Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Pacific and Maritimes Regions

Canadian Science Advisory Secretariat
Science Advisory Report 2016/003

EVALUATION OF HIERARCHICAL MARINE ECOLOGICAL CLASSIFICATION SYSTEMS FOR PACIFIC AND MARITIMES REGIONS

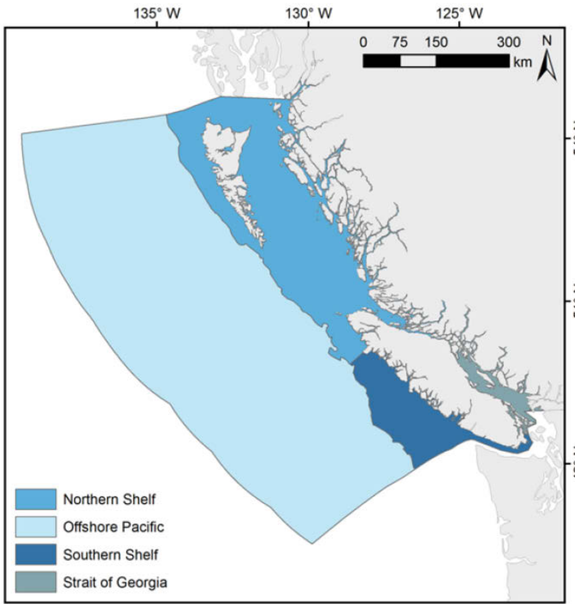

Figure 1. Four Bioregion units identified for the Canadian Pacific Ocean by a National CSAS process (DFO 2009).

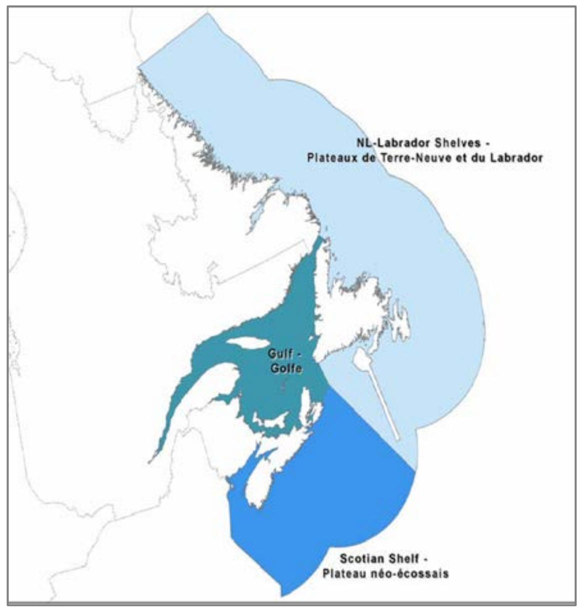

Figure 2. Three Bioregion units identified for the Canadian Atlantic Ocean by a National CSAS process (DFO 2009).

Context:

The need to develop a hierarchical marine ecological classification system for classifying the structure and distribution of Canada's marine biota and habitats at multiple spatial scales has been recognized regionally, nationally and internationally to ensure that all habitats, communities and ecosystems are effectively represented in marine spatial planning, and to ensure that a structured approach is used to consider biodiversity at local, regional and basin-wide scales.

Twelve major biogeographic units (bioregions) were identified for Canada's three oceans during a Fisheries and Oceans Canada (DFO) National Canadian Science Advisory Secretariat (CSAS) peer review process (DFO 2009). Each of the major biogeographic units can be disaggregated/subdivided further into smaller ecologically meaningful spatial units for marine spatial planning. A conceptual framework to disaggregate/subdivide Bioregions into smaller hierarchical spatial units based on their ecological attributes, i.e., a hierarchical marine ecological classification system (HMECS), was identified by a DFO Pacific Region CSAS process (DFO 2013).

Independent applications of the conceptual framework in the Pacific and Maritimes Regions led to the development of a harmonized marine ecological classification system that provides a systematic and spatially-explicit classification of benthic ecosystems at multiple scales, a database of spatially-referenced information for identifying and locating key ecological properties, and a set of spatially referenced information that can be integrated with other data layers (e.g., social, economic), to inform *marine spatial planning initiatives. These outputs are intended to support marine spatial planning and conservation, particularly Marine Protected Area (MPA) network design, in both the Pacific and Maritimes Regions.*

This Science Advisory Report is from the September 29 to October 2, 2015, zonal peer review on the Evaluation of Hierarchical Marine Ecological Classification Systems for Pacific and Maritimes Regions. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Two applications of a conceptual hierarchical marine ecological classification system (HMECS) framework (DFO 2013) were reviewed at a Zonal Peer Review meeting September 29 to October 2, 2015. The conceptual framework was applied independently to disaggregate the Fisheries and Oceans Canada (DFO) Pacific Region Northern Shelf and Southern Shelf Bioregions (PNSB and PSSB) and the DFO Maritimes Region Scotian Shelf Bioregion (MSSB) into smaller hierarchical spatial units based on ecological attributes.
- A harmonized classification for benthic ecosystems based on the Pacific and Maritimes Region results was developed and is recommended for future benthic classification applications. The harmonized HMECS represents a revision to the classification proposed in DFO (2013) and comprises 11 levels. Approaches for populating Levels 4-7 (below the Bioregion) were developed. Although this classification is hierarchical in terms of spatial scales, not all units or levels are perfectly nested within the level or scale above. For example, a single Geomorphic unit (Level 5) such as a trough, may span several Biophysical units (Level 4).
- The Pacific and Maritimes classifications represent variations of the same approach. The Pacific Region classification at the Biophysical level (Level 4) is based primarily on biological and environmental data, and the Maritimes classification is based primarily on environmental data that are weighted with information from previous biological analyses in the region. It should be noted that methods other than those reviewed through this process may be appropriate for classifying areas into ecological units at different levels of the hierarchy.
- The methods used to develop and populate levels in the harmonized HMECS, and the resulting delineation of Biophysical (Level 4) and Geomorphic (Level 5) units in classification maps for the Pacific Region, are robust and suitable for their intended purpose of supporting and informing marine spatial planning initiatives with respect to patterns in habitat and community diversity at multiple spatial scales, particularly the achievement of the representativity and replication criteria for MPA network design. The boundaries between Biophysical units may represent transition zones, rather than absolute spatial distinctions between habitats/communities considering the scale of the analysis, and may be an important Biophysical unit on their own.
- For the Maritimes Region, due to differences in the oceanography and bathymetry layers, which limited interpretation of the resultant Biophysical units layer, it was agreed that it would be better to use the oceanography and bathymetry layers separately in future marine spatial planning initiatives in the region rather than using the Biophysical units layer. An investigation is recommended of spatial patterns in species composition and multivariate environmental data over the entire Scotian Shelf in Maritimes Region to establish whether similar biogeographic and ecological patterns of species assemblages

persist at the Biophysical scale, i.e., to provide some validation of the Biophysical units defined by environmental data alone.

