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Review of Selected Biogeographic Classification Systems with Relevance to the Canadian Marine Environment

Examen de systèmes de classification biogéographique choisis liés au milieu marin du Canada

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ABSTRACT

Fisheries and Oceans Canada (DFO) hosted a national science advisory process on June 15-16, 2009 to develop a framework and principles for the biogeographic classification of Canadian marine areas in the Northwest Atlantic, North Pacific and the Arctic. In the past decade, there have been a number of international, national and regional biogeographic classification exercises (e.g. Large Marine Ecosystems, Global Open Oceans and Deep Seabed Biogeographic Classification, Marine Ecoregions of the World, Parks Canada, Environment Canada and DFO), lessons of which are useful in the development of a representative network of Marine Protected Areas in fulfilment of Canada's marine commitments under the Convention of Biological Diversity. This report provides a review and synthesis of ten relevant and recent marine biogeographic classification systems, including their development background, objectives, classification approach, data usage and resultant mappings of each system. These features are compared and contrasted, highlighting the principal similarities and differences. General observations that emerged from this review were also presented at the advisory meeting.

RÉSUMÉ

Pêches et Océans Canada (MPO) a été l'hôte d'un processus national d'avis scientifique les 15 et 16 juin 2009. L'objectif consistait à élaborer un cadre et des principes relatifs à la classification biogéographique des zones marines du Canada, plus particulièrement dans l'Atlantique Nord-Ouest, le Pacifique Nord et l'Arctique. Au cours de la dernière décennie, un certain nombre d'exercices internationaux, nationaux et régionaux de classification biogéographique ont été exécutés (p. ex. Grands écosystèmes marins, classification biogéographique des océans et des fonds marins dans le monde (GOODS), Écorégions marines du monde, Écorégions de Parcs Canada, d'Environnement Canada et du MPO). Les leçons tirées de ces exercices sont utiles pour élaborer un réseau représentatif des zones de protection marine afin de remplir les engagements du Canada en matière de milieu marin en vertu de la Convention sur la diversité biologique. Ce rapport présente un examen et un résumé de dix systèmes pertinents et récents de classification biogéographique marine, notamment de l'information sur le contexte de leur élaboration, leurs objectifs, leur approche de classification, l'utilisation des données et les cartes résultantes de chaque système. Ces éléments sont mis en comparaison et en opposition afin de faire ressortir les principales ressemblances et différences. Les observations générales découlant de cet examen ont également été présentées lors de la réunion consultative.

INTRODUCTION

At the 9th meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD), held in May 2008 in Germany, Canada (led by Fisheries and Oceans Canada; DFO) and Germany committed to co-host an international expert workshop (29 September to 2 October, 2009; Ottawa, Canada) aimed at reviewing progress related to the application of marine ecologically and biologically significant areas (EBSA) and biogeographic classification systems outside national jurisdiction.

In preparation for the aforementioned international CBD workshop, a national Canadian Science Advisory Secretariat (CSAS) national science advisory process was held (June 15-16, 2009; Ottawa) to provide recommendations on biogeographic classification systems that could inform the design of a representative network of Canadian marine protected areas in the Northwest Atlantic, North Pacific, and the Arctic (DFO, 2009). Biogeographic classification systems, such as the Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS), the World Wildlife Fund's (WWF) Marine Ecoregions of the World (MEOW), Parks Canada's Ecoregions, the nine Ecosystem Status and Trends Report (ESTR) zones of the Canadian Councils of Resource Ministers (CCRM), as well as the DFO Ecoregion classification were reviewed by participants.

This report provides a review and synthesis of the marine biogeographic classification systems that were considered at the aforementioned CSAS national science advisory meeting. First, an overview of each marine biogeographic classification system is provided which includes background, objectives, classification approach, data used, and maps produced. This is followed by a synthesis which compares and contrasts the objectives, classification approach, and data used. For those systems most relevant to Canada's three oceans, a detailed comparison of the biogeographic units is provided. The last section of the report provides commentary on the desirable features of a biogeographic classification system.

RATIONALE FOR SELECTION OF BIOGEOGRAPHIC CLASSIFICATION SYSTEMS

In undertaking this review, it was first necessary to choose which biogeographic classification systems to consider. Over the past decade, there has been considerable development of marine biogeographic classification systems worldwide. These systems vary in scale (from highly regional to global), approach (from those based almost entirely upon previous work to those based on new quantitative analyses of extant data) and scope (from those considering data from one dimension of the ecosystem to those considering all possible data sources). For instance, in their analysis of global coastal ecosystems, Spalding et al. (2007a) consulted a wide range of previous studies (Appendix 1), which UNESCO (2009) adapted for its analysis of global open and deep ocean ecosystems. This current analysis did not directly review all these studies, but rather focused on a subset which was most relevant to its terms of reference.

The factors considered in the selection of biogeographic classification systems to review included: i) the historical development of the classification system, ii) the relevance to Canadian marine ecosystems, and iii) the approach used.

As a number of the most recent studies relied heavily on previous work, the most recent biogeographic classification system in the chain of development was considered, where possible. This is particularly true of some of the biogeographic classifications developed in Canada. A number of global biogeographic classification systems have emerged in the past decade, each at a different spatial scale and ecosystem focus. The biogeographic classification systems considered in this report are relevant to the biogeographic classification of Canada's three oceans as they provide a broad perspective of marine ecosystems and employ a range of analytical procedures and data. The selection of more regionally-focused studies was restricted to North America and Canada. While many of the systems employed features which are considered appropriate, there are others that were considered as well given the features of their approach.

BIOGEOGRAPHIC CLASSIFICATION SYSTEMS CONSIDERED

The global biogeographic classification systems reviewed with a coastal focus were the Large Marine Ecosystems (LME) (Sherman and Alexander, 1986) and the Marine Ecosystems of the World (MEOW) (Spalding et al, 2007a). An open ocean biogeographic classification system called the Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS) (UNESCO, 2009) was also considered, as was the Biogeochemical Provinces of the Ocean (BGCP) (Longhurst, 2007) which focused on both open ocean and coastal areas.

Non-global biogeographic classification systems considered were the Marine Ecoregion Classification of North America (MECNA) (Wilkinson et al, 2009), and the Marine Ecoregion Classification of European Waters (ICES, 2004). In regards to Canada-specific classification systems, the marine ecoregion classifications developed by Fisheries and Oceans Canada (Powles et al, 2004), Environment Canada (Harper, 1998), Parks Canada (Harper et al, 1983), and the Canadian Council of Resource Ministers (Rankin et al, 2008) were reviewed.

A wide range of information sources were considered for each classification system. Through web searches and personal knowledge, the primary documents describing each classification system were located. These led to further searches on the background history, related publications and so on. In a number of cases, primary authors were contacted to both confirm the status of the reports and obtain information and clarifications additional to what was in these reports. In the case of GOODS and MECNA, the review was based upon pre-publications that were kindly provided to the author.

Descriptions were prepared for each biogeographic classification system. In some cases, clarifications on the content of these sections were required from the primary authors. The resultant descriptions of each biogeographic classification system are provided below. Each starts with the background, which outlines the context in which the study was undertaken and indicates its current status. In some cases, clear objectives for each study could not be identified and thus the motivations of the study were inferred from its publications. It should be noted that these objectives relate to what was initially intended rather than how the products of the study have subsequently been used or might be used in future. Next, the approach used to undertake the classification is outlined which includes the steps taken in the classification and how decisions were made on boundaries. Only an outline of the approach is provided as the details are generally (but not always) available in the source documents. General indication is then given on the classes of data (e.g. geology, physical, chemical and biological oceanography, plankton, fish, invertebrates, and marine mammals, etc.) used in the classification. It had been hoped that more detail would be available in the source documents. To the degree that it is available, statements on the current availability of the data used are provided. The last section describes the results of the classification, highlighting those ecoregions most relevant to Canada.

For seven of the classification systems (LME, MEOW, BGCP, MECNA, DFO, PC and CCRM), Geographic Information System (GIS) digitized files were obtained from the study's primary author and were used to facilitate comparisons. Descriptions on the ecoregions of the classification systems are available in the Appendices as either summaries or website links to in-depth descriptions.

LARGE MARINE ECOSYSTEMS (LME)

Background

The development of Large Marine Ecosystems (LME) was stimulated by the 1982 United Nations Law of the Sea Convention (UNCLOS), which granted coastal states sovereign rights to explore, manage, and conserve the natural resources of their Exclusive Economic Zones (EEZs). The concept was to define relatively large areas of the coastal ocean which encompassed the fisheries stocks being exploited by coastal states, and by so doing define the ecosystems in which these stocks lived and died. The intent was (and is) for management efforts within LME to take into consideration both the biological and technical interactions amongst stocks and the broader influential ecological processes (Sherman, 2006).

Since the initial work on LME in the early 1980s, the program has expanded to all parts of the globe (Sherman, 1994; Sherman and Alexander, 1986; Sherman et al, 1993). There is now a long history of LME case studies, with 14 LME volumes available in the literature, contributed by close to 500 authors since the publication of the first series by the American Association for the Advancement of Science (AAAS) during 1986-1993. Subsequent volumes have been published by Blackwell and Elsevier. About 95 percent of the world's annual marine fishery catch is now estimated to be produced by the 66 currently defined LME (Sherman et al., 2005).

Each year, more projects are added to the list of LME (Sherman, pers. comm.). At present, there are an estimated 2,500 LME practitioners engaged in 16 LME projects: The Caribbean Sea, Gulf of Mexico, Humboldt Current, Baltic Sea, Black Sea, Mediterranean Sea, Canary Current, Guinea Current, Benguela Current, Agulhas and Somali Current, Red Sea, Bay of Bengal, Gulf of Thailand, Yellow Sea, South China Sea, and Sulu Celebes LMEs. A partnership has been developed with the United Nations Environment Program (UNEP) wherein the LME projects provide assessment and management information pertinent to the existing regional seas conventions and action plans. Another partnership has been developed with the United Nations Development Program (UNDP), especially in projects around the coastal margins of Africa. The three participating countries of the Benguela Current LME (Angola, Namibia and South Africa) established the first ecosystem-based management Commission in 2006, followed shortly thereafter by an Interim Governance Commission for the 16 West African countries of the Guinea Current LME, extending from Guinea Bissau in the North to Angola in the South. At present, Korea and China are considering establishing a Yellow Sea LME Commission. Sherman (pers. comm.) reports that as a result of the multi-sectoral EBM approach, actions are underway to reduce the fishing effort in the Yellow Sea LME by 30 percent.

An important outcome of the LME approach are the partnerships that have been developed since 1995 with the Global Environment Facility (GEF), a financial mechanism located within the World Bank, and with developing countries interested in the application of ecosystem-based management, predicated on the LME assessment and management approach (Duda and Sherman, 2002). Ministers of the multi-sectors (e.g. fisheries, environment, mining, energy, tourism, etc.) in the 110 countries (Africa, Asia, Latin America and Eastern Europe) of the LME network are engaged in GEF sponsored LME projects. At present, $1.8 (USD) billion has been provided for planning and implementation of the LME approach which considers the multiple sectors described by five assessment and management modules (see below).

Objectives

The initial intent of the creation of LME was to overcome the sector-by-sector approach to marine resource assessment and management, a legacy of which has been the decline of ecosystem services critical to the maintenance, robustness and resilience of marine ecosystems around the globe (Sherman, pers. comm.). From numerous studies, it can be concluded that none of the world's 66 LME are in pristine condition. They are almost all subject to over-fishing, coastal pollution and nutrient over enrichment, habitat loss (e.g. sea grasses, coral reefs and mangroves), and loss of biodiversity. Consequently, the overarching objective of LME was to provide a governance basis for integrated management of ocean resources within a defined geographical area.

Perhaps a significant related objective of LME has been to aid understanding of the productive dynamics of ecosystems in which exploited ocean resources existed. As noted above, the LME program has resulted in numerous case studies on coastal ecosystems around the globe, a considerable number of which are in areas where previous ecosystem – level studies were lacking. Certainly, the LME program has significantly advanced knowledge on global marine ecosystem dynamics since its inception in the mid-1980s.

Classification Approach

All LME are distinguished on the basis of the following four criteria:
1) Bathymetry (bottom depth);
2) Hydrography (temperature, salinity, Sigma T, tides and currents);
3) Productivity (chlorophyll, dissolved oxygen, total zooplankton); and
4) Trophic linkages (plankton, demersal, and pelagic surveys).

Trophic linkages are the last criterion and distinguish LME from other classification systems. Commercial fish populations are important ecological components as prey and predators for other marine biota and due to their large size, these fish populations require a large living space as they feed over a large area. At the same time, these populations need to achieve geographical life cycle closure, where spawning areas, larval drift routes, juvenile nursery areas, feeding areas and spawning migrations form a spatial life cycle context in relation to ocean currents and circulation patterns. The distributions of commercial fish populations are therefore an important element to consider when delineating LME. Since their distributions reflect circulation and water mass distributions, this criterion is related to the other criteria of characteristic bottom topography, hydrography and productivity (ICES, 2004).

Examples of how criteria were used to determine the boundaries of LME can be found in the case studies provided in the 14 LME volumes. They appear to be determined through experts knowledgeable in the area in question considering the spatial and temporal patterns of indicators associated with the ecological criteria, looking for sensible discontinuities. In addition, the LME boundaries are only based on the four ecological criteria, thereby avoiding any political issues, and in no case have serious problems been encountered in setting LME boundaries beyond a few minor adjustments (Sherman, pers. comm.).

Given the LME's stated support for integrated management, Sherman et al. (2005) report that a five -module approach to the assessment and management of LME based on indicator suites of

(i) productivity, (ii) fish and fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance has been developed. The status of each LME in relation to these five indicator suites has recently been reported (Sherman and Hempel, 2009).

Data Usage

A wide array of oceanographic (physical, chemical and biological) and resource–related (e.g. species abundance and distribution) data are used to define LME. By necessity, this varies in type, scale, and character depending upon the part of the globe being studied. In many parts of the world, data and its management are quite sparse. One of the most significant contributions of the LME project has been in making these data more generally available (see the GIS data portal on the LME website at http://www.lme.noaa.gov/). Sherman (pers. comm.) reports that the website is being redesigned to facilitate access to LME–related datasets.

Products of Classification

The LME are all quite large, exceeding 200,000 square kilometres in area. While LME cover most coasts of the world, there are some areas in which LME do not cover the entire coastal area, most notably parts of the Arctic and Antarctic Oceans. In some areas, LME have been divided into smaller domains (see for instance the Adriatic). Detailed descriptions of each LME are too extensive to include in this report, however they can be found at http://www.lme.noaa.gov.

By ocean, the ten LME most relevant to Canada (Figure 1) are:

- Atlantic
  - Northeast US Continental Shelf
  - Scotian Shelf
  - Newfoundland–Labrador Shelf
- Arctic
  - Beaufort Sea
  - Hudson Bay
  - Arctic Ocean
  - Arctic Archipelago
  - Baffin Bay–Davis Strait
- Pacific
  - Gulf of Alaska
  - California Current

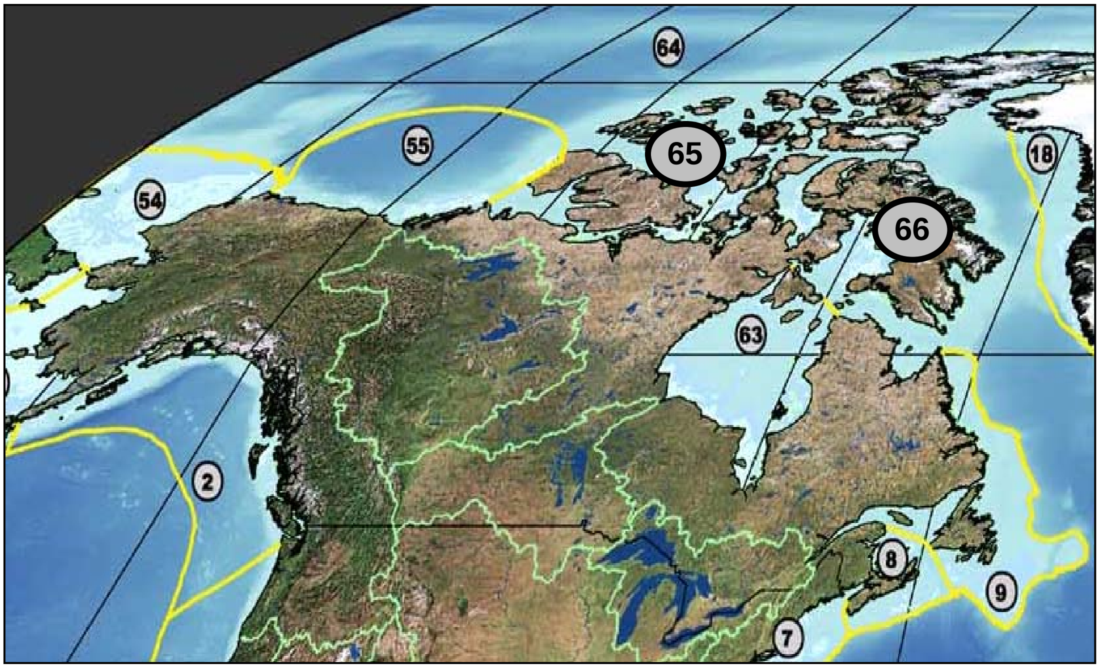

Figure 1. The Large Marine Ecosystems (LME) which are most relevant to Canada are: Gulf of Alaska (2), California Current (3), Northeast US Continental Shelf (7), Scotian Shelf (8), Newfoundland Shelf (9), Beaufort Sea (55), Hudson's Bay (63), Arctic Ocean (64), Arctic Archipelago (65), Baffin Bay–Davis Strait (66) (Sherman et al, 2006).

MARINE ECOREGIONS OF THE WORLD (MEOW)

Background

In the early 2000s, two international nature conservation organizations (The Nature Conservancy and World Wildlife Fund) recognized the global need for a marine biogeographic classification system, as well as the existence of a large number of incomplete global and regional systems. They invited a number of organizations to work with them to review existing marine biogeographic classifications and to develop a synthesized product - a system of Marine Ecoregions of the World (MEOW) with a focus on the marine coastal and shelf realms of the world's oceans. This work was conducted by a small MEOW working group with input from more than 40 independent experts.

This is not a new biogeography, but rather a mosaic of existing and recognized spatial units (CBD, 2006a; Spalding et al., 2007a). While the exercise focused on coastal and shelf regions, it is complementary to the GOODS project, considered below, which focused on open and deep ocean regions. Indeed, as reported by Spalding (pers. comm.), the MEOW project preceded that of GOODS, and in fact a draft of the MEOW biogeographic classification was provided to the CBD member states prior to its publication.

Regarding current status and further developments, the ultimate intent is to combine the products of the MEOW with those of the terrestrial and open ocean ecosystems. As indicated during the GOODS project (see below), there is a need to address gaps in the biogeographic maps between the coastal and open/deep ocean realms. Notwithstanding this, Spalding (pers. comm.) reported that while the MEOW team was asked about combining this with terrestrial classifications (there are close methodological ties with WWF's terrestrial and freshwater ecoregions), the ecological arguments for common boundaries are generally and surprisingly weak and only influential in perhaps a few locations.

Objectives

Spalding et al. (2007a) point out that biogeographic regions are '*natural frameworks for marine zoning…*'. Thus, the MEOW classification was developed to support analyses of patterns of marine biodiversity, in understanding processes, and in directing future efforts in marine resource management and conservation. The overall intent of MEOW is to identify the full range of the diversity of coastal ecosystems (from the low tide mark out to 200m depth) that would support ecosystem management efforts, one of which is the location of Marine Protected Areas (MPA). Importantly, it appears that it was not influenced by unique, vulnerable and/or high-profile ecosystem components, but rather more by the need to comprehensively map in a representative manner the full range of ecosystem biodiversity.

Classification Approach

The first step in the MEOW project was to develop guidelines on definitions and nomenclature to guide the initial data-gathering phase. These were iteratively refined on the basis of available data. Next, over 230 works including primary literature, Non-Governmental Organization (NGO) reports, government publications, and other sources were reviewed. This included the underlying data the process used to identify and define the biogeographic units, and the objectives of these previous studies. To facilitate comparisons, digital maps of many of the existing biogeographic units were used. As well, more than 40 independent experts were consulted to enhance the knowledge base. An approach that utilized the regional expertise represented in the many existing regional biogeographic subdivisions, while at the same time seeking to connect these to existing global systems, was endorsed (CBD, 2006a). Thus, as noted above, the MEOW classification system depended heavily on those previous, regional exercises as a starting point.

A critical element was developing definitions for the spatial scales of biogeographic classification. Spalding et al. (2007a) considered an ideal biogeographic classification system would be hierarchical and nested, and would allow for multi-scale analyses. Each level of the hierarchy would be relevant for conservation planning or management interventions at the appropriate spatial scale. It was felt that a tiered system would be of most value and that units of taxonomic integrity should be the key focus. At the broadest spatial scale, "Realms" are defined, and nested within these is a system of "Provinces" and ecological regions or "Ecoregions" (Table 1).

Table 1. Definitions of the different scales of biogeographic classification used by the Marine Ecoregions of the World (MEOW) biogeographic classification system (Spalding et al., 2007a).

Scale of Biogeographic Classification	Definition
Realm	The largest spatial units of MEOW, they follow the terrestrial concept of realms as "continent or subcontinent-sized areas with unifying features of geography and fauna/flora/vegetation". *Very large regions of coastal, benthic or pelagic ocean in which biotas are internally coherent at higher taxonomic levels as a result of a shared and unique evolutionary history. Realms will have high levels of endemism, not only at the species level, but also with unique taxa at generic and family levels in some groups. Driving factors behind the development of such unique biotas include water temperature, historical and broad-scale isolation and the influence (presence or absence) of dependence on the benthos.*
Provinces	The next level of biogeographic subdivision of MEOW, they are nested within realms and are cohesive units which encompass the broader life-history or ecological processes within them. *Large areas defined by the presence of distinct biotas that may have evolved over evolutionary timeframes. Provinces will hold some level of endemism, at least at the level of species. Although historical isolation will play a role, many of these distinct biotas have arisen as a result of distinctive abiotic features that circumscribe their boundaries. These may include geomorphological features (isolated island and shelf systems; semi-enclosed seas); hydrographic features (currents, upwellings, ice dynamics); or geochemical influences (broadest scale elements of nutrients supply and salinity).*
Ecoregions	The smallest-scale units in MEOW, which in many areas would be used for conservation planning. In ecological terms, these are strongly cohesive units, sufficiently large to encompass life history/ ecological processes for most benthic, sedentary, non-mobile species. Although some ecoregions may have important levels of endemism, this is not a key determinant in ecoregion identification and definition. *Areas of relatively homogeneous species composition that clearly differ in this regard from adjacent systems. This species composition is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the 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*.

Related to spatial scale was the issue of the outer boundary. Spalding et al. (2007a) suggest that the most appropriate outer boundary for these coastal and shelf realms, provinces, and ecoregions is the 200m isobath, which is a widely-used proxy for the shelf edge and often corresponds to an ecotone (Briggs, 1974). They report that such a sharp boundary can only be indicative (as shelf breaks are not always clear), the bathymetric location of an "equivalent" biotic transition is highly variable, and there is considerable overlap and influence between shelf, slope, and adjacent pelagic biota. At the same time, most of the classifications reviewed had been heavily influenced by data from nearshore and intertidal biota, with data from deeper water typically having a decreasing influence on boundary definitions. Spalding et al. (2007a) felt that beyond 200m, other biogeographic patterns will increasingly predominate, altering or hiding the patterns represented.

The MEOW working group then synthesized the available information into a draft of a coherent global marine coastal classification system. The synthesis was guided by the following principles (Spalding et al., 2007a):

Strong biogeographic basis

All spatial units were defined on a broadly comparable biogeographic basis. Existing systems rely on a broad array of source information (e.g. range discontinuities, dominant habitats, geomorphological features, currents, and temperatures) to identify areas and boundaries. In many cases, these divergent approaches were judged to be compatible, given the close links between biodiversity and the underlying abiotic drivers. The MEOW working group preferred to be informed by composite studies that combined multiple divergent taxa or multiple oceanographic drivers in the derivation of boundaries, as these were more likely to capture robust or recurring patterns in overall biodiversity. A number of systems were broadly biogeographic, but with adjustments to conform to political boundaries. Where it was possible to discern the biogeographic elements from the political, these systems were still used to inform the process.

Practical utility

The MEOW working group sought to develop a nested system, operating globally at broadly consistent spatial scales and incorporating the full spectrum of habitats found across shelves. It avoided very fine-resolution systems that separated coastal and shelf waters into constituent habitats. It chose not to try to define minimum or maximum spatial areas for bioregions, but in some cases sought systems that subdivided very large spatial units or that amalgamated fine-scale units such as single large estuaries or sounds.

Parsimony

There are a number of respected and widely utilized global and regional systems, and lack of agreement between such systems can be problematic. In developing a new system, the MEOW working group sought to minimize further divergence from existing systems, while obtaining a truly global classification system. It adopted a nested hierarchy that: i) utilized systems that are already widely adopted (e.g. the Nature Conservancy's system in much of the Americas and the Interim Marine and Coastal Regionalisation for Australia), and ii) fit closely within broader-scale systems or alongside other regional systems.

