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A Physiographic Coastline Classification of the Scotian Shelf Bioregion and Environs: The Nova Scotia Coastline and the New Brunswick Fundy Shore

Une classification côtière physiographique pour la biorégion du plateau néo-écossais et des environs : la côte néo-écossaise et la côte du Nouveau-Brunswick de la baie de Fundy

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ABSTRACT

Physiographic coastline classifications have been developed at a variety of scales for different management purposes. In one of their more common applications, such classifications have been used for predicting spatial patterns in biological populations and communities when relevant data are otherwise absent. A physiographic classification of the coastline in the Scotian Shelf Bioregion is needed for the Government of Canada's Marine Protected Area network planning process and will support other coastal management initiatives in Nova Scotia and New Brunswick, such as the Nova Scotia Coastal Strategy and the implementation of the Coastal Areas Protection Policy for New Brunswick. In the coastal zone, existing classifications are primarily terrestrial and were created using varying approaches, often for single or narrow management applications. The need for a classification of Nova Scotia's coastline to support a diversity of coastal management initiatives was recognized by several federal and provincial departments involved in coastal management. A working group was formed to develop a new classification for the entire province of Nova Scotia, building upon previous work. The working group includes representatives from Fisheries and Oceans Canada, Natural Resources Canada, Nova Scotia Environment, the Nova Scotia Department of Natural Resources and Dalhousie University. To complete the classification for the rest of the Bioregion, representatives from the New Brunswick Government met to classify the Bay of Fundy. This classification involved a Delphic approach to identify regional-scale coastline classes using physical and oceanographic data including, but not limited to: geological character (bedrock, surficial geology), coastal substrate (intertidal and backshore), shoreline orientation, topography, tidal range, turbidity and coastal geomorphic features (e.g., sand dunes, beaches, estuaries, cliffs). The resulting physiographic classification defines 23 physiographically distinct coastline segments within three larger coastline environments (the Atlantic coast of Nova Scotia, the Bay of Fundy, and the Southern Gulf of St. Lawrence).

RÉSUMÉ

Des classifications côtières physiographiques sont réalisées à différentes échelles pour différents objectifs de gestion. Dans l'une de leurs applications les plus courantes, de telles classifications sont utilisées pour prédire les tendances spatiales de populations et de communautés biologiques en l'absence de données pertinentes. La classification côtière physiographique pour la biorégion du plateau néo-écossais est réclamée dans le cadre du processus de planification du réseau d'aires marines protégées entrepris par le gouvernement du Canada. Elle viendra appuyer d'autres initiatives de gestion des côtes en Nouvelle-Écosse et au Nouveau-Brunswick, comme la stratégie côtière en Nouvelle-Écosse et la mise en œuvre de la politique sur la protection des régions côtières au Nouveau-Brunswick. Dans la zone côtière, les classifications existantes sont principalement terrestres et elles ont été établies en utilisant différentes approches, souvent pour des applications de gestion uniques ou restreintes. La nécessité d'établir une classification des côtes de la Nouvelle-Écosse pour appuyer diverses initiatives de gestion des côtes a été reconnue par plusieurs ministères fédéraux et provinciaux impliqués dans la gestion des côtes. Un groupe de travail a été constitué afin d'élaborer une nouvelle classification pour la totalité de la province de la Nouvelle-Écosse à partir de travaux précédents. Ce groupe de travail compte parmi ses membres des représentants de Pêches et Océans Canada, de Ressources naturelles Canada, du ministère de l'Environnement de la Nouvelle-Écosse, du ministère des Ressources naturelles de la Nouvelle-Écosse et de l'Université Dalhousie. Pour achever la classification du reste de la biorégion, des représentants du gouvernement du Nouveau-Brunswick se sont joints au groupe afin de classifier la baie de Fundy. Cette classification a été réalisée selon la méthode Delphi afin de déterminer les catégories côtières à l'échelle régionale en utilisant des données physiques et océanographiques comprenant, sans s'y limiter, le caractère géologique (substrat rocheux, géologie des dépôts meubles), le substrat côtier (intertidal et haut de plage), l'orientation de la ligne de côte, la topographie, l'amplitude de la marée, la turbidité et les caractéristiques géomorphologiques des côtes (p. ex. les dunes de sable, les plages, les estuaires, les falaises). La classification physiographique ainsi déterminée identifie 23 segments côtiers distincts sur le plan physiographique à l'intérieur des trois grands milieux côtiers (la côte atlantique de la Nouvelle-Écosse, la baie de Fundy et le sud du golfe du Saint-Laurent).

INTRODUCTION

Fisheries and Oceans Canada (DFO), together with the other federal partners and provinces, recently released the "National Framework for Canada's Network of Marine Protected Areas"[1] (MPAs), herein referred to as the National Framework for MPAs. Across Canada, MPA networks will be planned in each of Canada's 13 bioregions (Figure 1; Government of Canada 2011). The National Framework for MPAs has adopted the guidance of the Convention on Biological Diversity (CBD), which calls for the establishment of representative networks of MPAs. Guidance provided by DFO's Canadian Science Advisory Secretariat (CSAS) for planning representative MPA networks (DFO 2010) states that, "...representative MPAs should capture examples of different biogeographic subdivisions that reasonably reflect the full range of ecosystems which are present at the scale of network development, including the biotic and habitat diversity of those ecosystems." Planning for representation in MPA networks is preferably accomplished based on detailed knowledge of each species' distribution, abundance, life history and their interactions with other species, and the biophysical environment in which they exist (Banks and Skilleter 2007). However, there are major gaps in knowledge of the distribution and abundance of many species, especially in the marine environment. As a result, there is a need to use different approaches for mapping expected species diversity and distribution patterns. Surrogate approaches can include the use of physical habitats, species assemblages or higher taxonomic levels, environmental diversity or focal species (Greene et al. 1999; Greenlaw et al. 2011; Roff and Zacharias 2011).

To date, only broad-scale representative maps have been developed for the purpose of conservation planning in Canada. There are different forms of representative mapping, depending on the availability of data. The best-case scenario includes actual or predicted single species or assemblage distribution maps based on measured statistical relationships between biota and physical habitat layers. This is sometimes possible, given the large amount of data collected on some species (e.g., extensive Ecosystem Surveys of the Maritimes Region, shown used in Pitcher et al. 2012). However, often only physical variables are available at the extent of the required classification. These have been used as surrogates to predict biological species diversity and distribution (Greene et al. 1999; Roff et al. 2003; Greenlaw et al. 2011; Horsman et al. 2011) based on extensive literature on species-environment relationships (Riccardi and Bourget 1999; McArthur et al. 2010).

Physical variables can account for anywhere from 25-75% of community variability depending on the system (Stevens and Connolly 2004; Pitcher et al. 2009; McArthur et al. 2010; Pitcher et al. 2012). Physical variables are also an optimal choice in comparison to sampling species diversity and distribution aspects manually, as not only is it too difficult to comprehensively sample marine biodiversity and distribution in terms of labour and cost, it is truly impossible to effectively sample the ecosystem and all species that inhabit the environment.

To implement the National Framework for MPAs within DFO's Maritimes Region, a strategy is in development for planning and implementing a network of MPAs in the Scotian Shelf Bioregion. This is part of a first-order subdivision of marine biogeographic units, delineated in 2009 by DFO Science (Figure 1; DFO 2009). The Scotian Shelf Bioregion will likely be subdivided into three planning areas to facilitate consultations with different stakeholder groups, and to reflect data availability: the Atlantic Coast of Nova Scotia, the Offshore Scotian Shelf, and the Bay of Fundy. The boundaries between the Bay of Fundy and Atlantic Coast planning areas have also been

[1] Available at [Internet]: http://www.dfo-mpo.gc.ca/oceans/publications/dmpaf-eczpm/framework-cadre2011-eng.asp (accessed 29 July 2012).

determined through this coastline classification, which may be re-examined following the completion of a coastal sub-tidal classification[1] that is underway. For administrative and practical purposes, MPA network planning for the Scotian Shelf Bioregion will take place within the boundaries of DFO's Maritimes Region, which contains the entire Scotian Shelf Bioregion but overlaps with the Gulf of St. Lawrence Bioregion in the Sydney Bight area (see Figure 1 for DFO's Maritimes Region boundaries).

A group of federal and provincial protected area practitioners, the Coastal Protected Areas of Nova Scotia (CPANS) Working Group, agreed that a classification for the coastline of Nova Scotia is required for coastal conservation and management. In 2010, CPANS recommended the formation of an ad-hoc sub-working group to address this issue. Representatives from DFO, Natural Resources Canada (NRCan), Nova Scotia Department of Environment, Nova Scotia Department of Natural Resources (NSDNR) and a professor from Dalhousie University are members of the sub-working group, herein referred to as the Nova Scotia Coastal Classification Working Group (NS CCWG). Rather than adopt an existing classification, the NS CCWG recommended that a new classification be developed for the coastal zone of Nova Scotia that reflects the availability of data in the region and the diversity of mandates of federal and provincial departments responsible for coastal management. In order to complete the classification for the Maritimes Region as a whole, subsequent meetings were held in 2011-2012 with representatives from New Brunswick government departments and other federal employees with expert knowledge of the New Brunswick coastline in the Bay of Fundy. Fewer meetings were held with New Brunswick government departments due to experience in applying the methodology in Nova Scotia resulting in a more efficient approach, along with a smaller geographic area that was classified in New Brunswick. In addition, it was difficult to get participation from all relevant departments and academic experts. All members of the NS CCWG and New Brunswick experts that classified the Bay of Fundy are authors on this document. In addition to their work on a coastline classification, the NS CCWG recommended the creation of a classification for the coastal sub-tidal marine area (from the low-water mark to 100 m in depth), which is currently underway.

The objective of this research document is to present the regional-scale coastline classification that was collaboratively created by the NS CCWG and New Brunswick experts and is intended to be used by multiple government departments, Aboriginal groups, researchers, stakeholders and others that are responsible for coastal management in the region. These regional-scale representative areas are technically "physiographically distinct coastline classes" but for simplicity sake will be called classes throughout most of the document. Classes are presented at two different levels, larger "coastline environments" (containing the Atlantic coast of Nova Scotia, the Bay of Fundy, and the Southern Gulf of St. Lawrence) and 23 "coastline segments" and associated sub-segments.

CLASSIFICATION USE

This coastline classification will enable the establishment of conservation priorities at a variety of scales appropriate for management action (Connor et al. 2003; Ryan et al. 2003). It can be used on its own as a marine planning tool, for many purposes including informing habitat compensation, environmental assessments, and planning for baseline studies, but it will be

[1] Greenlaw, M. E., M. Doon, and P. Lawton. Unpublished data. A physiographic classification of the coastal sub-tidal Scotian Shelf Bioregion and environs.

most useful for protected area planning and may be incorporated into decision support tools, such as MARXAN (Ball et al. 2009). MARXAN enables the inclusion of other spatial marine information, i.e., Ecologically and Biologically Significant Areas (EBSAs; DFO 2004), biological species abundance and distribution data, species at risk, fitness data, aggregation data and human use data. A MARXAN analysis would enable the assignment of targets for multiple data layers and would ensure that the overall goals and objectives of the MPA network are met in an efficient manner that reduces socio-economic costs. However, due to a lack of region-wide biological data in the coastal zone, other approaches may be used to identify the coastal MPA network, such as a Delphic method to rank EBSAs coupled with a GIS overlay using both the intertidal and sub-tidal classifications.

