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Key elements in the development of a hierarchical marine ecological classification system to support ecosystem approaches to management in Pacific Canada

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The focus of this research document is to provide an understanding of the key elements needed to develop a hierarchical marine ecological classification system to support an ecosystem approach to management for the Pacific region of Canada. Ecosystem approaches to management would contribute to management activities such as:

- development of a network of MPAs for the conservation of marine species and habitat diversity at regional scales; and,
- coastal zone management and planning activities at local scales.

The ultimate goal of this document is to provide resource managers with a plan for a collaborative, coordinated, pragmatic and science-based approach for generating inventories and maps of marine species and habitat diversity and distribution at appropriate spatial extents and resolutions necessary to manage the anthropogenic stressors in the marine ecosystem. To accomplish this goal the hierarchical marine ecological classification system needs to meet the following criteria:

- be based on spatial scales that meet management objectives;
- identify species and habitat diversity within both the pelagic and benthic realms;
- be informed through the application of a suite of tools that analyze and summarize biotic and abiotic data; and,
- be designed so that it is adaptive and can readily incorporate new information and data as they become available.

Twenty case studies of British Columbia based marine planning applications were assessed along with a comparative literature review of global applications such as the Global open oceans and deep seabed (GOODS) biogeographic classification (Vierros, Cresswell et al 2009) to better understand the types of models, expert systems, and classification systems presently in use to describe species and habitat diversity in the pelagic and benthic realms of Pacific region, and to understand information/data requirements and gaps. The assessment revealed that:

1. species and habitat diversity mapping in Pacific region tends to consist of one-off, single-species based projects using relatively disjunct data sets;
2. no single habitat classification system has been used in the benthic or pelagic realms;
3. a few different species distribution models have used in the region with no clear guidance on ‘best’ practices or structured application,
4. relatively little research has been directed at pelagic realm diversity; and,
5. large gaps in multibeam acoustic data, particularly interpreted bottom backscatter data, are limiting descriptions of benthic realm diversity.

Based on these assessment findings, we recommend the following actions: that a pilot study to assess species distribution models be conducted; that standards for data collection be developed; that data storage and sharing agreements between resource management agencies and stakeholders be arranged; and finally that a modified Australian-based ecosystem-level classification system with a biotic focus be adopted and pilot-tested in Pacific region.

The hierarchical marine ecological classification system that we recommend is the end-result of discussions with more than 20 experienced practitioners in Pacific region, and ultimately will only succeed through further collaborative interactions between oceanographic, hydrographic, geological and biodiversity researchers and resource managers, and through adaptive modification of elements within the framework.

Éléments clés de l'élaboration d'un système de classification hiérarchique de l'écologie marine à l'appui d'approches écosystémiques de gestion dans les eaux canadiennes du Pacifique

RÉSUMÉ

L'objectif du présent document de recherche est d'expliquer les éléments clés nécessaires pour élaborer un système de classification hiérarchique de l'écologie marine destiné à appuyer une approche écosystémique de gestion pour la région canadienne du Pacifique. Les approches écosystémiques de gestion sont utiles pour les activités telles que :

- la mise en place d'un réseau de AMP pour préserver la diversité des espèces marines et des habitats à l'échelle régionale;
- la planification et la gestion des zones côtières à l'échelle locale.

Le but ultime du présent document est de fournir aux gestionnaires de ressources un plan d'approche collaboratif, coordonné, pragmatique et scientifique afin de produire des inventaires et des cartes de la diversité des espèces marines et de leur habitat aux échelles et aux résolutions spatiales appropriées pour permettre de gérer les agents de stress anthropiques dans l'écosystème marin. À cette fin, le système de classification hiérarchique de l'écologie marine doit répondre aux critères suivants :

- être fondé sur des échelles spatiales adaptées aux objectifs de gestion;
- relever la diversité des espèces et des habitats dans les milieux pélagiques et benthiques;
- s'appuyer sur l'application d'un ensemble d'outils d'analyse et de synthèse des données biotiques et abiotiques;
- être adaptatif et pouvoir facilement intégrer les nouvelles données et informations au fur et à mesure qu'elles sont disponibles.

On a évalué 20 études de cas d'applications de planification marine en Colombie-Britannique et procédé à l'analyse documentaire comparative d'applications globales comme la classification biogéographique mondiale des grands fonds marins et de la haute mer (GOODS) (Vierros, Cresswell *et al*. 2009) afin de mieux comprendre les types de modèles, les systèmes experts et les systèmes de classification utilisés à l'heure actuelle pour décrire la diversité des espèces et des habitats dans les milieux pélagiques et benthiques de la région du Pacifique, ainsi que pour cerner les données/informations nécessaires et les lacunes dans celles-ci. L'évaluation a montré que :

1. la cartographie de la diversité des espèces et des habitats dans la région du Pacifique tend à se limiter à des projets ponctuels monospécifiques qui utilisent des ensembles de données relativement disjoints;
2. aucun système de classification de l'habitat n'a été utilisé dans les milieux benthiques et pélagiques;
3. quelques modèles différents de répartition des espèces ont été utilisés dans la région, sans directive précise à l'égard des meilleures pratiques ou d'une application structurée;
4. relativement peu de recherche a été concentrée sur la diversité des milieux pélagiques;
5. de grandes lacunes dans les données acoustiques multifaisceaux, particulièrement dans l'interprétation de la rétrodiffusion du fond, limitent les descriptions de la diversité des milieux benthiques.

Ces constatations tirées de l'évaluation nous amènent à recommander les mesures suivantes : réaliser une étude pilote pour évaluer les modèles de répartition des espèces; élaborer des normes sur la collecte des données; conclure des ententes de stockage et de partage des données entre les organisations chargées de la gestion des ressources et les parties intéressées; enfin, adopter un modèle de classification écosystémique inspiré de celui de l'Australie et axé sur les milieux biotiques et l'utiliser pour une mise à l'essai pilote dans la région du Pacifique.

Le système de classification hiérarchique de l'écologie marine que nous recommandons est le résultat final des discussions tenues avec plus de 20 praticiens expérimentés de la région du Pacifique. Il ne pourra donner des résultats utiles que si les chercheurs en océanographie, hydrographie, géologie et biodiversité collaborent davantage avec les gestionnaires des ressources et si on apporte des modifications adaptatives aux éléments du cadre.

INTRODUCTION

The focus of this paper is to provide an understanding of the key elements needed to develop a hierarchical marine ecological classification (MEC) system to support an ecosystem approach to management of marine waters in the Pacific region of Canada. Local to global scale planning activities increasingly require spatial biodiversity and habitat information, i.e., knowledge of the distribution and diversity of species, habitats, communities, and species richness or other community attributes on the seabed or in pelagic realm. The major output of a hierarchical MEC is the creation of biodiversity maps needed to assess the risks to marine ecosystems and to develop management strategies that mitigate the impacts of anthropogenic activities and insure the sustainability of the biodiversity in the region. The request for this advice was jointly developed by resource managers in Fisheries and Oceans Canada (DFO) Pacific Fisheries and Aquaculture Management and Ecosystem Management Branches.

This research document is a regional follow-up to a national science advisory process (NAP) in which a Biogeographic system was developed for Canada (DFO 2009a). As a result of the 2009 NAP, 12 major biogeographic units (hereafter referred to as bioregions) were identified for Canada's three oceans (four in the Pacific, five in the Arctic, and three in the Atlantic). The national review concluded that each of the bioregions identified represent biodiversity at a "maximum scale" (i.e., coarsest resolution and largest spatial extent) and advised that each of the bioregions would need to be subdivided in an ecologically meaningful way to provide the biodiversity information necessary to inform bioregional management or policy issues. As this subdivision proceeds, information on instantaneous species specific occurrences and ranges become increasingly influential in delineating the analytical units.

CONTEXT FOR MANAGEMENT

There are several elements that need to be considered when developing a MEC system to inform marine ecosystem approaches to management (EAM). These elements include:

1. understanding the nature of resource management issues, the geographic extent of the problem and the conservation objectives that the MEC system would inform;
2. understanding MEC system outputs and how they would be used to inform a “management decision framework” (e.g., risk assessment framework);
3. understanding the tools and analyses that are required to populate a MEC system; and,
4. understanding the types, uncertainty and availability of the data required by the tools and analyses.

Resource managers must address issues arising from a broad range of marine and land based activities that affect marine environments. The nature of these effects varies as does the scale (spatial extent and resolution) of information needs. For resource management decision-making, it is necessary to understand the nature and extent of the pathways of effects of the various activities being managed. This understanding can be informed by the different potential pathways of effects associated with each activity and the factors that control the spatial extent of the effects. For example, a CSAS meeting was held in November 2012, to provide advice to resource managers about the factors controlling sediment remobilization resulting from commercial fishing activities around the core protection zone of the Queen Charlotte Sound and Hecate Strait Sponge reefs. Variations in the extent of the impact occurred as result of: the location of the interaction; the intensity of interaction between the various fishing gear types and the sediment; the type of sediment impacted; and the timing of the remobilization event in relation to the tidal currents in the area on hourly, daily and seasonal bases (Boutillier, Masson et al. 2013). These component parts require an understanding of the area that is well resolved both spatially and temporally.

The nature of local coastal marine use management issues encompasses a diverse range of activities including: aquaculture facilities, log-handling sites, urban infrastructure development, ocean dumping, cable laying, fishing, etc. Managers need to understand the nature and extent of the impacts for a particular activity and evaluate the risks imposed relative to the vulnerability, sensitivity and resilience of biodiversity (biological diversity), habitat[1] diversity and the community properties (ecosystem diversity) impacted. This information will also need to be integrated into a larger context so that risks of local scale impacts are also understood in relation to consequences at the bioregional, national and global scales.

Bioregional scale issues such as development of a network of MPAs will be driven by the conservation objectives of the network. If a proposed MPA network were to meet the commitment to the Convention of Biodiversity (CBD) as found in the Convention of Parties (COP) 9 Annex III, then the network must capture representativity within each of the bioregions. Representativity occurs when the network consists of areas representing the different subdivisions of the bioregion that reasonably reflects the full range of ecosystems, including the biotic and habitat diversity of those marine ecosystems. Conservation objectives for a representative network of MPAs designed to conserve and protect the structure and function of marine ecosystems fall into three major categories: provision of an insurance policy against catastrophic events; a baseline to assess the level of natural variations and as a potential seed stock for rehabilitation of impacted species (Rice and Houston 2011, Sheppard 2013).

Within a local scale management context, the outputs generated by a MEC system will ultimately identify the location, abundance and types of marine biotopes[2] and biological facies[3]. This information can be used to quantify the potential and realized impacts on biotope/ biological facies in relation to how much remains in an undisturbed state at local, bioregional, national and global scales. Assessment of the risks of the effects of an activity would be undertaken within an ecological risk assessment framework (O et al, 2015), which quantifies the activity impacts and the cumulative impacts of all impacts at the species/population, habitat and ecosystem/ community properties levels. The ecological risk assessment framework will allow for quantification of the risks by providing information on: area and extent of impacts in relation to the distributions of the: species being impacted, their habitats and the community properties of the ecosystems in which the species function.

At regional scales, MEC system outputs provide a way to assess the adequacy of management conservation strategies such as the development of a network of MPAs and the likelihood of this strategy in achieving representativity objectives.

OBJECTIVE

The objectives of this Research Document are to:

1. Review key elements for development of a marine ecological classification (MEC) systems/approaches relevant to British Columbia.

[1] The physical and chemical environment in which a species lives (Costello 2009).
[2] Spatial elements combining the concepts of physical habitat and biological community. (Last et al. 2010)
[3] Mappable units characterized by groups of particular species – usually sessile animals or plants/algae (Last et al 2010)

2. Propose a MEC that captures habitat, biotic and community diversity in sufficient detail to inform the conservation priorities and management frameworks used in the conservation of the full ecological scope of biodiversity.
3. Ensure that proposed MEC meets the following design criteria:
    i. Captures and addresses uncertainty at all stages of the system.
    ii. Spatial scalability (resolution and extent) is assessed in relation to management needs and that there are clear guidelines for application at different spatial scales.
    iii. Addresses levels of uncertainty when data are “imperfect” or information is incomplete.
4. Propose potential solutions to problems arising in capturing the data required to characterize habitat and biotic diversity within marine areas in Pacific Canada.
5. Recommend approaches to address issues related to the credibility of the methodology, transparency, and scientific defensibility of the MEC system.

DRAFT SCIENCE-BASED FRAMEWORK

Four major bioregions have been identified for Pacific region (DFO 2009a). Each bioregion represents a maximum scale that ought to be subdivided further into smaller units. Because it is logistically difficult and expensive to sample diverse marine biota at high resolution (e.g., 1:5,000), over large spatial extents (e.g., a bioregion), there is a need to understand some of the tools available to more effectively describe marine species and habitat distributions. It will be necessary to apply these tools to generate sufficient data to apply ecological classification and modelling systems in a bioregion. The sections below discuss the key elements of a science-based framework to achieve the goal of subdividing bioregions into smaller meaningful units for analysis and some of the important considerations when addressing the central question of **what** biodiversity occurs **where** within a bioregion.

The ultimate goal is to provide resource managers with an inventory and maps of marine biodiversity at appropriate spatial extent and data resolution required for the management and planning activities. These activities may vary from MPA network planning at bioregional scales, to coastal zone management and planning activities that affect pelagic and benthic diversity at local scales. The framework is intended to move this goal forward by providing a plan for a collaborative, coordinated and pragmatic approach for end users, such as the joint federal and provincial Oceans Coordinating Committee, DFO Pacific Fisheries and Aquaculture Management and Ecosystem Management Branches, other interested parties such as the West Coast Aquatic Management Board, Marine Planning Partnership for the North Pacific Coast (MaPP), the British Columbia Marine Conservation Analysis project (BCMCA), academia and industry. All of these potential users require scientifically defensible species and habitat diversity information. For example, MaPP is a collaborative planning process, involving the Province of British Columbia (BC), the Coastal First Nations-Great Bear Initiative, the North Coast-Skeena First Nations Stewardship Society, and the Nanwakolas Council, which includes 20 member First Nations. MaPP requires science-based species and habitat information as described below to develop ecosystem-based management indicators for coastal and marine areas in four sub-regions of British Columbia. Further, recent BCMCA analyses captured and ‘represented’ a series of recommended ecological features in areas of high conservation value. The analyses were dependent on spatial data for features. The recommended features included many individual species and several types of ecological or physical classifications to ensure a wide range of habitat types were represented in the results. The data sets used included:

1. BC’s 32 coastal classes and six exposure classes from ShoreZone data to represent the range and diversity of coastal habitats;
2. BC’s 12 ecosections to represent broad biogeographical regions;
3. 24 oceanographic regions identified by Parks Canada (Robinson and McBlain 2012) using a Delphic approach to represent the range and diversity of pelagic habitats; and
4. 64 benthic classes identified by Parks Canada (Robinson and Royale 2008) using a benthic terrain model, bathymetry data, and substrate data as proxies for the range and diversity of benthic habitats.

Annex III of the CBD COP 9 Decision IX/20 identified several steps for developing MPA networks. The second step is relevant to this Research Document and states “Develop/choose a biogeographic, habitat, and/or community classification system. This system should reflect the scale of the application and address the key ecological features within the area. This step will entail a separation of at least two realms: “pelagic and benthic.” The first guiding principle of the biogeographic classification of Canadian marine areas (DFO 2009a) is also germane and states that the benthic and pelagic environments should be considered separately. To ensure consistency with the CBD decision and DFO (2009a), the sub biogeographic regional framework must consist of two major realms: pelagic and benthic. Although the framework considers the two realms separately, it is recognized that they are inexorably linked (DFO 2009a), and thus the approach is more pragmatic than ecologically ideal. However, it is noted that this guiding principle does not preclude other realms, and the classification system will apply to habitats formed by the interaction of benthic and pelagic features (e.g., topographically driven upwelling and retention features).

Another consideration in the development of the framework is consideration of the ‘level’ of biodiversity to map in each realm based on management needs. DFO (2009a) notes that as the subdivision of a bioregion proceeds, information on species occurrences and ranges becomes increasingly influential in delineating units, which means that at the finer scales of the resolution within a MEC hierarchy, species composition data will receive increasing attention compared to abiotic data such as bathymetry and oceanographic processes. The importance of the application of this science guidance is obvious when managing local scale impacts but it is also critical in the development of a network of MPAs (DFO 2009b) which are intended to capture representative examples of all the different subdivisions of the bioregion that reasonably reflects the full range of ecosystems, including the biotic and habitat diversity of those marine ecosystems.

WHERE IS PACIFIC REGION TODAY?

Below is a conceptual overview of where Pacific region is today with regards to how survey, acoustic, optical and water property data are used to derive abiotic and biotic information, which is subsequently used in species distribution models, abiotic distribution models, Delphic ecological classification schemes, and habitat classification models. The outputs from the distribution models, schemes and systems have all been used in various combinations to produce different maps of biodiversity in Pacific region but these maps and tools are not effectively combined to provide a single consistent metric that can be used by resource managers in effective decision making.