The next step in the MEOW process was a three-day workshop in September 2005 where the draft classification scheme was refined through assessment and review of the numerous classification systems on a case by case basis. Following the workshop, a final draft of the coast and shelf biogeographic classification system was prepared by the MEOW working group and then vetted through independent experts.

As noted above, a number of sources of information were consulted in constructing the classification. In many cases, published primary sources were used to define boundaries, but were informed by secondary references and independent corroboration was sought from reference material close to the MEOW boundary. Finally, some boundaries were derived based on expert opinion of the authors, influenced by consideration of a broad array of biotic and abiotic information, as well as by other references. Overall, the classification system used an expert judgment approach to review and synthesize existing classification systems into a coherent whole.

Data Usage

As noted above, the MEOW classification system was primarily based on previous work. Spalding et al. (2007b) provide a key to the original papers and classification systems that they consulted. While it is not possible to state categorically all the variables that they used, it is evident that the predominant information accessed is data related to ecology (e.g. oceanography, species distributions). Spalding (pers. comm.) stated that political/governance boundaries were ignored. In a few cases where ecological and political boundaries are quite closely aligned, the MEOW working group always opted for the ecological. Consequently, there are numerous examples in the classification where a small part of a country has been clipped and placed in another ecoregion.

Products of Classification

The MEOW classification consists of a nested system of 12 realms, 62 provinces and 232 ecoregions. Approximately 30 ecoregions are situated around North America, with 15 of these relevant to Canada (Figure 2).

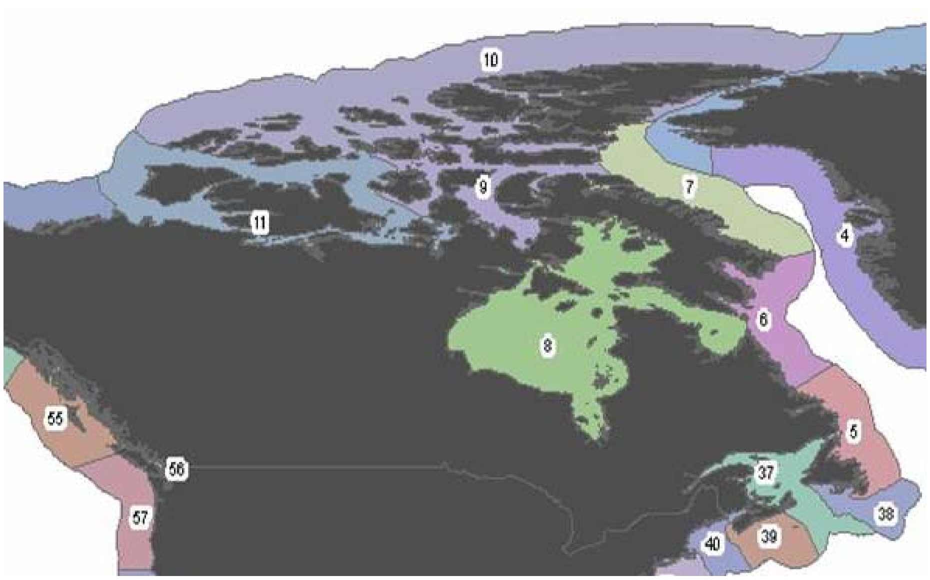

Figure 2. The ecoregions from the Marine Ecoregions of the World Biogeographic Classification which are most relevant to Canada are: Northern Grand Banks–Southern Labrador (5), Northern Labrador (6), Baffin Bay–Davis Strait (7), Hudson Complex (8), Lancaster Sound (9), High Arctic Archipelago (10), Beaufort-Amundsen-Viscount Melville-Queen Maud (11), Beaufort Sea–continental shelf and slope (12), Gulf of St. Lawrence–Eastern Scotian Shelf (37), Southern Grand Banks–South Newfoundland (38), Scotian Shelf (39), Gulf of Maine/Bay of Fundy (40), North American Pacific Fjordland (55), Puget Trough/Georgia Basin (56), Oregon, Washington, Vancouver Coast and Shelf (57) (Spalding et al, 2007a).

Detailed descriptions of each of these ecoregions could not be obtained for this report, however the rationale for these ecoregions is provided in the original report by Spalding et al. (2007b). In many cases, Powles et al. (2004) was the primary source. Some of these sources are used elsewhere in this report and the detailed descriptions of their classified ecoregions are included in the Appendices. The GIS shape files for the MEOW biogeographic classification maps were obtained from http://conserveonline.org/workspaces/ecoregional.shapefile/MEOW/view.html. These were used to construct the maps considered in the Synthesis section.

GLOBAL OPEN OCEANS AND DEEP SEABED BIOGEOGRAPHIC CLASSIFICATION (GOODS)

Background

With the continuing decline in the status of marine resources and biodiversity, international policy has increasingly focused on calls to effectively protect a full spectrum of life on earth, including the world's oceans, and the services that these oceans provide to mankind. This has resulted in the adoption of a number of targets relating to representative networks of marine protected areas. Specifically, the Johannesburg Plan on the implementation of the WSSD, in 2002 called on countries to:

"Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based upon scientific information, including representative networks by 2012."

Building on this, the Conference of the Parties to the Convention on Biological Diversity (CBD) adopted in 2004 a program of work on protected areas with the overall objective to:

"Establish and maintain, by 2010 for terrestrial areas and by 2012 for marine areas, comprehensive, effectively managed and ecologically representative systems of protected areas that, collectively, will significantly reduce that rate of loss of global biodiversity"

UNESCO (2009) describes bioregionalization as a classification process that aims to partition a large area into distinct geographical regions that contain groups of plants and animals and physical features that are sufficiently distinct or unique from their surroundings at a chosen scale. It considers that biogeographic classification systems should be hypothesis-driven exercises that intend to reflect biological units with a degree of common history and coherent response to perturbations and management actions. It is evident that in order to achieve the overall objective of the CBD, one must have knowledge of the global distribution of the elements of biodiversity. Without this, it would be difficult to assess the impact of human activities on biodiversity and the effectiveness of mitigation measures. Regions identified by a biogeographic classification are thus a necessary prerequisite for the identification of representative areas in each region (UNICPOLOS, 2007). Further, this implies that one has a set of criteria that allow identification of ecological and biologically significant areas within each region.

The aforementioned requirements set in motion a series of workshops, under the auspices of the CBD, designed to develop the necessary products for the deep and open ocean areas. These were complementary to the activities being undertaken by the WWF and the Nature Conservatory on the coastal and shelf areas, which produced the MEOW classification discussed above. While not the focus of this report, it should be noted that the CBD process also produced a comprehensive suite of scientific criteria to 1) guide the selection of areas to establish a representative network of MPA, and 2) identify ecologically and biologically significant marine areas. The details of these are provided in CBD (2007a) and address a wide range of ecological characteristics, including:

- MPA area selection
- Ecologically and Biologically Significant Areas
- Representativity
- Connectivity
- Replicated ecological features
- Adequate and viable sites
- Uniqueness and rarity
- Special importance for life history stages of species
- Importance for threatened, endangered or declining species and / or habitats
- Vulnerability, fragility, sensitivity, or slow recovery
- Biological productivity
- Biological diversity
- Naturalness

The first CBD workshop (6–8 December 2005; Ottawa, Canada) identified a range of criteria for identifying areas of ecological or biological significance (CBD, 2006b). The second workshop (22–24 January 2007; Mexico City, Mexico) focused on the biogeographic classification system reported below while the last workshop (2–4 October 2007; Azores, Portugal) refined the scientific criteria discussed in the first workshop (CBD, 2007a). The Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS) ultimately built upon the discussions of the three workshops, along with the subsequent input of experts.

Objectives

Marine protected areas (MPA) can be established to achieve a range of objectives such as protecting ecosystems, habitats and species with special ecological and economic value, protecting a representative range of marine habitats, protecting the special needs of threatened, endangered, native or migratory species, protecting important spawning areas, etc. As indicated by CBD (2006b), guidance on the objectives relating to MPA beyond the limits of national jurisdiction can be found in the Decisions of the 7th meeting of the Conference of the Parties (COP7). In accordance with CBD COP7 Decision VII/5, Appendix 2, the overall marine and coastal biodiversity management framework should: i) fulfill the three objectives of the Convention, ii) play a precautionary approach role to help halt losses in biodiversity and encourage recovery, iii) address all elements of biodiversity, at the genetic, species and ecosystem levels, and iv) address connectivity. Further, threats to sea mounts, hydrothermal vents, cold water corals and other vulnerable ecosystems should also be addressed. What is thus required is a biogeographic classification system which describes a wide and representative range of ecosystems and it is in this context that the GOODS classification system was developed.

Classification Approach

UNESCO (2009) noted that for deep and open ocean areas, biogeographic classification is far less developed than for terrestrial, coastal, and continental shelf areas. In addition, while there have been substantial efforts in the marine realm at the local, national, and regional scale, the only biogeographic classifications at the global scale are those by Longhurst (2007), Sherman and Alexander (1986), and Spalding et al. (2007a). UNESCO (2009) provides a summary of existing approaches, stating that the preferred biogeographic classification system should be consistent with available knowledge on taxonomy, physiognomy, palaeontology, oceanographic processes, and geomorphology (Table 2).

UNESCO (2009) advocates a classification approach that is primarily taxonomic–based, supported by physiognomic and ecological geographic considerations as appropriate. They outline a set of principles that guided their analysis:

- Consideration of the pelagic and benthic environments separately.
- Classification not based upon unique characteristics of distinctive areas or upon individual focal species. GOODS did not use properties such as distinctive areas, hotspots, ecologically and biological significant areas and the 'naturalness' of an area.
- Classification to reflect taxonomic identity, which is not addressed by systems that focus on biomes.
- Generally recognize communities of species and not require the presence of either a single diagnostic species or abrupt changes in whole species composition between regions.
- Recognize influences of both ecological structures and processes in defining habitats and their arrays of species.
- Hierarchical based upon appropriate scales of features.

A consequence of these principles is that broad scale biogeographic boundaries are situated in places of recognizable changes in physiognomic factors, while taxonomic factors are influential at finer spatial scales. The GOODS classification was then undertaken separately for the pelagic and benthic realm. For the pelagic realm, the first step was a Delphic (expert-driven) drafting of a first map of biogeographic zones based upon published classification systems. The boundaries of this first map were then checked against summaries of the available data and expert knowledge of the GOODS team. Next, where potential boundaries between biogeographic regions were emerging, the experts searched for oceanographic and bathymetric features and processes that could provide a physiognomic basis for the biogeographic patterns. In the majority of cases, coincidence of key references, data summaries, and major oceanographic features were sufficient to establish at least approximate boundaries. If not, additional sources of information were sought to resolve them. Then, experts were assigned to all derived ecoprovinces to conduct follow-up investigations. The final step was a cluster analysis to validate the pelagic classification. Three global data layers (bathymetry, sea surface temperature and primary productivity) were utilized. First, a non-hierarchical clustering algorithm was used to reduce the range of environmental heterogeneity (down to 200 groups) and then hierarchical clustering (UPGMA) used to obtain the final 20-group and 40-group clusterings. An overlay of the pelagic bioregions on the cluster analysis showed generally good correspondence between the clusters and the selected bioregions in most areas. The cluster analysis was also useful in indicating where using only physiognomic factors would miss important biogeographic boundaries.

For the benthic realm, given the paucity of data, the process relied heavily on expert input. At the Mexico meeting, a group of experts produced a preliminary map containing locations of what would be termed "the centers of distributions" of deep-sea provinces at bathyal and abyssal depths; separate hydrothermal vent geography was also produced. Then, as much hydrographic data as possible was compiled and the distribution of variables (i.e. water mass characteristics, bathymetry, temperature, salinity, oxygen and organic matter flux for discrete depth layers) that might correlate with the distribution of benthic organisms was mapped. In addition, the pertinent literature on deep-sea zoogeography produced since the 1970s was reviewed and biogeographic maps created using this literature and hydrographic data as a guide.

Table 2. Existing approaches to biogeographic classification of deep and open ocean areas from the Global Open Ocean and Deep Seabed Classification System (GOODS) (UNESCO, 2009).

APPROACH	BASIS		FACTORS
TAXONOMIC ('Conventional' biogeography)	Genetic differences		Evolutionarily Significant Unit (ESU)
	Species - distributions and ranges		Taxa themselves
	Genera – distributions and ranges		Taxa themselves
	Families - ditto		Taxa themselves
	Migrant/ Flagship species - distributions		Feeding, breeding areas
	Community distributions and ranges		Biocoenoces, biotopes
	Charismatic communities		Vents, sponges
PHYSIOGNOMIC	Geophysical	Oceanographic properties	Temperature, salinity, water masses, nutrient regime, O2 min layer, lysocline
		Physiographic	Depth and depth categories, substrate type, sediments
	Geomorphology	Topographic features	Ridges, seamounts, abyssal plains, continental slope etc.
ECOLOGICAL GEOGRAPHY	Combined Biological and Physical Factors	Biomes	Ocean basin, ocean gyres, water masses, sea colour (chlorophyll) productivity regimes, latitude, longitude, temperature regimes, community types
		Ecosystems	Oceanographic features, gyres, boundary currents, convergence zones, divergences, ocean currents
	Geological History and Palaeontology	Evolution of Ecological Boundaries	Plate tectonics, ocean ridges
SOCIO-ECONOMICS	Ecosystem-based management	Fisheries Economics	Historical fishing areas, Catch quotas, productivity regime
		Large Ocean Management Areas (LOMAs)	
		Fishing Areas	
	Resource exploitation	Non-renewable resources	Distribution of major resources i.e. metals of interest to industry and economics of Nations, rare elements, energetics.

UNESCO (2009) emphasized that particular attention was paid to the compatibility between GOODS and the MEOW biogeographic classifications. They were compatible in terms of approaches and definitions, which was enhanced through the participation of one of the principal authors of MEOW in the GOODS classification. Notwithstanding this, some incompatibilities remained. GOODS concentrated on marine areas beyond EEZs while MEOW focused on marine areas from the coast out to 200m depth. This sometimes left areas at 200-300m depth unclassified. Overall, though, the two systems have a high level of compatibility.

Data Usage

A wide range of data types were used in the GOODS project (Table 3). These data were sourced from a number of publicly available databases and from researchers working on the deep and open ocean. In addition to physical data (e.g. such as bathymetry, temperature, salinity and dissolved oxygen), the scientists also considered modeled detritus-sinking fluxes and primary productivity. Geomorphological data were also considered and included plate boundaries, seamounts, sediment thickness and hydrothermal vent locations. Purely biological data were, at this stage, limited to predicted and observed cold water coral reef locations and data on hydrothermal vent organisms. UNESCO (2009) intends to consider any additional biological data that becomes available in the future to further refine GOODS. It should be noted that not all available data were directly used in delineating bioregions. Some data, such as the sediment thickness data, were found not to have the necessary resolution for this purpose. Other data, such as the coldwater coral data, will likely be of importance in future refinements of finer-scale bioregions. These data were placed in a GIS (ArcGIS) to facilitate the analysis but unfortunately, these data could not be obtained for this report.

Table 3. Global datasets considered in the Global Open Ocean and Deep Seabed Classification System (GOODS) (UNECSO, 2009).

Features	Data	Sources	Extent
Temperature	Annualized Temperature (Surface, 800m, 2000m, 3500m, and 5500m)	World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html)	Global
Salinity	Annualized Salinity (Surface, 800m, 2000m, 3500m, and 5500m)	World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html)	Global
Dissolved Oxygen	Annualized Dissolved Oxygen (Surface, 800m, 2000m, 3500m, and 5500m)	World Ocean Atlas (http://www.nodc.noaa.gov/OC5/WOA05/woa05data.html)	Global
Detrital sinking flux	Detrital sinking flux (100m, 200m, 500m)calculated from Yool Model	Yool, Andrew et al., 2007, The significance of nitrification for ocean production, Nature, v. 447, p.999 – 1002, plus supplemental material from the author	Global
Primary productivity	Model estimates of ocean net primary productivity	Oregon State University (http://web.science.oregonstate.edu/ocean.productivity/standard.php)	Global
Sea Surface Temperature	1 Jan 2000 - 31 Dec 2007 mean derived from MODIS-Terra data	NASA (http://oceancolor.gsfc.nasa.gov/cgi/climatologies.pl?TYP=mtsst)	Global
Bathymetry	Global gridded (1 min) data	GEBCO (2003)	Global
Plate boundaries	Plate boundaries, including ridges, transforms, and trenches	University of Texas PLATES Project: (http://www.ig.utexas.edu/research/projects/plates/)	Global
Bathymetry, topography and depth masks		ETOPO2	Global
Seafloor sediment thickness		NGDC (National Geophysical Data Center)	Global
Seamounts	Predicted Seamount locations and depths	Kitchingman & Lai (2004). (http://www.seaaroundus.org/ecosystemsmaps/default.aspx)	Global
Cold water coral reefs	Distribution of known cold-water coral areas based on species distributions (includes *Lophelia pertusa*, *Madrepora oculata* and *Solenosmilia varialilis*). In addition, predicted distributions of cold water coral reefs.	UNEP-WCMC, provided by Andre Freiwald and Alex Rogers	Global
Hydrothermal vents	Hydrothermal Vent Locations and similarity/dissimilarity of benthic communities	InterRidge and Cindy VanDover	Global

Products of Classification

Based on the aforementioned criteria coupled with a review of existing classifications, the group of experts produced a map of pelagic bioregions, which included 29 provinces. While detailed descriptions of the GOODS bioregions were not available for this report, UNESCO (2009) goes into some depth describing the general characteristics of the bioregions of its classification. The GOODS provinces have unique environmental characteristics in regards to variables such as temperature, depth and primary productivity and those with relevance to Canada are shown in Figure 3.

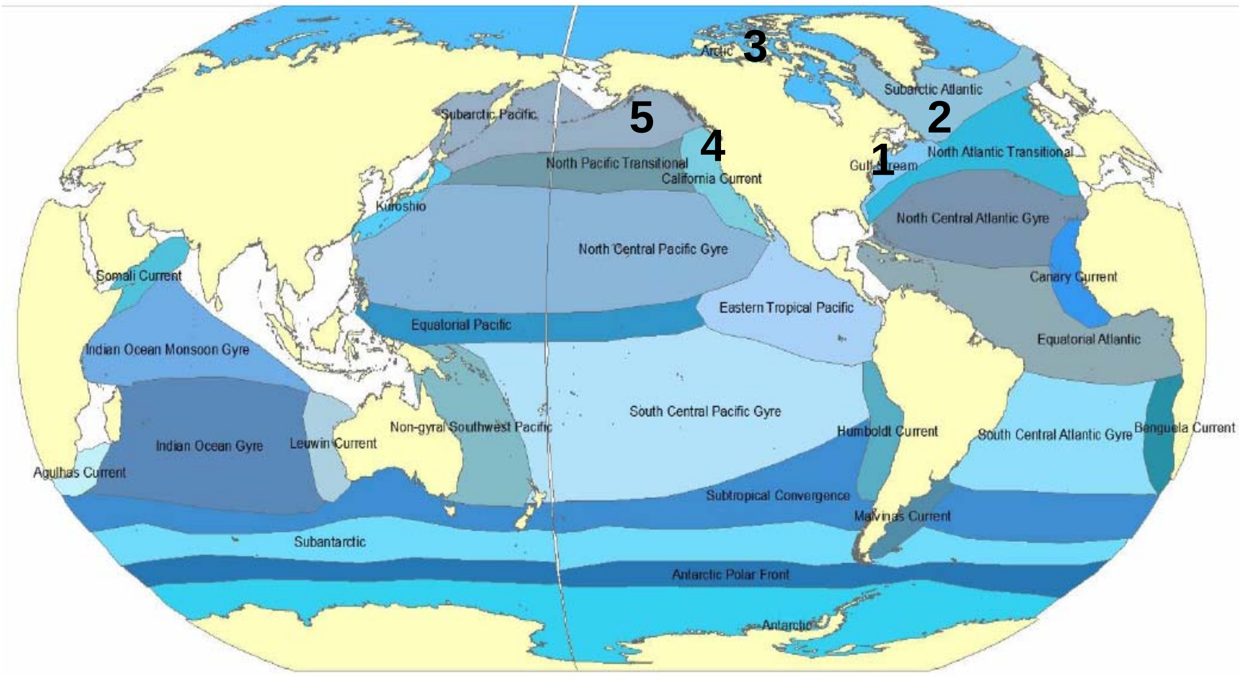

Figure 3. The bioregions relevant to Canada from the Global Open Ocean and Deep Seabed Classification System (UNESCO, 2009) are: Gulf Stream (1), Subarctic (2), Arctic (3), California Current (4) and Subarctic Pacific (5).

The proposed deep sea benthic classification encompasses three large depth zones: i) the bathyal (800-3500m); ii) the abyssal (3500-6500 m); and iii) the hadal (depths greater than 6500 m, which includes primarily trenches). The bathyal classification was further broken down into nine biogeographic provinces, the abyssal into 10 biogeographic provinces, and the hadal into 10 biogeographic provinces. Separate hydrothermal vent provinces were also delineated based on biological data and other records from field sampling and observation. The bathyal provinces relevant to Canada are: North Atlantic Boreal, Arctic, and North Pacific Boreal (Figure 4).

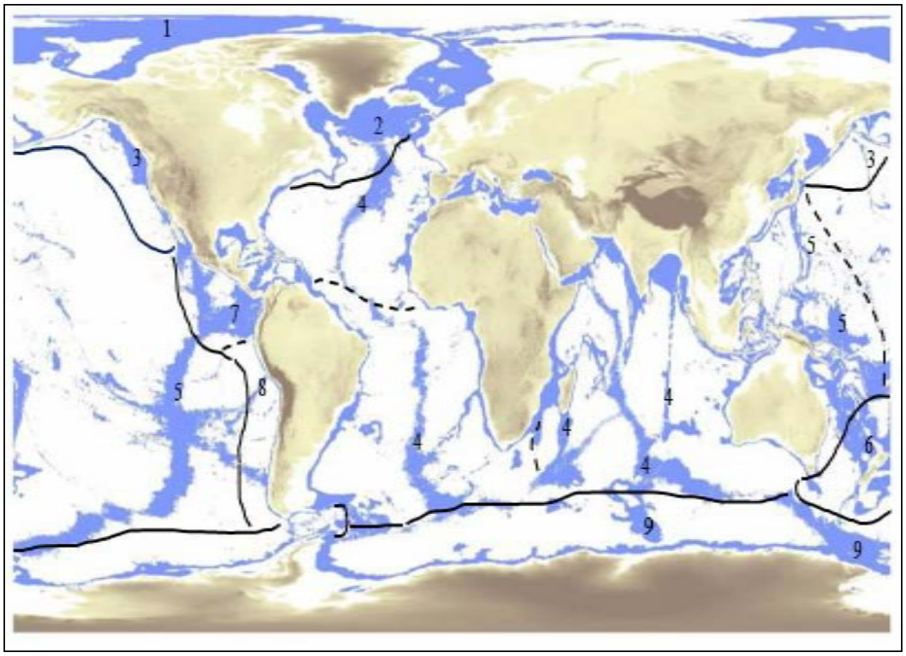

Figure 4. The bathyal provinces of the Global Open Ocean and Deep Seabed Classification System (GOODS) (UNESCO, 2009) with relevance to Canada are: Arctic (1), North Atlantic Boreal (2) and North Pacific Boreal (3).

The abyssal provinces relevant to Canada are: the North Atlantic, the Arctic Basin, and the Pacific Ocean (Figure 5).

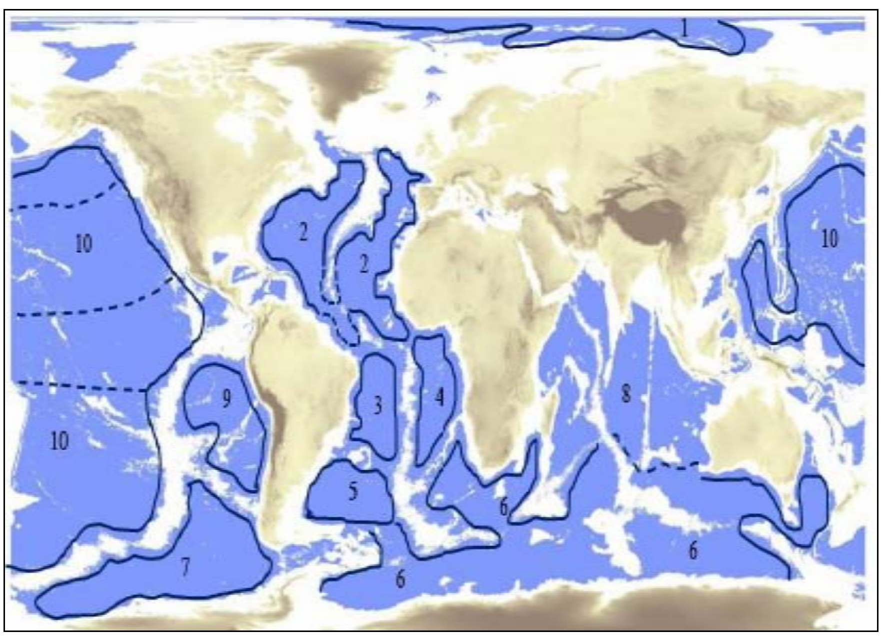

Figure 5. The abyssal provinces of the Global Open Ocean and Deep Seabed Classification System (UNESCO, 2009) which are most relevant to Canada are: Arctic Basin (1), North Atlantic (2), and Pacific Ocean (10).