SCALE AND METHOD SELECTION

The final MPA network plan for the coastal Maritimes Region could have various output scenarios, depending on the data layers available for planning, time, opportunity, and funding. It is important to consider that representation is a concept that can be applied at different scales throughout the ecosystem hierarchy from global (over thousands of kilometres) to micro-community (millimetres to centimetres) as described in Roff and Zacharias (2011). At the bioregional level, a single MPA could not be considered to capture the range of species and habitats of the region. Scientific guidance (DFO 2009) has suggested that there be further subdivisions of Canada’s marine bioregions and an upcoming Canadian Science Advisory Secretariat national science advisory process planned for 2012 will provide recommendations regarding the appropriate of sub-division for DFO network planning.

Depending on the resolution and type of data available within each bioregion, only certain levels of delineation of the ecosystem will be possible; these will inevitably differ (e.g., Arctic versus Maritimes) even within sections of a bioregion (pelagic versus benthic, coastal versus offshore). The choice of scale of the ecological classification (which can be thought of as being represented by eight scales, Table 1) was based on the resolution of data available. This choice was balanced by the accuracy of the classification, which depends both on the method of ecological classification chosen and the type and resolution of data available. Two main methods of ecological classification were available to choose from, which depend on the types of data that were available. The first type is a classification that uses only physical variables. This method is used when limited biological data are present. The assumption is that combinations of physical variables are predictive of biological species distribution and abundance patterns, which is based on the vast literature on species-environment relationships. These classification methods have advantages in that they are, in theory, designed to be representative of the entire ecosystem (from microfauna to macrofauna). However, they are not as accurate as classifications that use measured statistical relationships between physical and biological data. Physically-based classifications can be either quantitative or expert driven. Quantitative methods either assume that the physical variables are equally important for structuring the habitat of the communities present, or if not, a ranking can be applied based on user knowledge of the system. Expert-driven classifications assume that experts are very knowledgeable about the environment at hand, and have more information than mapping physical variables alone could provide. In this case, experts are consulted to suggest delineations at a certain scale. These classifications are usually created, as previously suggested, due to the absence of detailed biological data; however, they can be validated with high-resolution biological data as they become available.

The other type of classification is one that uses both physical and biological data. In these classifications, biological data are used either from the start, or in the end, to create an ecological classification that is quantifiably predictive of species distribution and abundance patterns. If the biological data are applied afterward, this is termed validation of the classification. The most accurate ecological classifications include biological species data from the beginning. These data include single or multiple species distributions. Single-species habitat maps are commonly used to determine associations between species distributions and physical factors. Recently, a biologically informed classification for multiple species has been designed, which is one of the first methods for mapping representative habitats for a variety of species (Pitcher et al. 2012).

For the classification presented in this document, an expert-driven classification approach was chosen because biological data distributed across the coastline were limited and expert knowledge of the area was high. Once more detailed biological data become available the classification can be validated to ensure its accuracy for certain species distributions. Sources of biological information that spanned the extent of the classification were provided from various sources during classification and Regional Advisory Process meetings. These data are provided as quantifiable and anecdotal verification that the classification is at least properly explaining patterns where limited data are available.

The coastline classification will focus on the regional scale (see Table 1), which is an appropriate starting point for coastal MPA network planning and is the scale for which most data are available. However, the classification has been designed as a hierarchical classification, so that finer-scale ecological units can be delineated when data at smaller scales become available. It is recognized that finer scale classification may be necessary for certain spatial planning uses.

DEFINING THE COAST FOR MPA NETWORK PLANNING

Defining the coast is not a simple task. The coast is often thought of as the place where land meets the sea; however, it is widely recognized that this term and definition does not encompass the broader area necessary for consideration in resource management (Province of Nova Scotia 2009). The term “coastal zone” is more widely used and is often defined according to the issue or task at hand (Ibid.).

For the purpose of DFO’s MPA network planning within the Scotian Shelf Bioregion, the seaward limit of the coastal zone is defined by the inshore limit of the DFO Research Vessel Trawl Survey which is approximately 100 m in depth or roughly 12 nautical miles (nm) offshore. This is consistent with, the seaward extent used for the DFO-Fishermen and Scientists Research Society (FSRS) Inshore Ecosystem Project (DFO 2006). The landward limit is defined as the high-water mark in accordance with the National Framework for MPAs (Government of Canada 2011). For the purposes of ecological classification, the NS CCWG decided that two separate but linked classifications are required for the coastal zone, representing two distinct coastal ecosystems: the ***coastline*** and the ***sub-tidal coastal area***. The coastline classification is described in this report; the sub-tidal coastal area will be documented in a separate report. These coastal ecosystems have been defined by the NS CCWG:

- ***Coastline***: The landward boundary is the inland limit of the marine waters and their sediment and saline influences, excluding atmospheric saline influences, which may penetrate many kilometers inland; the seaward boundary is 10 m below low-water limit (LW).
    - *Geographic extent:* The coastline within DFO’s Maritimes Region (Figure 2) and the rest of the coastline in the province of Nova Scotia for application in province-wide coastal management.

- ***Sub-tidal coastal area***: The inshore boundary is the 10 m depth limit (below LW) and the seaward (outer) boundary is approximately 100 m.
    - *Geographic extent:* The sub-tidal coastal area of DFO's Maritimes Region (Figure 2).

STUDY AREA DESCRIPTION

The Scotian Shelf Bioregion and the rest of Nova Scotia's coastline has a rich diversity of coastal landscapes that will only be discussed briefly as the inshore Scotian Shelf has recently undergone an Ecosystem Overview and Assessment that discusses in detail the general marine habitats and features present[1]. The inshore of the Bay of Fundy does not have a similar document, specific to inshore conditions; however, the Gulf of Maine as a whole has undergone an ecosystem overview with emphasis on offshore conditions and may provide useful background information (East Coast Aquatics 2011).

Physical conditions of the inshore of the Scotian Shelf and the Bay of Fundy differ sharply. The Bay of Fundy is largely sheltered from ocean swells; in contrast, the Atlantic Coast has practically unlimited fetch to the Atlantic Ocean at the mouth of the numerous embayments. Sediment patterns are highly variable along this stretch of coast. High exposure and continued sea-level rise, due in part to subsidence, contribute to the action of erosive forces, leading to a highly crenulated shoreline with many inlets on the Atlantic side (Gehrels et al. 2004). The Bay of Fundy portion of the Nova Scotia coastline has few large inlets and is made up of a higher relief cliff, transitioning into the large estuarine environment of the inner Bay of Fundy.

The outer Bay of Fundy is considered to experience more oceanic conditions with colder summer and warmer winter temperatures, while the inner Bay experiences more extreme temperatures, lower salinity and higher current velocities, along with higher amounts of suspended materials.

The Bay of Fundy has an extreme tidal range, where the shape of the Bay accentuates the tides within the region, resulting in a tidal range which increases from 6 m at its entrance to as much as 16 m at the head of the Bay. Strong tidal currents in areas and complex bottom topography result in tidal rips, whirlpools, upwelling and intense mixing throughout the region. Ice is occasionally present in the region in embayments such as Cumberland Basin and Shepody Bay, where broken ice cover may be kept in motion by the high tidal range and currents. Circulation in the Bay is counter-clockwise as a result of the incoming waters along the Nova Scotia shore of the Bay, as well as influence by the outflow of the Saint John River (Greenberg 1984).

The Atlantic Coast is also characterized by a heterogeneous tidal influence, but the range is considerably lower (ranging from 2 – 6 m) than in the Bay of Fundy, with semi-diurnal tides decreasing west to east (the highest tides closest to the entrance to the Bay of Fundy). Winds are primarily from the south-west in summer and from the west/north-west in winter, although circulation in the nearshore is dominated by the south-westward Nova Scotia Current on the Atlantic Coast.

[1] Bundy, A., J. Sperl, and C. Den Heyer. Unpublished data. Inshore of the Scotian Shelf. Ecosystem Overview and Assessment.

The estuaries on the Atlantic Coast are influenced by tide and wind-driven currents, with salinity progressively decreasing towards the heads of the estuaries (Davis and Browne 1996). River flow into the Atlantic Coast estuaries is usually not strong enough year-round to develop salt wedge estuaries; mostly well-mixed estuaries are found on the coast except during periods of spring runoff and heavy rainfall (Gregory et al. 1993). Headlands tend to be bedrock controlled projections (locally till-dominated) with little sediment cover, and embayments often have an associated seabed topographic depression, with a greater sediment cover over till or bedrock. Most of the sediments are from glacial deposits, which have been washed and sorted such that the clays and finer sediments spread to the deep basins. Most of the nearshore zone shallower than 80 m water depth is generally characterized by relatively rugged and hard bedrock outcrop terrain at or immediately below the seabed. This bedrock zone exhibits rough topography and little sediment cover. Estimates show commonly 70% of the area has bedrock outcrop or outcrop covered with gravel cobble and boulders[1].

The Nova Scotia Current, tidal mixing, topographic upwelling and wind-driven nearshore upwelling all contribute to persistent nearshore temperature and salinity patterns. The eastern region of the study area experiences the most variability in temperature and salinity due to summer stratification and the input of a large amount of seasonal freshwater from the northwest Gulf of St. Lawrence. The western portion of the study area and the Bay of Fundy experiences considerably less variation in temperature and salinity, as persistent tidal mixing along with topographic upwelling keeps the area well mixed (Petrie and Jordan 1993). Regional topographic upwelling also provides year-round nutrients in the southeast portion of the study area, contributing to the enhanced biological productivity of the Lobster Bay/Cape Sable area (Kohler 1986; Tee and Smith 1993). In February, the upper layer temperature in some areas is at or near freezing, while temperatures on the western portion of the study area are considerably warmer. Sea ice is not a consistent winter feature along the nearshore of the study area, although in February ice may be occasionally present, depending on winter temperatures, extending along the coast and entering embayments (Markham 1980).

PREVIOUS CLASSIFICATIONS AND CLASSIFICATION APPROACHES

Atlantic Canada's extensive coastline has long been the focus of exploration, scientific research, and technical documentation; however, most efforts have been developed with a terrestrial focus. Some of the earliest efforts of notable importance include Denys' (1672) seventeenth century narrative: *The description and natural history of the coasts of North America (Acadia)* and Johnson's (1925) physiographic overview of the New England – Acadian shoreline. The first coastal classifications of the region emerged between 1970 and 1990, a time when risks from extensive offshore oil and gas exploration promoted interest in coastal research and mapping. During this period, Atlantic Canada was included in global (e.g., Bird and Schwartz 1985; Davies 1972), continental (e.g., Dolan et al. 1975), and national (e.g., Owens 1977) classifications.

