Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2004/050 / **Document de recherche 2004/050**

Not to be cited without
Permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Boundary Definition for the Central Coast Integrated Management Area

Établissement des limites de la zone de gestion intégrée de la côte centrale

D. Johannessen[1], D. Haggarty[2], and J. Pringle[1]
Fisheries and Oceans Canada

[1] Institute of Ocean Sciences
Sidney, BC
V8L 4B2

[2] Pacific Biological Station
Nanaimo, BC
V9T 6N7

ISSN 1499-3848 (Printed / Imprimé)

Canada

Table of Contents

Table of Tables

Acknowledgements

We would like to thank the following people who contributed their time, advice, and expertise to improve this paper:

Jeff Ardron of the Living Oceans Society.

Bill Crawford, Dario Stucchi, Mike Foreman, and Moira Galbraith at the Institute of Ocean Sciences.

Michael Healey at the University of British Columbia.

Brenda Bauer, CCIM Co-ordinator, who supported this work both financially and with information and contacts.

Abstract

Fisheries and Oceans Canada (DFO) is currently defining Large Ocean Management Areas with the goal of developing Integrated Management Plans for these Areas. This process is based on Oceans Act policy which calls upon DFO to lead and facilitate a National Oceans Strategy. The Science Branch of Fisheries and Oceans Canada's Pacific Region was asked by the Central Coast Integrated Management (CCIM) Working Group to propose modifications to the Central Coast 'working boundary' based on scientific and ecosystem information. The basis for the proposed modifications in this paper is the use of scientific information to locate boundaries such that environmental characteristics on one side of the boundary differ significantly from those on the other. The physical attributes of bathymetry and substrate type were found to be the most useful in producing well defined changes in habitat, which in some cases were supported by data revealing differences in the biological communities. The resulting proposed CCIM Area roughly corresponds to the Queen Charlotte Sound, Queen Charlotte Strait and Johnstone Strait ecosections as defined by the British Columbia Marine Ecosystem Classification system. Differences between those ecosections and the proposed boundary include a modified northern boundary with Hecate Strait, a new definition of the base of the continental slope, the inclusion of a portion of the West Coast of Vancouver Island down to Brooks Peninsula, and the exclusion of Bute and Toba Inlets. The proposed landward boundary was defined using 'height of land' or watershed principles. The proposed boundary is based on currently available knowledge and data. Modifications to the boundary may be required as scientific progress defines, and fills, data gaps.

Résumé

Le ministère des Pêches et des Océans (MPO) établit actuellement des zones étendues de gestion des océans afin d'élaborer des plans de gestion intégrée pour ces zones. Ce processus est fondé sur la politique relative à la *Loi sur les océans* qui charge le MPO de diriger et de faciliter l'élaboration d'une Stratégie nationale sur les océans. Le groupe de travail sur la gestion intégrée de la côte centrale a demandé à la Direction des sciences de la Région du Pacifique du MPO de proposer des modifications aux limites actuelles de la côte centrale en fonction de données scientifiques et d'informations sur les écosystèmes. Les modifications proposées dans ce document sont fondées sur l'utilisation de données scientifiques pour établir des limites qui séparent des zones aux caractéristiques environnementales nettement différentes. Il a été déterminé que les caractéristiques bathymétriques et le type de substrat sont les éléments les plus révélateurs de changements bien définis sur le plan des habitats. Dans certains cas, des changements ont été confirmés par des données qui montrent des différences au sein des communautés biologiques. La zone de gestion intégrée de la côte centrale proposée correspond environ aux écosections du bassin de la Reine-Charlotte, du détroit de la Reine-Charlotte et du détroit de Johnstone, telles que définies par le système de classification des écosystèmes marins de la Colombie-Britannique. Parmi les différences entre ces écosections et les limites proposées, notons une limite nord modifiée avec le détroit d'Hécate, un nouveau tracé de la base de la pente continentale, l'inclusion d'une partie de la côte ouest de l'île de Vancouver, qui s'étend vers le sud jusqu'à la péninsule Brooks, et l'exclusion des bras Bute et Toba. La limite proposée du côté du littoral a été établie selon le principe de ligne de partage des eaux. Les limites proposées sont fondées sur les connaissances et données disponibles actuellement. Des modifications aux limites pourraient être requises au fur et à mesure que les progrès scientifiques permettent de cerner et de combler les lacunes dans les données.

Introduction: Defining Boundaries for Integrated Management

The Science Branch of Fisheries and Oceans Canada's Pacific Region was asked by the Central Coast Integrated Management (CCIM) Working Group to propose modifications to the Central Coast 'working boundary' based on scientific and ecosystem information. Traditionally, marine boundaries have been based on one type of criteria such as political information, management requirements, or ecosystem-based information. Thus, Canada's Pacific waters can be politically bounded by the Canada-US border to the north and south and by the 200 nautical mile limit of national jurisdiction. Canada's Pacific waters have also been bounded by a number of different administrative systems, such as Fisheries and Oceans Canada (DFO) management areas, as well as smaller polygons used to manage specific fisheries. Boundaries have also been developed that attempt to define marine ecosystems at various scales, as described in section two of this paper. Section three reviews the latest work by the British Columbia (BC) provincial government using GIS analysis to define marine ecosystems at two scales. Section four lists some of the existing boundaries in the Central Coast Area. Section five describes the criteria used to define the proposed changes and discusses in detail the reasoning behind each portion of the boundary.

The boundary modifications proposed in this document represent a relatively new approach to boundary definition. The boundary is intended to define the Large Ocean Management Area (LOMA) for BC's Central Coast as a pilot area for integrated management. According to the *Oceans Act*, these areas are to be drawn using a mix of ecological consideration and administrative boundaries (Fisheries and Oceans Canada 2002). Boundaries developed in Australia for the purpose of marine management have ostensibly been created using only ecological criteria (IMCRA 1998). What is unclear from this work is how various State and Commonwealth jurisdictions and interests will be integrated into this system of boundaries, particularly as much of the boundary development work was done by individual states using different data and criteria. Furthermore, political jurisdictions, such as state versus commonwealth waters, were clearly used in the boundary definition. This illustrates the fact that if resource management is the end purpose of the area, then the definition of the area cannot ignore political boundaries. The definition of the area must also consider whether the area is suitable for management. For example, the intertidal zone could be defined as a single ecosystem for the entire BC coast, but that would create a very long, thin, convoluted area which would be unsuitable for management as a single area.

The definition of an ecosystem is also problematic. Watson (1998) reviews a variety of these definitions and it is clear that they can range from purely scientific, to mixtures of scientific and management criteria. Canada's Oceans Strategy (based on the *Oceans Act*) defines an ecosystem as: "The system of interactive relationships among organisms (e.g. energy transfer), and between organisms and their physical environment (e.g. habitat) in a given geographical unit." (Fisheries and Oceans Canada 2002).

Given the difficulty and subjectivity in defining an ecosystem, and given that the question put to Science Branch is to propose modifications to an existing boundary, this paper does not attempt to define a single Central Coast ecosystem. Instead the general Central Coast area is taken as defined by the working boundary (Figure 1) and modifications to that boundary are proposed wherever there exists scientific information to support an alternative to the working boundary. Since the general area is based on management considerations and the proposed modifications are based on science, the resulting area fits the *Oceans Act* recommendation for defining LOMA boundaries based on a mixture of management and scientific considerations (mentioned above).

The main criterion used to define the proposed modifications of the boundary is evidence for a clear and sudden change in the physical environment (e.g. habitat). Longhurst (1998) states that "We naturally expect that boundaries between biogeographic or ecological provinces, if indeed these are definable, will be sharpest where there are the strongest discontinuities in the physical environment." A sharp change (as opposed to a diffuse or gradational change) is desirable for the purposes of boundary definition because it can more reasonably be represented by a boundary line. During the course of the project two specific factors, bathymetry and substrate material, were most often found to have readily available data, and to provide a sharply defined marine boundary. Whenever possible, biological or physical oceanographic information was also used to support the proposed boundary modification. The criteria used in this report are listed in the table below in the order in which available information was considered.

Criteria considered in the definition of proposed boundary modifications

Criteria	**Consideration**
bathymetry	- sudden change in depth
substrate	- distinct change in substrate type
oceanography	- differences in current directions, current speed, freshwater influence, etc.
biology	- edge of species distribution or association with identified habitat

Although all of the proposed modifications in this paper are based on scientific information, we also note where these modifications coincide with existing political, cultural or managerial boundaries.

The global oceans have been divided by two well known systems. The concept of Large Marine Ecosystems (LMEs) was developed by Kenneth Sherman and colleagues in the early 1990s and have most recently been discussed in Volume 12 of a series of books that gather research relevant to these LMEs (Hempel and Sherman 2003). The LME areas are defined largely by distinct bathymetry, hydrography, productivity, and trophic patterns (Watson et al. 2003, Pauly et al. 2000). Canada's west coast and Alaska both fall within the Gulf of Alaska LME (Figure 2). The criteria for Biogeochemical Provinces were first developed by Platt and Sathyendranath (1988) and then implemented in Longhurst et al. (1995 and Longhurst 1999). Here BC waters are split between an Alaska province to the north and a Coastal California province to the south (Figure 3). The boundary lies approximately at the northern tip of Vancouver Island. This boundary agrees reasonably well with physical oceanographic domains developed by Dodimead et al. (1963), and modified by Thomson (1981) and Ware and McFarlane (1989). The division between the Alaska Current domain and the California Current domain occurs roughly opposite the northern tip of Vancouver Island (Figure 4). The systems described above were developed at a global scale and are based on averaged data that is highly variable seasonally and annually. These systems are useful in placing Canada's Pacific waters in a global context, but do not have the detail required to define LOMA boundaries.

The terrestrial portion of Canada has been subdivided into 39 natural regions. The first effort made to define marine regions was in 1970 (Paish 1970 as cited in Harper et al. 1983). In 1979, Parks Canada recognised that "marine natural regions are not well represented in the national parks system" (Parks Canada 1979 as cited in Harper et al. 1983). Thus, the earlier work of Paish was reviewed and updated using teams of specialists who defined criteria for region delineation and used the most current information (Harper et al. 1983). The project developed six boundary maps for Canada's Pacific Coast based on physical oceanography, coastal environment, physiography, marine mammals, marine birds, and littoral communities. The first three and second three themes respectively were then combined into physical features and biological features boundary maps. This process involved prioritisation of some boundaries over others and/or compromises among differing boundaries. The resulting two maps were then combined to produce a final map with six Marine Regions for the Pacific Coast (Figure 5). The strength of this report is that each step of the process used to define the boundary is clearly laid out.