BIOGEOCHEMICAL PROVINCES OF THE OCEAN (BGCP)

Background

Longhurst (2007) set out to characterize the global distribution of ocean productivity based upon an analysis of measures of primary productivity. His central hypothesis is that ecosystems will be characterized by the oceanographic mixing processes that provide nutrients to the lower levels of the food chain (i.e. phytoplankton). Longhurst (2007) prefers to use the term 'biogeochemical provinces (BGCP)' rather than ecological provinces. The BGCP are regions or water masses with similar physical (e.g. sea surface temperature, mixed-layer depth, and bathymetry) and biological (e.g. chlorophyll *a* concentration, photosynthetic parameters, biomass vertical profile) characteristics. What perhaps makes the work of Longhurst (2007) stand out is that he explicitly bases his hypothesis on what processes determine the broad distributions of ecosystems and then undertakes an objective approach to test this hypothesis. Another feature that he emphasizes is that he is not defining fixed boundaries. Rather, he considers that ocean processes are too much in flux to permit this and thus his regions are to be considered generally defined areas of similar production. The emphasis is not on the boundaries but on the regions.

Regarding further developments, Longhurst (pers. comm.) reports that the classification system is routinely being used by oceanographers in their study of global ocean processes (see Honjo et al., 2008). Alain Fontenau (Longhurst, pers. comm.) has been using BGCP to better understand the global distribution of tuna catch statistics. To avoid the limitations that arise from the static arrangement of provinces with the rectilinear boundaries of Longhurst (2007), Devred et al. (2007) developed a dynamic method based on statistical analysis of geophysical and biological data to delimit BGCP boundaries in real time. While the analysis showed strong similarities between the static and dynamic definitions of ecological provinces in the Northwest Atlantic, the statistical method based on satellite data (e.g. sea surface temperature and chlorophyll *a* concentration), bathymetry and location provided a more objective definition of the provinces and allowed for seasonal variations. In its examination of global open and deep ocean pelagic realms and provinces, UNESCO (2009) also made use of the Longhurst (2007) BGCP.

Objectives

The overarching objective guiding the BGCP classification system of Longhurst (2007) is the delimitation of areas of the global ocean based upon the physical oceanographic Sverdrup processes which determine the biological oceanographic processes and in so doing influence the rest of the food chain. There was no intent to delimit the entirety of ecosystem processes in an area and there was no intent to delimit ocean areas for resource management purposes.

Classification Approach

The BGCP classification of Longhurst (2007) uses two spatial scales: biomes and provinces. Biomes in this context has the same use as in terrestrial plant geography, where they are used to denote a characteristic type of vegetation (e.g. tundra, wet tropical forest, dry grassland); biomes appear to be comparable in scale to the realms of Spalding et al. (2007a). Provinces are found within biomes, and are characterized by the Sverdrup model mixing processes.

Longhurst (2007) divides the world's oceans into a polar biome, westerlies and trades biomes, and a coastal biome based on how winds and sunlight interact to influence Sverdrup mixing processes, specifically on eight models (Longhurst, 2009):

- Model 1 - Polar irradiance-mediated production peak
- Model 2 - Nutrient-limited spring production peak
- Model 3 - Winter-spring production with nutrient limitation
- Model 4 - Small amplitude response to trade wind seasonality
- Model 5 - Large amplitude response to monsoon reversal
- Model 6 - Canonical spring-fall blooms of mid-latitude continental shelves
- Model 7 - Topography-forced summer production
- Model 8 - Intermittent production at coastal divergences

Each biome is associated with one of more of the models in the following arrangement:

- *Polar Biome*: where the mixed-layer depth is constrained by a surface brackish layer that forms each spring in the marginal ice zone (Model 1);
- *Westerlies Biome*: where the mixed-layer depth is forced largely by local winds and by local irradiance (Models 2 and 3);
- *Trades Biome*: where the mixed-layer depth is forced by geotropic adjustment on an ocean-basin scale to local or distant wind forcing (Models 4 and 5); and
- *Coastal Biome*: where many diverse coastal processes modify the mixed-layer depth and nutrient inputs (Models 6 to 8).

Longhurst (2007) corroborates the biome boundaries through an analysis of a global zooplankton database available at the Smithsonian Institute, which has for many years used a standardized first-order sorting technique for the plankton samples it archives, thus enabling a first-order analysis of the composition of zooplankton globally. The counts were allocated to six functional groups (e.g. gelatinous predators, raptorial predators, micro- and macro-particle herbivores, omnivores, and detritivores) and also amongst taxonomic groups (e.g. medusae, siphonophores, chaetognaths, polychaetes, ostracods, copepods, mysids, euphausiids, and pteropods). These counts were then stratified regionally and seasonally to represent first-order differences between oceans and continental shelf faunas of the polar, temperate, and tropical zones. The results enabled quantification of latitudinal trends and seasonal changes in plankton composition that were well known for only a few study sites, although also suspected to occur more generally. These trends generally supported the biome boundaries (Longhurst, 2007).

For determination of the BGCP provincial boundaries within biomes, a wider set of factors, especially those apt to define interfaces between physically, and therefore ecologically, distinct regions, were used. Factors that determine the characteristics of regional circulation and stratification at all scales were considered. For example, the resistance of the mixed layer to deepening and which is the primary determinant of biomes. Bathymetry, river discharge, characteristic coastal wind systems, location of islands, and the distribution of land masses were also considered. It is important to note that Longhurst (2007) used an overall target of 50 compartments globally, as suggested by Sathyendranath et al. (1995), to guide his partitioning of the pelagic ecosystem. Longhurst (2007) considers that this is a matter not only of practical convenience but also of necessity as the available number of observations of any ecological variable or parameter constrains the analysis. Where too few observations are binned among too many compartments, one might expect to have insufficient numbers in each to judge whether the characteristics of adjacent compartments are significantly different, and therefore whether the boundaries between them are real.

To define the BGCP Longhurst (2007) undertook the following steps:

1. Examination of all available regional and seasonal images of the surface Coastal Zone Colour Scanner (CZCS) chlorophyll field in a variety of formats for characteristic, observable, and repetitive regional patterns, both spatial and temporal. Where necessary, the individual images for critical regions were scanned to clarify the nature of blooms observed in the monthly and seasonal composites. This subjective technique of interrogating the images to locate boundaries was a proxy for the objective and numerical technique that Longhurst (2007) feels would be the method of choice.
2. Examination of the regional oceanography of all parts of the ocean not only by bibliographic search but also by consulting data archives (see next section). The physical oceanographic literature for each ocean basin was reviewed extensively to compare the seasonal and regional distribution of chlorophyll values found in the SeaWiFS images with current concepts of surface circulation, together with the distribution of oceanic frontal zones.

These data coupled with detailed consideration of many previous proposals for partitioning the oceans into a global set of provinces led, by a process of trial and error, to a proposal of a suite of 51 provinces. The notional boundaries of these provinces were placed onto a rectangular grid at a spatial scale chosen to facilitate the task of assigning data (such as SeaWiFS surface chlorophyll values) to individual provinces. The boundaries of the 51 BGCP were then tested through: i) a statistical test in which conditions differed in adjacent provinces, ii) comparison of data on the distribution of individual biota with boundaries between provinces, and iii) a analytical test (i.e. Empirical Orthogonal Function) to partition a relevant global data set. This suite of tests generally confirmed the boundaries of the 51 BGCP, providing an objective basis to the classification system.

Data Usage

The primary data that were used to delineate the BGCP were:
- Surface chlorophyll fields;
- Gaussian parameters describing the shape of the chlorophyll profile;
- Global climatologies of mixed layer depth;
- Surface nutrient fields;
- Brunt-Väisälä frequency; and
- Rossby internal radius of deformation.

From these primary data sets, it was possible to derive several secondary measures to assist in understanding the regional characteristics of the plankton ecosystem and the seasonal cycle of production and loss of phytoplankton, including:
- Photic depth (m);
- Algal biomass;
- Primary production rate;
- Rate of change of algal biomass; and
- Loss term for potential primary production.

Considerable processing of these data was required, the details of which are described in more detail by Longhurst (2007).

Products of Classification

The analysis defines four biomes and 51 BGCP, which are roughly equivalent to the realms and ecoprovinces of Spalding et al. (2007a). The BGCP most relevant to Canada's three oceans are shown in Figure 6.

A general description of each of these BGCP is provided in Appendix 2. Longhurst (pers. comm.) provided the GIS digitized files of the BGCP and they are available at http://www.vliz.be/vmdcdata/vlimar/downloads.php.

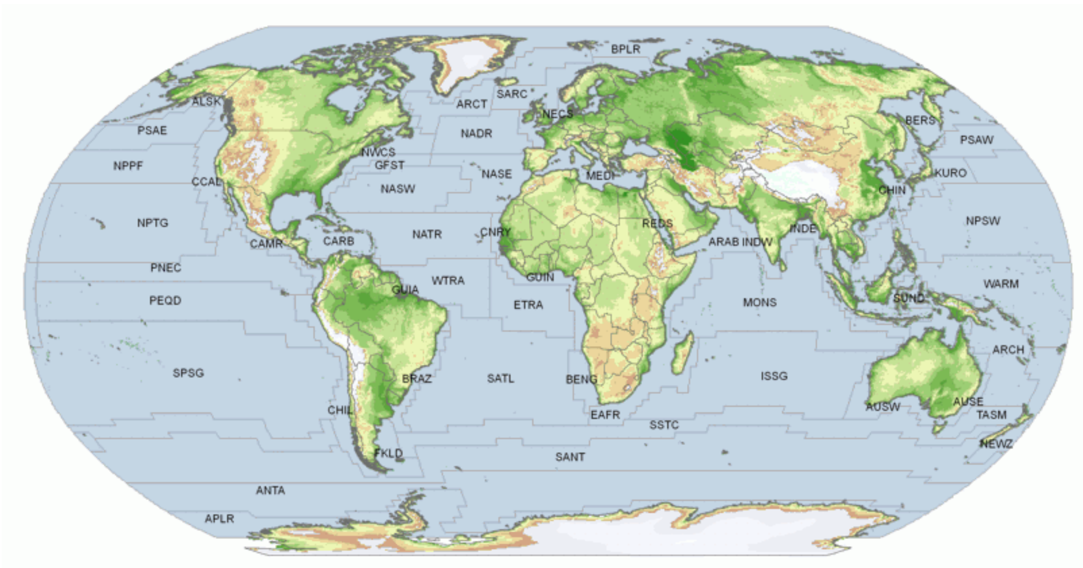

Figure 6. The Biogeochemical Provinces of Longhurst (2007) with relevance to Canada's three oceans are: Atlantic Arctic Province (ARCT), Northwest Atlantic Shelves (NWCS), Gulf Stream Province (GFST), Boreal Polar Province (BPLR), Alaska Downwelling Coastal Province (ALSK), California Current (CCAL), and the Pacific Subarctic Gyres (East) (PSAE).

MARINE ECOREGION CLASSIFICATION OF NORTH AMERICA (MECNA)

Background

Pioneering work in the 1960s and 1970s on the bioregionalisation of North America evolved from forest and climate classifications (Hills 1961; Flores et al. 1971; CETENAL (now INEGI) 1976; Bailey 1976). The first national compilations of ecological classifications for North America emerged in the mid-1980s (Wiken, 1986; Omernik 1987). These were holistic approaches that recognized the importance of considering a full range of physical and biotic characteristics to explain ecosystem regionality. They recognized that ecosystems of any size or level are not always dominated by one particular factor.

The Commission for Environmental Cooperation (CEC) became involved in the biogeographic classification of North America in the mid-1990s. The CEC is an international organization, created by Canada, Mexico and the United States under the North American Agreement on Environmental Cooperation (NAAEC) to address regional environmental concerns, help prevent potential trade and environmental conflicts, and to promote the effective enforcement of environmental law. NAAEC complements the environmental provisions of the North American

Free Trade Agreement (NAFTA). The CEC introduced the first combined terrestrial and marine ecosystem classification in 1996 (CEC, 1997). Over approximately the past five years, the CEC has worked with a number of agencies, including the Nature Conservancy, the National Oceanic and Atmospheric Administration (NOAA), Parks Canada, the Comision Nacional de Areas Naturales Protegidas of Mexico, and the Canadian Council on Ecological Areas (CCEA) to update this classification. The MECNA classification is the result of this work and is slated to be published in the near future; the CEC kindly provided the author with the pre-publication draft (Wilkinson et al., 2009) for this report. MECNA is one of several marine initiatives sponsored by the CEC as part of its Strategic Plan for North American Cooperation in the Conservation of Biodiversity.

Objectives

The objectives of the marine ecoregion classification conducted by the CEC were to:
1) Support the implementation, development and coordination of national and international mandates, conventions, policies and acts;
2) Support varied interests of stakeholders;
3) Provide information to the public, nongovernmental organizations, industries and governments; and
4) Support research and education, inventorying and monitoring and other planning efforts.

Wilkinson et al. (2009) indicate that the delineated ecoregions are to serve as a basis for regional and cooperative stewardship and management efforts and can be used as reference points for periodic assessments of ecosystems and their habitats, species and other environmental components. They can also help define representative and critical areas of the marine environment through a network of marine protected areas and special conservation areas (i.e. cornerstones of ecosystem-based conservation and sustainable development strategies). Thus, the MECNA was undertaken to serve a wide range of marine resource related needs.

Classification Approach

Wilkinson et al. (2009) provide a synopsis of the classification approach, which although general, provides a sense of the overall process. A group of experts from Canada, USA, and Mexico was formed to work on the MECNA initiative. They came from an array of sectors (e.g. governmental agencies, NGOs, academic institutions and scientific research centres) with expertise in a wide range of disciplines related to marine science and planning.

The MECNA was developed in three stages: 1) individual country drafting efforts; 2) a tri-national workshop to define the ecoregion classification, agree on the criteria, and delineate polygons (held in March 2002, in Charleston, South Carolina); and 3) a peer-review process.

A set of principles and general rules, developed by the tri-national group of experts, guided development of the MECNA classification:

1) The classification includes three levels that link the global and more regional or local perspectives. Level-I describes ecosystem differences at the broadest scale, determined by more continental or ocean basin processes and defining large water masses and currents, large enclosed seas, and regions of coherent sea surface temperature or ice cover. The cross-shelf domain of Level-I extends from the coasts to the deep oceans, although biogeographic patterns

and processes in the deeper regions are generally poorly understood. Level-II captures the break between neritic (near shore) and oceanic areas and is determined by large physiographic features (continental shelf, slope, and abyssal plain, as well as areas of oceanic islands and major trenches, ridges, and straits). This level reflects the importance of depth as a major determinant of benthic marine communities as well as the importance of major physiographic features in determining current flows and upwelling. Like Level-I it extends from the coasts to the EEZ. Level-III captures differences within the neritic zone and is based on more locally significant variables (local characteristics of the water mass, regional landforms, as well as biological community type). Level-III is limited to the continental shelf, since only this area has sufficient information for finer-scale delineation.

2) The classification is developed largely for North American waters within the Exclusive Economic Zone (EEZ). Levels-I and -II extend from the coastline to the outer edge of the EEZ. Level III covers an area from the coastline to the shelf edge or the 200-meter isobath on oceanic islands. While the EEZ was used to define the outer seaward limit of each country's territorial waters, it is acknowledged that ecosystems do not stop at political borders such as these. The map focuses on waters of continental North America, including all US states as well as territories relatively close to the continent, such as Puerto Rico and the US Virgin Islands.

3) The map is a tri-national collaborative effort, tailored to particular needs and requirements, and based largely on expert knowledge and existing frameworks, as well as the best available scientific data.

4) Hard lines are used to roughly approximate transitional boundaries.

5) The three-dimensional nature of the ocean is reflected to the greatest degree possible under the given restrictions.

6) The maps are not intended to specifically outline habitat, substrate type, etc., but rather to characterize ecosystems based on an alignment of selected characteristics at each level, distinguishing areas that may benefit from similar types of management and conservation measures. The classification thus allows for appropriate conservation strategies at the local, regional, or continental level.

7) The outer boundaries shown on the maps are approximate and illustrative. They do not necessarily reflect the boundaries of the EEZ claimed by the three countries involved.

Overall, the MECNA was largely developed through a Delphic-based approach (Rescher, 1998), with experts engaged in discussion, debate and consensus building among peers. Wilkinson et al. (2009) report that they built the classification on existing frameworks, using scientific data and information to support their decisions as needed.

Data Usage

Wilkinson et al. (2009) provide a general overview of the information used in the classification. Keeping in mind that the MECNA is built upon previous work, it appears that most variables used to define the ecoregions are oceanographic or physiographic, reflecting the range of conditions that influence species distribution, and serve as surrogates for biological data that are largely incomplete or inconsistent in format at the North American scale. When available (such as at Levels-I and Levels-III), information on faunal assemblages and community types was also used to help define the boundaries.

Products of Classification

The MECNA consists of 23 Level-I ecoregions (Figure 7). A detailed description of each of these (abstracted from Wilkinson et al., 2009) is available in Appendix 3.

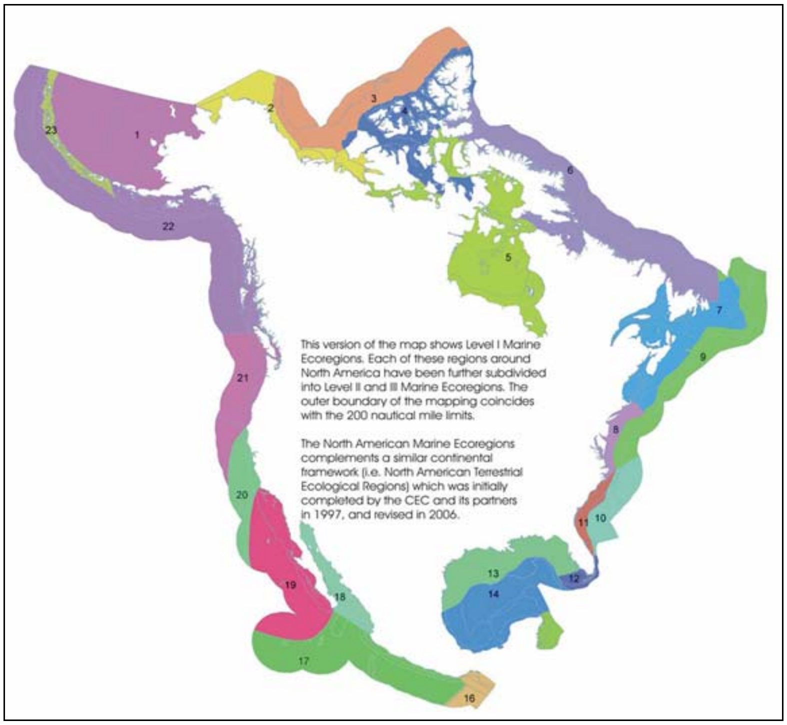

Figure 7. Level-I Marine Ecoregions of North America (Wilkinson et al., 2009) which are relevant to Canada are: Bering Sea (1), Beaufort / Chukchi Seas (2), Arctic Basin (3), Central Arctic Archipelago (4), Hudson/Boothian Arctic (5), Baffin/Labradoran Arctic (6), Acadian Atlantic (7), Northern Gulf Stream Transition (9), Columbian Pacific (21), and Alaska/ Fjordland Pacific (22).

Wilkinson et al. (2009) consider that the nested framework correlates well with systems defined by faunal distributions (e.g. Hayden et al. 1984), but represents regions at a finer scale than do the Large Marine Ecosystems (Sherman and Alexander 1986) or Biomes and Provinces (Longhurst, 2007), reflecting the finer-scale distribution of biodiversity within these. Wilkinson et al. (2009) considers that the MECNA classification corresponds and nests well with both current coarser and finer-scale systems. For Canada’s three oceans, Figure 8 shows the second level of spatial subdivision in MECNA.

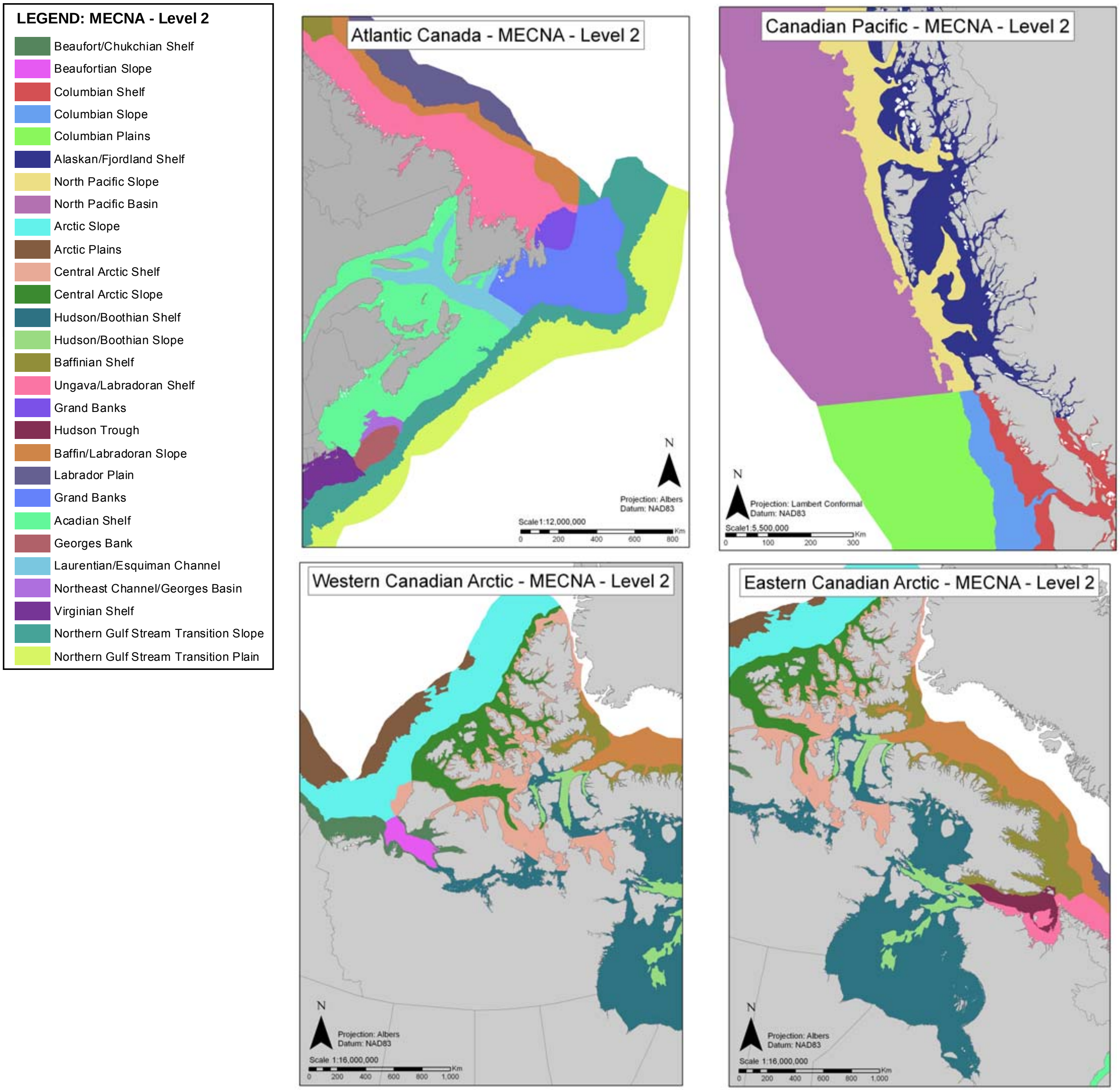

Figure 8. The Marine Ecoregions of North America (MECNA) with relevance to the Canadian Atlantic Ocean (Wilkinson et al., 2009).

MARINE ECOREGION CLASSIFICATION OF CANADA

Background

Since the mid-1980s, there have been a number of biogeographic classification exercises specifically devoted to Canada and many of the exercises have been closely linked. The difference initiatives have involved a number of government and non-government agencies such as Environment Canada (EC), Parks Canada (PC), Fisheries and Oceans Canada (DFO), the numerous federal, provincial and territorial councils of the Canadian Councils of Resource Ministers (CCRM), and the World Wildlife Fund (WWF).

Powles et al. (2004) provides a synopsis of three major 'threads' of Canadian classification systems since the mid-1980s, those of Wiken (1986), Harper et al. (1983) and Zacharias and Roff (2000) undertaken by EC, PC, and WWF, respectively. Powles et al. (2004) note that the two primary purposes of these initiatives have been: i) in the case of PC and the WWF, defining ecoregions within which to identify representative areas in order to establish national marine conservation areas (PC) and Marine Protected Areas (WWF), and ii) in the case of EC, defining areas for marine environmental quality monitoring programs. A fourth 'thread' is that of Powles et al. (2004), sponsored by DFO, which was initiated to identify marine areas as the basis for integrated management. Perhaps the most recent 'thread' is that of the CCRM, the main purpose of which is the reporting on the status and trends of Canada's terrestrial and marine ecosystems. For each of these 'threads', it is useful to trace their history and highlight the most current classification that exists.