Canadian ecological land classification (ELC) efforts have recognized coastal units at multiple spatial scales. In provincial (Neily et al. 2003; Zelazny 2007) and national (Marshall and Schut 1999) ELC frameworks, coastal units have been defined at ecoregion and ecodistrict levels, employing macro- to meso-scale climatic, geomorphic, and vegetative data (*sensu;* Lacate 1969). Nova Scotia's natural landscape (NSDEL 2002) and theme region classifications (Davis

[1] Bundy, A., J. Sperl, and C. Den Heyer. Unpublished data. Inshore of the Scotian Shelf. Ecosystem Overview and Assessment.

and Browne 1996) also defined coastal land units but have adopted methodological conventions and stratal nomenclatures outlined by Simmons et al. (1984). Unlike the federal and provincial ELCs, these latter two classifications employed both marine (e.g., wind and wave patterns) and terrestrial input data for classifying coastal units.

Owens provided a general description of Canadian coastal environments (Owens 1977). Following on Owens' (1977) broad description of Canadian coastal environments, Owens and Bowen (1977) developed a finer scale rationalization of coastal environments in the Maritime Provinces region. The classification was built on the authors' field observations and air photo interpretations, and on published provincial (e.g., Bowens et al. 1975) and sub-regional classifications (e.g., Owens and Harper 1972, Welsted 1974). Owens and Bowen (1977) identified 22 coastal environments where prevailing landforms and geomorphic processes were homogenous at a specific but unstated scale of resolution. Primary determinants used to classify coastal regions included bedrock geology, backshore relief, beach character, fetch and wave exposure, mean tidal range, and sediment availability. Owens and Bowen (1977) suggested their classification system as a framework for defining other coastal environments, but their methodological summary provides too little detail to adequately guide similar classification efforts elsewhere.

Owens and Bowen's (1977) classification was the first comprehensive and data-driven attempt to define distinct coastline segments in eastern Canada. Although a number of coastal classifications, maps, and descriptive summaries have been developed in subsequent years, few data-driven classifications have spanned the geographic range of this early work. More recent efforts of significance include: a series of aerial video surveys of Nova Scotia's coastline (e.g., Taylor and Frobel 1992, 1993, 1996, 1998, 2001; Taylor et al. 2002); overviews of regional geology (e.g., Taylor et al. 1990, 1991); geomorphological maps (Bérubé and Thibault 1988; Cameron et al. 1990); shoreline classifications of the Atlantic coast of mainland Nova Scotia (Munroe 1982), coastal Newfoundland (Catto et al. 1997; Catto et al. 1999) and the Bras d'Or Lakes (Shaw et al. 2006); and a geophysical classification of coastal inlets in Nova Scotia (Greenlaw et al. 2011). Localized studies have included Taylor et al. (1985), Ollerhead (1997), and O'Carroll (2010), among others. Similar to Owens and Bowen's (1977) framework, many of the aforementioned efforts were compiled using geomorphological, lithological, and sedimentological data.

Renewed interest in coastal management issues, particularly those relating to climate change risk analysis, has prompted establishment of numerous contemporary coastal classifications around the globe (Fairbridge 2004; Finkl 2004). Classifications have differed in scale, geographic range, definitional criteria, classification conventions, and input data. Much of this variability in classification structure and derivation can be attributed to the wide array of applications targeted during classification development (Cooper and McLaughlin 1998). Marine-based classifications are much less numerous than their terrestrial counterparts. Geological interpretations have formed the main interpretations of the marine seabed until recently, when seabed features and combinations of environmental variables have been used to develop representative classifications for the Scotian Shelf offshore environment. Roff et al. (2003) were the first to develop a representative classification for the Scotian offshore combining climatic zones based on sea surface temperature, depth classes and stratification classes to create pelagic seascapes and benthic temperature, exposure and slope, and sediment grain size to create benthic seascapes.

Later, Kostylev and Hannah (2007) developed a predictive benthic habitat classification based on Southwood's template of life history strategies. Their work predicts spatial distribution of benthic organisms with specific life history strategies (r and K) using only physical variables. In the habitat template model, different community compositions were predicted using two axes: *Disturbance* - the ratio of Frictional Velocity to the critical current, and *Scope for Growth* – using spring chlorophyll minus the summer stratification, annual bottom temperature, oxygen and salinity. These layers were used in the first iteration of the MPA planning exercise involving MARXAN on the Scotian Shelf along with a seabed classification of the Scotian Shelf and Bay of Fundy (Fader[1] 2007; WWF 2009).

A hierarchical classification of the seabed of the Gulf of St. Lawrence was recently completed by Dutil et al. (2011). This classification identifies 13 megahabitats (mesoscale) based on a cluster analysis of physical and oceanographic data. The data used in this analysis were consistent with the Wilkinson et al. (2009) approach to identify the Marine Ecoregions of North America, using data for salinity, temperature, dissolved oxygen, depth, slope, variation in landscape and sediments. The geographic extent of the classification by Dutil et al. (2011) was driven by the amount of data available and is therefore focussed in both coastal and offshore waters, but does not encompass many of the inlets or internal waters of the Gulf of St. Lawrence and does not include the intertidal zone, which is the area covered in this report.

Gradient forest (Ellis et al. 2012) is a method recently devised and applied to the Gulf of Maine (Pitcher et al. 2012), which creates a representative habitat layer for marine planning purposes. The method is considered an advance on previous approaches of representative mapping as it begins by determining regionally specific biological associations to physical habitat. The representative habitat layer is then created based on a weighting scheme of how “important” each physical variable was in explaining the variation in species distribution and abundance (summed over all species). The method has added benefits in that it is robust to compare across surveys using disparate sampling methods and tools. However, the method is resource-intensive as it requires dense biological community data and coalition of many physical factors that could be associated to species distribution and abundance patterns. As such, this method is not currently applicable for the coastline and coastal sub-tidal regions.

The Significant Habitats of the Atlantic Coast Initiative (SHACI) involved the division of the Atlantic coast of Nova Scotia from Yarmouth to Black Point, Cape Breton, into 12 ecological units based primarily on physical environmental factors (McCullough et al. 2005). These regions were identified qualitatively for organizational purposes and align quite closely with Davis and Browne’s (1996) theme regions. SHACI units are also compared with four nearshore sub-regions of the Scotian Shelf Region that were defined by Lane and Associates (1992) for the identification of Marine National Areas of Canadian Significance by Parks Canada within the Scotian Shelf Region. The four nearshore sub-regions were defined by geological and oceanographic boundaries: the South Shore, the Eastern Shore, the Canso-to-Cape Breton Shore, and the Bras d’Or Lakes (Lane and Associates Ltd. 1992). The SHACI units most closely relate to the classification presented in this document, as they were identified based on both terrestrial and marine information. However, the seaward extent of the SHACI units is 12 nautical miles (McCullough et al. 2005).

[1] Fader, B.J. Unpublished report. A classification of bathymetric features of the Gulf of Maine. Consultant’s report to WWF-Canada (2007).

METHODS

The classification was designed to separate physiographically distinct coastline classes at two hierarchical levels. The first level differentiated “coastline environments” that delineated major distinct coastline segments including the Atlantic coast, Bay of Fundy and Gulf of St. Lawrence coastline environments. The second level of the classification identified “coastline segments” and “coastline sub-segments”. Coastline segments and sub-segments are considered to be at the same general scale and are, therefore, not hierarchical to one another.

The NS CCWG met several times to examine environmental variables (Table 2) and determine patterns and break points between segments. Major coastline environments were differentiated where at least two features converged, including major oceanographic changes and major topographic and/or geological changes. Break points were made for coastline segments and coastline sub-segments when one or multiple variables clearly changed their pattern. Coastline segments are groupings of two or more coastline sub-segments, which are physiographically distinct but were grouped because they shared one of the criteria described in Table 2.

The classification was created using an incremental approach starting with the definition of coastline sub-segments, which were then grouped into larger coastline segments. In the case of Chedabucto Bay, the opposite was true (this is discussed below). Following the identification of coastline segments, larger coastline environments were delineated. Coastline environments were established in areas where major oceanographic and /or topographic changes were present. While identifying coastline segments and sub-segments, the key difference between the three coastline environments were considered but it was not decided where to place the breaks between them until the classification was finished at the smaller scale.

A summary of the coastline segments and coastline environments that were grouped according to each criterion identified in Table 2 is outlined in Table 3 in the Results section.

Existing environmental data layers were acquired and mapped using ArcGIS. The environmental data layers quantified coastal, terrestrial and marine influences on the coastline and were chosen based on two criteria, and prioritized using a ranking presented in Table 2:

1. Those that were identified as primary drivers for species diversity and distribution patterns at a regional scale (Table 1; Roff and Zacharias 2011); and
2. Those for which data were available for the entire study area at the scale of the classification or those data sets that were available for individual sub-regions: Bay of Fundy, Atlantic Coast and the Gulf of St. Lawrence (see Data Layers section).

Certain factors were regarded as more important influences on species diversity and distribution patterns and were a priority when deciding where breaks should be placed. Those variables included intertidal and backshore substrate, exposure, topography, changes in shoreline direction, and dominance of geomorphic features (e.g., beaches, dunes, tidal flats, etc.).

Substrate, exposure and depth are expected to be the most influential variables determining species diversity and distribution at a similar scale in the coastal zone. Depth in this classification was limited to between the backshore and lower intertidal zone and, therefore, did not vary greatly throughout the classification. Other physical factors were of less importance when determining breaks but are known drivers of species diversity and distribution (See Table 2). Those factors change only gradually across the region at this scale of the classification (e.g., temperatures and freshwater influence). It is acknowledged that at the local scale these factors would have more of an influence in determining break points.

A unique characteristic of the Bay of Fundy region, that is known to be highly influential to biota that resides in that region, is the unique tidal range. This factor was regarded as highly important where it changes dramatically as it influences other physical factors as well, including turbidity, stratification, and temperature. Other factors such as upwelling (for which data could not be acquired), are highly important for influencing biological characteristics, but are correlated to other physical characteristics, such as the orientation to prevailing wind direction or tidal characteristics, which can be used in lieu of factors that could not be acquired in these situations.

PRIORITIZATION AND GROUPING CLASSES

A comprehensive network of MPAs in the coastal zone would protect a representative sample of each coastline class; however, it is generally understood that a network of MPAs must be developed in stages. As a practical consideration, coastline classes can be prioritized by grouping them at a higher level by general substrate type present. Substrate type was chosen as it is generally considered the most important factor structuring species diversity and distribution (Galparsoro et al. 2011; McArthur et al. 2010; Pitcher et al. 2012). Classes were grouped (Figure 3) based on major substrate present (soft, mixed or hard substrate).

DATA LAYERS

Physical Variables

Intertidal and Backshore Substrate and Character

Backshore, mid-intertidal zone and lower-intertidal zone substrate for the Maritimes Region were derived from the Environment Canada Atlantic Shoreline Classification (Laflamme et al. 2005). The classification was developed for the Atlantic Sensitivity Mapping Program (ASMP), which is directed at oil spill response contingency planning. Characteristics were measured using various tools including low-altitude videographic survey, aerial photography, and ground survey.