In 1992, a report to Environment Canada on Marine Region monitoring showed that the original system had evolved into a hierarchy of boundaries (Harper et al. 1992). In this modified system the subdivision of the Pacific Marine Regions involved subdividing larger areas into smaller and smaller regions in a hierarchical or nested format. Table 1 shows the Classification of Pacific Margin Marine Realms organised as a hierarchy. Figure 6 is the map produced by this system showing the ten 4^{th} Order subdivisions. This system was slightly revised for the report "A Classification of the Marine Regions of Canada" (Harper et al. 1993). A few name changes occurred and the levels of the hierarchy were assigned the titles ecozones, ecoprovinces, ecoregions, and ecodistricts (Table 2). In this hierarchy marine ecozones were defined using ice regimes and oceanic basins; marine ecoprovinces were defined using oceanic surface circulation and continental margins; marine ecoregions were defined using marginal sea criteria, and marine ecodistricts were defined using water mixing and stratification data sets. This system retained the ten 4th Order subdivisions (renamed ecodistricts), with slightly changed boundaries as shown in Figure 7. The system was further revised and presented to Environment Canada's Marine Environmental Quality Advisory Group (MEQAG) by Harding et al. (1994). Table 3 and Figure 8 show that the major changes to produce this version include the incorporation of the Mainland Fjords Ecodistrict into the adjoining coastal ecodistricts, the creation of a Continental Slope Ecodistrict, and the division of the Johnstone Strait Ecodistrict into Johnstone Strait and Queen Charlotte Strait Ecodistricts resulting in a total of eleven ecodistricts.

The most recent version of this system came from the Land Use Coordination Office of B.C. (LUCO) and is called the British Columbia Marine Ecological Classification (BC MEC) (Howes et al. 1997). Here the most significant modification was the addition of a fifth level to the hierarchy called Ecounits. These areas were defined at a 1:250,000 scale using provincial Geographic Information System (GIS) layers for depth, current, subsurface relief, substrate, and wave exposure (Howes et al. 1997). The purpose of these finer scale units was to evaluate and further delineate the ecodistrict boundaries, which were renamed ecosections in this version of the classification system, and update the system with current information. A total of 619 ecounits were identified, which were then classified into 65 repetitive classes. The analysis of this information produced the hierarchy in Table 4, which includes the twelve ecosections produced by this system. Figure 9 shows the new boundaries of the ecosections with the ecounits nested within them. A summary of the physiographic, oceanographic, and biological features as well as a boundary rationale for each of these ecosections is detailed in Table 5 (this information evolved along with the boundary systems). The features used to define the ecounits were chosen based on available data and the defined boundaries will be changed as more data becomes available (Howes et al. 1997).

Booth et al. (1998) demonstrated the flexibility of this GIS based system by using it in the "Study to Identify Preliminary Representative Marine Areas in the Queen Charlotte Sound Marine Region" (QCSMR) for Parks Canada. The BC MEC ecounit GIS coverage was used to help define the borders of the QCSMR (Figure 10) and then to analyse data within the region to help achieve the goals of the study.

As promised in Zacharias et al. (1998), the BC MEC has recently been updated (AXYS 2000, 2001). New ecounits were created by including temperature, salinity, stratification and slope data. In addition, the relief layer was re-modelled, new data were added to the depth layer and depth was subsequently reclassified. Another significant alteration was the division of the system into pelagic and benthic ecounits as used in the national framework developed by Day and Roff (2000). Pelagic ranges are defined by surface salinity and stratification while depth, wave exposure, relief, slope, tidal current (nearshore), bottom temperature and substrate define the benthic ranges (AXYS 2001). Both the original and update BC MEC systems are discussed in section 3 below.

Fisheries and Oceans Canada is currently working on a national initiative to divide Canada's oceans into EcoRegions using strictly scientific criteria. It is not known when this project will be completed. There is also a project (still in its formative stages) to apply a benthic habitat mapping model using GIS as has been done by Natural Resources Canada and DFO in the east coast Maritimes region (Vladimir Kostylev personal communication). This project is somewhat unique for the Pacific Coast because it results in gradational or fuzzy boundaries on its benthic habitat map.

A Review of the British Columbia Marine Ecosystem Classification

The Province of British Columbia has done considerable work to classify BC's marine environment. The work has, however, come under criticism in two main areas: a lack of biological criteria, and questions concerning the scale/accuracy/resolution of the ecounit boundaries.

The BC Marine Ecosystem Classification (MEC) does not include any biological variables, nor does it reliably link the geophysical variables to biological communities (Levings and Jamieson 1999). Reasons given (Zacharias et al. 1998; Day and Roff 2000, Zacharias and Roff, 2000, 2001a) to explain why biological variables are not included in either the BC MEC, or in similar classification systems, are:

1. Biotic characteristics are, to a large degree, controlled by physical and chemical processes;
2. The influence of many biological processes such as predation and competition are often not well understood;
3. Human activities have altered the biological composition of marine systems to an extent that the natural state is difficult to characterise; and,
4. Physical and chemical data are more readily available at broad spatial scales and are easier to collect.

There are marine classification systems that consider biological as well as physical and chemical variables (e.g. Dethier 1990; Booth *et al*. 1998; Jamieson and Levings 2001; Ardron *et al*. 2002 unpublished report). Saloman *et al.* (2001) list many of the biotic characteristics and species interactions that cannot be described with physical variables, but which are important for the maintenance of biodiversity and thus the description of ecosystems. Examples include migratory patterns, optimal breeding sites and seasons, critical life-history stages, population and individual growth rates, specific habitat requirements, dispersal distances, and population response to low numbers and species interactions. One way to improve the biological reliability of the BC MEC would be to test how well it predicts biotic communities (Levings and Jamieson 1999). Some investigations of intertidal species distributions with respect to some of the BC MEC variables such as exposure, current, temperature and salinity have been conducted (Zacharias et al. 1999; Zacharias and Roff 2001b); however, these studies did not explicitly compare the distribution of biota with the ecounit or ecosection boundaries. As such, the biological relevance of the boundaries was not tested.

In the processes of modelling a network of marine protected areas for the Central Coast, Ardron *et al*. (unpublished report 2002) looked closely at the BC MEC ecounits as well as the data used to create them. Listed below are some of their suggested limitations of the BC MEC ecounits:

- Quality assurance tests of the model have never been performed in order to verify the scale of the classification. This is particularly important as some of the data layers used in the model cannot likely support the reported scale of 1:250,000;
- The method used to treat "slivers," or areas smaller than 15 km^2 is to eliminate them by aggregation with neighbouring polygons (Howes et al. 1997). This leads to a loss of information which is likely to be significant at this scale; and
- It is not clear exactly how the ecounits were created and how, in particular, the data layers were ordered during the amalgamation process. It does not appear that the layers were given any sort of hierarchical ordering. This is significant since different solutions with varying amounts of cumulative error will result from different orders.

For more detailed information, see Appendix 2 of Ardron *et al*. (unpublished report 2002).

As well, many of these limitations are inter-related and all affect the usefulness of the ecounits concept. The depth layer can be used as an example to demonstrate these inter-related problems. Bathymetry was divided into depth classes as follows: Photic (0-20 m), Shallow (20-200 m), Moderate (200-1000 m) and Abyssal (>1000 m). Photic areas are biologically important because the availability of sunlight makes them potentially highly productive. In an analysis of the number of the photic areas in the Central Coast, Ardron *et al*. (unpublished report 2002) found them to be a rarity according to the MEC classification. Further investigation revealed that most photic areas, which usually abut the shoreline, were often too small to appear at a scale of 1:250,000. In addition, small areas that did show up were often considered "slivers" that were subsequently swallowed up by neighbouring polygons during the amalgamation process (see map on p. 52 of Ardron *et al*. unpublished report 2002). In the BC MEC update, attempts were made to address this issue by revising the depth classes. The first three classes became; Shallow (0-20 m), Photic (20-50 m), Mid-depth (50-200 m). An analysis of the updated system has not yet been done, however, it is

probable that both the Shallow and Photic classes will be too small to appear at the mapping scale (Ardron *et al*. unpublished report 2002).
The changes promised in Zacharias *et al*. (1998) were made. While the original classification system has been reviewed by the Resource Inventory Committee (RIC) and published (Howes *et al.* 1997; Zacharias *et al*. 1998), the BC MEC update has yet to go through peer review. Higher levels in the classification hierarchy have also not yet been re-evaluated in light of the updated analysis. In addition, some of the limitations of the original BC MEC appear not to have been rectified in the update and some new methodological problems have been pointed out. For instance, the new data layers do not seem capable of supporting a mapping scale of 1:250,000. In an independent analysis of the BC MEC update, Ardron (2001 unpublished report) considered the data resolution, scale and spatial resolution of the ecounit boundary system and determined that the scale is somewhere between 1:4,000,000, and 1:29,000,000. Other problems associated with the increased complexity of the models concern the propagation of errors as described in Rastetter *et al*. (1992). Problems that still persist or that have been made worse through the increased complexity of the model are the removal of slivers and the consequent loss of information, and problems associated with the amalgamation of the data layers (Ardron 2001 unpublished report). Another major limitation of the update for the Central Coast in particular, concerns the coverage for the temperature, salinity and stratification data. For most of the Central Coast region, less than two samples per 100 km^2 are used (see Figures 12-14 in AXYS 2001). Data at this spatial accuracy are of questionable use.

Most of the above described limitations of the BC MEC ecounits relate to the mapping scale and to the level of accuracy of the classification. Despite the classification system's intended purposes (i.e. Zacharias and Howes 1998), it has been argued that the scale of the ecounits, even at 1:250,000, is insufficient for exercises such as planning Marine Protected Areas (Levings and Jamieson 1999, Ardron *et al.* unpublished report 2002). However, for the purpose of defining broad areas such as LOMA boundaries, use of the larger ecosection boundaries is reasonable, although they are based on physical parameters only. The finer scale ecounit boundaries should only be used with caution and would be best used with reference to the original data to ensure that their use is appropriate.

Watershed Boundaries

Figure 11 shows the BC Watershed Groups boundaries along with a line representing the "Coastal Divide". The watershed groups are a fine scale sub-division of watersheds and so certain watershed polygons consist of only a portion of one watershed, or include parts of more than one watershed. The boundaries are useful for defining landbased ecosystems so long as the hydrology (location and shape of drainage systems) which defines them is also used to guide the process. The "Coastal Divide" line is based on the coarser scale Nine Major BC Drainages (data from the Ministry of Sustainable Resource Management) and represents the division between waters that flow directly into the Pacific Ocean (excluding the Fraser River and those which flow through the Alaska panhandle), and those which flow inland.