Prior to the 1980s, Canada did not have a comprehensive biogeographic classification of its terrestrial ecosystems and thus the work by Wiken (1986) was undertaken under the auspices of EC to fill this gap. The concept of a hierarchy of ecosystems (e.g. ecozones, ecoregions, ecodistricts, etc.) at increasingly finer scales was introduced. In 1986, the Canadian Environmental Protection Act (CEAA) was passed which created a legislative requirement to report on the state of Canada's environment, both terrestrial and aquatic. While a national terrestrial classification system existed, such was not the case for the marine environment.

Therefore in 1992, a Marine Environmental Quality Advisory Group (MEQAG), with membership consisting of representatives of EC and PC, was commissioned to develop a marine ecological classification system for Canada. This group contracted the services of Harper et al. (1993) who developed a draft classification system based upon earlier work (Harper et al., 1983). After review, which resulted in a number of revisions (e.g. modifications to the Pacific Ecozone to more closely match the marine portions of the British Columbia provincial ecological system), the classification system (Harding, 1998; Hirvonen et al., 1995) was approved in March 1994 by the Marine Environmental Quality Working Group (co-chaired by DFO and EC) of the Interdepartmental Committee on Oceans (chaired by DFO). While deviating from the strictly hierarchical rule-based system developed by Harper et al. (1993), the new classification system was thought to be a practical approach to integrating federal and provincial systems. The EC classification outlined five marine ecozones (Pacific Marine, Arctic Basin Marine, Arctic Archipelago Marine, Northwest Atlantic Marine and Atlantic Marine), which were subsequently used by the Environmental Monitoring and Assessment Network (EMAN).

Powles et al. (2004) indicate that the aforementioned classification 'thread' is linked with that of the previously discussed MECNA, although there are significant differences between the two classifications. Also linked to this is the classification system of the CCRM. Rankin et al. (2008) describes the decisions and the process taken to determine the ecological units for the CCRM's

Canadian federal/provincial/territorial Ecosystem Status and Trends Report (ESTR). The ESTR is designed to meet the needs of Canada's 4th National Report to the UN Convention of Biological Diversity, achieve the 'assess' portion of the 'Healthy and Diverse Ecosystems' in the Canadian Biodiversity Outcomes Framework, and identify gaps and priorities in Canada's terrestrial, freshwater, and marine ecological monitoring network.

The Harper et al. (1983) thread started as an initiative by PC to identify marine regions within which to identify and select candidate representative national marine conservation areas. The process is akin to the long-established PC approach to identifying new national parks in the 39 terrestrial natural regions of Canada. A total of 29 aquatic regions (25 in Canada's oceans and five in the Great Lakes) were defined by this initiative, which can be tracked to those on the current PC website http://www.pc.gc.ca/progs/amnc-nmca/systemplan/index_e.asp. Criticisms of the Harper et al. (1983) classification included that the regions were not hierarchical, they required a 'land base' so that all regions included a coastal component, and that there was no common 'national' criteria used to define regions (Powles et al; 2004). As noted above, Harper et al. (1993) used a refined approach that was the basis for the EC classification.

The Zacharias and Roff (2000) initiative, sponsored by the WWF, was intended to provide a Canadian classification system to aid in the identification of ecological units for conserving marine biodiversity. This initiative continued until about the mid-2000s and around that time, WWF and the Nature Conservancy initiated the international MEOW initiative which ultimately resulted in the classification reported by Spalding et al. (2007a) and is described above. It is not clear how the Canadian and international WWF initiatives relate. However, for the purposes of this report it will be assumed that the Canadian WWF initiative has been addressed by the MEOW.

The DFO sponsored workshop on marine ecoregions which produced Powles et al. (2004) is the start of one of the most recent Canadian marine classification 'threads'. It was initiated as a consequence of the 1997 Canada Oceans Act which required the identification of marine areas, termed Large Ocean Management Areas (LOMA) for integrated management. The CCRM and the current Convention of Biological Diversity initiatives, which this report is to support, are considered here as further developments along this 'thread'.

Objectives

The mandates of EC, PC, DFO, the WWF/TNC, and the CCRM have generally dictated the objectives of each of Canadian classification systems. In relation to EC, the Wiken (1986) thread was primarily directed at identifying areas to monitor and report on marine environmental quality. In relation to PC, the Harper et al. (1983) thread was primarily directed at defining regions within which representative candidate marine conservation areas could be identified. Regarding DFO, the Powles et al. (2004) initiative was intended to provide scientifically–based boundaries for LOMA as a basis for integrated management. The Zacharias and Roff (2000) initiative of WWF and The Nature Conservancy was focused on representative areas within which MPA or other conservation areas could be identified. The CCRM classification is to provide the spatial basis for the reporting of ecosystem status and trends, largely in support of Canada's obligations under the CBD. All of these objectives are related and indeed have the same root objective, which is to identify ecological areas of the oceans which could be considered relatively distinct ecosystems and which would support multiple purposes associated with an ecosystem approach to management.

Classification Approach

Harding (1998) provides an overview of the classification approach taken by EC. Coastal and Ocean Resources Inc. (CORI) developed a proposal for discussion purposes which was based on earlier work by Harper et al. (1983) as well as information related to global marine classifications systems obtained from the open literature. In association with LGL Ltd., and coordinated by the MEQAG, CORI then held seven regional workshops to solicit input and feedback from approximately 70 marine scientists and science managers across Canada. At these workshops, participants considered appropriate diagnostic parameters and boundaries for various spatial ecological units of the three coasts of Canada (Harding, 1998). This resulted in revisions to the CORI proposal which was then discussed and revised within the MEQWG and subsequently adopted by Canada's Interdepartmental Committee on Oceans.

Regarding the PC initiative, Harper et al. (1983) describes their multi-step classification process in detail:

1) Experts developed a series of theme maps, each defining regions according to each theme (see below). These maps were developed for each Canadian coastal area: Atlantic, Arctic, Pacific and Great Lakes. The maps were first defined by experts, then later reviewed and revised in a workshop. Harper et al. (1983) lists the experts involved and the rationale on boundaries chosen.

2) The oceanographic, coastal environment and physiographic regional maps were combined in a physical base-case region map and the marine mammal, marine bird, fishery and invertebrate region maps combined into a biological base-case region map. The guidelines used for this combination were:

a) Where two or more theme boundaries coincide, adopt this as a base-case boundary;
b) Where two theme boundaries are near to each other and generally parallel, adopt a base-case boundary half way between the two;
c) Where a single theme boundary is very important, adopt it as a base-case boundary. Where a base-case boundary is not considered important, do not adopt it; and
d) Where three theme boundaries are near to each other and generally parallel, treat the two nearest to each other with guideline a) or b), and treat remaining boundary with guideline c).

Application of these guidelines in practice involved considerable expert judgment (Harper et al., 1983) and ultimately produced two base-case maps per coastal area. Again using the above guidelines, one marine region map per coastal area was developed by combining the physical and biological base maps. Each marine region base-case map was then evaluated at a workshop and via correspondence after the workshop. According to Harper et al. (1983), this step led to only minor changes to base maps. In the years since the Harper et al. (1983) regional framework was completed, PC has made a small number of regional boundary adjustments on the basis of new information, but these have not affected the total number of 29 marine regions (D. Yurick, pers. comm.).

Powles et al. (2004) provides an in-depth description of the process underlying the DFO classification initiative. Specialists were identified for each ocean and in relation to the classes of criteria (e.g. geological, physical oceanographical, and biological) of each region. These specialists were asked to bring information to a three-day workshop; one base map was provided for each of the three oceans and the patterns contributed were sketched onto transparencies of these base maps. The maps of the various properties were then overlain and compared. It was recognized that the structure of marine ecosystems occurs at many spatial scales, from ocean basins to local bays. While earlier classification exercises had taken a hierarchical approach with a nested structure (e.g. ecozone, ecoprovince, ecoregion, etc.), the focus of the Powles et al. (2004) exercise was at the scale of ecoregion (Table 1). Thus, while features below the ecoregion were considered, these were not explicitly used to delineate sub-ecoregions, but rather were used to inform the ecoregion boundaries. It should be noted that this approach did not yield consensus on all boundaries due to the conflicting nature of some of the patterns. As a result, some boundaries were chosen based upon the best possible arrangement for the purpose of the exercise, rather than through consistency amongst all criteria.

Rankin et al. (2008) report that the DFO classification (Powles et al, 2004) did not prove useful as a basis for the LOMA of integrated management required by the CCRM, as many important species have life histories using several ecoregions and the regions have little correspondence to the provision of ecosystem goods and services. The CCRM have indicated that work under the DFO Oceans Action Plan has provided a better understanding of the scale of the ecological units for which meaningful assessments can be done. For example, assessments which are integrated across physical and biological processes and consider the provision of ecosystem goods and services. The CCRM initiative (Rankin et al., 2008), which considered terrestrial, freshwater and marine ecoregions, was guided by four principles:

1) *Contiguous and integrating*: ecological units should be “place-based” and continuous, integrating many of the site-level ecosystems traditionally associated with vegetation composition and structure (e.g. grasslands, wetlands, etc.);

2) *Thematically consistent*: ecosystem boundaries will be consistent for all indicators throughout the Ecosystem and Status Trends Report (ESTR). This approach contrasts with other reports, which, for example, use administrative units for socio-economic data, bioclimatic units for climate change indicators, etc;

3) *Spatially exclusive*: every point on the Canadian map will be included in only one status assessment; and

4) *Flexibility*: Not all indicators are meaningful at the scale of an ecological unit. In many cases, data will only be collected for particular subunits or physiognomic units (e.g. rangeland assessments, freshwater biological integrity indices, etc.). Similarly, some trends will be different or even opposite in different parts of the ecological unit. Taking the average of differing trends can lead to misinformation, and in these cases subunits may be highlighted and treated separately from the surrounding ecological unit for that particular indicator.

The CCRM marine ecoregions were based upon DFO’s five LOMA, supplemented with additional expert judgment. Note that the WWF/Nature Conservancy classification approach is described under the MEOW initiative.

Data Usage

Regarding the PC initiative, Harper et al. (1983) indicate that the following classes of data were considered:

- Physical features
    - Oceanography
    - Coastal environment
    - Physiography

- Biological features
    - o Marine birds
    - o Marine mammals
    - o Fish
    - o Invertebrates

Regarding the EC initiative, in their update of the earlier classification, Harper et al. (1993) relied heavily on well-defined criteria of physical components which have overall ecological significance. The criteria were developed from global-scale delineation criteria down through continental/ocean basin criteria, to ocean mixing criteria which were applied nationally. Thus, the criteria by scale (from largest to smallest) were:

- Ecozone
    - o Ice and ocean basins
- Ecoprovince
    - o Major oceanic surface current systems and coastal margins
- Ecoregions
    - o Marginal seas
- Ecodistricts
    - o Mixing processes, stratification, smaller – scale currents
- Ecosections
    - o Depth and habitat

Harding (1998) modified this hierarchy (Table 5) for use in the EC classification system. In this system, marine ecological units are determined by physical variables such as shoreline configuration, bathymetry, currents and water column properties (including both physical properties such as temperature and chemical properties such as salinity and conductivity), and processes such as mixing.

The criteria selected are those with important ecological implications at the appropriate scales. These physical criteria pose constraints on which biota can live there, and on how they interact with each other and with their environment. This is analogous to EC's terrestrial classification system, where ecological units are determined by climate and physiography, but described by the ecological structures and functional relationships that they support. In developing the criteria, Harding (1998) worked from global-scale delineation criteria down through continental/ocean basin criteria to oceanic mixing criteria. The criteria are applied nationally so that the hierarchy remains consistent from region to region, and each regional or subregional boundary is explicitly defined by one or more criteria.

Regarding the DFO initiative, the following geological, physical oceanographic and biological properties were considered:

- Geological (i.e. degree of enclosure, bathymetry, surface geology);
- Physical oceanographic (i.e. ice cover, freshwater influence, water temperature, water masses, currents, and mixing/stratification); and
- Biological (i.e. primary productivity, species distributions, population structure, assemblages/communities).

Products of Classification

The marine region classification of EC consists of three ecozones (Figure 9) which are comprised of 12 ecoprovinces, 18 ecoregions, and 48 ecodistricts. In a number of cases, further subdivision of the ecological units was not considered possible (see Harding, 1998 for further details). GIS digitized files of the EC marine ecoregion classification could not be obtained for this report.

The marine biogeographic classification of PC consists of 29 ecoregions (Figure 10) and includes 10 ecoregions in the Atlantic, nine in the Arctic, and five in the Pacific, as well as five in the Great Lakes. The PC website (http://www.pc.gc.ca/progs/amnc-nmca/systemplan/index_e.asp) provides an overview of each of the ecoregions in their biogeographic classification system.

The DFO ecoregion classification consists of 17 marine ecoregions for Canada's three oceans (Figure 11). Under the DFO biogeographic classification system, there are seven ecoregions in the Atlantic, six in the Arctic, and four in the Pacific.

Powles et al. (2004) provides a description of the major geological, physical oceanographic and biological properties for each of these ecoregions (Appendix 4).

The CCRM classification (Rankin et al, 2008) generally defines ecological units at a higher spatial scale than that of DFO and Parks Canada and delineates each ocean into three ecoregions (Figure 12).

Table 5. The Marine Ecological Classification System of Harding (1998).

Classification Level (map scale)	Criteria	Classes	Ecological Criteria
ECOZONES **1st Order Subdivision (1:10 million)**	Ocean Basins, global climate and current patterns, permanent and seasonal ice cover	**Pacific** **Arctic** **Atlantic**	separate ocean basins created by tectonic and volcanic events; water masses distinctly different; biological systems evolved on geologic time scales in response to movement of continents, long term climatic events and sea level fluctuations.
	Coastal Zone	**Arctic** **Temperate-Subarctic**	near-coastal environments between or inshore of major oceanic basins.
ECOPROVINCES **2nd Order Subdivision** (1:5 million)	Major oceanic surface current systems	**Pacific subarctic** (Alaskan Current) **Pacific temperate** (California Current) **Atlantic subarctic** (Labrador Current) **Atlantic Temperate** (Gulf Stream)	major oceanic current patterns influence water source areas, water temperatures; may indirectly control recruitment; differences in productivity and distribution of species and plankton, fish, seabirds and marine mammals
	Continental Margins	**Oceanic Basin** (deep water and marine water characteristics) **Continental Shelf** (water depths usually less than a few hundred metres; freshwater influenced often with strong coastal buoyancy currents)	oceanic vs neritic: delineates between the "marine", deep ocean basins and the continental margins where freshwater strongly influences circulation ; nutrient sources associated with freshwater; different plankton species and productivity; gross differences in benthic species and processes; generally different fish, marine mammal and seabird species
ECOREGIONS **3rd Order Subdivision (1:3 million)**	Marginal Seas	**Marginal Sea** (freshwater dominated; generally semi-enclosed basins) **Marine Shelf** (more marine, open circulation than marginal sea)	generally areas of restricted circulation with a significant freshwater influence (usually large river sources); large nutrient source; seasonal variation in flow results in seasonal variation in nutrients, ecology
ECODISTRICTS **4th Order Subdivision** (1:1 million)	Mixing Processes/ Stratification/ Smaller-scale currents	**highly stratified** **stratified** **well mixed** **upwelling (polynya)**	mixing energy, usually resulting from tides, influences stratification and nutrient exchange between surface and subsurface waters; mixing may influence ice cover (polynya); strong stratification can limit nutrient exchange within water column

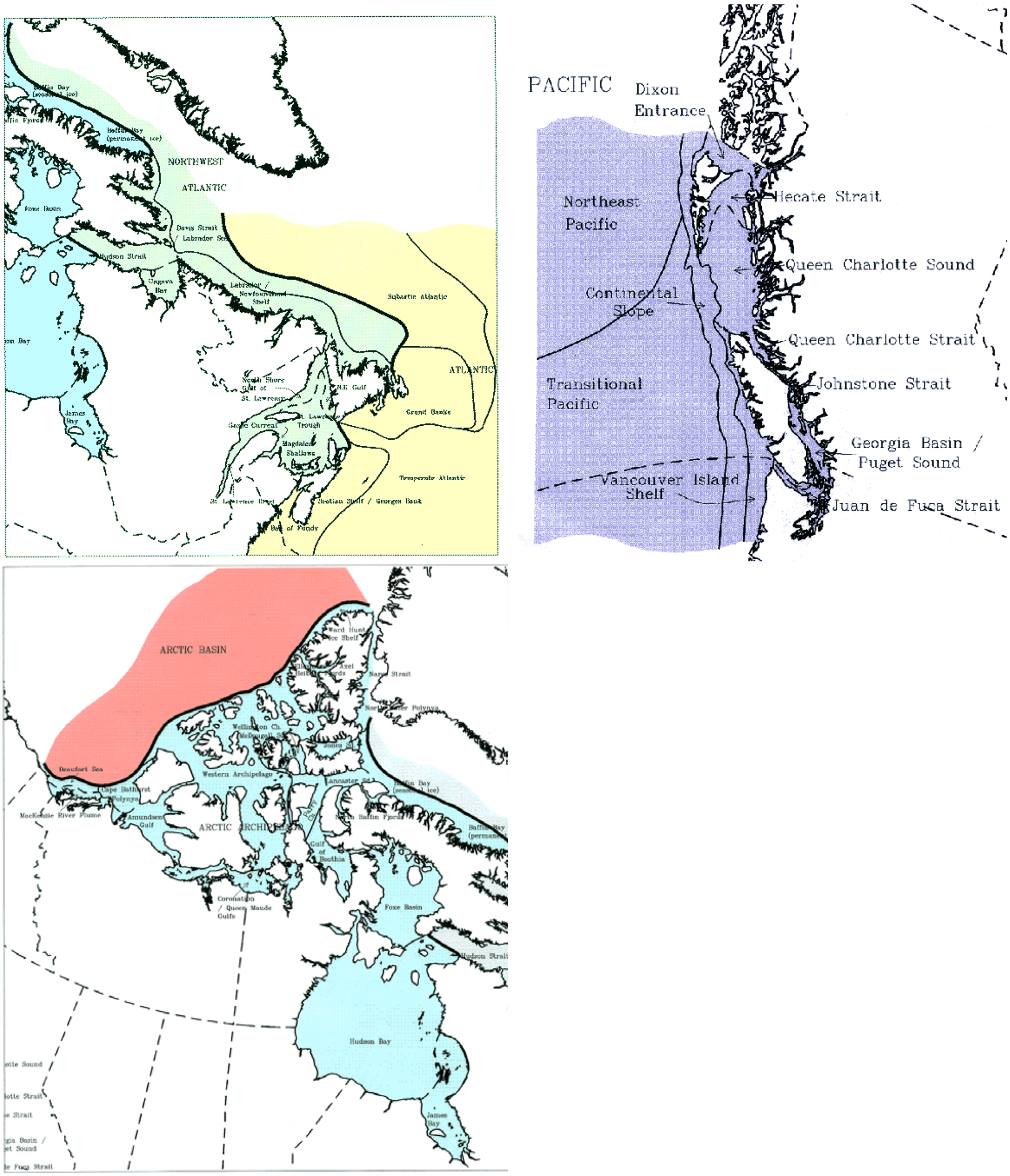

Figure 9. Marine Biogeographic Classification of Environment Canada (Harding, 1988).

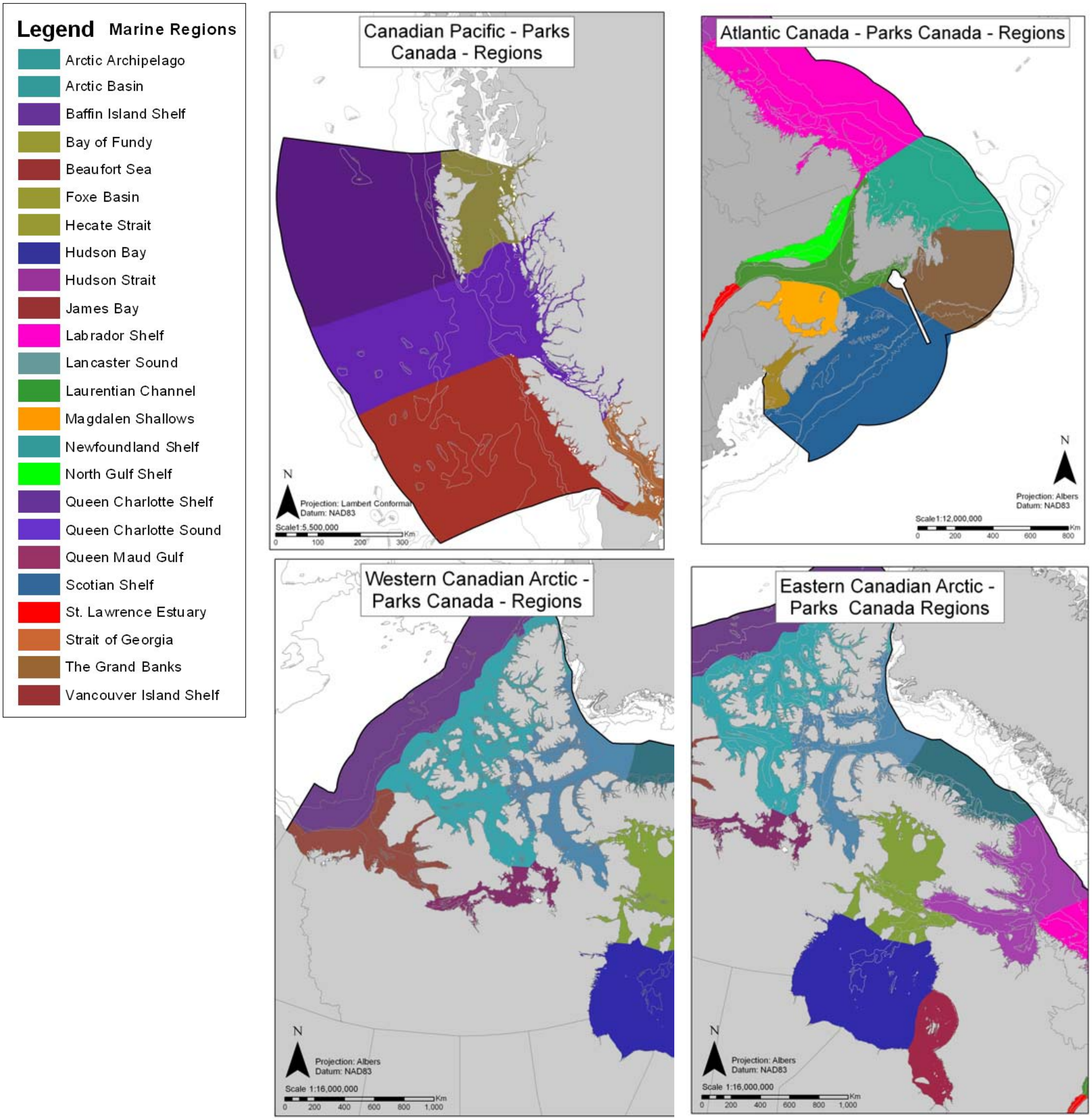

Figure 10. Canadian marine ecoregions using the Parks Canada biogeographic classification (Harper et al, 1993).

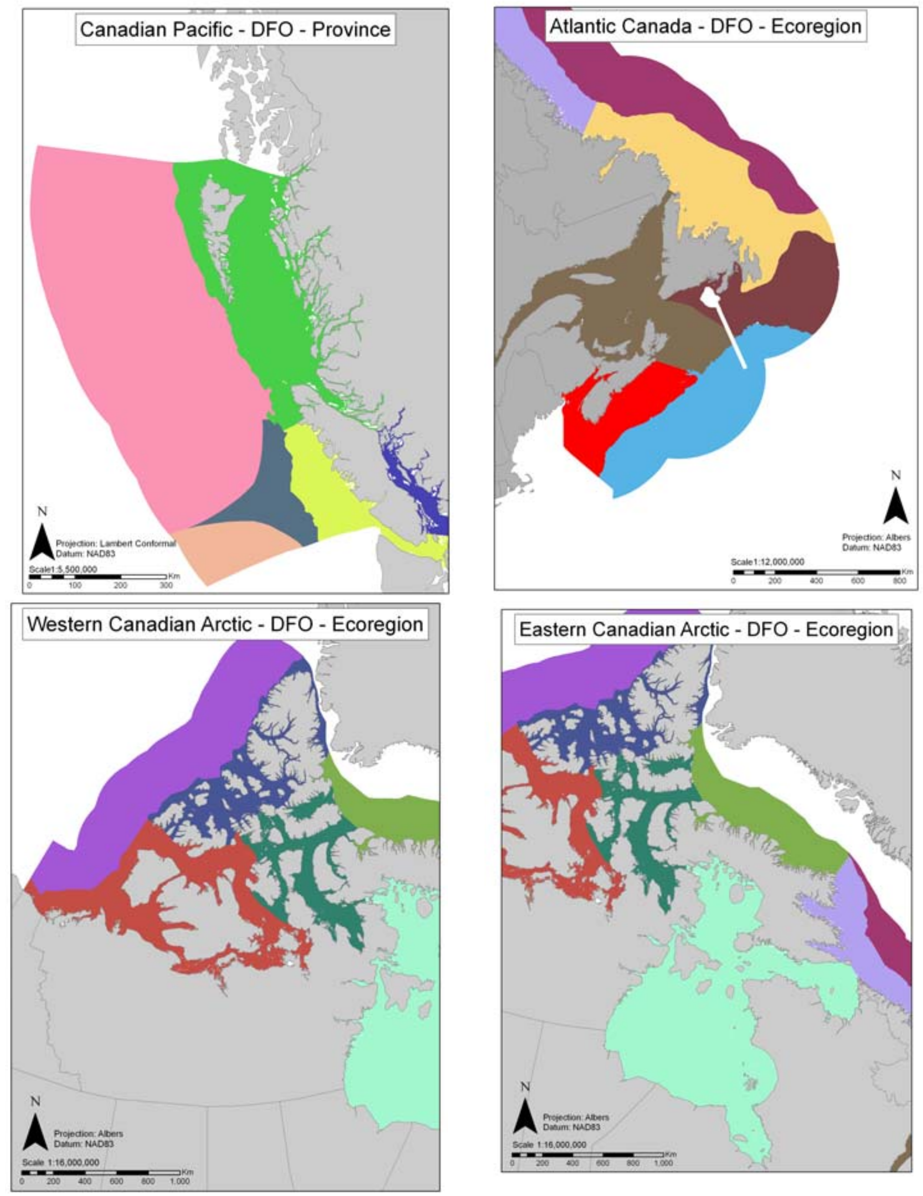

Figure 11. Canadian marine ecoregions using the Fisheries and Oceans Canada (DFO) biogeographic classification (Powles et al, 2004).