- A coastal/nearshore/inshore “unit” in the Biophysical level (Level 4) has not yet been identified in the Pacific Region, because there were insufficient data at the appropriate scale. Delineation of this unit may influence the boundaries of the adjacent Biophysical units.
- The Benthic Terrain Modeler (BTM) tool was used in the Pacific Region to identify Level 5 Geomorphic units on the seabed that are presumed to have important species associations; however, these biological correlations have not been validated. Present results are likely sufficient to begin marine spatial planning, but future work to more fully characterize these classifications according to their species associations is recommended.
- A bottom patch model using substrate data to describe habitat in nearshore waters < 50 m deep was proposed but not evaluated for populating the Level 6 Biotope units in the Pacific Region. Further work is recommended to investigate its application in deeper waters, and to deal with issues of scale. Other methods that incorporate biological information may also be appropriate and should be identified and explored.
- A method for Biotope classification in the Maritimes Region based on substrate characteristics was presented for the coastal Biophysical unit only, as coastal substrates are the only high resolution data available region-wide. It is recommended that substrate models be applied for classifying Biotope units when biological data are not available.
- Level 7 (Biological Facies) could be represented by focal species or habitats because the full range of biological data with sufficient resolution and scale are not available at present in either Region. It is recommended that all available distribution data for fine-scale Level 7 Biological Facies units (e.g., Glass Sponge reefs, Eelgrasses, and Kelp beds) should be collated, and models developed and evaluated to predict the distributions of these habitats in PNSB and PSSB.
- The development and application of a classification system for pelagic systems using the harmonized benthic HMECS as a template is recommended.
- Neither the Maritimes nor the Pacific Region classifications included the intertidal zone, although this unit has been classified independently in each Region. Because the intertidal zone may have value for some management processes, it is recommended that further investigation into the appropriate integration of these classifications into a coastal/nearshore/inshore "unit" be conducted in the future.
- Geospatial databases to manage the spatial data and layers are an essential component of the harmonized HMECS. Ongoing support to maintain this database is important for the successful application of HMECS to inform management decisions. Collaboration among DFO programs engaged in marine spatial planning initiatives (e.g., MPA planning, Marine Preparedness and Response, Aquaculture, Fisheries Protection) is recommended to develop an accessible and comprehensive geospatial database and to avoid duplication of efforts and inconsistencies in products.
- In order to populate the higher resolution levels of the HMECS, it is recommended that multiple datasets, including (but not limited to) third party environmental assessments, local ecological knowledge, First Nations knowledge, aquaculture siting studies, academic studies, and museum collections be reviewed to maximize the inclusion of biological data where possible and appropriate.

INTRODUCTION

The need to develop a hierarchical marine ecological classification system (HMECS) for classifying the structure and distribution of Canada's marine biota and habitats at multiple spatial scales has been recognized regionally, nationally and internationally for a variety of reasons, including:

- to ensure that all types of habitat, communities and ecosystems are effectively represented in marine spatial planning initiatives according to their ecological attributes; and
- to ensure that a structured approach is used to consider biodiversity at local, regional and basin-wide scales.

A Fisheries and Oceans Canada (DFO) National Canadian Science Advisory Secretariat (CSAS) peer review process identified 12 major biogeographic units (bioregions) for Canada's three oceans (DFO 2009). Each of these biogeographic units can be disaggregated/subdivided into smaller units that are ecologically meaningful. A DFO Pacific Region CSAS peer review process identified a conceptual framework (Pacific Marine Ecological Classification System [PMECS]) for development of a regional hierarchical ecological classification system that could be used to disaggregate bioregions to finer scale spatial units (DFO 2013). This conceptual framework was independently applied to the DFO Pacific Region Northern and Southern Shelf Bioregions (Rubidge et al.[1]) and the DFO Maritimes Region Scotian Shelf Bioregion (Greenlaw et al.[2]). The resulting classifications describe benthic habitat and community diversity at multiple spatial scales.

DFO Oceans, in both the Pacific and Maritimes Regions, requested that DFO Science provide an assessment of the methods and resulting classifications of the Northern and Southern Shelf Bioregions and Scotian Shelf Bioregion in support of marine spatial planning and conservation initiatives. The proximal goal is to use these descriptions of benthic habitat and community diversity to achieve the representativity and replication criteria of marine protected area (MPA) network design within each Bioregion. Ultimately, the classification is intended to inform marine spatial planning and conservation processes managed by DFO from local through regional spatial scales. These applications of HMECS should be informative for other DFO ecosystem-based management decisions at regional and local scales in all Canadian marine waters.

ASSESSMENT

The Pacific and Maritimes classifications are variations of the conceptual classification (DFO 2013) and differ according to the types of data available in each Region. The Pacific Region classification at the Biophysical level (Level 4) is based primarily on biological and environmental data, and the Maritimes classification is based on primarily environmental data weighted by the results of previous biological analyses in the Region. These differences in data availability led to some Region-specific variations in the number and type of areas being classified. The methods used in each Regional application may not be the only appropriate methods to achieve the goals of a HMECS.

[1] Rubidge, E., Gale, K.S.P, Curtis, J.M.R., McClelland, E., Feyrer, L, Bodtker, K., and Robb, C. 2015. Methodology of the Pacific Marine Ecological Classification System and its Application to the Northern and Southern Shelf Bioregions. CSAP Working Paper 2014OCN02a. In revision.

[2] Greenlaw, M., Smith, K., Rubidge, E., and Martin, R. A subtidal marine ecological classification system to represent species diversity and distribution patterns in the Maritimes Region. 2015. CSAP Working Paper 2014OCN02b In revision.

Hierarchical Marine Ecological Classification System

A “harmonized” hierarchical marine ecological classification system (HMECS) for benthic ecosystems was developed based on the DFO Pacific and Maritimes Regions applications (Table 1), and this operational HMECS is recommended for future benthic applications. A classification of pelagic habitats and communities systems using the harmonized benthic classification as a template is needed in both Regions. Because biological and environmental processes, and interactions in benthic and pelagic systems, will differ in spatial extent and distribution, a hierarchical marine ecological classification system for pelagic ecosystems may differ from the structure of the HMECS developed here for benthic ecosystems.

The harmonization effort focused on the Levels 4 through 8. Levels 1-3 (Realm, Province, Bioregion) and Levels 9-11 (Species, populations, Genes) remain as described in the conceptual hierarchy (DFO 2013). The harmonized HMECS (Table 1) is hierarchical based on spatial scales (scale becomes finer at higher levels), but not all units or levels are perfectly nested in the level or scale above.

Table 1. Operational hierarchical marine ecological classification system based on DFO Pacific and Maritimes Region applications of the conceptual framework (DFO 2013). Text in grey was inherited from the conceptual framework and not discussed.