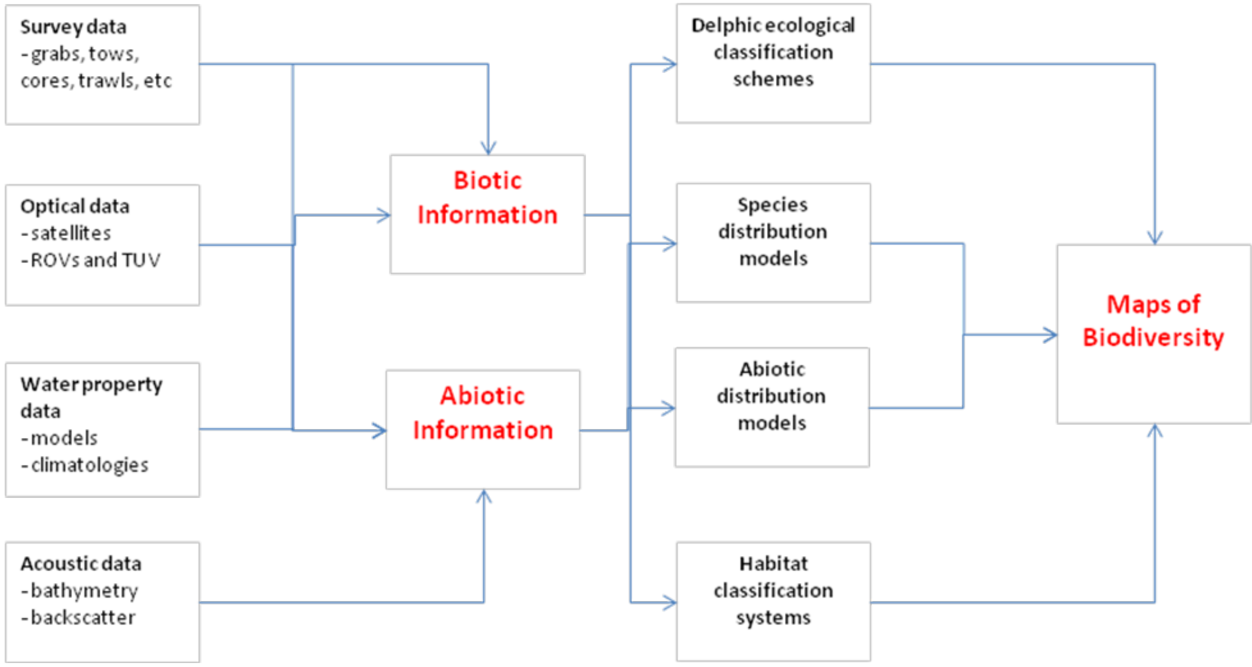

Figure 1. The present day relationships between data, models and systems, and biodiversity maps in Pacific Canada

FRAMEWORK ELEMENTS

The remainder of this working paper discusses the development of a science-based framework to provide objective advice in describing marine species and habitat diversity at different spatial scales in Pacific Canada. The science-based framework consists of the following elements, each of which is discussed below:

1. a marine ecological classification system for Pacific region (PMECS);
2. aboitic and biotic models and schemes used to generate information for element 1; and,
3. identification of important data sources and gaps for elements 1 and 2.

Element 1. Development of a Marine Ecological Classification System

Overview of terrestrial classification systems

The terrestrial realm has been the subject of many habitat classification systems with a long science-based tradition. A unique combination of European and North American biological science came together in British Columbia to develop and implement a robust and practical ecosystem classification (Haeussler 2011). Terrestrial ecological classification (TEC) schemes have greatly influenced the progress of resource and land use management. TEC is a key component in efforts to transition from single species/resource/land use to ecosystem based management in BC.

An account of the development of TEC in BC is given in Meidinger and Pojar (1991) and Haeussler (2011). The roots of TEC are in the development of the forestry industry. Initial work was motivated by a need for forest resource inventory to plan and promote development. It is also evident that some practitioners were motivated by a conservation ethic and a holistic approach to land management. Work on TEC remained a mostly academic pursuit until the late 1970s. By this time forest managers and land use planners began to appreciate that TEC would help implement an ecosystem approach to resource use planning. Two schemes became dominate in BC: Ecoregion Classification and Biogeoclimatic Ecosystem Classification (BEC).

The BC Ecoregion Classification

The BC ecoregion classification is a geographically based hierarchical habitat classification system that proceeds from global areas of broad climatic variation called ecodomains down to areas with minor physiographic and macroclimatic variations called ecosections (Demarchi et al. 1990; Stevens 1995). At the largest scale Ecoregions subdivide the terrestrial and marine landscapes of British Columbia into 139 units (called ecosections) ranging in size from 187 km^2 to 170,978 km^2. The BC Ecoregion Classification is the only habitat classification scheme that integrates aquatic and terrestrial realms.

Ecoregions have been applied in wildlife management for determining habitat capability and suitability for animals and in projects related to habitat enhancement and resource development (Meidinger and Pojar 1991). The Ecoregion classification is used for land and resource use in BC management planning, including protected area representation and gap analysis. This system was also used for the comprehensive biodiversity analysis presented in Taking Nature's Pulse: The Status of Biodiversity in British Columbia (Austin et al. 2008)

The BC Biogeoclimatic Ecosystem Classification

BC Biogeoclimatic Ecosystem Classification (BEC) is a multifactor, integrative hierarchical terrestrial ecosystem classification system. BEC combines methods from classical phytosociology and soil surveys to describe ecosystems according to their climate, parent materials, topography, soils, and biota (Haeussler et al 2011). The basic BEC unit (BEC Subzone) is defined by vegetation, soils, and topography linked together through the concept of zonal site where these parameters best reflect the regional climate (BC, 2002). The spatial patterns of BEC units aggregate up to define 16 BEC zones. BEC units are further refined by local soils, micro-scale climate and site vegetation communities into BEC Subzone Variants. BEC variants range in size from 11 km2 to 95,227 km2 dividing the province into polygons. BEC also has a chronological dimension as the zonal site is described based on the climax vegetation whereas the site series is inventoried on the extant seral stage.

The major practical difference between the Ecoregions and BEC classifications is that Ecoregions stratifies the landscape into geographical units that circumscribe all elevations whereas BEC delineates altitudinal belts of ecological zones with geographical units (Meidinger and Pojar 1991). BEC is also distinct as it lends to further division beyond Subzone Variants to larger scales using higher resolution vegetation and soil data.

The primary motivation for the development of BEC was forest management and, in particular, silviculture prescriptions. Since the system is based on zonal climates, soils, and climax vegetation it is interpretive and predictive. BEC is being applied beyond forestry to include wildlife management (Stevens 1995), land and resource management planning, and development of protected area network representation and gap analysis. In “Taking Nature's Pulse: The Status of Biodiversity in British Columbia”, Austin et al. (2008) relied on BEC for most of their ecosystem status analysis.

BEC has been used to inform other ecological mapping applications such as Broad Ecosystem Inventory, Ecological Aquatic Units (Ciruna et. al. 2007). Terrestrial Ecosystem Mapping and Predictive Ecosystem Mapping (BC Ministry of Environment, 2013).

Each classification scheme has a set of best applications. Those classifications that are based on a rigorous set of field data at fine scales find the broadest variety of applications. While the Ecoregion Classification has been applied in wildlife management and land use planning, the applications for BEC continue to expand from forestry and resource management to mapping the distribution of freshwater ecosystems (Ciruna et al. 2007) and climate change impact predictions (Hamann and Wang 2006)

The combination of two or more classification schemes can improve interpretive or predictive applications. Stevens (1995) used the combination of Ecoregions and BEC to describe distribution and habitat use for a large number of terrestrial vertebrates. Austin et al. (2008) combined Ecoregions and BEC and divided the result into 3rd order watershed to provide a base ecosystem map for analyzing the status of biodiversity in British Columbia. Integrated hierarchical classification that is founded in systematic field data has a great range of applications including applications not anticipated by the developers. Haeussler (2011) looking at trends in ecological science away from equilibrium theory towards non-linear, non-equilibrium ecosystem dynamics states that BEC's "holistic approach, developmental view of terrestrial ecosystems is fundamentally compatible with complexity theory".

Overview of marine classification systems

Marine habitat classification systems are required to place species and habitat distribution data into ecological and management context (Costello 2009). Most marine habitat classification schemes (Table 1) assess similar abiotic and biotic variables in a local area, and then assign standard names to describe habitat sub units (Valentine et al. 2005; Lund and Wilbur 2007; Greene et al. 2008; Costello 2009). An effective marine habitat classification system standardizes terminology, organizes data in a logical manner, and allows features to be coded for GIS analysis. Further, classification systems require consistent naming and coding systems to organize the data to facilitate effective communication to users. The most effective classification systems are organized in a nested hierarchy, with top levels describing large scale (coarse) abiotic features (e.g., continental shelf), while lower classes in the hierarchy describe biotic features in greater detail and spatial resolution (e.g., eelgrass meadow; Valentine et al. 2005; Lund and Wilbur 2007; Greene et al. 2008). The number of classes and levels in a hierarchy will depend upon the physical and biological heterogeneity of the marine environment, data availability, and the spatial scale and resolution as determined by project objectives. Thus, coastal and marine areas can be classified and mapped as narrowly or as broadly as the data and objectives require (Valentine et al. 2005). Ultimately, a marine habitat classification should be viewed as an evolving tool to standardize technical jargon and organize habitat information to facilitate habitat management (Lund and Wilbur 2007). Table 1 contains a brief summary from Lund and Wilbur (2007) and Greene et al. (2008) of several well-known marine habitat classification systems that have been used outside of Pacific Region.

Table 1. Lund and Wilbur (2007) and Green et al. (2008) reviewed several coastal marine habitat classification systems that have been commonly used around the world. A brief summary of these systems are described in the table below.

Classification scheme	Description	Reference
Classification of wetlands and deepwater habitats of the United States	A geographically comprehensive, nested hierarchical classification scheme for wetlands and deep-water habitats based on ecological parameters. Shortcomings were in marine and estuarine descriptions and a lack of high-energy environment descriptions	Cowardin et al. (1979)
The marine and estuarine habitat classification system	Modified Cowardin et al. (1979) scheme by adding energy as a level (e.g., exposed,	Dethier (1992)

Classification scheme	Description	Reference
for Washington State	moderately exposed and sheltered designations for rocky substrates). Focus was on marine and estuarine areas.	
A classification system of marine and estuarine habitats in Maine: An ecosystem Approach to habitats	A hierarchical classification organized by substratum, depth, energy level, and salinity. Does not include classification for pelagic areas, and lacks a coding system suitable for GIS.	Brown (1993)
Marine and estuarine ecosystem and habitat classification	Applies from landward extent of tidal influence to the outer edge of the continental shelf. Focus on applicability across regions, develops links between geologic, energy and biology.	Allee et al. (2000)
Our Living Oceans Benthic Habitat classification system	A hierarchical scheme including freshwater, estuarine, nearshore, offshore, and oceanic islands and banks.	Brown (2002)
Florida system for classification of habitats in estuarine and marine environments	Habitats included nearshore and neritic areas inhabited by corals, hard bottom and seagrass communities. Bounded by high tide line to the edge of the continental shelf. Lacks provision of geologic structure, coastal complexity, or hydrodynamic features.	Madley (2002)
Marine habitat classification for Britain and Ireland	The BIOMAR system is web-based and contains five levels of classification but it only covers marine habitats from high tide seaward (excluding marshes) and does not extend beyond 80 m depth. The focus is on marine areas close to shore with little attention to estuarine systems or connections to upstream watersheds.	Connor et al. (2004)
European Union Nature Information System	The European Environment Agency developed a classification scheme for aquatic and terrestrial habitats as part of the European Nature Information System (UNIS) for managing species, site and habitat information. Differs from BIOMAR in that it considers deep-water column. There are six levels: Level 1 splits off the marine from terrestrial and coastal habitats. Level 2 uses the biological zone and the presence/absence of rock as classification criteria. Level 3 introduces energy into the classification for hard substrata, and splits the softer substrata	Davies and Moss. (2004)

Classification scheme	Description	Reference
	by different sediment types. Level 4 uses major epifaunal taxa to discriminate rocky habitats. Level 5 discriminates based on both physical and biological characteristics of the habitats. Level 6 describes notable variations in community structure of Level 5 habitats.	
A comprehensive habitat and land use classification system for the National Estuarine Research Reserve System	Used to measure the magnitude and extent of habitat change in estuarine systems and linking observed changes to watershed practices. It is an ecologically based, hierarchical system based on Cowardin et al. (1979) but expanded to include upland and cultural habitats.	Kutcher et al. (2005)
Subtidal benthic marine habitat classification system	A standard technique for habitat designation of subtidal benthic habitats deeper than about 30m. It uses acoustic and/or optical remotely-sensed mapping data to classify the seafloor environment. It is hierarchical and uses information on physiography, depth, seafloor induration; geomorphology, texture and biology are used to classify seafloor habitats. The hierarchy is based primarily on spatial scale from small-scale features (e.g., biogenic structures) to large-scale features such as submarine canyons.	Greene et al. (1999, 2008)
Classification of marine sublittoral habitats with application to the north-eastern North America region	The partially hierarchical system is based on topographical, geological, biological and oceanographic attributes and natural processes. The focus is on sublittoral environments with emphasis on the seafloor, including subtidal areas to depths of 800m.	Valentine et al. (2005)
Marine benthic habitat classification: What's best for Alaska?	A spatially nested hierarchical geologic-centric classification that has been used in deep water (>30m) environments and does not include the water column.	Green et al. (1999, 2008).
Coastal and Marine Ecological Classification Standard (CMECS)	See below for more detail	Madden et al. (2005); FGDC (2012)

Four keys characteristics of a marine classification system were identified based on the studies shown in Table 1:

1. Classification systems incorporate both abiotic and biotic descriptors and modifiers to describe ecological sub units.

2. Effective classification systems are hierarchical, and use abiotic data to classify coarse scale features (e.g., submarine canyon) at the top of the hierarchy, and include more biotic data to classify finer spatial scale features (e.g., eelgrass meadow) at lower levels of the hierarchy.
3. Classification systems use a standard nomenclature to describe the abiotic and biotic sub units.
4. Ecological classification systems are restricted to describing ecological features; they are not intended to generate new classes of features from observational or modeled data. A method that generates new classes of ecological features by combining or modelling abiotic and/or biotic data is considered a modelling system.

Pacific region case studies related to classification systems

The marine habitat classification literature is vast and complex (e.g., Table 1), and the goal of the section above was not to review or synthesize this literature because several recent studies have already done so (e.g., Lund and Wilbur 2007, Greene et al. 2008). The goal for this Research Document is to determine if any habitat classification systems have been applied to marine ecosystems in the Pacific region, in either the benthic or pelagic areas or both. Three case studies relevant to Pacific Canada were identified and are described below.

Case study 1. Coastal and Marine Ecological Classification Standard (CMECS)

CMECS provides a US national framework for organizing information about coasts and oceans, and is a true classification system. The six components of the CMECS classification standard represent different aspects of the seascape, starting with broad systems (marine, estuarine and lacustrine) and narrowing to detailed physical and biological elements associated with specific habitats. CMECS is based on the best available scientific knowledge about the relationships between the environment and biota. CMECS was developed to address applications that range in scale from local to national to global, and hence allows users to address different objectives. It provides a comprehensive approach to classify all recognized marine ecological units, and answers the question "What is out there?" CMECS characterizes marine and coastal environments using aquatic or biogeographic settings and four components: water column, geoform, substrate, and biota. The settings may be used together or separately and they are applicable to all components. The water column component which is discussed here is non-hierarchical.

The water column component (WC) describes the environment from estuaries to oceans. This component identifies the structures, patterns, properties and processes of the water column relevant to ecological relationships and habitat-organism interactions. It extends from the land-sea margin to the deep oceans and vertically from the surface to the benthic interface. The WC describes the water column in terms of 4 major sub components:

1. a specific vertical layer in the water column referenced to the atmosphere, mid-depth or benthos (e.g., surface layer, upper water column, pycnocline, and lower water column);
2. water temperature and salinity characteristics of a water parcel;
3. hydroforms which describe physical hydrographic features such as currents, waves, water masses, gyres, upwellings and fronts; and
4. biogeochemical features describe phenomena such as biofilm, themocline and turbidity maxima.

Modifiers can also be selected and applied to any subcomponent to define characteristics such as trophic status, tide regime and energy regime.

Some of the limitations of this approach have been discussed in a pilot application in Muir Inlet, Alaska, and include: the WC is not hierarchical and attributes are independent of one another; the one attribute of temporal variability was not sufficient to capture patterns of temporal change among multiple aspects of the system, averaging of data across highly variable seasons lost important sources of variability and made the system appear homogeneous, despite strong spatial gradients. The water column depth zones did not capture important vertical variation in the water column (e.g., dynamic surface layers). Identification of boundaries and scales needed to define hydroforms. The life form and biotope attributes were not very useful. The main benefit of this approach is that it attempts to classify oceanographic processes and structures from the high tide line to deep water, it has become a national NOAA standard language for mapping studies, and it has been developed based on wide input from a variety of knowledgeable oceanographers.

Table 2. CMECS water column component classes.