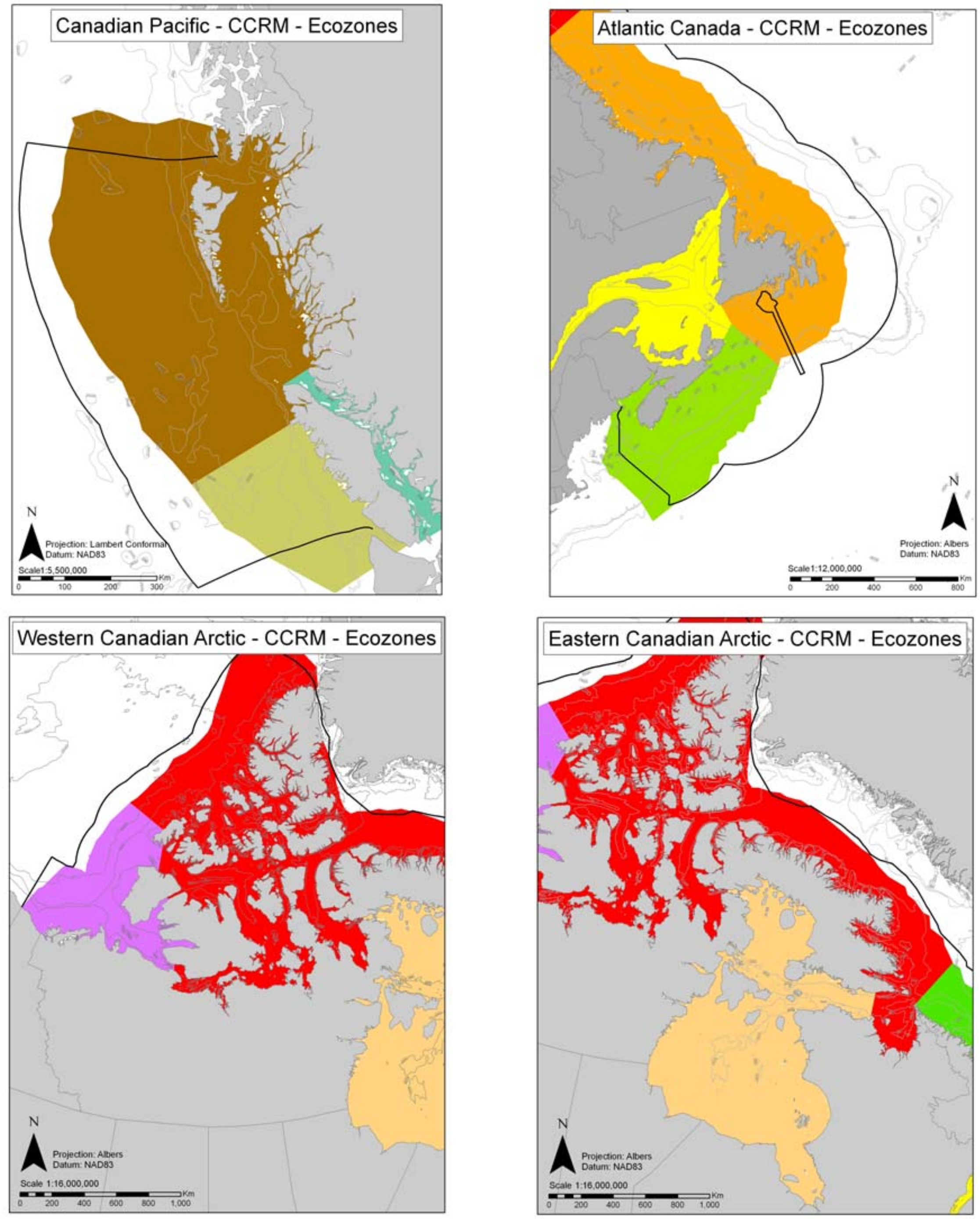

Figure 12. Marine biogeographic classification of the Canadian Council of Resource Ministers (CCRM) for the Canadian Atlantic Ocean (Rankin et al, 2008). The solid black line indicates Canada's Exclusive Economic Zone.

MARINE ECOREGION CLASSIFICATION OF EUROPEAN WATERS

Background

At the same time that efforts to define marine ecoregions in North America were underway, similar activities were being undertaken in Europe under the auspices of the International Council for Exploration of the Sea (ICES). The latter was requested by the European Commission to provide information and advice on appropriate ecoregion boundaries for implementation of an ecosystem approach in European waters no later than the end of 2004 (ICES, 2004). The resulting process that ICES used is instructive to the current initiative as it is illustrative of an expert-driven process driven by specific issues that the classification needed to address.

Objectives

The European Commission request to ICES was specific in that they desired ecoregions for which ecological objectives would be set when implementing an ecosystem approach in European waters. Thus, the main motivation for ecosystems was in support of an ecosystem approach to management.

Classification Approach

ICES convened a group of experts in October 2004 to develop the biogeographic classification for European waters. Their first step was to define what was to be included in 'European' waters as this had been left to the interpretation of the expert group. The European Commission request required that the ecoregion boundaries be based on biogeographic and oceanographic features, taking into account existing political, social, economic, and management divisions. Therefore, ecoregions were to be characterized by greater similarity in biogeographic and oceanographic characteristics within and amongst regions. Boundaries were to be defined unambiguously to guide research, objective setting, assessment, monitoring and enforcement. The evaluation followed a four-step process:

1. Existing biogeographic and management regions that might be used as ecoregions were catalogued;
2. A series of criteria (Table 6) that could be used to assess potential ecoregions (based upon oceanographic, biogeographic, ecological, management and policy perspectives) were identified;
3. Evaluation of existing biogeographic and management regions using the criteria, which included OSPAR regions, ICES areas, LMEs, Longhurst provinces, Dinter biogeographic regions, and Regional Advisory Council areas; and
4. Changes made to improve match to the criteria.

Table 6. Criteria for evaluating existing or proposed eco-regions and the expected qualities of ecoregions appropriate for implementation of an ecosystem approach in European waters (ICES, 2004).

Category/Criterion	Expectation for Ecoregion
Oceanography/Biogeography/Ecology	
Oceanographic characteristics	Clear oceanographic justification for boundaries
Distribution range of species / communities at relevant depths	Demarcation of pelagic and benthic species and communities
Application over management time-scale (i.e. decades)?	Boundaries would apply for decades or more
Spatial variation in response to ecoregion's physical characteristics, species and communities to climate variability and climate change	Low spatial variation so that rate of management adaptation to climate change similar throughout ecoregion
Level of material exchange	Low; ecoregion should be relatively self-sustaining
Oceanographic and biological variability	Smaller within than amongst ecoregions
Nested sub-regions with ecoregions	Ecoregions should divide clearly and completely into smaller (LE 3) subregions
Human Impacts and Management	
Management actions across ecoregions	Minimal response in one ecoregion to actions in another ecoregion
Compatibility with distribution and management of fisheries	Fish populations distributed and managed within same ecoregion
Consistency with management regions	High
Consistency with terrestrial management regions	Consistent to support integration of marine and terrestrial assessment & management
Linkage of research, assessment & monitoring	It should be possible to link research, assessment and monitoring of terrestrial and marine impacts to effectively support integrated management
Compatibility with patterns of land use type and change and distribution of human populations	Compatibilities between ecoregion & land use type and change and distribution of human populations
Nesting within eco-regions without gaps or inefficiencies	Eco-region should divide clearly and completely into small number (typically 3) of sub-regions
Shelf areas and the slope to a depth of at least 1000m	Shelf and slope to a depth of at least 1000m fall within same eco-region
Management / Policy	
Application of ecoregions to marine environment	Eco-regions should apply to the fullest possible extent to the marine environment
Compatibility with UNCLOS	Should be compatible
Jurisdictional gaps	None
Application of management conventions	Management responses should be consistent throughout the eco-region
Creation of management impediments	Boundaries should not create impediments to effective management
Partnerships	The eco-regions should facilitate partnerships
Subdivision into political and management regions with as few gaps as possible	Eco-region should divide clearly and completely into political and management regions

It was impossible to define a specific scoring system that could balance often-conflicting requirements of the criteria. Thus, expert judgment was used to determine the preferred boundaries, taking into account the relative strengths and weaknesses of the newly identified ecoregions in relation to the criteria. The expert group made a number of detailed decisions on the ecoregion boundaries which are documented in ICES (2004).

Data Usage

The evaluation used expert judgment to score the criteria defined in Table 6. These criteria included many of the classes of variables considered in other classification systems, as well as the significant addition of human impacts and their management.

Products of Classification

The proposed classification system met more of the evaluation criteria than any of the existing schemes that were reviewed, partly because they took account of biogeographic, oceanographic, ecological, and human impact/management issues that had often been treated more or less independently. One of the strengths of the exercise was the degree to which it was guided by a pre-defined set of criteria which emanated from the initial European Commission request. The exercise also pointed out the difficulties of using disparate and often conflicting criteria to define ecoregion boundaries. Descriptions of the Northeast Atlantic ecoregions were not considered necessary for this report and therefore GIS digitized files of the classification were not obtained.

SYNTHESIS OF BIOGEOGRAPHIC CLASSIFICATION SYSTEMS CONSIDERED

In this section, comparisons are provided for nine of the biogeographic classification systems considered according to their objectives, classification approach, data usage, and resultant maps. The ICES (2004) classification is not considered in these comparisons as it was not intended to map ecosystems associated with North America. Given the range of information available it was not possible to undertake these comparisons at an in-depth level. Rather, the focus of the comparisons was on the principal similarities and differences amongst the classification systems considered.

SPATIAL SCALE

Before comparing and contrasting the nine biogeographic classification systems, it is first important to address the issue of spatial scale. Ecosystem processes occur across a wide range of spatial scales, often with lower level processes hierarchically arranged within higher level ones. The classification systems reviewed in this report considered a wide range of spatial scales; some primarily considered the large scale (e.g. Longhurst, 2007) while others considered the relatively small scale (e.g. Powles et al., 2004). Most classifications used a hierarchical approach, with small spatial units organized within larger ones. Spalding et al. (2007a) considered that a hierarchical approach is a desirable feature of a biogeographic classification system as it allows choice of the appropriate ecological level of organization based upon the particular needs in question. A number of terms were used in the studies to describe the different spatial scales of organization. Some studies used terms current in the ecological literature while others were less specific in their terminology. From large to small scale, these are:

Biomes (BGCP), Realms (MEOW), Provinces (GOODS) and Ecozones (EC)

Biomes describe different types of ecosystems at a very large scale (e.g. polar vs. coastal ecosystems) and Longhurst (2007) reports that a biome in the BGCP system has the same use as those in terrestrial plant geography. This is consistent with the use of this term by UNESCO (2009) which considers a biome as '*a major regional ecological community of plants and* *animals extending over large natural areas'*. In the sea, these equate to geological units or hydrographic features such as coastal, demersal, shelf and slope, abyssal, neritic, epipelagic, mesopelagic and bathypelagic. In the classification of the benthic environment, biomes are biogeographic units based on primary bathymetric units and faunal communities that are nested within provinces.

Spalding et al. (2007a) use the term 'realm' for very large regions of coastal, benthic, or pelagic ocean across which biotas are internally coherent at higher taxonomic levels, as a result of a shared and unique evolutionary history (Table 1). UNESCO (2009) uses the term 'province' for its pelagic ecological units. These are larger in scale than the 'provinces' of the other classifications, which used the term for the next hierarchical subdivision down. Ecozones (Harding, 1998) are similarly defined at the very large, ocean basin scale (Table 5).

While it can be argued that realms and ecozones are smaller in geographic scale than biomes, for the purposes of the comparisons made in this report, they are both used to describe the largest geographical units considered and will be considered to be generally at the same spatial scale.

Biogeochemical Provinces (BGCP), LME, Provinces (MEOW), Level-I Ecoregions (MECNA) and Ecoprovinces (EC)

Longhurst (2007) is the only one of the nine biogeographic classification systems considered to use the term biogeochemical province (BGCP). BGCP are relatively large in size (e.g. the coastal California Current province ranges down the entire Pacific coast of North America) but they are not as large as biomes or realms.

Large Marine Ecosystem (LME) is the term used by only one classification system (Sherman and Alexander, 1986) and similar to BGCP, LME tend to be quite large, some being in excess of 200,000 km^2; however, they do not appear to be on the same scale as biomes.

Spalding et al. (2007a) defines provinces (Table 1) as large areas defined by the presence of distinct biotas that have at least some cohesion over evolutionary time frames. They may include geomorphological features (e.g. isolated island and shelf systems, semi-enclosed seas, etc.), hydrographic features (e.g. currents, upwellings, ice dynamics, etc.), or geochemical influences (e.g. broadest-scale elements of nutrient supply and salinity). Spalding et al. (2007a) considers their provinces to be at a similar scale as BGCP and LME. Harding (1998) considers ecoprovinces are characterized by major faunal assemblages, meso-scale ocean processes, and climate driven ecological features.

Wilkinson et al. (2009) refer to Level I ecoregions as their largest scale of biogeographic organization. As noted in the previous section, Level I ecoregions describes ecosystem differences which are determined by continental or ocean basin processes along with defining large water masses and currents, large enclosed seas, and regions of coherent sea surface temperature or ice cover. They appear to be similar in scale to the MEOW provinces, BGCP and LME.

While there are differences amongst the above definitions, for the comparisons made in this report, they will be considered as describing ecological processes which are occurring at generally the same spatial scale.

Ecoregions (MEOW, EC, PC, DFO), Level-II ecoregions (MECNA) and Ecozones (CCRM)

Spalding et al. (2007a) defines ecoregions (Table 1) as areas of relatively homogeneous species composition, clearly distinct from adjacent systems with species composition likely determined by the predominance of a small number of ecosystems, and/or a distinct suite of oceanographic or topographic features. Powles et al. (2004) uses the Harper et al. (1993) definition (which is that used by EC and PC) of an ecoregion (i.e. part of a larger marine area (ecoprovince) characterized by continental shelf-scale regions that reflect regional variations in salinity, marine flora and fauna, and productivity). Wilkinson et al. (2009) describe Level-II ecoregions as those determined by large-scale physiography (e.g. continental shelf, slope, and abyssal plain, as well as areas of oceanic islands and major trenches, ridges and straits). Rankin et al. (2008) use the term ecozone which, while not specifically defining the term, are consistent with the MECNA Level-II ecoregions. Overall, the above definitions all appear to apply to generally the same spatial scale.

Level-III Ecoregions (MECNA), Ecodistricts (EC)

Wilkinson et al. (2009) is the only classification system which uses Level-III ecoregions. They are intended to describe differences within the neritic realm and are based on more locally significant variables (e.g. local characteristics of the water mass, regional landforms, biological community type). Harper et al. (1993) and Harding (1998) use the terms ‘ecodistrict’ and ‘ecosection’, as defined by mixing processes, stratification, smaller-scale currents in the first case, and depth and habitat in the second. Level-III ecoregions are considered here as generally equivalent with these smaller scale classification units. A summary of the spatial scale definitions for the aforementioned biogeographic classification systems is shown in Table 7.

Table 7. Summary of the spatial scale definitions for a variety of biogeographic classification systems.

Biogeographic Classification System	**Small Scale**	**Medium Scale**	**Large Scale**	**Largest Scale**
Large Marine Ecosystems (LME)			LME	
Marine Ecoregions of the World (MEOW)		Ecoregion	Province	Realm
Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS)				Province
Biogeochemical Provinces of the Ocean (BGCP)			BGCP	Biome
Marine Ecoregion Classification of North America (MECNA)	Level III Ecoregion	Level II Ecoregion	Level I Ecoregion	
Environment Canada (EC)	Ecodistrict	Ecoregion	Ecoprovince	Ecozone
Parks Canada (PC)		Ecoregion		
Fisheries and Oceans Canada (DFO)		Ecoregion		
Canadian Council of Resource Ministers (CCRM)		Ecozone		

Four studies examined the largest spatial scale (MEOW, GOODS, BGCP and EC), five the large scale (LME, MEOW, BGCP, MECNA and EC), six the medium scale (MEOW, MECNA, EC, PC, DFO and CCRM) and two the small scale (EC and MECNA). Hierarchal approaches were used by MEOW, BGCP, MECNA and EC although it is evident from the Harper et al. (1983) roots of the PC and DFO classification systems that these can be considered hierarchical with only one spatial scale being considered in these studies. It is recognized that the above comparisons of the spatial scales used in the nine biogeographic classification systems reviewed is coarse. Notwithstanding this, it facilitates general comparisons among the maps of the nine systems and can also aid as a tool to highlight when comparisons among maps may be appropriate.

OBJECTIVES

It is important to understand the primary motivations underpinning the nine biogeographic classifications considered when making comparisons of their mapping and other products. Most of the nine biogeographic classification systems considered in this report were developed in support of some element of an ecosystem approach to management. Some were very specific in their focus (e.g. scientific basis for location of MPA) while others were more general (e.g. science for integrated management). Still others focused on one aspect of the ecosystem (e.g. habitat) while others were broader in scope (e.g. ecosystem processes). A number of studies considered the objectives of an ecosystem approach to management (Jamieson et. al., 2001; Sainsbury and Sumaila, 2003). While they differ in detail, they are generally based upon the dimensions of sustainable development (i.e. conservation, social and economic-well being and institutional arrangements) (WCED, 1987), with conservation generally considering the structural (biodiversity), functional (productivity), and habitat components of an ecosystem. These classes of objectives can facilitate the comparisons across the nine biogeographic classifications:

- Conservation
    - Biodiversity: representative mapping of biodiversity in support of conservation efforts, where representative implies that there was no intent to only map special ecosystem components e.g. vulnerable and/or significant species
    - Productivity: mapping of marine resources in support of human use e.g. fisheries
    - Habitat: mapping in support of the impacts of human activity on habitat e.g. marine environmental quality
- Social and economic well–being
    - Mapping in support of the human communities that use them
- Institutions
    - Mapping in support of the institutions of integrated management

The main objectives of the biogeographic classification systems considered are shown in Table 8.

Table 8. Summary of the main objective(s) of each biogeographic classification system considered. The cell shadings give a general indication of primary (dark) and secondary (grey) objectives sought, where applicable.

Class of Objective	Biodiversity	Productivity	Habitat	Socio-Economic	Institutions
Large Marine Ecosystems (LME)					
Marine Ecoregions of the World (MEOW)					
Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS)					
Biogeochemical Provinces of the Ocean (BGCP)					
Marine Ecoregion Classification of North America (MECNA)					
Environment Canada (EC)					
Parks Canada (PC)					
Fisheries and Oceans Canada (DFO)					
Canadian Council of Resource Ministers (CCRM)					

The LME were initially developed to provide the science in support of integrated management and thus to address multi-sector issues (Sherman, pers. comm.). While LME can service the suite of other objectives, they appear to be primarily institutions to facilitate the sustainable use of ecosystems. While the MEOW and GOODS biogeographic classification systems were developed broadly to provide the ecological basis for an ecosystem approach to management, their more specific objectives relate to the conservation of biodiversity through the identification of zones upon which a representative network of MPA could be based. Longhurst (2007) developed BGCP as a means to characterize the oceanographic processes that define an ecosystem's productivity. There was no explicit intent to define areas of the ocean that could be used for management purposes. Of the nine systems considered in this report, that of Longhurst (2007) is the only one which has no direct connection with ocean management. MECNA was developed to service a number of objectives, but overall it is in support of ecosystem–based management efforts around North America. Explicit mention in the objectives is made of the need a network of conservation areas as well as the need to support the needs of stakeholders. Thus, its objectives profile is similar to that of the LME. The biogeographic classification system of PC was developed to map marine biogeographic diversity at the ecoregion scale in support of a national system of representative marine conservation areas; thus, there is both a biodiversity and institutional element to the objectives, similar to those of MEOW and GOODS. The DFO, EC, and CCRM classification systems were developed to support management institutions, in the first case the Large Ocean Management Areas of integrated management, and in the second and third cases ecoregions in support of ecosystem monitoring and reporting (i.e. one for MEQ, the other for biodiversity). However, all are intended to service a wide spectrum of needs for an ecosystem approach to management, similar to the situation with LME and MECNA. In summary, most classifications were developed to support an ecosystem approach to management; some are focused on aspects of this while others are more broadly based.

CLASSIFICATION APPROACHES

A number of approaches were used in the biogeographic classification systems considered in the report. However, while they differed in detail, there were common elements. Although they varied significantly in detail, all of them established either hypotheses or criteria at the beginning of the classification to guide the process. Longhurst (2007) stated eight models of ocean processes that guided his classification. Others stated the classes of variables that would be used in the classification (e.g. LME, DFO) while others (i.e. MEOW) were more general in their guiding criteria, having to depend heavily on the products of previous classification exercises.

All systems considered undertook a significant information and data gathering stage which compiled the source material to be used in the classification. This generally involved the identification of experts to undertake the compilation of this material.

Based upon the criteria and the compiled information, classification maps were then produced. The details as to how this was done varied significantly. Some classification systems used a one–step process in which the source material was considered by a team of experts using a Delphic process (Rescher, 1998) and subsequently the classification maps were produced. Other systems used a two–step process in which the initial classification produced by an individual or team was then challenged either through a further expert Delphic process or through quantitative analyses that either confirmed the initial mapping or led to modifications. In both cases, the mapping was generally done by data class (e.g. physical, chemical, biological) which were then overlain to determine ecological unit boundaries. A good example of a qualitative challenge is that used by ICES (2004). A team of experts rated a given set of area definitions against the criteria (Table 7) through a Delphic process, to produce the final biogeographic classification. Longhurst (2007) and UNESCO (2009) provide good illustrations of quantitative approaches in which multivariate statistical techniques (e.g. Cluster Analysis, EOR) were used to evaluate whether or not the initial mapping was consistent with the data. Table 9 summarizes the major differences in classification approach followed by the nine studies.

Table 9. Summary of the major difference in biogeographic classification approach among the nine systems considered.

<table>
<tr><th>Classification Process</th><th>One - Step</th><th>Two – Step Qualitative Challenge</th><th>Two – Step Quantitative Challenge</th></tr>
<tr><td>Large Marine Ecosystems (LME)</td><td bgcolor="#b3b3b3"></td><td></td><td></td></tr>
<tr><td>Marine Ecoregions of the World (MEOW)</td><td></td><td bgcolor="#b3b3b3"></td><td></td></tr>
<tr><td>Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS)</td><td></td><td></td><td bgcolor="#b3b3b3"></td></tr>
<tr><td>Biogeochemical Provinces of the Ocean (BGCP)</td><td></td><td></td><td bgcolor="#b3b3b3"></td></tr>
<tr><td>Marine Ecoregion Classification of North America (MECNA)</td><td></td><td bgcolor="#b3b3b3"></td><td></td></tr>
<tr><td>Environment Canada (EC)</td><td></td><td bgcolor="#b3b3b3"></td><td></td></tr>
<tr><td>Parks Canada (PC)</td><td></td><td bgcolor="#b3b3b3"></td><td></td></tr>
<tr><td>Fisheries and Oceans Canada (DFO)</td><td bgcolor="#b3b3b3"></td><td></td><td></td></tr>
<tr><td>Canadian Council of Resource Ministers (CCRM)</td><td bgcolor="#b3b3b3"></td><td></td><td></td></tr>
</table>

The LME, DFO, and CCRM biogeographic classifications appear to have been produced using a one-step process. For instance, Powles et al. (2004) convened a workshop of a large number of experts from a wide array of disciplines to produce the DFO maps. There was no subsequent process that formally challenged these maps either through an expert or quantitative analysis. Regarding the two–step qualitative challenge, the MEOW, MECNA, EC, and PC classifications were all produced using this approach. The MEOW was a synthesis of previous studies but consisted of a working group of experts creating a draft map based on the compiled material and then having this subsequently vetted through a workshop of experts. This appears to have been similar to the process used to produce the MECNA. Harper et al. (1983) indicates that this was the process used for the PC classification. Both the BGCP and GOODS (for the pelagic zone) classifications followed the two–step quantitative challenge process in which the initially-derived maps (for BGCP by an individual, and for GOODS by a team) underwent statistical analyses to corroborate the initial mapping. In the case of the BGCP, the veracity of the models used in the initial mapping was explicitly challenged. In this sense, it is perhaps the best example of hypothesis testing in the biogeographic classifications considered in this report.

