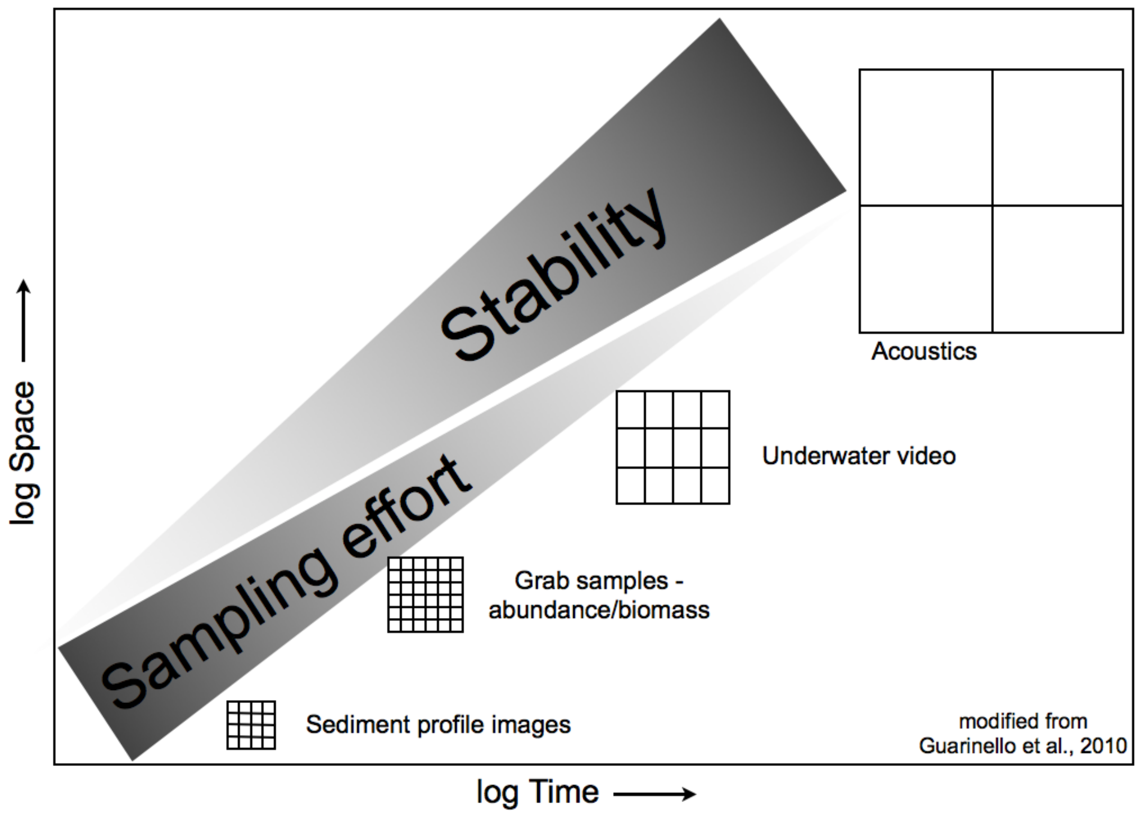

Figure 11.3. The Stability of Ecosystem Features as they Relate to Sampling Efforts and Strategies are Shown in a Spatial-Temporal Framework.
To capture ecosystem components that are highly spatially and temporally variable, sampling effort is high. At broad scales, ecosystem components are in general, larger and more stable; therefore sampling effort is relatively low.

Ecosystem valuation is rapidly becoming an important tool in the ecosystem-based management of our oceans (e.g., Derous et al. 2007). Establishing relationships between the biology and its physical environment—and then extrapolating those relationships in space and time—may be the only practical way to inventory and assess large portions of the marine environment. The spatial-temporal framework within CMECS (1) makes these relationships explicit and (2) constrains the scales over which these relationships can be meaningfully applied. An explicit, quantitative, spatial-temporal framework was recently utilized by Wilhelmsson et al. (2010) to assess the magnitude of the impacts from the construction and operation of renewable energy structures (in the marine environment) on a wide range of ecosystem components—from the benthos to hydrology. This approach allowed the estimation of cumulative impacts, discussion of mitigation options, and identification of knowledge gaps and uncertainties.

Finally, the spatial-temporal framework can serve as a communication tool among scientists, managers, and the public; the framework helps convey information about ecosystem complexity, variability, available resources, and management goals (Guarinello, Shumchenia, and King 2010). The spatial-temporal framework serves as a simplified ecosystem model (Thrush and Dayton 2010), which is easily understood by a broad range of users.

11.3 CMECS Components in the Spatial-Temporal Framework

11.3.1 Biogeographic and Aquatic Settings

The Biogeographic and Aquatic Settings are the largest-scale units addressed in CMECS (Figure 11.4). Aside from setting the upper boundaries in space and time for the ecosystems under study, the geographic location of these components may speak to the ecosystems' expected spatial-temporal variability. For example, in the coming decades, ecosystem variability is expected to increase with latitude due to climate change (Parry et al. 2007).

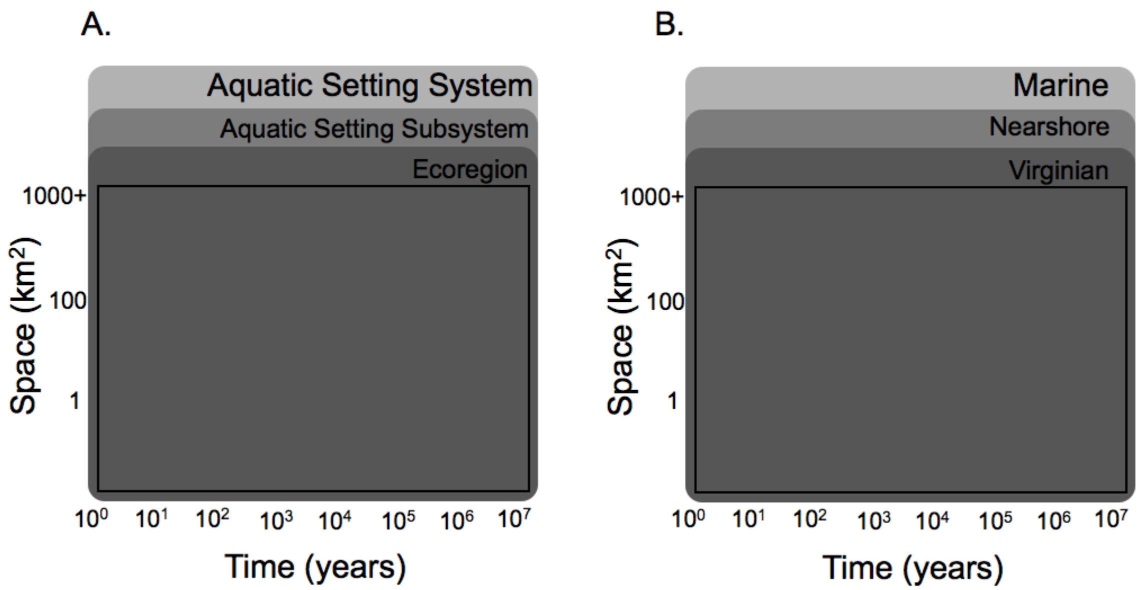

Figure 11.4. Spatial and Temporal Distribution of Biogeographic and Aquatic Settings.
(A) The CMECS Biogeographic and Aquatic Settings exist spatially and temporally outside of the bounding scales of the other physical and biological components. (B) The System, Subsystem and Ecoregion (within the Biogeographic Setting) provide a general setting for more fine-scale CMECS units.

11.3.2 Water Column Component

The Water Column Component encompasses a range of spatial and temporal scales that are wider than most other CMECS components (Figure 11.5). The water column is an extraordinarily dynamic environment and all observations should be reported in spatial and temporal context so as to give order to units that may overlap and grade into one another.

The spatial and temporal variability in water column and oceanographic features is the primary control on biological pattern over much of the globe. The multi-scale variability in oceanographic features influences marine life of all sizes and in all realms. For example:

- The relationship between (a) oceanographic features and (b) phytoplankton abundance and species composition is relevant to short-term oceanic productivity and long-term climate variability (Cermeño et al. 2010).
- Water column variability affects the regional distribution of benthic organisms (Post 2008) and fish recruitment variation (Caselle, Kinlan, and Warner 2010).
- By classifying water column properties through time, trends in ocean warming and acidification can be tracked in order to understand how climate change is influencing the distribution of corals (De'ath, Lough, and Fabricius 2009).

- Even highly mobile megafauna have been shown to respond to variability in oceanographic features. For example, variations in this three-dimensional habitat influence the small-scale variability in whale populations (Skov et al. 2008), sea birds (Kappes et al. 2010), and Steller sea lions (Lander et al. 2009).

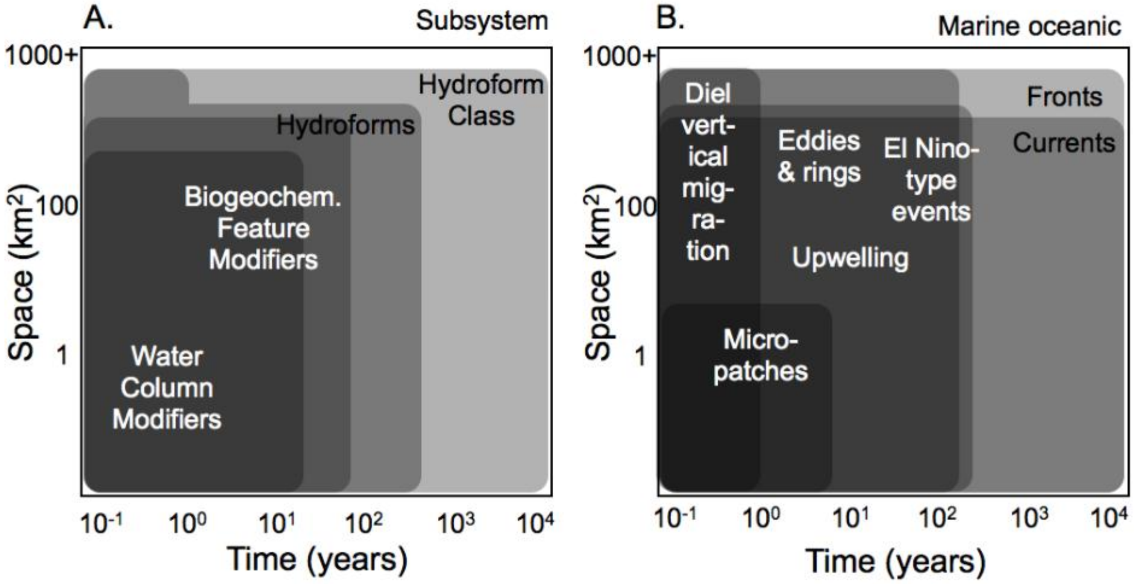

Figure 11.5. Water Column Component Spatial and Temporal Distribution. (A) The elements of the Water Column Component in a spatial-temporal framework showing the hierarchical format. (B) An example classification of Hydroform Classes and hydroforms. At fine scales (i.e., the lower left side of the plots) relevant processes may occur on very short temporal intervals (diel and sub-diel). At broad scales (i.e., the upper right section of the plots), Hydroform Classes such as fronts and currents may help describe patterns in global climate.

11.3.3 Geoform Component

Marine geologic processes act on varying time scales and influence features of various sizes. For example, at the largest spatial and longest temporal scales, tectonic processes influence continental and ocean margins. At geologically intermediate scales of space and time, glacial cycles have affected the North American continent and many of the coastal geomorphologies that are observed today. On the finest scales addressed by the Geoform Component, tidal currents influence the shape and composition of submerged forms on sub-kilometer scales and over the course of days (Figure 11.6).

The Geoform Component consists of a series of spatially and temporally hierarchical units. By acknowledging the spatial and temporal scales of influence on Geoform Component units, the antecedent and present geologic processes are linked to the spatial patterns observed today. Linking process and pattern is an important step in understanding how environments will respond to different types of geologic forcing, biological modification, and/or climate change. Understanding the range of scales relevant to a particular geologic feature will be essential to model—conceptually or mathematically—these changes. For example, overlaying Geoform Component units in the spatial-temporal framework with units in the Biotic Component will help practitioners understand the biotic level at which variability in the geology might influence biological patterns. The spatial and temporal variability in geomorphology has been shown to be important for mapping regional biodiversity (McArthur et al. 2010), modeling tropical/reef habitats (Hamylton and Spencer 2011), predicting fish distributions (Kendall, Christensen, and Hillis-Starr 2003; Anderson et al. 2009), and designing marine reserve networks (Heyman and Wright 2011).

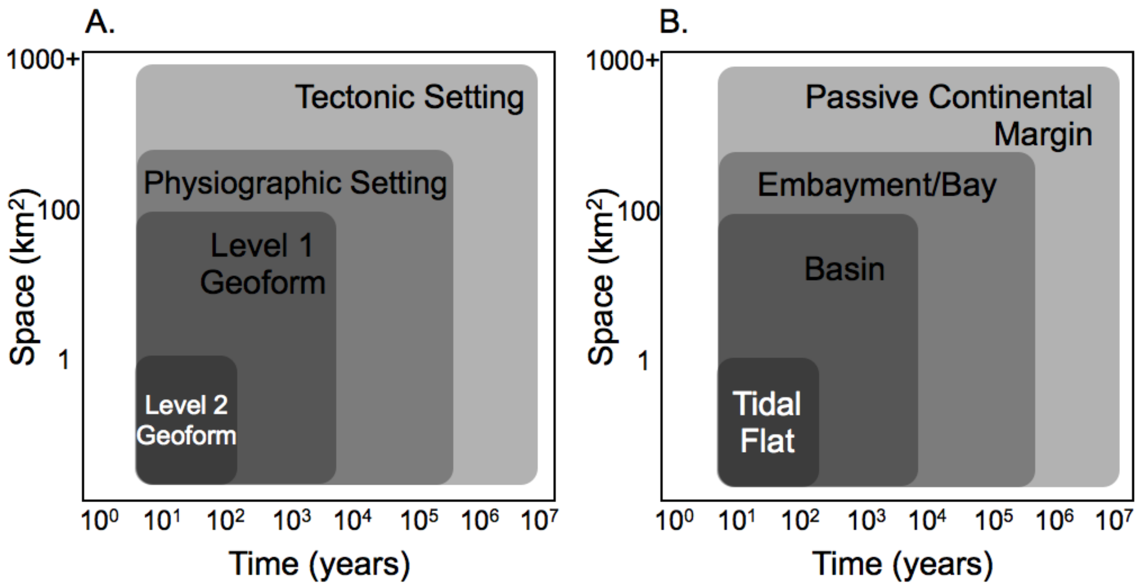

Figure 11.6. Geoform Component Spatial and Temporal Distribution.
(A) The elements of the Geoform Component shown in a spatial-temporal framework with a hierarchical format. (B) A more specific example, which shows the classification of a tidal flat within a bay on the East Coast of the United States. At fine scales (i.e., the lower left side of the plots) processes such as tides, wind and waves are important in influencing the geomorphology of the flat. At broad scales (i.e., the upper right section of the plots), the geologic context and stability of the regional geology is established by the Tectonic and Physiographic Settings.

11.3.4 Substrate Component

The units within the Substrate Component exist on spatial and temporal scales that are narrower than the other CMECS components. The fine-scale, spatial-temporal variability of seafloor substrates is key to understanding fine-scale, biological variability, characterizing the physical disturbance regime, determining the fate of contaminants, and monitoring other anthropogenic impacts (Reid et al. 2005).

Where observations and classifications of substrate begin to exceed the upper limit of the spatial and temporal scales of the Substrate Component (Figure 11.7), the Geoform

Component may be used to continue the geological classification. Observations of substrate that are limited in spatial and/or temporal extent should be classified with the Substrate Component, because such observations often cannot be applied or extrapolated beyond the initial scale of observation—unless an empirical relationship with another, broad-scale environmental factor has been previously established.

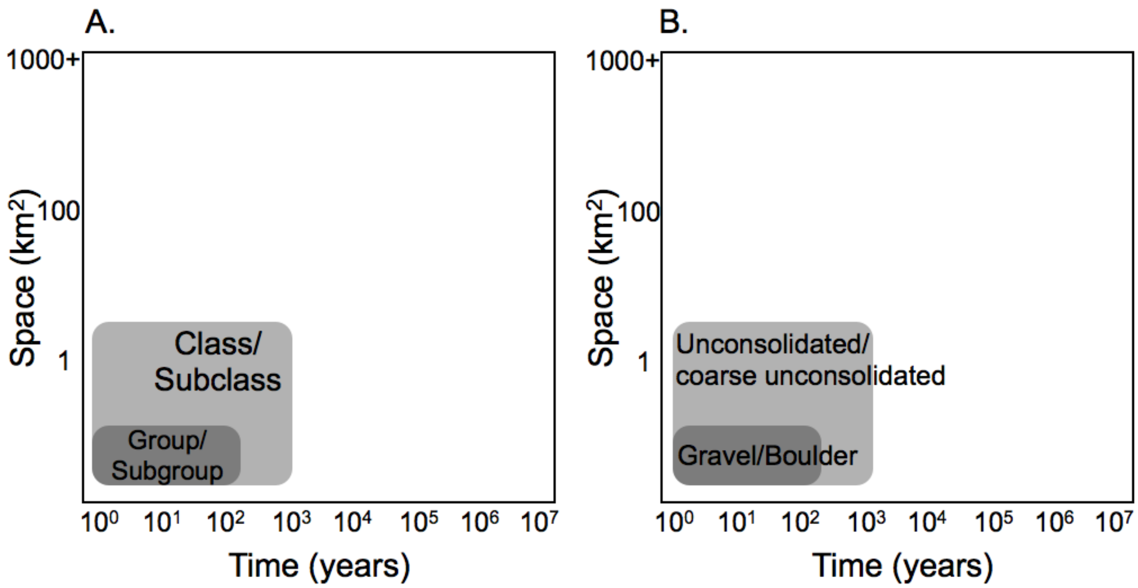

Figure 11.7. Substrate Component Spatial and Temporal Distribution.
(A) The elements of the Substrate Component shown in a spatial-temporal framework with a narrow spatial-temporal range of units. (B) A more specific example, which shows the classification of a gravel/boulder substrate.

11.3.5 Biotic Component

Marine communities vary considerably across spatial and temporal scales. The level of variability will affect how people study biotic elements, design experiments and monitoring programs, and manages resources. Therefore, it is essential to acknowledge this variability when classifying biological data.

The hierarchical elements of the Biotic Component are organized in a spatial-temporal framework that makes these concepts explicit (Figure 11.8). At the smallest spatial and temporal scales, this component identifies species assemblages and the functional groups of marine communities. At these fine scales, biotic interactions (such as competition and predation) tend to have the most influence on the distribution and persistence of organisms (Menge 1976). At larger scales, biological information classified in the Biotic Setting and Biotic Class reflects the physical habitat preferences of the biota. Indeed, it is at these scales that physical factors (such as currents, tides, and nutrient availability) exert the most influence on biological patterns (Menge 1976; Schoch 1996). By noting a biological element's place in the spatial-temporal framework, practitioners can then overlay elements from other components to understand more about species-environment relationships in their study area. At the smallest scales, this information can be used to design experiments regarding causal relationships; at the largest scales, the information can be used to develop species distribution models and predict biological associations (given observed biological-physical linkages).

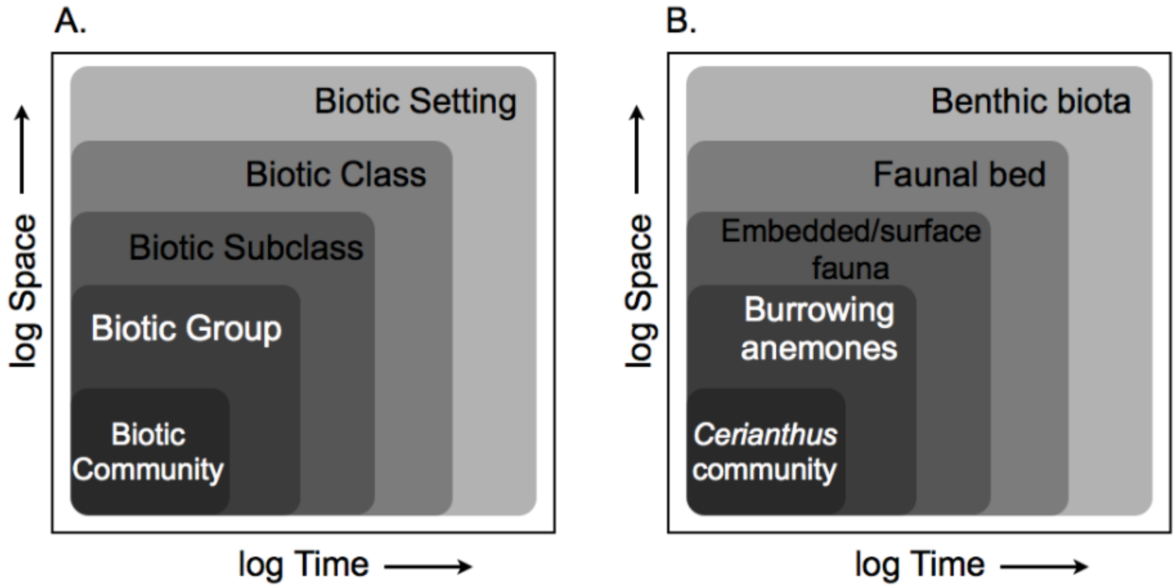

Figure 11.8. Biotic Component Spatial and Temporal Distribution.
(A) The elements of the Biotic Component shown in a spatial-temporal framework with a hierarchical format. (B) A more specific example, which shows the classification of a *Cerianthus* community in the spatial-temporal framework. At small scales (i.e., the lower left side of the plots), biotic interactions exert direct influences over the distribution and persistence of organisms (e.g., competition, predation, grazing, recruitment). At large scales (i.e., the upper right section of the plots), physical factors exert indirect influences over species occurrence (e.g., geomorphology, currents, wave exposure, food availability).

11.3.6 Modifiers

CMECS modifiers provide an additional, and in some cases very specific, acknowledgement of the spatial-temporal relevance of an ecological unit. Spatial and/or temporal modifiers can be used to avoid over-simplifying dynamic and complex environments. For example, sea grass beds may be described with percent cover and seasonal occurrence descriptors that can be used to populate spatial and temporal modifiers. Modifiers used in this way may aid in conducting very fine-scale ecological research comparing sea grass bed growth during different parts of the year, or bed density at different locations within the same contiguous bed.

Spatial and temporal modifiers may be essential for CMECS units that encompass wide spatial and/or temporal ranges in their generic form. For example, a hydrothermal plume (Water Column Component) may persist on timescales ranging from days to decades. A temporal persistence modifier for a hydrothermal plume on a dynamic ocean ridge will help distinguish it from another plume in a different, less dynamic ridge system.

Modifiers used in this way allow CMECS to be simultaneously globally applicable and locally relevant.

The use of modifiers to support the spatial-temporal framework of CMECS can ultimately lead to addressing broad-ecological assessment and management questions. For example, the successional stage modifier, while not explicitly a temporal modifier, includes an implicit acknowledgement of recognizable and repeatable changes to marine communities. Because patterns in succession are usually predicted with reference to a disturbance event, the successional stage modifier can be used as a temporal assessment tool. The modifier can indicate a baseline condition by which further changes are marked, or can be used to infer recent change over time since a previous unrecorded disturbance event.

12. Applying CMECS in Data Development and Mapping

The settings and components of CMECS represent a way of organizing information to describe all the aspects of the coastal and marine environment important to living communities. This is unlike many classification systems that selectively focus on features detectable through a specific observational method. The component structure of CMECS offers enhanced opportunities for environmental analysis, but it also may present challenges to those accustomed to developing data using a single technology or for a particular purpose. The following section describes important concepts related to this mapping and data development: the difference between classification and mapping, how CMECS classification approaches traditional mapping issues, the practical relationships between the components, and how elements from each component can be integrated and visualized to address research questions and management issues. This section is not intended to serve as a mapping or modeling protocol; it is provided to give users some guidance as they employ CMECS in their own project activities.

12.1 Classification versus Mapping

An ecological classification is not the same as a "map classification." CMECS is a classification of taxonomic concepts—where units are defined based on observations that have conceptual thresholds (often the average expression of repeated field observations). The definitions represent the variation in expression of the unit across its entire range of occurrence—not just a local mapping area, and the definitions are not constrained by a given observation technology. Map classifications (as portrayed by map legends) are often representations of the units that are (a) in a given area at a given time and (b) detected or practically portrayed with available observation methods and technology and resources.