System	Depth Zones	Water Column Structure	Macrohydroforms	Mesohydroforms	Life Form	Biotope
Estuarine	Sea surface	Upper (mixed) water layer	Coastal water mass	Counter current	Phytoplankton bloom	-
Freshwater -influenced	Epipelagic	Pycnocline	Gyre	Convergence	Floating microbial mat	-
Nearshore marine	Mesopelagic	Bottom water layer	Plume	Divergence	Floating vegetation mat	-
Neritic	Bathylpelagic	Benthic boundary layer	Freshwater lens	Effluent	Zooplankton swarm	-
Oceanic	Abyssalpelagic	-	Frontal boundary	Entrainment	Zooplankton patch	-
-	Hadalpelagic	-	Mesoscale eddy	Tributary discharge	Jelly fish assemblage	-
-	-	-	Major ocean current	Groundwater seep	Floating macroalgae	Sargassum natans mats
-	-	-	Density current	River current	Phytoplankton maximum layer	-
-	-	-	Plunging current	Small fresh water lens	-	-
-	-	-	Turbidity current	Internal wave	-	-
-	-	-	Downwelling	Surface wave	-	-
-	-	-	Upwelling	Surf	-	-

System	Depth Zones	Water Column Structure	Macrohydroforms	Mesohydroforms	Life Form	Biotope
-	-	-	Ocean counter current	Surface foam	-	-
-	-	-	Warm and cold core rings	Salt wedge	-	-
-	-	-	Ice	Langmuir cell	-	-
-	-	-	Hydrothermal vents	-	-	-
-	-	-	Turbidity current	-	-	-

The substrate component (SC) of CMECS (ver. 4) is a characterization of the composition and particle size of the non-living aspects of a plan-view perspective of the seafloor at comparable spatial scales. Different grain or particle size definitions present a significant complication in the unification of a common substrate classification system. CMECS adopted the Wentworth (Wentworth 1922) standard for mineral grain size because it reflects long-standing marine traditions and it is used by a majority of marine scientists. After a sample is assessed for particle size distribution, a convenient and descriptive way to characterize the mixture and classify the sample is required. CMECS utilizes the Folk ternary diagrams and threshold values for gravel-sand-mud and sand-silt-clay combinations, and it has good descriptive powers because it incorporates the Wentworth grain size classes. To enable maximum flexibility of methods (e.g., observations of the seafloor come from sediment cores, grabs, sediment profiles, plan-view photographs, video, and high resolution acoustic images) the percent cut-offs that define SC bins may be reported in percent weight, percent cover, or in percent composition. The reported scale of substrate patchiness is determined by the scale of observation and thus method-dependent. To assist with comparability, users are required to report sampling methods, unit scale of observation and scales of reporting. The SC hierarchy is designed to be compatible with a wide variety of possible sampling tools, and includes several levels:

1. substrate origin which is subdivided into geologic, biogenic, and anthropogenic substrates;
2. substrate class and substrate subclasses that are determined by the composition and particle size of the dominant origin in the surface sediments; and
3. substrate group and substrate subgroup as determined by Folk mixes for geologic sediments and by taxa for biogenic substrates;

Overall, some of the benefits of the CMECS systems include:

1. NOAA National standard used in Alaska, and potentially Washington-California;
2. classification of both abiotic and biotic elements;
3. both benthic and pelagic classification descriptors; and
4. consideration of habitats from the high intertidal to the deep abyssal zones

The major limitations of CMECS from the perspective of applying it to Pacific region include:

1. the water column component is non-hierarchical in structure;

2. some of the water column hydroform classes may not be applicable to BC waters, and some hydroform descriptors may be missing; and
3. CMECS has not yet been tested in BC waters either directly or through cross-walking the results from other systems to CMECS

Table 3 (a and b) below gives an example of CMECS SC classification structure.

Table 3. Examples of the abiotic and biotic classification of CMECS. (adapted from FGDC 2012)

a. Substrate Component

Substrate Origin	Substrate Class	Substrate Subclass	Substrate Group	Substrate Subgroup
Biogenic Substrate	Shell Substrate	Shell Rubble	Clam Rubble	*Coquina* Rubble
			Crepidula Rubble	-
			Mussel Rubbel	-
			Oyster Rubbel	-
		Shell Hash	Clam Hash	*Coquina* Hash
			Crepidula Hash	-
			Mussel Hash	-
			Oyster Hash	-
		Shell Sand	*Coquina* Sand	-
	Worm Substrate	Sabellariid Susbstrate	Sabellariid Reef Substrate	-
			Sabellariid Rubble	-
			Sabellariid Hash	-
		Serpulid Substrate	Serpulid Reef Substrate	-
			Serpulid Rubble	-
			Serpulid Hash	-
Anthropogenic Substrate	Anthropogenic Rock	Anthropogenic Rock Reef Substrate	-	-
		Anthropogenic Rock Rubble	-	-
		Anthropogenic Rock Hash	-	-
		Anthropogenic Rock Sand	-	-
		Anthropogenic Rock Mud	-	-
	Anthropogenic Wood	Anthropogenic Wood Reef Substrate	-	-
		Anthropogenic Wood Rubble	-	-
		Anthropogenic Wood Hash	-	-

b. Biotic Component: Biotic Setting, Biotic Class, Biotic subclass, Biotic Community

Biotic Setting	Biotic Class	Biotic Subclass	Biotic Group	Biotic Community
Planktonic Biota	Zooplankton	Crustacean Holoplankton	Amphipod Aggregation	*Hyperia* Aggregation
				Caprellid Aggregation
			Copepod Aggregation	*Acartia* Aggregation
				Calanus Aggregation
			Krill Aggregation	*Euphausia* Aggregation
				Thysanoessa Aggregation
		Crustacean Meroplankton	Decapod Larval Aggregation	Brachyuran Crab Larval Aggregation
				Anomuran Crab Larval Aggregation
				Pandalus Larval Aggregation
			Mixed Crustacean Larvae	-
		Coral Meroplankton	Coral Spawning and Larval Aggregation	Acroporid Spawning Aggregation
				Monstastraea Larval Aggregation
			Coral Larval Aggregation	Acroporid Larval Aggregation
				Monstastraea Larval Aggregation
		Echinoderm Meroplankton	Mixed Echinoderm Larval Aggregation	Ophiuroid Larval Aggregation
				Asteroidean Larval Aggregation
				Holothurian Larval Aggregation
		Fish Meroplankton	Fish Spawning and Larval Aggregation	Damselfish Spawning and Larval Aggregation
				Grouper Spawning and Larval Aggregation
				Surgeonfish Spawning and Larval Aggregation
			Fish Larval Aggregation	Clupeid Larval Aggregation
				Engraulid Larval Aggregation
				Sciaenid Larval Aggregation
		Gelatinous Zooplankton	Ctenophore Aggregation	*Beroe* Aggregation
				Mnemiopsis Aggregation
				Pleurobrachia Aggregation
			Jellyfish Aggregation	*Aurelia* Aggregation
				Chrysaora Aggregation

Case Study 2. ShoreZone mapping system

The ShoreZone system is a benthic coastal habitat mapping and inventory system with about 100,000 km of contiguous coastline mapped in Alaska, British Columbia, and Washington that was developed in the late 1970s and revised in the early 1990s with the addition of biological mapping attributes (Harper et al. 1994; (Searing and Frith 1995)). The system is biased towards a mapping system rather than a classification system per se (Harper, person. comm.) because most attributes are features that can actually be seen on coastal, low-tide aerial imagery or directly inferred from the imagery (e.g., coastal stability). ShoreZone is used for oil spill response planning, conservation planning, and habitat capability modeling. The challenge of a mapping system is to characterize features of interest into simple, discrete, and useful classes of information. Variations in landforms and biota are often gradational, so a “system” or “methodology” is required to consistently identify and summarize important features. The ShoreZone system provides an efficient methodology for systematically characterizing shore-zone features from visual observations over large areas. It describes the geomorphic and biological resources of the intertidal and nearshore habitats. Features such as eroding cliffs, sand and gravel beaches, sand flats and wetlands are some of geomorphic forms mapped. Visible macrobiota, such as wetland grasses, intertidal algae, and subtidal vegetation such as eelgrass or kelp, are also mapped. One key limitation to the system is that features that are small, inconspicuous, buried in sediments, shaded by vegetation, or deep under water are not visible and are not mapped. The inventory divides the shoreline into homogenous stretches called units. Within each unit, the shoreline is further divided into a series of across-shore components. Units are primarily represented spatially by line segments, but can be polygons or points, which is another limitation of the system. Ultimately, the ShoreZone system should be considered a conservative representation of the actual extent of foreshore resources. The data were collected from a helicopter and thus many small or seasonally ephemeral features were missed. The following rule of thumb was used to determine what features were included in the inventory: “Could I have seen the feature from the window of a helicopter traveling at 60 mph and 300 feet above the ground?” Overall, the inventory is a valuable regional data set because it surveyed thousands of miles using consistent methods during a relatively short time frame. However, it cannot replace higher resolution techniques or site-specific surveys.

Example of parameters used to define a shoreline unit type in ShoreZone:

- Substrate: Rock, Rock + Sediment, Sediment, Anthropogenic
- Sediment: Gravel, Sand & Gravel, Sand, Man-made
- Width: Narrow (<<30m), Wide (>30m)
  Slope: Steep (>20°), Inclined (5-20°) ,Flat (<<5°)
- Exposure: VP: very protected wave exposure with modified effective fetch less than 1 km, P: protected from wave exposure, SP: semi-protected wave exposure, SE: semi-exposed wave exposure, E: exposed wave exposure.

Case Study 3. What’s best for Alaska?

Greene et al. (2008) describe a deep water (> 30 m) benthic habitat classification and mapping system which is based on remote sensing (e.g., multi-beam bathymetry and backscatter) geophysical and geological techniques that are used to define and map the seafloor. The interpretations of these geophysical and geological data have been ground-truthed using in situ biological and seafloor observations. Physiography, depth, seafloor induration, geomorphology, texture and biotic modifiers are used to describe and classify seafloor habitats. A potential marine benthic habitat describes the physical, chemical and biological conditions at the seafloor that are associated with the species or populations of interest. These conditions consist of, but are not limited to, depth, temperature, light, turbidity, salinity, nutrients, currents, substrate type, geomorphology, and structure forming organisms (Greene et al. 2008). Thus, the critical elements of a habitat mapping and classification scheme should include information on the above elements. Further, because definitions of substrate type and geomorphology are scale dependent (Greene et al. 2008), the classification system is hierarchical and contains descriptions of megahabitat (e.g., large, > 1km, features), mesohabitat (e.g., submerged canyons), macrohabitat (e.g., 10s of m, kelp beds), and microhabitat (small features < 1-2 m, anenomes). Remote sensing (e.g., multibeam sonar) is used to collect data at the scale of 10s of kilometers to 1 meter, and data is categorized using: Megahabitat, Seafloor Induration, Meso/Macrohabitat, Modifier, Seafloor Slope, Seafloor Complexity, and Geologic Unit. Visual observations at scales of 10m to < 1m are used for additional categories of Macro/Microhabitat, Seafloor Slope, and Seafloor Complexity, and biotic modifier. The classification system has been used in California, Alaska, and Washington in a variety of environments including sediment ladened continental shelves, estuaries, and inland seas. The classification system has also been applied to multi-beam acoustic bottom backscatter data collected in the southern Strait of Georgia. The main limitation of this system is that it does not consider intertidal or estuarine systems, or the water column, and contains relatively few biotic modifiers.

A modified summary of ten major classes of information included in the Greene et al. (1999, 2008) subtidal marine habitat classification system is shown below.

- Determined from Remote Sensing Imagery (for creation of large-scale habitat maps)
    1. Megahabitat – based on depth and general physiographic boundaries and is used to distinguish regions and features on a scale of 10s of kilometers to kilometers.
    2. Seafloor Induration – Seafloor induration refers to substrate hardness, and hard, mixed, and soft substrate can be further subdivided into distinct sediment types.
    3. Meso/Macrohabitat – Consists of seafloor features ranging from 1 kilometer to 1 meter.
    4. Modifier –Describe the texture or lithology of the seafloor.
    5. Seafloor Slope – Slope is calculated for a survey area from x-y-z multibeam data.
    6. Seafloor Complexity – Complexity is calculated from slope data using neighborhood statistics and reported in standard deviation units.
- Determined from video, still photos, or direct observation (for designation of small-scale habitat types)
    7. Macro/Microhabitat –Macro/Microhabitats is subdivided between geologic and biologic attributes.
    8. Seafloor Slope –The clarity of this estimate can be made at smaller scales and ground-truthed.
    9. Seafloor Complexity –Based on seafloor rugosity values calculated as the ratio of surface area to linear area along a measured transect or patch.

Comparison of Pacific region ecological classification case studies

The review of case studies of ecological classification systems revealed that no pelagic classification systems have been applied to Pacific region. The lack of pelagic applications is a critical omission for the successful implementation of the proposed science-based framework. Somewhat more surprising was the finding that no single benthic habitat classification has been applied to Pacific region. Only the intertidal-based ShoreZone system has been used in a spatially comprehensive manner in BC, but it is restricted to the intertidal and it is considered by its developers to be more of a mapping system rather than a classification system. However, the ShoreZone system does have some of the elements and utility of a classification system because it uses a standardized nomenclature for abiotic and biotic coastline units, and it has been applied along shorelines from Alaska south to the Washington coast.

John Harper (Coastal and Oceans Resources Inc., Victoria. BC, pers. comm.) cross-walked ShoreZone into the CMECS benthic habitat classification system. Three pilot areas from Sitka Sound were selected to test the cross-walk approach. These areas represented about 122 km of shoreline, 522 alongshore units and 1,966 across-shore components. A variety of exposures, landforms, substrates, biota and salinity regimes are represented within these three pilot sections. The mapping units of ShoreZone component data were cross-walked to the Biotic Cover Component, Surficial Geology Component and Geoform Components of CMECS. Harper (Coastal and Oceans Resources Inc., Victoria. BC, pers. comm.) reported several lessons "learned". First, about 75-80% of the ShoreZone data could be transferred into the CMECS system. Summary indicator type attributes could not be transferred. Second, the two systems have fundamentally different mapping units – in ShoreZone line segments are the primary mapping unit and across-shore components are a secondary mapping subdivision. Third, while the detailed substrate characterization of ShoreZone could be transferred to CMECS at the detailed classification level, about 30% of the intertidal zone is a combination of rock and sediment, which does not roll up conveniently into the more general levels of the CMECS classification.

Harper concluded the evaluation with several recommendations:

1. because CMECS is a classification system, there is little mention of the spatial unit types and mapping scales;
2. the CMECS classification is somewhat east-coast centric and a number of additions are required for implementation in Alaska (and hence BC);
3. although the major CMECS components were developed as independent layers in the classification system, geomorphology and substrate are likely to be used for delineating spatial units in mapping applications. Some guidance is required on combining this information;
4. some substrate features are not presently captured in CMECS (e.g., rock and sediment combinations), and need to be included to accurately reflect coastal habitats

Conclusions and the way forward

Although a number of hierarchical habitat systems have been proposed for different jurisdictions, none has been consistently used in pelagic and benthic areas of Pacific region. The key to moving forward will be to choose a classification system that:

1. is designed for the ecosystems in mind
2. is presently used for marine resource management
3. is providing information at the spatial extent and data resolution required by resource managers
4. has a strong biotic component

None of the classification systems discussed so far meets these requirements. However, we believe that the hierarchical framework developed for classifying Australian seabed biodiversity offers a template for Pacific region to explore and modify. The classification system developed for Australia (Last, Lyne et al. 2010) differs from other systems for classifying marine biota by explicitly recognizing the overarching influence of large-scale biodiversity patterns at realm, provincial and bathometric (depth-related) levels. Further, according to their scheme, marine biodiversity is characterized in a systematic way that captures the scale-dependence and hierarchical organization of the biota. Levels are defined with respect to their functional roles and spatial scales, in a manner that directly supports the incorporation of biodiversity information into regional-scale planning by biodiversity richness and priority information needs. Last et al. (2010) indicated that whereas species are the fundamental units of biodiversity, biological facies are likely the smallest practical unit for conservation management at bioregional scales. At each level of the hierarchy, attributes and surrogates are defined to reflect the scale and range of biogeographic and ecological processes that determine the spatial and temporal distribution of marine biota. This ecosystem-level classification approach (see Table 4) appears to be amenable to the high diversity of marine species observed in Pacific region.

Table 4. Summary of level and components of the Australian ecosystem scale classification system. Refer to Last et al. (2010).

Level	Component	Description	Unit
1	Biogeographic Provinces	unique biotic composition and structure	Province-level biogeographic assemblages.
2	Bathome	distribution of fauna is driven primary by bathymetry, extends along all levels of the classification	Estuarine, coastal, continental shelf, Continental slope and abyssal bathomes.
3	Geomorphological	mappable structures, easily identifiable, assumed to be surrogates for distinctive biological assemblages	Coastal bathomes includes fringing reefs, beaches, estuaries, tidal flats, mudflats; Continental shelves includes coral cays, glaciation structures, sand banks; and continental slopes and the abyssal sea floor includes submarine canyons
4	Primary biotope	smallest geographical unit (spatial elements) that can be delimited by convenient boundaries and characterized by its biota	soft, hard and mixed substrates
5	Secondary biotope	nested within primary biotopes, smaller in size, and characterized by specific types of physical substrate	igneous, calcareous and sedimentary bedrock, silts, mud, sands, gravels, and seagrass and mangrove stands

Level	Component	Description	Unit
6	Biological facies	mappable units characterized by groups of particular species (e.g., seagrasses, corals)	Macrocystis (kelp) and Zostera (seagrass) stands, and coral communities
7	Micro-communities	small-scale assemblages of often highly specialized species that depend on other member species or groups of species within host facies.	endofaunal associations of kelp holdfasts and sponges, and the infauna of muddy sediments
8	Species	levels of genetic relatedness.	species-level taxa, operational taxonomic units (OTUs) and evolutionary significant units (ESUs).
9	Populations	attributes of species important at local spatial scales	subspecies, phenotypes, and monospecific assemblages of geographic and extralimital isolates
10	Genes	diversity at the molecular level	alleles and DNA sequences

The Pacific Marine Ecological Classification System

Based on discussions among the co-authors of this Research Document, the Last et al. (2010) classification system was modified to better reflect ecosystem level characterization of the Pacific region and to make it potentially useful as a Canadian Marine Ecosystem Classification System within all three of Canada's Oceans. The new ecosystem classification system described in the remainder of this Research Document is referred to as the Pacific Marine Ecological Classification System (PMECS). The modifications discussed below act as a starting point to facilitate further discussions of the framework elements, but it remains for future research to fully develop the benthic and pelagic class descriptors for each level of PMECS. In the section below, the major levels of PMECS are described, with examples for each level and the approximate linear and aerial spatial extent of information that would be required to characterize classes or features at each PMECS level shown in Tables 4 and 5, respectively.