DATA USAGE

While it is apparent that the nine biogeographic classification studies included in this report considered a wide range of information and covered all aspects of the ecosystem, it was often not possible from the documentation to precisely determine which data were specifically used. Some studies relied heavily on previous work (e.g. MEOW and EC) and thus all these sources are relevant. In other cases, the source and treatment of the data were very detailed (e.g. BGCP). Given the wide array of data and information available, it was only possible to compare the data classes that were used in each classification. To facilitate the comparison, the data classes as described by Powles et al. (2004) were used. A fourth category was added to address administrative efficiency. Table 10 provides a comparison of the data used in the nine biogeographic classification systems considered. It was apparent from some of the systems that a constraint on the maximum number of ecological units was imposed based upon either scientific (e.g. data availability) or management considerations:

- Geological
    - Degree of enclosure
    - Bathymetry
    - Surficial geology
- Physical oceanographic
    - Ice cover
    - Freshwater influence
    - Water temperature
    - Water masses
    - Currents
    - Mixing / Stratification
- Biological
    - Primary productivity
    - Species distributions
    - Population structure
    - Assemblages / communities
- Administrative efficiency
    - Scientific issues (e.g. data availability)
    - Management considerations

Table 10. Comparison of the types of data used in the nine biogeographic classification systems considered.

Data Type	Geological Properties	Physical Oceanographic Properties	Biological Properties	Administrative Efficiency
Large Marine Ecosystems (LME)				
Marine Ecoregions of the World (MEOW)				
Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS)				
Biogeochemical Provinces of the Ocean (BGCP)				
Marine Ecoregion Classification of North America (MECNA)				
Environment Canada (EC)				
Parks Canada (PC)				
Fisheries and Oceans Canada (DFO)				
Canadian Council of Resource Ministers (CCRM)				

All studies used some form of geological, physical oceanographic, and/or biological data. Regarding administrative efficiency, a number of studies emphasized that current administrative boundaries did not influence the biogeographic classification. For example, Sherman (pers. comm.) emphasized that LME boundaries did not conform to administrative boundaries; Spalding et al. (2007a) made the same observation. Conversely, Longhurst (2007) set the maximum number of his BGCP based upon data availability rather than solely on ecological properties. Rankin et al. (2008) state that '*work under the Ocean Action Plan has provided a better understanding of the scale of ecological units for which meaningful assessments can be done, particularly for assessments which are to be integrated across physical and biological processes and consider the provision of ecosystem goods and services'*. This implies some consideration of human uses in setting the classification's boundaries.

The data usage differences among the systems considered are not significant and are perhaps more related to details on how the information was used (e.g. scale, weighting of data, approach, etc.). More importantly is how the classes of data were used at the different scales of the biogeographic organization. UNESCO (2009) recommends that these classes of data be used in a tiered approach, with large spatial scale classified using the physiognomic data and increasing use of taxonomic and ecological information at finer scales. This is consistent with the data usage by Harper et al. (1983), Harding (1998), Longhurst (2007), Powles et al. (2004) and Wilkinson et al. (2009).

PRODUCTS OF CLASSIFICATION

Comparisons of the biogeographic maps for the nine classification systems considered were undertaken for each of Canada's three oceans, organized by spatial scale. There is a significant amount of information in these maps that a recent workshop (DFO, 2009) explored in detail and which drew its own conclusions. The comparisons presented here only highlight similarities and differences based upon the author's subjective examination of these maps, and thus the observations are open to interpretation. For the BGCP, LME, MEOW, MECNA, DFO, PC and

CCRM classifications, the maps were made from the GIS data that were available. For the other classifications, the maps which were presented in the previous sections were used.

In general, scale–specific comparisons between the biogeographic classification systems for Canada's three oceans highlight a number of similarities and differences. In some cases, the differences appear to be due to the appropriateness of the scale considered. Also, there were a number of cases where one classification covered the same general ecological area but with more subunits.

Atlantic Ocean

At the highest spatial scale, the following ecological units were identified for the Atlantic:

- Temperate Northern Atlantic realm (MEOW; Figure 13)
- Gulf Stream Province (GOODS; Figure 3)
- Subarctic Atlantic Province (GOODS; Figure 3)
- Atlantic Polar Biome (BGCP; Figure 6)
- Atlantic Coastal Biome (BGCP; Figure 6)
- Atlantic Marine Ecozone (EC; Figure 9)
- Northwest Atlantic Ecozone (EC; Figure 9)

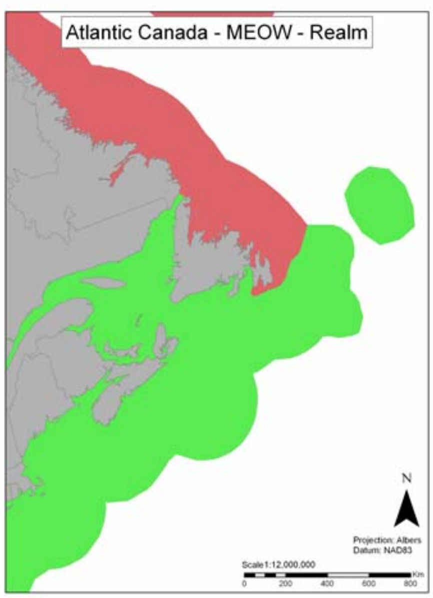

Figure 13. The highest spatial scale of subdivision for the Atlantic in the Marine Ecoregions of the World (Spalding et al., 2007a).

All of the aforementioned ecological units have a boundary off the east coast of Newfoundland. This also applies to the GOODS units which are in the pelagic open ocean. MEOW and BGCP have southern boundaries well down the coast of North America through to Florida. In general, the boundaries of these units are comparable. However, the Northwest Atlantic Ecozone of EC includes the Gulf of St. Lawrence, whereas the latter is included in the Temperate Northern Atlantic realm of the MEOW. The latter includes the Labrador Shelf in the Arctic realm. Table 11 indicates the identified ecological units for the second-order spatial subdivision.

Table 11. Spatial units for the Atlantic Ocean at the second-order of subdivision for the relevant biogeographic classification systems considered.

Biogeographic Classification System	Second-order Subdivision Spatial Units
Large Marine Ecosystems (LME)	• Newfoundland – Labrador Shelf • Scotian Shelf • Northeast US Continental Shelf
Marine Ecoregions of the World (MEOW) Provinces	• Cold Temperate Northwest Atlantic
Biogeochemical Provinces of the Ocean (BGCP)	• Atlantic Arctic • Northwest Atlantic Shelves
Marine Ecoregion Classification of North America (MECNA) Level-I Ecoregions	• Baffin / Labradoran Arctic • Acadian Atlantic • Northern Gulf Stream Transition
Environment Canada (EC) Ecoprovinces	• Davis Strait / Labrador Shelf • Atlantic Shelf • Subarctic Atlantic • Temperate Atlantic • Grand Banks • Scotian Shelf / Georges Bank

There are a number of significant differences in the boundaries of these ecological units for the Atlantic coast. To the north, the Newfoundland–Labrador Shelves LME covers the range of a number of the MEOW provinces but doesn't stretch as far north. On the other hand, the MECNA Baffin/Labrador Arctic Level-I ecoregion goes very far north, including areas that other classifications consider in the Arctic Ocean. The BGCP provinces are quite large in comparison to the ecological units of the other classifications, this in part due to the fact that they do not include subdivisions. Notwithstanding this, Longhurst (pers. comm.) considers that the smaller provinces of MEOW are compatible with the larger coastal BGCP provinces. He considers that the MEOW provinces could be aggregated up into the BGCP biomes relatively easily, and one could identify at least one of the eight Longhurst production models that would fit the production system in each MEOW province. The Davis Strait/Labrador Shelf EC ecoprovince is comparable in extent to the LME but does not include the Grand Banks which is in a separate province. Further to the south, most classifications include the Scotian Shelf in one province but some (i.e. EC) include Georges Bank while others (i.e. LME) do not. The comparisons with the EC classification are difficult as they are generally smaller than the other ecological units which are generally not subdivided further.

There are a large number of detailed differences at the finest scale of subdivision (Table 12). The comparisons can be somewhat simplified by recognizing that the MEOW classification has many elements derived from that of DFO, and the CCRM classification was at least partly based on the DFO classification as well. To the north, the EC and PC classification of the Grand Banks is similar but a number of differences exist for the Labrador Shelf. For the reasons stated above, the MEOW and DFO classifications for this area are similar but different from that of the CCRM.

Table 12. Spatial units for the Atlantic at the finest scale of subdivision for the relevant biogeographic classification systems considered.

Biogeographic Classification System	Finest-scale spatial units
Marine Ecoregions of the World (MEOW)	• Gulf of Saint Lawrence – Eastern Scotian Shelf • Gulf of Maine – Bay of Fundy • Southern Grand Banks – South Newfoundland • Scotian Shelf
Fisheries and Oceans Canada (DFO)	• Northern Labrador • Northern Grand Banks – Southern Labrador • Labrador Sea • Southern Grand Banks – South Newfoundland • Western Scotian Shelf – Gulf of Maine • Gulf of St. Lawrence – Eastern Scotian Shelf • Gulf Stream
Environment Canada (EC)	• Sub-Arctic Atlantic • Davis Strait – Labrador Shelf • Temperate Atlantic • Grand Banks • Labrador-Newfoundland Shelf • Gulf of St. Lawrence • Scotian Shelf
Parks Canada (PC)	• Hudson Strait • Labrador Shelf • Newfoundland Shelf • North Gulf • St. Lawrence Estuary • Magdalen Shallows • Laurentian Channel • Grand Banks • Scotia Shelf • Bay of Fundy
Canadian Council of Resource Ministers (CCRM)	• Newfoundland and Labrador Shelves • Gulf of St. Lawrence and St. Lawrence Estuary • Gulf of Maine and Scotian Shelf
Marine Ecoregion Classification of North America (MECNA) Level-II Ecoregions	• Northern Gulf Stream Transition Slope • Northern Gulf Stream Transition Plain • Grand Banks • Acadian Shelf • Georges Bank • Laurentian/Esquiman Channel • Northeast Channel/Georges Basin

Some significant issues relate to how the Gulf of St. Lawrence and Scotian Shelf are treated. Partly based upon work by Mahon et al. (1985; 1998), the DFO classification split the Scotian Shelf into an Eastern and Western component (with the Eastern component combined with the Gulf of St. Lawrence). Other classifications keep the Scotian Shelf together as one ecoregion and separate from that of the Gulf of St. Lawrence. The EC and PC treatment of the Gulf of St. Lawrence are comparable, but different from that of DFO and the CCRM. The classification of Georges Bank and the Bay of Fundy are generally similar across classifications although MECNA separates Georges Bank out into a separate ecoregion.

Arctic Ocean

At the highest level of spatial subdivision, the following ecological units were identified for the Arctic:

- Arctic Realm (MEOW; Figure 14)
- Arctic Province (GOODS; Figure 3)
- Atlantic Polar Biome (BGCP; Figure 6)
- Arctic Archipelago Marine Ecozone (EC; Figure 9)
- Arctic Basin Ecozone (EC; Figure 6)

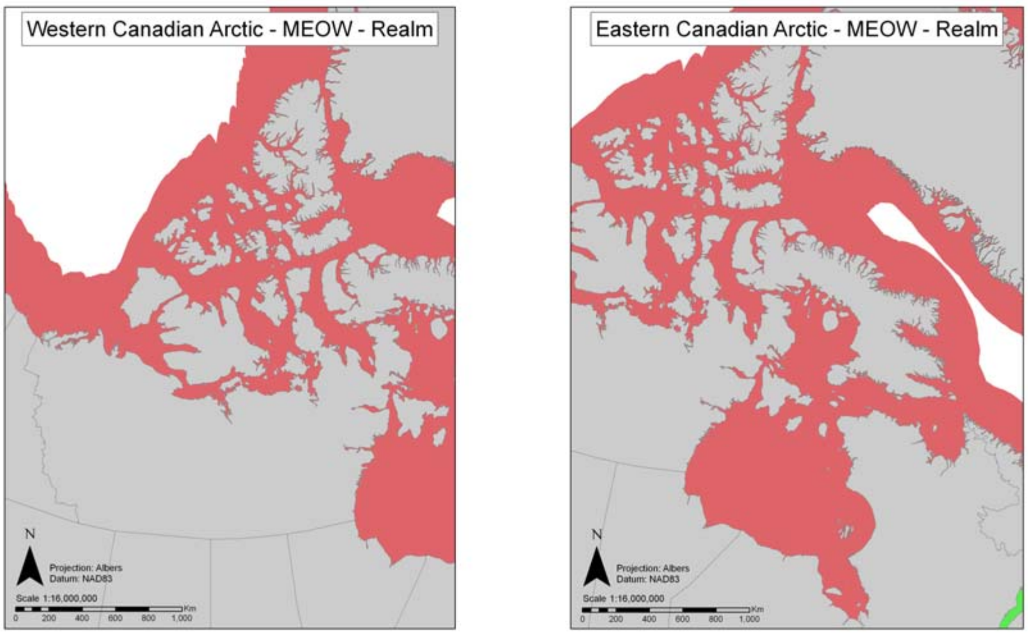

Figure 14. The highest spatial scale of subdivision for the Arctic in the Marine Ecoregions of the World (Spalding et al., 2007a).

A significant issue to address at the highest level of the ecological unit hierarchy is whether or not the Arctic Ocean should be split into two ecological units as done by the EC classification or left as a single unit, as done by the other classifications. The treatment of the Labrador Shelf (Arctic vs. Atlantic) was already noted above. Otherwise, the spatial extent of the ecological units at this scale is comparable across classifications (Table 13).

Table 13. Arctic spatial units for the relevant biogeographic classification systems considered.

LME	MEOW Provinces	BGCP	MECNA Level-I Ecoregions	EC Ecoprovinces
• Arctic Ocean • Hudson's Bay • Beaufort Sea • Arctic Archipelago • Baffin Bay – Davis Strait	(No provinces defined)	• Boreal Polar Province	• Hudson / Boothian Arctic • Central Arctic Archipelago • Arctic Basin • Beaufort / Chukchi Seas	• Northern Arctic • Southern Arctic • Arctic Basin (ecozone)

The LME classification splits the Arctic region into five ecological units. This treatment of the Arctic Ocean is generally similar to the divisions made by the other classifications, except for the BGCP which keeps the Arctic as one province. As well, the Beaufort Sea LME is split into two Level-I ecoregions by MECNA. The north/south split (Arctic Archipelago / Hudson's Bay) is used by the MECNA and EC classifications. Table 14 identifies how the ecological units found in the finest level of spatial subdivision were delineated.

Table 14. Spatial units for the Arctic at the finest scale of subdivision for the relevant biogeographic classification systems considered.

MEOW Ecoregions	MECNA Level-II Ecoregions	EC Ecoregions	PC Ecoregions	DFO Ecoregions	CCRM Ecozones
• Northern Grand Banks – Southern Labrador • Northern Labrador • Baffin Bay – Davis Strait • Hudson Complex • Lancaster Sound • High Arctic Archipelago • Beaufort-Amundsen-Viscount Melville-Queen Maud • Beaufort Sea – continental shelf and slope	• Baffinian Shelf • Ungava/Labradoran Shelf • Grand Banks • Hudson Trough • Baffin/Labradoran Slope • Labrador Plain • Hudson/Boothian Shelf • Hudson/Boothian Slope • Central Arctic Shelf • Central Arctic Slope • Arctic Slope • Arctic Plains	• Western Islands Ecoregion • Eastern Arctic Shelf Ecoregion • Beaufort / Amundsen Gulf Ecoregion • Coronation / Queen Maude Ecoregion • Hudson / James Bay Ecoregion • Arctic Basin Ecozone	• Arctic Basin • Beaufort Sea • Arctic Archipelago • Queen Maud Gulf • Lancaster Sound • Baffin Island Shelf • Foxe Basin • Hudson Bay • James Bay	• Arctic Basin • High Arctic Archipelago • Beaufort – Amundsen – Viscount Melville – Queen Maud • Hudson Complex • Baffin Bay – Davis Strait • Lancaster Sound	• Canadian Arctic Archipelago • Beaufort Sea • Hudson & James Bay & Foxe Basin

As with the Atlantic Ocean classifications, there are a number of differences in classification at the ecoregion level of the Arctic. As noted earlier, the extent of inclusion of Labrador Shelf ecosystems into this area is an issue to be resolved and is included in the MEOW and MECNA classifications. The Hudson Bay area is handled differently by six of the classifications considered, particularly in regard to whether or not the Hudson Bay, Foxe Basin, and James Bay are combined or kept separate. The same is true of the Arctic Archipelago and the Beaufort Sea, with some classification systems (i.e. MEOW, PC, DFO and CCRM) keeping each of them as one ecoregion and others (i.e. MECNA) splitting them each apart. The most aggregated ecoregions are found in the CCRM classification with progressively more splitting by DFO, PC, EC, MECNA and MEOW. Overall, it appears that the issue is primarily what ecological areas to combine, rather than making large scale changes to the boundaries.

Pacific Ocean

At the highest spatial scale, the following ecological units were identified for the Pacific:

- Temperate North Pacific Realm (MEOW; Figure 15)
- California Current Province (GOODS; Figure 3)
- Subarctic Pacific Province (GOODS; Figure 3)
- Pacific Coastal Biome (BGCP; Figure 6)
- Pacific Westerly Winds Biome (BGCP; Figure 6)
- Pacific Ecozone (EC; Figure 9)

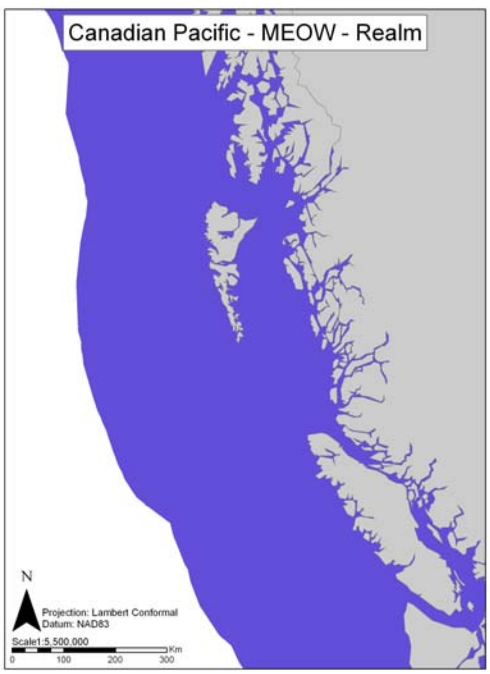

Figure 15. The highest spatial scale of subdivision for the Pacific in the Marine Ecoregions of the World (Spalding et al., 2007a).

The northern boundary of the BGCP and MEOW Pacific ecological units at this scale approaches Alaska, whereas the EC classification has this boundary further south. The southern boundary of the MEOW realm is located off of Oregon, whereas that of the BGCP is off California, in general correspondance with the open ocean classification of GOODS, which splits the Subarctic Pacific and California provinces off the northern tip of Vancouver Island. The EC classification does not stretch below the Canada/US border. Table 15 shows how ecological units at the next spatial subdivision were delineated.

Table 15. Spatial units for the Pacific at the second-highest scale of subdivision for the relevant biogeographic classification systems considered.

LME	MEOW Provinces	BGCP	MECNA Level-I Ecoregions	EC Ecoprovinces
• Gulf of Alaska • California Current	• Cold Temperate Northeast Pacific	• Alaska Downwelling Coastal Province • California Current Province • Pacific Subarctic Gyres	• Alaskan / Fjordland Pacific • Columbian Pacific	• Northeast Pacific • Transitional Pacific • Pacific Shelf / Fjords

The Gulf of Alaska LME is very large, stretching from the Aleutians to the Canada/USA border of the Pacific Coast. This is similar in size to the Cold Termperate Northeast Pacific Province of the MEOW classification (note that in the MEOW description above, only the Canadian related ecological units were considered), the Alaska Downwelling Coastal Province of the BGCP, and the Alaskan/Fjordland Pacific Level I ecoregion of MECNA. The California Current LME is also similarly treated by the MEOW, BGCP, and MECNA biogeographic classification systems. Alternately, the EC classification is different as it is confined to the Canadian Pacific Coast. Table 16 identifies how the ecological units found in the last spatial subdivision were delineated.

Table 16. Spatial units for the Pacific at the finest scale of subdivision for the relevant biogeographic classification systems considered.

MEOW Ecoregions	MECNA Level-II Ecoregions	EC Ecoregions	PC Ecoregions	DFO Ecoregions	CCRM Ecozones
• North American Pacific Fjordland • Puget Trough / Georgia Basin • Oregon, Washington, Vancouver Coast and Shelf	• Alaskan/ Fjordland Shelf • North Pacific Slope • Aleutian Trench • North Pacific Basin • Columbian Slope • Columbian Plains • Columbian Shelf	• Northeast Pacific Ecoprovince • Transitional Pacific Ecoregion • Continental Slope Ecoregion • Georgia Basin Ecoregion • Pacific Shelf Ecoregion	• Queen Charlotte Shelf • Hecate Strait • Queen Charlotte Sound • Vancouver Island Shelf • Strait of Georgia	• Northern Shelf • Southern Shelf – West Coast of Vancouver Island • Offshore • Strait of Georgia	• North Coast & Hecate Strait / Haida Quinnia • West Coast of Vancouver Island • Strait of Georgia

As represented by the CCRM classification, the main ecological areas in the Pacific Ocean are the Strait of Georgia, the West Coast of Vancouver Island, the North Coast, and the Hecate Strait/Haida Quinnia. The EC, CCRM, PC, and DFO classifications treat these areas similarly but differences arise in the other three classifications considered in this report. The MECNA classification appears to split the aforementioned main ecological areas into finer ecodistricts which are more comparable to the ecological units in the other classifications. The MEOW ecoregions are larger in size and cover a larger area, making direct comparisons difficult.

CONCLUDING REMARKS

The review of the ten classification systems considered in this report covered a wide range of issues, from the principal objectives of each study and the classification process, to the comparisons of the resultant maps.

The objectives sought by the various classification initiatives were divided between those that sought to identify representative ecological areas as a basis for a network of MPAs and those that sought to more broadly identify areas as a basis for an ecosystem approach to management. A number of studies emphasized that governance boundaries were not a consideration, although two studies made reference to the need to consider these, as well as other considerations.

An issue that should be addressed is how many areas are desirable to identify as a maximum (i.e. the coarsest spatial scale)? Longhurst (2007) did this for his global BGCPs, noting that the organization of the ocean is fractal and where one draws a boundary is somewhat arbitrary and may be guided by issues such as data availability, administrative convenience and so on. This report highlighted how ecological scales were interpreted and characterized in the different studies. Knowing which scale was being described also facilitated comparisons across the studies. A number of studies (e.g. Harding, 1998; Harper et al., 1983; Spalding et al. 2007a) considered that the application of a hierarchically–based classification system, in which finer scales were arranged within larger ones, had advantages over non-hierarchical systems. Further, Harper at al. (1993) and Longhurst (2007) considered that the higher levels of a biogeographic classification were likely influenced more by geomorphologic and oceanographic processes than lower levels where biological processes increasingly dominate.

Another issue is the classification process. For the foreseeable future, primarily due to variability in data availability, biogeographic classification will likely rely heavily upon expert judgment and Delphic processes. One must then consider an approach that is robust to the selection of the experts. Having two sets of experts develop two different classification systems for the same ecosystem is counterproductive. It is useful to consider, as some studies did, a second step challenge of a draft classification. The process undertaken by Longhurst (2007) is perhaps exemplary of this process. First, a hypothesis of what the expected mapping would be is developed. In the case of the BGCP, this was one person (A. Longhurst) deriving maps based upon eight models of ocean processes. It could also be a team of scientists using expert judgment to develop the draft mapping, as most teams appeared to do. In either case, the draft mapping would be guided by hypotheses using available data, published literature, and expert judgment. If one accepts that different spatial scales are influenced by different processes, this implies that different teams of experts and different hypotheses would be associated with each level. This also has the benefit of ensuring that the appropriate expertise is brought to bear on the appropriate component of the overall classification. This is essentially the approach used by Harper et al. (1983). Once these expert teams have produced their draft mappings, it is then possible to challenge these, either through qualitative or quantitative analysis. Regarding qualitative analyses, ICES (2004) illustrates the effectiveness of using a set of qualitative criteria to judge the appropriateness of a developed mapping. Longhurst (2007) and UNESCO (2009) provide illustrations of quantitative (e.g. cluster analysis) approaches. Determining quantitative approaches to biogeographic classification is a growing field. Growns and West (2008) describe a Genetic Algorithm for Rule–Set Production (GARP) which they used to produce distributional maps for native freshwater fish species in New South Wales. Snelder et al. (2006) provide examples of non-hierarchical and hierarchical cluster analysis in their marine classification of the New Zealand region. Accad et al. (2005), using a case-study from Queensland, compare data-based and expert-based classification approaches, pointing out that expert judgment can be efficiently incorporated into the modeling through priors in a Bayesian framework. Thus, a number of alternatives to the traditional Delphic process are starting to emerge. These methods allow challenges of the draft model and updates to be made based upon objective criteria. If the mapping and challenges were undertaken by class of information (e.g. physical oceanography, biological oceanography, etc.), then the overall classification should be a layered composite of these individual mappings and if ecological scale is truly hierarchical, this should naturally emerge from this composite.