Level	Unit	Spatial extent	Spatial resolution	Benthic Description
1	Realm	10,000’s km	1,000 km^2	Broad-scale geographic units such as the north Pacific Ocean.
2	Province	1,000’s km	~100 km^2	Broad-scale geological units such as continental blocks, basins and abyssal plains.
3	Bioregions	1,000’s km	~10-100 km^2	Distinctive, recurring and small-scale physical oceanographic processes (e.g., separation between California Current and Alaska Current regions). Research and analysis is required to understand how marine species diversity differs among these Bioregions.
4	Biophysical	100’s-1,000’s km	~10-100 km^2	Distinct physiographic and oceanographic conditions/processes, including bathymetry, related to biotic composition if data are available or evidence in the literature.
5	Geomorphic	100s km	1-10 km^2	Discrete geomorphological structures assumed to have distinctive biological assemblages; Individually defined by shape, size and topographic variation. May span other levels of hierarchy.
6	Biotopes (Habitats and Communities)	100’s m-100’s km	100’s m^2 - 1km^2	Discrete taxonomic assemblages characterized by associated substrate and environmental factors.
7	Biological Facies	100’s m	<10 m^2	Groups of biogenic habitat or foundation species identified by one or more indicator species. Biological Facies are patchy and nested within biotopes. Most examples are biogenic habitats, e.g., Glass Sponge reefs, Cold-Water Corals, Eelgrass beds, Kelp forest.
8	Micro-assemblage	10’s m	< 1 m^2	Distinct assemblages of often highly specialized species. For example, Kelp forest holdfast community.
9	Species	-	-	Operational taxonomic units
10	Populations	-	-	Spatially structured subgroups of a species; includes phenotypes, evolutionary significant units, conservation units
11	Genes	-	-	Alleles and DNA sequences

For example, Geomorphic units (Level 5) such as troughs may span several Biophysical units (Level 4). Subdivisions within each level may be desirable to capture specific patterns, and were used in both the Pacific and Maritimes Region applications. It is recommended that standard descriptions and nomenclature be used to identify geomorphic units (troughs, banks, rises, etc.) such as those proposed by Greene et al. (1999). A Biological Facies will be nested in a Biotope, but a Biotope does not necessarily contain a Biological Facies. Similarly, a Microassemblage will always be nested within a Biotope, but not always within a Biological Facies. The harmonized HMECS supports the conclusion that the methods developed for Levels 4 and 5 are suitable for characterizing habitats and communities in each Region.

Methods were demonstrated to classify benthic ecosystems down to Levels 4 and 5, excluding coastal areas in the Pacific Region. Some methods were proposed for classifying Level 6 (Biotopes), but classification at this level was not completed in either Region owing to data limitations. Data that are both better resolved and widely distributed region-wide are needed to accurately define Biotope units. It is recommended that these high-resolution data and classification of the Biotope and Biological Facies units should be pursued over time as classification at fine resolution will be valuable to marine spatial planning and management decisions relevant to the DFO Fisheries Protection Program, DFO Species-at-Risk Program, and DFO Aquaculture management sectors. In the interim, the data that are currently available and the classifications in each Region are suitable for supporting current marine spatial planning objectives, notably fulfilling the representativity and replication criteria in MPA network design. It is important to note when identifying units in the classification, that data aliasing, i.e., differences in the spatial or temporal scales and resolution of the biological and environmental datasets, can impair the detection of meaningful ecological associations between biological and environmental data and thus the location of boundaries between adjacent units. Neither the Maritimes nor the Pacific classifications were applied to the intertidal zone, although this unit has been classified independently in each Region. It is recommended that further investigation into the integration of these classifications into a coastal/nearshore/inshore "unit" be conducted in the future.

Pacific Northern Shelf and Southern Shelf Bioregions

The Pacific Northern Shelf Bioregion (PNSB) covers approximately 102,000 km^2 from the Canada-Alaska border to northwest Vancouver Island, including the waters of Dixon Entrance, the west coast of Haida Gwaii, Hecate Strait, Queen Charlotte Sound and Queen Charlotte Strait (Figure 1). The Bioregion extends from the coastal inlets and fjord complex in the east to the base of the continental slope west of Haida Gwaii and Vancouver Island. The Pacific Southern Shelf Bioregion (PSSB) extends from the inlets and fjords along the west coast of Vancouver Island westward to the base of the continental slope and includes the Strait of Juan de Fuca. These Bioregions share a boundary near Brooks Peninsula (on the west coast of Vancouver Island), which corresponds to the approximate location of an oceanographic transition zone (DFO 2009) where the North Pacific Current splits into the northward moving Alaska Current and the southward moving California Current. This zone moves north or south annually depending on the dominance of the atmospheric pressure systems whose winds drive the oceanic gyres and large-scale forcing events such as El Niño conditions. The California Current system off the west coast of Vancouver Island is characterized by northwest winds and upwelling along the edge of the continental shelf, which supports high productivity, whereas those same northwest winds create downwelling conditions along the edge of the continental shelf in the Alaska Current. The continental shelf and slope are bisected by large troughs in the PNSB and large submarine canyons in the PSSB, including Barkley and Juan de Fuca Canyons.

Geospatial Database

Existing and relevant marine environmental and biotic spatial data from Canada's Pacific Region were compiled into a central geodatabase. The initial application focused on benthic ecosystems in the PNSB and PSSB, but both benthic and pelagic species data for all four Pacific Bioregions, out to the Exclusive Economic Zone, were compiled, annotated and stored in a geospatial database for future applications. Each data layer collected or created has detailed metadata associated with it, including the source data, references, and any additional analyses applied to generate the layer. All taxonomic names were compared to the World Register of Marine Species (WoRMS) or the Integrated Taxonomic Information System (ITIS) to check for synonyms and misspellings; records with taxonomic names that were not present in either registry were excluded. The geospatial database currently contains about 600 abiotic and biotic spatial layers, not all of which were used in the analyses reviewed here. These data are accessible for analyses in support of other objectives related to marine protected area network design and marine spatial planning in general, but the accuracy and completeness of this database was not reviewed in the present process.

Fifty-nine environmental layers were collated from multiple sources and a description of known uncertainties or possible estimation errors was recorded with each layer. These raster layers include 15 environmental variables: chlorophyll a, sea surface temperature, depth, bottom temperature, bottom salinity, non-tidal current velocity, tidal velocity and direction, modelled benthic particle size, adversity and disturbance indices, nitrate, silicate, and phosphate concentrations, pH, and dissolved oxygen level.

Level 4 Biophysical Units

Biophysical units are areas of distinct physiographic and oceanographic conditions and processes that shape species composition (Table 1). Biophysical units were identified through analyses of spatial patterns in species composition and multivariate environmental data to establish whether predictable biogeographic and ecological patterns of species assemblages persist at the Biophysical scale. This biological approach consisted of two steps:

1) a cluster analysis based on the similarity of species composition among sites to group sites with similar species into distinct biological assemblages; and
2) a random forest analysis to identify environmental correlates of the biological assemblages identified by the cluster analysis and the application of this model to predict the biological assemblage present in areas with too few biological data.