Geology

Bedrock

The terrestrial geology layer contains layers for geological features such as: bedrock geologic units, faults, geological contacts, isotope ages, other geological features (Fisher and Poole 2006). The original data for this layer were compiled and digitized from over 60 maps and sources of information.

Bedrock mapping for New Brunswick was obtained from the New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division (NBDNRE 2000). The map is intended to provide an overview of the bedrock geology of the province at a scale of 1:500,000.

Surficial

Surficial geology of the province of Nova Scotia was derived from the NSDNR digital surficial geology map (Fisher 2006).

Surficial geology for the province of New Brunswick was derived from New Brunswick Department of Natural Resources and Energy (Rampton 1984).

Tidal Characteristics

Tidal range was compared across the extent of the classification from data recorded in the Environment Canada Shoreline Classification (Laflamme et al. 2005) described above.

Shoreline Complexity

A complex shoreline creates a greater variety of microhabitat types than a more uniform shoreline, a greater total niche space, and provides refuge in the form of structural complexity (Gringold et al. 2010; Greenlaw et al. 2011; Thrush et al. 2011). The shoreline complexity metric used was from the Greenlaw Inlet classification (Greenlaw et al. 2011); details of the calculation method can be found in Greenlaw[1] (2009).

Topographic Characteristics

Topographic characteristics of the coastline and general exposure of stretches of shoreline were used to distinguish areas that were characterized by distinct topography (e.g, long drowned estuaries, areas with large amounts of islands, or long straight stretches of shoreline). Shoreline direction influences the biological characteristics of the shoreline, as the direction determines the orientation to the prevailing wind direction. The orientation to the prevailing wind direction influences the biota occurring at a given location, as it has a direct influence on upwelling and yearly temperature conditions. Qualitative observations were based on the Department of Natural Resources Coastline layer (Province of Nova Scotia 2012).

Sea Ice

Sea ice information was obtained using Environment Canada's online database of Frequency of Sea Ice maps (Environment Canada 2011). The "Frequency of Presence of Sea Ice (%)" charts consider the likelihood of total concentration of ice greater than or equal to 1/10 throughout the course of a year and are anticipated to give the reader an idea of the likelihood that ice will occur at a particular location for the appropriate date. The charts can be interpreted as the "odds of encountering sea ice for the dataset". The charts depict above-normal extent (1 to 33%), near-normal extent (34 to 66%) and below-normal extent (67 to 99%). The 0% line represents the maximum extent of sea ice; beyond it no ice was reported in the dataset; the 100% line represents the minimum extent of sea ice; within it there has always been ice reported in the dataset. There is a high level of confidence throughout this atlas series.

Landscapes

Natural Landscapes

Natural Landscapes are a product of the Nova Scotia Department of the Environment (NSDEL 2002). Eight Natural Landscapes have been delineated along the Atlantic coast. The Natural Landscape Classification distinguishes coastal landscapes from adjacent terrestrial landscapes

[1] Greenlaw, M.E. Unpublished thesis (M.Sc.). A classification of coastal inlets of mainland Nova Scotia, using geophysical information to define ecological representation and to evaluate existing and proposed protected areas. Acadia University, Wolfville, Nova Scotia (2009).

having similar bedrock, surficial materials, drainage patterns, and topography on the basis of the presence of coast-specific landforms (e.g., beaches, dunes, cliffs, and headlands) and ecosystems (e.g., stunted forests, coastal bogs and barrens, salt marshes), which have developed as a result of marine influences such as waves, wind, and salt spray.

Ecological Land Classification (ELC)

NSDNR developed its ELC (Neily et al. 2003) using similar criteria as the Natural Landscape Classification, except in coastal areas where marine criteria were excluded from ELC mapping protocols.

Wetlands

The NSDNR Wetlands and Coastal Habitats Inventory was used as an indication of wetland and coastal habitat features including: bogs, fens, marshes, flooded flats, swamps, saline ponds, dunes, beaches, and marine and estuarine flats (NSDNR 2000). However, some of these spatial data are no longer considered reliable (e.g., EF = Estuarine Flat; MF= Marine Flat).

Oceanographic Characteristics

Oceanographic characteristics were derived from numerous sources. Their compilation is described in the report of Smith[1] (2005). Oceanographic characteristics included benthic temperature average and variability, benthic salinity average and variability, and stratification. Temperature and salinity layers were derived from Naimie et al. (1994). Mean annual temperature and salinity data from Naimie et al. (1994) were used for the temperature and salinity averages, while temperature and salinity variability were calculated as the seasonal max-min. The calculation of seasonal layers ignores variability due to river plume movement, shelf break variations and warm core rings, leading to artificially low variability in frontal and nearshore regions. Interannual variability is also ignored. As such, the layers were used to define a general offshore condition, rather than actual values. These layers have benefit in describing regions of similarity.

Sub-tidal and Backshore Relief

A terrestrial Digital Elevation Model (DEM) from NSDNR was used to visualize the Nova Scotia backshore relief. Sub-tidal relief was modeled from a DEM created by combining point and contour data from the Canadian Hydrographic Service, Natural Resources Canada and the Nova Scotia Geomatics Centre into a single resolution (30 m) digital elevation model[2].

Watersheds and Embayments

The consideration of watersheds and embayments is more relevant for Nova Scotia than for New Brunswick. Nova Scotia has hundreds of coastal embayments and generally smaller watersheds, while New Brunswick's Bay of Fundy coastline varies between a few major river watersheds and a less crenulated shoreline with small river watersheds.

Primary watershed delineations for Nova Scotia, originally defined in the 1980s, were quite coarse for the coastal classification exercise and their boundaries tended to divide embayments,

[1] Smith, K.W. Unpublished report. A benthic habitat model for the Gulf of Maine (2005).
[2] Greenlaw, M. Unpublished data. Creation of a Maritimes Region Digital Elevation Model.

instead of enclose them. Therefore, it was decided to consider secondary watersheds flowing into single embayments. The Nova Scotia watersheds used in this classification exercise were based on the secondary watershed delineations from Nova Scotia Department of Environment (Charles S. Williams, version 18 May 2010, CSRS UTM Zone 20). For more details, refer to the Watershed Layer - Secondary Watersheds (lines).

Embayment delineations were based on Greenlaw et al. (2011), Gregory et al. (1993), Musquash Marine Protected Area definition and the historic scientific research area of Maces Bay.

Sub-tidal Substrate

Sub-tidal substrate was examined from two data sources including data from the Geological Survey of Canada (GSC; mud, gravel and sand grab points) and Canadian Hydrographic Service (CHS) substrate identifications from Hydrographic Service maps (digitized from NS Geomatics Centre; rock, boulder, sand, mud, clay, etc.).

Biological Information

Bird Information

The Canadian Wildlife Service's Key Marine Habitats for Migratory Birds on Eastern Canada's Atlantic Coast project described in Gromack et al. (2010) uses several data sets that have been used to describe bird distribution in each class. These datasets include: the Coastal Waterfowl Database (CWS Atlantic Region), the COEISDS Database – Common Eider and Sea Duck Surveys (CWS Quebec/Atlantic Regions), the Piping Plover Survey Database (CWS Quebec and Atlantic Regions), the ACSS Database – Atlantic Canada Shorebird Survey (CWS Atlantic Region), and the ARCD – Atlantic Region Colony Database (CWS Atlantic Region).

Macroalgae

Information on macroalgae was provided by Herb Vandermeulen, Habitat Ecologist with DFO's Science Branch, through personal communication (2012) based on macroalgae surveys. A study by Novaczek and McLachlan (1989) to determine the vertical and geographic distribution of marine algae in Nova Scotia in the Maritime Provinces was also used. Results from this study show that tidal amplitude, intertidal slope, wave exposure, ice scour, water temperature, and, to a lesser extent, geology, can affect the distribution of marine plants.

RESULTS

The coastline classification was broken into three coastline environments, the Bay of Fundy, the Atlantic coast of Nova Scotia, and the Gulf of St. Lawrence coastlines. The Bay of Fundy included 8 representative coastline segments with 15 sub-segments. The Atlantic Coast included 11 representative coastline segments with 18 sub-segments. The Gulf of St. Lawrence coast included 4 coastline segments with 8 sub-segments. Table 3 summarizes the dominant features of each of the three coastline environments and Table 4 summarizes the dominant features for each coastline segment and sub-segment.

Substrate, geology (bedrock and surficial) and topography were often the most useful factors when making decisions on a break point on the Atlantic or Gulf of St. Lawrence shorelines. Other factors taken into account were: tidal range, meso-scale temperature and salinity, turbidity, wave exposure, tidal range, ice presence, and frictional velocity. In the Bay of Fundy, oceanographic factors such as tidal range and turbidity change are greater and, therefore, were factors driving breakpoints in that region.

Classes were continuous, with a few exceptions, as it is recognized that there is a change in oceanographic factors across the study area that influences connectivity and larval supply. The exceptions included Annapolis Basin within the North Mountain Range and the highly variable Chedabucto Region. Efforts were made to keep embayments together within single classes as it is recognized that watershed characteristics including nutrient runoff, oceanographic influences influencing larval supply, and sedimentation are more consistent within embayments than outside of them. This was one of the primary criteria for grouping coastline sub-segments into larger segments, as outlined in Table 2. Embayments were kept together within coastline segments, but they were often divided into sub-segments due to variability in non-oceanographic factors. Chedabucto Bay and St. Georges Bay were broken into sub-segments within larger coastline segments after much discussion and debate. Chedabucto Bay was an area of contention due to obvious shoreline differences between the south and north sides of the bay, causing its division into sub-segments, with the same arguments made for St. Georges Bay. It was recognized that, from an oceanographic standpoint, these bays would have fairly uniform conditions and they were, therefore, grouped into larger coastline segments. In addition to keeping embayments together, other sub-segments were grouped together into larger segments using the criteria described in Table. Table 5 provides a summary of the sub-segments that were grouped according to each criterion.

The Northumberland Strait coastline was characterized by similar sets of coastal features occurring repeatedly over a relatively long distance, and so was classified as a single coastal line segment - one of the largest in the region.

If human influence had caused a change in the environmental condition or features of the region (e.g., dams and dykes), the group considered the previous state of the environment when determining break points, if it was known.

It is noteworthy that the shoreline segment where the watershed/embayment factor became an especially important consideration was Annapolis Basin. Other shoreline segments that used watershed/embayments as a significant consideration for determining appropriate endpoints were: Chedabucto Bay, St. Margarets Bay/Mahone Bay separation point, St. Marys Bay/Digby Neck area and Passamaquoddy Bay.

Evidence of how marine plant and bird species abundance and distribution vary between coastline environments and segments is described in Table 4. Class 10 (Lobster Bay Salt Marshes and Islands) is unique in its high abundance and diversity of macroalgae (DFO 1998). Classes 9-12 are dominated by the rockweed species *Ascophyllum nodosum,* which is highly abundant and, heading eastward from class 12, *Ascophyllum* becomes much less abundant (H. Vandermeulen, pers. comm. 2012), which is reflected in highly reduced harvesting levels. Heading westward from class 18, *Fucodium nodosum* begins to dominate due to changes in temperature and ice cover in winter months (H. Vandermeulen, pers. comm. 2012).