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APPENDICES

APPENDIX 1. EXISTING GLOBAL MARINE BIOGEOGRAPHIES (ANNEX FROM CBD, 2006A).

It is reported that the synthesis of the Marine Ecosystems of the World (MEOW) biogeographical classification, leant heavily on a number of classification systems, although they did not provide sufficient resolution to enable finer-scale assessment and planning (and some did not offer a complete global coverage). MEOW attempted to build a system that can be linked to some of these existing units at different spatial scales. Below is listed some of the key global studies and systems that have been widely cited, some of which are in active use.

Zoogeography of the Sea (Ekman, 1953)
One of the first classic volumes originally published in German in 1935, this recognises, but does not clearly map a number of “faunas”, “zoogeographic regions”, and “subregions”.

Marine Biogeography (Hedgpeth, 1957)
This work points back to that of Ekman, but also reviews many other contributors and produces a first global map showing the distribution of the highest level “littoral provinces”.

Marine Zoogeography (Briggs, 1974)
Perhaps the most thorough taxonomic-based classifications devised, this work still forms the basis for much ongoing biogeographic work. The work focusses on shelf areas and does not provide a biogeographic framework for the high seas. Briggs developed a system of regions and provinces, with the latter defined as areas having at least 10% endemism. These remain very broad-scale, with 53 Provinces in total. The MEOW system uses many of the boundaries developed by Briggs to inform its own subdivisions, however it is felt that the strict definition is both difficult to apply and leads to bias in favour of subdividing species-poor areas and in ignoring major differences in community composition.

Classification of Coastal and Marine Environments (Hayden et al., 1984)
An important attempt to devise a simple system of spatial units to inform conservation planning. The coastal units are closely allied to those proposed by Briggs.

Large Marine Ecosystems (Sherman and Alexander, 1989)
One of the mostly widely used classifications these are “relatively large regions on the order of 200,000 km^2 or greater, characterized by distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations”. They have been devised through expert consultation. At the present time, the system is restricted to shelf areas and, in some cases, to adjacent major current systems and does not include island systems. As shown by the definition these units are not defined by their constituent biotas: although in many cases there are close parallels due to the influence of the abiotic characters in driving biotas this is not always the case. The MEOW system uses many of the same boundaries as LMEs either for its Provinces or Ecoregions, but in a few areas the fit is poor.

A Global Representative System of Marine Protected Areas (Kelleher et al., 1995)
Not strictly a classification, this is one of the only global efforts to look at global marine protected areas coverage. Contributing authors were asked to consider biogeographic representation in each of 18 areas and this volume provides important pointers to biogeographic literature and potential spatial units.

Ecological Geography of the Sea (Longhurst, 1998)

This system of broad biomes and finescale “biogeochemical provinces” is centred on abiotic measures. They are largely determined by satellite derived measures of surface productivity and refined by observed or inferred locations of change in other parameters (including mixing and the location of the nutricline). The direct “measurability” of this system has appealled to a number of authors. It would further appear that some of the divisions lie quite close to lines suggested by taxonomic biogeographers. At the same time, it should be pointed out that this system does not strictly follow the surface circulation patterns in a number of areas. Some of the broader-scale biomes cut right across major ocean gyres, splitting in half some of the most reliable units of taxonomic integrity, while the finer-scale units would appear unlikely to capture true differences in taxa, but could perhaps be open to interpretation as finerscale ecoregions.

Ecoregions: the ecosystem geography of the oceans and continents (Bailey, 1998)

Bailey has provided much of the critical input into the development of terrestrial biogeographic classification, but his work also provides a tiered scheme for the high seas. The higher level “domains” are based on latitudinal belts similar to Longhurst (1998), while the finer-scale divisions are based patterns of ocean circulation.

APPENDIX 2. DESCRIPTION OF BIOGEOCHEMICAL PROVINCES OF LONGHURST (2007)

Comprehensive descriptions of the biomes and provinces are provided in Longhurst (2007). Below are provided short descriptions of the major determining characteristics of each Biogeochemical Province as provided by Longhurst (2009).

Atlantic Ocean

Atlantic Polar Biome/Atlantic Arctic Province

- Productivity is light limited, its seasonal cycle being symmetrical about the local irradiance maximum, taking zero value during winter darkness where this occurs.
- Where ice-cover does not form, the shallow polar halocline induces stability earlier in the spring than at lower latitudes, though deep winter mixing occurs in the more equatorward provinces.
- Chlorophyll accumulates during the period when productivity increases, and tracks its initial decline.
- A subsequent secondary accumulation of chlorophyll during the late summer period of declining primary production rate is consistent with reduced consumption as herbivores descend out of photic zone to overwintering depths or, alternatively,with reduced sinking rates.

Atlantic Coastal Biome/Northwest Atlantic Shelves Province

- Short, rapid pulse of increased productivity and chlorophyll is induced by early water column stability and fuelled by accumulated winter nutrients.
- Summer stratification of water column is associated with relatively low productivity, principally fuelled by regenerated nutrients.
- Progressive autumnal breakdown of stratification induces renewed productivity and chlorophyll fuelled by nutrients accumulated below the summer pycnocline.

Atlantic Westerly Winds Biome/Gulf Stream Province

- Productivity is not light limited, and increases during winter as the progressive deepening of the mixed layer recharges photic zone nitrate.
- Nutrient-limitation occurs in early summer, resulting in a decrease of production rate, and of chlorophyll accumulation.
- Photic depth in summer (seasonally at its deepest) occurs within the pycnocline (seasonally at its shoalest), so that the nutricline is illuminated and nitrate-based production continues in an SCM.
- Phytoplankton accumulates during winter months, but accumulation ceases in spring.

Arctic Ocean

Atlantic Polar Biome/Boreal Polar Province

- Productivity is light limited, its seasonal cycle being symmetrical about the local irradiance maximum, taking zero value during winter darkness where this occurs.

- Where ice-cover does not form, the shallow polar halocline induces stability earlier in the spring than at lower latitudes, though deep winter mixing occurs in the more equatorward provinces.
- Chlorophyll accumulates during the period when productivity increases, and tracks its initial decline.
- A subsequent secondary accumulation of chlorophyll during the late summer period of declining primary production rate is consistent with reduced consumption as herbivores descend out of photic zone to overwintering depths or, alternatively,with reduced sinking rates.

Pacific Ocean

Pacific Coastal Biome/Alaska Downwelling Coastal Province

- Spring increase in productivity is coincident with increase in light and the shoaling of mixed layer in spring.
- High production rates of spring are maintained until late summer through the continued entrainment of nutrients by the interaction between topography and circulation induced by high regional wind stresses.
- Phytoplankton accumulation and consumption are approximately balanced year-round.

Pacific Coastal Biome/California Current Province

- Mixed layer shoals, and primary production rate takes high values when coastal winds, and depth of nutricline are appropriate for upwelling, usually in summer, so that deep nitrate-rich water is entrained into the photic zone.
- Chlorophyll accumulation coincides with duration of upwelling periods and accumulation of chlorophyll is balanced by advection and consumption loss terms.

Pacific Westerly Winds Biome/Pacific Subarctic Gyres

- Mixed layer may undergo a deep excursion in winter, in which case exchange with deep nitrate-rich water occurs.
- Production rate is both light and nutrient limited; in spring the rate increase is constrained by nutrient limitation before the summer mixed layer is fully formed
- Spring accumulation of chlorophyll initially tracks the spring productivity increase but is constrained by consumption before peak production rate is achieved.
- A secondary summer-autumn chlorophyll accumulation occurs at higher latitudes where herbivores descend to overwinter, and accumulation is progressively balanced by herbivore consumption equatorwards.
- Only during summer does the photic depth occurs within the pycnocline so that the nutricline is illuminated only after the date of maximum production rate.

APPENDIX 3. DESCRIPTION AND RATIONALE OF MARINE ECOREGIONS OF NORTH AMERICA RELEVANT TO CANADA (WILKINSON ET AL., 2009)

Bering Sea

Level II seafloor geomorphological regions include:
1.1 Bering Shelf
1.2 Bering Slope
1.3 Bering Basin

Level III coastal regions include:
1.1.1 Bristol Bay and Kuskokwim Bay
1.1.2 Norton Sound
1.1.3 Middle and Outer Bering Sea Neritic

Rationale: defined by SST, the semi-enclosed physiography of the sea and very high primary productivity.

Surface: 1,468,220 km^2

SST: Avg. <2^oC (winter), 6^o–14^oC (summer).

Major currents and gyres: dominated by tidal flows. A counter-clockwise Aleutian North Slope Current and Bering Slope Current flow along the north edge of the Aleutians and west edge of the Bering Shelf respectively. The major direction of flow is northward through the Bering Strait.

Salinity: average 31.5–32.0 PSU.

Physiography: The wide coastal shelf is bounded by the Aleutian Island chain to the south and the Bering Strait to the north.

Depths: shelf (roughly 0–200 m): 51%; slope (roughly 200–2,500/3,000 m): 14%; abyssal plain (roughly 3,000+ m): 35%.

Substrate type: generally muddy sand and gravel.

Major community types and subtypes: seasonal sea ice, high productivity pelagic systems, polar and subpolar communities.

Species at risk: bowhead whale, blue whale, fin whale, gray whale, North Pacific right whale, Pacific walrus, Steller sea lion, northern fur seal, short-tailed albatross, red-legged kittiwake, Steller's eider, king eider.

Human activities and impacts: commercial and subsistence fishing and hunting, oil exploration and recovery.

Beaufort/Chukchi Seas

Level II seafloor geomorphological regions include:
2.1 Beaufort/Chukchian Shelf
2.2 Beaufortian Slope

Level III coastal regions include:
2.1.1 Kotzebue Sound
2.1.2 Mackenzie Estuarine Area
2.1.3 Chukchian Neritic
2.1.4 Beaufortian Neritic

Rationale: defined by SST and a transition between boreal and Arctic faunas[1]

Surface: 446,009 km^2

SST: <12°C (summer), 8°C (average) in the southwest and along the Beaufort coast

Major currents and gyres: Cape Bathurst Polynya. A smaller polynya in Lambert Channel appears in the spring.

Salinity: avg. 31.0–31.5 PSU. Relatively low due to the influence of the Mackenzie River.

Depth: shelf (roughly 0–200 m): 88%; slope (roughly 200–2,500/3,000 m): 12%; abyssal plain (roughly 3,000+ m): 0% Note that the deepest point in the Canadian area of this region is the Amundsen Gulf (600 m in the center).

Substrate type: sandy to silty, sand and gravel beaches.

Major community types and subtypes: seasonal sea ice, polar and subpolar communities, coastal wetlands and delta communities.

Species at risk: polar bear, bowhead whale, beluga whale, and gray whale.
Human activities and impacts: oil and gas, commercial fisheries, mining.

Arctic Basin

Level II seafloor geomorphological regions include:
3.1 Arctic Slope
3.2 Arctic Plains

Level III coastal regions include:
Not applicable

Rationale: ice regimes (faunal assemblages as a result).

Surface: 911,771 km^2

SST: largely permanent ice in the long winter as well as short summer seasons.

Major currents and gyres: the Arctic Ocean Gyre/the Beaufort Gyre.

*Salinit*y: relatively low.

Other oceanographic variables: ice covers 90–100 percent of the ecoregion in any given year. Ice cover over the year is not continuous, however, and numerous leads of open water do occur. The water column is relatively stable, with a permanent layer of relatively low salinity in the upper 100 m. Very low productivity limited by sunlight and ice cover, roughly equivalent to 1 percent of that of the Atlantic Ocean.

Depth: shelf (roughly 0–200 m): 0%; slope (roughly 200–2,500/3,000 m): 73%; abyssal plain (roughly 3,000+m): 27%. Note that to the west of the Queen Elizabeth Islands, the Canada Basin plummets to an average depth of about 3,600 m, and adjacent to the North Pole, it rises to 1,000 m depth at the Lomonosov Ridge, a narrow, submarine mountain range.

Major community types and subtypes: ice algae and phytoplankton are important primary producers; Arctic cod, sculpins (*Artediellus uncinatus*), eelpouts and snailfish (*Liparidae*) are present; whales are rare, and polar bear and ringed seal are the main marine mammals; Arctic

[1] On the basis of bathymetry and productivity, this region has been partitioned into a separate low productivity Beaufort Large Marine Ecosystems (LME) and shallow, moderately high productivity Chukchi LME. The LME delineation of this heterogeneous region may therefore be more useful for certain purposes.

benthic organisms such as anemones, clams, sea worms, sea stars and sponges are also present.

Species at risk: polar bear.

Key habitat: polynyas provide important feeding grounds for marine mammals and birds and serve as islands of high productivity within a sea of ice.

Human activities and impacts: pesticides used in agriculture in southern and western latitudes are carried by wind to northern latitudes including the Arctic Ocean.

<u>Central Arctic Archipelago</u>

Level II seafloor geomorphological regions include:
4.1 Central Arctic Shelf
4.2 Central Arctic Slope

Level III coastal regions include:
4.1.1 Central Arctic Estuarine Areas
4.1.2 Central Arctic Neritic

Rationale: ice regimes (faunal assemblages as a result).
Surface: 673,054 km^2
SST: largely permanent ice in the long winter as well as short summer seasons.
Major currents and gyres: Cape Bathurst polynya.
Salinity: low
Other oceanographic variables: tides less than 2 m; summer sea ice is variable throughout, with a more consistent summer cover in the northern portion than in the south.
Physiography: predominantly a system of channels, straits, and fjords surrounding the Arctic islands.
Depth: shelf (roughly 0–200 m): 60%; slope (roughly 200–2,500/3,000 m): 40%; abyssal plain (roughly 3,000+ m): 0%. Note that the deepest area, reaching 900 m, is around the Queen Elizabeth Islands.
Major community types and subtypes: estuaries, rocky shores.
Species at risk: polar bear, beluga whale and narwhal.
Key habitat: major seabird, waterfowl, and shorebird feeding, staging, and moulting areas.
Human activities and impacts: Pesticides used in agriculture in southern and western latitudes are carried by wind to northern latitudes including the Arctic islands; hunting, fishing, adventure tours; oil and gas exploration and recovery; climate change.

<u>Hudson/Boothian Arctic</u>

Level II seafloor geomorphological regions include:
5.1 Hudson/Boothian Shelf
5.2 Hudson/Boothian Slope

Level III coastal regions include:
5.1.1 Coronation/Queen Maud Gulf
5.1.2 Peel/Boothian Neritic
5.1.3 Foxe Basin
5.1.4 Central Hudson Bay
5.1.5 Southern Hudson/James Bay

Rationale: Arctic water mass and seasonal ice regimes
Surface: 1,294,989 km^2
SST: -2–4°C
Major currents and gyres: North Water Polynya in Baffin Bay
Salinity: 32–34 PSU with seasonal variations
Depth: shelf (roughly 0–200 m): 89%; slope (roughly 200–2,500/3,000 m): 11%; abyssal plain (3,000+ m): 0%. Note that water depths of 150–400 m are typical. In Hudson and James Bays the waters are shallow (50–150 m).
Substrate type: rocky to muddy
Major community types and subtypes: estuaries and mud flats
Species at risk: beluga whale, polar bear, walrus, narwhal, bowhead whale, peregrine falcon
Key habitat: Polynyas of northern Foxe Basin support high densities of bearded seals and walrus; high-density polar bear denning areas of Southampton Island and Churchill, Manitoba; the region supports most of world's narwhal as well as one-third of North America's beluga—high density along the west coast of Hudson Bay, particularly Nelson River estuary, in summer; whales in high density are found in North Water Polynya in Baffin Bay in winter; adjacent tidal flats and inland marshes are key area for shorebirds and waterfowl.
Human activities and impacts: hunting and fishing by indigenous peoples, mining on adjacent lands, hydroelectric development on adjacent rivers, deposition of long-range transported pollutants (e.g. PCB, DDT, mercury)

Baffin/Labrador Arctic

Level II seafloor geomorphological regions include:
6.1 Baffinian Shelf
6.2 Ungava/Labradoran Shelf
6.3 Grand Banks
6.4 Hudson Trough
6.5 Baffin/Labradoran Slope
6.6 Labrador Plain

Level III coastal regions include:
6.1.1 Baffin Estuarine Areas
6.1.2 Baffinian Neritic
6.2.1 Labrador Estuarine Areas
6.2.2 Ungava/Outer Banks/Labradoran Neritic
6.3.1 Grand Banks Neritic

Rationale: transitional region between northern cold waters and more temperate southern waters; seasonal ice.
Surface: 1,449,632 km^2
SST: August surface temperatures vary between 3–19ºC
Major currents and gyres: Labrador Current and West Greenland Current.
Salinity: 30–35 PSU with seasonal fluctuations.
Depth: shelf (roughly 0–200 m): 53%; slope (roughly 200–2,500/3,000 m): 35%; abyssal plain (roughly 3,000+m): 11%
Substrate type: rather rocky and barren with talus that skirts coastal cliffs that rise steeply from the sea.
Major community types and subtypes: Although the intertidal zone is quite barren due to the scouring action of sea ice, the subtidal benthic community is rich. Fish diversity is low, and Arctic cod is dominant. Other species that are found in the region include bowhead, northern

bottlenose, sperm, blue, fin, sei, minke, humpback, pilot, killer and beluga whales; narwhal; harp, hooded and ringed seas; walrus; polar bears; thick-billed and common murres; razorbills; King eiders; Atlantic puffins.

Species at risk: Atlantic cod; blue, beluga, fin, right and humpback whales; leatherback sea turtle

Key habitat: Steep, rocky cliffs and thousands of islands provide ideal habitat for some of the largest seabird colonies in eastern North America.

Human activities and impacts: fishing (overfishing of cod, in particular), tourism, mineral mining, oil and gas, shipping.

Acadian Atlantic

Level II seafloor geomorphological regions include:
7.1 Grand Banks
7.2 Acadian Shelf
7.3 Georges Bank
7.4 Laurentian/Esquiman Channel
7.5 Northeast Channel/Georges Basin

Level III coastal regions include:
7.1.1 Southeast Shoal
7.1.2 Grand Banks Neritic
7.2.1 St. Lawrence Estuarine Area
7.2.2 North Gulf Neritic
7.2.3 Magdalen Shallows
7.2.4 Scotian Neritic
7.2.5 Gulf of Maine/Bay of Fundy
7.3.1 Georges Bank Neritic

Rationale: The region is defined by current regime, physiography and cold SST. Cold, low salinity water is transported in the Labrador Current from the Arctic Ocean southward into the Gulf of St. Lawrence and the Gulf of Maine. Distribution of many species breaks at southern boundary at Cape Cod. Its eastern boundary is at the shelf break, and its northern boundary at the permanent ice line north of Labrador.[2]

Surface: 823,991 km^2

SST: avg. -1–17.5ºC (winter), 10–23°C (summer).

Major currents and gyres: Labrador Current, West Greenland Current; important pathway in the Gulf of Maine transports the western part of Labrador Current north to south with exits through the Great South Channel; upwellings occur around Georges Bank and the Flemish Cap.

Salinity: varies from very low in the St. Lawrence Estuary (≤35 PSU) to mesohaline in the Gulf of Maine to about 35 PSU in the Labrador Sea and throughout the offshore waters of the region.

Other oceanographic variables: high diurnal tide range; strong frontal passages in winter; partially ice covered in winter.

[2] On the basis of bathymetry, hydrography and productivity, this region has been partitioned into three separate Large Marine Ecosystems (LMEs): the southern end of the Newfoundland-Labrador Shelf LME, the Scotian Shelf LME, and the northern half of the Northeast US Continental Shelf LME (Zwanenburg *et al.* 2002). The Acadian Region may therefore represent a heterogeneous region and for certain purposes, the LME delineation may be more useful.

Physiography: broad shelf marked by steep channels, deep trenches and numerous banks (Grand Banks, Flemish Cap, Georges Bank, Brown's Bank); highly crenelated coastline.

Depth: shelf (roughly 0–200 m): 86%; slope (roughly 200–2,500/3,000 m): 14%; abyssal plain (roughly 3,000+ m): 0%. Note that shelf was calculated from shore to shelf break at 500 m in northern region around Newfoundland and to 200 m shelf break in southern extent.

Substrate type: silts, cobble, gravel, resistant rock.

Other physiographic variables: extreme complexity in coastline physiography; shoals, banks and complex series of channels and basins.

Major community types and subtypes: Characteristic biological communities of rocky coastal zones, estuaries, salt marshes, tidal flats, sandy beaches, shoal, deep-sea, slope communities.

Species at risk: North Atlantic blue, right, fin, sei and humpback whales; leatherback sea turtle; Atlantic and shortnose sturgeons; barndoor skate; and sand tiger shark.

Important introduced and invasive species: compound sea squirt. In the wetlands environment, purple loosetrife is an invasive species.

Key habitat: Pocket salt marshes along New England coast; important region for estuarine dependent species in Cape Cod, Boothbay Harbor; whale feeding habitat along shelf break; Atlantic cod habitat in shallows around upwellings at Georges Bank.

Human activities and impacts: coastal development, especially around urban areas, fishing, ocean aquaculture, tourism, commercial shipping and navigation.

Northern Gulf Stream Transition

Level II seafloor geomorphological regions include:
9.1 Northern Gulf Stream Transition Slope
9.2 Northern Gulf Stream Transition Plain

No Level III coastal regions are found in this region.

Rationale: characterized by current and SST influence from the adjacent Gulf Stream, including moderated water temperatures and the frequent presence of warm core and cold core rings; a pelagic area offshore of the NW Atlantic extending from the shelf break to the EEZ and Cape Hatteras where the Gulf Stream diverges north east.

Surface: 796,365 km^2

SST: avg. 10–18°C (winter), 12–25°C (summer).

Major currents and gyres: warm core rings formed from the Gulf Stream, adjacent.

Salinity: roughly 35 PSU

Physiography: One of the few non-coastal regions, this ecoregion extends from shelf break to the deep ocean.

Depth—shelf (roughly 0–200 m): 0%; slope (roughly 200–2,500/3,000 m): 45%; abyssal plain (roughly 3,000+ m): 55%

Major community types and subtypes: deep ocean benthos, pelagic fisheries, deep-water gorgonian corals, octocoral gardens.

Species at risk: sperm, fin, humpback and North Atlantic right whales; loggerhead and leatherback turtles; Atlantic white marlin.

Human activities and impacts: Overfishing has affected some species. For instance, the white marlin, found throughout the western Atlantic usually above the thermocline in deep pelagic waters, is a victim of overfishing and current stocks are 5–15 percent of carrying capacity. Bluefin tuna have also been heavily overfished in the region.

Columbian Pacific

Level II seafloor geomorphological regions include:
21.1 Columbian Shelf
21.2 Columbian Slope
21.3 Columbian Plains
21.4 Medocino Fracture Zone

Level III coastal regions include:
21.1.1 Columbia River Estuarine Area
21.1.2 Columbian Neritic
21.1.3 Strait of Juan de Fuca
21.1.4 Puget Sound Estuarine Area
21.1.5 Strait of Georgia Estuarine Area

Rationale: the region has a temperate fauna and flora, quite different than its northern and southern neighbors

Surface: 574,781 km^2

SST: avg. 9–11°C (winter), 13–15 °C (summer) relatively warm surface waters in inland sea locations.

Major currents and gyres: California Current, Davidson Current, Vancouver Island Coastal Current.

Salinity: avg. 33.4–34.2 (winter), 33.4–33.8 (summer).

Other oceanographic variables: Juan de Fuca Eddy is of high productivity.

Physiography: mountainous shoreline with a relatively narrow shelf, widening at the Heceta escarpment; the Straits of Juan de Fuca, Georgia and Puget Sound are semi-enclosed bodies with estuarine influences; complex ridges, canyons and channels are found in deeper waters.

Depth: shelf (roughly 0–200 m): 10%; slope (roughly 200–2,500/3,000 m): 12%; abyssal plain (roughly 3,000+ m): 78%

Substrate type: mostly sand with areas of rock nearshore and rock, gravel and mud-sand offshore

Major community types and subtypes: bays and estuaries, sandy beach and rocky intertidal communities, kelp forests, benthic and pelagic communities of the continental shelf, submarine canyons and cold seeps, deep sea and seamounts, offshore islands and banks.

Endemics: none known, although there are some salmon endemic sub-populations.

Species at risk: blue, finback, northern right, humpback, killer, gray and sperm whales; sea otter; marbled murrelet; leatherback sea turtle; Pacific salmon (steelhead, chinook, coho and chum salmon); Pacific hake, cowcod rockfish, bocaccio; black and pinto abalones.

Important introduced and invasive species: Over 100 invasive species have been identified in estuaries. Important species include Japanese eel grass, Atlantic cordgrass, purple varnish clam, Asian clam, and European green crab.

Human activities and impacts: forestry, fishing, shipping, tourism and marine recreation.

Alaskan/Fjordland Pacific

Level II seafloor geomorphological regions include:
22.1 Alaskan/Fjordland Shelf
22.2 North Pacific Slope
22.3 Aleutian Trench
22.4 North Pacific Basin

Level III coastal regions include:
22.1.1 Fjordland Estuarine Areas
22.1.2 Fjordland Neritic
22.1.3 Gulf of Alaska
22.1.4 Cook Inlet

Rationale: separated from the Columbian Region by the bifurcation of the North Pacific Current to form the cooler Alaska Current.