Level 1. Oceanic Realm: The top level of the classification system describes how marine biota exhibit distributional patterns based on evolutionary processes, and is often recognized as the largest marine geographical subdivision from a global perspective. DFO (2009a) reviewed several global biogeographic classification systems (e.g., their Table 8), and we have used the term 'realm' to describe this first level of the ecosystem classification hierarchy.

Level 2. Biogeographic Provinces: The second levels of PMECS, Biogeographic Provinces, have a relatively unique biotic composition and structure; broad transitional areas mark the 'boundaries' between Biogeographical Provinces. Along the Pacific coast of North America for example, two distinctive fish faunas meet and intermingle in British Columbia: a southern fauna from the Oregonian zoogeographic Province extending southward to Point Conception and a northern fauna from the Aleutian zoogeographic Province. The transitional area between these two zoogeographic Provinces falls somewhere in PNCIMA depending upon the authority consulted and ocean climate (Allen and Pondella 2006). Similarly the kelp flora of North America has been divided into three segments, the southern segment extending from Baja California to southern Vancouver Island, the northern segment extending from northern Vancouver Island to Yakutat, Alaska, and the western segment extending through the Bering Sea (Druehl 2000). The latitudinal extent of Vancouver Island represents a transition area between the northern and southern segments (e.g., six kelp species reach their northern extent and nine kelp species reach their southern extent in this transitional area). Based on the kelp examples noted above, Canada's Pacific region can be divided into two Biogeographical Provinces and a transition zone between northern and southern provinces.

Level 3. Bioregions: The fact that the marine faunal groups of BC lie within transitional areas between major northern and southern Provinces requires a finer subdivision of the Provinces into areas that can be defined by distinctive, recurring and small-scale physical oceanographic processes (e.g., separation between California Current and Alaska Current regions). On the Pacific coast of Canada, DFO (2009a) identified four major bioregions based primarily on physical properties:

1. Strait of Georgia
2. West Coast Vancouver Island
3. Pacific North Coast Integrated Management Area
4. Offshore Pacific Research

Analysis is required to understand how marine species diversity differs among these Bioregions.

Level 4. Ecosections: Bioregions are delimited on the basis of Province level-wide oceanographic processes like major current systems, but they also may be sub-divided for management purposes using information on larger spatial scale processes. Ecosections are sub areas of Bioregions that can be defined by distinct, recurring and larger-scale physical oceanographic processes. For example, the Vancouver Island Coastal Current and the Juan de Fuca Eddy are major oceanographic features occurring within the northern California Current region that in part defines the West Coast of Vancouver Island Bioregion. The pelagic habitats of the southern Strait of Georgia Bioregion have been subdivided into nine Ecosections based on distinctive oceanographic processes (Robinson and Royale 2008). The surrogacy of the Ecosections with respect to marine diversity remains to be determined. In addition, it remains to determine how the Ecosections, which are primarily related to abiotic pelagic oceanographic processes, relate to benthic ecosystems.

Level 5. Bathomes: Depth is considered to be one of the strongest environmental correlates of fish and invertebrate community structure because of relationships between species distributions and light, physiological constraints (e.g., pressure) and production; hence depth is considered a useful surrogate for capturing changes in community structure within a Province (Last et al. 2010). Bathomes are large (> 1,000s of km2) and continuous throughout higher levels of PMECS such as the Bioregion and Ecosection levels, unlike lower levels of the PMECS that are spatially disjunct and patchy (Last et al. 2010). Sub areas of a Bioregion defined on the basis of depth should be defined using well known and standard systems and nomenclature. Well known benthic Bathomes would include terms such as inner shelf (50-150m), continental shelf (<200 m), and continental slope (200-1000m). Pelagic Bathomes would include: Neritic zone, Epipelagic zone, Mesopelagic zone, Bathypelagic zone, and

Abyssopelagic zone. Last et al. (2010) note that because biotic compositions of demersal bathomes are typically different from each other they can be treated/mapped as independent ecological units. Pelagic-based bathomes however, likely exhibit greater spatial overlap of biotic composition because of diurnal vertical migrations, and thus additional research will be required to associate pelagic biota with specific depth strata. For example, Allen and Pondella (2006) have identified several groups of pelagic fish species in California associated with different depth zones (e.g., open ocean pelagic, Bay estuary, coastal pelagic, etc.) and a similar approach might be applied to BC fauna.

Level 6. Geozones: Last et al. (2010) used the term geomorphological units to describe mappable mesoscale units easily identified from each other based primarily on geomorphological or abiotic features that were assumed to be surrogates for distinctive biological assemblages. We use the term Geozones, applied to both benthic and pelagic areas. Last et al. (2010) found that accurately identifying and mapping geomorphological units in each Bathome was a critical initial step for identifying key elements of the regions biodiversity. Examples of benthic Geozones in Pacific include seamounts and submarine canyons, while pelagic Geozones include estuaries and coastal upwelling zones.

Level 7. Primary Biotope: Last et al. (2010) defined a primary biotope as the smallest geographic unit of 'habitat' that can be delimited by conventional boundaries and is characterized by its biota. Coarsely defined substrate types (e.g., soft, hard, mixed substrate) were used because they were easily identifiable and mappable and considered important determinants of sea floor biota. We recommend defining primary benthic biotopes based on one of the benthic habitat classification systems discussed above. For pelagic systems, the identification of primary biotopes for PMECS might use coarsely defined water property data (e.g., sea surface temperature, SST; sea surface salinity, SSS; and dissolved oxygen, DO) to identify water masses, assuming that distinctive water masses (primary pelagic biotopes) would contain distinctive biota. These pelagic primary biotopes may be validated with existing plankton data (DFO zooplankton database) along with plankton data. Examples of primary pelagic biotopes might include: estuarine plumes, small tidal mixing areas, inlets, and small bays. Ultimately, a pelagic based habitat classification system may be required to identify appropriate combinations of water property data and to adequately identify and name primary pelagic biotopes.

Level 8. Secondary Biotope: Nested within primary biotopes are smaller-scale abiotic and biotic sub structural units characterized by specific types of physical substrates or oceanographic processes and their associated biota. For example, coarse primary substrates were divided by Last et al. (2010) into silt, mud, and sand classes and their associated biota such as macrobenthos, seagrasses, sponge gardens, etc. It is uncertain if secondary biotopes can be defined for pelagic systems because of the high mixing of the water column by wind and tides and the high mobility of vertebrate taxa. Additional research will be required to address this uncertainty.

Level 9. Biological facies: Last et al. (2010) considered biological facies to be the fundamental units for management of biodiversity. Biological facies are nested within all levels of the above hierarchy and act as surrogates for all levels below. Facies are mappable units characterized by groups of particular species. Further, biological facies are considered to be biotopic units existing as small patches at scales of kilometers or smaller, and are identified by one or more indicator species that act as surrogates for the broader biological assemblage. In Australia, facies were limited to species of seagrasses, corals, sponges and other macro-biota groups. Pelagic species were not considered informative descriptors of facies because of their mobility. In Pacific region, sponge reefs might be a reasonable example of a biological facie. It is interesting to note that Last et al. (2010) considered habitat classification systems to be schemes for naming and distinguishing facies. Further research is required to determine if biological facies can be identified in pelagic systems.

Level 10. Micro communities: Micro communities were defined as small-scale assemblages of highly specialized species that depend on member species of the Biological Facies. An example in Pacific region is species communities associated with kelp hold-fasts. Additional research is required to identify the suite of micro-communities that might be described in Pacific.

Level 11. Species: Last et al. (2010) indicated that species level units are generally less important in a biodiversity classification scheme directed at marine planning and management. However, species are dependent on different higher-level ecosystem based classification units at different life history stages so the link between ecosystem-based and species-based levels of biodiversity should not be underestimated. Complete knowledge of all relevant species and their distributions would be invaluable for marine planning purposes but the state of knowledge is such in the marine environment that this is not achievable at this time. The reality is that in most cases the present state of knowledge of marine species and their distributions will dictate a pragmatic biodiversity conservation scheme that will be delivered by relying on surrogacy of bioregional scales at the levels above species. This pragmatic approach however, will not be adequate when providing the required management to address the needs of threatened or endangered species.

Table 5. Examples of classes and descriptors for the 10 levels of the proposed Pacific Marine Ecological Classification System (PMECS). Detailed pelagic and benthic descriptors for each level of the classification system will be developed in a future working paper.

PMECS levels	**Examples of each PMEC level**				
Realm	North Pacific				
Province	Aleutian	Oregonian	Transition area	-	-
Bioregions	Pacific North Coast Integrated Management Area	West Coast Vancouver Island	Strait of Georgia	Offshore	-
Ecosections	Juan de Fuca Strait	Central Strait and Fraser River Plume	Southern Strait mixing zone	Mainland fjords	Inner Gulf Islands
Bathomes	Kelp zone (< 30m)	Inner shelf (< 100m)	Continental shelf (< 200m)	Continental Slope (200-1000m)	-
Geozones	Seamounts	Submarine Canyon	Hydrotherm al vents	Coastal upwelling area	Estuary

PMECS levels	Examples of each PMEC level				
Primary biotopes	Hard substrate	Soft substrate	Cold, saline water masses	Warm, fresh water masses	-
Secondary biotopes	Mud	Medium-coarse sand	Gravel	Rocky	-
Biological facies	Hot black smokers	Sponge reefs	Floating kelp mats	-	-
Micro communities	Tube community	Individual sponge community	Holdfast community	-	-
Species	-	-	-	-	-

Table 6. The aerial and linear spatial extent of the 10 proposed levels of the Pacific marine ecological classification system (PMECS).

Level	Abbreviation	Level Name	Spatial extent (linear and areal)
1	RM	Realm	1,000s of km 100 km^2
2	PR	Province	100s - 1,000s km 10-100 km^2
3	BI	Bioregion	10s – 100s km 1-10's km^2
4	ES	Ecosections	Few- 100s km 100s m -few km^2
5	BA	Bathomes	100s m -100's km 100s m -1 km^2
6	GZ	Geozone	1-10s km 10s -100s m^2
7	PB	Primary biotopes	100s m -few km 10s m^2

Level	Abbreviation	Level Name	Spatial extent (linear and areal)
8	SB	Secondary biotopes	10 – 100s m 1-10s m^2
9	BF	Biological facies	1-100s m 1-10s m^2
10	MC	Micro communities	1-10s m < $1m^2$
11	-	Species	<1m to 1,000s km m^2 to km^2

Element 2. Identification of models and schemes used in Pacific region that will contribute data to PMECS

The Canada-BC Marine Protected Areas Implementation team (MPAIT) met in spring of 2012 to discuss potential case studies to assess the availability and utility of models and systems for identifying species and habitat diversity in pelagic and benthic realms in Pacific region and ultimately to supply appropriate diversity information to PMECS. The case studies assembled are not considered exhaustive since they include studies that have described pelagic and benthic realm species and habitat diversity in Pacific region, but they will allow for generalizations to be made about the utility of their approaches.

A standardized questionnaire was developed and applied to the case studies to facilitate knowledge transfer from case studies and practitioners to this Research Document. The responses to the questionnaires are found in Appendix 1. Tables 6 and 7 identify the participants and highlights the questions asked of the authors reviewing each of the case studies. The information obtained from the case studies was supplemented with information from the scientific literature, and is summarized for the pelagic realm (Section 4.1) and the benthic realm (Section 4.2). The main intent of the assessment was to understand where Pacific region stands today with respect to the application and development of methods to generate data for mapping species and habitat diversity in both the benthic and pelagic realms.

Table 7. List of subject experts that contributed to descriptions of ecological tools and data being used in Pacific region to describe species and habitat diversity in the pelagic and benthic realms. Studies chosen were representative of methods, rather than an exhaustive list of studies conducted in the region.

Participant	Organization
D. Biffard	BC Parks
K. Bodtker	Living Oceans Society
J. Boutillier	DFO Science

Participant	Organization
V. Barrie	Natural Resources Canada
W. Crawford	DFO Science
J. Finney	DFO Science
M. Foreman	DFO Science
E. Gregr	SciTech Environmental Consulting
M. Greenlaw	DFO Science
J. Spencer, J. Bernhard and K. Head	West Coast Aquatic Management Board
D. Jackson	Canadian Hydrographic Service
D. Masson	DFO Science
C. Robinson	Oceanus Ecological Services
K. Royle	Parks Canada
C. Short	BC Integrated Lands Management
J. Smith	Marine Planning Partnership
T. Therriault	DFO Science

Table 8. The list of questions sent to subject experts listed in 6. See Appendix 1 for the expert responses.

Questions
1. What types of data were used for the analysis? 2. Are the data available for further use? 3. Data limitations? Solutions to limitations? 4. Has model uncertainty been documented? 5. What areas of the Canadian Pacific marine environment been covered in this analysis? 6. What are the spatial scales/resolutions of the analyses? 7. What has the end product been used for at this time? 8. Are there other potential applications?

Questions

9. Are the results available for other applications?
10. How have these techniques been applied toward marine use planning and resource management in other parts of Pacific, Canada, or globally?
11. What would it take to apply this coast wide: data gaps, time to conduct analysis?
12. Can it answer questions related to the development of network of MPAs?
13. Can it answer questions related to aquaculture and habitat impacts?
14. Could the analysis be more useful but is restricted by resolution of the data?
15. How does the model or analysis deal with temporal variability?
16. Is this the only system available to model the feature (habitat) of interest? If not, what other systems model similar features?
17. Have the model results been validated against biological diversity? If so, how, where and what species.
18. Has the model been published in peer review literature (what is the citation), or some other peer reviewed process (describe)?

The remainder of this section presents a summary of pelagic and benthic case studies that describe the generation of marine species and habitat information for Pacific Canada. The information is presented according to general models or systems:

1. species distribution models,
2. abiotic models, and
3. Expert systems.

Information from these types of models and expert systems is required to populate PMECS.

Species distribution models

Species distribution modeling (SDM) is commonly used in marine systems to describe species distributions. SDMs have been developed in marine systems to support conservation planning, essential fish habitat designations, climate change adaptation studies, invasive species distributions, and understanding of processes that drive biogeographic patterns (Robinson et al. 2011). Most published SDMs consider large vertebrate taxa such as fish and marine mammals; less modelling has been done for plankton, benthic invertebrates and algae likely because there are few ways available to represent the dynamics of these taxa at the necessary high resolution. SDMs typically assume that the abiotic environment exerts a dominant control over the natural distribution of a species. Further, SDM modelling based on presence-absence data are more likely to reflect the existing distribution, or realized niche, of a species, while presence-only data are more likely to describe the potential species distribution (Palialexis et al. 2011). Palialexis et al. (2011) also discussed the wide variety and availability of SDMs used in marine studies, including generalized additive models, generalized additive mixed models, regression tree models, multivariate analysis and regression splines, maximum entropy, support vector machines, general algorithm for the rule-set prediction, envelope score, bioclim envelope model, environmental distance, associative neural network and artificial network ensemble. These authors concluded that techniques using species presence-absence data are generally more accurate in predicting species distributions especially when derived from designed surveys and using a ‘sufficient number’ of high resolution abiotic variables. “Support vector machines” was the best performing SDM method among approaches that use presence-only data, while general additive models were found to be the best regression based approach. As might be expected, the fitting efficiency and predictive capacity that characterize an SDM was highly dependent upon the quality of the data used.

Another recent review concluded that marine SDMs typically ignore four key ecological considerations (Robinson et al. 2011). Correlative based SDMs do not directly consider species dispersal in a neighboring spatial context, or explicitly consider species interactions, including the direct effects of biotic interactions, such as competition and feeding, on species distributions. Further, habitat associations of species are typically described using adult stage information only, and species-environmental relationships are often modeled as linear and almost always stationary processes, when in reality species distributions are linked to nonlinear, dynamic aggregation processes. The authors also discuss key practical modelling considerations including the fact that marine data are typically biased towards sites closer to the coast and in shallow water, while ignoring deep ocean habitats, and that the relatively coarse scale resolution in space and time of abiotic input data may not be sufficient to adequately resolve fine-scale species distributions (i.e., there is frequently a mismatch in abiotic versus biotic data scales – see Wiens 1989).

Rather than just using species presence-absence data in these SDM modelling approaches, there have been a number of predictive mapping studies that have used measures of species diversity, such as species richness (Carlson et al. 2007), or community composition (biodiversity composition, turnover; Ferier et al. 2007, Pitcher et al. 2012) to identify areas for conservation planning, essential fish habitats designations etc.