An indicator species analysis was also conducted to identify the species most commonly associated with each cluster or ecological unit.

The PNSB and PSSB areas were divided into 4 km x 4 km grid cells (sites) and all demersal fish (pelagic species were excluded) and benthic invertebrate species occurrences within a grid cell were considered to be located at the same site. This approach to data compilation tends to overemphasize the importance of rare or unique species. However, species reported in less than 1% of sites were removed from the analysis, and sites where only one species was recorded were also removed, so that they would not obscure patterns of true similarity among more data-populated sites. All sites that intersected with land were removed from the analysis, and coastal sites (sites on the continental shelf shoreward of the 50 m isobath or depth) were not included due to insufficient data at the appropriate scale, leaving the coastal area to be analyzed separately in the future. The fish and invertebrate data used in this analysis were selected because they are derived from multispecies surveys datasets with no limit on the number of species recorded, and the north–south spatial coverage of the survey spanned the

PNSB and PSSB. Localized or patchy datasets were excluded from the analysis, except when these datasets covered sites not represented. Only records with taxonomic identification to the species-level were used in the present analysis to avoid confounding effects on community patterns that may occur when mixing taxonomic levels in the same analysis. The final dataset for analysis included 96 species of demersal fish and 78 species of benthic invertebrates at 3,615 sample sites. Species composition data were converted to presence-absence, and a matrix of pairwise species composition similarities for each site relative to all other sites was calculated using the β_{sim} distance (Simpson distance or Simpson dissimilarity index) metric.

Cluster analysis of the species composition similarity data was conducted using the unweighted pair group arithmetic mean method. The number of clusters was determined by cutting the dendrogram at a β_{sim} value of 0.55. Five Biophysical units with relatively high evenness in cluster size that contained more than 96% of the sites (3499/3615 sites) were identified. These units are the Continental Shelf, Troughs, Dogfish Bank, Other Banks, and the Continental Slope (Figure 3). The indicator species analysis associated Grooved Tanner Crab, *Chionoecetes tanneri,* Giant Grenadier, *Albatrossia pectoralis,* and Pacific Grenadier, *Coryphaenoides acrolepis,* with the Continental Slope cluster; Pacific Sand Sole, *Psettichthys melanostictus*, with Dogfish Bank cluster, Redbanded Rockfish (*Sebastes babcocki*) and Pacific Ocean Perch (*Sebastes alutus*) with the Troughs cluster; and Yelloweye Rockfish (*Sebastes ruberrimus*) with the Continental Shelf cluster. No species were strongly associated with the Other Banks cluster.

A random forest analysis was conducted using cluster membership as the response variable and 14 environmental variables as predictors that were resampled to a 4 km grid resolution to match the biological data. Depth, salinity and temperature range were identified as the most important environmental correlates of the five clusters identified above. The resulting model was used to predict the distribution of the five biophysical units throughout the study area (Figure 3). Although the overall model was internally consistent with the data, uncertainty measured as the percentage of votes to designated cluster, was also mapped. The areas associated with boundaries between units had higher uncertainty than areas within the core of each biophysical unit. This uncertainty is noticeable at the southern boundary of Dogfish Bank, around the Other Banks unit, and running along the length of the boundary between the Shelf and Slope units. The location of the uncertainty is important as it coincides with transition zones between adjacent biophysical units, where the species composition is changing across environmental gradients and poorer performance of the random forest model is expected. An additional area with high uncertainty in the model is around the southern end of the PSSB. The model performs poorly in the Juan de Fuca Strait, possibly because the influences of complex local currents, and because eddies in the area are not accurately captured in the broad-scale environmental data used to predict the biophysical units.

A coastal/nearshore/inshore "unit" (shoreward of the 50 m isobath) at the Biophysical level (Level 4) was not formally identified in the Pacific Region, because there were insufficient data at the appropriate scale. There are a number of ways to delineate this unit including bathymetry, distance to shore and euphotic zone or some combination of these factors. Results from classification at lower levels also may be relevant to delineating this unit. It should be noted that delineation of this unit may influence the boundaries of the adjacent biophysical unit, and it is recommended that this work be completed when the appropriate data are available.

A boundary between the PNSB and PSSB at Brooks Peninsula (see DFO 2009) was not evident in the benthic biological data used in this analysis. As this boundary was established on the basis of expert knowledge and oceanographic information, a boundary may be identifiable in similar analyses of pelagic biological data.

Level 5 Geomorphic Units

Geomorphic units are discrete geomorphological structures defined by shape, size and topographic variation on the seafloor that are associated with distinctive biological assemblages (Table 1). Although the spatial scale of Geomorphic units is nested within Biophysical units, a single Geomorphic unit such as a trough may span more than one Biophysical unit. Bathymetry data with 75 m resolution from Natural Resources Canada were analyzed with the Benthic Terrain Modeler (BTM) tool developed by NOAA Coastal Services to classify the seafloor into specific features. The BTM tool uses a bathymetry position index (BPI) to scale feature identification to features of interest.

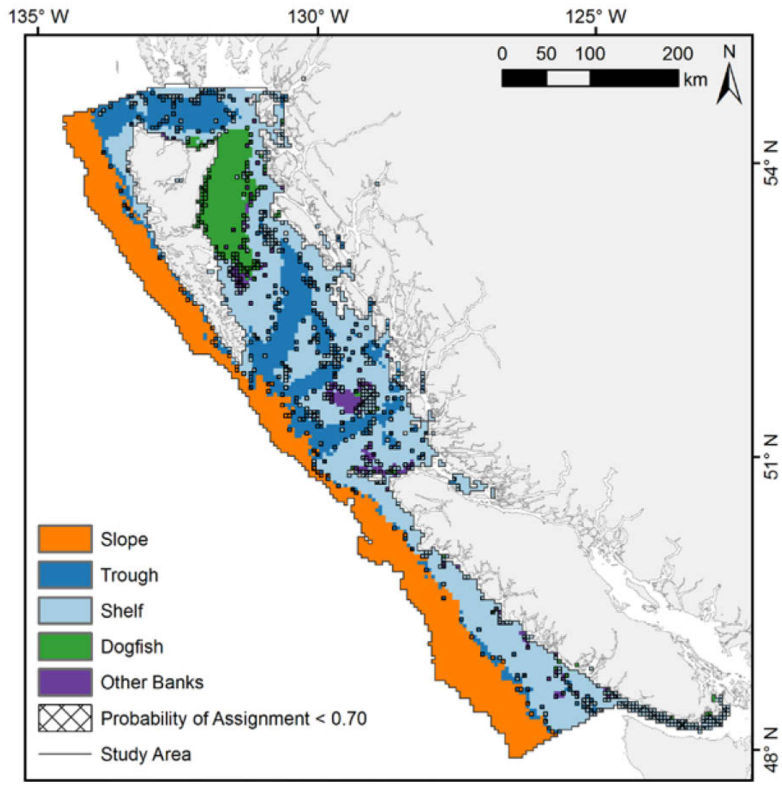

Figure 3. Biophysical unit classification of the Pacific Northern and Southern Shelf Bioregions using random forest model-predicted output. Transition zones are highlighted by areas with lower (< 0.70) probability of assignment by the random forest model. Probabilities are calculated as the proportion of trees in which a site is assigned to a class ("votes") out of the number of trees assembled in the random forest (10,000).