Surface: 2,029,679 km^2

SST: 1–9°C (winter) and 10–16°C (summer) and reaching 20°C in sheltered areas during the warmest months.

Major currents and gyres: Alaskan Current/Stream, Alaska Coastal Current, North Pacific Current.

Other oceanographic variables: high productivity ecosystem.

Physiography: rocky coastlines, numerous islands, fjords and embayments, narrow continental shelf, large number of seamounts rise from the deeper waters offshore.

Depth: shelf (roughly 0–200 m): 18%; slope (roughly 200–2,500/3,000 m): 22%; abyssal plain (roughly 3,000+ m): 60%

Substrate type: mainly rock and mud inshore with sand, rock and gravel offshore.

Major community types and subtypes: mud flats, tidal marshes, rocky reefs, rocky shorelines, kelp beds, eelgrass beds, seamounts, hydrothermal vents.

Endemics: none known, however seamount fauna has not been well studied.

Species at risk: bowhead, sperm, sei, beluga, right, humpback, gray, and blue whales; Steller sea lion; sea otter.

Important introduced and invasive species: at least seventeen non-indigenous species identified in south-central Alaska.

Human activities and impacts: fishing, marine recreation, tourism, oil and gas exploration and recovery.

APPENDIX 4. DESCRIPTION AND RATIONALE OF THE DFO MARINE ECOREGIONS (POWLES ET AL., 2004)

ATLANTIC OCEAN

Northern Labrador

Geological Properties
The southern boundary of this ecoregion is characterized by the presence of the deep Hopedale channel, which runs perpendicular to the coast of Labrador. The ecoregion is separated on the west from the Hudson complex ecoregion at the entrance to Hudson Strait.

Physical Oceanographic Properties
The northern limit of relatively warm bottom water, from Cape Dyer to Greenland, represents the northern boundary of this ecoregion. The whole ecoregion is characterized by seasonal ice cover.

Biological Properties
The southern portion of this ecoregion is associated with a region of high maximum productivity, but a low annual average due to the short bloom season. Primary productivity indices are different in this ecoregion from those in the Northern Grand Banks – Southern Labrador ecoregion to the south: in northern Labrador, blooms occur later, with later occurrence of maxima, and are of shorter duration than in the northern Grand Banks-Southern Labrador ecoregion. Along the coast, the bloom occurs later than offshore due to the presence of ice.

The northern boundary of the ecoregion coincides with the northern limit of temperate marine mammal species and the southern boundary coincides with the southern range limit of belugas migrating from the Hudson complex. The southern boundary also represents a significant boundary in Arctic and Atlantic seabird distributions. The distribution of Arctic seabirds, including the glaucous gull (Larus hyperboreus) and the Iceland gull (Larus glaucoides), stops at this boundary, whereas Atlantic species generally do not occur north of this boundary.

Substructure – geological and physical oceanographic properties.
This ecoregion shares geological substructure with the northern Grand Banks-south Labrador ecoregion: complex bathymetry due to the coastal trench and a trench perpendicular to the coastline north of the major boundary trench.

As with the northern Grand Banks-south Labrador ecoregion, three separate water masses running parallel to the Labrador coast are present: coastal, defined by its strong freshwater influence coming from the Hudson complex, shelf, and slope water masses. Two distinct currents flow parallel to the coast: inner slope current and the slope current. Along the Labrador coast, bottom water temperatures are very cold, but further north there is a warm deepwater mass that goes from Baffin Island to Greenland.

Substructure – biological properties
As with the northern Grand Banks-south Labrador ecoregion, there are three distinct fish communities in this ecoregion: cold coastal, bank/slope, and deep water communities. The southern boundary of this ecoregion is defined by a dip inshore of the deep water community due to the presence of a deep trench. This trench however does not represent an ecological boundary for fish species as they all continue into the Labrador – Northern Grand Banks

ecoregion. Along the coast, the spring phytoplankton bloom occurred later than offshore due to the presence of ice.

<u>Northern Grand Banks – southern Labrador</u>

Geological Properties
This ecoregion is separated from the offshore ecoregion by the shelf break, which occurs around the 200m contour line. The northern boundary of this ecoregion is defined by the presence of the deep Hopedale channel, which runs perpendicular to the coast.

Physical Oceanographic Properties
The area is characterised by generally southerly flow of the inner slope and slope currents but there is considerable substructure in physical oceanographic properties (see below). The bottom water along the coast of Labrador is typically very cold, with the southern boundary of the ecoregion characterized by the very strong temperature front on the Grand Banks.

Biological Properties
The northern boundary (Hopedale channel) is a dividing line between distributions of Arctic and Atlantic seabirds. Arctic seabirds include the glaucous gull and the Lceland gull, whereas Atlantic species include the gannet (Morus bassanus), razorbill (Alca torda), great black-backed gull (Larus marinus), Leach's storm petrel (*Oceanodroma leucorhoa*) and Wilson's storm petrel (*Oceanites oceanicus*). The southern boundary of the ecoregion coincides with the southern distribution limit of certain species of seabirds (Northern fulmar (*Fulmarus glacialis*), black legged kittiwake (*Rissa tridactyla*)). The northern boundary is the southern limit of marine mammals, notably Arctic stocks of beluga, which migrate to this area in the winter.

Primary productivity indices are different in this ecoregion from those in the Northern Labrador ecoregion to the north; in northern Labrador, blooms occur later, with later occurrence of maxima, and are of shorter duration than in the northern Grand Banks – Southern Labrador ecoregion.

Substructure – geology
There are three perpendicular trenches along the Labrador shelf within this ecoregion, similar to but smaller than the Hopedale channel. A marginal trough parallels the coastline, giving this system a very complex bathymetry.

Substructure – Physical Oceanography
Three separate water masses running parallel to the Labrador coast are found within this ecoregion. The one closest to the coast (with a width of 50-70 km) is defined by its strong freshwater influence coming from the Hudson complex, and is associated with a zone of high stratification and strong seasonal ice cover. This is followed by a shelf water mass, and then a slope water mass. Although the more coastal water mass is restricted to Labrador, the other two are also found off Newfoundland and on the Grand Banks, and all three water masses are shared with the Northern Labrador ecoregion.

Two distinct currents corresponding to the shelf and slope water masses flow parallel to the coast. These are the inner slope current and the slope current. The slope current is part of a system that originates in Greenland, flows into Davis Strait, and down to the Grand Banks.

Substructure – Biological properties
Fish distribution appears to be coincidental with water masses, with three distinct fish communities running parallel to the coast. The first is the cold coastal community, followed by the bank/slope community, and then the deep water community. Typical species of the cold coastal community include the fourline snakeblenny (Eumesogrammus praecisus), spiny lumpfish (Cyclopterus lumpus), arctic alligatorfish (Ulina olrikii), Atlantic poacher (Leptagonus decagonus), spatulate scuplin (Icelus spatula), arctic cod (Boreogadus saida), arctic eelpout (Lycodes retulates) and Greenland cod (Gadus ogac). The bank / slope community has wamer water species which include Atlantic cod (Gadus morhua), American Plaice (Hippoglossoides platessoides), redfish (Sebastes spp.), monkfish (Lophius americanus) and white hake (Urophycis tenuis). Representatives of the deep water community are the blue hake (Antimora rosrata), various grenadiers, Greenland halibut (Reinhardtius hippoglossoides), esmarks eelpout (Lycodes esmarks), spiny eel (Notacanthus chemnitzii), Arctic scuplin (myoxocephalus scorpioides), and spinytail skate (Bathyraja spinicauda).

The northern boundary of this ecoregion is characterized by a dip inshore of the deep water community due to the presence of the Hopedale channel, although all three communities extend further north along the coast of Labrador. In the Grand Banks, the cold coastal community spreads out along the northern banks, and forms a delineation between the northern and southern grand banks, although they both share distinct primary productivity features.

<u>Labrador Sea</u>

Geological Properties
This ecoregion is found off the continental shelf of Newfoundland and Labrador and is characterised by depths greater than 1000m.

Physical Oceanographic Properties
The Labrador Sea typically remains ice free throughout the year despite its cold water temperature.

Biological Properties
The Labrador Sea is characterized by a pelagic fish community that is distinct from the warmer water species found in the Gulf Stream and the shelf and slope communities of the Grand Banks and Labrador shelf and slope.

<u>Southern Grand Banks-South Newfoundland</u>

Geological Properties
This region is characterized by shallow water, generally less than 100m in depth. The southern boundary is the Laurentian Channel with its deep water and the northern boundary is the 100 m contour running across the Grand Banks from the Avalon Peninsula.

Physical Oceanographic Properties
The ecoregion is characterized by flow of the Labrador current across the Grand Banks and along the southern Newfoundland coast. This region typically remains ice free throughout the year and is associated with warm water temperatures due to shallowness and the influence of the Gulf Stream. The northern boundary of this ecoregion corresponds to a strong temperature front, with a 6 to 7 degree change over a short distance between the colder northern Grand Banks and warmer southern Grand Banks. This region also has a high level of stratification.

Biological Properties
The southern Grand Banks has a warm water fish community, including yellowtail flounder (*Limanda ferruginea*), monkfish (*Lophius americanus*), and historically haddock (*Melanogrammus aeglefinus*), which is distinct from that found on the northern Grand Banks. The macrobenthic community is similar to that found on the eastern Scotian Shelf.

<u>Western Scotian Shelf – Gulf of Maine</u>

Physical Oceanographic Properties
The influence of the Gulf Stream, tapering off toward the coast, results in this region remaining ice free throughout the year. The Scotian Shelf is characterised by a generally southerly flow which eddies and disperses into the Bay of Fund and Gulf of Maine. The Bay of Fundy is associated with colder water due to a lesser influence of the Gulf Stream, and strong mixing is found both on Georges Bank and in the Bay of Fundy. The deep basins of the Gulf of Maine and the Emerald Basin are associated with warmer slope waters.

Geological properties
The "Gully", a deep valley running westward from the edge of the Scotian shelf between Sable Island Bank and Banquereau Bank, is located at the eastern boundary of this ecoregion.

Biological Properties
The eastern boundary of this ecoregion is defined by biological properties: primary productivity, and distribution of bottom-living fishes and invertebrates. The western Scotian Shelf exhibits different primary productivity patterns than the eastern Scotian Shelf: the eastern Scotian Shelf is characterized by later (i.e. timing) and shorter (i.e. duration) blooms, but of higher maximum values.

Warm water invertebrate species (for example scallop, *Placopecten magellanicus*) have their center of distribution in this ecoregion, and become rare beyond the eastern boundary on the Scotian Shelf. Cold water invertebrates (snow crab (*Chionectes opilio*), Iceland scallops (*Chlamys islandicus*), common on the eastern Scotian Shelf), are rare on the western Scotian Shelf. Cancer crabs (*Cancer irroratus*) and lobsters (*Homarus americanus*) are found shelf wide throughout this ecoregion due to the warm bottom water but are restricted to the coast further north on the eastern Scotian Shelf. There is a change in fish community structure at the eastern boundary of this ecoregion and there is a change in *Sebastes* species: *fasciatus* on the western Scotian shelf, hybridized *fasciatus/mentella* on the eastern Scotian shelf and Laurentian channel.

Substructure – Geological
This ecoregion contains much substructure, including the Bay of Fundy as an enclosed subsystem, as well as considerable patterning in bottom sediments featuring sandy banks on the Scotian Shelf and a muddy basin in the Gulf of Maine.

Substructure - Biological
Georges Bank has a Virginian macrobenthic community, which is distinct from the rest of this ecoregion. The Bay of Fundy and Georges Bank are both areas of high productivity. Georges Bank does not have a high maximum spring bloom, but is productive year round.

Gulf of St-Lawrence – Eastern Scotian Shelf

Physical Oceanographic Properties
The primary uniting feature of this ecoregion is water flow, which is essentially continuous from Belle Isle Strait through the Gulf and onto the eastern Scotian shelf. Freshwater influence is present throughout, particularly in the southern part of the ecoregion, with the St. Lawrence River flow moving throughout the southern gulf and onto the eastern Scotian Shelf. The Gulf and the eastern Scotian Shelf therefore share the same water mass.

This ecoregion is characterized by seasonal ice cover. Ice is found during the winter in most parts of the Gulf of St. Lawrence and periodically is present on parts of the eastern Scotian shelf.

Geological Properties
The Gulf of St-Lawrence is bounded to the north by the narrow Strait of Belle-Isle. The Laurentian Channel represents the boundary to the northeast of the Scotian shelf.

Biological Properties
The Southern Gulf and Eastern Scotian Shelf share the same seabird community, which includes common terns (Sterna hirundo) and double-crested cormorants (Phalacrocorax auritus).

Substructure – geological
The northern portion of the Gulf, defined in part by the Laurentian Channel and the connecting Esquiman Channel, is characterized by relatively deep waters (>400m), in contrast to the shallow southern Gulf of St. Lawrence (the Magdalen Shallows) where the average depth is under 100m.

Substructure – physical oceanography
The southern Gulf of St. Lawrence has much warmer water temperatures than other parts of the ecoregion due to its shallowness, and has greater stratification. The St. Lawrence estuary has colder water than the rest of the ecoregion and is considered a mixing hotspot. Other mixing hotspots are found in the Strait of Belle-Isle, Northumberland Strait south of PEI, and north of Anticosti Island.

Substructure – biological
High primary productivity is found at the mouth of the St. Lawrence estuary, and in the southern gulf.

The northern Gulf and the estuary share a seabird community with the northern Grand Banks – Labrador ecoregion, which is composed of razorbill (Alca torda), northern gannet (Morus bassanus), herring gull (Larus argentatus) and great black-backed gull (Larus marinus).

Three generally distinct fish communities occur in this ecoregion. The bank/slope fish community is found along the Laurentian Channel and Esquiman Channel, and is shared with the two Labrador ecoregions. While the southern Gulf and the eastern Scotian Shelf have many species in common (e.g. cod, thoryn skatew, mailed scuplin), there are also many species that distinguish the two areas (e.g. windowpane flounder, butterfish, found on the eastern Scotian Shelf but not in the Gulf of St. Lawrence; pipefish found in the southern Gulf but not on the eastern Scotian Shelf).

The southern Gulf stands out by having a very distinct remnant Virginian macrobenthic community, similar to that found on Georges Bank. In the rest of the ecoregion, snow crab is found in intermediate depths and shrimp is found in the deep channels. Distinct populations of a number of species are found north and south of the Laurentian Channel in the Gulf of St. Lawrence (Atlantic cod, snow crab).

Gulf Stream

Geological Properties
This ecoregion is found off the continental shelf and is characterised by depths greater than 1000m.

Physical Oceanographic Properties
The Gulf Stream region is characterized by relatively high temperatures and remains ice free throughout the year thanks to the influx of warm water from the more southern latitudes.

Biological Properties
The Gulf Stream is associated with distinct warm water seabird, whale and pelagic fish communities. Characteristic seabirds found in this area include Cory's shearwater (*Calonectris diomedea*) and Fea's Petrel (*Pterodroma fea*). Large pelagic fishes include swordfish, tunas and large pelagic sharks, while several of the more tropical marine mammals (e.g. bottlenose dolphins), occur occasionally or seasonally in this area.

ARCTIC OCEAN

Arctic Basin

Geological Properties
This ecoregion is primarily defined by depth, as it is located off the continental shelf. Most of the area has depths greater than 1000m and it is bounded by the 200m contour close to the High Arctic Archipelago.

Physical Oceanographic Properties
Much of this area is covered by permanent ice.

Biological Properties
Primary productivity is low due to the permanent ice cover, which also results in a general absence of marine mammals and seabirds. There is very limited information pertaining to fish and benthic communities.

High Arctic Archipelago

Geological Properties
The high Arctic Archipelago is largely defined by degree of enclosure, as it consists of a large number of straits between islends with relatively shallow water. Very little else is known about its geological properties.

Physical Oceanographic Properties
The entire region is covered with permanent ice.

Biological Properties
Due to the permanent ice cover, this region is characterized by low primary productivity and a general absence of marine mammals and seabirds. Seals are found in the Southeastern part of the Arctic Archipelago and their distribution determines the boundary between Lancaster Sound and the Arctic Archipelago ecoregions in this area. There is limited information pertaining to fish and benthic communities.

Beaufort-Amundsen-Viscount Melville-Queen Maud

Geological Properties
This region is relatively shallow throughout, with an average depth considerably less than 200m, and has two particularly shallow areas, one being the Queen Maud Gulf and the other located at the boundary between Viscount Melville and Lancaster Sound.

Physical Oceanographic Properties
Two different patterns of ice cover are present in this ecoregion. The northern part is characterized by the presence of pack ice, whereas the southern part has seasonal ice. Some data suggests that Viscount Melville Sound has a permanent ice cover, but the tracking of marine mammals in this area implies that there are enough gaps in the ice for them to breathe.

Biological Properties
The most important biological feature in this ecoregion is the shallow water boundary between Viscount Melville and Lancaster Sounds, which is also associated with a permanment plug of ice in the Lancaster Sound west of Somerset Island. Combined, the shallow water and the ice plug create a boundary between western and eastern populations of belugas and possibly bowhead whales, and a western boundary to the narwhals from Lancaster Sound. This boundary area and its longitude to the south also corresponds to a general boundary for seabirds and waterfowl, bounding populations (e.g. Common Eider (Somateria mollissima), King Eider (Somateria spectabillis), thick-billed Murre (Uria lomvia) and Northern Fulmar (Fulmarus glacialis) which is winter migrate to western and eastern areas. The northern edge of this ecoregion also represents a boundary for marine mammals and seabirds, as this is where permanent ice cover begins. Both bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) are found in the Beaufort Sea, and belugas migrate into the Amundsen Gulf and Viscount Melville. Overall, this region contains a mix of Pacific and true Arctic species.

Substructure
The southern part of this ecoregion can be considered a subregion based on freshwater influence and primary productivity. The Beaufort Sea is characterized by the presence of a polynya, which coincides with the Mackenzie River freshwater plume and the Beaufort gyre. Queen Maud Gulf also has a strong freshwater influence. High primary productivity in this region coincides with the Mackenzie River freshwater plume in the Beaufort Sea, extends into the Amundsen Gulf and partly into the Dolphin and Union Strait.

Hudson Complex

Geological Properties
This system is initially characterized by degree of enclosure, with the mouth of Hudson Strait as its eastern boundary and the Fury and Hecla Strait as its western boundary. Depth is approximately 200m for Hudson Bay and Foxe Basin, with greater depth in Foxe Channel and Hudson Strait.

Physical Oceanographic Properties
Water flow unites the various parts of this ecoregion. Tides are an important physical oceanographic feature, which control mixing in the whole complex. Another strong influence comes from the large input of freshwater from Quebec, with the plume starting in James Bay and following the Quebec coast to the north, all the way to the tip of Labrador. Because of this freshwater influence, stratification in Hudson Bay is from north to south and west to east. Ice cover in this system is seasonal, with the presence of two polynyas, one in northwestern Hudson Bay and another in north western Foxe Basin. Foxe Basin and Hudson Bay are characterized by cyclonic circulation systems.

Biological properties
One biological property shared throughout the system is high primary productivity, which is only found to be low in the centre of Hudson Bay. This high productivity is partly the result of strong tidal mixing. There is a change in *Pandalus* species at the mouth of Hudson Strait; *P. montagui* in the Strait, *P. borealis* outside.

Substructure - Biological Properties
Although this system is treated as a single ecoregion, it in fact contains several ecological subdivisions. In terms of species distribution, there is a southern distribution limit for Arctic specialist waterfowl species, at the mouth of Foxe Basin. There are generally no seabirds in Hudson Bay and Foxe Basin due to the absence of birding cliffs, but they are present in Hudson Strait. These seabirds feed primarily on capelin (*Mallotus villosus*), sand lance (*Ammodytes spp.*) and benthic organisms.

For marine mammals, bowhead whales are found primarily in Hudson Strait and Foxe Basin, whereas narwhals are found near Southhampton Island, and beluga whales in Hudson Bay and Ungava Bay. Rosewellton Strait to the west of Southampton Island was historically an area of high bowhead harvests. Walrus (*Odobemus rosmarus*) are found in Foxe Basin and on the Coats and Mansel Islands, whereas Harbour seals (*Phoca vitulina*) are found from the northern shore of Hudson Strait and south into Hudson and Ungava Bays. Shrimp (*Pandalus spp.*) and Greenland halibut (*Reinhardtius hippoglossoides*) occur in the Hudson Strait and Ungava Bay.

On the basis of these distributions, three subregions could be defined: Hudson Strait, Hudson and James Bays, Foxe Basin. The area surrounding Southampton Island might be considered a fourth subregion.

<u>Baffin Bay Davis Strait</u>

Geological Properties
There is a very well defined shelf line off north eastern Baffin Island, separating the shallow inshore from the deep (>1000m) offshore.

Physical Oceanographic Properties
Davis Strait is characterized by the presence of seasonal ice, with the duration of the ice cover being longer on the inshore than offshore regions. The inshore area of Davis Strait is also strongly influenced by tides and the input of freshwater. The southern boundary is associated with the northern limit of a warm deepwater mass; the boundary was drawn from north of Cumberland Sound (Cape Dyer) to Greenland.

Biological Properties
Primary productivity is relatively high all along the northern and eastern coasts of Baffin Island, and becomes substantially lower as you move offshore. The southern boundary identified by bottom water temperature also corresponds to limits in the distribution of marine mammal and of large colonies of Northern fulmars and black-legged Kittiwakes (Rissa tridactyla). Shrimp (*Pandalus borealis*) and Greenland halibut occur in the southern portion of this ecoregion, and may be found further north, but there is no available fishery data. Turbot are produced in the offshore regions and then move inshore towards Baffin Island, demonstrating the connectivity within the ecoregion. It also represents part of the wintering area of narwhals.

<u>Lancaster Sound</u>

Geological Properties
This ecoregion is characterized by depths typical of the continental shelf (less than 1000 m in this region).

Physical Oceanographic Properties
This ecoregion is characterized by seasonal ice and includes a polynya, which starts at the mouth of Lancaster Sound and goes north to Cape Dunsterville on the eastern shore of Ellesmere Island.

Biological Properties
Primary Productivity is relatively high into Lancaster Sound, Prince Regent Inlet, and at the entrance of Admiralty Inlet. Seabirds, belugas and narwhals are present throughout the ecoregion and their distribution ends at the shallow water/ice boundary with the Viscount Melville region. Marine mammals (belugas, narwhals) and seabirds migrate seasonally within this ecoregion from Lancaster Sound to the eastern coast of Baffin Island. Seals are found into the southeastern part of the Arctic archipelago and their distribution determines the boundary between inshore Baffin-Lancaster Sound and the Arctic Archipelago ecoregions in this area.

<u>PACIFIC OCEAN</u>

<u>Strait of Georgia</u>

Geological Properties
The Strait of Georgia is primarily defined by degree of enclosure; it is an enclosed system, bordered by archipelagoes and shallow depths in the north and in the south.

Physical Oceanographic Properties
The region is bounded by strong tidal fronts to the north and south, and has significant freshwater influence coming from the Fraser River. The freshwater plume in the Strait of Georgia is generally restricted to the first few centimetres of the water column.

<u>Southern Shelf – West coast of Vancouver Island</u>

Geological Properties
The northern boundary of this ecoregion is the Brooks peninsula of the northwest coast of Vancouver Island, which extends almost to the 200 m contour and accordingly almost divides the continental shelf at this point. The southern boundary was not defined as this ecoregion extends into United States waters. The Strait of Juan de Fuca is a transition zone between the Strait of Georgia and the southern shelf.

Biological Properties
Brooks peninsula, at the northern boundary of this ecoregion, represents the northern distribution limit of many southern marine species such as hake (*Merluccius productus*), pandalid shrimp and the southern resident killer whales (*Orcinus orca*).

Northern Shelf

Geological Properties
The Pacific northern shelf is bounded to the south by the Brooks Peninsula and extends northward into United States waters. A distinctive geological feature in this ecoregion is the shallow water area located between Queen Charlotte Islands and the mainland coast. However this was considered to represent substructure within the defined ecoregion.

Physical Oceanographic Properties
The shallow water area east of Queen Charlotte Island is resulting in a warm water front and strong mixing. This area is considered to be a weak boundary within the ecoregion.

Biological Properties
Many species of the northern shelf community do not have distributions extending southward past Brooks Peninsula. Examples of northern species are the tanner crab (*Chionoectes bairdi*), Pacific cod (*Gadus macrocephalus*), northern resident killer whales, and the Steller sea lions (*Eumetopias jubatus*). Brooks Peninsula is also an important divide for seabirds, as a number of species summer and breed north of that point.

Offshore

Geological Properties
The Pacific offshore ecoregion is all that area seaward of the bottom of the continental slope, which is here defined as the line where the slope gradient becomes less than 2.7%.

Biological Properties
The shelf edge is an important boundary for seabirds as some birds such as Laysan albatross (*Phoebastria immutabilis*) and petrels are only found offshore from the shelf edge.

Substructure - Physical Oceanographic Properties
This ecoregion can be divided into three subregions defined by the splitting of the North Pacific current as it approaches the coast. This splitting results in part of the current going northward towards Alaska, and part going towards the southern U.S. This results in a northern subregion (Alaska Gyre), a southern subregion (California Gyre), and a transition zone near the continental shelf boundary at the fork. The locations for these subregions are not stable as they move northward and southward seasonally and interannually with shifts in the current. The Alaska gyre is associated with upwelling and the California gyre with downwelling.