Pelagic species distribution model case studies

Distler et al. (2012) and Dalla Rosa et al. (2012) used boat-based survey data on seabirds and whales, respectively, to derive species distribution maps. The mapped scales were comparable (1-2 km^2) and both studies incorporated multi-year surveys in the analysis. These studies differ in that Distler et al. (2012) conducted analysis and species distribution mapping of biotic data only, while Dalla Rosa et al. (2012) used general additive models to synthesize biotic and oceanographic data and remote sensing derived abiotic data. The latter study was able to predict potential humpback whale distribution in relation to key environmental factors such as distance to the 100 m isobath. Further, the authors surmised that high concentrations of humpback whales were associated with topographically induced oceanographic processes that are known to influence (concentrate) prey (euphausiid) distribution. The authors stressed the need to undertake large scale (detailed) studies to shed light on species interactions with prey and their environment, and to integrate this understanding into broad scale habitat models that take advantage of remote sensing technologies. This is a key point that applies to the results of all SDMs.

Overall, species distribution modelling tools show promise in contributing to the mapping of species diversity in Pacific region, and warrant additional investigation. There are several considerations when developing SDMs for marine species (Robinson et al. 2011, Smith, Walker et al 2012), including ontogenetic shifts in habitat use, environmental tolerances of mobile species, and the influence of non-linear species-environmental relationships. Further, SDM approaches also should be applied to less mobile taxa such as invertebrates and marine algae, rather than focusing solely on highly mobile vertebrate taxa.

Benthic species distribution modeling case studies

There were many more examples of species distribution modeling and abiotic habitat distribution modeling (ADM) for the benthic realm compared to the pelagic realm of Pacific region. Most of the SDMs identified were single species focused and only the preliminary (unpublished) gradient forest analysis (Ellis et al 2012) of Finney on groundfish data used a multispecies approach. A key observation in the evaluation of the use of SDMs is that the different modelling exercises often used common abiotic parameters such as Sea Surface Temperature (SST) however the values of the parameters used in the models were different as they were taken from different datasets. In part, this is due to the perceived and required spatial resolution of the data in influencing the distribution of the target species. To conduct a meaningful comparisons of SDM methods will require the development of a virtual archive of standardized abiotic data sets.

Abiotic distribution models

The term abiotic distribution model (ADM) refers to methods or models that segment continuous abiotic marine properties into regions or units where environmental conditions are similar and yet different enough from neighbouring regions to warrant calling them distinct regions. The common assumptions in the literature is that these regions ultimately reflect differences in biological characteristics, whether at the species level or perhaps at a biotope level (referring to an associated community of species) and that differences in abiotic properties will result in distinctive shifts in biotic composition and a shift in species composition from one region to the next. Note that these concepts are discussed for benthic habitats, but presumably they are valid for the pelagic realm as well (e.g., Gregr and Bodtker 2007). However, species-environment relationships are seldom linear as assumed (e.g., Robinson et al. 2012) and few studies have yielded convincing verification of habitat-species surrogacy. For example, Przeslawski et al. (2011) tested whether a continental scale classification of Australian benthic seascapes and derived environmental data were viable abiotic surrogates of epibenthic invertebrate diversity at a scale of 10s of kilometres. They found that seascapes were not consistently useful surrogates because the relationships between seascape type and epibenthic invertebrate community structure changed among seascapes, regions and spatial scales. In addition, benthic abiotic seascapes were not useful proxies for biodiversity in heterogeneous regions. This conclusion is true even at ‘local’ spatial scales on coral reefs (Heap et al 2011). Another example of the difficulty in validating such models beyond fitting the dataset is described in the UKSeaMap project (Connor et al. 2006).

Brown et al. (2011) conclude that there is a lack of strong evidence for ADM products and biological surrogacy which is primarily due to inadequacies between spatial scales of abiotic and biotic variables used in the models and analyses, or simply to the inherent complexities of the marine system that cannot be explained with a simple paradigm. Despite these caveats, results from ADM can provide useful representations of environmental patterns for conservation planning purposes (Southwood 1977, 1988). ADMs offer a starting point for understanding and mapping habitat diversity, but no matter how abiotic data layers are analyzed or combined, at some stage it is necessary to combine them with biotic data in order to create a true “habitat” map (Brown et al. 2011).

Pelagic abiotic model case studies

Gregr and Bodtker (2007) used data from the regional ocean modeling system (ROMS) oceanographic model to compare North Pacific regions with surface chlorophyll concentrations derived from satellite imagery (adaptive classification of marine ecosystems). This classification approach identified only one large region for the BC coast mainly because the study examined the entire North Pacific. However, we included this study in our review because it presents a quantitative method for applying image classification algorithms to a comprehensive description of the ocean's surface, derived from an oceanographic circulation model. The authors also considered interannual and seasonal differences in the marine regions, and assessed the biological relevance of the regions from satellite derived estimates of chlorophyll. This might be considered a first order verification of the pelagic habitat model because the satellite derived products do not differentiate phytoplankton species, and the focus is necessarily on the ocean surface. Overall, the approach could potentially be applied at higher spatial resolution (Devred et al. 2007) in Pacific region because the ROMS is well developed for the region (see below), and remote sensing data are available at a higher resolution than the data used by Gregr and Bodtker (2007). This method may help address the lack of focus on mapping of large-scale or micro oceanographic pelagic habitats which are likely common in the top few hundred meters of the water column (Robinson et al. 2012).

The BCMEC (Zacharias et al. 1998) analysis is based on a first order assessment of pelagic realm habitats that uses three classes of salinity and four classes of stratification plus an unknown category to generate 13 distinct classes of pelagic ecounits. In turn these 13 distinct classes generated 155 discrete polygons of pelagic ecounits over the BC coast. Neither the relationship between these pelagic ecounits and biotic diversity nor their ability to capture oceanographic variability in pelagic habitats is known at present. Further, the smallest ecounits were arbitrarily defined as $15km^2$, which is too large to capture local-extent oceanographic features. Since the BCMEC does not use biological data, it is more of a physical classification rather than an ecological classification scheme. Given the recent advances in oceanographic modeling, remote sensing and water property data, the BCMEC approach should be updated and field-tested.

Benthic abiotic model case studies

Several geodiversity (Roff, Taylor et al 2003, Harris and Baker 2012) distribution models have been developed in the Pacific region benthic realm ranging from shallow subtidal areas to deeper offshore areas. The major issue related to the development of these models is the availability of high resolution (both spatial and geologic) substrate data. The most preferred data source, interpreted multi-beam acoustic bottom backscatter, is only available for patches scattered throughout the region (see framework introduction for an acoustic backscatter data image), and is generally absent from the "white-strip" (depths < 30 m) along the shoreline. The lack of acoustic backscatter data in the white strip is due to limited access by DFO survey ships, lack of shallow water multi-beam equipment, and low organizational priority. The lack of high resolution seafloor substrate data is the Achilles heel of benthic habitat mapping and has spawned several novel methods of combining disparate sources of substrate data into meaningful spatially broad and comprehensive datasets (Gregr, 2012).

Expert systems

A modified Delphic (or expert-driven) process, where regional scientific experts were surveyed to identify Important Areas (IAs) that met the a pre-defined set of ecological criteria, was used to define ecological and biologically significant areas (EBSA) for three of the four bioregions of the Pacific coast of Canada including the northern shelf break (PNCIMA), the west coast of Vancouver Island southern shelf break (WCVI) and the Strait of Georgia (SoG) (Clarke and Jamieson 2006; Levesque and Jamieson 2015a, b). This approach has been used in the USA and Australia to identify marine areas that should receive enhanced management attention (Muldoon 1995). The thematic layers produced from the EBSA process in Pacific region mapped biotic information of species of fish, invertebrates, birds, marine mammals, and reptiles along with abiotic information on oceanographic features.

The Delphic derived EBSA process in the Pacific region was an ecological classification system based on expert scientific understanding of the occurrence of one or more EBSA defined criteria important in supporting components of biodiversity. The predefined EBSA criteria were derived from Canada's Oceans Act and the Convention on Biological Diversity (CBD COP IX) and included uniqueness, aggregation and fitness consequences, which in turn could be weighted by two other dimensions (resilience and naturalness) (CBD COP IX) (DFO 2004). The metrics used for the three EBSA criteria and two weighting factors are defined in DFO (2004) as follows:

1. Uniqueness as a measure of the degree to which the characteristics of areas are unique, rare, distinct, and have no alternatives. The spectrum of uniqueness ranges from regional to national to international scales.
2. Aggregation as a measure of the extent to which the area: a) is utilized by individuals of a species to congregate together for part of the year, b) is utilized by most individuals of a species/population for an important life history functions or c) contains a structural feature or ecological process with relatively high density.
3. Fitness consequences as a measure of the degree to which the area itself contributes to the fitness of a population or species. This is ranked from areas where the life history activity (activities) undertaken have a major contribution to the fitness of the population or species present to areas where the actual life history activity taking place there only makes a marginal contribution to fitness.
4. Resilience is considered a weighting factor in the evaluation of sites for EBSA identification (DFO 2004) using a scale that ranges from areas that contain habitat structures or species which are sensitive, easily disturbed, and slow to recover to areas that contain habitat structures or species that are robust, resistant to perturbation, or readily return to the pre-perturbation state.
5. Naturalness is a weighting factors that is measured by the degree to which areas are pristine or undisturbed and contain native species verses areas which are highly perturbed by anthropogenic activities and /or with high abundances of introduced or cultured species.

The ranking from one of the first three dimensions can be increased if it ranks low in resilience and high in naturalness.

A review of the EBSA process was conducted in a national CSAS process on Lessons Learned (DFO 2011) and the expert approach in relation to delivery of this classification system was reviewed in the original EBSA documents for Pacific Region (Clarke and Jamieson 2006;Levesque and Jamieson 2015a, b). These authors noted the pros of a Delphic process included that:

1. it is a relatively quick way process to come up with a very complex classification system;
2. errors in analysis and interpretation of the unfamiliar data set was reduced using the resident suite of experts;
3. data collection limitations and bias are best understood by the expert especially when derive spatial and temporal patterns; and,
4. not all sources of data are readily available and it takes an expert to provide a view of the data that meets confidentiality agreements.

The lessons learned process (DFO 2011) identified issues related to data collection, interpretation, and data management and recommended a number of procedural directions if the process were carried out again. The general themes for these changes include:

- the need to ensure consistency of interpreted layers used in the identification of EBSAs;
- proper documentation to ensure that users can access each layer of information that was compiled for the identification process;
- a need for metadata that includes:
    - o the type of data/information/knowledge used, its origin and scale, spatial and temporal range, and quality,
    - o the level of uncertainty associated with each layer, and
    - o any weighting or other prioritization methods associated with each data layer;
- the need to understand any bias that may be related to the age of the data layer;
- minimum standards for the application of extrapolated spatial data when used in defining the EBSA boundaries;
- procedures to collect and use scientific ecological knowledge/traditional ecological knowledge/local ecological knowledge (SEK/TEK/LEK) must follow established protocols
- map products that clearly indicate the difference between where there was no data, where data were collected; and extrapolated data;
- databases which are "living", kept up to date, and reviewed on a set schedule;
- databases which meet DFO and government policies for data management; and a peer review process for data, information or knowledge not readily published.

Gregr et al. (2012) recently formalized the EBSA approach as an adaptive method that integrates existing classification in an efficient, holistic and transparent manner by explicitly considering important marine features and biologically sensitive areas.

Pelagic expert system case studies

Clarke and Jamieson (2006) and Levesque and Jamieson (2015a, b) used a Delphic approach in Pacific region and a large number of biotic data sets to identify congruence between biologically important areas (IAs) and oceanographic features, identified by experts, including vertically mixed waters via tidal currents, thermally and salinity driven stratified waters, the Fraser River plume, and biological fronts, etc. The value of the EBSA approach is that it used multiple taxa datasets and abiotic information to subdivide major biogeographic units. This approach is limited however because it focuses on uniqueness, aggregation, fitness consequences, naturalness and resilience dimensions rather than pelagic species or habitat distribution per se.

The oceanographic regionalization approach (Robinson and McBlane 2012) was also Delphic and relied on modeled oceanographic data in combination with chlorophyll data derived from satellite imagery. The 24 sub-regions that it produced are quite large and the boundaries were intended to capture the variability in very large, recurring oceanographic processes such as the tidal mixing at Cape St. James. The variability in large oceanographic processes within the boundaries of the oceanic sub regions is likely high, and thus warrants further subdivision and field-truthing against biotic data to prove meaningful for species and habitat distribution mapping.

Both of these expert-based approaches highlight the importance of understanding the scale of expert knowledge examined because certain knowledge holders may be required for identifying diversity at bioregion scales (e.g., over the entire Strait of Georgia), while different knowledge holders may be required to document local-scale diversity (e.g., Departure Bay).

Benthic expert system case studies

The expert-based process of EBSAs for the benthic realm was not as well developed as it focus on species utilizing the pelagic realm. With the exception of rare and unique areas (Sponge Reefs), most of the EBSAs identified were driven by observations and knowledge of pelagic species and an understanding of both empirical and modeled oceanographic data. These limited results points to either a bias in selecting expert knowledge or a lack of benthic knowledge in Pacific region.

The major approaches used to map the pelagic realm in Pacific region and the limitations of these approaches are summarized Table 9 and Table 10, respectively. The more limited set of applications to map the benthic realm in Pacific region are described in Table 10.

Table 9. Summary of approaches used to map pelagic realms in the Pacific region of Canada.

Approach		**Method and data required**	**Main outputs and resolution**
General	**Specific**		
Species distribution models	Marine important bird areas	Used cluster analysis to identify density pelagic 'hotspots' for 23 seabird species generated using comprehensive shipboard surveys of seabirds.	~1 km^2 21 pelagic hotspots identified along BC coast
	Whale distribution	Used GIS and generalize additive models to analyze multi-year whale survey data with depth, slope, sea surface temperature, distance to features, tidal speed and modelled salinity and temperature.	~2km^2 Strong associations with latitude and bathymetric features. Three important areas: south Dixon Entrance, Hecate Strait and La Perouse region
Abiotic distribution models	Adaptive classification marine ecosystems	An unsupervised classification algorithm required data on monthly averages for wind stress, surface current velocity, sea surface height, sea surface salinity, sea surface temperature.	100 km^2 15 distinct Pacific Ocean regions 1 region for the BC coast
	BCMEC	Generate pelagic ecounits by overlaying salinity and stratification data, where three salinity classes were derived from empirical data, and four stratification classes from salinity observations and from the Hunter-Simpson stratification index.	~1 km^2 155 pelagic ecounits comprising 13 unique combinations of salinity and stratification

Approach		Method and data required	Main outputs and resolution
General	Specific		
Delphic ecological schemes	EBSAs	Expert opinion to identify species important areas (IAs) based on uniqueness, aggregation and fitness consequences. Combined physical features (oceanographic processes, bottle-necks, biogenic structures) and species IAs to identify EBSAs.	Output has variable resolution six EBSAs for Strait of Georgia seven EBSAs for West Coast Vancouver Island 15 EBSAs for PNCIMA
	Oceanographic regionalization	Expert knowledge and interpretation of stratification, modelled bathymetry, model generated maps of tidal velocity, and satellite derived sea surface temperature, and spring Chlorophyll concentration.	$100m^2$-$1km^2$ 29 coastal BC regions

Table 10. Summary of the major limitations of each approach used in the pelagic realm.

Approach		Major limitations
General	Specific	
Species distribution Models	Marine important bird areas	Although the approach used the best available data there are still major gaps in spatial coverage. Only focus on one taxon and excludes abiotic data for predicting distribution in survey poor areas
	Whale distribution	Modeled habitat distribution of a single species
Habitat distribution Models	Adaptive classification of marine ecosystems	The spatial scale is very coarse but related to the large area of interest. The data used is from ROMS models that are constantly improving but their correspondence to real world conditions at fine scales are uncertain. It has not been validated against real biodiversity observations and so the validity of the regions are unknown.
	BCMEC	During the processing of point data, polygons less than $15km^2$ were merged with the largest neighbouring polygon. The uncertainty of the input models to generate the

Approach		Major limitations
General	**Specific**	
		physiographic maps is unknown. It combines physiographic data into ecounits that are presumed to have some measure of homogeneity as well as accuracy in representing the actual environment. It relies on a variety of input datasets each with a range of spatial scales across the study area. Most inputs to BC MEC are enduring with little or no seasonal or even long-term variability. It has not been any systematic work to ground-truth BC MEC as a predictor of biological diversity.
Delphic processes	EBSAs	Data quality varied from poor to rich, and relied entirely on expert opinion. The analysis concentrated on commercial, at-risk and iconic (charismatic) species. It is estimated that < 1% of marine biodiversity was considered.
	Oceanographic regionalization	This is not an objective analysis but relied heavily on expert opinion. The satellite imagery could not be interpreted reliably in some areas (e.g., Strait of Georgia) because of water clarity issues, and the spatial resolution was ~ 1 km^2 for the satellite imagery. The oceanographic sub-regions were not validated against empirical primary or secondary diversity data.

Table 11. Summary of studies reviewed that have been applied in the Pacific region benthic realm.