Relevant Fisheries and Oceans Canada Boundaries

Figure 12 shows Fisheries and Oceans Canada's (DFO) Pacific Region Operational Areas and the Pacific Fisheries Management Areas, which are also called DFO Statistical Areas. The Operational Areas are the main management divisions of the Pacific Region. The landward boundaries of these areas coincide with watershed boundaries. The seaward boundaries appear to be restricted to a line labelled the 'surfline'. The Statistical Areas are simply a straight line polygonal division of the ocean into numbered areas which can be used for fisheries management. The marine portions of these boundaries are examples of management-based rather than ecosystem-based boundaries.

Provincial Planning Boundaries

Figure 13 shows the Land and Coastal Resource Management Plan (LCRMP) boundaries. The landward boundaries of the Central Coast LCRMP areas are similar to the DFO Operational Areas and, with a few exceptions, appear to be based on BC Watershed Group boundaries.

First Nations Land Claims Statement of Intent Boundaries

Figure 14 shows the boundaries of the land and ocean claimed by those First Nations bands within the Central Coast Area that have entered the treaty process. These boundaries can be useful in this process as some traditional land boundaries are believed to coincide with boundaries of ecological or physiographic significance. In many cases the boundaries appear to follow 'height of land' or watershed boundaries and therefore often coincide with the proposed CCIM landward boundary.

Proposed Central Coast Integrated Management Plan Large Ocean Management Area Boundary

The proposed CCIM boundary is shown in Figures 1 and 15. The following paragraphs describe in detail the source of, and reasoning behind, each proposed modification of the CCIM boundary.

Marine Boundary

The basic CCIM Area, as defined by the working boundary, roughly corresponds to three of the twelve BC MEC ecosections: Queen Charlotte Sound, Queen Charlotte Strait, and Johnstone Strait. Portions of the Vancouver Island Shelf, Continental Slope, and North Coast Fjords ecosections are included as well (Figure 9).

Taking the initial broad area as defined by the working boundary (Figure 1), the task remains to propose fine scale modifications where scientific information warrants the change. Given that a poor boundary is one where there is no clear or recognizable difference between the water/habitat on either side, a good boundary must be one for which there is some recognized difference on either side of the boundary. The marine realm is changeable and diffuse making a line boundary difficult to define. For this reason, criteria were searched for which are reasonably consistent through time (i.e. not seasonal or short lived) and can be found to provide a relatively sharp change. Bathymetry and substrate type are both features that are consistent through time and in some cases change suddenly. These features are commonly used by other habitat and ecosystem classification systems and are recognized as having implications for associated physical and biological changes (e.g. Day and Roff 2000, IMCRA 1998, Fader et al. 2000, Bax et al. 1999). For example, many organisms are limited to the photic zone of the ocean, thus it can be expected that a shallow shelf system would differ significantly from that of a deep trough. A number of scientific studies have also shown that benthic organisms can often be associated with certain substrate types (e.g. Bax *et al.* 1999, Kostylev *et al.* 2001). Due to the availability of bathymetric and some substrate data, and their clear applicability to physical habitat definition, these criteria were the first to be considered in the boundary modifications discussed below, followed by other available scientific information for that area (see table in introduction). We used the BC MEC ecounit boundaries only where a boundary connection was needed and no other scientific information was available, or when available scientific data supported the ecounit boundary.

Western boundary (base of continental slope)

The westernmost (seaward) boundary of the CCIM Area was modified from the ecosection boundary which defined the top and bottom of the continental shelf slope at 200m and 1000m depths respectively. It was deemed that the CCIM Area ought to include the shelf slope as that feature best defined the difference between the abyssal plain of the open ocean and the shallower waters bounding continents. Furthermore, some species of groundfish are caught both on the shelf and the slope, while fish species found in the deep ocean are quite different.

Instead of choosing an approximation of the slope base by choosing a depth contour, we contracted a GIS analyst to perform a slope analysis to define the base of the slope in detail. The methodology of this analysis is described in Appendix 2 and the Central Coast portion of the line is shown in Figure 16. Although this line is limited by bathymetry data quality and the assumptions and judgements required in the analysis (Ardron, personal communication 2003), we consider this line to be a significant improvement over previous boundary systems, which used an arbitrarily chosen bathymetry line to approximate the base of the slope.

Northern marine boundary (Moresby Trough)

The northern marine portion of the CCIM working boundary is based on DFO statistical area polygons and is thus purely management based. The northern boundary of the BC MEC Queen Charlotte Sound ecosection consists of a large bulge into Hecate Strait (Figure 9). This boundary shape is supported by similar features in previous ecosystem boundaries (Figures 5 - 8). However, three pieces of information were used to suggest that a better boundary lies along the northern edge of Moresby Trough.

Firstly, bathymetry was considered, along with its effect on currents and water bodies. Hecate Strait is often described as being made up of two areas; the relatively flat and shallow Laskeek and Dogfish Banks, and the steep sided, deep, Moresby Trough (Figure 15). This difference in water depth and morphology is reflected in the physical oceanography. Figure 17a shows that the strongest northward surface current in winter occurs over the northern portion of Moresby Trough. Meanwhile, a portion of the general northward current through Queen Charlotte Sound curves around North Bank and forms a counter clockwise gyre which moves water south-westwards at the southern end of Moresby Trough. This gyre is thought to be important for retaining coastal waters and fish larvae within Hecate Strait and there is a correlation between high wind winters (when the gyre is less prevalent) and subsequent poor Pacific Cod recruitment years (Bill Crawford, personal communication). In the summer, the strongest surface current comes south off of Laskeek bank while a clockwise gyre is now formed around North Bank bringing waters northwards up the southern portion Moresby Trough before curving southwards where the trough narrows (Figure 17b). However, bottom temperature and salinity maps show that while surface waters are generally being drawn away from the coast in summer, cold, saline, nutrient rich, deep ocean waters move northwards towards the coast along the bottom of Moresby Trough (Figures 18 and 19). The significant upwelling area just west of Banks Island is likely fed by this bottom current. Tidal currents also show a significant difference between the two areas of Hecate Strait, being fast over the shallow banks and much slower over the deep troughs (Figures 20 and 21).

Secondly, the difference between the two areas is illustrated by a distinct difference in the substrate materials. This is likely a result of current speed differences between the two areas. It is clear from Figures 22-26 that the trough is dominated by finer sediments (clay, silt, and mud) which are not so prevalent on the shallow banks. The relatively distinct line of change shown by the finer sediments was used to define the northern boundary. This boundary line places all five of the known siliceous sponge reefs within the proposed CCIM Area. These sponge reefs are a unique form of biota that may support a significant biological community that includes groundfish rearing areas and refugia (Conway *et al.* 1991, Conway 1999, Jamieson and Chew 2002). The reefs are known to form at depths around 200m which places all of them in the troughs of the Queen Charlotte Sound (Figure 27).

Thirdly, biological assemblages differ between the two areas. Early work showed that trawls in the deeper Moresby Trough area caught a fish assemblage that was distinct from that caught over the banks (Fargo and Tyler 1991, 1992, Perry et al. 1994). Recent, unpublished multi-agency research involving work by Al Sinclair (DFO) and Vaughn Barrie (Natural Resources Canada), has shown a correlation between substrate type and the dominant species in trawl catch data (Al Sinclair, personal communication).

These three pieces of evidence all suggest that the northern edge of Moresby Trough (as defined by substrate type and depth) is a reasonable feature to be used to represent a distinct, sharp, and consistent change in the environment/habitat.

Connection: Moresby Trough to BC mainland

The only significant criteria found to guide the boundary in this area was the fact that Douglas Channel has a deep water connection to Camano Sound and then to Moresby Trough, which is part of the CCIM Area. Because the waters of Douglas Channel probably exchange almost exclusively with the CCIM Area, it was deemed logical that it should be included in the Area. Considering this, the most logical boundary would cross from the top of Banks Island east to the mainland, separating the narrow and restricted waterways of Principe, Petrel, and Grenville channels from the more open waters to the north. The waters to the north are also more influenced by freshwater, (i.e. the Skeena and the Nass Rivers) than the adjacent waters within the CCIM Area. The waters of the Strait of Georgia to the south are also heavily influenced by freshwater (the Fraser River). Thus, the CCIM Area is bracketed by significant watersheds while the waters within the CCIM Area are influenced by relatively small, steep watersheds.

There is little available information to guide the exact placement of this boundary, thus it could be considered more open to modification based on non-scientific criteria in the final definition of the CCIM Area boundary.

Connection: Brooks Peninsula to base of continental slope

The boundary at Brooks Peninsula was chosen based on currents and the distribution of biota (plankton, fish, and birds).

At the northern end of Vancouver Island, the proposed boundary differs from the Queen Charlotte Sound ecosection boundary, which follows the Scott Islands (Figure 9). Part of the rational for the BC MEC ecosection boundary is that the west coast of Vancouver Island has a greater freshwater influence than Queen Charlotte Sound due to the relatively warm and low salinity Coastal Buoyancy Current which flows northwards along the continental shelf off of Vancouver Island (Table 6, Figure 17a). However, recent information shows that this current generally curves away from Vancouver Island at the Brooks Peninsula in the summertime (Bill Crawford personal communication) as shown in Figure 17b. This causes horizontal transport of southern zooplankton species offshore. A more northern zooplankton community has been identified north of Brooks Peninsula (Moira Galbraith personal communication). These phenomena likely occur because Brooks Peninsula forms a significant barrier to water movements along the relatively wide continental shelf off the west coast of Vancouver Island (Figure 15). The biogeochemical provinces shown in Figure 3 appear to place a boundary at the tip of Vancouver Island. However, the scale of this analysis would likely prevent differentiation between the Island's tip and Brooks Peninsula. Considering the oceanographic and biological differences discussed above, it is likely that a finer scale version of the analysis would pick Brooks Peninsula as a biogeochemical boundary. Further investigation may find other ecological differences between waters to the north of Brooks Peninsula versus those to the south.

Ware and McFarlane (1989) investigated whether the physical oceanographic domains of Dodimead (1963) and Thomson (1981) would correspond to the known distribution of fish populations (Figure 4). Their research found that 50°N often formed the northern or southern boundary of common species. This latitude falls just south of Brooks Peninsula.