A map of an ecological classification is a spatial representation of the geographic distribution, extent, patterns, and variation of the taxonomic concepts (FGDC 2008) in a given area. The taxonomic concepts and map legend units may not always have one-to-one relationships, because mapping efforts may be constrained by the predetermined map scale, available technology, funding, or the study objectives. For example, some classification units may form complex mosaics, each smaller than the minimum mapping unit. In this case, CMECS allows the user to move upward in the hierarchy, using more general units that include multiple constituents as long as they both fall within the same higher level category. However, mappers should describe the relationships between the map units and CMECS units when they do not have a one-to-one relationship.

12.2 Spatial Considerations

Spatial heterogeneity is a fundamental characteristic of all landscapes, and describing this characteristic accurately is a major challenge in landscape ecology. The degree of observed spatial heterogeneity is method dependent because it is determined by the scale of observation (Wu et al. 2000). Because of this issue, there is inherent subjectivity in the definition of landscape units. However, the placement of areal boundaries has real implications for landscape-change studies, habitat inventories, and geostatistical analyses. Ecological classification works best if boundaries are placed in a manner such that units are homogenous; however, this is often impossible or impractical.

When evaluating mixes, the spatial scale of the variability of the mixture (the "patch size") becomes an important concept. Although a particular organism may be used to define classification units or biotopes, it is not uncommon for other distinctive or significant organisms (such as larger, mobile predators) to be present in an observational or reporting unit. This information may be captured using a Co-occurring Element modifier. As with other modifiers, use of this attribute is optional.

Users may also add a descriptor to indicate the quantity of the secondary element within an observational unit. CMECS provides a Percent Cover for those situations. See the percent cover modifier in Section 10 for categories and values.

12.3 Temporal Considerations

CMECS recognizes that the seafloor and water column are dynamic; with some units, such as coral reefs (persisting for thousands of years) and others such as algal beds (lasting only for a single season). A given area of seafloor may be may be characterized differently over time. Users of CMECS are encouraged to identify all CMECS units present during an observation—regardless of their likely longevity. Any CMECS observation should be considered a "snapshot in time," in order to provide the most information. When it is important to convey that a community is unlikely to be present during follow-up observations, the Temporal Persistence modifier can be used. It is up to the user to identify the appropriate time series for observation and data collection so as to capture important, temporally variable or ephemeral units.

12.4 CMECS and Spatial Data

Information on ecological communities is inherently spatial in nature due to its association with a particular place in the landscape. Traditionally, spatial data have been organized and represented in four general formats: points, lines, polygons, and grids. Although CMECS has been focused on biological communities, CMECS units are very amenable to each of the major spatial data types. The following sections provide examples of how CMECS units could be represented. They should not be considered a required way of attributing or displaying those units.

12.4.1 Point Data

Point data are ideal for representing in-situ observations taken at discrete locations where the area being observed is very small (generally on the order of several meters or less). Technologies that typically result in point data are include, grab sampling, coring, plan view videography, single-beam acoustics, and quadrat measurements. The following example (Figure 12.1) shows grab samples collected in Apalachicola Bay, Florida and analyzed for sediment characteristics. Thes data were classified according to the Folk system and translates directly into CMECS Substrate Component units.

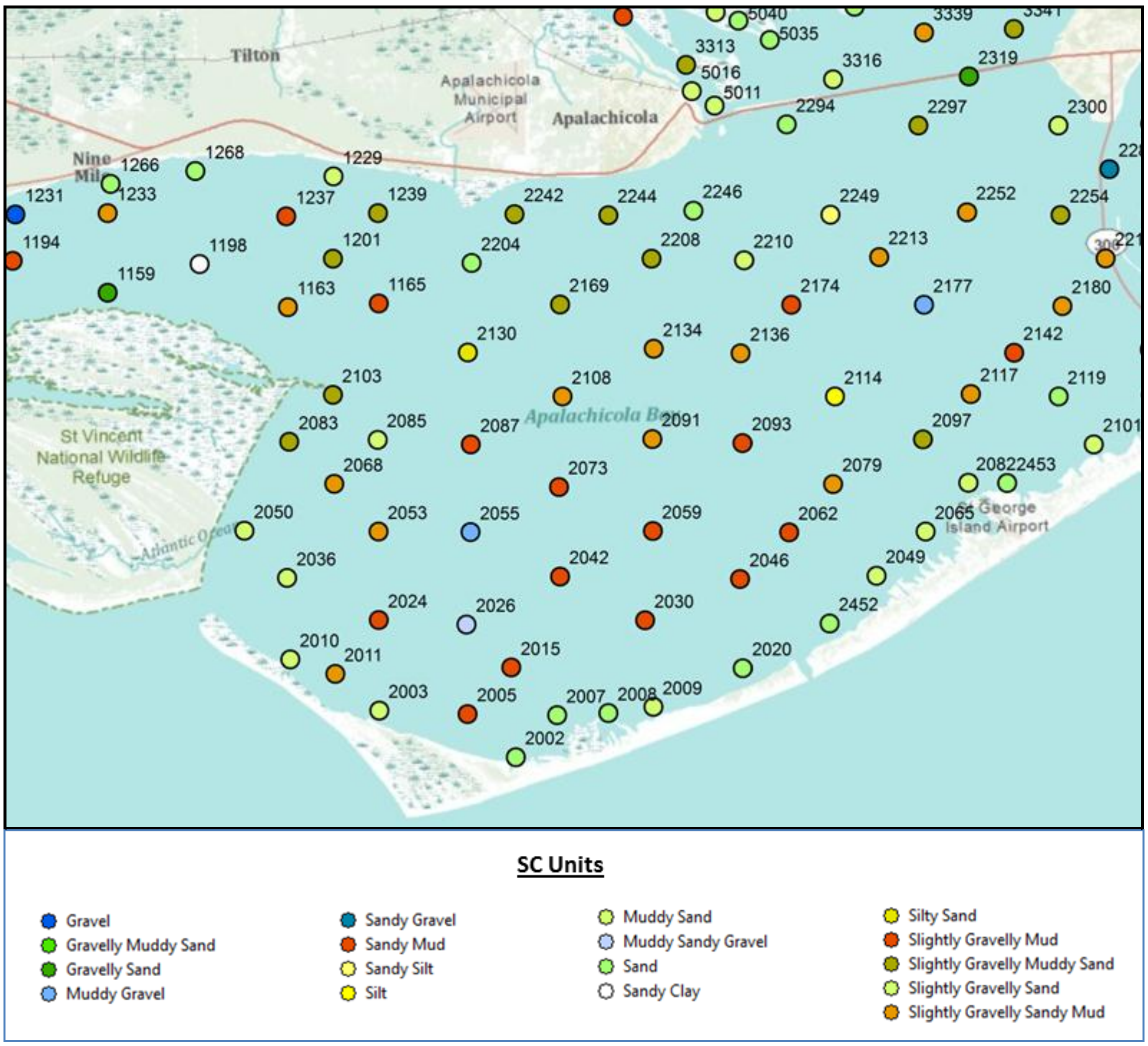

Figure 12.1. Sediment Grab Samples: Apalachicola Bay, Florida. Attributed using CMECS Substrate Component units.

12.4.2 Line Data

Shoreline character, video transects and laser line scanner data lend themselves to a line data format, where information is continuous in one vector. These data support inventory purposes and is well suited to analyzing transition zones. The following example (Figure 12.2) shows a shoreline characterization on the central California coast, organized by GC units, which can include additional SC or BC attributes.

Figure 12.2. Shoreline Characterization.
California coast, showing GC units as segments with Substrate Component attributes.

12.4.3 Polygon Data

A polygon data structure is often used where there is comprehensive information over an area. Normally the primary attribute for any polygon is determined by the source data such as optical imagery, acoustic backscatter imagery, or bathymetric grids. Often there are rule sets for determining the principle attribute and addressing mixed areas. Additional attributes or modifiers can be added through field data and ancillary sources.

The following example (Figure 12.3) from Redfish Bay, Texas, shows how CMECS units can be delineated as discrete polygonal boundaries.

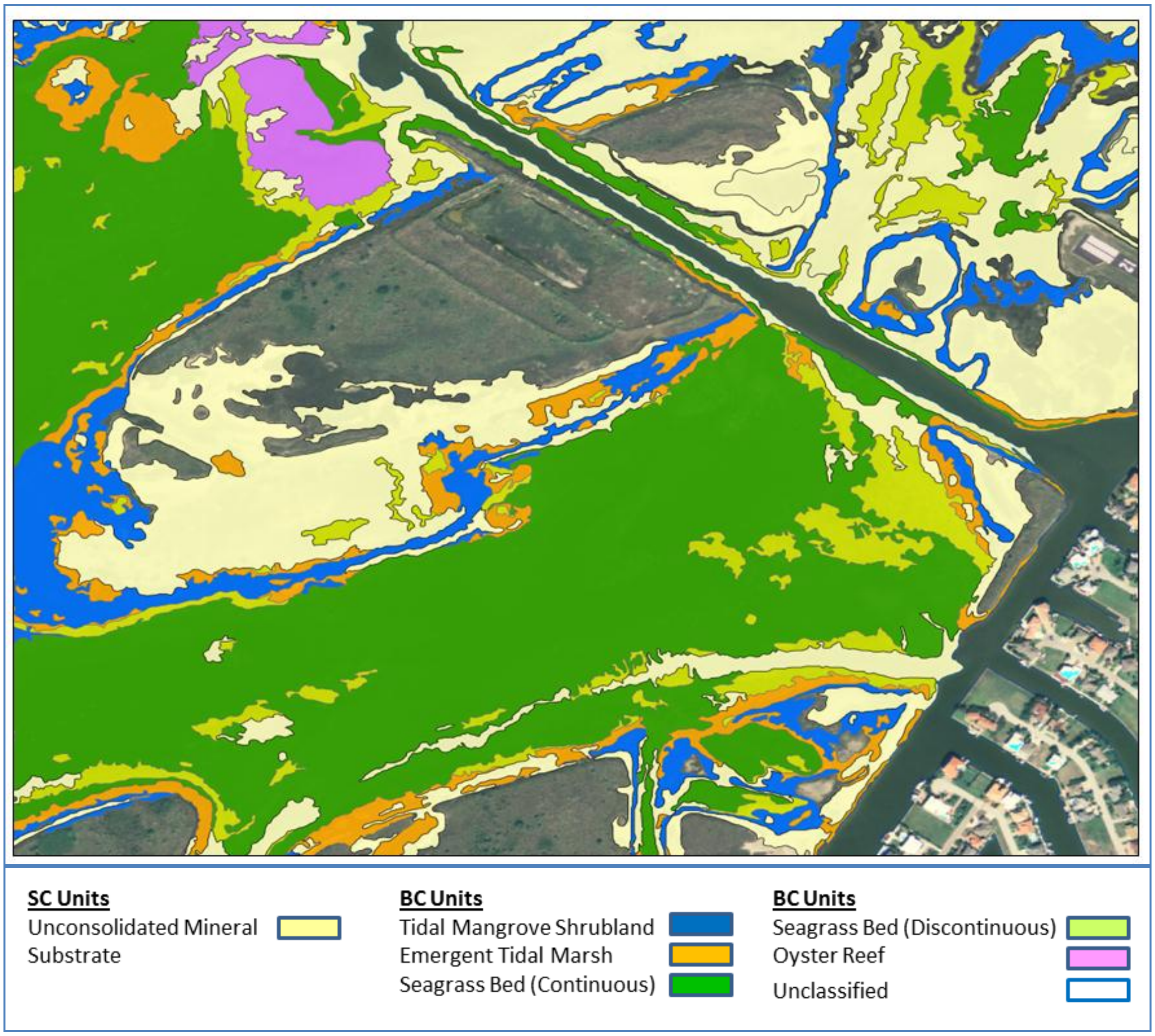

Figure 12.3. Shallow-water Benthic Habitats in Redfish Bay, Texas.
Image showing simple polygons with attributes from CMECS Biotic and Substrate Components.

12.4.4 Grid Data

In a grid data structure information is organized into a matrix of rows and columns with individual pixels as the data element, with the size of the pixel being the spatial resolution of the data. The same comprehensive source data mentioned in Section 12.4.3 can be analyzed to produce a gridded output. This is useful when the boundary of the unit itself is less of a concern and map elements grade smoothly into each other. The following example (Figure 12.4) shows how satellite derived sea surface temperature imagery can be classified at the pixel level to display CMECS WC units.

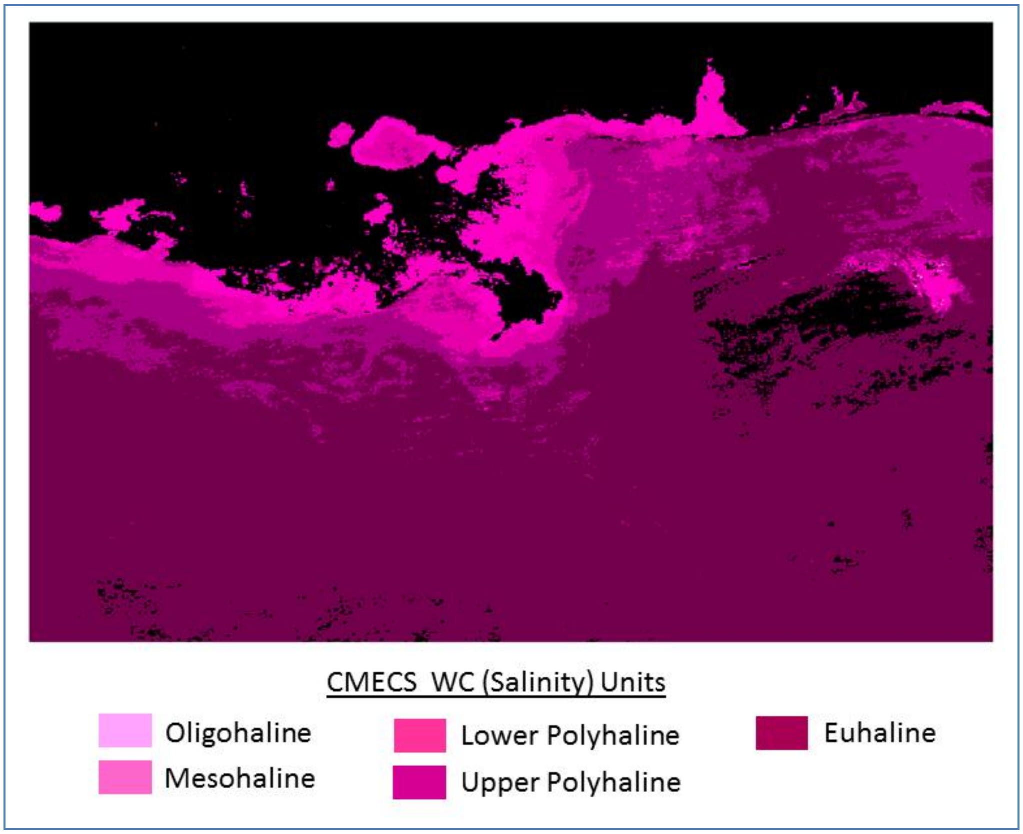

Figure 12.4. MODIS Satellite Image Classified According to CMECS WC Salinity Units, Mississippi Delta, Gulf of Mexico.

12.5 Mapping CMECS

Unlike many classification systems, CMECS was not intended to support a particular mapping program, which would entail specific scale thresholds, technologies, and resolution requirements. Rather, CMECS was envisioned as being usable by technicians employing a wide range of observational methods—from *in-situ* grab sampling, to diver- or camera-collected species lists, to regional mapping through satellite remote sensing. For this reason, there is no explicit scale requirement or minimum mapping unit associated with CMECS. Users are able to define their own mapping requirements based on local geographies and project needs, while still taking advantage of the CMECS framework.

CMECS components start with general- or landscape-scale units in the upper levels and narrow to detailed, fine-scale units at the lowest levels. The appropriate hierarchical level of bio-physical description in any component should be determined based on user needs and project objectives. To create maps, the complexities of aquatic biology usually need to be reduced to a manageable number of meaningful categories—so that polygons can be delineated, interpolated, or modeled. For broad-scale mapping with rapid sampling tools, the more observational identification to subclass and modifiers (or to biotic group), may be well suited to project objectives. While a full attribution of any observation is desirable, users are not required to make determinations at levels below which they can reliably observe (or speculate about the larger context of an observation), if this is not practical. Users can apply units from multiple levels or components as their technology, sampling density, and ancillary data will allow. There is no requirement to report on units for which an observation cannot be made.

In addition to employing units throughout the components as needed, users are encouraged to apply CMECS modifiers in developing their maps. These descriptors can add information to previously delineated polygons—or they can be used to subdivide the polygons. In some cases, users may want to include modifier units as actual mapping categories along with other component units in a map, or they can be used as standalone maps for a single modifier (such as rugosity or slope). Modifiers may be used when information allows, but their use is not required.

The list of CMECS modifiers has been developed based on a wide range of potential information needs and data types. However, users are free to apply additional modifiers based on their own project needs. An example of this might be in further characterizing intertidal oyster reefs. In addition to the CMECS modifier Percent Cover, South Carolina resource managers commonly use their own modifier, Strata, which is an assessment of the amount and posture of live shell on a reef (South Carolina Department of Natural Resources 2008). Users who apply their own modifiers should ensure that they do not overlap (or conflict) with existing CMECS units. It is also important that users define those modifiers and describe their use to allow others to take advantage of the additional information.

12.6 Integrating the Components

12.6.1 Building Derived CMECS Units

CMECS units are the basic building blocks that can be used to define and describe ecological units at many scales. Units from any component, subcomponent, and level of the hierarchy can be combined to define new units based on user needs. For example, a user interested in developing global scale biological units for conservation assessment might find that the biotic group is too broad for their needs, but the biotic community too fine to apply practically at a global scale. These users might consider defining new units by subdividing the BC biotic groups by BS provinces (e.g., Warm Temperate Northwest Atlantic Seagrass Beds and Tropical Northwestern Atlantic Seagrass Beds Seagrass Bed). If derived based on known patterns of biodiversity, these new units would allow the user to describe more detailed units without having to know the specifics of global distribution of seagrass biological communities. It is the responsibility of the user to ensure that the units they create represent the ecological meaning they intend to describe.

12.6.2 Integrating Units in Mapping

The individual components of CMECS commonly overlap in space and time, and they can be considered as layers in a traditional Geographic Information System (GIS). Mappers have the option of developing a comprehensive map for each component for their study area, or they may map selected units from various components to assemble a single “flat” map. The elements in this type of map may be based strictly on the capabilities of the observational technology—for example, those units detectable through aerial photography or those related to the specific habitat requirements of a species of interest. A map based on aerial photography will only contain information on the large-scale “cover” of intertidal and shallow subtidal areas. Conversely, a map designed to show rockfish habitat might focus on specific substrate types, geoforms, depth zones, and water conditions; obtaining data for that map would require multiple technologies.

The decision to integrate components into one map—or to create separate component maps—should be based on the information needs of the project, type of source data, project logistical constraints, and spatial exclusivity between those units being integrated in the map. For example, in cases where boundaries between component units (such as between SC substrates and BC biotic groups) are very different, then it may be advisable to first generate separate data layers for each component, and then later integrate them in a GIS environment for analysis (in order to avoid an overly complex single dataset).

Figure 12.5 illustrates how elements from various CMECS components could be assembled into a single, flat spatial dataset. In this case, the source data technology is an aerial optical instrument with 0.5-meter pixel size and a minimum mapping unit of 10x10 meters. The map includes the CMECS units that (a) can be detected using this technology and (b) are of concern for this mapping project. This approach may be preferred where the units are generally spatially exclusive (that is, boundaries between units from one component generally agree with those of another) and where a single technology is being employed.

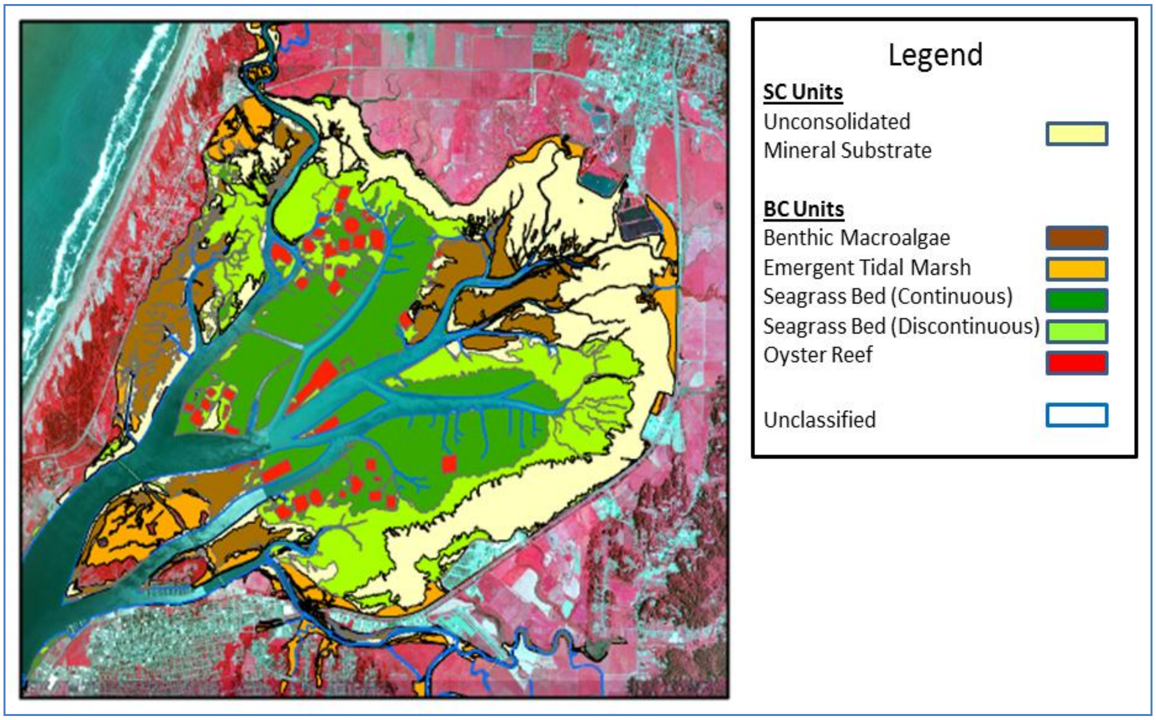

Figure 12.5. Benthic Habitat Map for Arcata Bay, California.
This flat map includes units from two CMECS components and employs a percent cover modifier.

The following three figures illustrate the maps that would result from creating separate feature layers for each component. Despite being topologically separate data, they can be integrated as feature classes within a geodatabase data structure. This approach may be preferable where (a) wall-to-wall information is desired for each component and (b) there is minimal spatial exclusivity between components (that is, landscape units [polygons] in one component tend to cross borders in the other components).

Independent-component maps will often have multiple, unclassified areas in which information on a component is unavailable. These are in contrast with “null” areas where no observation was attempted or possible. Unclassified areas may be the result of several factors, including insufficient resolution to detect units for that component (for example, epifaunal or infaunal biota in the unconsolidated substrate areas) and an inability to use a given component unit as a reliable proxy for a unit in another component. An example of a successful proxy is the presence of eelgrass as a proxy for unconsolidated substrate based on the strong association between the two. Finally, unclassified areas can be due to fundamental limitations of the technology, in this case aerial optical imagery which cannot penetrate the submerged portions of the scene sufficiently to provide information on the benthos. Mappers taking the multi-layer approach should provide documentation on the cause of unclassified areas in their data so that users do not make erroneous assumptions about what may or may not be present in those areas.