General Approach	Model or System	Summary
Species distribution models	Northern Abalone critical habitat model	Used abalone abundance data and several abiotic variables (Depth (0-10 m), Kelp (variable – points), Substrate (sand, mud, hard, unknown), Tidal currents (none, moderate, high), and wave exposure to estimate total potential habitat suitable for northern abalone over selected areas of the BC coast
	Sand lance habitat suitability model [4]	Used presence/absence sand lance data and 3 abiotic layers (Tidal mixing layer, Bathymetry, and sand substrate) to predict the distribution of sand lance burying habitat in the Strait of Georgia.
	Marine invasive species distribution model[5][6][7][8][9][10][11][12]	The Genetic Algorithm for Rule-set Prediction environmental niche modeling approach was used for green crab and tunicate distributions. Abiotic data included temperature, salinity, and dissolved oxygen and annual surface chlorophyll data from satellite.
	Gradient forest analysis	Conducted a preliminary gradient forest analysis of groundfish synoptic survey data with data from ROMS: frictional velocity, wave velocity, summer and winter current speed, summer and winter salinity, summer and winter temperature, bathymetry, slope, and chlorophyll concentration.
Geodiversity distribution models	Bottom Patch model	To support the spatial representation of this region, this analysis creates a continuous representation of substrate from the best available bottom type data. The following data were used: CHS bathymetry, bottom type from CHS charts, DFO shellfish surveys, and DFO herring surveys. A polygon layer was produced with variable spatial resolution that is determined by the density of source data.
	NTC benthic	The studied used the benthic habitat model developed by

[4] Robinson et al 2013
[5] Epelbaum et al 2009
[6] Herborg et al 2008
[7] Therriault and Herborg 2007
[8] Therriault and Herborg 2008
[9] Therriault et al 2009 a
[10] Therriault et al 2008 b
[11] Therriault et al 2010
[12] Therriault et al 2012

General Approach	Model or System	Summary
	habitat model	Ferdana et al. (2006) to apply marine ecoregional planning. It combined three parameters: (i) landscape features, (ii) depth, and (iii) substrate in order to identify areas of similar benthic characteristics. The model generated 48 subtidal classes that were not verified against biotic data.
	WWF Sediment model	A model was developed to predict substrate (by mean grain size) using General Additive Models. The approach correlates data on best available grain size (from NRCAN expedition substrate database) with the independent variables bottom type and energy. The model provides a method by which bottom type predictions can be incrementally improved as better sediment data become available.
	BCMEC benthic ecounits	Combines abiotic data such as: Depth (five classes), Slope (three classes), Relief (three classes), Temperature (three classes), Substrate, Current velocity, and Wave exposure to generate 263 unique benthic ecounits of minimum 15km^2 size.
	WWF Habitat disturbance model [13]	A benthic classification was developed using a habitat template, intended to characterize benthic areas with similar driving forces resulting in particular life history characteristics or survival strategies. The model had a resolution of 100m^2 over 30-200m depth range.
Delphic systems	EBSA	Expert opinion and available biotic data were used to derive biologically important areas which were then combined with information on oceanographic processes, bottleneck and biogenic habitats to identify EBSA in the Strait of Georgia, PNCIMA, and WCVI.
Biological assemblage analyses	Hecate Strait dynamic fish assemblages [14]	Analyzed data from the Hecate Strait commercial fishery trawl surveys conducted between 1984 and 2003. Three distinct fish communities dominated by flatfish species were identified as occurring between 20-220 meters. The fish assemblages persisted over time with little bathymetric variation.

[13] Model developed after Kostylev 2004 and Kostylev et al 2005
[14] Fargo 2012

General Approach	Model or System	Summary
	Fish as sampling tools	Used stomach contents from commercially caught trawl species as a value-added analysis of invertebrate diversity distribution. This study was not conducted in Pacific region but could be given the availability of stomach contents data from DFO databases.
	Analysis of fish assemblages of California	The approach assembled and synthesized large amount of fish species diversity information from 77 studies and 168 sites to reduce 244 fish species into 42 fish groups and 15 major habitat types. The approach has not been applied to the BC coast.

Element 3. Identify data requirements for PMECS

Regardless of the species or habitat distribution model or expert system selected for describing biodiversity in the benthic or pelagic realms and for supplying information to PMECS, a key issue is the availability and resolution of foundational data. From a cursory review of species and habitat diversity case studies for Pacific region, the two most important abiotic datasets in demand by practitioners were modelled water property and multi-beam acoustic bottom backscatter data. The following sections briefly discuss the availability and gaps in these data sources to end users of PMECS.

Modelled water properties data

DFO oceanographers (Table 12) were contacted to provide an update on the best available oceanographic model outputs that could be used use in distribution modelling and classification systems.

Table 12. DFO oceanographers were contacted for water property data and oceanographic model outputs

Oceanographer	Model-data set
Dr. Mike Foreman	Coast-wide seasonal SST and SSS climatologies
Dr. Mike Foreman	Tide model output
Dr. Mike Foreman	FVCOM
Dr. Diane Masson	Coast-wide ROMS
Dr. Diane Masson	Strait of Georgia ROMS
Dr. Bill Crawford	DO map for coast (except SoG)
Dr. Angelica Pena	Phytoplankton model results/data for Strait of Georgia
Dr. Angelica Pena	Seasonal climatology for chlorophyll from satellites?

Coast-wide climatologies of salinity and temperature

Coast-wide 3D salinity and temperature summer and winter climatologies are described in Foreman et al. (2008). Summer climatologies spanned July through September while winter climatologies spanned January through March. Seasonal temperature and salinity climatologies were computed from all available conductivity-temperature-depth (CTD), bottle, expendable bathy-thermograph (XBT), and Argo data in National Oceanic and Atmospheric Administration (NOAA), Marine Environmental Data Service (MEDS), and Institute of Ocean Sciences archives. Calculations were carried out in 65 subregions of the model domain and up to 52 level surfaces extending down to 5000 m. Seasonal averages were computed as the median of yearly seasonal values (e.g., Figure 2). Note the climatologies were updated in 2010, not just with more recent information, but also to include spring and fall information.

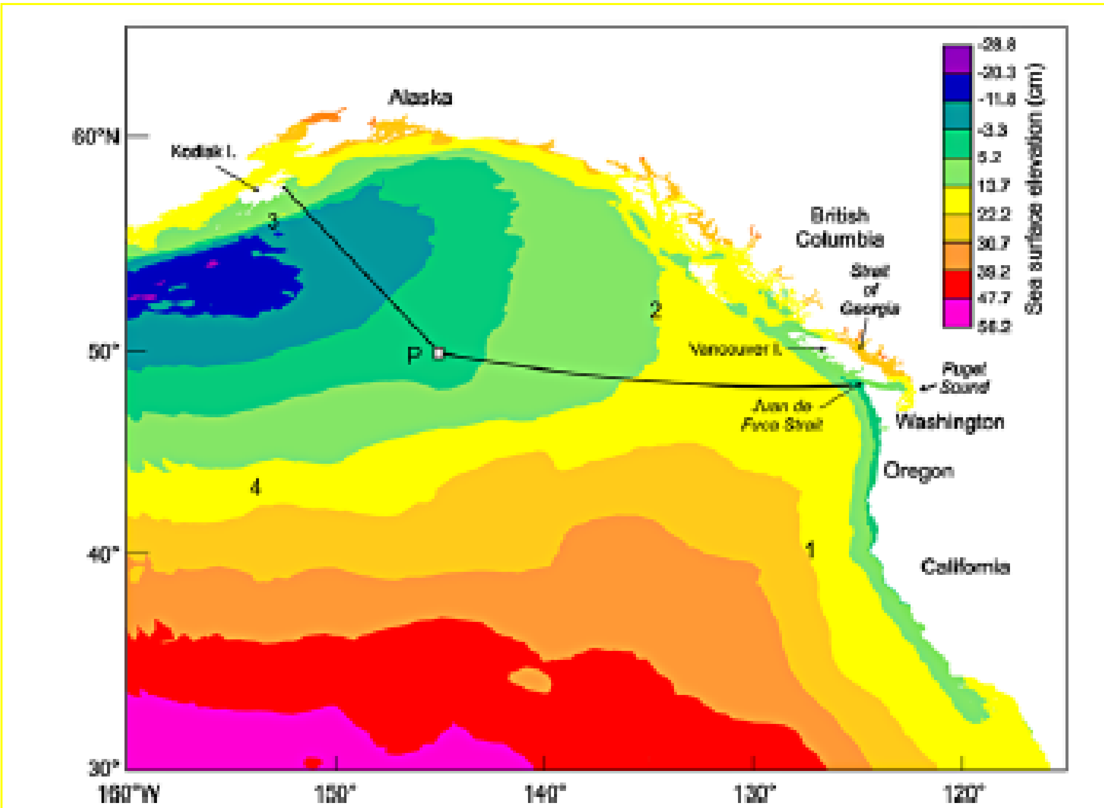

Figure 2. Average summer dynamic ocean topography (DOT, cm) computed from temperature and salinity climatology and NCEP wind stress. (1) California Current, (2) Alaska Current, (3) Alaskan Stream, (4) North Pacific Current, all flowing with higher sea levels on their right.

Tidal models

Foreman et al. (2000) described a high resolution, non-linear, barotrophic finite element tidal model for the BC coast. Currents and elevations for the tidal constituents M2, S2, N2, K2, K1, O1, P1 and Q1 are computed using boundary forcing from a global tidal model and the assimilation of satellite altimetry. Tidal elevations and currents are calculated at triangular grid points ranging from 10s of m to km separation and from depths of -5 m to – 4000 m for the BC coast (Figure 3).

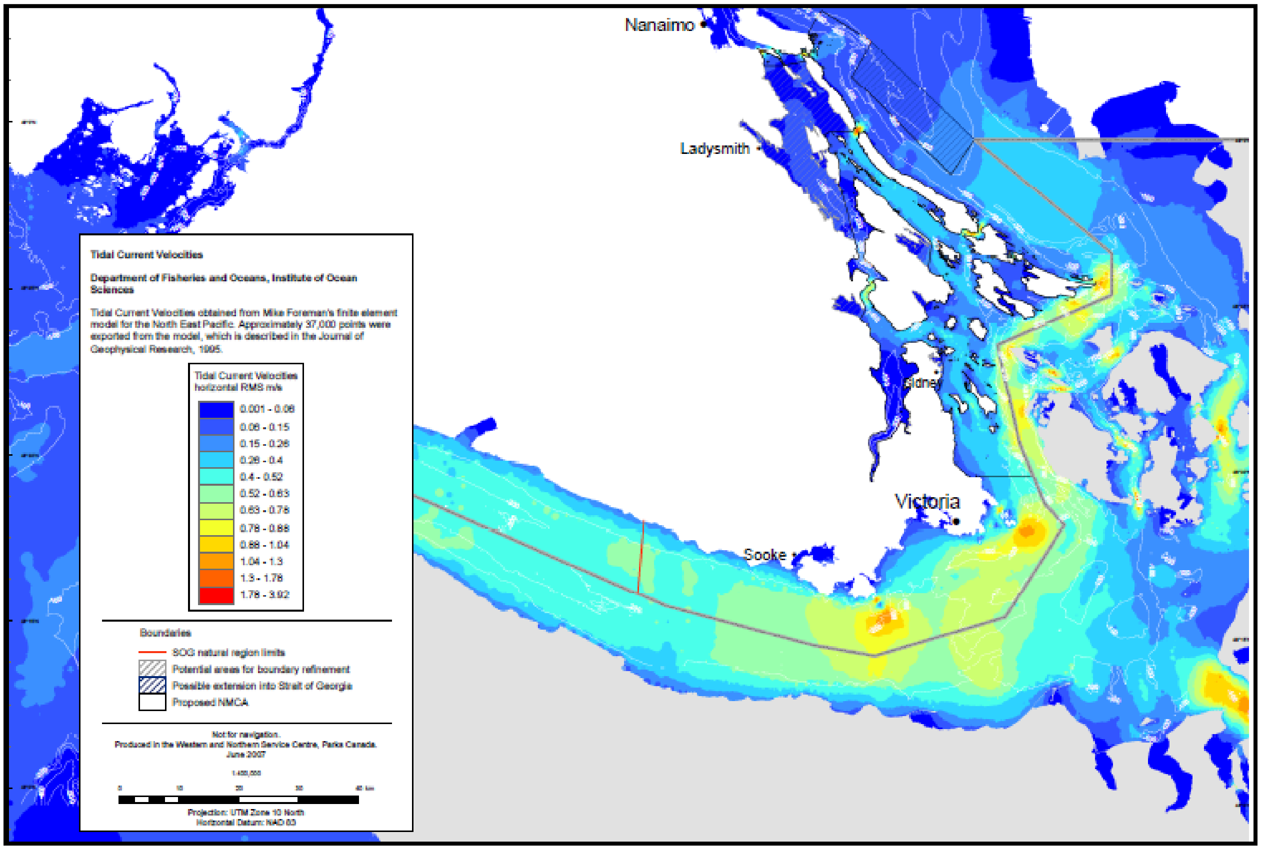

Figure 3. Tidal current velocities for southern Vancouver Island

Finite Volume Coastal Ocean Models (FVCOM)

FVCOMs solve the 3-D hydrodynamic equations for velocity and surface elevation and 3-D transport-diffusion equations for salinity and temperature in the presence of turbulent mixing. These models also employ a variable resolution triangular grid to provide much more flexibility than a regular rectangular grid in representing regions with complicated coastline and bathymetry such as BC coast. Three FVCOM models have been developed and an area has been identified for a fourth model for the BC coast:

1. Broughton Archipelago
2. Discovery Islands
3. Northwest Vancouver Island (NWVI) with high resolution in Kyuquot Sound
4. Central Strait of Georgia – Baynes Sound (Figure 4)

All are developed for aquaculture applications and are still being modified. The finite volume circulation model applied to the Broughton Archipelago region was used to simulate the three-dimensional velocity, temperature, and salinity fields as described in Foreman et al. (2009). The finite volume, ocean circulation model applied to the Discovery Islands was also used to simulate the three-dimensional velocity, temperature and salinity fields and is described in Foreman et al. (2012). The Kyuquot/NWVI model is still preliminary, and a primary publication does not yet exist describing the model, however the approach being used is similar to that followed in the application of FVCOM to the Broughton Archipelago and Discovery Islands. Recently the Central Strait of Georgia – Baynes Sound area has been identified for modelling, the data are being compiled and the model will be developed once the data are ready.

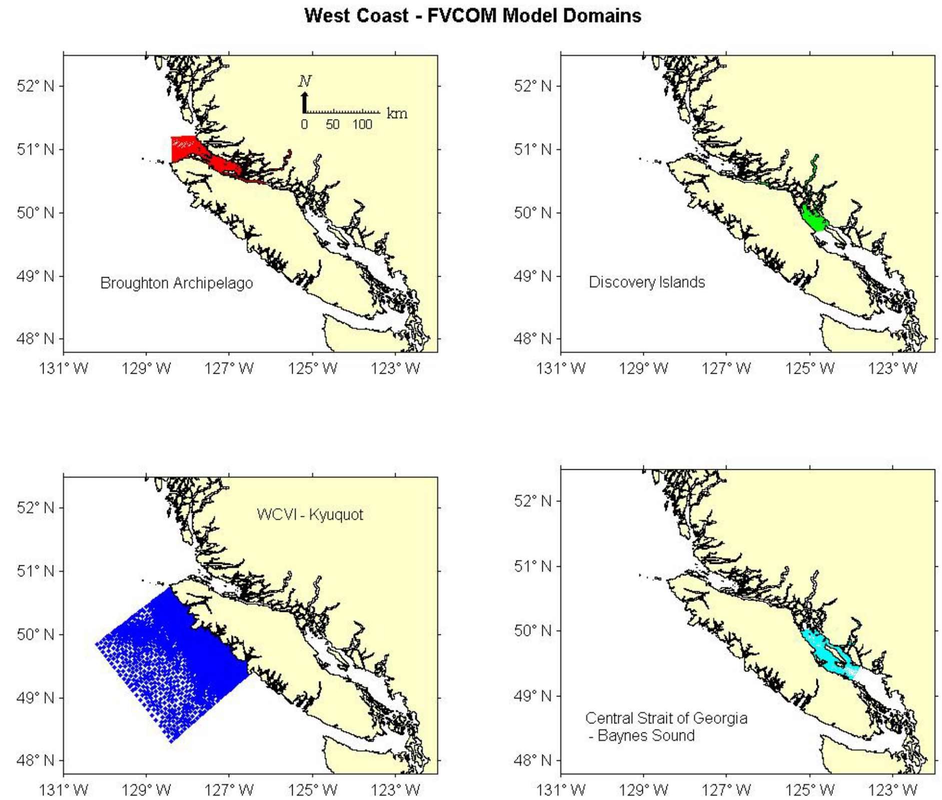

Figure 4. FVCOM model domains available in BC Broughton Archipelago, Discovery Islands and NW Vancouver Island.

Broughton FVCOM

The depth domain of the Broughton model is described as follows (Foreman et al. 2009): The model bathymetry was generated from Canadian Hydrographic Service single-beam digital charts with some sections updated from multi-beam surveys. The depths ranged from 3 m in coastal regions and rivers to 520 m within Knight Inlet, with 21 modeled layers. Though FVCOM has a provision for wetting-and-drying, the generally steep-sided nature of shorelines in the region means that mud flats play a very minor role in the overall circulation dynamics and can be ignored. In the horizontal, the grid sides ranged from a maximum of 2.3 km in Queen Charlotte Strait to < 50 m in some narrow channels within the Archipelago. The model is forced by tides, river discharge, and wind forcing. Initial three-dimensional salinity and temperature conditions were computed from historical observations.