A further reason to keep the boundary out of the middle of the Scott Islands is that the island chain provides habitat for a number of organisms including colonial marine birds. These islands are the breeding and rearing area of almost all of BC's Horned and Tufted Puffins and the majority of BC's Cassin's Auklets, which make up 80% of the world's breeding population (Rodway 1991). The CCIM Area boundary should attempt to encompass a reasonable portion of the foraging area of the birds inhabiting the Scott Island colonies for both ecological and marine use planning reasons.

On a finer scale, there is little information to guide the exact location and shape of the boundary from the end of Brooks Peninsula to the base of the continental slope. Thus, the boundary was chosen to come as close as possible to existing DFO Statistical Area boundaries in order to facilitate the retrieval and use of fisheries data. The exact Statistical Area line was not followed in order to avoid bisecting Solander Island, another significant marine bird colony. The resulting boundary agrees well with the Nuu-chah-nulth Tribal Council SOI Boundary (Figure 14), which is also the boundary used for the West Coast Vancouver Island Aquatic Management Board. The land boundary which results from the marine boundary landing point, agrees well with the land boundary systems discussed below (DFO Management Areas and watershed boundaries). Thus, the division of the northern tip of Vancouver Island from the more southern portion of the West Coast of Vancouver Island has precedent in both land and marine boundary systems.

Johnstone Strait / Strait of Georgia boundary

Many boundary systems encompass Bute Inlet (and/or Toba Inlet) as part of Johnstone Strait, including the BC MEC ecosections (Figure 9), the Coastal Information Team boundary (Figure 28), and the DFO Central Coast Area (Figure 29). However, we present here some oceanographic reasons that argue against this.

Bute Inlet is a deep inlet at the northern end of Georgia Strait. The main deep water passage of the inlet is over a deep sill (370 m) in Calm Channel. From there, water passes through Sutil Channel and into the Strait of Georgia. Connection to the northern waters of Johnstone Strait is greatly limited by Johnstone Strait's shallow depth and narrow channels (Figure 30). A long term study (1957-2000) of several coastal inlets (Stucchi 2003), showed that Bute Inlet's deep waters more closely resemble the inlets of the Strait of Georgia, such as Jervis Inlet, than they do Knight Inlet to the north. Stucchi (2003) compared the long term trends of deep water properties in Bute, Jervis, and Knight Inlets. The data reveal higher mean temperatures, and lower salinity and oxygen levels and longer residence times in the southern inlets (Dario Stucchi personal communication). Thus, oceanographically, Bute Inlet should be grouped with the other Strait of Georgia inlets.

Substrate types and current speeds can further distinguish Johnstone Strait and the Strait of Georgia (Figure 30). The high speed tidal currents of the shallow, restricted Johnstone Strait act to scour the bottom, while the deeper and more open Strait of Georgia has lower tidal current speeds, which allows for the deposition of fine sediments(Figure 31). Thus, there is a clear change from a high energy, hard bottomed, shallow system, to a low energy, soft bottomed, deep system. Such an extreme, sharp, and consistent change makes this a logical location for a boundary.

Land Boundary

The land boundaries of the CCIM Area must include fresh water inputs and the activities affecting the quality and quantity of that water. Thus, the CCIM Area land boundaries are designed to capture the watersheds of all the rivers and streams emptying into its marine waters. In many cases, these watershed boundaries coincide with existing management area boundaries as described below. In order to connect the main landward boundary with the marine boundary, a few short connecting lines were also needed where no pre-existing boundary was available. In these cases hydrology and topography were used to find a local watershed line. Thus, all of the land boundary recommendations detailed below are based on watershed boundaries.

DFO Central Coast Area boundary

The pre-existing DFO Central Coast Area boundary can be used for the majority of the mainland and Vancouver Island land boundary (Figure 32). This boundary is used because it is based on watershed boundaries and a significant portion coincides with the Pacific 'coastal divide' (Figure29).

BC Central Coast Land and Coastal Resource Management Plan boundary

The southern portion of the mainland watershed-based boundary coincides with the provincial boundary for the Central Coast Land and Coastal Resource Management Plan (CCLCRMP) (Figure 32). This boundary is preferable to the DFO Central Coast Area boundary because it excludes the watershed of Bute Inlet (determined advisable in previous Johnstone Strait/Strait of Georgia boundary discussion).

BC Watershed Groups boundary

In areas where neither the provincial nor the federal watershed-based management boundaries were suitable, BC Watershed Groups boundaries were used as defined by data from the Ministry of Sustainable Resource Management.

Hand Digitised boundaries

Four short sections of land boundary were hand digitised to connect land boundaries with the exact landfall of the marine boundaries. These sections are at the western end of Brooks Peninsula, the mainland east of Grenville Channel, south of Campbell River on Vancouver Island, and at the mouth of Bute Inlet (Figure 32). In all four cases 1:50,000 topography and hydrology were used to define the boundary in such as way as to ensure that waters flowing into the CCIM marine area would be included and those not doing so would be excluded (e.g. mouth of Bute Inlet, Figure 33).

Conclusions

It was concluded:

- that scientific information is available to suggest modifications to the working boundary of the Central Coast Integrated Management Area.
- that these proposed changes do not represent the creation of ecosystem boundaries; rather they depict boundaries where there is some evidence for a distinct change in environmental conditions (habitat).
- that information on bathymetry and, to a limited extent, on substrate are readily available and provide a good indication of areas where there is a consistent and sharp change in environmental conditions.
- that the proposed boundary changes (Figure 1) be considered in the final development of a Central Coast LOMA boundary, along with other factors such as management, economic, and social concerns.

References

Ardron, J.A., J. Lash, and D.R. Haggarty. 2002. Modelling a Network of Marine Protected Areas for the Central Coast of British Columbia. Version 3.1. July 2002. Living Oceans Society. Sointula, B.C. (http://www.livingoceans.org/library.htm).

Ardron, J.A. 2001. Review of B.C. Classification Update Final Report. Part 1: Issues of scale, Resolution, and Accuracy. Unpublished Report. Living Oceans Society, Sointula, B.C. jardron@livingoceans.org.

AXYS Environmental. 2000. British Columbia Marine Ecounit Classification Update: Methods Options. Submitted to BC Land Use Coordination Office, Victoria, BC. 46 p.

AXYS Environmental 2001. British Columbia Marine Ecounit Classification Update: Final Report. Submitted to: Ministry of Sustainable Resource Management, Victoria. 33 p.

Bax, N, Kloser, R, Williams, A, Gowlett-Holmes, K, and Ryan, T 1999. Seafloor Habitat Definition for Spatial Management in Fisheries: A Case Study on the Continental Shelf of Southeast Australia. Oceanologica Acta **22**: 705-719.

Booth, J., Coastal and Oceans Resources Inc., Clover point Cartographics, 1998. Study to identify preliminary representative areas in the Queen Charlotte Sound Marine Region. Report prepared for National Parks, Parks Canada, Canadian Heritage.

Breeze, H, Fenton, D. G, Rutherford, R. J, and Silva, M. A. 2002. The Scotian Shelf: An Ecological Overview for Ocean Planning. Canadian Technical Report of Fisheries and Aquatic Sciences. 2393 1-259.

Clark, J.R. 1996. Coastal Zone Management Handbook. CRC Press. New York. 694 p.

Conway, K. W, Barrie, J. V, Austin, W. C, and Luternauer, J. L. 1991. Holocene Sponge Bioherms on the Western Canadian Continental Shelf. Continental Shelf Research. No.8-10(11). 771-790.

Conway, K. W. 1999. Hexactinellid Sponge Reefs on the British Columbia Continental Shelf: Geological and Biological Structure with a Perspective on their Role in the Shelf Ecosystem. Canadian Stock Assessment Secretariat Research Document. (99/192). http://www.dfo-mpo.gc.ca/csas/CSAS/English/Publications/Research_Doc_e.htm.

Crawford, W.R., M.J. Woodward, M.G.G. Foreman, and R.E. Thomson. 1995. Oceanographic features of Hecate Strait and Queen Charlotte Sound in Summer. Atmosphere-Ocean 33(4): 639-681.

Day, J. and J.C. Roff. 2000. Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans. Report prepared for World Wildlife Fund Canada, Toronto. www.wwf.ca/MPA_planning/.

De Young, B., R.M. Peterman, A.R. Dobell, E. Pinkerton, Y. Breton, A.T. Charles, M.J. Fogarty, G.R. Munro, C.T. Taggart. 1999. Canadian Marine Fisheries in a Changing and Uncertain World. Can. Spec. Publ. Fish. Aquat. Sci. 129. 199 p.

Dethier, M.N. 1990. A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Dept. Natural Resources. Olympia, Wa. 56 p.

Dodimead, A. J., Favourite, F., and Hirano, T. 1963. Salmon of the North Pacific Ocean – Part II. Review of oceanography of the subarctic Pacific region. International North Pacific Fisheries Commission Bulletin. 13: 195p.

Fader, G. B. J, Pickrill, R. A, Todd, B. J, Courtney, R. C, and Parrott, D. R. 2000. The Emerging Role of Marine Geology in Benthic Ecology. Science Review 1996 and 1997 Bedford Institute of Oceanography, Gulf Fisheries Centre, Halifax Fisheries Research Laboratory, St.Andrews Biological Station. Maritimes Region of the Department of Fisheries and Oceans Canada, Science Review. 1-9.

Fargo, J. and A.V. Tyler. 1991. Sustainability of flatfish-dominated fish assemblages in Hecate Strait, British Columbia, Canada. Netherlands Journal of Sea Research. 27 (3/4): 237-253.

Fargo, J. and A.V. Tyler. 1992. Statistical testing of research trawl data with implications for survey design. Netherlands Journal of Sea Research. 29 (1-3): 97-108.

Favorite, F., Dodimead, A. J., and Nasu, K. 1976. Oceanography of the subarctic Pacific region, 1960-71. International North Pacific Fisheries Commission Bulletin. 33: 187p.

Fisheries and Oceans Canada. 2002. Canada's Oceans Strategy: Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada. Oceans Directorate, Ottawa, Ontario. (http://www.cos-soc.gc.ca/doc/pdf/IM_e.pdf).

Foreman, M.G.G., R.F. Henry, R.A. Walters, and V.A. Ballantyne. 1993. A finite element model for tides and resonance along the north coast of British Columbia. Journal of Geophysical Research 98: 2509-2531.