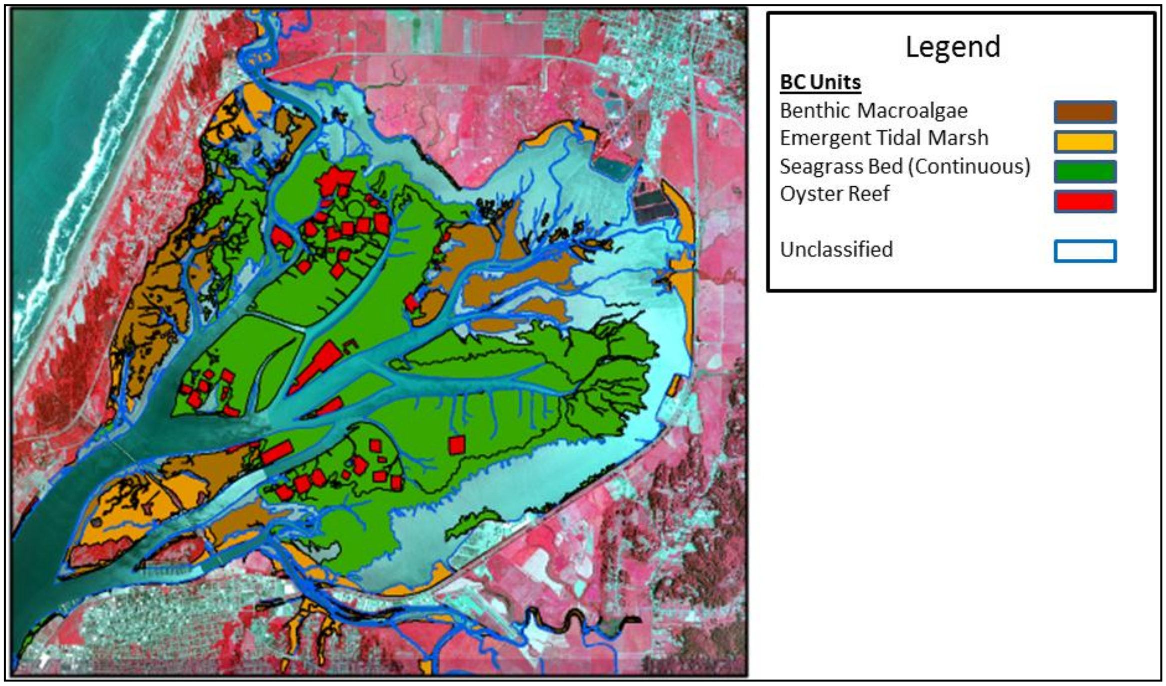

Figure 12.6. Biotic Component Map for Arcata Bay, California.
Unclassified areas in this map include water and intertidal mudflats with insufficient biologic signatures to assign a BC attribute.

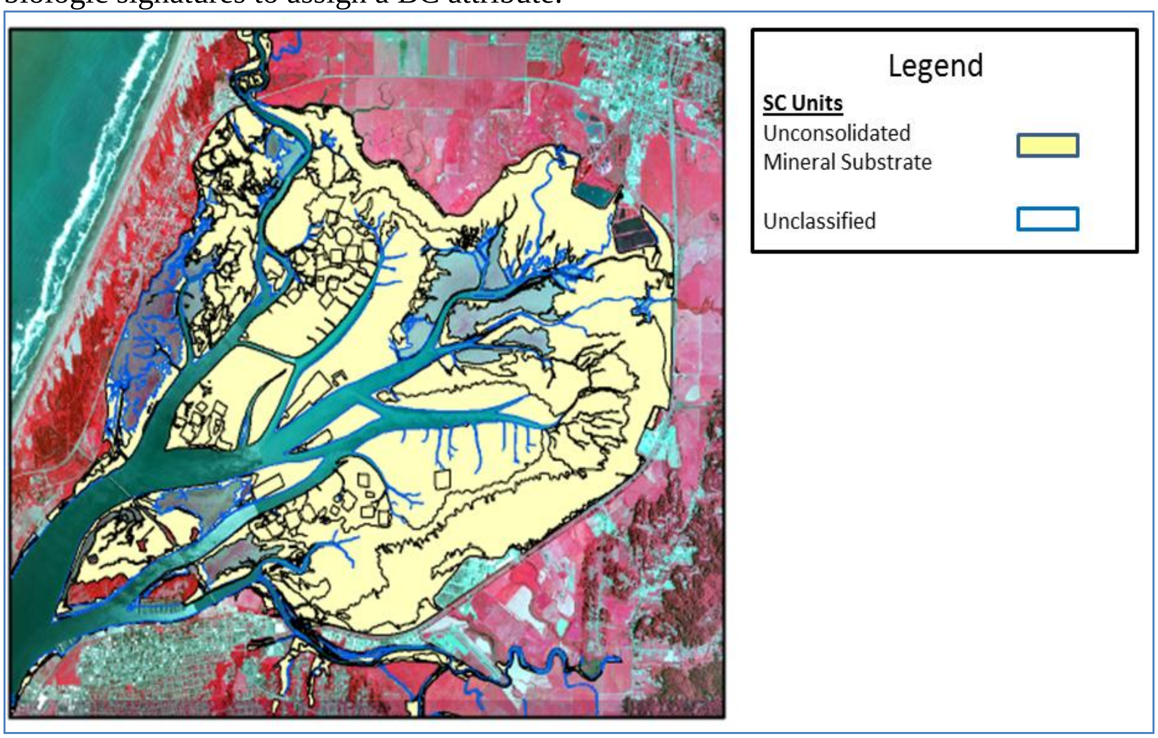

Figure 12.7. Substrate Component Map for Arcata Bay, California.
In this map, unconsolidated substrate is assumed beneath the seagrass beds—but cannot be assumed beneath the algal beds, because these can also occur on hard substrate.

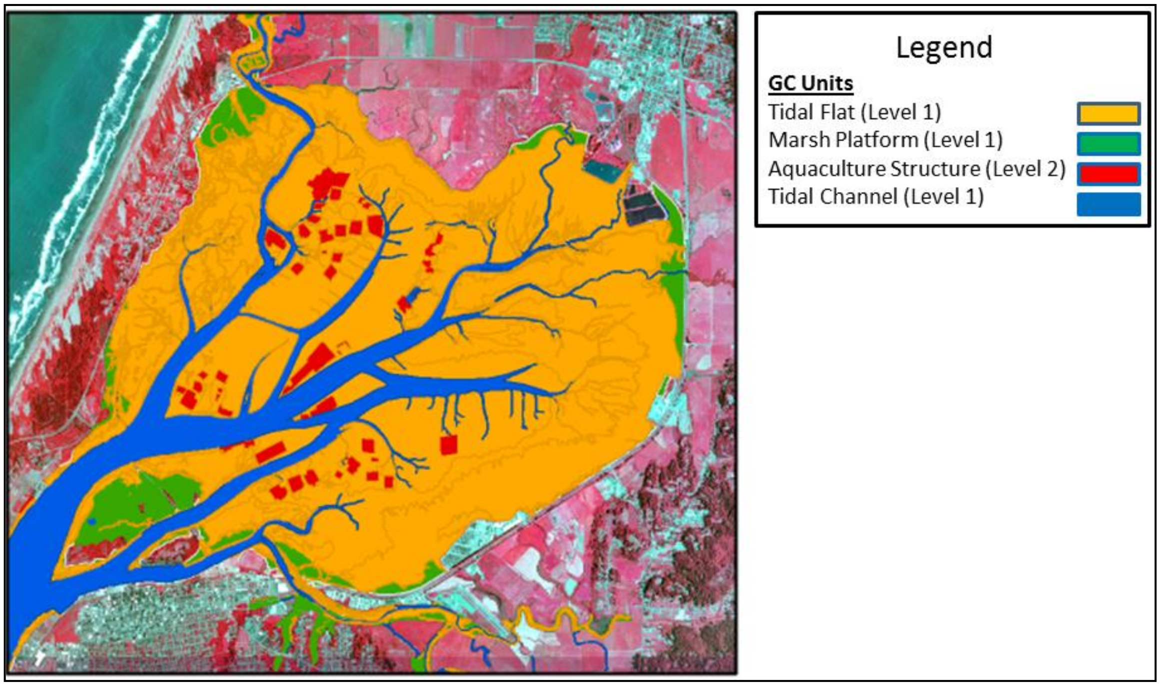

Figure 12.8. Geoform Component Map for Arcata Bay, California.
The geoform map does not have unclassified areas, because all of the features produce signatures detectable at this scale—and the presence of overlying biota does not hamper identification. For this reason, geoform maps can be a useful bounding framework for the BC and SC data.

Regardless of how the component information is initially captured and organized, GIS analysis will be facilitated by creating separate feature layers for each component. The ESRI geodatabase structure allows multiple layers (component maps) to be queried and visualized according to criteria determined by the user. It also allows rule-sets to be established governing the relationships and analysis weights associated with different, spatially overlapping data.

12.7 Sharing CMECS Data

Because CMECS users are free to define so many fundamental aspects of data development based on their own needs, assembling a regional perspective from separate mapping activities could present a challenge. An approach that allows CMECS units first to be used and applied at the local level and then later to be translated upward to compile a regional assessment will maximize the (1) potential user base and (2) number of management issues that could be addressed using any individual dataset. This can be accomplished through the effective use of FGDC-compliant metadata with attention to a number of data elements. In addition to spatial location, the metadata elements important to CMECS integration are:

- Minimum Mapping Unit

- CMECS units used
- Date/Time and duration of the study (to address temporal issues)
- Ancillary data used to support the analysis (e.g., a bathymetric grid used to determine tidal zones)
- Resolution/Sampling density of the source data

Ideally, users will decide to use the CMECS system at the outset of any project. However, many groups have already developed trend information based on an existing classification, and there may be management imperatives that make adopting CMECS impractical. In those cases, a crosswalk from an existing system into CMECS is the best way to preserve local relevance and also support regional assessment. It is important to note that successful crosswalking is dependent on an understanding of the parameters behind the original data development and equivalency between classification systems—not only at the unit definition level, but also in hierarchical context. Appendix H presents guidance on how to accomplish and document crosswalks between data.

13. Dynamic Content within the CMECS Standard

As CMECS use increases, there will be a need to add information to the standard. Continued research is likely to discover new ecosystem features, habitats, biotic communities, or biotopes. Similarly, appreciation of the functioning, roles, and importance of ecosystem components may require the redefinition or expansion of units recognized by CMECS. To accommodate the dynamic nature of the science underlying CMECS, the standard includes a mechanism to augment (or revise) ecological units.

New ecological units shall be introduced through a peer-review process. An authoritative process is necessary to maintain the consistency, credibility, orderly change, and rigor of the classification. Peer review of proposals for new units—as well as for changes proposed to component concepts—is essential to the long-term utility and progressive development of CMECS. The peer process requires that those proposing new units make a convincing case based on a clear explanation of the data, methods, and results. In order for a comprehensive classification of coastal and marine ecological units for the United States to be viable, it must include peer review of proposed units as an integral part.

A CMECS team will follow detailed protocols for provisional and final acceptance of new units. These will be modeled on the protocols for updates to the *National Vegetation Classification Standard*, FGDC-STD-005-2008 (FGDC 2008) and from procedures outlined in the *Marine Habitat Classification for Britain and Ireland*, Version 04.05 (Connor et al. 2004).

13.1 Revising CMECS

A CMECS Peer-Review Panel shall be established to evaluate proposed revisions to the standard. Specific operational procedures shall be developed and announced by the Panel after its establishment. The Panel shall include one or more subgroups to deal with issues relating to CMECS settings and components. Additional subgroups may be constituted to deal with other technical matters, should the need arise.

13.2 Peer-Review Process

a. The objectives of the peer-review process are to:

   i. Ensure compliance with classification nomenclature and documentation standards;
   ii. Maintain reliability of data and documentation for ecosystem units and biotic communities data;
   iii. Eliminate conflicts with existing or proposed CMECS units; and
   iv. Minimize conflict or ambiguity with other classifications.

b. The CMECS Peer-Review Panel (the "Panel") is responsible for ensuring that criteria specified in the standard are followed. The Panel shall adhere to the guiding principles of CMECS, and they shall ensure the good order and scientific credibility of the classification.

c. The overall peer-review process shall be administered by the Panel (authorized and overseen by the lead agency, the National Oceanic and Atmospheric Administration [NOAA]).
   i. NOAA shall be the lead agency for administering the process of reviewing ecosystem units; and
   ii. NOAA may delegate lead responsibility for specific sub-units to other federal agencies that have specific expertise in relevant disciples.

d. The Panel may structure a peer review process that varies among the various elements of the standard and/or among peer review subgroups. Tailored processes may be needed to address issues intrinsic to the science and practice associated with individual elements. Similarly, procedures for peer review subgroups may be customized to reflect the matters under consideration.

e. Investigators wishing to contribute to CMECS by proposing changes to the classification shall submit proposals for new (or revised) units to the Panel. The Panel (or its subgroups) shall issue specific directions, including requirements for proposed candidate additions and alterations to the standard. This may include a requirement to use a prescribed template.

f. The Panel shall maintain a publicly available account of official actions, which shall include official changes to the list of CMECS units and supporting information for those changes. The Panel shall issue separate guidance on the operation and maintenance of the public account of official actions.

g. The peer-review process shall be completed within a reasonable time frame (to be specified by the Panel) and it shall balance potentially conflicting needs for CMECS technical enhancement and CMECS stability.

h. A comprehensive, publically available list of CMECS units will be on a website hosted by the sponsoring agency (NOAA) or its designee. The list shall be maintained and updated regularly; it shall include explicit dates and versioning information.

14. Literature Cited

Abell, R., M. Thieme, C. Revenga, M. Bryer, M. Kottelat, N. Bogutskaya, B. Coad, et al. 2008. "Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation." *BioScience* 58 (5): 403–414.

Allee, R. J., M. Dethier, D. Brown, L. Deegan, G. R. Ford, T. R. Hourigan, J. Maragos, et al. 2000. *Marine and Estuarine Ecosystem and Habitat Classification*. National Oceanic and Atmospheric Administration technical memorandum. NMFS-F/SPO-43. National Oceanic and Atmospheric Administration.

Anderson, T. J., Syms, C., Roberts, D. A., Howard, D. F. 2009. "Multi-Scale Fish–Habitat Associations and the Use of Habitat Surrogates to Predict the Organisation and Abundance of Deep-Water Fish Assemblages." *Journal of Experimental Marine Biology and Ecology* 379(1-2): 34-42.

Baek, S. H., H. H. Shin, H-W Choi, S. Shimode, O. M. Hwang, K. Shin, and Y-O. Kim. 2011. "Ecological Behavior of the Dinoflagellate *Ceratium furca* in Jangmok Harbor of Jinhae Bay, Korea." *Journal of Plankton Research* 33 (12): 1842-1846.

Bailey, R. G., P. E. Avers, T. King, and W. H. McNab, eds. 1994. *Ecoregions and Subregions of the United States*. Colored map; scale 1:7,500,000. Accompanied by a supplementary table of map unit descriptions compiled and edited by W. H. McNab and R. G. Bailey. Prepared for the U.S. Department of Agriculture, Forest Service. Washington, DC: U.S. Geological Survey.

Barnes, R. D. 1980. *Invertebrate Zoology*. Philadelphia: Saunders College / Holt, Rinehart and Wilson.

Bates, R. L., and J. A. Jackson, eds. 1984. *Dictionary of Geological Terms*. 3rd ed. Garden City, NY: Anchor Press.

Blair, T. C. and J. G. McPherson. 1999. "Grain-Size and Textural Classification of Coarse Sedimentary Particles." *Journal of Sedimentary Research* 69: 6-19.

Boothroyd, J. C., N. E. Friedrich, and S. R. McGinn. 1985. "Geology of Microtidal Coastal Lagoons: Rhode Island." *Marine Geology* 63: 35–76.

Bradley, M.P., and M.H. Stolt. 2006. "Landscape-Level Seagrass-Sediment Relationships in a Coastal Lagoon." *Aquatic Botany* 84:121-128.

Cairns, S. D. 1992. "Worldwide Distribution of the Stylasteridae (Cnidaria: Hydrozoa)." *Scientia Marina* 56: 125–130.

Caselle, J. E., B. P. Kinlan, and R. R. Warner. 2010. "Temporal and Spatial Scales of Influence on Nearshore Fish Settlement in the Southern California Bight." *Bulletin of Marine Science* 86 (2): 355–385.

Cermeño, P., C. de Vargas, F. Abrantes, and P. G. Falkowski. 2010. "Phytoplankton Biogeography and Community Stability in the Ocean." *PloS one* 5 (4): e10037.

Cicchetti, G., J. S. Latimer, S. A. Rego, W. G. Nelson, B. J. Bergen, and L. L. Coiro. 2006. "Relationships between Nearbottom Dissolved Oxygen and Sediment Profile Camera Measures." *Journal of Marine Systems* 62: 124–141.

Cleland, D. T., J. A. Freeouf, J. E. Keys, G. J. Nowacki, C. A. Carpenter, and W. H. McNab. 2005. *Ecological Subregions: Sections and Subsections for the Conterminous United States.* Colored map; scale 1:3,500,000. Washington, DC: U.S. Department of Agriculture, Forest Service.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, et al. 2003. *Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems.* Arlington, VA: NatureServe.

Commonwealth of Australia. 2010. "*National Marine Bioregionalisation of Australia*." Department of Sustainability, Environment, Water, Population and Communities.

Connor, D. W. 1995. "The Development of a Biotope Classification in Great Britain and Ireland—Principles and Structure of Classification." In *Classification of Benthic Marine Biotopes of the North–East Atlantic*, 30–46. Edited by K. Hiscock. Proceedings of a BioMar-Life workshop held in Cambridge, November 16–18, 1994. Peterborough, UK: Joint Nature Conservation Committee.

Connor, D. W. 1997. *Marine Biotope Classification for Britain and Ireland*. Peterborough, UK: Joint Nature Conservation Review.

Connor, D. W., J. H. Allen, N. Golding, L. M. Lieberknecht, K. O. Northen, and J.B. Reker. 2003. "Introductory Text." In The National Marine Habitat Classification for Britain and Ireland. Version 03.02. Peterborough, UK: Joint Nature Conservation Committee.

Connor, D. W., J. H. Allen, N.Golding, K. L. Howell, L. M. Lieberknecht, K. O. Northen, and J. B. Reker. 2004. *The Marine Habitat Classification for Britain and Ireland.* Version 04.05. Peterborough, UK: Joint Nature Conservation Committee. http://jncc.defra.gov.uk/MarineHabitatClassification.

Cunliffe, M., and J. C. Murrell. 2009. "The Sea-Surface Microlayer Is a Gelatinous Biofilm." *The ISME Journal* 3:1001–1003.

Curtis, J. T. 1959. *The Vegetation of Wisconsin: An Ordination of Plant Communities*. Madison, WI: University of Wisconsin Press.

Cushing, D. H. 1990. "Plankton Production and Year-Class Strength in Fish Populations: An Update of the Match/Mismatch Hypothesis." *Advances in Marine Biology* 26: 249–294.

Davies, C.E., D. Moss, and M.O. Hill. 2004. *EUNIS Habitat Classification Revised 2004*. Report to European Environment Agency, European Topic Center on Nature Protection and Biodiversity

Davis, R. A., Jr. 1994. "Barrier Island Systems—A Geologic Overview." In *Geology of Holocene Barrier Island Systems*, 1–46. Edited by R. A. Davis. New York: Springer-Verlag.

Dean, W. E., M. Leinen, and D. A. V. Stow. 1985. "Classification of Deep-Sea, Fine-Grained Sediments." *Journal of Sedimentary Petrology* 55: 250-256.

De'ath, G., J. M. Lough, and K. E. Fabricius. 2009. "Declining Coral Calcification on the Great Barrier Reef." *Science* 323: 116–119.

Degraer, S., E. Verfaillie, W. Willems, E. Adriaens, M. Vincx, and V. Van Lancker. 2008. "Habitat Suitability Modelling as a Mapping Tool for Macrobenthic Communities: An Example from the Belgian Part of the North Sea." *Continental Shelf Research* 28: 369-379.

Demas, G.P., Rabenhorst, M.C., and Stevenson, J.C. 1996. "Subaqueous Soils: A Pedological Approach to the Study of Shallow-Water Habitats." *Estuaries* 19:229-237.

Derous, S., T. Agardy, H. Hillewaert, K. Hostens, G. Jamieson, L. Lieberknecht, J. Mees, et al. 2007. "A Concept for Biological Valuation in the Marine Environment." *Oceanologia* 49 (1): 99–128.

Dethier, M. 1990. *A Marine and Estuarine Habitat Classification System for Washington State*. Washington State Department of Natural Resources.

Diaz, R. J., G. R. Cutter, and D. C. Rhoads. 1994. "The Importance of Bioturbation to Continental Slope Sediment Structure and Benthic Processes off Cape Hatteras, NC." *Deep-Sea Research II* 41: 719–734.

EPA (Environmental Protection Agency). 2001. *Draft Level III and IV Ecoregions of EPA Region 4*. Map; scale 1:2,000,000. Corvallis, OR: U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Western Ecology Division.

Fisher, J. J., and E. J. Simpson. 1979. "Washover and Tidal Sedimentation Rates as Environmental Factors in Development of a Transgressive Barrier Shoreline." In *Barrier Islands from the Gulf of St. Lawrence to Gulf of Mexico*, 127–148. Edited by S. P. Leatherman. New York: Academic Press.

FGDC (Federal Geographic Data Committee). 1996a. *FGDC Standards Reference Model*. Reston, VA: Federal Geographic Data Committee.

FGDC (Federal Geographic Data Committee). 1996b. FGDC- STD-004. *Classification of Wetlands and Deepwater Habitats of the United States*. Reston, VA: Federal Geographic Data Committee.

FGDC (Federal Geographic Data Committee). 1997. FGDC-STD-006. *Soil Geographic Data Standard*. Reston, VA: Federal Geographic Data Committee.

FGDC (Federal Geographic Data Committee). 2001. FGDC-STD-001.2-2001. *Metadata Profile for Shoreline Data*. Reston, VA: Federal Geographic Data Committee.

FGDC (Federal Geographic Data Committee). 2008. FGDC-STD-005-2008. *National Vegetation Classification Standard*, Version 2. Reston, VA: U.S. Geological Survey.

FGDC (Federal Geographic Data Committee). 2010. *Draft Coastal and Marine Ecological Classification Standard*, released for public review on August 15, 2010. Reston, VA: Federal Geographic Data Committee.

Flemming, B.W. 2000. "A revised textural classification of gravel-free muddy sediments on the basis of ternary diagrams." *Continental Shelf Research* 20: 1125-1137.

Fletcher, A. 1973. "The Ecology of Marine (Supra Littoral) Lichens on Some Rocky Shores of Anglesey." *Lichenologist* 5: 401–422.

Folk, R.L., 1954. "The Distinction between Grain Size and Mineral Composition in Sedimentary-Rock Nomenclature." *The Journal of Geo*logy 62: 344-359.

Folk, R. L. 1974. Petrology of Sedimentary Rocks. Austin, TX: Hemphill Publishing Company.

Garbary, A., A. Miller, R. Scrosati, K. Kim, and W. Schofield. 2008. "Distribution and Salinity Tolerance of Intertidal Mosses from Nova Scotian Salt Marshes." *The Bryologist* 111 (2): 282–291.

Gilbert, O. L., and V. J. Giavarini. 1997. "The Lichen Vegetation of Acid Watercourses in England." *Lichenologist* 29: 347–367.

Gleason, H. A. 1926. "The Individualistic Concept of the Plant Association." *Bulletin of the Torrey Botanical Club* 53: 7–26.

Greene, H. G., J. J. Bizzarro, V. M. O'Connell, and C. K. Brylinsky. 2007. "Construction of Digital Potential Marine Benthic Habitat Maps Using a Coded Classification Scheme and Its Applications." In *Mapping the Seafloor for Habitat Characterization*, 141–155. Special Paper 47. Edited by B. J. Todd and H. G. Greene. Geological Association of Canada.

Grizzle, R. E., and C. A. Penniman. 1991. "Effects of Organic Enrichment on Estuarine Macrofaunal Benthos: A Comparison of Sediment Profile Imaging and Traditional Methods." *Marine Ecology Progress Series* 74: 249–262.

Guarinello, M., E. J. Shumchenia, and J. W. King. 2010. "Marine Habitat Classification for Ecosystem-Based Management: A Proposed Hierarchical Framework." *Environmental Management* 45 (4): 793–806.

Hamylton, S.M. and T. Spencer. 2011. "Geomorphological Modelling of Tropical Marine Landscapes: Optical Remote Sensing, Patches and Spatial Statistics." *Continental Shelf Research* 31(2), S151-S161.

Hansel, C. M., and C. A. Francis. 2006. "Coupled Photochemical and Enzymatic Mn(II) Oxidation Pathways of a Planktonic *Roseobacter*-like Bacterium." *Applied Environmental Microbiology* 72(5): 3543–3549.

Harden, S. L., and D. F. Williams. 1989. "Stable Carbon Isotopic Evidence for Sources of Particulate Organic Carbon Found in Sea Foam." *Estuaries and Coasts* 12(1):49-56.

Harris, M. S., P. T. Gayes, J. L. Kindinger, J. G. Flocks, D. E. Krantzft, and P. Donovan. 2005. "Quaternary Geomorphology and Modern Coastal Development in Response to an Inherent Geologic Framework: An Example from Charleston, South Carolina." *Journal of Coastal Research* 21: 49–64.

Hawksworth, D. L. 2000. "Freshwater and Marine Lichen-Forming Fungi." In *Aquatic Mycology Across the Millennium*. Edited by K. D. Hyde, W. H. Ho, and S. B. Pointing. *Fungal Diversity* 5: 1–7.