Two passes of the BTM with broad and fine-scale BPI parameters were used to define Geomorphic units on the continental shelf (with and without coastal fjords) of the PNSB and the entire continental slope in Pacific Region. The features identified by the BTM were cross-referenced against undersea feature names in the Canadian Gazetteer (downloaded from the Geogratis data repository). The continental shelf fjords were classified into walls, rises, slopes, depressions, and channel bottoms; the continental shelf into crests, rises, slopes, depressions, and trough bottoms; and the continental slope into ridges, gentle and steep slopes, and canyon bottoms (Figure 4). The point locations of undersea features in the gazette do not always match spatially with the features that were associated with that name, i.e., the point locations of features named in the gazette are not always accurate or informative, particularly for large features. Although the classification of these seabed features supports current marine spatial planning needs, future work to more fully characterize these classifications according to their species associations is recommended.

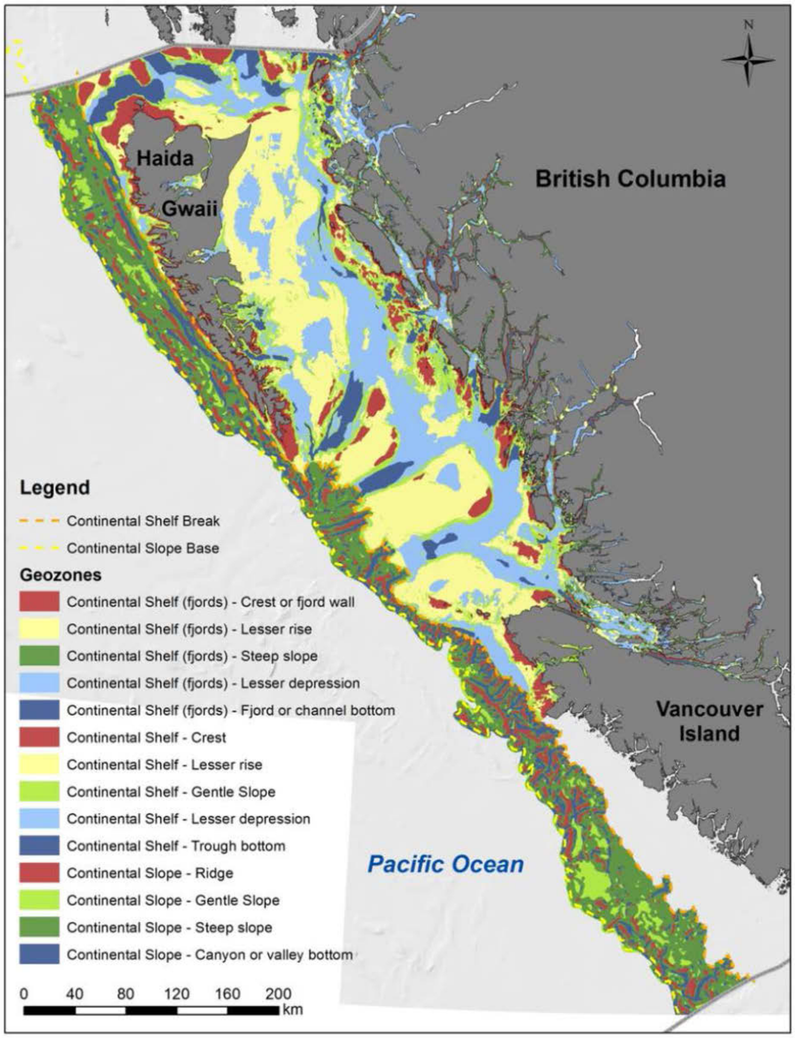

Figure 4. Geomorphic unit classification of the continental shelf within the Pacific Northern Shelf Bioregion and the entire continental slope within the Pacific Region, based on a broad-scale and fine-scale analysis using the Benthic Terrain Modeler tool.

Levels 6 and 7 Biotopes and Biological Facies

Biotope units (Level 6) are discrete taxonomic assemblages characterized by substrate and environmental factors nested spatially within Geomorphic units and classified into soft, hard or mixed substrate types (Table 1). There is no substrate layer with sufficient resolution to delineate Biotope units and their associated biological communities in the PNSB or PSSB at present. Gregr et al. (2013) evaluated the ecological performance of a nearshore benthic habitat classification tool (the bottom patch model) using observed shellfish distributions and found observations of Pacific Geoduck Clam (*Panopea generosa*), an infaunal species, and Red Sea Urchin (*Mesocentrotus franciscanus*), a species strongly associated with hard bottom, were significantly associated with soft and hard patches, respectively, identified by the model. The bottom-patch model was developed to classify bottom type from the high water line to 50 m depth at the resolution of the available data, and thus has potential to classify areas into Biotope units. Modifications for deeper depths and coarser scale in the input data will need to be developed and evaluated prior to implementation. Other methods also may be appropriate for classifying areas into Biotope units.

Biological Facies (Level 7) units are groups of biogenic or foundational species characterized by one or more indicator species (Table 1). Biological Facies are surrogates for the broader species assemblage and they are expected to be patchily distributed in space and contained within a Biotope unit. Examples of Biological Facies in the Pacific Region are biogenic habitats such as Glass Sponge reefs, Eelgrass beds, and Kelp forests. This level is important for the management of biological diversity, but the distribution of Biological Facies across the PNSB and PSSB is only partially known at present. The use of species distribution models to map known and predicted distributions of Biological Facies may be an appropriate approach to inform management and conservation planning, while more comprehensive data are collected. Other methods also may be suitable for classifying areas into Biological Facies units.