Discovery FVCOM

A description of the spatial resolution of the Discovery model was taken from Foreman et al. (2012): The triangular grid for the Discovery Island FVCOM application has 35,609 nodes, 65,473 elements and a horizontal grid resolution that varies from approximately 90 m in Seymour Narrows to 1.7 km in the Strait of Georgia (SOG). The depths ranged from 5 m in coastal regions and rivers to over 700 m within Bute Inlet, and there are 21 depth layers. Initial three-dimensional fields of salinity and temperature were computed by combining seasonal historical climatology interpolated to 1 April with conductivity, temperature, depth (CTD) measurements taken over the period 1–4 April 2010. The simulation periods in the FVCOMs are very limited and only describe three and four week periods in 2008 and 2010. Note that since this description was published, Foreman's group is working on a March-July 2009 simulation for the Broughton and a July-October 2010 simulation for the Discovery FVCOMs. The problem is getting adequate forcing fields, particularly atmospheric (wind and heat flux). The models produce hourly values of sea surface level relative to mean sea level and 3D fields of temperature, salinity and horizontal velocity. Average values or values associated with specific tidal frequencies have been computed from these outputs. Foreman et al. (2009, 2012) describe the limitations of the FVCOM modelling approach. These models do not perfectly reproduce simultaneous observations, which means their results should be used with some caution. Further because the simulations only cover a small time span, they do not adequately account for potential seasonal and inter-annual variations. Lastly, a major limitation for biodiversity modelling is that spatial coverage of FVCOMs is not large relative to the BC coast, and they require fairly extensive forcing data sets to function properly.

Modelling interannual variability in coastal BC oceanography

Masson and Fine (2012) developed a regional ocean circulation model to examine ocean variability along the Pacific coast of Canada, from the Columbia River to the Alaska Panhandle (Figure 5). The Regional Ocean Modeling System (ROMS) was applied to hind cast the period 1995–2008. ROMS is a terrain following, primitive equation model and implementation includes a third-order upstream-biased scheme for horizontal advection, radiative boundary conditions with adaptive nudging, K-profile parameterization for the vertical mixing, and quadratic bottom stress. The model is forced by tides and winds and monthly freshwater discharge from 21 watersheds. The model depth domain extends from the surface to seafloor, excluding the near shore (<30m, i.e., the white strip). The major model outputs are sea surface height, ocean currents, water temperature and salinity as a function of depth. The spatial resolution of the coast wide model is 3 km horizontally, with 30 variable levels in the vertical. At the moment the model output is stored as 15 day averages in netcdf format. A second ROMS model has been developed for the Strait of Georgia which has 1 km horizontal resolution and 1 day average temporal resolution.

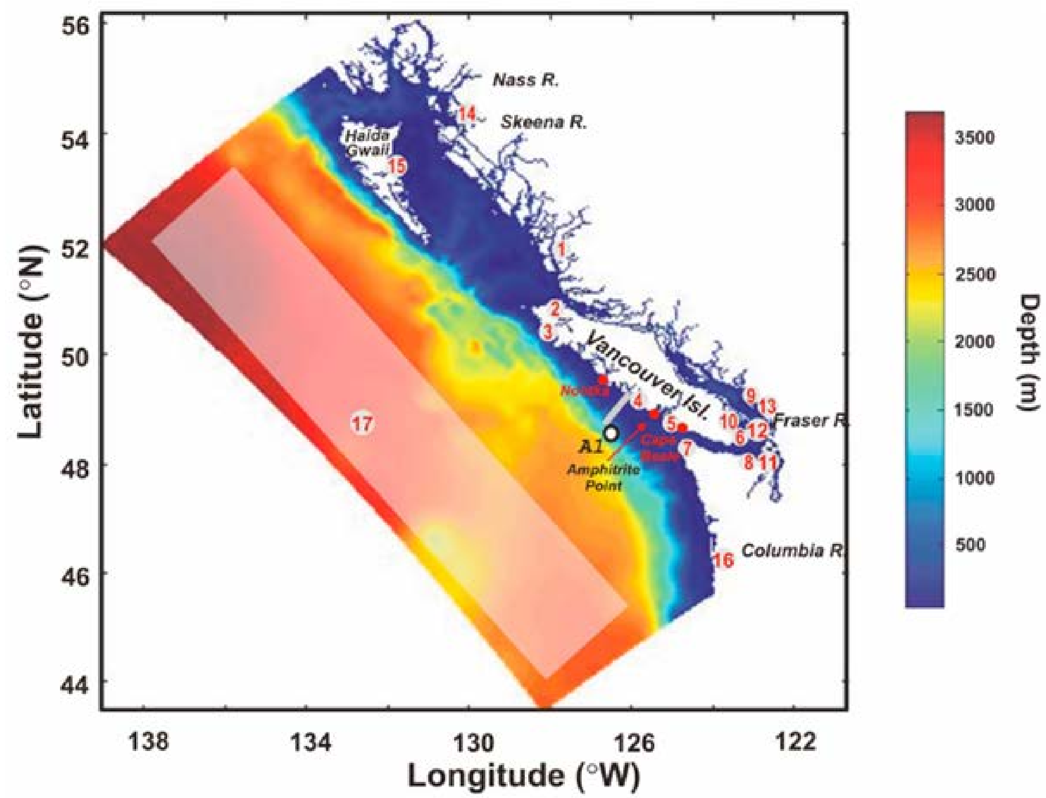

Figure 5. Regional ocean modeling system (ROMS) model grid for the BC coast from the Columbia River to the Alaska panhandle: numbers indicate tide gauge stations. Also indicated are the location of major rivers and lighthouse stations

Phytoplankton model results for Strait of Georgia

A. Pena (Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, pers. comm.) described a phytoplankton model with a spatial domain that includes the Strait of Georgia, Puget Sound, Juan de Fuca Strait and adjacent inlets (Figure 6). The vertical domain of the model ranges from 7 m to about 450 m in 31 non-uniform vertical levels, with clustering near the surface. Because the model uses sigma levels, vertical resolution varies depending on water column depth. The model does not extend into the kelp zone. The model calculates daily averages of nutrients (nitrate, ammonia and silica), phytoplankton (diatoms and Nano-phytoplankton), primary production, and zooplankton (micro and meso-zooplankton) for the 2007-2009 period, All of the outputs have a horizontal resolution of 1 km2 and the vertical resolution of the surface layer is 0.2 m in the shallowest areas (7 m) and ~1.6 m at the deepest depth (> 450 m). The absolute values of model outputs are less reliable than spatial and temporal trends. Although the model output compares well with available observations, there are few data for temporal and spatial comparisons. The model output (netcdf files) could be stored on a share driver, but storage space may be a limitation since one year of daily concentration of model output requires ~90GB without storing rate variables (e.g., production, grazing rate, etc). An additional 125 to 285GB of extra space may be required depending on how many daily rate variables are stored. The main limitation of the model is its limited spatial extent, and the lack of validation of model output.

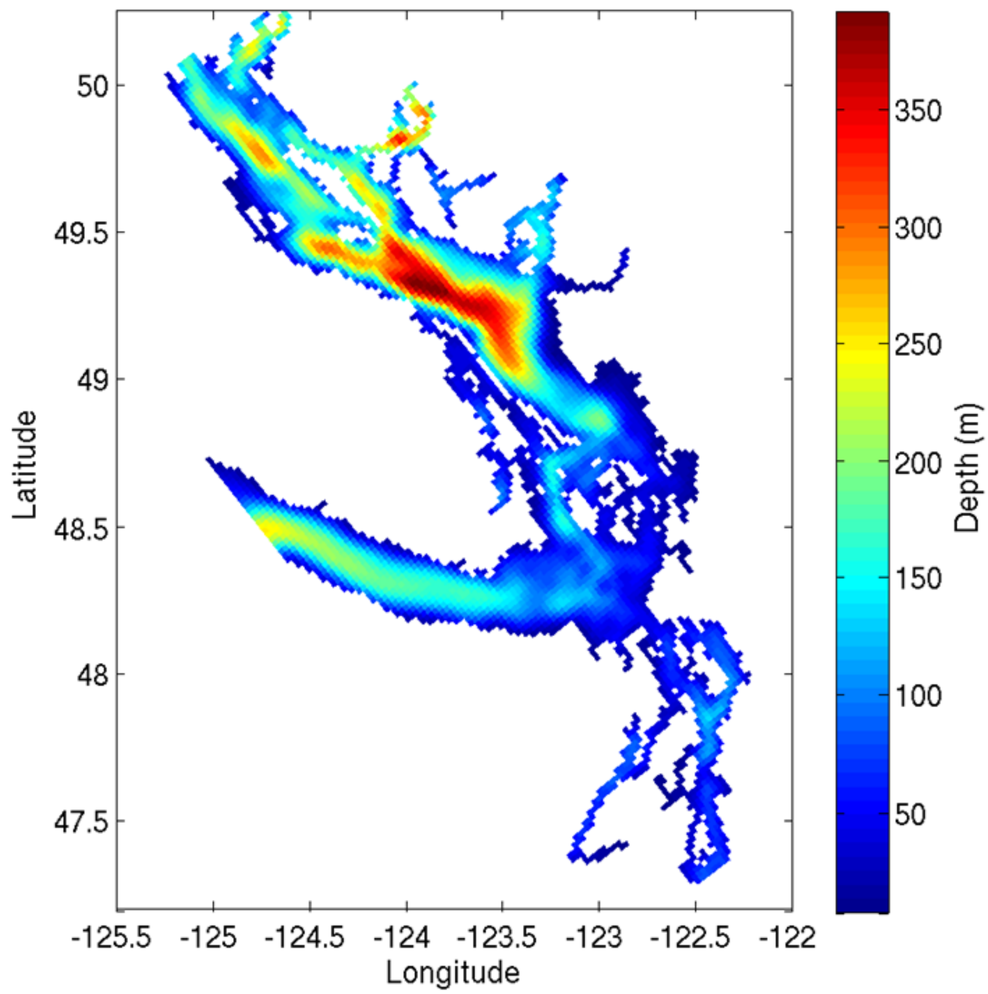

Figure 6. Phytoplankton concentrations output from the Pena phytoplankton model.

Seasonal climatology of chlorophyll from satellites

A. Pena (Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, pers. comm.) indicates that seasonal climatologies of near-surface chlorophyll (a proxy for phytoplankton biomass) from the defunct SeaWiFS satellite (1997 to 2010) and MODIS (2002 – present) have been produced globally and can be viewed on-line. Sensors on both satellites have 4 and a 9 km spatial resolution, depending upon the product selected. The main limitation is that satellite derived estimates of chlorophyll are produced at a coarse scale and estimates are negatively influenced by cloud cover and the presence of colored dissolved organic matter.

Acoustic data

Multi-beam acoustic bottom backscatter (eventually interpreted as seabed substrate) and bathymetry data are two key inputs for most species and habitat distribution models. Acoustic data practitioners and experts from the Canadian Hydrographic Service (CHS) and Natural Resources Canada (NRCAN) provided insight into data availability and gaps, acoustic data limitations, and the need for Pacific region standards (Table 13).

Table 13. Steps and issues associated with obtaining physical habitat classification

Step 1. Collection of multibeam acoustic data (bathymetry and backscatter)	Step 2. Processing of acoustic data	Step 3. Ground truthing data	Step 4. Application of a classification system
Issue 1. What areas along the BC coast have been acoustically mapped?	**Issue 1.** Are acoustic data processed using a standard method (software)?	**Issue 1**. Where along the BC coast have visual data (TUV, ROV, SCUBA) been collected that could be used for ground-truthing acoustic data?	**Issue 1**. What classification systems have been used for seafloor substrate particle size and composition?
See Figure 7 supplied by NRCan	NRCAN and CHS use geocoder software for backscatter processing, and is the mostly widely used globally. Bathymetry data are processed by CHS using CARIS hydrographic information processing software.	DFO is presently compiling coast-wide locations of 1) remotely operated vehicle transects, 2) towed underwater video transects, 3) SCUBA surveys.	No standard seabed classification is in use in Pacific Canada
Issue 2. How compatible are the different MEBS datasets?	**Issue 2**: Is there a 'back-log' of unprocessed acoustic backscatter data?	**Issue 2**. Where along the BC coast have physical samples (grabs, cores) been collected?	**Issue 2**. What classification systems have been used for biological information associated with visual data?
No response received from CHS at this time.	NRCAN has processed about 60 % of all backscatter collected by CHS and will be up to greater than 75 % by the new fiscal year.	NRCAN has developed the Expedition database listing information on grab and core samples coast-wide.	none
Issue 3.	Issue 3.	**Issue 3**. Is there a standard process (including software) for analyzing visual data?	Issue 3.
-	-	DFO has used video miner	-

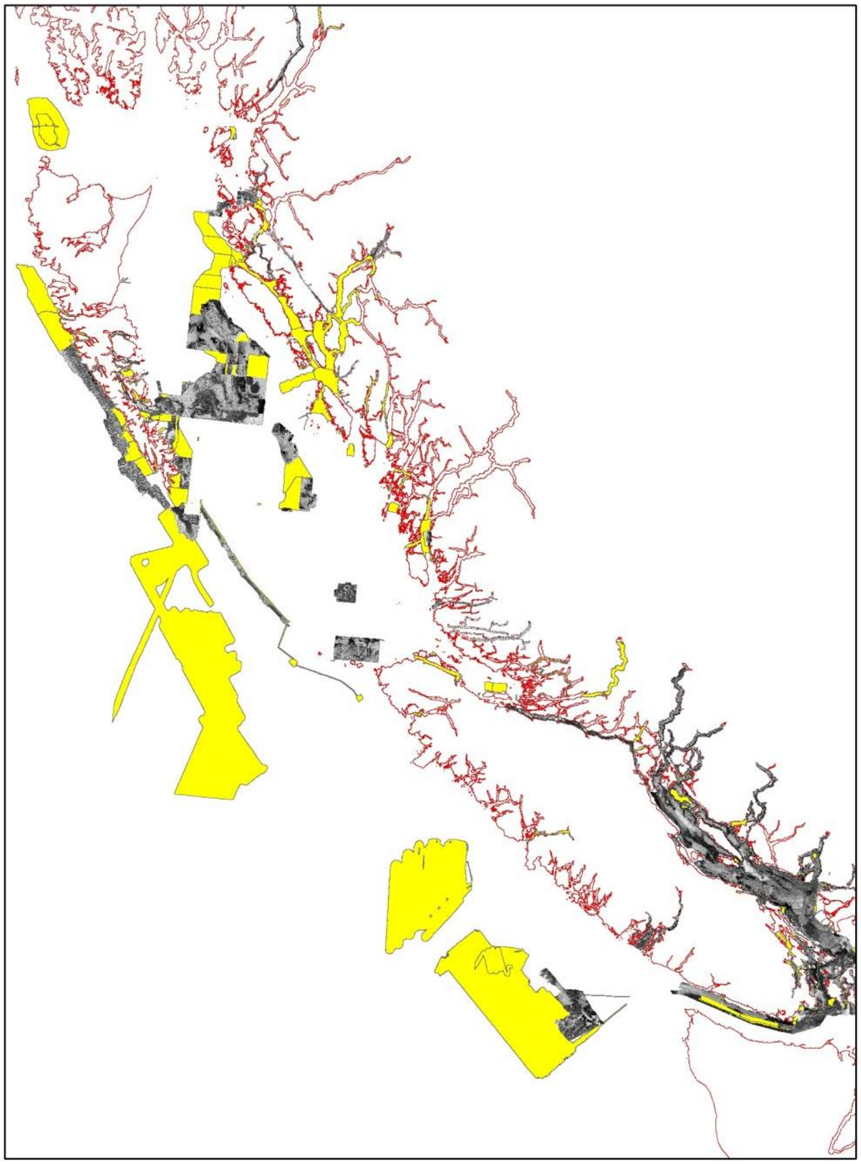

Figure 7. NRCAN multi-beam acoustic coverage in coastal BC to 2010 in yellow overlain with processed backscatter (grey areas). Offshore yellow blocks collected by NOAA and do not have associated backscatter data.

Survey data (physical sample data)

In this study, survey data refers to data that are collected to gain knowledge by means of direct or indirect observations. The examples that were used in defining the kinds of data collections (biological stock assessment surveys, grab samples, observer programs, etc.) are all methods that allow for collection of biotic (community, species or genetic samples) or abiotic (bottom sediment samples) physical samples for further assessment.

Biotic samples

Most biotic sampling is conducted through stock assessment programs that carry out directed research programs or fisheries observer programs. The utility of the surveys to provide biotic data at the community, species or genetic level that can be used in the modeling of species or ecosystem properties depends on a number of factors including:

1. Selectivity of the sampling method with respect to the size and species composition retained by the gear. For example, trawls lose many of the organisms they encounter if the mesh size is large;
2. Vulnerability of the organisms to the gear or the catchability of species. For example, trap surveys are a poor tool to collect sessile organisms while dives survey are appropriate for sessile and low mobility organisms;
3. The willingness and priority given to collecting other information in addition to the data necessary to meet the prime program objective. For example, it would be difficult for a single species assessment program on a small vessel to collect additional information without compromising the prime objective because of space and staffing constraints;
4. The ability to relate a species encounter to a specific location. For example, trawl survey tows often cover over a kilometer of distance and commercial observer operations of groundfish bottom trawls sample sets cover an average of 6 km; and
5. The ability of the sampler to identify the species. Proper identification can be a problem especially for many species where taxonomic keys are not readily available for identification and retention of the samples is an issue.

Bottom samples

Most bottom sampling is obtained through benthic grabs to validate the bottom type. An ISO standard is available for the collection of these data but there are few directed sampling programs using these standards. Priority for bottom samples is the collection of abiotic data and the biotic community is generally ignored as there are usually no requests for the additional effort.

The majority of bottom sampling is carried out by DFO to meet fisheries species assessments. However, a number of other groups routinely collect bottom data for various reasons, e.g., academia to meet education requirements, consultants who are carrying out ecological assessment and monitoring projects, public aquariums for display collections, museums for specimen collections, etc. The problem is that the data collected by these groups are usually not managed in a manner that makes them readily accessible for other purposes.