Hewitt, J. E., S. F. Thrush, P. Legendre, G. A. Funnell, J. Ellis, and M. Morrison. 2004. "Mapping of Marine Soft-Sediment Communities: Integrated Sampling for Ecological Interpretation." *Ecological Applications* 14: 1203–1216.

Heyman, W. D., and D. J. Wright. (2011) "Marine Geomorphology in the Design of Marine Reserve Networks." *The Professional Geographer* 63 (4): 429–442.

Higgins, J. V., M. T. Bryer, M. L. Khoury, and T. W. Fitzhugh. 2005. "A Freshwater Classification Approach for Biodiversity Conservation Planning." *Conservation Biology* 19(2): 432-445.

Hiscock, K., and H. Tyler-Walters. 2003. "Assessing the Sensitivity of Seabed Biotopes to Human Activities and Natural Events." In *Marine Life Information Network: Biology and Sensitivity Key Information Sub-Programme*. Plymouth, UK: Marine Biological Association of the United Kingdom. Last access ed June 13, 2005. http://www.marlin.ac.uk/PDF/Biotope_sens_brochure.pdf.

Holthus, P. F., and J. E. Maragos. 1995. "Marine Ecosystem Classification for the Tropical Island Pacific." In *Marine and Coastal Biodiversity in the Tropical Island Pacific Region. V. 1: Species Systematics and Information Management Priorities*, 239–278. Edited by J. E. Maragos, M. N. Peterson, L. G. Eldredge, J. E. Bardach, and H. F. Takeuchi. Honolulu: Program on Environment, East-West Center.

Howes, D. E., J. R. Harper, and E. Owens. 1994. *British Columbia Physical Shore-zone Mapping System*. British Columbia, Canada: Resource Inventory Committee.

IUPAC. Compendium of Chemical Terminology, 2nd ed. (the "Gold Book"). 1997. Compiled by A. D. McNaught and A. Wilkinson. Oxford: Blackwell Scientific Publications. XML on-line corrected version: http://goldbook.iupac.org (2006-) created by M. Nic, J. Jirat, B. Kosata; updates compiled by A. Jenkins.

Jackson, J. A., ed. 1997. *Glossary of Geology*. Alexandria, VA: American Geological Institute.

Jennings, M. D., D. Faber-Langendoen, O. L. Loucks, R. K Peet and D. R. Roberts, 2006. "Standards for Associations and Alliances of the U.S. National Vegetation Classification." *Ecological Monographs* 79(2): 173-199.

Johnson, R. G. 1972. "Conceptual Models of Benthic Marine Communities." In *Models in Paleobiology*, 148–159. Edited by T. J. M. Schopf. San Francisco, CA: Freeman, Cooper and Company.

Kappes, M., S. Shaffer, Y. Tremblay, D. G. Foley, D. M. Palacios, P. W. Robinson, and S. J. Bograd. 2010. "Hawaiian Albatrosses Track Interannual Variability of Marine Habitats in the North Pacific." *Progress in Oceanography* 86 (1-2): 246–260.

Keary, P., K. A. Klepeis, and F. J. Vine. 2009. *Global Tectonics*. 3rd ed. Hoboken, NJ: Wiley-Blackwell.

Keen, T. R. and K. T. Holland. 2010. The Coastal Dynamics of Heterogeneous Sedimentary Environments: Numerical Modeling of Nearshore Hydrodynamics and Sediment Transport. Report. NRL/MR/7320--10-9242 Naval Research Laboratory. Ocean Dynamics and Prediction Branch. Oceanography Division. Stennis Space Center, MS 39529-5004. 140 pp.

Kendall, M. S., J. D. Christensen, and Z. Hillis-Starr. 2003. "Multi-Scale Data Used to Analyze the Spatial Distribution of French Grunts, *Haemulon flavolineatum*, Relative to Hard and Soft Bottom in a Benthic Landscape." *Environmental Biology of Fishes* 66: 19–26.

Kendall, M.S., M.E. Monaco, K.R. Buja, J.D. Christensen, C.R. Kruer, and M. Finkbeiner, R.A. Warner. 2001. *Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands*. Silver Spring, MD: National Oceanic and Atmospheric Administration (NOAA). National Ocean Service (NOS), National Centers for Coastal Ocean Science (NOS) Biogeography Program.

Keys, J. E., Jr., C. A. Carpenter, S. L. Hooks, F. G. Koenig, W. H. McNab, W. E. Russell, and M-L. Smith. 1995. *Ecological Units of the Eastern United States - First Approximation.* Colored map and booklet of map unit tables; presentation scale 1:3,500,000. Atlanta, GA: U.S. Department of Agriculture, Forest Service.

Kleypas, J., J. W. McManus, and L. A. B. Menez. 1999. “Environmental Limits to Coral Reef Development: Where Do We Draw the Line?” *American Zoologist*, 39:146-159.

Kutcher, T. E. 2008. *Habitat and Land Cover Classification Scheme for the National Estuarine Research Reserve System*. Silver Spring, MD: National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, Estuarine Reserves Division.

Lander, M. E., T. R. Loughlin, M. G. Logsdon, G. R. Van Blaricom, B. S. Fadely, and L. W. Fritz. 2009. “Regional Differences in the Spatial and Temporal Heterogeneity of Oceanographic Habitat Used by Steller Sea Lions.” *Ecological Applications* 19 (6): 1645–1659.

Latz, M. I., M. Bovard, V. VanDelinder, E. Segre, J. Rohr, and A. Groisman. 2008. “Bioluminescent Response of Individual Dinoflagellate Cells to Hydrodynamic Stress Measured with Millisecond Resolution in a Microfluidic Device.” *Journal of Experimental Biology* 211: 2865-2875.

Lee, Z. P., A.Weidemann, J. Kindle, R. Arnone, K. L. Carder, and C. Davis. 2007. "Euphotic Zone Depth: Its Derivation and Implication to Ocean-Color Remote Sensing" *Marine Science Faculty Publications.* Paper 11. http://scholarcommons.usf.edu/msc_facpub/11.

Lion, L. W., and J. O. Leckie. 1981. “The Biogeochemistry of the Air-Sea Interface.” *Annual Review of Earth and Planetary Sciences* 9: 449-484.

Littler, M. M., D. S. Littler, and P. R. Taylor. 1983. “Evolutionary Strategies in a Tropical Barrier Reef System: Functional-Form Groups of Marine Macroalgae.” *Journal of Phycology* 19: 229–237.

Lobban, C. S., and P. J. Harrison. 1997. *Seaweed Ecology and Physiology*. Cambridge, UK: Cambridge University Press.

Lorenson, T. D., F. D. Hostettler, R. J. Rosenbauer, K. E. Peters, K. A. Kvenvolden, J. A. Dougherty, C. E. Gutmacher, F. L. Wong, and W. R. Normark. 2009. *Natural Offshore Seepage and Related Tarball Accumulation on the California Coastline; Santa Barbara Channel and the Southern Santa Maria Basin; Source Identification and Inventory*. U.S. Geological Survey Open-File Report 2009-1225 and Minerals Management Service report 2009-030.

Madden, C. J., and D. H. Grossman. 2004. *A Framework for a Coastal/Marine Ecological Classification Standard*. Arlington, VA: NatureServe.

Madden, C. J., D. H. Grossman, and K. L. Goodin. 2005. *Coastal and Marine Systems of North America: Framework for an Ecological Classification Standard: Version II*. Arlington, VA: NatureServe.

Madden, C. J., R. Smith, E. Dettmann, and N. Detenbeck. 2008. “A Typology of Estuaries Supporting the Development of a National Nutrient Criteria Framework for Estuarine Systems.” Chap. 3 in *Development of Nutrient Criteria for the Nation’s Estuaries: Technical Document.* Edited by P. Glibert et al. Report of the National Nutrient Criteria Development Workgroup. U.S. Environmental Protection Agency.

Madley, K., A. B. Sargent, and F. J. Sargent. 2002. *Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida*. Report to the U.S. Environmental Protection Agency Gulf of Mexico Program (Grant Assistance Agreement MX-97408100). St. Petersburg, FL: Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission.

McArthur, M. A., B. P. Brooke, R. Przeslawski, D. A. Ryan, V. L. Lucieer, S. Nichol, A. W. McCallum, et al. 2010. “On the Use of Abiotic Surrogates to Describe Marine Benthic Biodiversity.” *Estuarine, Coastal and Shelf Science* 88: 21–32.

McDougall, P. T., M. Janowicz, and R. F. Taylor. 2007. *Habitat Classification in the Gulf of Maine: A Review of Schemes and a Discussion of Related Regional Issues*. Gulf of Maine Council on the Marine Environment.

McIntosh, R. P. 1993. “The Continuum Continued: John T. Curtis’ Influence on Ecology.” In *John T. Curtis: Fifty Years of Wisconsin Plant Ecology*, 95–122. Edited by J. S. Fralish, R. P. McIntosh, and O. L Loucks. Madison, WI: Wisconsin Academy of Sciences, Arts and Letters.

Menge, B. A. 1976. “Organization of the New England Rocky Intertidal Community: Role of Predation, Competition, and Environmental Heterogeneity.” *Ecological Monographs* 46 (4): 355–393.

Ministry of Fisheries and Department of Conservation. 2008. *Marine Protected Areas: Classification, Protection Standard and Implementation Guidelines*. Wellington, NZ: Ministry of Fisheries and Department of Conservation.

Murawski, S., J. Steele, P. Taylor, M. Fogarty, M. Sissenwine, M. Ford, and C. Suchman. 2010. "Why Compare Marine Ecosystems?" *ICES Journal of Marine Science* 67: 1–9.

Neuendorf, K. K. E., J. P. Mehl, Jr., J. Jackson. 2005. *Glossary of Geology*. 5th ed. Alexandria, VA: American Geological Institute.

Nilsson, H. C., and R. Rosenberg. 1997. "Benthic Habitat Quality Assessment of an Oxygen Stressed Fjord by Surface and Sediment Profile Images." *Journal of Marine Systems* 11: 249–264.

Nilsson, H. C., and R. Rosenberg. 2000. "Succession in Marine Benthic Habitats and Fauna in Response to Oxygen Deficiency: Analyzed by Sediment Profile Imaging and by Grab Samples." *Marine Ecology Progress Series* 197: 139–149.

NOAA (National Oceanic and Atmospheric Administration). 1997. *NOAA's Estuarine Eutrophication Survey, Vol. 4: Gulf of Mexico Region*. Silver Spring, MD: NOAA, Office of Ocean Resources and Assessment.

NOAA (National Oceanic and Atmospheric Administration). 2001. *Benthic Habitats of Puerto Rico and the U.S. Virgin Islands. Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands.* Silver Spring, MD: National Centers for Coastal Ocean Science, Biogeography Program.

Odum, E. P. 1969. "The Strategy of Ecosystem Development." *Science* 164: 262–270.

Olenin, S., and J. Ducrotoy. 2006. "The Concept of Biotope in Marine Ecology and Coastal Management." *Marine Pollution Bulletin* 53: 20–29.

OMB (Office of Management and Budget). 2002. *OMB Circular A-16*, Coordination of Geographic Information, and Related Spatial Data Activities. Washington, DC: Office of Management and Budget.

Omernik, J. M. 1995. "Ecoregions: A Framework for Environmental Management." In *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* Edited by W. S. Davis and T. P. Simon. Boca Raton, FL: Lewis Publishers.

Pahl-Wostl, C., and R. E. Ulanowicz. 1993. "Quantification of Species as Functional Units within an Ecological Network." *Ecological Modeling* 66: 65–79.

Parks, N. 2002. "A *Lingua Franca* for Marine Habitat Classification—an Idea Whose Time Has Come." *BioScience* 52(4): 324.

Parry M. L., O. F. Canziani, J. P. Palutikof, P. J. van der Linden, C. E. Hanson, eds. 2007. *Climate Change 2007: Impacts, Adaptation And Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change. Last accessed October 2, 2011. http://www.ipcc.ch/ipccreports/ar4-wg2.htm.

Pearson, T. H., and R. Rosenberg. 1976. "A Comparative Study of the Effects on the Marine Environment of Wastes from Cellulose Industries in Scotland and Sweden." *Ambio* 5: 77–79.

Pearson, T. H., and R. Rosenberg. 1978. "Macrobenthic Succession in Relation to Organic Enrichment and Pollution of the Marine Environment." *Oceanography and Marine Biology: An Annual Review* 16: 229–311.

Peterson, F. F. 1981. *Landforms of the Basin and Range Province Defined for Soil Survey*. Technical Bulletin No. 28. Reno, NV: Nevada Agricultural Experiment Station.

Pond, S. and G. L. Pickard. 1983. *Dynamical Oceanography*. Pergamon Press. 320 pp.

Poppe, L.J., A.H. Eliason, and M.E. Hastings. 2003. "A Visual Basic Program to Classify Sediments Based on Gravel-Sand-Silt-Clay Ratios." *Computers and Geosciences* 29: 805-809.

Post, A. L. 2008. "The Application of Physical Surrogates to Predict the Distribution of Marine Benthic Organisms." *Ocean and Coastal Management* 51 (2): 161–179.

Reid, B. J. M., J. A. Reid, C. J. Jenkins, M. E. Hastings, S. J. Williams, L. J. Poppe, G. A. Norton, et al. 2005. *usSEABED: Atlantic Coast Offshore Surficial Sediment.* U.S. Geological Survey.

Reilly, F., Jr., R. Spagnolo, and E. Ambrogio. 1999. "Marine and Estuarine Shallow Water Science and Management: The Interrelationship among Habitats and Their Management." *Estuaries* 22 (3B): 731–734.

Resource Information Standards Committee. 2002. *British Columbia Marine Ecological Classification: Marine Ecosections and Ecounits*, Version 2. British Columbia, Canada: Resources Information Standards Committee.

Rhoads, D. C., and J. D. Germano. 1982. "Characterization of Organism-Sediment Relationships Using Sediment Profile Imaging: An Efficient Method of Remote Ecological Monitoring of the Seafloor (REMOTS® System)." *Marine Ecology Progress Series* 8: 115–128.

Rhoads, D. C., and J. D. Germano. 1986. "Interpreting Long-Term Changes in Benthic Community Structure: A New Protocol." *Hydrobiologia* 142: 291–308.

Rhoads, D. C., and D. K. Young. 1970. "The Influence of Deposit Feeding Organisms on Sediment Stability and Community Trophic Structure." *Journal of Marine Research* 28: 150–178.

Ritter, C., P. A. Montagna, and S. Applebaum. 2005. "Short-Term Succession Dynamics of Macrobenthos in a Salinity Stressed Estuary." *Journal of Experimental Marine Biology and Ecology* 323: 57–69.

Ritter, D. F., R. C. Kochel, and J. R. Miller. 1995. *Process Geomorphology*. 3rd ed. Dubuque, IA: Wm. C. Brown, Publishers.

Roberts, J. M., A. J. Wheeler, and A. Freiwald. 2006. "Reefs of the Deep: The Biology and Geology of Cold-Water Coral Ecosystems." *Science* 213: 543–547.

Roberts, J.M., A. Wheeler, A. Freiwald, and S. Cairns, S. 2009. *Cold-Water Corals: the Biology and Geology of Deep-Sea Coral Habitats.* Cambridge: Cambridge University Press.

Rosenberg, R. 1976. "Benthic Faunal Dynamics during Succession Following Pollution Abatement in a Swedish Estuary." *Oikos* 27: 414–427.

Rosenberg, R. 1977. "Benthic Macrofaunal Dynamics, Production, and Dispersion in an Oxygen-Deficient Estuary of West Sweden." *Journal of Experimental Marine Biology and Ecology* 26: 107-133.

Rosenberg, R. 2001. "Marine Benthic Faunal Successional Stages and Related Sedimentary Activity." *Scientia Marina* 65: 107–119.

Rosenberg, R., H.C. Nilsson, and R.J. Diaz. 2001. "Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient." *Estuarine, Coastal, and Shelf Science* 53: 343-350.

Schlee, J.S. 1973. *Atlantic Continental Shelf and Slope of the United State--Sediment Texture of the North-Eastern Part.* U.S. Geological Survey Professional Paper 529-L.

Schoch, G. C. 1996. "The Classification of Nearshore Habitats: A Spatial Distribution Model." Master's thesis, Oregon State University.

Schoch, G. C. 1999. *Identifying Replicate Habitats in the Nearshore: Partitioning the Heterogeneity of Complex Shorelines*. Report. Corvallis, OR: Oregon State University.

Schoeneberger, P. J., and D. A. Wysocki. 2005. *Geomorphic Description System.* Version 3.3. Lincoln, NE: U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center.

Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, and W. D. Broderson, eds. 2002. *Field Book for Describing and Sampling Soils.* Version 2.0. Lincoln, NE: U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center.

Shepard, F. P. 1954. "Nomenclature Based on Sand-Silt-Clay Ratios." *Journal of Sedimentary Petrology* 24: 151–158.

Short, A.D. 2006. "Australian Beach Systems—Nature and Distribution." *Journal of Coastal Research* 22(1): 11-27.

Shumchenia, E. J., and J. W. King. 2010. "Comparison of Methods for Integrating Biological and Physical Data for Marine Habitat Mapping and Classification." *Continental Shelf Research* 30: 1717–1729.

Skov, H., T. Gunnlaugsson, W. P. Budgell, J. Horne, L. Nøttestad, E. Olsen, H. Søiland, G. Víkingsson, and G. Waring. 2008. "Small-Scale Spatial Variability of Sperm and Sei Whales in Relation to Oceanographic and Topographic Features Along the Mid-Atlantic Ridge." *Deep Sea Research II* 55: 254-268.

Soil Survey Staff. 2010. *Keys to Soil Taxonomy, 11th edition.* USDA-NRCS, U.S. Government Printing Office, Washington, D.C.

South Carolina Department of Natural Resources, Marine Resources Division. 2008. *Final Report for South Carolina's 2004–2005 Intertidal Oyster Survey and Related Reef Restoration/Enhancement Program: An Integrated Oyster Resource/Habitat Management and Restoration Program Using Novel Approaches*. Final report completed for National Oceanic and Atmospheric Administration Award No. NA04NMF4630309. South Carolina Department of Natural Resources.

Spalding. M. D., H. E. Fox, G. R. Allen, N. Davidson, Z. A. Ferdana, M. Finlayson, B. S. Halpern, et al. 2007. "Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas." *BioScience* 57 (7): 573–583.

Stakes et al. 1999. "Cold-Seeps and Authigenic Carbonate Formation in Monterey Bay, California." *Marine Geology* 159 (1-4): 93–109.

Steneck R. S. 1988. "Herbivory on Coral Reefs: A Synthesis." *Proceedings of the 6th International Coral Reef Symposium: Vol. 1: Plenary Addressess and Status review*. Volume 1: Plenary Addresses and Status Review. Townsville, Australia.

Steneck, R. S., and M. N. Dethier. 1994. "A Functional Group Approach to the Structure of Algal-Dominated Communities." *Oikos* 69 (3): 476–598.

Stephenson, T. A., and A. Stephenson. 1972. *Life between Tide Marks on Rocky Shores*. San Francisco, CA: W.H. Freeman.

Stolt, M., M. Bradley, J. Turenne, M. Payne, E. Scherer, G. Cicchetti, E. Shumchenia, M. Guarinello, J. King, J. Boothroyd, B. Oakley, C. Thornber, and P. August. 2011. "Mapping Shallow Coastal Ecosystems: A Case Study of a Rhode Island Lagoon." *Journal of Coastal Research* 27:1-15.

Teal, L.R., R. Parker, G. Fones, and M. Solan. 2009. "Simultaneous Determination of *In Situ* Vertical Transitions of Color, Pore-Water Metals, and Visualization of Infaunal Activity in Marine Sediments." *Limnology and Oceanography* 54: 1801-1810.

Thrush, S. F., and P. K. Dayton. 2010. "What Can Ecology Contribute to Ecosystem-Based Management?" *Annual Review of Marine Science* 2 (1): 419–441.

Ulanowicz, R. E. 1996. "Ecosystem Development: Symmetry Arising?" *Symmetry: Culture and Science*. 7 (3): 321–334.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 1981. "The Practical Salinity Scale 1978 and he International Equation of State of Seawater 1980." Appendix I, *Tenth Report of the Joint Panel on Oceanographic Tables and Standards*. Paris: UNESCO. UNESCO Technical Papers in Marine Science No. 36.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2009. *Global Open Ocean and Deep Seabed (GOODS)—Biogeographic Classification*. UNESCO-Intergovernmental Oceanographic Commission. IOC Technical Series No. 84.

U.S. Army Corps of Engineers. 2003. "Surf Zone Hydrodynamics." Chapter 4 in *Coastal Engineering Manual*. Vicksburg, Mississippi: Coastal and Hydraulics Laboratory, Waterways Experiment Station. http://chl.erdc.usace.army.mil/Media/1/8/1/CEM_Part-II_Chap-4.pdf.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2008. "Glossary of Landform and Geologic Terms." *National Soil Survey Handbook (NSSH)*, 629–685. Title 430-VI. U.S. Department of Agriculture. http://soils.usda.gov/technical/handbook/.

Valentine, P.C., B.J. Todd and V.E. Kostylev. 2005. "Classification of Marine Sublittoral Habitats, with Application to the Northeastern North America Region." *American*

Wells, D.V., R.D. Conkwright, J.M. Hill, and M.J. Park. 1994. *The Surficial Sediments of Assawoman Bay and Isle of Wight Bay, Maryland: Physical and Chemical Characteristics.* Baltimore, MD: Coastal and Estuarine Geology File Report Number 94-2, Maryland Geological Survey.

Wentworth, C. K. 1922. "A Scale of Grade and Class Terms for Clastic Sediments." *The Journal of Geology* 30: 377–392.

Wetzel, R. G. 2001. *Limnology*. *Lake and River Ecosystems*. San Diego, CA: Academic Press.

Whittaker R. H. 1962. "Classification of Natural Communities." *Botanical Review* 28: 1–80.

Whittaker, R. H. 1975. *Communities and Ecosystems*. New York: MacMillan.

Wilhelmsson, D., T. Malm, R. Thompson, J. Tchou, G. Sarantakos, N. McCormick, S. Luitjens, et al., eds. 2010. *Greening Blue Energy: Identifying and Managing the Biodiversity Risks and Opportunities of Offshore Renewable Energy*, 102. Gland, Switzerland: International Union for Conservation of Nature.

Wilkinson, T. A. C., E. Wiken, J. B. Creel, T. F. Hourigan, T. Agardy, H. Herrmann, L. Janishevski, C. Madden, L. Morgan, and M. Padilla**.** 2009. *Marine Ecoregions of North America*. Montreal, Canada: Commission for Environmental Cooperation.

Wu, J. 1999. "Hierarchy and Scaling: Extrapolating Information along a Scaling Ladder." *Canadian Journal of Remote Sensing* 25: 367–380.

Wu, J. et al. 2000. "Multiscale Analysis of Landscape Heterogeneity: Scale Variance and Pattern Metrics." *Geographic Information Sciences* 6 (1): 6–19.

Zacharias, M. A., D. E. Howes, J. R. Harper, and P. Wainwright. 1998. "The British Columbia Marine Ecosystem Classification: Rationale, Development, and Verification." *Coastal Management* 26: 105–124.

Zajac, R. N., R. B. Whitlach, and S. F. Thrush. 1998. "Recolonization and Succession in Soft-Sediment Infaunal Communities: the Spatial Scale of Controlling Factors." *Hydrobiologia* 375/376: 227–240.

Zale, A.V., and S.G. Merrifield. 1989. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida) – Reef-Building Tube Worm.* U.S. Fish Wildlife Service. Biol. Rep. 82(11.115). U.S. Army Corps of Engineers, TR EL-82-4.

Zhao, B. and P-Y. Qian. 2002. "Larval Settlement and Metamorphosis in the Slipper Limpet *Crepidula onyx* (Sowerby) in Response to Conspecific Cues and the Cues from Biofilm." *Journal of Experimental Marine Biology and Ecology* 269: 39–5.

Zitello, A. G., L. J. Bauer, T. A. Battista, P. W. Mueller, M. S. Kendall, and M. E. Monaco. 2009. *Shallow-Water Benthic Habitats of St. John, U.S. Virgin Islands*. National Oceanic and Atmospheric Administration Technical Memorandum NOS NCCOS 96. Silver Spring, MD: National Oceanic and Atmospheric Administration.