Maritimes Scotian Shelf Bioregion

The Scotian Shelf Bioregion extends along the Atlantic Coast of Nova Scotia from the Laurentian Channel in the northeast to the Northeast Channel to the southwest, including the Bay of Fundy (Figure 2). The Bioregion encompasses the area from the coastline outward across the continental shelf, the continental slope, and the abyssal plain within Canada’s Exclusive Economic Zone. The continental shelf is characterized by shallow, offshore banks 25 m to 100 m beneath the ocean surface, with deep basins and troughs between them that vary in depth from 160 m to 300 m and a submarine canyon called the Gully, which is more than 1,000 m deep (DFO 2012). Physical conditions exhibit considerable variability from the Bay of Fundy, which is largely sheltered from ocean swells, to the Atlantic Coast, which has unlimited fetch to the Atlantic Ocean (DFO 2012). Southward currents flowing through the Gully mix offshore waters with the Nova Scotia Current, leading to increased biological productivity toward the east, across the Continental Shelf. The northeastern boundary of the Bioregion along the Laurentian Channel is the southern limit of sea ice in the Atlantic Ocean.

Level 4 Biophysical Units

Biophysical units were delineated using two environmental layers; oceanography and depth, weighted by previously established biological relationships. The oceanography layer included bottom temperature, salinity and current stress, which were readily available as modeled variables across the entire MSSB, and were identified as important explanatory variables of benthic biodiversity by Pitcher et al.'s (2012) gradient forest analysis. These variables were weighted by their “importance” (a metric from the gradient forest analysis) for structuring biodiversity composition; benthic temperature 40%, chlorophyll a 35%, salinity 15%, and benthic current stress 15%, when creating the oceanography layer, which identified ten oceanography domains (Figure 5, top). The oceanographic variables compiled for the oceanography layer are from historical data sources (1992 and earlier) and, as a result the original density, resolution, and error associated with these data are not known at present.

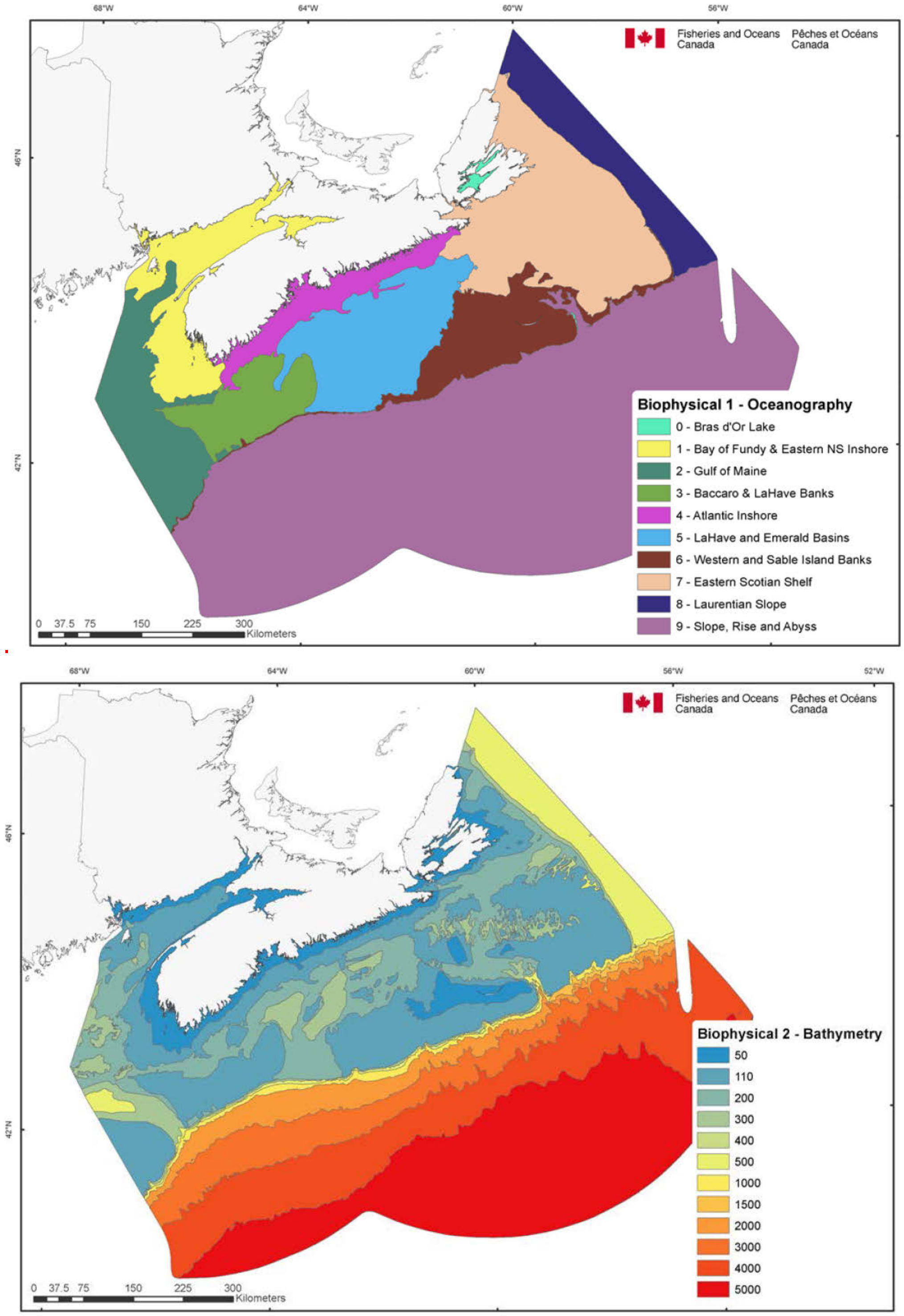

Figure 5. Distinct physiographic and oceanographic areas related to biotic composition (Top) and bathymetric zones (Bottom) used to identify Biophysical (Level 4) units in the Scotian Shelf Bioregion. The oceanography and bathymetric layers are based on gradient forest analysis results (Pitcher et al., 2012) using data from the Gulf of Maine and two-thirds of the Scotian Shelf.

Depth zones were derived from high resolution (1-10 m) bathymetry (Figure 5, bottom). Breakpoints defining the zones were identified along the depth gradient based on changes in species and habitat diversity and distribution (SHDD) patterns from a gradient forest analysis (Pitcher et al. 2012) using data from the Gulf of Maine and two-thirds of the Scotian Shelf. The oceanography and bathymetry layers in Figure 5 were overlaid to define Biophysical units, and boundaries in this Biophysical units layer were smoothed where overlaps between the oceanography and bathymetry layers were spatially separated. However, due to differences in the oceanography and bathymetry layers, which limited interpretation of the Biophysical units layer, it was agreed that it would be better to use the oceanography and bathymetry layers separately in future marine spatial planning initiatives rather than using the Biophysical units layer. A coastal unit was classified separately based on oceanographic and geologic variables and identified 14 Biophysical units.

Although the HMECS classification system supports the needs of current marine spatial planning initiatives, an investigation of spatial patterns in species composition and multivariate environmental data over the entire Scotian Shelf are needed in the future to establish whether similar biogeographic and ecological patterns of species assemblages persist at the Biophysical scale in DFO Maritimes Region, i.e., to provide validation of the Biophysical units defined by environmental data alone.