DISCUSSION

This classification was created in a Delphic (expert-driven) process to derive coastline regions that are physiographically similar for application in ecosystem-based management initiatives including MPA planning. Using a Delphic process was considered the best option for the area to link biological patterns to physiographic changes within this region, where region-wide biological data are lacking. In a Delphic process such as this, decisions are sometimes subjective. Many of the classification breaks involved much discussion between experts, and the classification could have a different result depending on the experts involved. The Delphic approach brings invaluable knowledge and expertise of those involved that is not collectively captured in literature, bringing a variety of perspectives to the process that resulted in a classification that is not only agreed upon but, in fact, aligns with many of the previous classifications done in this region for single management purposes. The individuals involved in this process were identified as key experts in this subject matter with an extensive knowledge of Nova Scotia's coastline and, therefore, the authors have a high confidence in the resulting classification.

The classification was created at two main scales to facilitate its use in coastal management, marine spatial planning, and conservation planning. These scales represent the first levels necessary to develop a fully ecologically relevant hierarchical classification of coastal and marine environments (Table 1). Eventually, finer scales should be described and delineated for the purpose of representative MPA planning.

The main use to date for the work described in this report has been MPA planning. For this use, the classification will have to be used in conjunction with other information, including EBSAs, where a prioritization exercise could be used to determine which areas might be recommended next for protection. Subsequent protected areas should be representative of different types of ecological units that are not already protected.

With 19 coastline segments (32 including sub-segments) on the Atlantic Coast, representing each of these classes may not be practical for MPA network planning purposes. Within the coastline segments, the coastline sub-segments were preserved to recognize the differences between sub-segments that should be taken into account when designing a protection scheme within the segment. However, to recognize a practical number of groupings that might be protected, even at the coastline segment level, classes may have to be grouped based on similar physical factors most important for influencing species diversity and distribution (e.g., substrate, Figure 3).

It should be determined how much of the coastline and EBSA area are currently protected and in which physiographic regions these protected areas lie. This will help to determine what types of ecosystems are currently missing protection and how the protection of specific EBSAs could contribute towards representing different ecosystems in a protection scheme. There are various protected area types along the coast of varying protection levels. However, very few of these existing protected areas extend seaward into the intertidal zone, and those that do are often single-species focused with few, if any, habitat protection provisions (if this is the case, they're not really protected areas, e.g., migratory bird sanctuaries, and should not be described as such). These areas require assessment against MPA network criteria to determine whether or not they will be counted as MPAs or contributory sites in the MPA network for the Scotian Shelf / Bay of Fundy Bioregion. A gap analysis to determine the classes that are not yet represented by protected areas will be required, and it may be a relatively simple exercise.

Efforts have been made to validate this classification using distributional data and information on marine algae, eelgrass, and birds. Based on comparison with these data, the physiographic patterns recognized in this classification are reflective of biodiversity changes across the coastal environments. This classification should be continually evaluated against additional biological data as they become available.

Within each physiographic region, there will be a variety of geomorphic units, and within each geomorphic unit will be a variety of primary habitats (Table 1). The design of protected areas within each physiographic region should reflect the variety of geomorphic units and primary habitats within that region. To accomplish this, further classification at smaller scales is required. On the coastline, a next step would be to classify specific geomorphic units (beaches, dunes, rocky intertidal stretches). However, this is a long-term process that is not required to move forward with MPA network planning. It is recommended that this coastline classification coupled with the coastal sub-tidal classification that is being developed by Greenlaw et al.[1] be used for MPA network planning in their current state and adapted as necessary by managers. Environment Canada's shoreline classification and NSDNR's Wetland and Coastal Habitat Inventory can be used to ensure that a high proportion of primary habitats within each class are captured when designing MPAs.

POSSIBLE NETWORK OBJECTIVES

There are various possible configurations for a comprehensive network of MPAs in the coastal zone, depending on conservation priorities, data availability, funding, personnel availability, political will, public support, etc. It is recommended that classifications are developed first to support planning for representation at the regional level, with the eventual goal of classification at a primary habitat level. Classification of primary habitats would require physical factors at the resolution of at least tens of kilometres and the classification of substrate-based units at the same scale for benthic and coastal habitats. These scales are not yet approachable in many of the ecoregions of Canada, especially the Arctic.

Example MPA network objectives for the coastal areas of the Scotian Shelf Bioregion that ensure representation is incorporated in the MPA network, at decreasing spatial scales, are:

1. Regional Scale: Protect one or more examples of each coastline and sub-tidal coastal class (e.g., figures 2 and 3).

2. Geomorphic Unit Scale: Protect a certain percentage of each geomorphic unit, if possible, within each class or each group of classes. Geomorphic units are the next level in the ecological hierarchy (Table 1). Given data layers that are currently available in certain portions of the coastal and offshore regions of the Maritimes Region, it may be possible to protect a certain percentage of each geomorphic unit within each representative class. Offshore classifications such as Fader's[2] (2007) seabed feature classification (e.g., banks, basins, channels) have been used in a MARXAN analysis where the aim was to protect a target percentage of each seabed feature. In the offshore MARXAN analysis, a conservation target of 10% for each of the representative layers was used in the best solution scenario (Horsman 2011). In the nearshore sub-tidal zone, Greenlaw et al. (2011) completed a classification of 11 different types of inlets that could be used to protect a certain proportion of these features in a sub-tidal classification. A

[1] Greenlaw, M. E., M. Doon, and P. Lawton. Unpublished data. A physiographic classification of the coastal sub-tidal Scotian Shelf Bioregion and environs.
[2] Fader, B.J. Unpublished report. A classification of bathymetric features of the Gulf of Maine. Consultant's report to WWF-Canada (2007).

possible next step to the coastline classification would be to identify geomorphic units such as dunes, rocky intertidal areas and sandy beaches.

3. Primary Habitat Scale: Establish a conservation target for primary habitats, i.e., within each region protect 20% of muddy habitats, 20% of cobble habitats, 20% of rocky habitats, 20% of sandy habitats. For the coastline this could be accomplished using Environment Canada's shoreline classification data (e.g., Figure 4). A sub-tidal substrate layer[1] is being developed in coordination with the sub-tidal classification[2].

Iterations of examples one and two above are likely to be the primary objectives used to identify the MPA network until ample data are available for setting objectives to protect features at finer scales in the classification hierarchy, as described in example three.

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Table 1. Hierarchical classification scheme for marine environments. As seen in Greenlaw[1] (2009) and Roff and Zacharias (2011), originally modified from Butler et al. (2001) and Beaman (2005).

Level	Unit Name	Scale	Description
1	Province	Province (1000s+ of km)	Broad-scale geological units such as continental blocks, basins and abyssal plains. May include distribution data of fish assemblages.
2	Ecoregion	Regional (1000s of km)	Distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the ecoregions 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.
3	Regional	Regional (100s to 1000s of km)	Broad-scale gross geomorphology nested within Provinces, e.g., continental shelf, slope, abyssal plain and offshore continental blocks.
4	Geomorphic Units	Regional (100s of km)	Areas with similar seabed geomorphology and usually with distinct biotas, e.g., seamounts, canyons, rocky banks, inlets, submarine canyons and sand wave fields.
5	Primary Habitats	local (10s of km)	Nested within Geomorphic Units are soft, hard or mixed substrate-based units, together with their associated substrate-based units and their associated biological communities.
6	Secondary Habitats	site (<10 km)	Generalized types of biological and physical substrate within the soft, hard or mixed substrate, e.g., limestone, granite, shelly sand and muddy sand.
7	Biological Facies	site (<10 km)	Biological indicator or suite of species used as a surrogate for a community, e.g., species of seagrass, group of hardcorals or sponges.
8	Microcommunities	site (<10 km)	Assemblages of species that depend on member species of the Biological Facies, e.g., holdfast communities in giant kelp.

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Table 2. Criteria for identifying classes at different scales: Coastline Environment scale (3 classes), Coastline Segment scale (23 classes), and Coastline Sub-segment scale (approximately 30 sub-classes). Factors are ordered by the proportion of time criteria were considered when deciding on break points.

Coastline Environments	Coastline Segments	Coastline Sub-segments
• Major oceanographic changes • Major topographic and geologic changes	• The same factors applied as at the sub-segment level but with the following considerations: • Larger geomorphic units (e.g., keeping bays of 20 km2 together, grouping classes on the same island together) • Aggregations/repeating of common landforms (e.g., repeating dunes, sandy beaches, mudflats, such as in the Inner Bay of Fundy) • Grouped in single unique features that were smaller in scale (e.g., Annapolis Basin) • Grouped areas with small differences; e.g., difference in one factor, small changes among multiple factors	• Intertidal and backshore substrate (grain size more influential, but geological origin also considered) • Shoreline direction/ Exposure • Topography (relief and shoreline complexity) • Dominance of coastal physiographic features (e.g., beaches, dunes and tidal flats, etc.) • Geological Character (bedrock and surficial) • Turbidity • Freshwater/Salinity • Temperature • Tidal Range • Ice Presence • Current/Frictional Velocity

Table 3. Overview of the dominant features and justification for breakpoints for the three coastline environments (adapted from Owens and Bowen 1977, marine algae information from Novaczek and McLachlan (1989)).

Bay of Fundy	Atlantic Coast of NS	Gulf of St. Lawrence
Major Oceanographic Differences		
• Tidal range from 4-15m (macrotidal regime) • High turbidity • High current velocity	• Tidal range from 2-4m (mesotidal regime) • Low to moderate turbidity	• Tidal range from 1-2m (microtidal regime) • Moderate turbidity • Influenced by the colder, less saline waters of Laurentian Channel • (warmer in summer and colder in winter than Atlantic coast and Bay of Fundy) • Greater freshwater input from much of Eastern Canada transported by the Laurentian Channel
Major Topographic Differences		
• Few coastal landscape features, dominant features include cliffs and mudflats; topographically simple shoreline • Geology: resistant igneous and unresistant sedimentary rocks overlain by till or outwash • Moderately exposed compared to the Atlantic coast and Gulf • Minimal ice coverage • Sediment supply abundant in Upper Bay of Fundy but scarce elsewhere • Dominant linear topographic feature (basalt ridge) separates the Bay of Fundy from the Atlantic coast	• Generally low-lying, resistant, highly crenulated rocky shoreline • High variety of coastal landscape features including sandy beaches, estuarine and marine flats, barrier beaches and sand dunes. • Geology: predominantly igneous or metamorphic rock overlain by till or drumlins • Highly exposed shoreline with several inlets that provide some shelter • Ice in sheltered bays in winter months • Sediment supply scarce or very scarce	• Highly exposed in some areas but mainly sheltered • Several estuaries, high abundance of landscape features such as dunes, sandy beaches, barrier beaches, and low-lying cliffs. • Geology: predominantly unresistant Carboniferous sedimentary rocks with metasediments and igneous rocks in eastern areas: overlain by thin till deposits • Ice coverage for 7-8 months of the year • Sediment supply is generally abundant • Highly impacted by storm surges due to unresistant rock and low relief in some areas
Biological Differences		
• Very extensive salt marshes, absence of eelgrass • Macroalgae diversity in intertidal zone is lower than on Atlantic coast but higher than in the Gulf of Saint Lawrence	• Pockets of salt marshes and eelgrass beds • Highest diversity of macroalgae species in intertidal zone compared to other coastal environments	• Several salt marshes and eelgrass beds • Lowest diversity of macroalgae species in intertidal zone, conversely has highest diversity in sublittoral zone.