Appendix A (Normative): CMECS Biogeographic Setting

Table A1 Biogeographic Setting, United States Subset (Spalding et al. 2007). Realm, Province, and Ecoregion

Realm	Province	Ecoregion
Arctic	Arctic (no provinces identified)	Beaufort Sea Continental Coast and Shelf
		Chukchi Sea
		Eastern Bering Sea
Temperate Northern Atlantic	Cold Temperate Northwest Atlantic	Scotian Shelf
		Gulf of Maine/Bay of Fundy
		Virginian
	Warm Temperate Northwest Atlantic	Carolinian
		Northern Gulf of Mexico
Temperate Northern Pacific	Cold Temperate Northeast Pacific	Aleutian Islands
		Gulf of Alaska
		North American Pacific Fijordland
		Puget Trough/Georgia Basin
		Oregon, Washington, Vancouver Coast and Shelf
		Northern California
		Southern California Bight
Tropical Atlantic	Tropical Northwestern Atlantic	Eastern Caribbean
		Greater Antilles
		Southwestern Caribbean
		Floridian
Central Indo-Pacific	Tropical Northwestern Pacific	Mariana Islands
Eastern Indo-Pacific	Hawaii	Hawaii
	Marshall, Gilbert and Ellis Islands	Marshall Islands
	Central Polynesia	Line Islands
		Phoenix/Tokelau/Northern Cook Islands
		Samoa Islands

Appendix B (Normative): CMECS Aquatic Setting

Table B1 Aquatic Setting: System, Subsystem, and Tidal Zone.

System	Subsystem	Tidal Zone
Lacustrine	Littoral	
	Limnetic	
Estuarine	Coastal	Supratidal Zone
		Intertidal Zone
		Subtidal Zone
	Open Water	Subtidal Zone
	Tidal Riverine Coastal	Subtidal Zone
		Intertidal Zone
	Tidal Riverine Open Water	Subtidal Zone
Marine	Nearshore	Supratidal Zone
		Intertidal Zone
		Subtidal Zone
	Offshore	Subtidal Zone
	Oceanic	Subtidal Zone

Appendix C (Normative): CMECS Water Column Component

Table C1 Water Column Component: Layer, Salinity and Temperature Regimes, Hydroform Class, Hydroform Type, and Biogeochemical Feature.

Water Column Layer	Salinity Regime	Temperature Regime			
Estuarine Coastal Surface Layer	Oligohaline Water	Frozen/Superchilled Water	Current	Boundary Current	Easter
Estuarine Coastal Upper Water Column	Mesohaline Water	Very Cold Water			Weste
Estuarine Coastal Pycnocline	Lower Polyhaline Water	Cold Water		Buoyancy Flow	Downw
Estuarine Coastal Lower Water Column	Upper Polyhaline Water	Cool Water			Upwell
Estuarine Open Water Surface Layer	Euhaline Water	Moderate Water		Current Meander	
Estuarine Open Water Upper Water Column	Hyperhaline Water	Warm Water		Deep Boundary Current	
Estuarine Open Water Pycnocline		Very Warm Water		Deep Circulation	Abyss
Estuarine Open Water Lower Water Column		Hot Water			Abyss
Estuarine Tidal Riverine Coastal Surface Layer		Very Hot Water			Bathyl
Estuarine Tidal Riverine Coastal Upper Water Column				Deep Convection	
Estuarine Tidal Riverine Coastal Pycnocline				Density Flow	
Estuarine Tidal Riverine Coastal Lower Water Column				Ekman Flow	Ekmar
Estuarine Tidal Riverine Open Water Surface Layer					Ekmar
Estuarine Tidal Riverine Open Water Upper Water Column				Inertial Current	
Estuarine Tidal Riverine Open Water Pycnocline				Langmuir Circulation	
Estuarine Tidal Riverine Open Water Lower Water Column				Mean Surface Current	North I
Marine Nearshore Surface Layer					South
Marine Nearshore Upper Water Column				Mesoscale Eddy	Cold C
Marine Nearshore Pycnocline					Warm
Marine Nearshore Lower Water Column				Residual Current	Fjord C
Marine Offshore Surface Layer					Partial
Marine Offshore Upper Water Column					Revers
Marine Offshore Pycnocline					Salt W
Marine Offshore Lower Water Column					Well-m
Marine Oceanic Surface Layer				Sub-mesoscale Eddy	
Marine Oceanic Epipelagic Upper Layer				Thermohaline Eddy	
Marine Oceanic Epipelagic Pycnocline				Tidal Flow	Diurna
Marine Oceanic Epipelagic Lower Layer					Mixed
Marine Oceanic Mesopelagic Layer					Semi-c
Marine Oceanic Bathypelagic Layer				Turbidity Flow	
Marine Oceanic Abyssopelagic Layer				Wave-driven Current	Longsh
Marine Oceanic Hadalpelagic Layer					Rip Cu
					Undert
				Wind-driven Current	

Table C1 Water Column Component (Continued).

Water Column Layer	Salinity Regime	Temperature Regime			
			Front	Coastal Upwelling Front	
				Shelf-break Front	
				Tidal Front	
			Water Mass	Background Mesoscale Field	
				Fumarole Plume	
				Hydrothermal Plume	Detach
				Ice	Drift Ic
					Fast Ic
					Frazil
					Ice Fie
					Ice Flo
					Pack I
					Panca
					Polnya
				Mesoscale Lens	River/E
					Meddy
				Microscale Lens	Small
				Winter Water Mass	
			Wave	Anthropogenic Wave	
				Coastally Trapped Wave	Interna
					Extern
					Shelf V
					Topogr
				Edge Wave	
				Equatorial Wave	
				Non-Equatorial Wave	
				Internal Wave	
				Seiche	
				Storm Surge	
				Surf Zone	
				Surface Wave	
				Surface Wind Wave	
				Surface Swell	
				Tsunami	

Appendix D (Normative): CMECS Geoform Component

Table D1 Geoform Component: Tectonic and Physiographic Settings, Geoform Origin, Geoform and Geoform Types.

Tectonic Setting	Physiographic Setting					
Abyssal Plain	Abyssal/Submarine Fan	Geologic	Apron	x		
Convergent Active Continental Margin	Barrier Reef		Bank	x		
Divergent Active Continental Margin	Bight		Bar	x	x	Bay Mouth Bar
Fracture Zone	Borderland					Longshore Bar
Spreading Center	Continental/Island Rise					Point Bar
Mid-Ocean Ridge	Continental/Island Shelf					Relict Longshore Ba
Passive Continental Margin	Continental/Island Shore Complex		Basin	x		
Transform Continental Margin	Continental/Island Slope		Beach	x	x	Barrier Beach
Tectonic Trench	Embayment/Bay					Mainland Beach
	Fjord					Pocket Beach
	Inland/Enclosed Sea					Tide-Modified Beach
	Lagoonal Estuary					Tide-Dominated Bea
	Major River Delta					Wave-Dominated Be
	Marine Basin Floor		Beach Berm	x	x	
	Ocean Bank/Plateau		Boulder Field	x		
	Riverine Estuary		Cave		x	
	Shelf Basin		Channel	x	x	Pass/Lagoon Chann
	Shelf Break					Sand Channel
	Sound					Slough
	Submarine Canyon					Tidal Channel/Creek
	Trench		Cone	x	x	
			Cove	x	x	Barrier Cove
						Mainland Cove
			Delta	x	x	Glacial (Kame) Delta
						Ebb Tidal Delta
						Flood Tidal Delta
						Flood Tidal Delta Slo
						Levee Delta
			Delta Plain	x		
			Depression		x	Scour Depression
			Diapir	x	x	Salt Dome
			Dike		x	
			Drumlin		x	

Table D1 Geoform Component (Continued).

Geologic	Drumlin Field	x		
	Dune Field	x		
	Dune		x	
	Fan	x	x	Alluvial Fan
				Basin Floor Fan
				Shoreline Fan
				Washover Fan
	Flat	x	x	Back Barrier Flat
				Barrier Flat
				Ebb Tidal Delta Flat
				Flood Tidal Delta Fla
				Tidal Flat
				Washover Fan Flat
				Wind Tidal Flat
	Fluvio-Marine Deposit	x	x	
	Fracture	x	x	
	Hole/Pit		x	Scour Hole
				Solution Hole/Pit
	Hydrothermal Vent Field	x	x	
	Hydrothermal Vent		x	
	Inlet	x	x	Tidal Inlet
				Relict Tidal Inlet
	Island	x	x	Barrier Island
	Karren		x	
	Knob		x	
	Lagoon	x	x	
	Lava Field/Plain	x		
	Ledge	x	x	
	Marine Lake	x		
	Marsh Platform	x	x	
	Megaripples	x		

Table D1 Geoform Component (Continued).

Tectonic Setting	Physiographic Setting	Geoform Origin	Geoform	Level 1	Level 2	Geoform
		Geologic	Moraine	x		Disintegration Morain
						End Moraine
						Ground Moraine
						Kame Moraine
						Lateral Moraine
						Recessional Moraine
						Terminal Moraine
			Mound/Hummock	x	x	Tar Mound
			Mud Volcano		x	
			Natural Levee	x		Lava Levee
			Overhang (Cliff)	x	x	
			Panne		x	
			Pavement Area	x	x	
			Platform	x	x	Wave-Cut Platform
			Pockmark Field	x		
			Pockmark		x	
			Ridge	x	x	Beach Ridge
						Esker
			Ripples		x	
			Rock Outcrop	x	x	Authigenic Carbonate
			Rubble Field	x		
			Runnel/Rill		x	
			Sediment Wave Field	x	x	
			Scarp/Wall	x	x	Fault Scarp
						Erosion Scarp
						Beach Scarp
			Scar	x	x	Iceberg Scour Scar/F
						Slump Scar
			Seamount	x		Guyot
						Knoll Seamount
						Pinnacle Seamount
			Sediment Sheet		x	

Table D1 Geoform Component (Continued).

Tectonic Setting	Physiographic Setting					
		Geologic	Shelf Valley	x		
			Shoal	x	x	Moraine Shoal
			Shore Complex	x		
			Shore	x	x	Foreshore
						Backshore
			Slope	x	x	Washover Fan Slope
			Spit	x		
			Stack		x	
			Submarine Slide Deposit	x		
			Swale/Slack		x	
			Terrace	x		Fluviomarine Terrace
						Wave-Built Terrace
						Marine Terrace
			Tidepool		x	
			Till Surface	x	x	
			Tombolo	x		
		Biogenic	Atoll	x		Submerged Atoll/Atc
			Burrows/Bioturbation		x	Tilefish Burrow
			Coral Reef Island	x	x	
			Mollusk Reef	x	x	Fringing Mollusk Ree
						Linear Mollusk Reef
						Patch Mollusk Reef
						Washed Shell Moun
			Deep/Cold-Water Coral Reef	x	x	Biogenic Deep Coral
						Deep Coral Carbonat
			Shallow/Mesophotic Coral Reef	x	x	Aggregate Coral Ree
						Shallow/Mesophotic
						Coral Head/Bomme
						Coral Pinnacle
						Fragile Mesophotic C
						Fringing Coral Reef
						Halo

Table D1 Geoform Component (Continued).

Tectonic Setting	Physiographic Setting					
		Biogenic				Linear Coral Reef
						Patch Coral Reef
						Pinnacle Coral Reef
						Spur and Groove Cor
			Tree Fall		x	
			Whale Fall		x	
			Worm Reef		x	Patch Worm Reef
						Linear Worm Reef
		Anthropogenic	Aquaculture Structure	x	x	
			Artificial Bar	x		Harbor Bar
			Artificial Dike	x		Artificial Levee
			Artificial Reef		x	
			Artificial Scar		x	Prop Scar
						Trawling Scar
			Buoy		x	
			Breakwater/Jetty		x	Groin
			Breachway		x	
			Bulkhead		x	
			Cable Area	x		
			Cable		x	
			Canal	x	x	
			Dam	x	x	
			Dock/Pier		x	
			Dredged/Excavated Channel	x	x	
			Dredge Deposit	x	x	Dredge Deposit Shoa
						Dredge Deposit Ban
			Dredge Disturbance		x	
			Drilling (Oil and Gas) Rig		x	
			Fill Area		x	Landfill
			Fish Pond		x	
			Harbor	x		

Table D1 Geoform Component (Continued).

Tectonic Setting	Physiographic Setting					
		Anthropogenic	Lock		x	
			Lost/Discarded Fishing Gear		x	
			Marina/Boat Ramp		x	
			Mooring Field	x		
			Mosquito Ditch		x	
			Outfall/Intake		x	
			Pilings		x	
			Pipeline Area	x		
			Rip Rap Deposit		x	
			Salt Pond Complex	x		
			Salt Pond		x	
			Seawall	x		
			Tidal/Wave Energy Structure		x	
			Trash Aggregation	x	x	
			Wharf		x	
			Wind Energy Structure		x	
			Wreck		x	

Appendix E (Normative): CMECS Substrate Component

Table E1 Substrate Component: Substrate Origin, Substrate Class, Substrate Subclass, Substrate Group, and Substrate Subgroup.

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate SubGroup
Geologic Substrate	Rock Substrate	Bedrock		
		Megaclast		
	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	Gravel	Boulder
				Cobble
				Pebble
				Granule
			Gravel Mixes	Sandy Gravel
				Muddy Sandy Gravel
				Muddy Gravel
			Gravelly	Gravelly Sand
				Gravelly Muddy Sand
				Gravelly Mud
		Fine Unconsolidated Substrate	Slightly Gravelly	Slightly Gravelly Sand
				Slightly Gravelly Muddy Sand
				Slightly Gravelly Sandy Mud
				Slightly Gravelly Mud
			Sand	Very Coarse Sand
				Coarse Sand
				Medium Sand
				Fine Sand
				Very Fine Sand
			Muddy Sand	Silty Sand
				Silty-Clayey Sand
				Clayey Sand
			Sandy Mud	Sandy Silt
				Sandy Silt-Clay
				Sandy Clay

Table E1 Substrate Component (Continued).

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate SubGroup
Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Mud	Silt
				Silt-Clay
				Clay
Biogenic Substrate	Algal Substrate	Algal Sand	*Halimeda* Sand	
		Rhodolith Substrate	Rhodolith Rubble	
			Rhodolith Hash	
			Rhodolith Sand	
	Coral Substrate	Coral Reef Substrate		
		Coral Rubble		
		Coral Hash		
		Coral Sand		
	Organic Substrate	Organic Debris	Peat Debris	
			Woody Debris	Fine Woody Debris
				Coarse Woody Debris
				Very Coarse Woody Debris
		Organic Detritus		
		Organic Mud		
	Ooze Substrate	Carbonate Ooze	Coccolithophore Ooze	
			Foraminiferan Ooze	*Globigerina* Ooze
			Pteropod Ooze	
		Siliceous Ooze	Diatomaceous Ooze	
			Radiolarian Ooze	
	Shell Substrate	Shell Reef Substrate [277]	Clam Reef Substrate	*Coquina* Reef Substrate
			Crepidula Reef Substrate	
			Mussel Reef Substrate	
			Oyster Reef Substrate	

Table E1 Substrate Component (Continued).

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate SubGroup
Biogenic Substrate	Shell Substrate	Shell Rubble	Clam Rubble	*Coquina* Rubble
			Crepidula Rubble	
			Mussel Rubble	
			Oyster Rubble	
		Shell Hash	Clam Hash	*Coquina* Hash
			Crepidula Hash	
			Mussel Hash	
			Oyster Hash	
		Shell Sand	*Coquina* Sand	
	Worm Substrate	Sabellariid Substrate	Sabellariid Reef Substrate	
			Sabellariid Rubble	
			Sabellariid Hash	
		Serpulid Substrate	Serpulid Reef Substrate	
			Serpulid Rubble	
			Serpulid Hash	
Anthropogenic Substrate	Anthropogenic Rock	Anthropogenic Rock Reef Substrate		
		Anthropogenic Rock Rubble		
		Anthropogenic Rock Hash		
		Anthropogenic Rock Sand		
		Anthropogenic Rock Mud		
	Anthropogenic Wood	Anthropogenic Wood Reef Substrate		
		Anthropogenic Wood Rubble		
		Anthropogenic Wood Hash		

Table E1 Substrate Component (Continued).

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate SubGroup
Anthropogenic Substrate	Construction Materials	Construction Reef		
		Construction Rubble		
		Construction Hash		
	Metal	Metal Reef Substrate		
		Metal Rubble		
		Metal Hash		
	Trash	Trash Rubble		
		Trash Bits		

Appendix F (Normative): CMECS Biotic Component

Table F1 Biotic Component: Biotic Setting, Biotic Class, Biotic Subclass, Biotic Group, Biotic Community

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Planktonic Biota	Zooplankton	Crustacean Holoplankton	Amphipod Aggregation	*Hyperia* Aggregation
				Caprellid Aggregation
			Copepod Aggregation	*Acartia* Aggregation
				Calanus Aggregation
			Krill Aggregation	*Euphausia* Aggregation
				Thysanoessa Aggregation
		Crustacean Meroplankton	Decapod Larval Aggregation	Brachyuran Crab Larval Aggregation
				Anomuran Crab Larval Aggregation
				Pandalus Larval Aggregation
			Mixed Crustacean Larvae	
		Coral Meroplankton	Coral Spawning and Larval Aggregation	Acroporid Spawning Aggregation
				Montastraea Spawning Aggregation
			Coral Larval Aggregation	Acroporid Larval Aggregation
				Monstastraea Larval Aggregation
		Echinoderm Meroplankton	Mixed Echinoderm Larval Aggregation	Ophiuroid Larval Aggregation
				Asteroidean Larval Aggregation
				Holothurian Larval Aggregation
		Fish Meroplankton	Fish Spawning and Larval Aggregation	Damselfish Spawing and Larval Aggregation
				Grouper Spawning and Larval Aggregation
				Surgeonfish Spawning and Larval Aggregation
			Fish Larval Aggregation	Clupeid Larval Aggregation
				Engraulid Larval Aggregation
				Sciaenid Larval Aggregation
		Gelatinous Zooplankton	Ctenophore Aggregation	*Beroe* Aggregation
				Mnemiopsis Aggregation
				Pleurobrachia Aggregation
			Jellyfish Aggregation	*Aurelia* Aggregation
				Chrysaora Aggregation

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Planktonic Biota	Zooplankton	Gelatinous Zooplankton	Salp Aggregation	*Thalia* Aggregation
				Pegia Aggregation
			Siphonophore Aggregation	*Bargmannia* Aggregation
				Nanomia Aggregation
				Physalia Aggregation
		Mixed Zooplankton	Mixed Zooplankton Aggregation	Chaetognath, Salp, and Fish Larval Aggregation
				Ctenophore, Worm and Copepod Aggregation
		Molluscan Holoplankton	Pteropod Aggregation	*Carolla* Aggregation
				Clione Aggregation
		Molluscan Meroplankton	Veliger Aggregation	Bivalve Veliger Aggregation
				Gastropod Veliger Aggregation
		Protozoan Holoplankton	Foraminiferan Aggregation	*Globigerina* Aggregation Layer
			Radiolarian Aggregation	*Acantharea* Aggregation
				Polycistina A ggregation
		Worm Holoplankton	Chaetognath Aggregation	*Flaccisagitta* Aggregation
				Sagitta Aggregation
			Polychaete Aggregation	Syllid Aggregation
				Tomopteris Aggregation
		Worm Meroplankton	Larval Worm Spawning Aggregation	*Neanthes* Spawning Aggregation
				Nereid Spawning Aggregation
				Palolo (*Eunice*) Spawning Aggregation
			Larval Worm Aggregation	Nereid Larval Aggregation
				Nemeretean Larval Aggregation
				Polychaete Larval Aggregation
	Floating/Suspended Plants and Macroalgae	Floating/Suspended Macroalgae	Algal Rafts	*Gracilaria* Rafts
				Kelp Rafts
				Rockweed Rafts
				Sargassum Rafts
				Ulva Rafts

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Planktonic Biota	Floating/Suspended Plants and Macroalgae	Floating/Suspended Macroalgae	Algal Particles	*Gracilaria* Particles
				Kelp Particles
				Rockweed Particles
				Sargassum Particles
				Ulva Particles
		Floating/Suspended Vascular Vegetation	Floating/Suspended Freshwater and Brackish Vegetation	*Eichornia* Mats
				Pistia Mats
	Phytoplankton	Chlorophyte Phytoplankton	Chlorophyte Aggregation	*Chlorella* Aggregation
			Chlorophyte Bloom	*Pyramimonas* Bloom
			Chlorophyte Maximum Layer	*Ostreococcus* Maximum Layer
		Chrysophyte Phytoplankton	Chrysophyte Aggregation	*Apindella* Aggregation
			Chrysophyte Bloom	*Aureococcus* Bloom
			Chrysophyte Maximum Layer	*Dinobryon* maximum Layer
		Coccolithophore Phytoplankton	Coccolithophore Aggregation	*Coccolithus pelagicus* Aggregation
			Coccolithophore Bloom	*Emiliania huxleyi* Bloom
			Coccolithophore Maximum Layer	*Crenalithus* Maximum Layer
		Cryptophyte Phytoplankton	Cryptophyte Aggregation	*Chrysophaeum* Aggregation
			Cryptophyte Bloom	*Myrionecta* Bloom
			Cryptophyte Maximum Layer	*Teleaulax* Maximum Layer
		Cyanophyte Phytoplankton	Cyanophyte Aggregation	*Nodularia* Aggregation
			Cyanophyte Bloom	*Synechococcus* Bloom
			Cyanophyte Maximum Layer	*Trichodesmium* Maximum layer
		Diatom Phytoplankton	Diatom Aggregation	*Thalassiosira* Aggregation
			Diatom Bloom	*Skeletonema* Bloom
			Diatom Maximum Layer	*Asterionellopsis* Maximum Layer
		Dinoflagellate Phytoplankton	Dinoflagellate Aggregation	*Noctiluca* Aggregation
			Dinoflagellate Bloom	*Karenia* Bloom
			Dinoflagellate Maximum Layer	*Gymnodinium* Maximum Layer

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Planktonic Biota	Floating/Suspended Microbes	Films and Strands		
		Microbial Foam		
		Microbial Aggregation		
Benthic/Attached Biota	Reef Biota	Deepwater/Coldwater Coral Reef Biota	Deepwater/Coldwater Stony Coral Reef	*Enallopsammia* Reef
				Goniocorella Reef
				Lophelia Reef
				Madrepora Reef
				Oculina Reef
				Solenosmilia Reef
			Deepwater/Coldwater Stylasterid Coral Reef	Mixed Stylaster Reef
				Stylaster Reef
			Colonized Deepwater/Coldwater Reef	Black Coral Colonized Deepwater/Coldwater Reef
				Gold Coral Colonized Deepwater/Coldwater Reef
				Gorgonian Colonized Deepwater/Coldwater Reef
				Mix Colonized Deepwater/Coldwater Reef
				Sponge Colonized Deepwater/Coldwater Reef
		Shallow/Mesophotic Coral Reef Biota	Branching Coral Reef	Branching *Acropora* Reef
				Branching *Madracis* Reef
				Branching *Pocillopora* Reef
				Branching *Porites* Reef
			Columnar Coral Reef	Columnar *Dendrogyra* Reef
				Columnar *Psammocora* Reef
			Encrusting Coral Reef	Encrusting *Millepora* Reef
				Encrusting *Portes* Reef
			Foliose Coral Reef	Foliose *Agaricia* Reef
				Foliose *Milipora* Reef

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Reef Biota	Shallow/Mesophotic Coral Reef Biota	Massive Coral Reef	Massive *Diploria* Reef
				Massive *Montastraea* Reef
				Massive *Porites* Reef
			Plate Coral Reef	Plate *Agaricia* Reef
				Plate *Leptoseris* Reef
				Plate *Montastraea* Reef
			Table Coral Reef	Table *Acropora* Reef
			Turbinate Coral Reef	Turbinate *Madracis* Reef
			Mixed Shallow/Mesophotic Coral Reef	
			Colonized Shallow/Mesophotic Reef	Black Coral Colonized Shallow/Mesophotic Reef
				Gold Coral Shallow/Mesophotic Reef
				Calcalcareous Algae Colonized Shallow/Mesophotic
				Coral Garden Reef
				Coralline/Crustose Algae Colonized Shallow/Mesop Reef
				Gorgonian Colonized Shallow/Mesophotic Reef
				Soft Coral Colonized Shallow/Mesophotic Reef
				Sponge Colonized Shallow/Mesophotic Reef
		Glass Sponge Reef Biota	Glass Sponge Reef	*Hexactinosida* Reef
		Mollusk Reef Biota	Gastropod Reef	*Crepidula* Reef
				Vermetid Reef
				Serpulorbis Reef
			Mussel Reef	*Modiolus* Reef
				Mytilus Reef
		Mollusk Reef Biota	Oyster Reef	*Crassostrea* Reef
				Ostrea Reef
		Worm Reef Biota	Sabellariid Reef	*Phragmatopoma* Reef
				Sabellaria Reef
			Serpulid Reef	*Serpula vermicularis* Reef