Level 5 Geomorphic Units

Geomorphic Units were established for offshore areas following Fader (2007[3]), which was applied to the Gulf of Maine and Scotian Shelf. This classification was modified to include inlets, topographically complex areas, flats, canyons, slope, continental rise and the abyssal plain (Figure 6). In the coastal zone, inlets on the Atlantic coast were joined with the offshore Geomorphic units and expanded to capture inlets in the Bay of Fundy and on the coast of Cape Breton (Figure 6). Six coarse resolution Geomorphic units were classified including Inland Seas, Inner Shelf, Shelf, Slope, Continental Rise and Abyssal Plain. These units correspond to Planning Regions used in the Maritimes Region. Fine resolution Geomorphic units also were delineated, including Inlets, Banks, Basins, Flats, Channels, Topographically Complex Banks, Topographically Complex Basins, and Canyons. Coarse and fine resolution Geomorphic units were combined to create the resulting Geomorphic unit layer (Level 5: Figure 6).

Level 6 Biotopes

A method for Biotope classification based on substrate characteristics was presented for the coastal Biophysical unit only, as coastal substrates are the only high resolution data available region-wide. Substrate information in the other Biophysical units is an important data gap. Variables such as surficial grain size, dominant grain size, range of grain sizes, primary benthic type (hard, mixed, soft) were used in a preliminary classification of Biotope units in the Coastal zone, reflecting the glacial history in the region. Over 60% of sediments on the continental shelf are predominantly relict, exhibiting characteristics of past environments with little modern influence, which is problematic for biologically-based habitat descriptions. For example, the classification of glacial till (Scotian Shelf Drift) allows for a wide variety of mud, sand and gravel mixtures to be summarized within a coherent depositional unit (till) directly deposited by glacial ice as a moraine. It is recommended that such substrate models be applied for classifying Biotope units when biological data are not available.

[3] Fader, B. J. 2007. A classification of bathymetric features of the Gulf of Maine. Unpublished consultant's report to WWF-Canada.

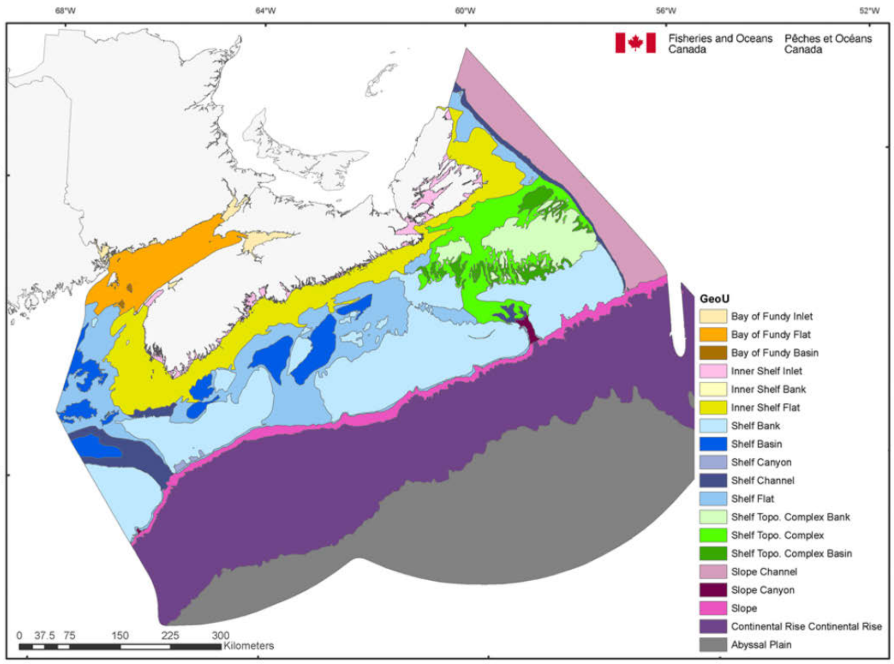

Figure 6. Geomorphic Units (Level 5) identified in the Scotian Shelf Bioregion using a modified version of Fader's (2007) classification of geomorphic features for the Gulf of Maine and Scotian Shelf.

Applicability to DFO Marine Spatial Planning Processes

The intent of the harmonized HMECS (Table 1) is to support management decision-making at multiple spatial scales. Spatial data may be used in multiple DFO decision-making processes related to marine spatial planning and conservation, and multiple spatial scales may be used in these decisions (e.g., Table 2). The spatial level used to support decision-making will depend on the specific objectives to be achieved. Table 2 represents a first approximation of the present context in DFO, future applications of spatial data may be different.

Sources of Uncertainty

The HMECS applications in both the DFO Pacific and Maritimes Regions focused on methodology, analyses and classifications of benthic ecosystems across multiple spatial scales. Classifications of pelagic ecosystems were beyond the scope of this work.

A hierarchical classification relying on physical and environmental "surrogates" to represent patterns in habitat and community structure may not perform as well as biologically informed classifications at fulfilling the biodiversity representativity criterion in conservation planning.

Biological data from several sources, each with their own associated biases, are pooled in this analysis with unknown impact on the results. Substantial data gaps were noted in some areas, e.g., coastal features have not been identified as a biophysical domain in the Pacific Region owing to insufficient data at the appropriate scale, which may influence the boundaries of adjacent units.

The location and boundaries of some spatial units may change over time as a result of changing environmental processes, conditions and interactions in response to global events such as climate change. Application of the methods reviewed here produce a snapshot of habitat and community structure, but they do not capture temporal changes. Temporal change can be accommodated by developing a process for updating the system and source data used for the classifications on an ongoing basis, including the components used to define Biophysical units. A forecasting approach, where the source data are updated using oceanographic forecasts and the classification re-applied, provides a way to assess the temporal change anticipated under different climate scenarios.

Table 2. Proposed scales of data (extent and resolution) for some of the management issues encountered within DFO at present. The management issues shown here do not constitute an exhaustive list of marine spatial planning needs. Specific objectives related to decision making will determine necessary spatial level. Dark grey indicates that spatial information at a particular level is expected to be used in decision making and light grey indicates that there is less certainty among meeting participants in the use of spatial information for decision-making. White indicates that a level is not expected to be used in decision-making.