Harding, L. and H. Hivonen. 1996. A marine ecosystem classification system for Canada. *In* Proceedings, Marine Ecosystem Monitoring Network Workshop, Nanaimo, B.C., March 28-30, 1995. *Eds*. D.E. Hay, R.D. Waters, and T.A. Boxwell. Can. Tech. Rep. Fish. Aquat. Sci. 2108: 160 p.

Harding, L., H. Hirvonen, and J. Landucci. 1994. Marine ecological classification system for Canada. Environment Canada Marine Environmental Quality Advisory Group (MEQAG). 21 p.

Harper, J.R., J. Christian, W.E. Cross, R. Frith, G. Searing, and D. Thomson. 1992. Draft report: Canadian marine region status and trends monitoring network. Coastal and Ocean Resources Inc., Sidney, B.C., 66 p.

Harper, J.R., J. Christian, W.E. Cross, R. Frith, G. Searing, and D. Thomson. 1993. A classification of the marine regions of Canada: Final Report. Coastal and Ocean Resources Inc. Sidney, B.C., 77 p.

Harper, J.R., G.A. Robillard, and J. Lathrop. 1983. Marine Regions of Canada: Framework for Canada's System of National Marine Parks. For parks Canada. Woodward-Clyde Consultants, Victoria, B.C.

Hempel, G. and Sherman K. 2003. Large Marine Ecosystems of the World: Trends in Exploitation, Protection, and Research. Volume 12 in the Large Marine Ecosystems Series. Elsevier. Amsterdam, the Netherlands. 423p.

Howes, D.E., M.A. Zacharias, and J.R. Harper. 1997. British Columbia Marine Ecological Classification: Marine Ecosections and Ecounits. For the Resource Inventory Committee, Coastal Task Force. (http://www.for.gov.bc.ca/ric/pubs/coastal/marine/).

IMCRA (Interim Marine and Coastal Regionalization for Australia Technical Group). 1998. Interim marine and Coastal Regionalisation for Australia: an ecosystem based classification for marine and coastal environments. Version 3.3. Environment Australia, Commonwealth Department of the Environment. Canberra. 102p.

Jamieson, G.S. and L. Chew. 2002. Hexactinellid sponge reefs: Areas of Interest as Marine Protected Areas in the North and Central Coast Areas. Pacific. DFO Canadian Science Advisory Secretariat. Research Document 2002/122. (http://sci.info.pac.dfo.ca/PSARC/resdocs/02-habitat.htm).

Jamieson, G.S. and C.D. Levings. 2001. Marine protected areas in Canada-implications for both conservation and fisheries. Can. J. Fish. Aquat. Sci. 58: 138-156.

Kostylev, V. E, Todd, B. J, Fader, G. B. J, Courtney, R. C, Cameron, G. D. M, and Pickrill, R. A 2001. Benthic Habitat Mapping on the Scotian Shelf Based on Multibeam Bathymetry, Surficial Geology and Sea Floor Photographs. Marine Ecology Progress Series **219**: 121-137.

Levings, C.D. and G.S. Jamieson. 1999. Evaluation of ecological criteria for selecting MPAs in the Pacific region: A proposed semi-quantitative approach. Canadian Stock Assessment Secretariat Research Document. 99/210.

Longhurst, A. 1995. Seasonal cycles of pelagic production and consumption. Progress in Oceanography. 36: 77-167.

Longhurst, A. 1998. Ecological Geography of the Sea. Academic Press, San Diego, California. 398p.

Paish, H. and Associates Ltd., 1970. The Canadian marine environment as a national park theme: a reconnaissance study. Unpublished report, Vancouver B.C., to Dept. Indian and Northern Development, National and Historic Parks Branch, Ottawa. 43 p.

Parks Canada, 1979. Parks Canada Policy. Parks Canada, Environment Canada. Ottawa, 69 p.

Pauly D., Christensen, V., Froese, R., Longhurst, A., Platt, T., Sathyendranath, S., Sherman, K., and Watson, R. 2000. Mapping fisheries onto marine ecosystems: a consensus approach for regional, oceanic and global integrations. ICES 2000 Annual Science Conference. Theme session on classification and mapping of marine habitats – CM 2000/T:14. 16p.

Perry, R.I., M. Stocker, and J. Fargo. 1994. Environmental effects on the distribution of groundfish in Hecate Strait, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 51: 1401-1409.

Platt, T. and Sathyendranath, S. 1988. Oceanic primary production: estimation by remote sensing at local and regional scales. Science. 241: 1613-1620.

Rastetter, E.B., A.W. King, B.J. Cosby, G.M. Hornberger, R.V. O'Neill, J.E. Hobbie. 1992. Aggregating fine-scale ecological knowledge to model coarser-scale attributes of ecosystems. Ecological Applications. 2(1) 55-70.

Rodway, M.S. 1991 Status and conservation of breeding seabirds in British Columbia. Pages 43-102 *In* Croxall, J.P. (ed.) Seabird status and conservation: a supplement. ICBP Technical Publication No. 11, Cambridge, U.K.

Saloman, A.K., J.L. Ruesink, B.X. Semmens, and R.T. Paine. 2001. Incorporating human and ecological communities in marine conservation: an alternative to Zacharias and Roff. Conservation Biology. 15(5): 1452-1455.

Stucchi, D. 2003. Long term trends of deep water properties of BC inlets. Institute of Oceans Sciences, Department of Fisheries and Oceans. http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/bcinlets/intro_e.htm. Last updated: 2003-01-16.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Can. Spec. Publ. Fish. Aquat. Sci. 56: 291 p.

Ware, D.M., and McFarlane, G.A. 1989. Fisheries production domains in the Northeast Pacific Ocean, pp. 359-379. *In* R.J. Beamish and G.A. McFarlane [eds.] Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Canadian Special Publication of Fisheries and Aquatic Sciences. 108.

Watson, J. 1998. A review of ecosystem classification: delineating the Strait of Georgia. *In* Approaches to Marine Ecosystem Delineation in the Strait of Georgia: Proceedings of a D.F.O. Workshop, Sidney, B.C., 4-5 November 1997. Eds. C.D. Levings, J.D. Pringle, F. Aitkens. Can. Tech. Rep. Fish. Aquat. Sci. 2247: 165 p. plus 83 p. diskette.

Watson, R., Pauly D., Christensen, V., Froese, R., Longhurst, A., Platt, T., Sathyendranath, S., Sherman, K., O'Reilly, J., and Celone, P. 2003. Mapping Fisheries onto Marine Ecosystems for Regional, Oceanic and Global Integrations. pp. 375-395 *In* Large Marine Ecosystems of the World. K. Sherman and G. Hempel [Eds.] Elsevier.

Zacharias, M.A., D.E. Howes. 1998. An analysis of marine protected areas in British Columbia, Canada, using a marine ecological classification. Natural Areas Journal. 18: 4-13.

Zacharias, M.A., D.E. Howes, J.R. Harper, and P. Wainwright. 1998. The British Columbia Marine Ecosystem Classification: Rationale, Development, and Verification. Coastal Management, 26:105-124.

Zacharias, M.A., M.C. Morris, and D.E. Howes. 1999. Large scale characterization of intertidal communities using a predictive model. Journal of Experimental Marine Biology and Ecology. 239: 223-242.

Zacharias, M.A. and J.C. Roff. 2000. A hierarchical ecological approach to conserving marine biodiversity. Conservation Biology. 14(5): 1327-1334.

Zacharias, M.A. and J.C. Roff. 2001a. Zacharias and Roff vs. Saloman et al.: who adds more value to marine conservation efforts? Conservation Biology. 15(5): 1456-1458.

Zacharias, M.A. and J.C. Roff. 2001b. Explanations of patterns of intertidal diversity at regional scales. Journal of Biogeography. 28: 1-13.

Personal Communications

Ardron, Jeff. GIS Manager, Living Oceans Society, and member of Coast Information Team. Box 755 Salt Spring Island, BC, V8K 2W3.

Crawford, Bill. Discussions around BC coastal currents and Central Coast boundaries. Institute of Ocean Sciences.

Galbraith, Moira. 101-2527 Quadra St., Victoria, BC. V8T 4E1.

Stucchi, Dario. Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC. V8L 4B2.

Kostylev, Vladimir. Bedford Institute of Oceanography, Natural Resources Canada Atlantic, Bedford, NS.

GIS Data Sources

- Ardron 2003. Base of Continental Slope. Prepared for DFO using GIS Analysis as described in Appendix 2.
- CIT (Coast Information Team). 2002. Boundary of the Coast Information Team Study Area. http://www.citbc.org/
- Fisheries and Oceans Canada. 1999a. DFO Pacific Region Operation Areas.
- Fisheries and Oceans Canada. 1999b. Pacific Fisheries Management Area Boundaries, a.k.a. DFO Statistical Areas/Subareas.
- Indian and Northern Affairs. 2001. First Nation Statement of Intent Traditional Territory Boundaries.
- LUCO (B.C. Land Use Coordination Office). 1999. Boundaries of the Land and Coastal Resources Management Plan Areas.
- LUCO (B.C. Land Use Coordination Office). 1998. British Columbia Marine Ecological Classification: Marine Ecosections and Ecounits.
- MSRM (Ministry of Sustainable Resource Management). 1998. Watershed Groups and Nine Major Drainages of BC. Captured from 1:50 000 NTS Mapsheets. FTP site at ftp://ftp.env.gov.bc.ca/dist/arcwhse/watershed_atlas/watershed_groups/
- NRCAN (Energy Mines and Resouces Canada). ~1960a. topographic contour lines based on 1:50 000 NTS sheets and put into BC Albers projection by BC MELP (Ministry of Environment, Lands and Parks).
- NRCAN (Energy Mines and Resouces Canada). ~1960b. hydrology based on 1:50 000 NTS sheets and put into BC Albers projection by BC MELP (Ministry of Environment, Lands and Parks).

Table 1: From ‘Classification of Pacific Margin Marine Realms’ (Harper et al. 1992).

1st Order	2nd Order	3rd Order	4th Order
Pacific (1.)	Subarctic Pacific (1.1)	(1.1.1)	(1.1.1.1)
	Temperate Pacific (1.2)	(1.2.1)	(1.2.1.1)
	Pacific Shelf (1.3)	Strait of Georgia / Puget Sound (1.3.1)	Johnstone Strait (1.3.1.1)
			Central Strait of Georgia (1.3.1.2)
			Juan de Fuca Strait (1.3.1.3)
		Dixon Entrance (1.3.2)	(1.3.2.1)
		Undifferentiated (1.3.3)	Mainland Fjords (1.3.3.1)
			Hecate Strait (1.3.3.2)
			Vancouver Island (1.3.3.3)
			Queen Charlotte Sound (1.3.3.4)

Table 2: From ‘A Classification of the Marine Regions of Canada’ (Harper et al. 1993).