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Faunal Bed	Attached Fauna	Mineral Boring Fauna	Boring *Cliona celata*
				Boring *Penitella*
				Boring *Lithophaga*
			Wood Boring Fauna	Boring *Bankia*
				Boring *Limnoria*
				Boring *Teredo*
			Diverse Colonizers	Anemone/Mussel/Bryozoan Colonizers (Large Mac
				Mollusk/Sponge/Tunicate Colonizers (Large Megafa
				Sponge/Gorgonian Colonizers
			Attached Tube-Building Fauna	Attached Phoronids
				Attached Pogonophorans
				Attached *Sabellaria*
				Attached *Serpula*
				Attached *Serpulorbis*
			Vent/Seep Communities	*Calyptogena* Communities
				Riftia Communities
			Attached Anemones	Attached *Aiptasia*
				Attached *Metridium*
			Barnacles	*Balanus* Communities
				Chthamalus Communities
			Attached Basket Stars	Attached *Astrophyton*
				Attached *Gorgonocephalus*
			Attached Brachiopods	Attached *Crania*
				Attached *Laqueous*
				Attached *Terebratalia*
			Brittle Stars on Hard or Mixed Substrates	*Amphipholis* Communities
				Ophioderma Communities
				Ophiothrix Communities

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Attached Fauna	Attached Bryozoans	Attached *Bugula*
				Attached *Celleporaria*
				Attached *Tubulipora*
			Chitons	Attached *Acanthopleura*
				Attached *Katharina*
				Attached *Nutallina*
			Attached Corals	Attached Black Corals
				Eugorgia Communities
				Attached Gold Corals
				Attached Gorgonians
				Isididae Communities
				Paragorgia Communities
				Attached Soft Corals
			Attached Crinoids	Attached *Comanthus*
				Attached *Diplocrinus*
			Mobile Crustaceans on Hard or Mixed Substrates	Caprellid Communities
				Crangon Communities
				Pagurus Communities
			Sessile Gastropods	Attached *Acmaea*
				Attached *Crepidula*
				Attached *Haliotis*
				Attached Vermetids
			Attached Holothurians	Attached *Parastichopus*
				Attached *Psolus*
			Attached Hydroids	Attached *Sertularia*
				Attached *Tubularia*
			Mobile Mollusks on Hard or Mixed Substrates	*Bittium* Communities
				Littorina Communities
				Urosalpinx Communities

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Attached Fauna	Attached Mussels	Attached *Modiolus*
				Attached *Mytilus*
			Attached Oysters	Attached *Crassostrea*
				Attached *Ostrea*
			Attached Sponges	Attached *Cliona*
				Attached *Halichondria*
				Attached *Hyalonema*
				Attached *Microciona*
				Attached *Scypha*
			Attached Starfish	Attached *Asterias*
				Attached *Pisaster*
			Attached Tunicates	Attached *Didemnum*
				Attached *Molgula*
			Attached Sea Urchins	Attached *Strongylocentrotus droebachiensis*
				Attached *Strongylocentrotus purpurata*
		Soft Sediment Fauna	Larger Deep-Burrowing Fauna	*Balanoglossus* Bed
				Boniella Bed
				Glycera Bed
				Nephtys Bed
				Sipunculid Bed
			Small Surface-Burrowing Fauna	Capitellid Bed
				Harpacticoid Bed
				Leptocheirus Bed
				Lumbrinerid Bed
				Nematode Bed
				Oligochaete Bed
				Turbellarian Bed

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Soft Sediment Fauna	Diverse Soft Sediment Epifauna	*Aphrodite* Bed
				Bryozoan/Anemone Bed (Megafauna)
				Holothurian/Ophiuroid Bed
				Sand Dollar/Sea Pansy/Mobile Mollusk Bed (Large Megafauna)
			Larger Tube-Building Fauna	Robust *Ampelisca* Bed
				Asabellides Bed
				Asychis Bed
				Chaetopterus Bed
				Diopatra Bed
				Lagis Bed
				Loimia Bed
				Phoronid Bed
				Phoronopsis Bed
			Small Tube-Building Fauna	Thin *Ampelisca* Bed
				Chone Bed
				Paraprionospio Bed
				Polydora Bed
				Streblospio Bed
			Tunneling Megafauna	*Callichirus* Bed
				Lepidophthalmus Bed
				Lopholatilus Bed
				Neotrypaea Bed
				Nephrops Bed
				Squilla Bed
				Upogebia Bed
			Oligozoic Biota	Anoxic Oligozoic Bed
				Bacterial Bed
				Meiofaunal Bed

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Soft Sediment Fauna	Burrowing Anemones	*Cerianthus* Bed
				Edwardsia Bed
			Soft Sediment Basket Stars	*Asteronyx* Bed
				Gorgonocephalus arcticus Bed
			Brachiopod Bed	*Glottidia* Bed
				Lingula Bed
			Soft Sediment Brittle Stars	*Amphiura* Bed
				Ophiothrix Bed
				Ophiura Bed
			Soft Sediment Bryozoans	*Bugula* Bed
				Celleporaria Bed
				Schizoporella Bed
			Cephalochordates	*Amphioxus* Bed
				Branchiostoma Bed
			Clam Bed	*Arctica* Bed
				Donax Bed
				Macoma Bed
				Mercenaria Bed
				Mulinia Bed
				Mya Bed
				Nucula Bed
				Rangia Bed
				Spisula Bed
				Venus Bed
				Yoldia Bed
			Soft Sediment Crinoids	*Comanthus* Bed
				Diplocrinus Bed
				Rhizocrinus Bed

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Soft Sediment Fauna	Mobile Crustaceans on Soft Sediments	Caprellid Bed
				Emerita Bed
				Haustoriid Bed
				Mysid Bed
				Pagurus Bed
			Echiurid Bed	*Echiurus* Bed
				Listriolobus Bed
				Urechis Bed
			Holothurian Bed	*Caudina* Bed
				Kolga Bed
				Leptosynapta Bed
				Stichopus Bed
			Hydroid Bed	*Sertularia* Bed
				Tubularia Bed
			Mobile Mollusks on Soft Sediments	Nassariid Bed
				Olivella Bed
				Polinices Bed
				Scaphopod Bed
				Turritellid Bed
			Mussel Bed	*Modiolus* Bed
				Mytilus Bed
			Oyster Bed	*Crassostrea* Bed
				Ostrea Bed
			Pennatulid Bed	*Halipteris* Bed
				Pennatula Bed
				Renilla Bed
				Stylatula Bed
			Sand Dollar Bed	*Clypeaster* Bed
				Dendaster elongatus Bed
				Mellita Bed

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Faunal Bed	Soft Sediment Fauna	Scallop Bed	*Argopecten* Bed
				Placopecten Bed
			Sponge Bed	*Monoraphis* Bed
				Tetilla mutabilis Bed
			Starfish Bed	*Asterias* Bed
				Astropecten Bed
			Tunicate Bed	*Ciona* Bed
				Didemnum Bed
			Burrowing Urchins	*Echinocardium* Bed
				Lovenia cordiformis Bed
			Sea Urchin Bed	*Lytechinus anamesus* Bed
				Lytechinus pictus Bed
		Inferred Fauna	Egg Masses	*Busycon* Egg Cases
				Polychaete Mucus Cases
				Polynices Egg Collars
				Squid Egg Masses
			Fecal Mounds	*Arenicola* Castings
				Balanoglossid Castings
				Holothurian Castings
			Pelletized, Fluid Surface Layer	Fluidized Capitellid Layer
				Fluidized Deposit Feeder Layer
				Fluidized Maldanid Layer
				Fluidized *Yoldia* Layer
			Tracks and Trails	Decapod Tracks
				Gastropod Trails
				Holothurian Trails
	Microbial Communities	Structure Forming Microbes	Xenophyophores	*Occultammina* Communities
				Syringammina Communities
			Stromatolites	Stromatolite Mound Communities

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Microbial Communities	Mat/Film Forming Microbes	Microphytobenthos	Diatom Felt
				Microbial Stain
			Bacterial Mat/Film	*Beggiatoa* Communities
			Bacterial Decay	*Beggiatoa* Communities on Decaying Materials
			Vent Microbes	*Thiobacillus* Communities
				Thermoacidophiles Communities
	Moss and Lichen Communities	Freshwater Tidal Lichens	Freshwater Submerged and Regularly Flooded Tidal Lichen Zone	
			Freshwater Irregularly Flooded Tidal Lichen Zone	
		Marine Lichens	Marine Intertidal Lichen Zone	*Cocotrema* Communities
				Lecanora Communities
				Intertidal *Verrucaria* Communities
			Marine Supratidal Lichen Zone	*Anaptychia* Communities
				Caloplaca Communities
				Ramalina Communities
				Xanthoria Communities
				Supratidal *Verrucaria* Communities
		Freshwater Tidal Moss	Submerged Freshwater Tidal Moss	*Fontinalis antipyretica* Nonvascular Vegetation
			Emergent Freshwater Tidal Moss	
	Aquatic Vegetation Bed	Benthic Macroalgae	Calcareous Algal Bed	*Corallina* Communities
				Halimeda Communities
				Jania communities
				Penicillus Communities
			Canopy-Forming Algal Bed	*Alaria* communities
				Laminaria saccharina Communities
				Macrocystis Communities
				Mixed Kelp Communities
				Nereocystis Communities

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Coralline/Crustose Algal Bed	*Hildenbrandia* Communities
				Lithothamnion Communities
				Lithophyllum Communities
				Peyssonnelia Communities
				Porolithon Communities
				Phymatolithon Communities
			Filamentous Algal Bed	*Aghardiella* Communities
				Chaetomorpha Communities
				Chordaria Communities
				Cladophora sericia Communities
			Leathery/Leafy Algal Bed	*Ascophyllum* Communities
				Caulerpa Communities
				Chondrus Communities
				Codium Communities
				Fucus distichus Communities
				Palmaria Communities
			Mesh/Bubble Algal Bed	*Dichyosphaeria* Communities
				Valonia Communities
				Ventricaria Communities
			Sheet Algal Bed	*Agardhiella* Sheet Algae Communities
				Grinella americana Communities
				Monostroma grevillei Communities
				Ulva lactuca Communities
			Turf Algal Bed	Mixed Algal Turf Communities
			Freshwater and Brackish Tidal Aquatic Vegetation	*Ceratophyllum demersum - Vallisneria americana -* spp. Tidal Herbaceous Vegetation
				Ruppia maritima - Stuckenia pectinata Herbaceous Vegetation

Table F1 Biotic Component (Continued).

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Benthic/Attached Biota	Aquatic Vegetation Bed	Aquatic Vascular Vegetation	Seagrass Bed	*Ruppia maritima* Herbaceous Vegetation
				Syringodium filiformis - (Thalassia testudinum) Herl Vegetation
				Halodule wrightii Herbaceous Vegetation
				Halophila decipiens Herbaceous Vegetation [Provis
				Halophila engelmannii Herbaceous Vegetation
				Halophila hawaiiana Herbaceous Vegetation [Provis
				Halophila johnsonii Herbaceous Vegetation [Provisi
				Halophila minor Herbaceous Vegetation [Provisiona
				Halophila ovalis Herbaceous Vegetation [Provisiona
				Phyllospadix scouleri Herbaceous Vegetation [Prov
				Phyllospadix serrultus Herbaceous Vegetation[Prov
				Phyllospadix torreyi Herbaceous Vegetation [Provis
				Thalassia testudinum - Syringodium filiformis Herba Vegetation
				Thalassia testudinum Herbaceous Vegetation
				Vallisneria americana Estuarine Bayou Herbaceous Vegetation
				Zostera marina Herbaceous Vegetation
	Emergent Wetland	Emergent Tidal Marsh	Brackish Marsh	*Amaranthus cannabinus* Tidal Herbaceous Vegetat
				Calamagrostis nutkaensis - Argentina egedii - Junc balticus Herbaceous Vegetation
				Carex hyalinolepis Tidal Herbaceous Vegetation
				Paspalum vaginatum - Spartina patens Oligohaline Herbaceous Vegetation
				Phragmites australis Tidal Herbaceous Vegetation
				Sagittaria subulata - Limosella australis Tidal Herba Vegetation
				Schoenoplectus americanus - (Spartina patens) - Ty spp. Herbaceous Vegetation
				Schoenoplectus pungens Tidal Herbaceous Vegeta

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Emergent Wetland	Emergent Tidal Marsh	Brackish Marsh	*Schoenoplectus robustus - Spartina alterniflora* Her Vegetation
				Spartina alterniflora - Lilaeopsis chinensis Herbace Vegetation
				Spartina alterniflora - Polygonum punctatum - Amar cannabinus Herbaceous Vegetation
				Spartina cynosuroides Herbaceous Vegetation
				Spartina patens - Typha spp. Chenier Plain Oligoha Herbaceous Vegetation
				Spartina patens - Vigna luteola Mississippi River De Plain Herbaceous Vegetation
				Typha angustifolia - Hibiscus moscheutos Herbace Vegetation
				Typha domingensis Tidal Herbaceous Vegetation
			Freshwater Tidal Marsh	*Acorus calamus* Tidal Herbaceous Vegetation
				Ambrosia trifida Herbaceous Vegetation
				Bidens cernua Herbaceous Vegetation [Provisional]
				Carex obnupta - Argentina egedii ssp. *egedii* Herba Vegetation
				Carex obnupta - Juncus patens Herbaceous Veget
				Carex obnupta Herbaceous Vegetation
				Carex stricta - Peltandra virginica - Sagittaria (lancif media, latifolia) Tidal Herbaceous Vegetation
				Cladium mariscus ssp. *jamaicense* Tidal Herbaceo Vegetation
				Deschampsia caespitosa - Horkelia marinensis He Vegetation
				Eleocharis fallax - Eleocharis rostellata - Schoenop americanus - Sagittaria lancifolia Herbaceous Vege
				Eleocharis rostellata - Rhynchospora colorata - Rhynchospora microcarpa Herbaceous Vegetation
				Eleocharis rostellata - Sagittaria lancifolia Oligohali Herbaceous Vegetation

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Emergent Wetland	Emergent Tidal Marsh	Freshwater Tidal Marsh	*Eriocaulon parkeri - Polygonum punctatum* Herbace Vegetation
				Hibiscus moscheutos - Polygonum punctatum - Pel virginica Tidal Herbaceous Vegetation
				Impatiens capensis - Peltandra virginica - Polygonu arifolium - Schoenoplectus fluviatilis - Typha angust Tidal Herbaceous Vegetation
				Isoetes riparia Tidal Herbaceous Vegetation
				Juncus balticus - Carex obnupta Herbaceous Vege [Provisional]
				Juncus effusus var. brunneus Pacific Coast Herbac Vegetation
				Juncus falcatus - Trifolium wormskioldii Herbaceou Vegetation
				Juncus roemerianus - Pontederia cordata Herbaceo Vegetation
				Justicia americana - Peltandra virginica Herbaceou Vegetation [Provisional]
				Nelumbo lutea Tidal Herbaceous Vegetation
				Nuphar advena Tidal Herbaceous Vegetation
				Nuphar sagittifolia Tidal Herbaceous Vegetation
				Peltandra virginica - Pontederia cordata Tidal Herba Vegetation
				Peltandra virginica - Schoenoplectus (pungens, tabernaemontani) Tidal Herbaceous Vegetation
				Phragmites australis - (Sagittaria platyphylla, Vigna Tidal Herbaceous Vegetation
				Sagittaria lancifolia - Glottidium vesicarium - Solida sempervirens - Lythrum lineare Herbaceous Vegeta
				Sagittaria lancifolia Mississippi River Deltaic Plain Herbaceous Vegetation
				Sagittaria latifolia - Sagittaria platyphylla - (Colocas esculenta) Deltaic Herbaceous Vegetation

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Emergent Wetland	Emergent Tidal Marsh	Freshwater Tidal Marsh	*Schoenoplectus californicus* Tidal Herbaceous Veg
				Schoenoplectus pungens - (Osmunda regalis var. *spectabilis*) Herbaceous Vegetation
				Spartina cynosuroides - Panicum virgatum - Phyla lanceolata Herbaceous Vegetation
				Zizania aquatica Gulf Coast Herbaceous Vegetatio
				Zizania aquatica Tidal Herbaceous Vegetation
				Zizaniopsis miliacea - Panicum hemitomon Herbac Vegetation
				Zizaniopsis miliacea Tidal Herbaceous Vegetation
			High Salt Marsh	*Argentina egedii - Juncus balticus* Herbaceous Veg
				Argentina egedii - Symphyotrichum subspicatum Herbaceous Vegetation
				Carex lyngbyei - Argentina egedii Herbaceous Vege
				Deschampsia caespitosa - Argentina egedii Herbac Vegetation
				Deschampsia caespitosa - Sidalcea hendersonii Herbaceous Vegetation
				Eleocharis rostellata - Spartina patens Herbaceous Vegetation
				Festuca rubra - (Argentina egedii) Herbaceous Veg
				Juncus roemerianus Herbaceous Vegetation
				Panicum virgatum - (Cladium mariscus ssp. jamaic Juncus roemerianus) Herbaceous Vegetation
				Panicum virgatum - Spartina patens Herbaceous V
				Schoenoplectus americanus - Spartina patens Herb
				Schoenoplectus pungens - Eleocharis parvula Herb
				Spartina bakeri - Kosteletzkya virginica Herbaceou Vegetation
				Spartina bakeri Herbaceous Vegetation

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Emergent Wetland	Emergent Tidal Marsh	High Salt Marsh	*Spartina patens - Agrostis stolonifera* Herbaceous
				Spartina patens - Distichlis spicata - (Juncus roeme Herbaceous Vegetation
				Spartina patens - Festuca rubra - (Spartina pectinat Herbaceous Vegetation
			Low and Intermediate Salt Marsh	*Acrostichum aureum - (Acrostichum danaeifolium)* Herbaceous Vegetation
				Carex lyngbyei - (Distichlis spicata, Triglochin marit Herbaceous Vegetation
				Carex lyngbyei Herbaceous Vegetation
				Deschampsia caespitosa - (Carex lyngbyei, Distichl spicata) Herbaceous Vegetation
				Distichlis spicata - (Salicornia virginica) Herbaceou Vegetation
				Distichlis spicata - Ambrosia chamissonis Herbace Vegetation
				Salicornia (bigelovii, virginica) Tidal Herbaceous Ve [Provisional]
				Salicornia virginica - Brassica nigra Herbaceous Ve
				Salicornia virginica - Distichlis spicata - Jaumea ca Tidal Herbaceous Vegetation
				Salicornia virginica - Distichlis spicata - Triglochin n (Jaumea carnosa) Herbaceous Vegetation
				Salicornia virginica - Frankenia salina - Suaeda cali Herbaceous Vegetation
				Salicornia virginica / Algae Herbaceous Vegetation
				Salicornia virginica Herbaceous Vegetation
				Sesuvium portulacastrum Tidal Herbaceous Vegeta [Placeholder]
				Spartina alterniflora - Distichlis spicata - Spartina pa Mesohaline Tidal Herbaceous Vegetation
				Spartina alterniflora - Juncus roemerianus - Distichl spicata Louisianian Zone Salt Tidal Herbaceous Ve

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Emergent Wetland	Emergent Tidal Marsh	Low and Intermediate Salt Marsh	*Spartina alterniflora - Distichlis spicata* Tidal Herba Vegetation
				Spartina alterniflora / (Ascophyllum nodosum) Acadian/Virginian Zone Herbaceous Vegetation
				Spartina alterniflora Carolinian Zone Herbaceous Ve
				Spartina patens - Distichlis spicata - (Juncus gerard Herbaceous Vegetation
				Spartina patens - Schoenoplectus (americanus, pur *(Distichlis spicata)* Herbaceous Vegetation
				Spartina foliosa Herbaceous Vegetation
				Triglochin maritima - (Salicornia virginica) Herbaceo Vegetation
		Vegetated Tidal Flats	Vegetated Freshwater Tidal Mudflat	
			Vegetated Salt Flat and Panne	*Batis maritima - Sarcocornia pacifica* Dwarf-shrubla
				Batis maritima Dwarf-shrubland
				Distichlis spicata - (Sporobolus virginicus) Herbace Vegetation
				Monanthochloe littoralis Herbaceous Vegetation
				Salicornia (virginica, bigelovii, maritima) - Spartina *alterniflora* Herbaceous Vegetation
				Salicornia bigelovii - Triglochin maritima Herbaceou Vegetation
				Sarcocornia pacifica - (Batis maritima, Distichlis sp Dwarf-shrubland
				Spartina spartinae - Monanthochloe littoralis - Suaed *linearis* Herbaceous Vegetation
				Spartina spartinae - Sporobolus virginicus Tidal Her Vegetation
				Sporobolus virginicus - Distichlis spicata Herbaceo Vegetation
				Sporobolus virginicus - Paspalum vaginatum Herba Vegetation

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Scrub-Shrub Wetland	Tidal Scrub-Shrub Wetland	Brackish Tidal Scrub-Shrub	*Lonicera involucrata / Argentina egedii* Tidal Shrubl [Provisional]
			Freshwater Tidal Scrub-Shrub	*Alnus (incana* ssp. *rugosa, serrulata*) - *Cornus amc* Shrubland
				Alnus maritima / Acorus calamus Shrubland
				Alnus serrulata - Salix nigra / Pilea (fontana, pumila Shrubland
				Alnus serrulata / (Zizania aquatica, Zizaniopsis mili Shrubland
				Amorpha fruticosa Tidal Shrubland
				Morella cerifera - Rosa palustris / Thelypteris palust pubescens Shrubland
				Morella cerifera - Toxicodendron radicans / Spartina Shrubland
			Saltwater Tidal Scrub-Shrub	*Borrichia arborescens* Shrubland
				Borrichia frutescens / (Spartina patens, Juncus roemerianus) Shrubland
				Borrichia frutescens / Spartina spartinae Shrubland
				Baccharis halimifolia - Iva frutescens - Morella cerif vomitoria) Shrubland
				Baccharis halimifolia - Iva frutescens / Panicum vir Shrubland
				Iva frutescens ssp. *frutescens - Baccharis halimifo Spartina spartinae* Shrubland
				Iva frutescens / Spartina patens Shrubland
				Avicennia germinans / Spartina alterniflora Shrubla
				Morella cerifera - Baccharis halimifolia / Eleocharis Shrubland
				Iva frutescens / Spartina cynosuroides Tidal Shrubl

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Scrub-Shrub Wetland	Tidal Scrub-Shrub Wetland	Tidal Mangrove Shrubland	*Rhizophora mangle* Shrubland
				Rhizophora mangle - Avicennia germinans - Lagunc racemosa / Batis maritima Shrubland
				Rhizophora mangle - Avicennia germinans - Lagunc racemosa Shrubland
				Rhizophora mangle - Avicennia germinans Shrublar
				Avicennia germinans / Batis maritima Shrubland
				Avicennia germinans / Sarcocornia pacifica Shrubla
	Forested Wetland	Tidal Forest/Woodland	Brackish Tidal Forest/Woodland	*Picea sitchensis / Lonicera involucrata - Malus fusc* Woodland [Provisional]
			Freshwater Tidal Forest/Woodland	*Juniperus virginiana var. silicicola / Morella cerifera Kosteletzkya virginica - Bacopa monnieri* Woodland
				Nyssa aquatica Tidal Forest
				Nyssa biflora - Nyssa aquatica - Taxodium distichu Saururus cernuus Forest
				Pinus taeda - Nyssa biflora - Taxodium distichum / cerifera / Osmunda regalis var. *spectabilis* Forest
				Nyssa biflora - (Taxodium distichum, Nyssa aquatic Morella cerifera - Rosa palustris Tidal Forest
				Taxodium distichum / Carex hyalinolepis Woodland
				Taxodium distichum / Typha angustifolia Woodland
				Taxodium distichum / Zizania aquatica - Carex cane ssp. *disjuncta* Woodland
				Taxodium distichum Tidal Woodland [Provisional]
				Taxodium distichum / Pontederia cordata - Peltandr virginica Tidal Woodland
				Taxodium ascendens - Cliftonia monophylla - Pinus var. elliottii - Chamaecyparis thyoides / Hypericum r Cladium mariscus ssp.
				Taxodium distichum - Nyssa aquatica - Persea palu Forest

Table F1 Biotic Component (Continued).