	Level	Unit	Spatial Extent	Spatial Resolution	MPA Network Planning	Representation Criterion – MPA Network Design	Environmental Assessment for Project Siting[1]	Delineating Critical Habitat (SARA)	Ecological Restoration	Species Management	Marine Spill Response	Cumulative Effects for Planning
ECOSYSTEM-BASED	1	Realm	10,000s km	1,000s km^2	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used
	2	Province	1,000's km	~100 km^2	High certainty will be used	High certainty will be used	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used
	3	Bioregion	1,000's km	~10-100 km^2	High certainty will be used	High certainty will be used	Not Used	High certainty will be used	Not Used	Not Used	Not Used	Not Used
	4	Biophysical	100s-1,000s km	~10-100 km^2	High certainty will be used	High certainty will be used	Not Used	High certainty will be used	Not Used	Not Used	Lower certainty will be used	Lower certainty will be used
	5	Geomorphic	100s km	1-10 km^2	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	Not Used	Not Used	High certainty will be used	Lower certainty will be used
	6	Biotope	100s m-100s km	<1 km^2	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	Lower certainty will be used
	7	Biological Facies	10s – 100s m	<100 m^2	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	Lower certainty will be used
	8	Micro-assemblage	10s m	< 1 m^2	High certainty will be used	Not Used	Lower certainty will be used	High certainty will be used	High certainty will be used	Not Used	High certainty will be used	Lower certainty will be used
SPECIES-BASED	9	Species	-	-	High certainty will be used	Not Used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	Lower certainty will be used
	10	Populations	-	-	High certainty will be used	Not Used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	High certainty will be used	Lower certainty will be used
	11	Genes	-	-	High certainty will be used	Not Used	Not Used	Lower certainty will be used	Lower certainty will be used	High certainty will be used	Lower certainty will be used	Not Used

[1] *Environmental Assessments for Project Siting includes, but is not limited to, aquaculture sites, liquefied natural gas terminals, log dumps and other facilities for which DFO review or approval may be required.*

CONCLUSIONS AND ADVICE

A harmonized classification for benthic ecosystems based on the Pacific and Maritimes Region results was developed and is recommended for future benthic classification applications. The harmonized HMECS represents a revision to the classification proposed in DFO (2013) and comprises 11 levels. Approaches for populating Levels 4-7 (below the Bioregion) were developed. Although this classification is hierarchical in terms of spatial scales, not all units or levels are perfectly nested within the level or scale above. For example, a single Geomorphic unit (Level 5) such as a trough, may span several Biophysical units (Level 4).

The methods used to develop and populate levels in the harmonized HMECS, and the resulting delineation of Biophysical (Level 4) and Geomorphic (Level 5) units in classification maps for each Region, are robust and suitable for their intended purpose of supporting and informing marine spatial planning initiatives with respect to patterns in habitat and community diversity at multiple spatial scales, particularly the achievement of the representativity and replication criteria for MPA network design. The boundaries between Biophysical units may represent transition zones rather than absolute spatial distinctions between habitats/communities considering the scale of the analysis and may be an important Biophysical unit.

The Pacific and Maritimes classifications represent variations of the same approach. The Pacific Region classification at the Biophysical level (Level 4) is based primarily on biological and environmental data, and the Maritimes classification is based primarily on environmental data that are weighted with information from previous biological analyses in the region. It should be noted that methods other than those presented and reviewed through this process may be appropriate for classifying areas into ecological units at different levels of the hierarchy.

An investigation is recommended of spatial patterns in species composition and multivariate environmental data over the entire Scotian Shelf in Maritimes Region to establish whether similar biogeographic and ecological patterns of species assemblages persist at the Biophysical scale, i.e., to provide some validation of the Biophysical units defined by environmental data alone.

Neither the Maritimes nor the Pacific Region classifications included the intertidal zone, although this unit has been classified independently in each Region. Because the intertidal zone may have value for some management processes, it is recommended that further investigation into the appropriate integration of these classifications into a coastal/nearshore/inshore "unit" be conducted in the future.

The Benthic Terrain Modeler (BTM) tool was used in the Pacific Region to identify Level 5 Geomorphic units on the seabed presumed to have important species associations; however, these biological correlations have not been validated. Present results are likely sufficient to begin marine spatial planning, but future work to more fully characterize these classifications according to their species associations is recommended.

A bottom patch model using substrate data to describe habitat in nearshore waters < 50 m deep was proposed but not evaluated for populating the Level 6 Biotope units in the Pacific Region. Further work is recommended to investigate its application in deeper waters, and to deal with issues of scale. Other methods that incorporate biological information may also be appropriate and should be identified and explored.

Level 7 Biological Facies could be represented by focal species or habitats, given that the full range of biological data with sufficient resolution and scale are not available at present in either Region. It is recommended that all available distribution data for fine-scale Level 7 Biological Facies units (e.g., Glass Sponge reefs, Eelgrasses, and Kelp beds) should be collated, and models developed and evaluated to predict the distributions of these habitats in PNSB and PSSB.

The development and application of a classification system for pelagic systems using the harmonized benthic HMECS as a template is recommended.

Geospatial databases to manage the spatial data and layers are an essential component of the harmonized HMECS. Ongoing support to maintain this database is important for the successful application of HMECS to inform management decisions. Collaboration among DFO programs engaged in marine spatial planning initiatives (e.g., MPA planning, Marine Preparedness and Response, Aquaculture, Fisheries Protection) is recommended to develop an accessible and comprehensive geospatial database and to avoid duplication of efforts and inconsistencies in products.

In order to populate the higher resolution levels of the HMECS, it is recommended that multiple datasets, including (but not limited to) third party environmental assessments, Local Ecological Knowledge, First Nations Knowledge, aquaculture siting studies, academic studies, and museum collections be reviewed to maximize the inclusion of biological data where possible and appropriate.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 29 to October 2, 2015 zonal peer review on the Evaluation of Hierarchical Marine Ecological Classification Systems for Pacific and Maritimes Regions. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 2009. Development of a Framework and Principles for the Biogeographic Classification of Canadian Marine Areas. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/056.

DFO. 2012. Marine Protected Area Network Planning in the Scotian Shelf Bioregion: Objectives, Data, and Methods. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/064.

DFO. 2013. Key elements in the development of a hierarchical marine ecological classification system to support ecosystem approaches to management in Pacific Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/065.

Greene, H.G., Yoklavich, M.M., Starr, R.M., O'Connell, V.M., Wakefield, W.W., Sullivan, D.E., McRea, Jr., J.E., and Cailliet, G.M. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22: 663-678.

Gregr, E.J., Lessard, J., and Harper, J. 2013. A spatial framework for representing nearshore ecosystems. Prog. Oceanogr. 115: 189-201.

Pitcher, R., Lawton, P., Ellis, N., Smith, S.J., Incze, L.S., Wei, C.-L., Greenlaw, M.E., Wolff, N.H., Sameoto, J.A., and Snelgrove, P.V.R. 2012. Exploring the role of environmental variables in shaping patterns of seabed biodiversity composition in regional-scale ecosystems. J. Appl. Ecol. 49: 670-679.

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2016. Evaluation of Hierarchical Marine Ecological Classification Systems for Pacific and Maritimes Regions. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/003.

Aussi disponible en français :

MPO. 2016. Évaluation des systèmes de classification hiérarchique de l'écologie marine pour les régions du Pacifique et des Maritimes. Secr. can. de consult. sci. du MPO, Avis sci. 2016/003.