Ecozones	Ecoprovinces	Ecoregions	Ecodistricts
Pacific	Subarctic Pacific	Subarctic Pacific	Subarctic Pacific
	Transitional Pacific	Transitional Pacific	Transitional Pacific
	Pacific Shelf	Strait of Georgia / Puget Sound	Johnstone Strait
			Central Strait of Georgia
			Juan de Fuca Strait
		Dixon Entrance	Dixon Entrance
		Pacific Marine Shelf	Mainland Fjords
			Hecate Strait
			Vancouver Island Shelf
			Queen Charlotte Sound

Table 3: From Marine Ecological Classification System for Canada (Harding et al. 1994).

Ecozones	Ecoprovinces	Ecoregions	Ecodistricts
Pacific	Northeast Pacific	Northeast Pacific	Northeast Pacific
	Transitional Pacific	Abyssal Plain	Abyssal Plain
		Continental Slope	Continental Slope
	Pacific Shelf	North Coast	Dixon Entrance
			Hecate Strait
			Queen Charlotte Sound
			Queen Charlotte Strait
			Vancouver Island Shelf
			Johnstone Strait
		Georgia Basin	Strait of Georgia
			Juan de Fuca Strait

Table 4: Hierarchy from 'British Columbia Marine Ecological Classification System' (Howes et al. 1997).

Ecozones	Ecoprovinces	Ecoregions	Ecosections
Pacific	Northeast Pacific	Northeast Pacific	Northeast Pacific
	Transitional Pacific	Abyssal Plain	Abyssal Plain
		Continental Slope	Continental Slope
	Pacific Shelf	North Coast	Dixon Entrance
			Hecate Strait
			Queen Charlotte Sound
			Queen Charlotte Strait
			Vancouver Island Shelf
			Johnstone Strait
		Georgia Basin	Strait of Georgia
			Juan de Fuca Strait

Table 5: Ecosection (or ecodistrict) features (Watson 1998 modified after Harding and Hirvonen 1996, Harper et al. 1993, and Howes et al. 1997).

Marine Ecosections	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rational
Johnstone Strait	Narrow, constricted channels.	Protected coastal waters with strong currents; well-mixed, poorly stratified.	Migratory corridor for anadromous fish; rich sessile, hard substrate invertebrate community; diverse species assemblage of benthic fish.	Johnstone Strait has greater mixing and more channels than areas to south; Queen Charlotte Strait is more marine.
Continental Slope	Steep sloping shelf.	Strong across slope and downslope turbidity currents.	Upwelling zone; productive coastal plankton communities and unique assemblages of benthic species.	Transitional area between continental shelf and abyssal plane.
Dixon Entrance	Across-shelf trough with depths mostly < 300m; surrounded by low-lying coastal plains (Hecate Depression).	Strong freshwater influence from mainland river runoff drives north-westward flowing coastal buoyancy current and estuarine-like circulation.	Mixture of neritic and subpolar plankton species; migratory corridor for Pacific salmon; some productive and protected area for juvenile fish and invertebrate development.	Distinguished from area to south by strong freshwater discharge influence.
Strait of Georgia	Broad shallow basin surrounded by coastal lowlands (Georgia Depression).	Protected coastal waters with significant freshwater input, high turbidity and seasonally stratified; very warm in summer.	Nursery area for salmon, herring; abundant shellfish habitat; neritic plankton community.	Stronger Fraser River signature than areas to north or west.
Juan de Fuca Strait	Deep trough; a major structural feature accentuated by glacial scour.	Semi-protected coastal waters with strong “estuarine-like” outflow current (coast-hugging buoyancy current to north); Major water exchange conduit with “inland sea”	Migratory corridor for anadromous fish; moderately productive; mixture of neritic and oceanic plankton species.	Much more marine than Strait of Georgia; less “open shelf” than Vancouver Isl. Shelf.
Queen Charlotte Strait	Predominantly shallow (<200m), high relief area with deeper fjord areas.	High current and high relief area; very well mixed; moderate to high salinities with some freshwater inputs in the inlets and fjords.	Very important for marine mammals; migratory corridor for anadromous fish; moderate shellfish habitat.	More marine than Johnstone Strait; much more shallow with high relief and high currents than Queen Charlotte Sound.
North Coast Fjords	Deep, narrow fjords cutting into high coastal relief.	Very protected waters with restricted circulation and often strongly stratified.	Low species diversity and productivity due to poor water exchange and nutrient depletion; unique species assemblages in benthic and plankton communities.	Unique physiography and stratification compared to bordering surrounding regions.

Table 5: Cont.

Marine Ecosections	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rational
Hecate Strait	Very shallow strait dominated by coarse bottom sediments; surrounding coastal lowlands.	Semi-protected waters with strong tidal currents that promote mixing; dominantly “marine” waters.	Neritic plankton communities with some oceanic intrusion; nursery area for salmon and herring; abundant benthic invertebrate stocks; feeding grounds for marine mammals and birds.	Marine in nature but much shallower, with associated greater mixing, than areas to the south.
Subarctic Pacific	Includes abyssal plain and continental rise; a major transform fault occurs along the west margin and a seamount chain trends NW/SE.	The eastward flowing subarctic current bifurcates at coast with northerly flowing Alaska Current; current flow is generally northward throughout the year.	Summer feeding ground for Pacific salmon stocks; abundance of pomfret, Pacific saury, albacore tuna and kack mackerel in summer, boreal plankton community.	The northern and western boundaries are undefined. The eastern boundary is coincident with the continental rise. The southern boundary is indistinct but is meant to be located.
Queen Charlotte Sound	Wide, deep shelf characterised by several large banks and inter-bank channels.	Ocean wave exposures with depths mostly >200m and dominated by oceanic water intrusions.	Mixture of neritic and oceanic plankton communities; northern limit for many temperate fish species; lower benthic production.	More oceanic (deep) and marine than Vancouver Island Shelf and Hecate Strait.
Transitional Pacific	Includes abyssal plain, and continental rise; also includes spreading ridges, transform faults, triple junction and plate subduction zone.	Area of variable currents; southerly areas may be affected by southward flowing California Current in summer but remainder of area characterised by weak and variable currents; Davidson Current along shelf edge flows north in winter, south in summer.	Transition zone between southerly, temperate, and northerly boreal plankton communities; mixing of oceanic and coastal plankton communities adjacent to the coastal shelf.	The northern boundary is indistinct and approximately coincident with the southern limit of the Alaskan Current (winter). The eastern boundary is at the continental rise. The southern and western boundaries are undefined.
Vancouver Island Shelf	Narrow, gently sloping shelf.	Open coast with oceanic wave exposures; northward, coast-hugging buoyancy current due to freshwater influence; seasonal upwelling at outer margin	Highly productive with neritic plankton community; northern limit for hake, sardine, northern anchovy, and Pacific mackerel; productive benthic community; rich fishing grounds for benthic fish and invertebrates.	More open shelf than Juan de Fuca Strait; more freshwater influence (coastal buoyancy current) than Queen Charlotte Sound.

<u>Appendix 1</u>

Figures for the

Proposed Central Coast Integrated Management Plan Area Boundary

Table of Figures

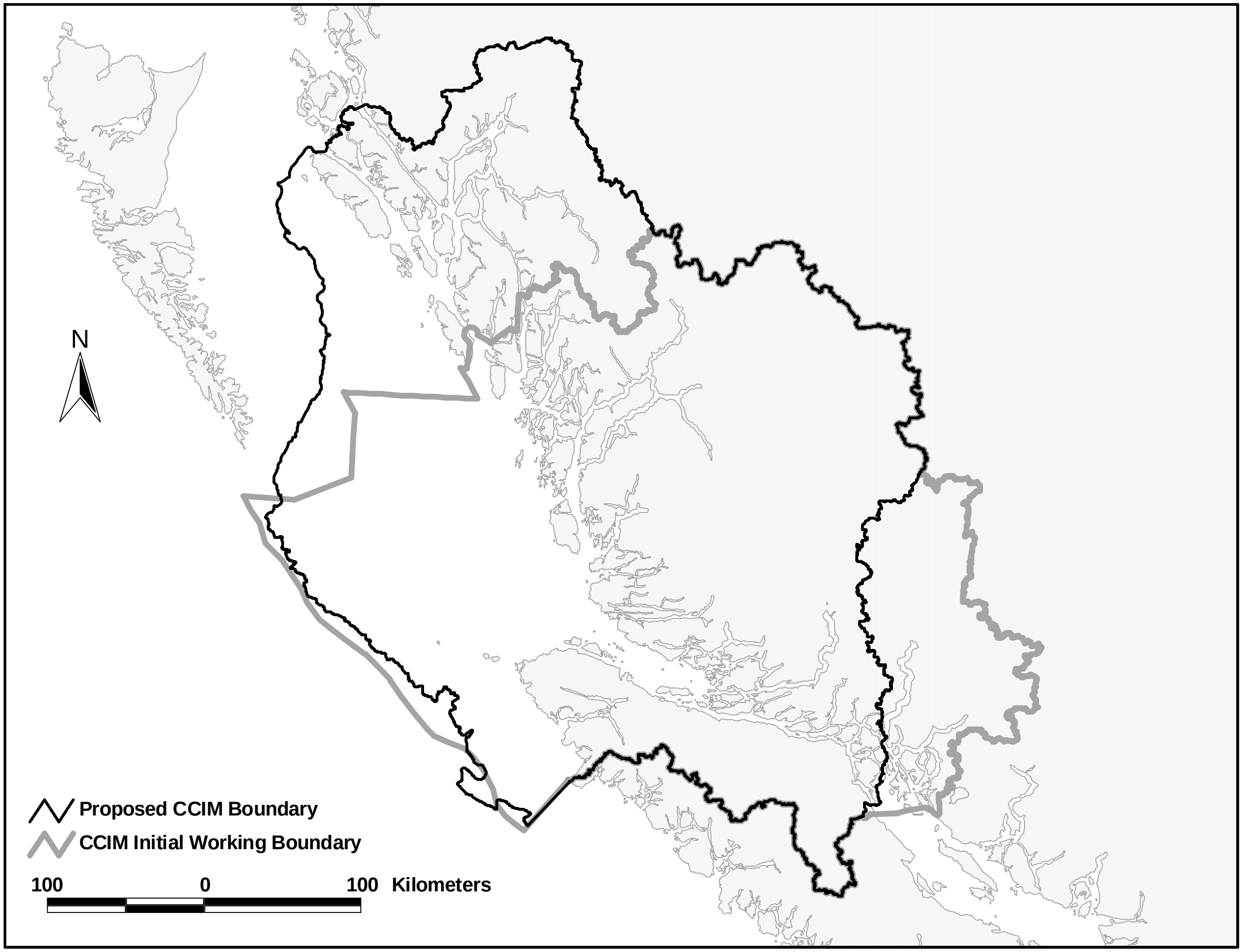

Figure 1. Map showing the initial CCIM Working Boundary and the Proposed Modified Boundary.