Table 4. An overview of the dominant features and justification for breakpoints of the coastline segments and sub-segments.

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
Bay of Fundy – New Brunswick					
Grand Manan	1a	Grand Manan Cliffs	Topography, uncomplex cliff shoreline with gravel lower intertidal	Class 1 (generally): High abundance of *Palmaria palmate* (dulse)*	N:Northern Head S:Southern Head
	1b	Grand Manan Archipelago	Complex shoreline and archipelago with bedrock shoreline	Important bird area (seaducks, geese and bayducks)	N: Northern Head S: Southern Head
Quoddy Region	2a	Letete Passage and Islands	Complex topography Higher current Predominantly rocky shoreline substrate		S: Green Point N: Goose Point
	2b	Passamaquoddy Bay and St. Croix Estuary	Sheltered by islands Mixed muddy and rocky shoreline		W: Goose Point E: Frost Cove
	2c	Letete Inner Reach	Sheltered complex estuary		N: Green's Point S: Pea Point
	3	Maces Ledges	Complex topography Exposed shoreline		W:Pea Point E: Welch Cove
	4	Musquash Marshes and Beaches	Backshore salt marsh and bedrock shoreline		W: Welch Cove E: Sheldon Point
	5	Saint John Bluffs	Topography bluffs		W: Sheldon Point E: Cape Spencer
	6a	Fundy High Cliffs	Predominantly unerodable bedrock cliffs		W: Cape Spencer E: Frownes Head (Near St. Martins)
	6b	Fundy Erodable Cliffs and Coarse Beaches	Shoreline straight Predominantly bedrock cliffs		W: Frownes Head (Near St. Martins)E: Cape Enrage
Bay of Fundy – Nova Scotia					
Inner Bay of Fundy	7a	Chignecto Bay Tidal Flats and Salt Marshes	Substrate predominately mud Extreme tides: very large tidal range High turbidity Extensive estuarine/marine flats	Several extensive salt marshes	W: Cape Enrage E: Cumberland basin, Ragged Reef point.
	7b	Cape Chignecto Cliffs	Backshore substrate predominately unresistant bedrock Intertidal substrate alternates between sand-gravel and pebble/cobble	The only backshore pebble-cobble found in the Bay of Fundy is found here and at Blomidon	N: Cumberland basin, Ragged Reef point. S: Five Islands (Clarke Head)

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
				Topography: relatively straight shoreline	
	7c	Cobequid Bay Tidal Flats and Salt Marshes	Very high turbidity Substrate predominately sand with mud in estuaries Very extensive estuarine flats, some cliffs Extreme tides: very large tidal range	Several extensive salt marshes Class 6 and 7 have the most extensive estuarine flats in the Bay of Fundy Shoreline somewhat sheltered	S: Five Islands (Clarke Head) S: Split rock, after Johnson Cove
	7d	Minas Basin Tidal Flats	High turbidity (although not as turbid as class 6) Substrate predominately mud with sand Very extensive estuarine flats, topographically complex, some cliffs Extreme tides: very large tidal range	Extensive salt marshes Shoreline is more complex and sheltered than in class 6 Aggregations of sand pipers Class 6 and 7 have the most extensive estuarine flats in the Bay of Fundy and likely the whole Maritimes Region	E: Split rock, after Johnson Cove W: Blomidon Provincial Park
North Mountain Bedrock Cliffs and Annapolis Basin	8a	North Mountain Bedrock Cliffs	Shoreline is very straight Cliffs are dominant landform; very few other coastal features Substrate is predominantly resistant bedrock	Scott's Bay is a unique feature in this class (wide tidal flat) Dominant marine algae species is *Palmaria palmate* (dulse) which tolerates highly disturbed and rocky areas*	E: Blomidon Provincial Park W: Long Island – East ferry at the south point of Digby neck
	8b	Annapolis Basin	Shoreline is sheltered and more complex Substrate is predominately sand Estuarine and marine flats present	Salt marshes present Known as important area for clamming	W: Prim Point E: Victoria Beach
Atlantic Coast of Nova Scotia					
Meteghan Cliffs and Beaches	9a	St. Mary's Bay	Topographically unique from surrounding regions: long, narrow bay with straight shoreline Presence of extensive marine flats Shoreline direction change from class 8 and more sheltered than surrounding classes	General change in tidal characteristics from surrounding regions Higher turbidity in St Mary's Bay compared to further south Substrate is mixed sand/gravel and pebble/cobble	N: Long Island – East ferry at the south point of Digby neck S: St. Mary's Bay (Church Point)
	9b	Meteghan Cliffs and Beaches	Straight shoreline with small intermittent coves Cliffs are the dominant landform Highly exposed shoreline	Substrate is very mixed: sand/gravel, pebble/cobble and bedrock - Topography change from large drowned river estuaries	N: St. Mary's Bay (Church Point) S: Chegoggin Point

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
				(i.e., Lobster Bay) to straight small beaches	
	10	Lobster Bay Salt Marshes and Islands	Topographically unique: complex shoreline with numerous islands Substrate unique: predominately mud with sand and gravel Beginning of very large tidal range going from the Atlantic coast into the Bay of Fundy: persistent upwelling causing warmer average yearly temperatures and high productivity in the outer bay	Several extensive salt marshes Unique species of coastal plains flora Extensive eelgrass beds Known as a unique area for its high diversity and abundance of intertidal macroalgae, especially rockweed and Irish moss*	W: Chegoggin Point E: Shag Harbour (Prospect Point)
	11	South Shore Sandy Beaches	Substrate is predominately sand and gravel Largest concentration of sandy beaches of all classes Topographically unique: several long narrow inlets with low shoreline complexity Diversity of coastal landforms: beaches, dunes, estuarine and marine flats	Salt marshes present Extensive eelgrass beds in inlets Major change in tidal range at Shag Harbour, known as the region where tides “turn the corner” around NS	W: Shag Harbour (Prospect Point) E: Medway Harbour (Pollock Point)
Mahone Bedrock Shore and Islands	12a	Mahone Bay Islands	Very complex shoreline with several islands Substrate is coarse and rocky (pebble/cobble and bedrock)	Few and small (but diverse) coastal landforms including beaches, marine flats and salt marshes	W: Medway Harbour (Pollock Point) E: Aspotogan Bay (White Point)
	12b	Chebucto Bedrock Shore and Islands	Substrate is predominately boulder and bedrock Tidal range drops below 2 m for most of class (wind driven)	Coastal landforms including beaches and marine and estuarine flats Class 12a&b: More warm water fish species can be found here due to the effect of warm core rings from the Gulf stream* *Ascophyllum* is abundant and *Codium* is common; sparse eelgrass*	W: Aspotogan Bay (White Point) E: Halifax Harbour (Purcels Cove)

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
	13	Eastern Shore Beaches and Drumlins	Very extensive estuarine flats are prominent feature Highly complex, sheltered coastline Diversity of coastal landforms and sensitive features including sandy beaches, barrier beaches, dunes and coastal saline ponds	Very extensive salt marshes Very extensive eelgrass beds Offshore substrate is primarily sandy Very few islands Substrate alternates between sand, pebble/cobble, gravel and mud Benthic community structure similar throughout this class with abundant *Fucus* and kelps and a diversity of marine algae in general. Some dense eelgrass beds exist*	W: Halifax Harbour (Herring Cove) E: Clam Bay (Little Harbour Head)
	14	Sheet Harbour Islands	Topographically unique: very complex shoreline with many islands – extensive, undeveloped archipelago; islands create sheltered effect Substrate predominately rocky (bedrock, pebble/cobble, boulder)	Offshore substrate is primarily resistant bedrock	W: Clam Bay (Little Harbour Head) E: Liscomb Harbour (Liscomb Point)
Country Harbour Headlands	15a	Country Harbour Headlands	Shoreline somewhat complex with elongated inlets Substrate predominately mixed coarse substrate and sand	Coastal features/landforms include some sandy beaches and marine and estuarine flats	W: Liscomb Harbour (Liscomb Point) E: Tor Bay (Flying Point)
	15b	Canso Bedrock Shore and Islands	Substrate predominately boulder and bedrock Large headlands with few inlets Very few other coastal landforms, only small marine flats		W: Tor Bay (Flying Point) E: Glasgow Head
Chedabucto Bay and Canso Strait	16a	Chedabucto Bedrock and Pocket Beaches	A fault line cuts through Chedabucto Bay, causing the north and south shorelines to have different bedrock and some differences in substrate. The substrate throughout this class is predominately rocky with more sand on the north shoreline of Chedabucto Bay. Surficial geology is predominately till plain (ground moraine)		S: Glasgow Head N: Toby Point

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
	16b	Chedabucto Bay Beaches and Till Cliffs	There are relatively straight coastline with few coastal landforms: small marine flats throughout the class, a few coastal saline ponds and beaches (including barrier beaches) on the north shore	More rockweed than classes 16a and 16c*	S: Toby Point N: Eddy Point Note: This class also extends onto Isle Madame (from Crichton Island to Petit Nez Beach) and on Cape Breton Island (from Point Brulee to Point Michaud)
	16c	Canso Strait and Lennox Passage	Shoreline is very complex with several islands and most of this class is quite sheltered Coastal landforms include marine flats, a few estuaries, coastal saline ponds and some beaches Substrate is diverse but predominately mixed coarse in the intertidal and sand in the lower intertidal	A few salt marshes Narrow fringe of intertidal rockweed (*Ascophyllum*), less abundant than class 16b*	W: Heffernan Point (North edge of Canso Strait) S: Eddy Point and Crichton Island to Petit Nez Beach on Isle Madam E: Point Brulee (St. Peter's Bay)
Framboise Cliffs and Beaches	17a	Framboise Till Cliffs and Beaches	Substrate: resistant bedrock with sand beaches in the lower intertidal Barrier beaches and coastal saline ponds are a prominent coastal feature Topographically simple with long straight coastline	Surficial geology is consistent in this region (glaciofluvial deposits) Clear change in macrophyte community compared to class 16c to a high energy invertebrate and coralline algae dominated community where rockweed thins out*	W: St. Peter's Bay (Michaud Point) E: Louisbourg Harbour (Blackrock Point)
	17b	Scatarie Bedrock Cliffs	Substrate is predominately resistant bedrock with mixed coarse in intertidal zone and primarily bedrock in the lower intertidal Cliffs are dominant coastal landform	Offshore substrate is very rocky Bedrock is predominately	W: Louisbourg Harbour (Blackrock Point) E: Moque Head
East Cape Breton Cliffs	18a	Sydney Cliffs and Beaches	Shoreline has several repeating features: bays, barrier beaches and coastal saline ponds Contains the only natural connections	Salt marshes and eelgrass beds found within coastal saline ponds Significant river input due to	E: Moque Head W: Carey Point