Benthic/Attached Biota	Forested Wetland	Tidal Forest/Woodland	Freshwater Tidal Forest/Woodland	*Taxodium distichum - Nyssa biflora - Magnolia virgi* *Fraxinus profunda* Forest
				Nyssa biflora - Magnolia virginiana / Cyrilla racemifl Forest
				Nyssa biflora - Magnolia virginiana - Sabal palmetto *Juniperus virginiana* var. *silicicola* Forest
				Acer rubrum - Fraxinus pennsylvanica / Polygonum Forest
				Acer rubrum / Sambucus canadensis / Ampelopsis *Sicyos angulatus* Forest
				Fraxinus profunda - Nyssa biflora - (Fraxinus penns */ Ilex verticillata / Polygonum arifolium* Forest
				Fraxinus pennsylvanica - (Ulmus americana) - Pinus *Morella cerifera - Juniperus virginiana var. silicicola* Forest
			Saltwater Tidal Forest/Woodland	Tamarisk Tidal Forest [Provisional]
				Melaleuca Tidal Forest [Provisional]
			Tidal Mangrove Forest	*Avicennia* germinans Forest
				Conocarpus erectus Forest
				Rhizophora mangle Basin Forest
				Rhizophora mangle Fringe Forest
				Rhizophora mangl e Medium Island Forest
				Rhizophora mangle Overwash Island Forest
				Rhizophora mangle Tall Fringing Forest
				Rhizophora mangle - (Avicennia germinans, Lagunc *racemosa)* Riverine Forest
				Rhizophora mangle - Dalbergia ecastaphyllum - Pa *paludicola* Forest

Appendix G (Informative): CMECS Crosswalk with the Classification of Wetlands and Deepwater Habitats in the United States, FGDC-STD-004

Developers of Coastal and Marine Ecological Classification Standard (CMECS) have worked closely with staff of the National Wetland Inventory to establish as much consistency between CMECS and FGDC-STD-004 as possible—while still attaining the goals of CMECS. The desired outcome of this coordination was to enable a logical seam between FGDC-STD-004 and CMECS that would ensure a continuous database from the continental divide to beyond the continental shelf. The earliest attempts to define this seam have not stood up to critical thinking. Currently, the simplest breakpoint seems to be between wetlands and subtidal or permanently flooded-tidal habitats. Therefore, staff supporting FGDC-STD-004 proposed the following to simplify the seam and establish a solution that can stand the test of time:

"The National Wetlands Classification Standard (NWCS) will be used to map all non-tidal deepwater habitats except for the Great Lakes and all wetlands except for permanently flooded-tidal freshwater wetlands. Once CMECS is endorsed by the FGDC, CMECS will be used to map deepwater habitats in the Great Lakes and in the Marine and Estuarine Systems, as well as all permanently flooded-tidal freshwater habitats (deepwater and wetland). The NWCS will use 0.5 parts per thousand (ppt) ocean-derived salinity as the upstream boundary for the Estuarine System and CMECS will use head of tide."

At the highest level, FGDC-STD-004 classifies wetlands and deepwater habitats into systems and subsystems; the subsystems are defined by tidal regime. In CMECS, the subsystems are primarily defined by depth. CMECS was developed this way to enable users to better classify marine ecosystem as depth plays a significant role in the ecological functioning of these systems.

The tables below provide a crosswalk between CMECS units and FGDC-STD-004.

Table G1. Crosswalk between FGDC-STD-004 and CMECS Systems, Subsystems, and Tidal Zone.

FGDC-STD-004 System/Subsystem	**CMECS System/Subsystem/Tidal Zone**
Marine	Marine
	Oceanic (Z_m is > shelf break)
Subtidal	Subtidal
	Offshore (Z_m is > 30 meters up to shelf break)
Subtidal	Subtidal
	Nearshore (Z_m is 0–30 meters)
Subtidal	Subtidal
Intertidal	Intertidal
No equivalent	Supratidal

FGDC-STD-004 System/Subsystem	CMECS System/Subsystem/Tidal Zone
Estuarine	Estuarine
	Estuarine Coastal (Z_m is 0–4 meters)
Subtidal	Subtidal
Intertidal	Intertidal
No equivalent	Supratidal
	Estuarine Open Water (Z_m is > 4 meters)
Subtidal	Subtidal
	Tidal Riverine Coastal (Z_m is 0–4 meters)
Subtidal	Subtidal
Intertidal	Intertidal
No equivalent	Supratidal
	Tidal Riverine Open Water (Z_m is > 4 meters)
Subtidal	Subtidal
Lacustrine	Lacustrine
Limnetic	Limnetic
Littoral	Littoral

Table G2. Crosswalk between FGDC-STD-004 and CMECS Substrate Component Classes and Subclasses. Because CMECS Substrate Component goes into greater detail on substrate origin and composition, the CMECS units for Substrate Origin and Group are also shown.

FGDC-STD-004 Class/Subclass	**CMECS Substrate Component Origin/Class/Subclass/Group**
	Geologic Substrate
Rocky Shore/Rock bottom Class	Rock Substrate Class
Bedrock Subclass	Bedrock Subclass
Rubble Subclass	***No equivalent***
No equivalent	Megaclast Subclass
Unconsolidated Shore/Bottom Classes	Unconsolidated Mineral Substrate Class
Cobble/Gravel Subclass	Coarse Unconsolidated Substrate Subclass
Subclass level	Gravel Group
Subclass level	Gravel Mixes Group
Subclass level	Gravelly Group
Class level	Fine Unconsolidated Substrate Subclass
No equivalent	Slightly Gravelly Group
Sand Subclass	Sand Group
No equivalent	Muddy Sand Group
No equivalent	Sandy Mud Group
Mud Subclass	Mud Group
	Biogenic Substrate
No equivalent	Algal Substrate Class
No equivalent	Algal Sand Subclass
No equivalent	*Halimeda* Sand Group
No equivalent	Rhodolith Substrate Subclass
No equivalent	Rhodolith Rubble Group
No equivalent	Rhodolith Hash Group
No equivalent	Rhodolith Sand Group
Reef Class	Coral Substrate Class
Coral Subclass	Coral Reef Substrate Subclass
Coral Subclass	Coral Rubble Subclass
Coral Subclass	Coral Hash Subclass
Coral Subclass	Coral Sand Subclass
	Organic Substrate Class
Organic Subclass	Organic Debris Subclass
Organic Subclass	Peat Debris Group
Organic Subclass	Woody Debris Group

FGDC-STD-004 Class/Subclass	CMECS Substrate Component Origin/Class/Subclass/Group
Organic Subclass	Organic Detritus Subclass
Organic Subclass	Organic Mud Subclass
No equivalent	Carbonate Ooze Subclass
No equivalent	Coccolithophore Ooze Group
No equivalent	Foraminiferan Ooze Group
No equivalent	Pteropod Ooze Group
No equivalent	Silicious Ooze Subclass
No equivalent	Diatomaceous Ooze Group
No equivalent	Radiolarian Ooze Group
Reef Class	Shell Substrate Class
No equivalent	Shell Reef Substrate Subclass
No equivalent	Clam Reef Substrate Group
No equivalent	*Crepidula* Reef Substrate Group
No equivalent	Mussel Reef Substrate Group
Mollusk Subclass	Oyster Reef Substrate Group
Reef Class	Shell Rubble Subclass
No equivalent	Clam Rubble Group
No equivalent	*Crepidula* Rubble Group
No equivalent	Mussel Rubble Group
Mollusk Subclass	Oyster Rubble Group
No equivalent	Shell Hash Subclass
No equivalent	Clam Hash Group
No equivalent	*Crepidula* Hash Group
No equivalent	Mussel Hash Group
Mollusk Subclass	Oyster Hash Group
No equivalent	Shell Sand Subclass
No equivalent	Coquina Sand Group
Worm Subclass	Worm Substrate Class
No equivalent	Sabellariid Substrate Subclass
No equivalent	Sabellariid Reef Substrate Group
No equivalent	Sabellariid Rubble Group
No equivalent	Sabellariid Hash Group
No equivalent	Serpulid Substrate Subclass
No equivalent	Serpulid Reef Substrate Group
No equivalent	Serpulid Rubble Group
No equivalent	Serpulid Hash Group

FGDC-STD-004 Class/Subclass	CMECS Substrate Component Origin/Class/Subclass/Group
	Anthropogenic Substrate
No equivalent	Anthropogenic Rock Class
No equivalent	Anthropogenic Rock Reef Substrate Subclass
	Anthropogenic Rock Rubble Subclass
No equivalent	Anthropogenic Rock Hash Subclass
No equivalent	Anthropogenic Rock Sand Subclass
No equivalent	Anthropogenic Rock Mud Subclass
No equivalent	Anthropogenic Wood Class
	Anthropogenic Wood Reef Substrate Subclass
	Anthropogenic Wood Rubble Subclass
	Anthropogenic Wood Hash Subclass
No equivalent	Construction Materials Class
No equivalent	Construction Reef Substrate Subclass
	Construction Rubble Subclass
	Construction Hash Subclass
	Metal Class
	Metal Reef Substrate Subclass
	Metal Rubble Subclass
	Metal Hash Subclass
	Trash
	Trash Rubble
	Trash Bits

Table G3. Crosswalk between FGDC-STD-004 and CMECS Biotic Component Classes and Subclasses. Because CMECS Biotic Component establishing biotic classes and subclasses based largely on the location of the biota, the Biotic Setting is also shown. Biotic Groups are not provided in the table because there are an extensive number of groups and no equivalent units occur in FGDC-STD-004.

FGDC-STD-004 Class/Subclass	**CMECS Biotic Component Setting/Class/Subclass**
	Planktonic Biota
No equivalent	Zooplankton Class
No equivalent	Crustacean Holoplankton Subclass
No equivalent	Crustacean Meroplankton Subclass
No equivalent	Coral Meroplankton
No equivalent	Echinoderm Meroplankton
No equivalent	Fish Meroplankton
No equivalent	Gelatinous Zooplankton
No equivalent	Mixed Zooplankton
No equivalent	Molluscan Holoplankton
No equivalent	Molluscan Meroplankton
No equivalent	Protozoan Holoplankton
No equivalent	Worm Holoplankton
No equivalent	Worm Meroplankton
Aquatic Bed Class	Floating/Suspended Plants and Macroalgae Class
No equivalent	Floating/Suspended Macroalgae Subclass
Floating Vascular Subclass	Floating/Suspended Vascular Vegetation Subclass
No equivalent	Phytoplankton Class
No equivalent	Chlorophyte Phytoplankton Subclass
No equivalent	Chrysophyte Phytoplankton Subclass
No equivalent	Coccolithophore Phytoplankton Subclass
No equivalent	Cryptophyte Phytoplankton Subclass
No equivalent	Cyanophyte Phytoplankton Subclass
No equivalent	Diatom Phytoplankton Subclass
No equivalent	Dinoflagellate Phytoplankton Subclass
No equivalent	Floating/Suspended Microbes Class
No equivalent	Microbial Films and Strands Subclass
No equivalent	Microbial Foam Subclass
No equivalent	Microbial Discoloration Subclass

FGDC-STD-004 Class/Subclass	**CMECS Biotic Component Setting/Class/Subclass**
	Benthic/Attached Biota
Reef Class	Reef Biota Class
Coral Subclass	Deepwater/Coldwater Coral Reef Biota Subclass
Coral Subclass	Shallow/Mesophotic Coral Reef Biota Subclass
Mollusk Subclass	Mollusk Reef Biota Subclass
Worm Subclass	Worm Reef Biota Subclass
No equivalent	Faunal Bed Class
No equivalent	Attached Fauna Subclass
No equivalent	Soft Sediment Fauna Subclass
No equivalent	Inferred Fauna Subclass
No equivalent	Microbial Communities Class
No equivalent	Structure-Forming Microbes Subclass
No equivalent	Mat/Film-Forming Microbes Subclass
Moss-Lichen Wetland Class	Mosses and Lichen Communities Class
Moss Subclass	Freshwater Tidal Moss Subclass
Lichen Subclass	Freshwater Tidal Lichens Subclass
Lichen Subclass	Marine Lichens Subclass
Aquatic Bed Class	Aquatic Vegetation Class
Algal Subclass	Benthic Macroalgae Subclass
Aquatic Moss Subclass	***Tidal Moss Subclass under Mosses and Lichens Class***
Rooted Vascular Subclass	Aquatic Vascular Vegetation Subclass
Floating Vascular Subclass	***Floating/Suspended Vascular Vegetation Subclass under Floating/Suspended Plants and Macroalgae Class***
Emergent Wetland Class	Emergent Wetland Class
No equivalent	Emergent Tidal Marsh Subclass
No equivalent	Sparsely Vegetated Tidal Flats Subclass
Persistent Subclass	***Modifier***
Non-Persistent Subclass	***Modifier***
Scrub-Shrub Wetland Class	Scrub-Shrub Wetland Class
No equivalent	Tidal Scrub-Shrub Wetland Subclass
Needle-Leaved Evergreen Subclass	***No equivalent***
Broad-Leaved Evergreen	***No equivalent***
Needle-Leaved Deciduous	***No equivalent***
Broad-Leaved Deciduous	***No equivalent***
Dead	***No equivalent***

FGDC-STD-004 **Class/Subclass**	**CMECS** **Biotic Component** **Setting/Class/Subclass**
Forested Wetland Class	
No equivalent	Tidal Forest/Woodland Subclass
Needle-Leaved Evergreen Subclass	***No equivalent***
Broad-Leaved Evergreen Subclass	***No equivalent***
Needle-Leaved Deciduous Subclass	***No equivalent***
Broad-Leaved Deciduous Subclass	***No equivalent***
Dead Subclass	***No equivalent***

Appendix H (Informative): CMECS Best Practices in Crosswalking

Introduction

One of the critical objectives of the Coastal and Marine Ecological Classification Standard (CMECS) is interoperability with other classifications and datasets. Once CMECS is endorsed as a Federal Geographic Data Committee (FGDC) standard, users receiving federal funds for classification of coastal and marine ecological units will be required to, at a minimum, crosswalk their source classification units to the CMECS standard. This guidance outlines the concepts and issues associated with crosswalking data from individual source classifications to the CMECS classification, and it also provides guidance on best practices for reporting source units into the CMECS framework.

Concepts

Crosswalking can be done to compare the conceptual units from one classification to units in another classification (unit-to-unit crosswalking) or relate observational data (samples, plots, or mapped polygons) that are collected using one classification to another classification (observation-to-unit crosswalking).

Unit-to-Unit Crosswalking

Unit-to-unit crosswalking is needed for identifying the relationship between individual units from a source classification and CMECS units. Unit-to-unit crosswalking requires a comparison of the concepts and circumscriptions of the units in both classifications in order to make the relationships between them explicit. Examples of situations where unit-to-unit crosswalking may be required include identifying the relationships between the units in a specific classification (the FGDC Wetland Classification [FGDC 1996] to CMECS) or e.g., assigning a CMECS unit name to a unit described in the literature that uses a different classification scheme.

Observation-to-Unit Crosswalking

Making the best use of existing data is a critical need for most users. Users have two potential pathways to take advantage of existing observation data for reporting to CMECS. These include re-analysis of the source data and re-interpretation of observation data.

Re-analysis of Source Observation Data

Re-analysis of source data requires *de novo* classification of the data using the CMECS framework; it does not require any crosswalking. Whenever feasible, re-analysis of the source data using the CMECS framework will result in the most accurate reporting of CMECS units, assuming the data needed to assign CMECS units are available in the source datasets.

Re-interpretation of Observation Data or Derived-Data Products

Re-interpretation of observation data or derived-data products (like maps) requires the user to make explicit the relationship between the observations (e.g., samples, plots, and polygons) and CMECS units. Perhaps the most common examples of re-interpretation of data products are (a) crosswalking individual map polygons to CMECS or (b) labeling grab samples with CMECS units. Because observation data have specific measurable parameters associated with them (rather than a range for a conceptual unit description), they can often be more precisely attributed to a CMECS unit—provided the necessary data have been collected.

Crosswalking Methodology

Making the relationships between the units in the source classification and CMECS explicit is essential to effectively crosswalking the units. Comparison of units from one classification to another requires a thorough understanding of all the units, their thresholds, and any implementation conventions.

The following guidance suggests the minimum required metadata for the crosswalking process. This approach is an adaptation of the Taxonomic Data Working Group (Franz, Peet, and Weakley 2008) crosswalking model. The approach applies both to unit-to-unit crosswalking and to observation-to-unit crosswalking.

General Approach

- Wherever possible, review the original source data for the project. If these are available, they will allow more informed crosswalking from the source unit to the CMECS unit.
- Create a unit-to-unit crosswalk as a first step, employing the crosswalking approach described below to make the relationships explicit. Spreadsheets or tables are useful tools to help visualize the relationships. If the units are numerous and the relationships complex, creating a database that tracks the relationships between units may be a worthwhile effort.
- Automate where possible to help make the connections between observations and units. Develop algorithms for observation-to-unit crosswalks to facilitate crosswalking. However, it should be noted that some relationships can only be rectified with human interpretation of the source data.
- Incorporate other ancillary data if that meets your objectives. If source data for a study were not collected with CMECS thresholds in mind, identify other datasets that can be combined with the source data to help make the relationship to CMECS units clearer.

- When crosswalking observations to CMECS units, maintain any specific data that are at a finer scale than CMECS units and consider applying CMECS modifiers so the necessary detail is not lost.
- Only crosswalk to CMECS based on the source data you have. If the data are not available, it may be impossible to crosswalk some data.

Crosswalking Standard

Complete the following fields of information for each unit in the source classification. See Table H1 for an example of the standard applied to a unit-to-unit crosswalk between FGDC-STD-004 (FGDC 1996) classification substrate types and CMECS substrate units.

- **Unit Name in the Source Study** – Names of the units that are noted in the study using the source terminology.

- **Concept Reference for Source Unit** – Name and reference for the source classification.

- **CMECS Name** – The most closely related CMECS name(s) for the unit(s) identified in the study, from any level or any component that is related to the units in the first field. Users can list one-to-many CMECS names that relate to the data, preferably at the most appropriate level of the hierarchy.

- **Relationship of the Source Units to CMECS Unit(s)** – Description of the relationship between the unit(s) in the study and the CMECS unit name(s) listed with the following qualifiers:

  - *Equal (=)*: There is a one-to-one relationship between the source unit and the CMECS unit. The names of the units may or may not be the same. Units with “equal” relationships—but different names—are considered synonyms.

    Example: The terms “gravel” and “pebbles” are used in different classifications to mean the same thing.

  - *Nearly Equal* (≈): The source unit is nearly equivalent to the CMECS unit. The thresholds or concepts vary by a small—but insignificant—way for most practical applications.

    Example: The definition for “Mud” in the FGDC (1996) classification has a very small difference in the threshold for particle size than the “Undifferentiated Silt and Clay (mud)” unit in CMECS. The difference is less than 0.012 millimeters.

  - *Greater Than (>)*: The source unit is more broadly defined than the CMECS unit. The threshold range for the source unit definition is wider than the threshold range of the CMECS unit definition. The concept of the source unit fully contains the concept of the CMECS unit, but the source unit also includes additional entities.

Example: There is a one-to-many relationship between the Florida SCHEME classification (Madley, Sargent, and Sargent 2002) for the “Reef/Hardbottom” class and the CMECS Coral Reef, Mollusk Reef, Worm Reef, and Bedrock units. The Reef/Hardbottom Class is greater than each of the related CMECS units.

- *Less Than (<)*: The source unit is more finely classified than the CMECS unit. The threshold range for the source unit definition is narrower than the threshold range of the CMECS unit definition. The source unit concept is fully included in the CMECS unit, but the latter concept contains additional entities.

  Example: The FGDC (1996) “Bedrock” unit is finer than the CMECS “Bedrock” unit. The FGDC threshold for defining bedrock requires that the area be covered by at least 75% bedrock, whereas the CMECS definition requires the area to be covered by at least 50% bedrock. So although the names are the same, the concept definitions based on their threshold values are different.

- *Overlapping (><)*: The source unit is not clearly broader or finer than the CMECS unit. The two concepts contain at least one common entity, and each concept also contains at least one entity that the other does not contain. Neither concept is fully contained in the other.

- *No Equivalent (<>)*: The source unit does not have a clearly related unit in the CMECS classification.

  Example: The SCHEME (Madley, Sargent, and Sargent 2002) classification recognizes a type called “Platform Reef” that has no related concept in CMECS, and CMECS recognizes a “Microbial Mat” unit that has no related concept in SCHEME. This case most often arises when a source classification has a different objective than that of CMECS—or if the source classification has been developed to describe local, more detailed ecological units.

- *Unknown (?)*: The relationship between the source unit and CMECS units is unknown. Although some correlation is likely, a determination cannot be made from the data provided in the source study.

CMECS Relationship Confidence

For each value entered in the "Relationship to CMECS Unit" column, use the following values to indicate confidence in assigning the relationship between the CMECS unit names and the habitat units in the study.

- *Certain*: Either CMECS was used as the habitat classification for the study, or there is evidence (textual or data) in the study for the relationship between habitat names in the study and CMECS units. If exact CMECS names are not used, well-established synonyms or geographic associations make clear the relationship between CMECS units and the units in the study (e.g., gravel = pebbles).

- *Somewhat Certain*: The relationship between the habitat descriptions in the study and CMECS can be inferred, but is not explicitly stated and synonyms are not clear.

- *Not Certain*: There is a connection between the habitats in the study and CMECS habitats, but the relationship is not clear. Connection is based on the best educated guess by the party coding the study.

Relationship Notes

For each source unit, specify or clarify the relationships to related CMECS units. Identify where clear nesting of units occurs as well as any threshold differences.

Table H1 Example of Crosswalk of FGDC (1996) Substrate Classes and Subclasses to CMECS, applying the CMECS metadata standard.

Cowardin Class/Subclass	Relationship to CMECS	CMECS Class/ Subclass	Confidence	Relationship Notes
Rocky Shore	<	Rock Substrate	Certain	CMECS Rock substrate = Cowardin Rocky Shore + Rock Bottom. Shore is considered in the CMECS Geoform Component.
Bedrock	<	Bedrock	Certain	Thresholds vary.
Rubble	=	Boulder	Some-what certain	Cowardin Rubble = CMECS Boulder.

Cowardin Class/Subclass	Relationship to CMECS	CMECS Class/ Subclass	Confidence	Relationship Notes
				(Boulder is under Unconsolidated Substrate in CMECS.) Cowardin does not specify size of boulders.
Unconsolidated Shore	<	Uncon-solidated Substrate	Certain	CMECS Unconsolidated Substrate = Cowardin Unconsolidated Shore +Unconsolidated Bottom. Shore is considered in the CMECS Geoform Component.
Cobble/Gravel	<	Coarse Uncon-solidated Substrates	Certain	Cowardin Cobble Gravel does not include Boulders.
Sand	≈	Sand	Certain	Very small (0.012 millimeters) lower threshold difference. Cowardin doesn't recognized Muddy Sand as a separate entity.
Mud	≈	Mud	Somewhat Certain	Cowardin doesn't recognize Sandy Mud as a separate entity.
Organic	≈	Organic Substrate	Somewhat Certain	

Cowardin Class/Subclass	Relationship to CMECS	CMECS Class/ Subclass	Confidence	Relationship Notes
Rock Bottom	<	Rock Substrate	Certain	CMECS Rock Substrate = Cowardin Rocky Shore + Rock Bottom.
Unconsolidated Bottom	<	Uncon-solidated Substrate	Certain	CMECS Unconsolidated Substrate = Cowardin Unconsolidated Shore +Unconsolidated Bottom.

Map Crosswalking Challenges and Solutions

The list below outlines some of the specific complexities encountered when crosswalking a mapped observation to CMECS. In general, it is best to first label polygons with the most closely related CMECS unit(s), and then document the relationship and uncertainty. However, sometimes it will be necessary to report on units that are a level or two higher in the CMECS classification to find common ground.

- **Challenge: Units in the source map relate to more than one CMECS unit.** This occurs when the source unit concept is greater than the CMECS unit concept, but it also may occur when the project's minimum mapping unit is large (allowing for heterogeneous polygons).

  Solution: Report all of the CMECS units that are represented in the polygon.

- **Challenge: The source map recognizes more detailed polygons than CMECS.** Often local or regional map applications have specific objectives that require finer classification units than are described in CMECS. This is an example of the "less than" scenario described above.

  Solution: Label the polygon with the single related CMECS type. Also, consider labeling each polygon with a CMECS modifier (to avoid losing the detailed information in the map). If it is not necessary to maintain the detailed information, consider lumping together adjacent polygons that represent the same CMECS unit, where appropriate.

- **Challenge: The source map boundaries for a unit are located in a different place than the CMECS boundaries would be located.** Most often, this occurs when the source classification units and CMECS units vary in their thresholds for defining concepts. For example, CMECS defines the up-river boundary of an estuary as the head of tide, whereas FGDC (1996) defines it on the basis of salinity. In this case, the boundary line of the estuary on maps of these two classifications would not match. Here, the concept of "Estuarine" is greater in CMECS than in the FGDC (1996). On a map, this results in discordant boundaries.

Solution 1: This essentially the same as the case where the source unit is either broader or finer (depending on the situation) than the CMECS unit. Keep the existing line and follow the protocols described in the scenarios above.