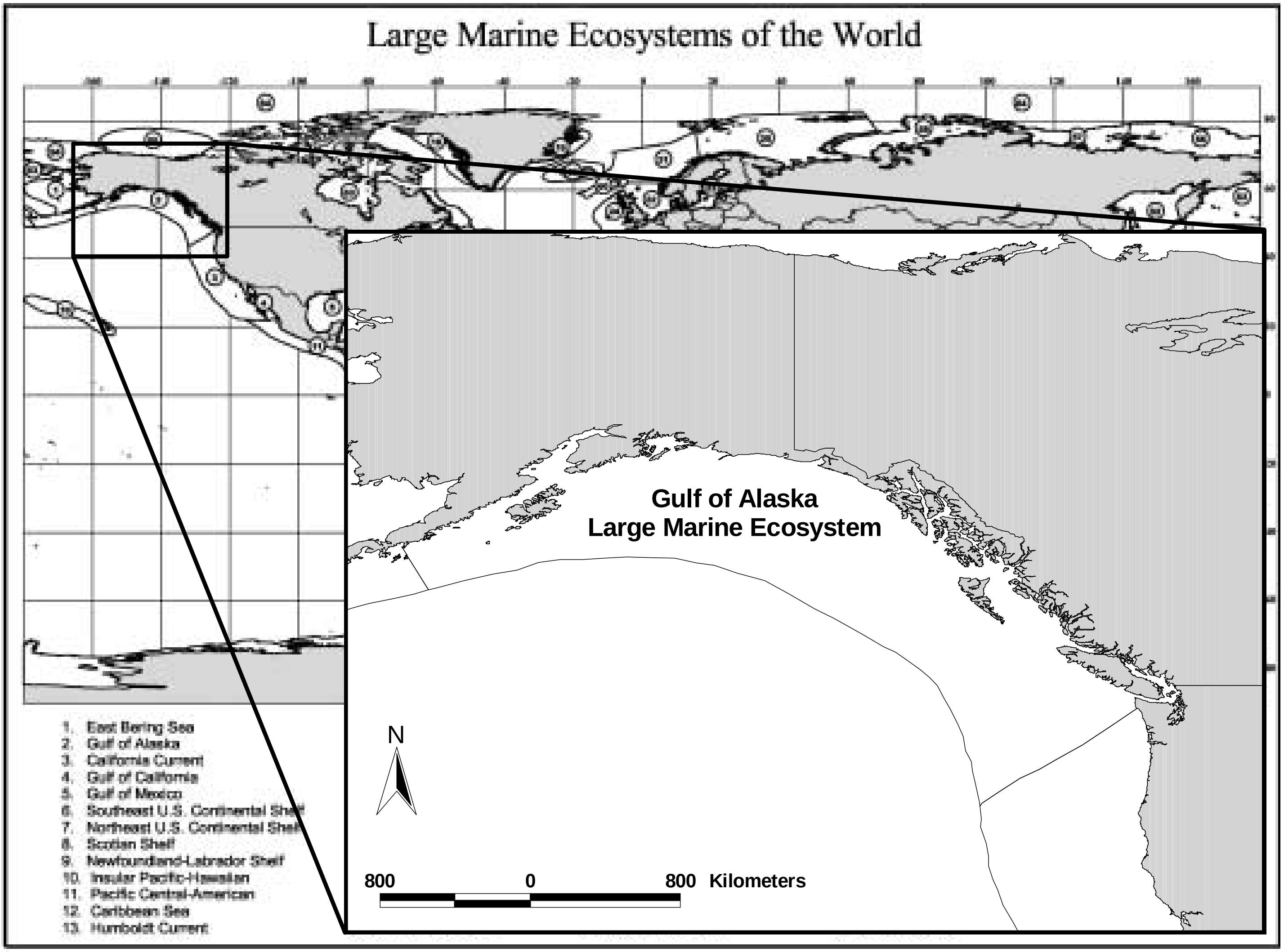

Figure 2. Map of the 64 Large Marine Ecosystems of the world with inset detail of the Gulf of Alaska LME (data and image from http://www.edc.uri.edu/lme/).

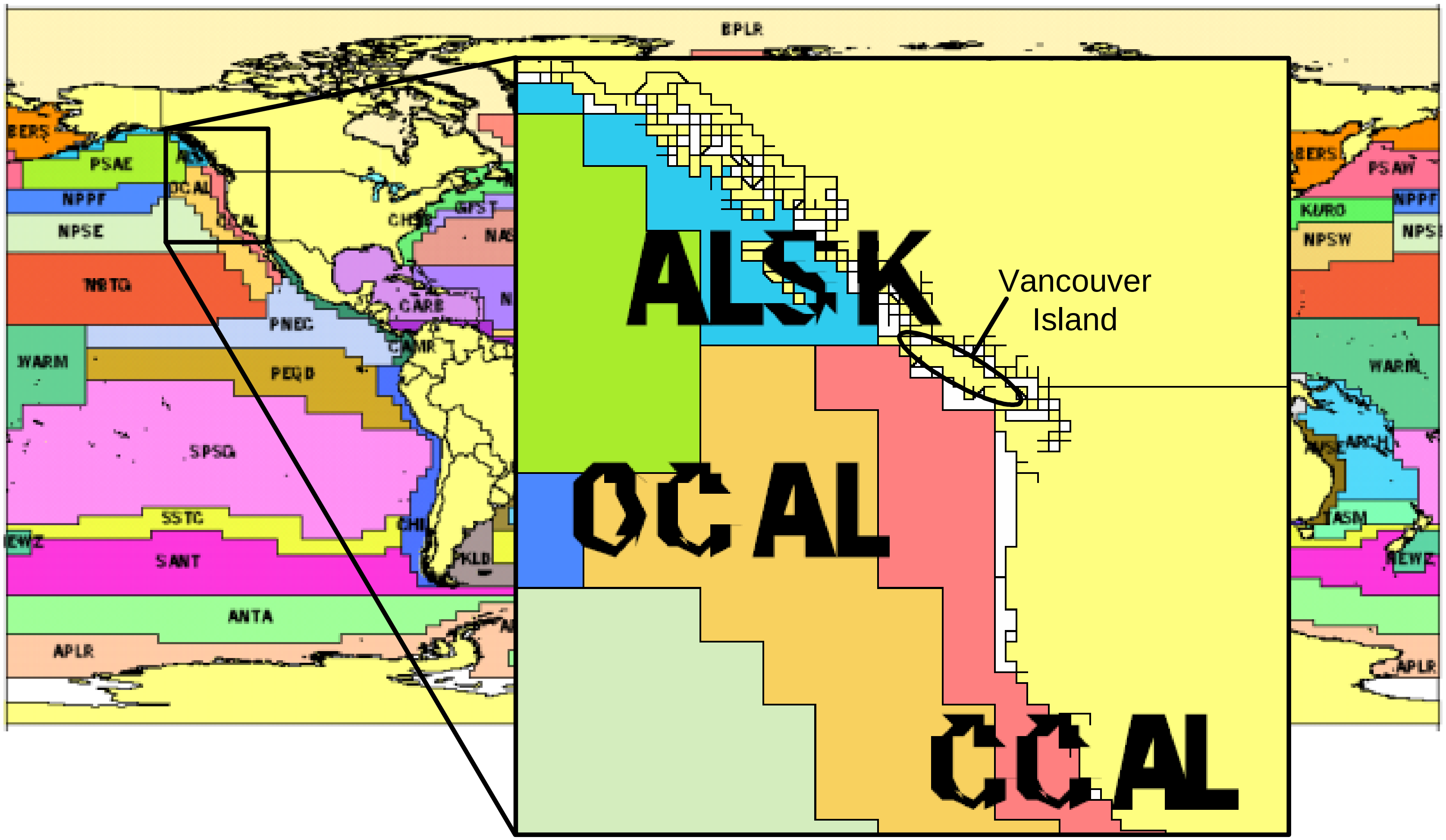

Figure 3. Map of the 57 biogeochemical provinces of the world with inset detail of the provinces found in the coastal waters of BC, Washington and Alaska (image from Pauly et al 2000).