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
			between the Bras d'Or Lakes and the Atlantic (Great Bras d'Or and Little Bras d'Or Channels) Substrate is predominately bedrock with pockets of sand in the intertidal	connection with Bras d'Or Lakes Surficial geology predominately stony till plain Bedrock predominately	
	18b	Ingonish High Cliffs	Topographically simple with a predominately long straight coastline and a few bays with barrier beaches and large coastal saline ponds Substrate is predominately mixed coarse with sand in bays and occasional bedrock Very little river input	Bedrock is very diverse Surficial geology is predominately	E: Carey Point W: Cape North
Southern Gulf of St. Lawrence Coast					
Northern Cape Breton High Cliffs	19a	Cape St. Lawrence High Bedrock Cliffs	Dominant coastal feature is very high cliffs (Cape Breton Highlands) Topographically simple with very straight shoreline Substrate is predominately bedrock	Surficial geology is predominately colluvial deposits Meat Cove could be pulled out as a unique feature at a finer scale	E: Cape North W: Cheticamp River
	19b	Margaree Cliffs and Beaches	Substrate is predominately boulders in the backshore and sand and gravel in the lower intertidal Topographically simple, very straight shoreline Very few coastal landforms; mainly cliffs and marine flats	Marsh grass occasionally in the lower intertidal	E: Cheticamp River W: North of Mabou mountains
St. Georges Bay	20a	Judique Beaches	Topographically simple with long straight coastline, no inlets but there are two distinctive islands in the north This shoreline is more sheltered, the shoreline faces directly west unlike other NS classes in this Gulf Substrate is predominately mixed coarse (pebble/cobble and sand/gravel)		N: North of Mabou mountains W: Heffernan Point
	20b	South River Sandy Beaches and Estuaries	Topographically complex with several estuaries Barrier beaches are the dominant	Large estuarine flats Extensive salt marshes and eelgrass beds	E: Heffernan Point W: Mahoneys Beach

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
			coastal landform; dunes and coastal saline ponds also present Substrate predominately mixed coarse along straight shoreline, predominately sand in the lower intertidal with some mud		
	20c	Cape George Cliffs	Topographically simple shoreline with few inlets Substrate predominately mixed coarse with some bedrock	Diverse bedrock and surficial geology	W: Lismore E: Mahoneys Beach
	21	Northumberland Estuaries, Beaches and Cliffs	Topographically complex with a pattern of rocky shorelines interspersed with estuaries and associated coastal landforms: estuarine and marine flats, barrier beaches, fringing beaches, dunes and coastal saline ponds Shoreline is sheltered by PEI Substrate predominately sandy in the lower intertidal and mixed coarse (pebble/cobble) in intertidal and backshore Tidal range is 2-4m (change from the rest of Southern Gulf of St. Lawrence (NS) and eastern shore of Atlantic coast which is only 0-2m)	Several extensive salt marshes and eelgrass beds Surficial geology is predominately silty till plain Wallace Bay and Tatamagouche could be broken out into smaller classes at a finer scale	W: NB Border E: Lismore
Other					
Bras d'Or	22a	Great Bras d'Or	Long narrow inlets and channels More circulation and mixing than class 33 More ice cover than class 33 Contains the only natural connections between the Bras d'Or Lakes and the Atlantic (Great Bras d'Or and Little Bras d'Or Channels)	Seven sub-watersheds drain into this area Small salt marshes Extensive eelgrass beds Small marine flats and beaches are prominent coastal landforms, but small compared to rest of NS More abundant and larger eelgrass beds than class 22b*	N: Great Bras d'Or Channel S: Barra Strait

Class Name	#	Sub-Class Name (former class #)	Dominant Feature(s)	Other Important Features (incl. biological)	Breaks
	22b	Big Bras d'Or	Topographically complex with numerous islands and large bays More exposure and greater wave and wind action than class 22a Larger and more extensive coastal landforms than class 22a: marine flats, estuarine flat in Denys Basin, coastal saline ponds, and beaches	Five sub-watersheds drain into this area Connection between the Bras d'Or Lakes and the Atlantic at St. Peters Canal Small salt marshes Extensive eelgrass beds, especially in Denys Basin Highly productive rocky reefs with *Phyllophora* and red turf algae on a large cobble bottom.	N: Barra Strait S: St. Peter's Canal
	23	Sable Island	Physiographically unique as a standalone island 200 km southeast of mainland NS composed entirely of unconsolidated sand, shaped by wind and waves Dune ridges and beaches characterize the island and are the only coastal landform Sand	Very little vegetation; only dune grass and associated flora and fauna	N/A (entire island)

*H. Vandermeulen, DFO Science Branch, pers. comm. 2012.

Table 5. Criteria used to group each coastline sub-segment into larger coastline segments according to each criterion outlined in Table 2.

Criteria for Defining Coastline Segments	Coastline Segments
• Larger geomorphic units	• Segment 1: Grand Manan Island • Segment 2: Passamaquody Bay • Segment 16: Chedabucto Bay • Segment 20: St. Georges Bay • Segment 22: Bras d'Or Lakes
• Aggregations/repeating of common landforms	• Segment 7: Inner Bay of Fundy – Repeating cliffs and mudflats • Segment 12: Repeating landforms including beaches, islands, and small wetlands • Segment 18: Sydney Bight coastline – Repeating landforms including cliffs and barrier beaches; all sub-segments have very little freshwater input.
• Grouped in single unique features that were smaller in scale	• Segment 8: Annapolis Basin is a unique feature that otherwise breaks up this segment
• Grouped areas with small differences; e.g., difference in one factor, small changes among multiple factors	• Segment 9: Changes in exposure but topography and substrate very similar (long straight/simple coastline) • Segment 12: Very small changes in substrate, geology • Segment 15: Small change in substrate and coastal landforms. • Segment 17: Small changes in substrate and geology. • Segment 19: West coast of Cape Breton – small changes in substrate but topographically very similar

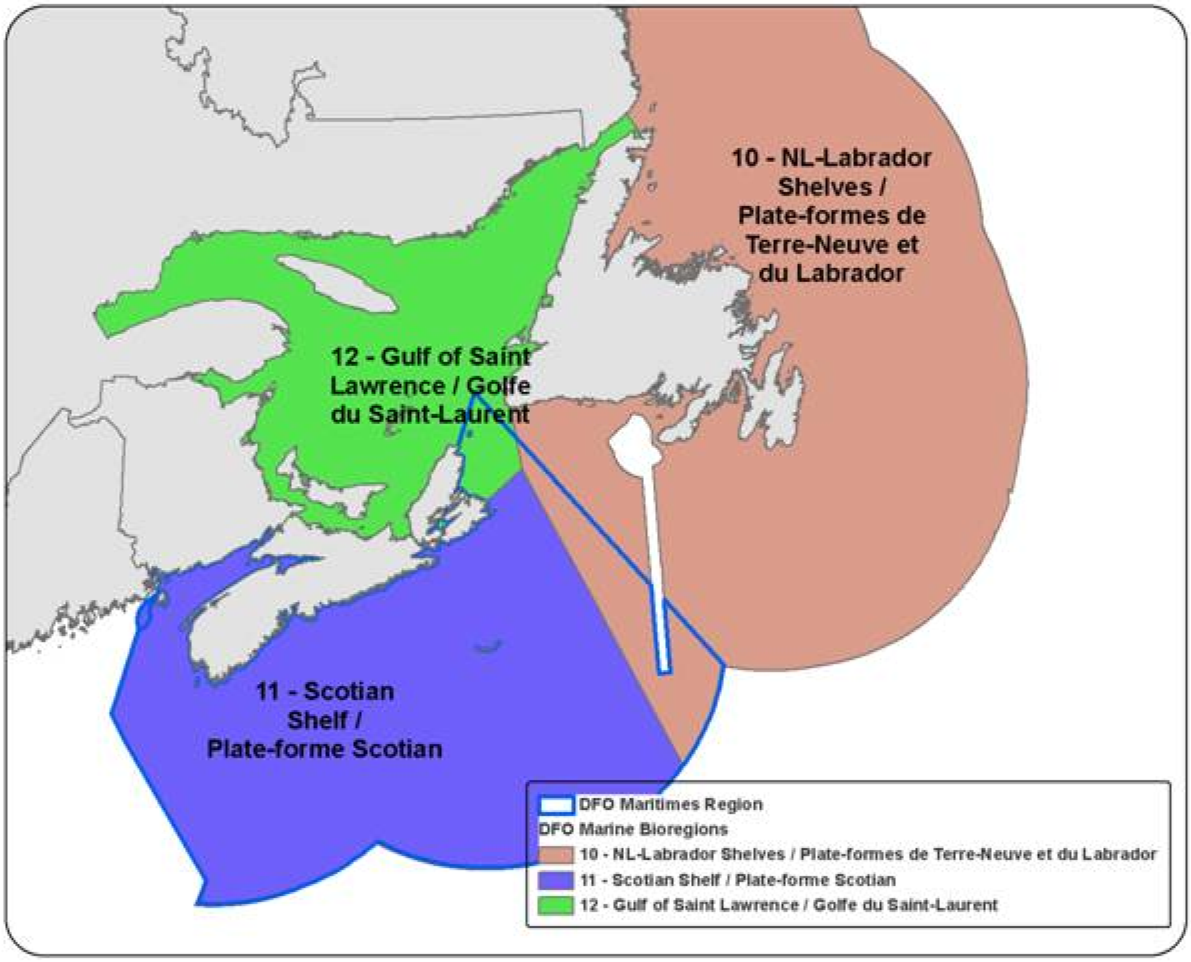

Figure 1. Biogeographic Regions from (DFO 2009).