Solution 2: If ancillary data that reflect the CMECS boundaries are available, incorporate them to modify the map to reflect the appropriate CMECS boundary.

- **Challenge: The relationships between the classification units are so complex that it is difficult to reassemble the map units into coherent CMECS classes.** Most often, this case occurs when the relationship between the source units and CMECS units are based on fundamentally different concepts—and the resulting many-to-many relationships make rectification extremely challenging.

  Solution: If the relationships between the source unit and CMECS units are many-to-many, either apply the most closely related unit higher in the CMECS hierarchy and then indicate the complexity, or maintain the source units and document the intersections using the crosswalking methodology.

- **Challenge: Map units don't allow differentiation of CMECS units, because the source data does not reflect the necessary CMECS thresholds.** Datasets collected with another classification scheme in mind often do not include the information that is needed to identify CMECS units—or the scale of the source data aren't sufficiently resolved to identify CMECS units.

  Solution 1: Incorporate additional ancillary data that will allow attribution (within limits of project objectives).

  Solution 2: If ancillary data are not available and existing data do not support crosswalking to CMECS even at a higher level, do not proceed with the crosswalk. Instead, label the unit with the name from the source classification, and indicate that there is not enough information to determine a CMECS unit.

- **Challenge: The map unit has no apparent equivalent CMECS unit.**

  Solution: Check the CMECS modifiers to see if there is an equivalent. Check to see if there are units up a level or two in the CMECS classification to find common ground. If there is no related type higher in the hierarchy or in modifiers, label the unit with the name from the source classification, and indicate that there is no CMECS equivalent. Propose the new unit for inclusion into CMECS.

Literature Cited

FGDC (Federal Geographic Data Committee). 1996. FGDC-STD-004. *Classification of Wetlands and Deepwater Habitats of the United States*. Reston, VA. Federal Geographic Data Committee.

Franz, N., R. K. Peet, and A. S. Weakley. 2008. "On the Use of Taxonomic Concepts in Support of Biodiversity Research and Taxonomy." Section 5 in *The New Taxonomy,* 63–86. Systematics Association Special Volume 74. Symposium Proceedings. Edited by Q. D. Wheeler. Boca Raton, FL: Taylor & Francis. http://www.bio.unc.edu/faculty/peet/pubs/Cardiff.pdf.

Madley, K., A. B. Sargent, and F. J. Sargent. 2002. *Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida*. Report to the U.S. Environmental Protection Agency Gulf of Mexico Program (Grant Assistance Agreement MX-97408100). St. Petersburg, FL: Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission.

Appendix I (Informative): CMECS Example Classification Units

Appendix I (Informative): Example Images and Classification Units.

This appendix provides images to illustrate classifications within different Components of CMECS. The images are intended to show practitioners ecological units at the scale of human observation. These data are communicated in the form of high-resolution still images, but in many cases the images do not provide the resolution necessary to reveal some details important for full classification under a given Component. Thus, many of the scenes are classified only to the level of detail allowed by the image. The photographs are provided to show several CMECS Components, and so are not grouped in any specific order.

Example 1: Key West, Florida

Image: C. Moses

Biogeographic Setting:
Realm: Tropical Atlantic
Province: Tropical Northwestern Atlantic
Ecoregion: Floridian

Aquatic Setting:
System: Marine
Subsystem: Marine Nearshore
Tidal Zone: Marine Nearshore Subtidal

Water Column Component:
Water Column Layer: Marine Nearshore Lower Water Column
Salinity Regime: Euhaline Water
Temperature Regime: Warm Water

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Barrier Reef
Geoform Origin: Biogenic
Level 1 Geoform: Shallow/Mesophotic Coral Reef
Level 1 Geoform Type: Patch Coral Reef
Level 2 Geoform: Lagoon
Level 2 Geoform Type: Aggregate Patch Coral Reef

Substrate Component:
Substrate Origin: Biogenic Substrate
Substrate Class: Coral Substrate
Substrate Subclass: Coral Reef Substrate
Modifier: Layering: Sand Veneer

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Reef Biota
Biotic Subclass: Shallow/Mesophotic Coral Reef Biota
Biotic Group: Massive Coral Reef
Biotic Community: Massive *Montastraea* Reef

Example 2: Narragansett Bay, Rhode Island

Image: G. Cicchetti

Biogeographic Setting:
Realm: Temperate North Atlantic
Province: Warm Temperate Northwest Atlantic
Ecoregion: Virginian

Aquatic Setting:
System: Estuarine
Subsystem: Estuarine Coastal
Tidal Zone: Estuarine Subtidal

Water Column Component:
Water Column Layer: Estuarine Coastal Lower Water Column
Salinity Regime: Upper Polyhaline Water
Temperature Regime: Moderate Water

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Embayment/Bay
Geoform Origin: Geologic
Level 1 Geoform: Cove
Level 1 Geoform Type: Mainland Cove

Substrate Component:
Substrate Origin: Geologic Substrate
Substrate Class: Unconsolidated Mineral Substrate
Substrate Subclass: Fine Unconsolidated Substrate
Substrate Group: Sandy Mud

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Aquatic Vegetation Bed
Biotic Subclass: Benthic Macroalgae
Biotic Group: Filamentous Algal Bed
Biotic Community: Filamentous *Aghardiella* Communities
Co-occurring Element: Sheet Algal Bed: *Ulva* Communities

Example 3: Punta Cana, Dominican Republic

Image: G. Cicchetti

Biogeographic Setting:
Realm: Tropical Atlantic
Province: Tropical Northwestern Atlantic
Ecoregion: Greater Antilles

Aquatic Setting:
System: Marine
Subsystem: Marine Nearshore
Tidal Zone: Marine Nearshore Subtidal

Water Column Component:
Water Column Layer: Marine Nearshore Lower Water Column
Salinity Regime: Euhaline Water
Temperature Regime: Very Warm Water

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Continental/Island Shore Complex

Geoform Origin: Geological/Anthropogenic
Level 1 Geoform: Shoal
Level 2 Geoform: Wreck

Substrate Component:
Substrate Origin: Anthropogenic Substrate
Substrate Class: Metal
Substrate Subclass: Metal Reef Substrate

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Aquatic Vegetation Bed
Biotic Subclass: Benthic Macroalgae
Biotic Group: Leathery/Leafy Algal Bed
Associated Taxa: Sergeant Majors (*Abudefduf saxatilis*)

Example 4: Long Beach Harbor, California

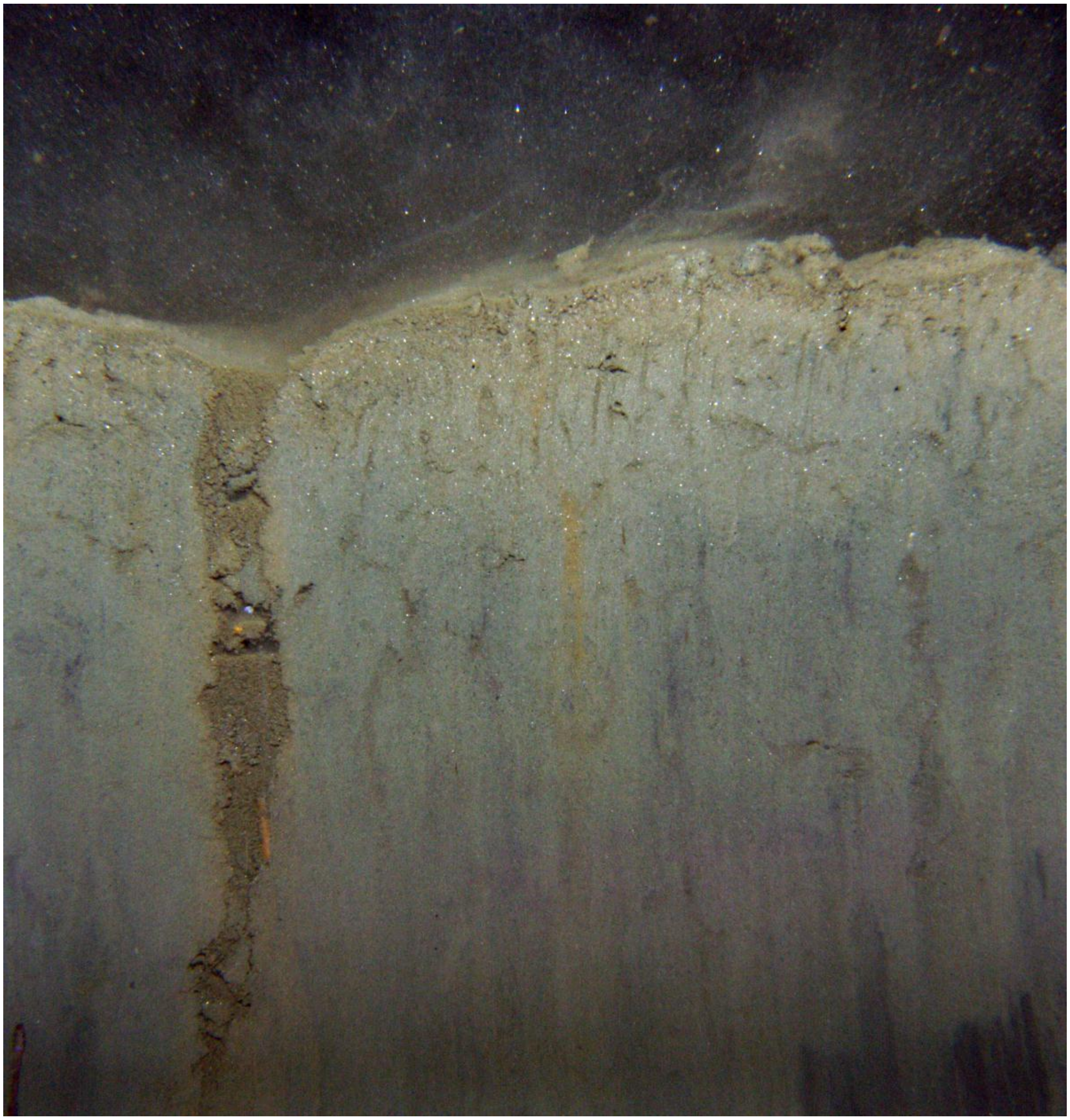

Image: G. Cicchetti

This sediment profile image shows a vertical slice through the substrate, with the sediment-water interface near the top of the image. For scale, the image is 15 cm wide. Small burrows (marks and lines in the upper few centimeters of sediment) and a large burrow (larger vertical feature at left of image) are visible.

Biogeographic Setting:
Realm: Temperate Northern Pacific
Province: Cold Temperate Northeast Pacific

Ecoregion: Southern California Bight

Aquatic Setting:
System: Marine
Subsystem: Marine Nearshore
Tidal Zone: Marine Nearshore Subtidal

Water Column Component:
Water Column Layer: Marine Nearshore Lower Water Column
Salinity Regime: Euhaline Water
Temperature Regime: Cool Water

Geoform Component:
Tectonic Setting: Convergent Active Continental Margin
Physiographic Setting: Continental/Island Shore Complex
Geoform Origin: Anthropogenic
Level 1 Geoform: Harbor

Substrate Component:
Substrate Origin: Geologic Substrate
Substrate Class: Unconsolidated Mineral Substrate
Substrate Subclass: Fine Unconsolidated Substrate
Substrate Group: Sandy Mud

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Faunal Bed
Biotic Subclass: Soft Sediment Fauna
Biotic Group: Larger Deep-Burrowing Fauna
Co-occurring Element: Small Surface-Burrowing Fauna

Example 5: York River, Lower Chesapeake Bay, Virginia.

Image: G. Cicchetti

Biogeographic Setting:
Realm: Temperate North Atlantic
Province: Warm Temperate Northwest Atlantic
Ecoregion: Virginian

Aquatic Setting:
System: Estuarine
Subsystem: Estuarin Coastal
Tidal Zone: Estuarine Coastal Intertidal

Water Column Component:
Water Column Layer: Estuarine Tidal Riverine Coastal Lower Water Column
Salinity Regime: Lower Polyhaline Watre
Temperature Regime: Moderate Water

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Riverine Estuary
Geoform Origin: Geologic
Level 1 Geoform: Marsh Platform

Level 2 Geoform: Channel
Level 2 Geoform Type: Tidal Creek

Substrate Component:
Substrate Origin: Geologic Substrate
Substrate Class: Unconsolidated Mineral Substrate
Substrate Subclass: Fine Unconsolidated Substrate
Substrate Group: Muddy Sand

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Emergent Wetland
Biotic Subclass: Emergent Tidal Marsh
Biotic Group: Low and Intermediate Salt Marsh
Biotic Community: *Spartina alterniflora* Virginian Zone Herbaceous Vegetation

Example 6: Buzzards Bay, Massachusetts

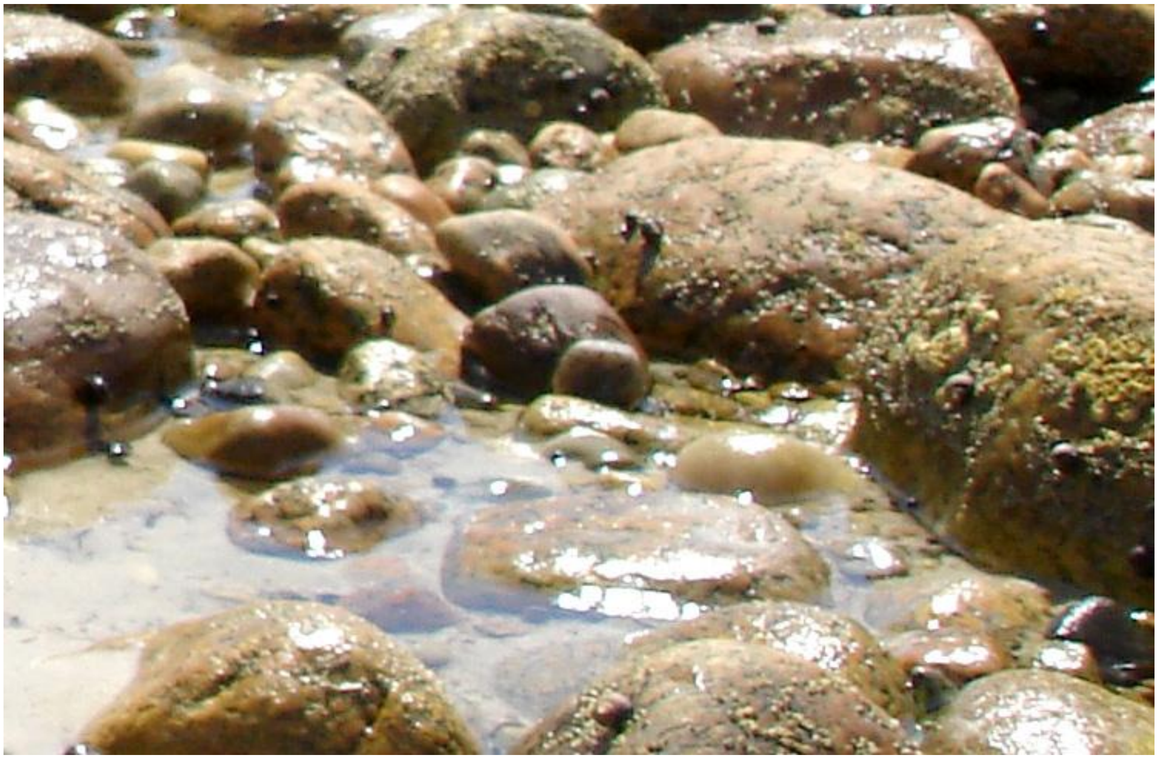

Image: G. Cicchetti

Biogeographic Setting:
Realm: Temperate North Atlantic
Province: Warm Temperate Northwest Atlantic
Ecoregion: Virginian

Aquatic Setting:
System: Estuarine
Subsystem: Estuarine Coastal
Tidal Zone: Estuarine Intertidal

Water Column Component:
Water Column Layer: Estuarine Coastal Lower Water Column
Salinity Regime: Upper Polyhaline Water
Temperature Regime: Cool Water

Geoform Component:
Tectonic Setting: Passive Continental Margin
Physiographic Setting: Embayment/Bay
Geoform Origin: Geologic
Level 1 Geoform: Cove
Level 1 Geoform Type: Mainland Cove
Level 2 Geoform: Beach

Level 2 Geoform Type: Wave-dominated Beach

Substrate Component:
Substrate Origin: Geologic Substrate
Substrate Class: Unconsolidated Mineral Substrate
Substrate Subclass: Coarse Unconsolidated Substrate
Substrate Group: Gravel
Substrate Subgroup: Cobble
Co-occurring Element: Sand (< 20%)

Biotic Component
Biotic Setting: Benthic Biota
Biotic Class: Faunal Bed
Biotic Subclass: Attached Fauna
Biotic Group: Barnacles
Biotic Community: *Semibalanus balanoides* Communities
Co-occurring Element: Mobile Gastropods: *Littorina littorea*

Appendix J (Informative): CMECS Development Participants

Appendix J. CMECS Development Participants

The CMECS Implementation Group (Development Team) wishes to acknowledge the support of the many scientists, researchers and natural resource managers who contributed their expertise to the development of this standard. This standard, the first of its kind for the United States, represents many years of collaboration and cooperation. Without their contribution, we would not have been able to achieve our goal of developing this national standard.

This document is dedicated to the memory of Dail Brown, who supported CMECS development from the very beginning.

The following identifies the many individuals and organizations involved in CMECS development.

CMECS Implementation Group (IG) Members: These contributors were responsible for the initial conception and overall structure of CMECS, for gathering and incorporating input from experts, for maintaining the effort, for generating content, and for the bulk of writing. They were also de facto members of the WG (see below). IG members were the primary authors of the document.

Rebecca J. Allee, NOAA Ocean Service, Gulf Coast Services Center
Giancarlo Cicchetti, U.S. EPA, Atlantic Ecology Division
Mark A. Finkbeiner, NOAA Ocean Service, Coastal Services Center
Kathleen L. Goodin, NatureServe
Lawrence R. Handley, USGS, National Wetlands Research Center
Christopher J. Madden, NatureServe
Garry F. Mayer, NOAA Fisheries, Office of Habitat Conservation
Emily Shumchenia, University of Rhode Island, Graduate School of Oceanography
Judy Soule, NatureServe

CMECS Working Group (WG) Members: These experts contributed invaluable content and ideas, and generated text for CMECS Sections and sections. They invested their time over two years, and were also the first-line reviewers of the document.

Tim Battista, NOAA Ocean Service, National Centers for Coastal Ocean Science
Mike Bradley, University of Rhode Island, Environmental Data Center
Guy R. Cochrane, USGS, Pacific Coastal & Marine Science Center
Jeffrey N. Cross, NPS, Natural Resource Program Center
Robert Diaz, Virginia Institute of Marine Science
Kathryn H. Ford, Massachusetts Division of Marine Fisheries
John King, University of Rhode Island, Graduate School of Oceanography
K.V. Koski, NOAA National Marine Fisheries Service, Habitat Conservation Division

Janice C. Kurtz, U.S. EPA, Gulf Ecology Division
Steven E. Lohrenz, University of Southern Mississippi, Department of Marine Science (Retired)
Mike Long, U.S. EPA, Office of Environmental Information
Cliff McCreedy, NPS, Ocean and Coastal Resources Branch
Katharine B. Miller, NOAA Fisheries, Habitat Conservation Division
Duane N. Morrison, USACE Research and Development Center, Topographic Engineering Center
Christopher S. Moses, NOAA Oceanic and Atmospheric Research, International Activities Office
Bryan A. Oakley, University of Rhode Island, Geosciences
Jay Odell, The Nature Conservancy
Mike Rasser, BOEMRE, Environmental Sciences Branch
Edward Rutherford, NOAA Oceanic and Atmospheric Research, Great Lakes Environmental Research Laboratory
Kathleen Sullivan-Sealey, University of Miami, Department of Biology
James Simons, Texas A&M University, Corpus Christi
Mark H. Stolt, University of Rhode Island, Department of Natural Resources Science
Saundra Upchurch, ACE Basin National Estuarine Research Reserve
Jeffrey A. Weber, Oregon Coastal Management Program, Department of Land Conservation and Development
William O. Wilen, USFWS, National Wetland Inventory
Jennifer M. Wozencraft, USACE, Joint Airborne Lidar Bathymetry Technical Center of Expertise

CMECS Peer Reviewers: These scientists, selected to represent a broad range of expertise and geography, provided critical reviews of the completed document at key stages of its development. Their comments led to significant changes and improvements to the document.

Jorge Brenner, The Nature Conservancy
Mark Costello, University of New Zealand, Leigh Marine Laboratory
Graham Edgar, University of Tasmania, Australia
Jim Maragos, USFWS (Retired)
Dave Palandro, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute
Mike Rasser, BOEMRE, Environmental Sciences Branch
Chris Romsos, Oregon State University, Oceanic/Atmospheric Sciences
P.G. Ross, College of William & Mary, Virginia Institute of Marine Science, Eastern Shore Laboratory
Kathryn Scanlon Catanach, USGS, Coastal and Marine Geology Program
Philip Schoeneberger, USDA Natural Resources Conservation Service, National Soil Survey
Paul Seelbach, USGS Great Lakes Science Center

Mary Young, California State University, Monterey Bay, Seafloor Mapping Lab
Mark Zacharias, University of Victoria (Canada), Geography
Roman Zajac, University of New Haven, Dept of Biology and Environmental Science

CMECS Contributors: These individuals provided specific knowledge, skills, and input that led to important improvements to the document. Many of them contributed via participation in one or more of the CMECS workshops. Their thoughts and efforts were vital to the success of CMECS.

Danielle Bamford, The Baldwin Group
Stephen Brown, NOAA Fisheries, Office of Science and Technology
Brianne Connolly, IM Systems Group
Jennifer Dare, The Baldwin Group
Gerald Esch, NOAA Ocean Service, Coastal Services Center
Gary Greene, Moss Landing Marine Laboratories, Center for Habitat Studies (Retired)
Dennis Grossman, Conservation Biology Institute
Tom Hourigan, NOAA Fisheries, Office of Habitat Conservation
Rebecca Love, The Baldwin Group
Marti McGuire, NOAA Restoration Center
Kate Nielsen, NOAA Ocean Service, Management and Budget Office
Bill Stevenson, IM Systems Group
Pace Wilber, NOAA Southeast Regional Office, Habitat Division

CMECS Workshop Participants: Throughout the course of CMECS development many workshops were held to identify essential elements that should be considered for the standard. The following list identifies participants of two workshops that contributed to CMECS, one focusing on the Water Column Component held in January 2011, and a workshop addressing mapping issues held in June 2007. Some of these participants may also be listed above.

<u>Water Column Workshop – January 2011 New Orleans, Louisiana</u>

Dick	Crout	NOAA Data Buoy Center
Toby	Garfield	San Francisco State University
Rick	Gould	Naval Research Lab
Marian	Hanisko	NOAA Gulf Coast Services Center (facilitator)
John	Harding	Northern Gulf Institute
Darryl	Keith	EPA Narragansett Lab
Britta	Knefelkamp	University of Vechta
Dong-Shan	Ko	Naval Research Lab
Scott	Milroy	University of Southern Mississippi
Donald	Olson	University of Miami
Claire	Paris-Limouzy	University of Miami
Ed	Rutherford	NOAA Great Lakes Environmental Research Lab

Heidi	Stiller	NOAA Gulf Coast Services Center (facilitator)
Saundra	Upchurch	ACE Basin National Estuarine Research Reserve
Mark	Zacharias	Ministry of Science and Universities

Mapping with the CMECS Standard Workshop – June 2007 Charleston, South Carolina

Jen	Aitkin	OpTech International Inc.
Drew	Cary	CoastalVision
Guy	Cochrane	U.S. Geological Survey
Scott	Cross	NOAA National Coastal Data Development Center
Bob	Diaz	Virginia Institute of Marine Science
Kass	Green	The Alta Vista Co.
Gary	Greene	Moss Landing Marine Lab
Vince	Guida	NOAA/NMFS Northeast Fisheries Science Center
Jeff	Hyland	NOAA Center for Coastal Health and Biomolecular Research
Dana	Infante	Michigan State University
Kevin	Madley	LEC Enviromental Consultants
Marti	McGuire	NOAA Restoration Center
Dave	Palandro	Florida Fish and Wildlife Research Institute
Maggie	Payne	U.S. Dept. of Agriculture
Jason	Stradtner	NOAA National Coastal Data Development Center
Jenny	Waddell	NOAA National Centers for Coastal Ocean Science
Jeff	Weber	Oregon Coastal Zone Management Program
Pace	Wilber	NOAA/NMFS Southeast Regional Office
Tony	Wilbur	Massachusetts Coastal Zone Management Program