Optical data

Video and still photo images are collected in a variety of ways for a variety of reasons by various researchers in government, academia, community groups and the general public. There are a number of issues associated with this kind of data:

- The techniques for collection of high quality data are improving, but access to equipment is not readily available or in some cases affordable;
- Some of the equipment requires extensive training to use properly;
- Interpretation of the images requires access to personnel with specialized knowledge (e.g. good taxonomists or satellite image analysis and interpretation);
- Many species cannot be identified at the species taxonomic level based on images alone; and
- Rapid image recognition video assessment capabilities are not presently available to most government agencies (i.e., towed camera arrays to be used on ships of opportunity to collect imagery during quiet periods but processing the data takes on average 5 hours for every hour of video).

DISCUSSION AND RECOMMENDATIONS ON THE WAY FORWARD

The proposed framework shown below illustrates how information generated from species distribution models, abiotic distribution models and/or expert systems could be vetted through, or cross-walked into, the Pacific Marine Ecological Classification System (PMECS) to adequately map species and habitat diversity, and to facilitate comparison of diversity information within and among the Pacific coastal bioregions.

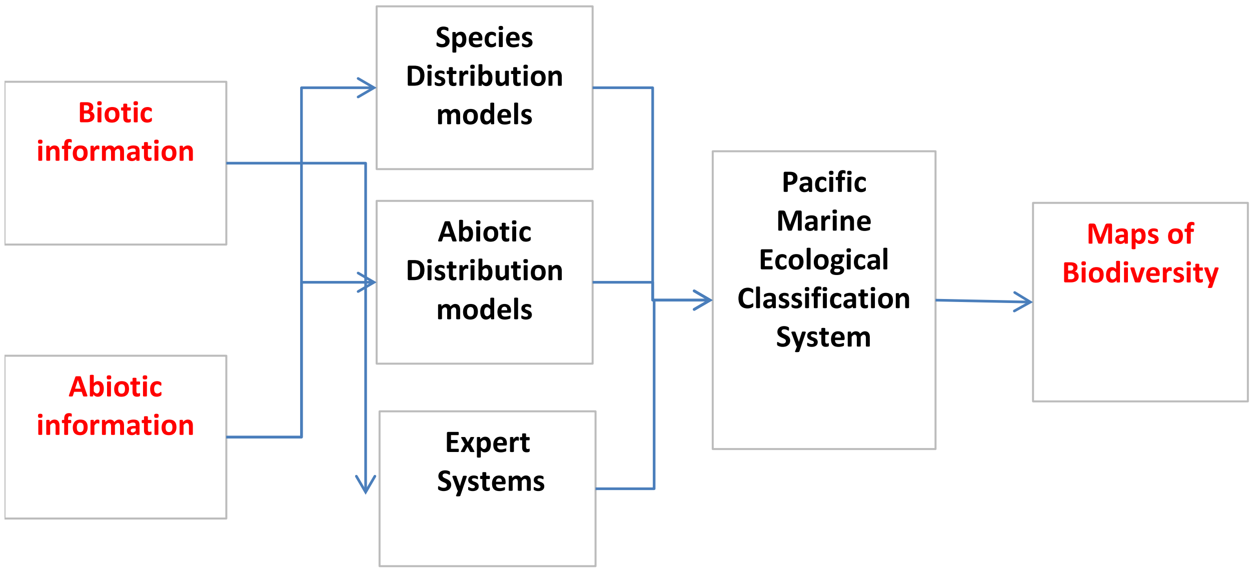

Figure 8. Proposed PMECS system showing how the information generated from Species distribution models, Abiotic distribution models and Expert system would be cross-walked in PMECS to facilitate comparison of the diversity of information

SPATIAL CONSIDERATIONS

The spatial resolution of analyses described in the Pacific region pelagic case studies varied widely and depended upon the objectives and the resolution of the input data, but characteristically was coarse (> 1km^2). All of the studies reviewed conducted pelagic realm analyses at a coast-wide extent, and no methods were used in large scale (e.g., 1: 10,000) applications. These observation could mean either that there is a lack of interest in mapping large scale oceanographic processes, or that the scale of oceanographic features or processes (e.g., upwelling) is best described at smaller spatial scales. Further, the two SDM studies considered wide-ranging nekton species which may bias analysis towards using small-scale and coarse resolution abiotic data. We did not find plankton SDM studies for the Pacific region but again presumably the interest would be in identifying bioregional abiotic processes. Note that the lack of mapping of large scale oceanographic features/processes is not due to the lack of available modelled oceanographic data, as discussed in the introductory framework section. The focus of many SDMs and abiotic models is on the ocean surface, mainly because of the availability of abiotic data and the use of the surface by biota of interest. Although Dalla Rosa et al. (2012) and Levesque and Jamieson (2015a, b) imply that their results encompass water column processes and aggregations, the boundaries were not displayed in three-dimensions. The availability of three-dimensional oceanographic models (e.g., ROMS) may provide high spatial resolution and good vertical resolution for the mapping of the distribution of sub surface pelagic micro habitats.

Most of the benthic-based species distribution and habitat distribution model case studies (see Appendix 1 section B) covered only portions of the BC coast and so were limited in spatial extent. The introduced species distribution models (Appendix 1 Ba) cover the entire coast except the model for green crab is restricted to <50m depth and the tunicate model to depths < 300m. Neither of these models included or required a substrate layer, and hence could be applied to the entire coast. The spatial extent and the resolution of predicted species and potential habitat distributions is a direct function of the available resolution of the abiotic data in general, and the lack of high resolution and spatially comprehensive substrate data in particular.

Overall, the spatial extent (both linear and areal) of information produced by pelagic and benthic species distribution models, habitat suitability models, abiotic models and expert systems varies greatly, and will need to be compared against each other to determine how they contribute to filling the classification levels of the PMECS.

Outputs from Pacific region pelagic and benthic case studies are classified into levels of the PMEC in Tables 14 and 15 respectively. The tables show the extent of the spatial output (e.g., diversity results mapped in linear or areal extent) from each model or method and how this relates to the various the PMECS levels. For example, if every row in the classification table for a given method or study (column) is filled, then the output derived from that method/study is both high resolution (< $1m^2$) and it can cover a broad spatial extent (1,000s of km). If the method/study only occupies one cell in a column then it is restricted in the type of spatial information that it can provide for mapping distributions of marine diversity within the context of the proposed classification system.

We recommend that an assessment of the trade-offs between models and systems be conducted to understand how outputs can be applied to PMECS.

*Table 14. A comparison of studies conducted in Pacific region **pelagic** ecosystems with regards to the spatial extent and resolution of the model (study) results versus the spatial extent of each PMECS level. Note that for pelagic ecosystems it is unlikely that the lower three levels of PMECS are supported, but this will be determined in a later working paper. Abbreviations: HSM: habitat suitability model; ACME: adaptive classification of marine ecosystems; BCMEC: BC marine ecological classification; Ocean reg: Oceanographic sub-regionalization; EBSA: Ecological and Biologically significant areas. NS: not suitable for pelagic ecosystems.*

Level	Spatial extent (aerial and linear)	Marine bird areas	Hump back HSM	ACME	BCMEC	Ocean Reg	EBSA
Realms	1,000s of km 100 km^2	-	-	X	-	-	-
Provinces	100s - 1,000s km 10-100 km^2	-	-	X	-	-	
Bioregions	10s – 100s km 1-10’s km^2	-	-	X	X	X	-
Ecosections	Few- 100s km 100s m -few km^2	-	X	-	X	X	X

Level	Spatial extent (aerial and linear)	Marine bird areas	Hump back HSM	ACME	BCMEC	Ocean Reg	EBSA
Bathomes	100s m -100's km 100s m -1 km^2	-	-	-	-	X	X
Geozones	1-10s km 10s -100s m^2	X	X	-	-	-	X
Primary biotopes	100s m -few km 10s m^2	X	X	-	-	-	X
Secondary biotopes	10 – 100s m 1-10s m^2	NS	NS	NS	NS	NS	NS
Biological facies	1-100s m 1-10s m^2	NS	NS	NS	NS	NS	NS
Micro communities	1-10s m < $1m^2$	NS	NS	NS	NS	NS	NS

Table 15. A comparison of studies conducted in Pacific region ***benthic*** *ecosystems with regards to the spatial extent and resolution of the model (study) results versus the spatial extents of each PMECS level. Abbreviations: NACHM: Northern abalone critical habitat model; PSL HSM: Pacific sand lance habitat suitability model; MIS DM: Marine invasive species distribution model; GFA: Gradient forest analysis; BPM: Bottom patch model; WWF SM: World Wildlife sediment model; NTC BHM: The Nature Conservancy benthic habitat model; WWF HDM: World Wildlife Fund Habitat disturbance model; EBSA: Ecological and Biologically significant areas.*

Level	Spatial extent (aerial and linear)	NA CHM	PSL HSM	MIS DM	GFA	BPM	WWF SM	NTC BHM	WWF HDM	EBSA
Realms	1,000s of km 100 km^2	-	-	-	-	-	-	-	-	-
Provinces	100s - 1,000s km 10-100 km^2	-	-	-	-	-	-	-	-	-

Level	**Spatial extent (aerial and linear)**	**NA CHM**	**PSL HSM**	**MIS DM**	**GFA**	**BPM**	**WWF SM**	**NTC BHM**	**WWF HDM**	**EBSA**
Bioregions	10s – 100s km 1-10's km^2	-	-	-	-	-	-	-	-	-
Ecosections	Few- 100s km 100s m -few km^2	-	-	X	-	-	-	-	-	-
Bathomes	100s m - 100's km 100s m -1 km^2	-	X	X	X	-	X	X	X	-
Geozones	1-10s km 10s -100s m^2	-	X	X	X	-	-	-	-	X
Primary biotopes	100s m -few km 10s m^2	-	X	X	-	-	X	X	X	X
Secondary biotopes	10 – 100s m 1-10s m^2	X	X	-	-	X	X	X	X	X
Biological facies	1-100s m 1-10s m^2	X	-	-	-	X	-	X	-	-
Micro communities	1-10s m < $1m^2$	X	-	-	-	X	-	-	-	-

GROUND-TRUTH CONSIDERATIONS

Biotic data are rarely collected to test relationships between physically derived pelagic sub-units and actual species diversity. The absence of validation testing or ground-truthing is an important omission because a common assertion for benthic classifications is that they act as surrogates for species diversity. Existing DFO Pacific databases could be used to explore relationships between pelagic habitat surrogacy and species diversity. For example, the Pacific Region Zooplankton Database holds about 350,000 detailed species records from about 9,500 oceanographic sampling stations, from 42-65°N and 120-180°W in the North Pacific Ocean.

The major assumption of all these models and schemes is that the resulting outputs are associated with particular types of habitat and that these 'habitats' are essential to the survival of a characteristic species or community. Unfortunately, there are few tests of this assumption in the scientific literature at present. This lack of testing requires immediate attention to move the validity of abiotic benthic habitat modeling forward in Pacific region.

Several studies were identified that were not considered modelling approaches per se but their methods provide novel insights into mapping potential species diversity using empirical data. The examination of stomach contents data (Allen and Pondella, 2006) from multiple species collect in trawls, and the analysis of multispecies associations from more than 77 studies in California provided insight into the utility of multispecies level analyses. Ideally, multispecies data in Pacific region should also be used in SDMs. These are examples of generating fish diversity data and assemblage maps using a variety of novel analytical techniques. These are examples that are based on biological occurrence data to derive habitats from associations**.** Comparing the results from the novel analytical techniques for assemblage identification with abiotic model outputs may provide a first level of ground truthing to outputs of these two separate analyses.

UNCERTAINTY

Uncertainty in mapping marine species and habitat diversity is influenced by:

1. the spatial scale and extent of the diversity map or study objective
2. the quality and quantity of base-line data
3. the species distribution model or abiotic model selected
4. the spatial output of the various models and systems

Uncertainty will even exist in the expert opinion used to map the marine diversity within a region or locale. Although in some cases uncertainty cannot be reduced because it may be too costly or logistically difficult to collect sufficient, high quality information, it should be emphasized that documenting uncertainty at each step in the process towards populating the PMECS becomes important for end users and outside users to understand and interpret the validity of the diversity mapping.

CONCLUSION

The main recommendation of this working paper is for DFO to work with partners to further develop the biotic and abiotic descriptors for each level of the proposed Pacific Marine Ecological Classification System, and then apply the PMECS to management objectives with different spatial scales (e.g., local versus regional). The application of PMECS at different spatial scales will facilitate an assessment of the usefulness of different species distribution models, habitat suitability models, abiotic models and expert systems. Further, PMECS will drive the need to collect certain types of information at appropriate spatial scales and extents to reduce uncertainty and to ensure adaptability of the system for future management needs.

In the sections, below several important issues related to the development of PMECS are discussed.

DATA MANAGEMENT ISSUES

Abiotic and biotic data are required to feed PMECS and there is recognition that these data will come from a variety of sources including government, industry, academia, environmental organizations, and community groups. To facilitate data use and exchange, the creation of the following standards are recommended:

- An investment in infrastructure aimed at increasing and improving Government data management and storage capabilities. Two examples driving this need are: the challenges of storing digital media oceanographic models that create large volumes of output and the lack of storage and retrieval systems for historical optical data;
- Access to raw and interpreted data. For example, one of the major frustrations described by data users is the difficulty in identifying and obtaining water column and/or seabed information for a particular locale or even for a bioregion. It is recommended that the major federal government departments responsible for collecting this information (DFO, CHS, National Research Council of Canada, NRCan), collaborate on the creation of a publically accessible repository of meta-data (using a recognized geospatial metadata standard such as FGDC-1998 or ISO 19115), describing the collective spatial data holdings of Pacific region;
- Establish a working group to develop a roadmap for the Pacific region to move forward with data storage and access issues, and to develop meta-data standards; and
- Use the data collection and assessment permitting systems within the government management system to obtain access to raw and interpreted data from industry and academia.

DATA COLLECTION ISSUES AND RECOMMENDATIONS

The collection of sufficient and appropriate abiotic and biotic data is critical in generating high quality maps of diversity. High priority should be given to addressing the issues outlined in the Acoustic, Survey and Optical data sections of this document. There a number of ways of addressing these critical gaps as outlined below but they will require collaboration and cooperation from all agencies.

- One of the key steps to move forward with understanding and mapping seabed biodiversity will be to continue to collect high-resolution multi-beam acoustic data (backscatter and bathymetry), particularly in areas where there are data gaps. The challenge is to select an appropriate shallow-water technology and platforms and apply it rapidly to the ~28,000 km of BC coastline.
- Research cruises should be designed to meet both stock assessment needs and ecological assessment needs. For example, a standardized multi-species small mesh trawl survey similar to East Coast
- Combine optical sampling techniques with regular assessment survey protocols to evaluate the value of the addition information. Examples include the use of diver head mounted GoPro HD video cameras to capture community properties during single species assessments, use of trawl mounted cameras to capture and qualify the abiotic feature of the habitat where different organisms were encounter during a tow, and collection of bottom grabs with mounted camera to evaluate the sample in relation to other bottom characteristics.
- Standards for data collection, analysis and storage are required, and could be implemented as part of the present sample collection permitting systems. For example, data collection standards should be used as part of the permitting process for the siting of log dumps, aquaculture operations, etc.

SPECIES DISTRIBUTION MODELS ISSUES AND RECOMMENDATIONS

Marine species distribution information is required as inputs to PMECS, but it is unrealistic to expect that comprehensive biotic information from surveys would be available within a bioregion. Thus, methods such as species distribution models (SDMs) are required to generate species distribution information for PMECS. Presently, there is a large, evolving and growing literature on the use of species distribution models, and the key issue is identifying the most “appropriate” SDMs for Pacific region to generate data for biodiversity mapping. We recommend:

- Development of a pilot program to test and apply several SDMs using the same abiotic and biotic datasets to understand their utility in the Pacific region context. Ideally the pilot program would consider small areas with high quality data sets that will allow for the comparison of mapped biodiversity results and allow for the results to be validated on the grounds;
- the development and implementation of a process for SDM assessments to allow for rapid updating the PMECS inputs as additional biotic data on key vulnerable and valued ecosystem taxa (e.g., invertebrates and algae) becomes available; and,
- development of a rapid assessment process that includes a mechanism which facilitates the updating of PMECS maps with new model outputs in a timely manner (this is standard practice for the terrestrial ecological classification system) to insure that management decision-making is based on the best information available.

ABIOTIC DISTRIBUTION MODELS

Abiotic distribution models are potentially useful for mapping biotic diversity, if biotic information is used to test the surrogacy assumption of the models. Both the benthic and pelagic marine ecosystems could benefit greatly from the development of abiotic distribution models that are tested with biotic data. An excellent review of how seafloor geomorphology is used to describe benthic habitat was recently published (Harris and Baker 2012). These authors describe the importance of mapping benthic habitats and then review 57 case studies relating geomorphic features and their associated habitats in order to identify common issues faced by these studies, which include many but not all of the issues mentioned above:

- The need for a thorough consultation and planning of habitat mapping surveys including consultation with scientists directly involved, industry practitioners, indigenous people and GeoHab scientists in the area of survey design;
- The need to understand the naturalness of the habitats in the area;
- The need for standard methods and protocols for marine data collection;
- The need to conduct a literature review to optimize the selection of biological and physical variables to be measured (you can’t measure everything)
- The need for archiving and storage of collected data, including privately funded data where confidentiality may be an issue; The need for accessibility to stored and archived data, particularly raw data where appropriate; and The need to make use of existing information (fisheries, oceanographic, museum collection etc.) and to make available for reuse data collected during a habitat survey data “Map once, use many ways”.

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