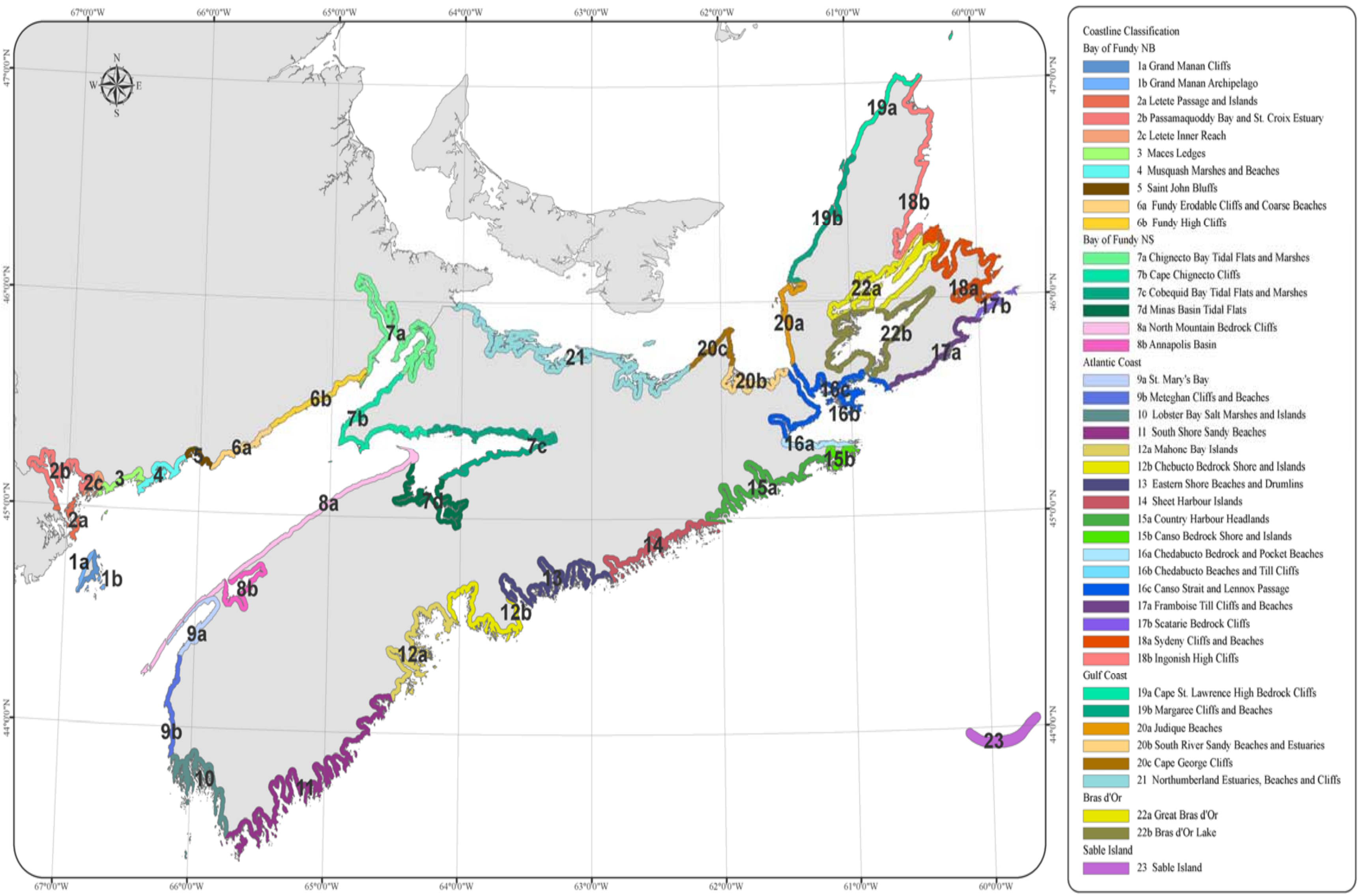

Figure 2. The 23 representative coastline classes on the Nova Scotia and New Brunswick Bay of Fundy coastline.

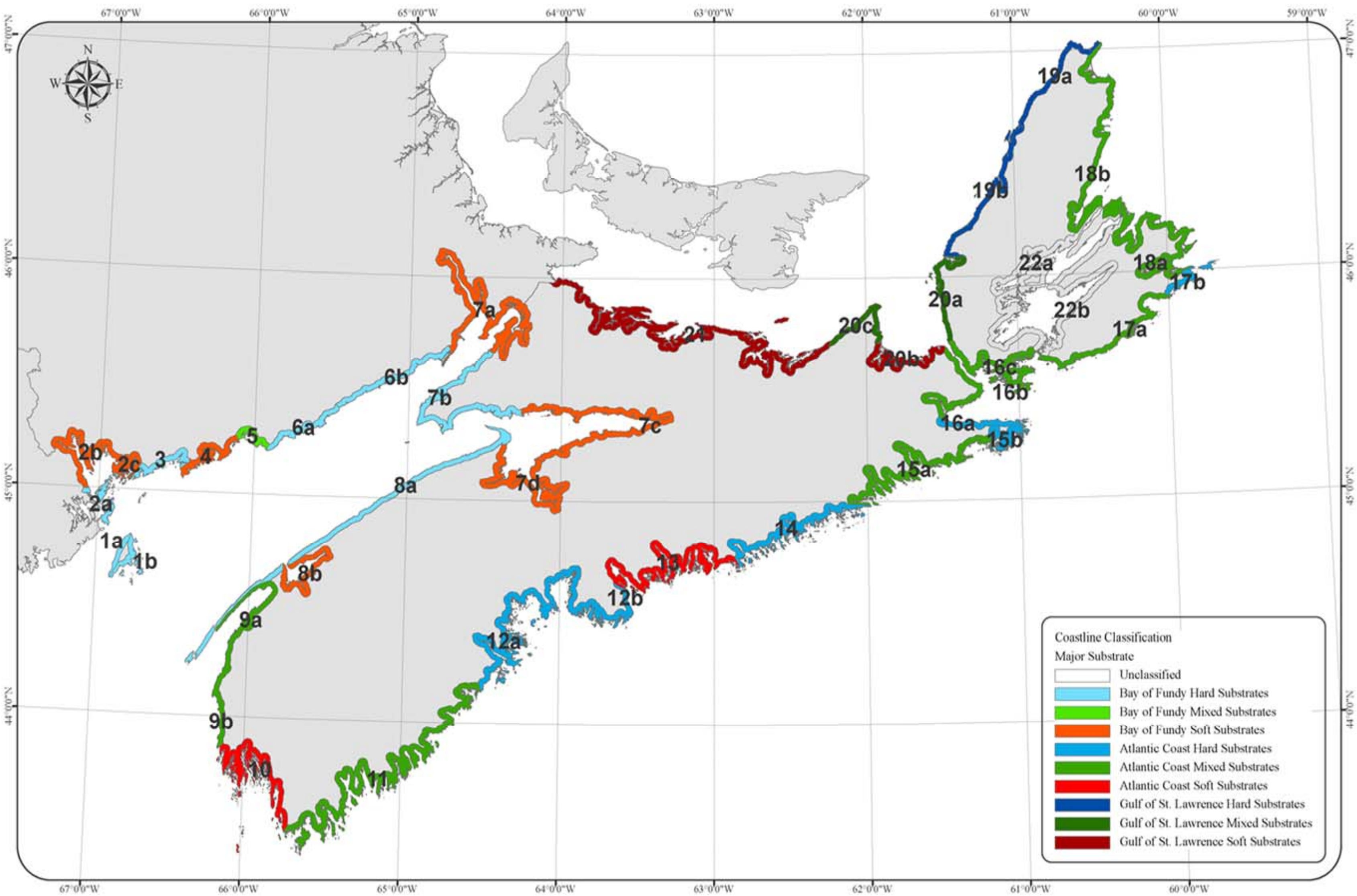

Figure 3. Coastline classes in each of the Coastal Environments grouped by their major substrate present including: soft, mixed and hard substrates.

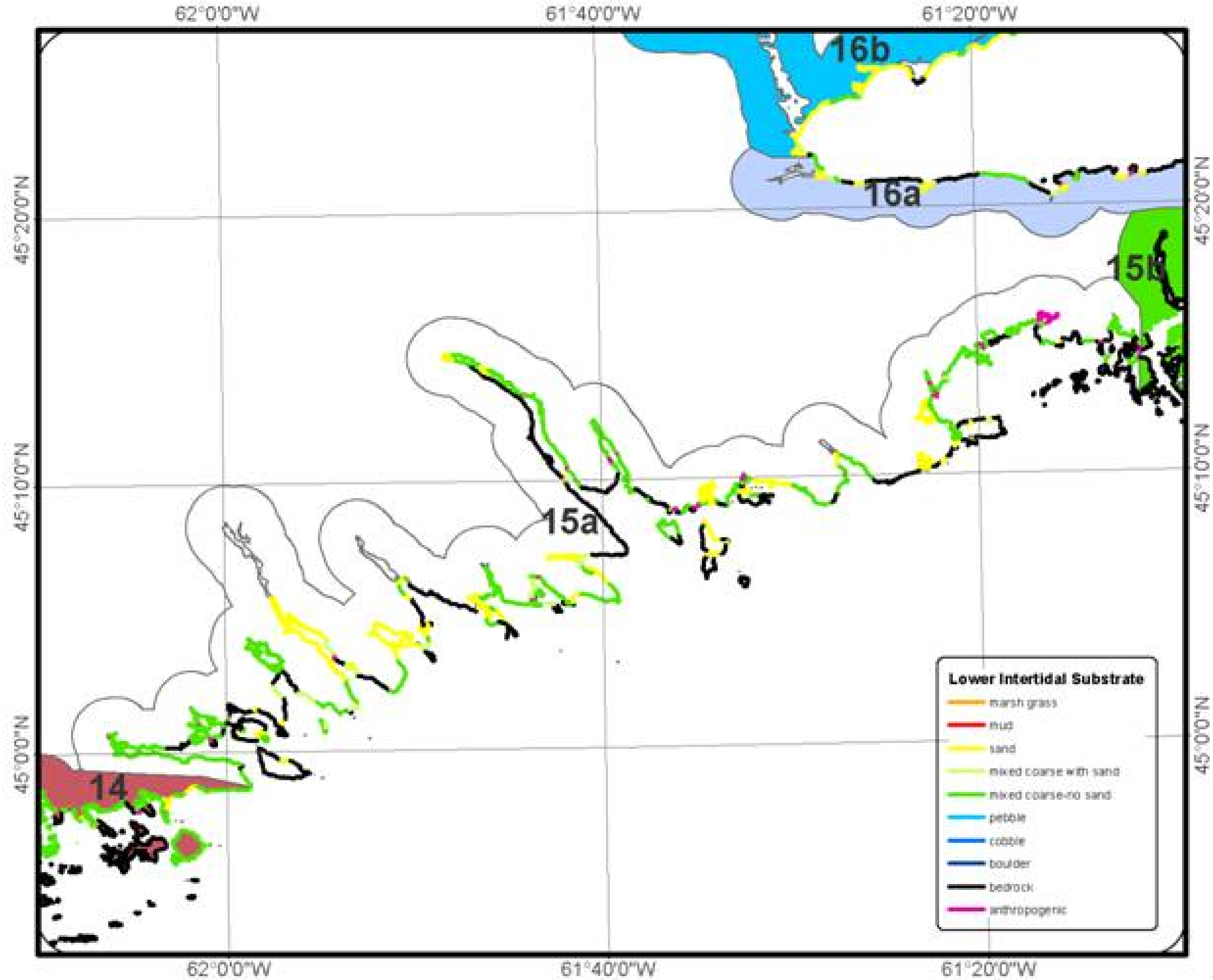

Figure 4. Example of Environment Canada's Shoreline Classification data overlaid onto class 15a – Country Harbour Headlands, showing the variety of substrates present including bedrock, mixed-coarse, sand and mud. These different primary habitats are all characteristic of the physiographic region and should all be reflected in an MPA protection plan.