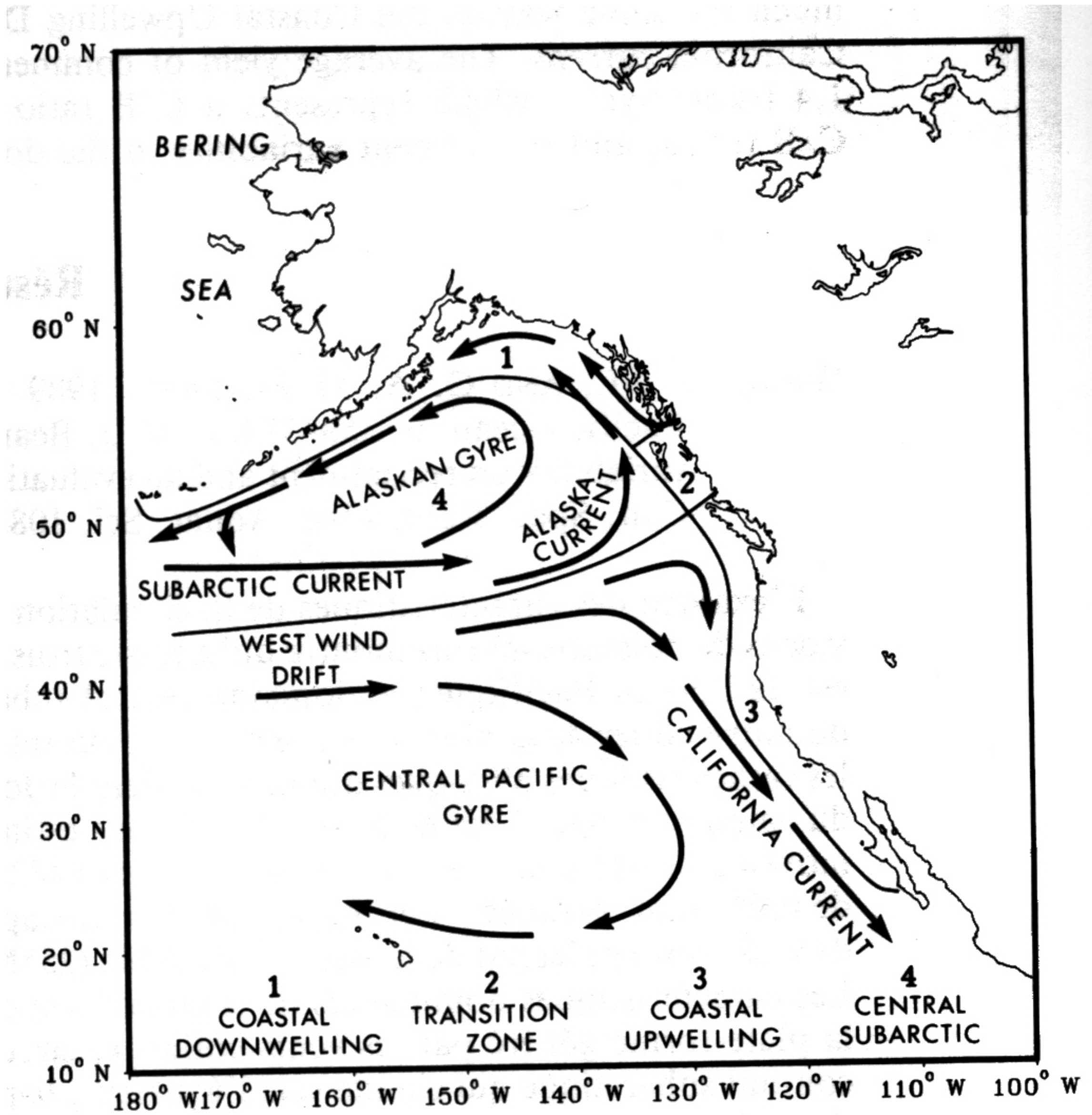

Figure 4. Approximate areas of oceanic domains and prevailing current directions in the Northeast Pacific Ocean (from Ware and Mcfarlane 1989, modified after Favorite et al. 1976, and Thomson 1981)

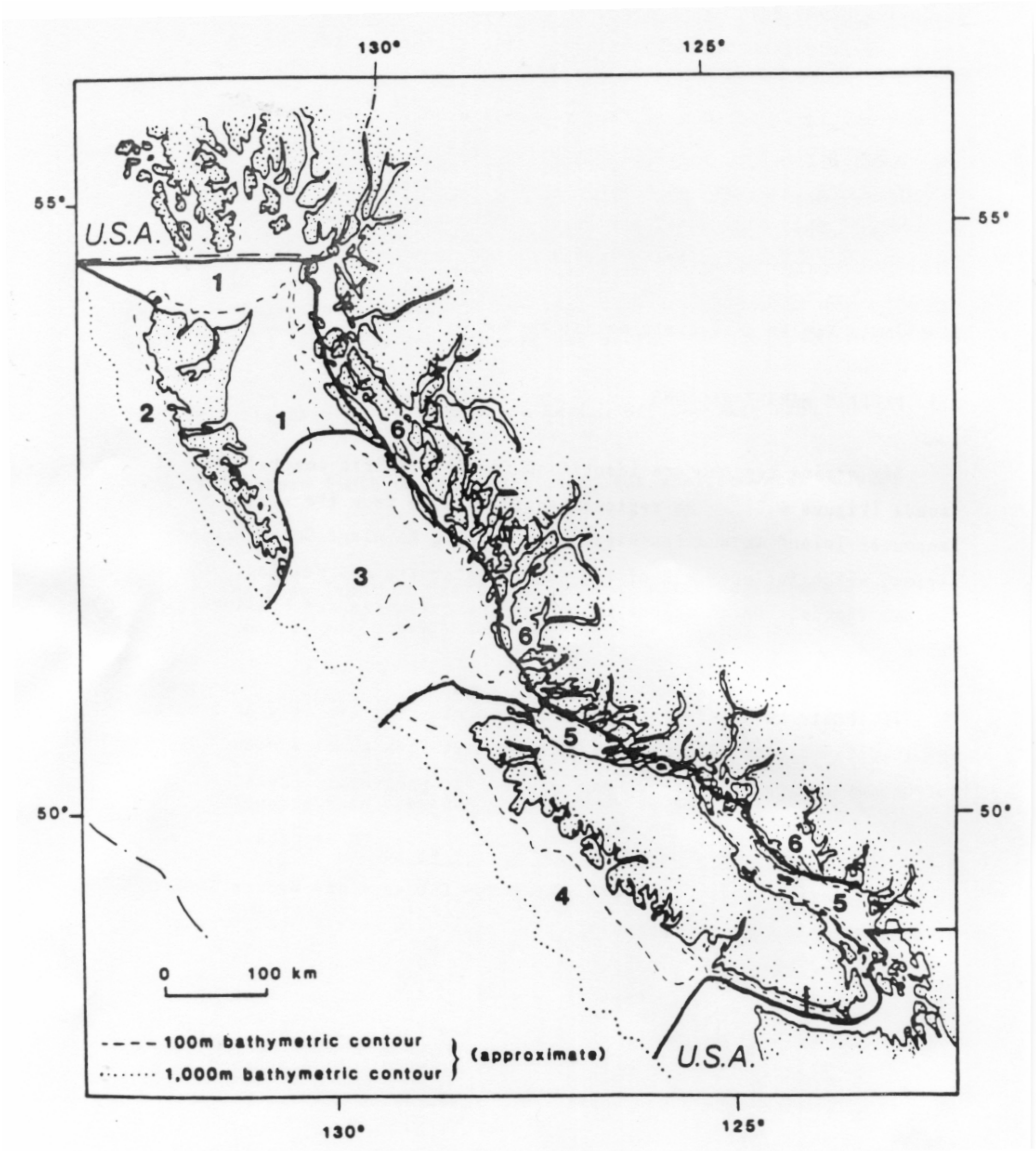

Figure 5. The Marine Regions of the Pacific Coast as defined by Harper et al. (1983). The Marine Regions are:

1. Dixon Entrance – Hecate Strait;
2. Western Queen Charlotte Islands
3. Queen Charlotte Sound
4. Vancouver Island Shelf]
5. Vancouver Island Inland Sea
6. Pacific Mainland Coast.

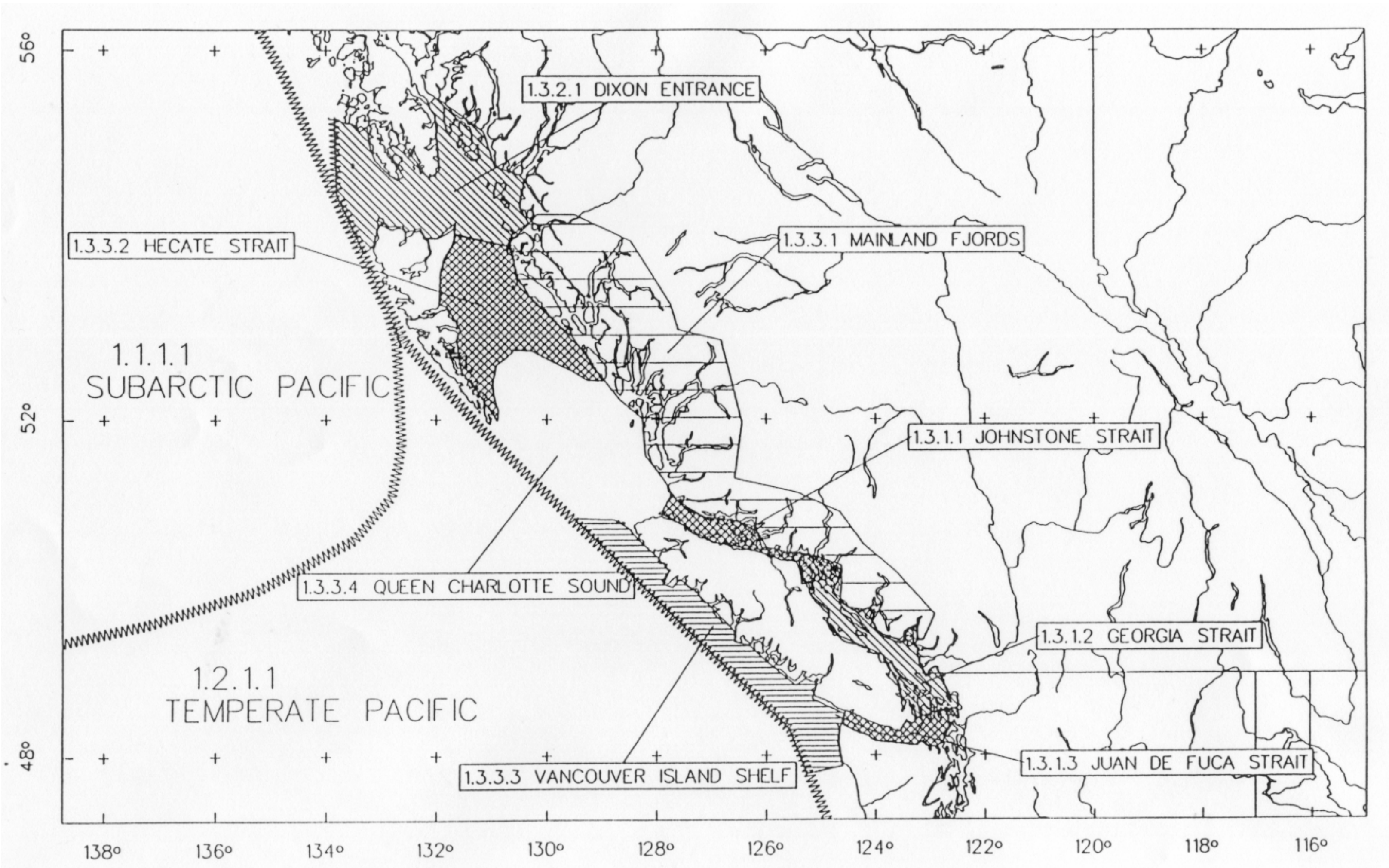

Figure 6. 4th Order subdivision of the Pacific coast showing the 10 Marine Realms defined by Harper et al. (1992).

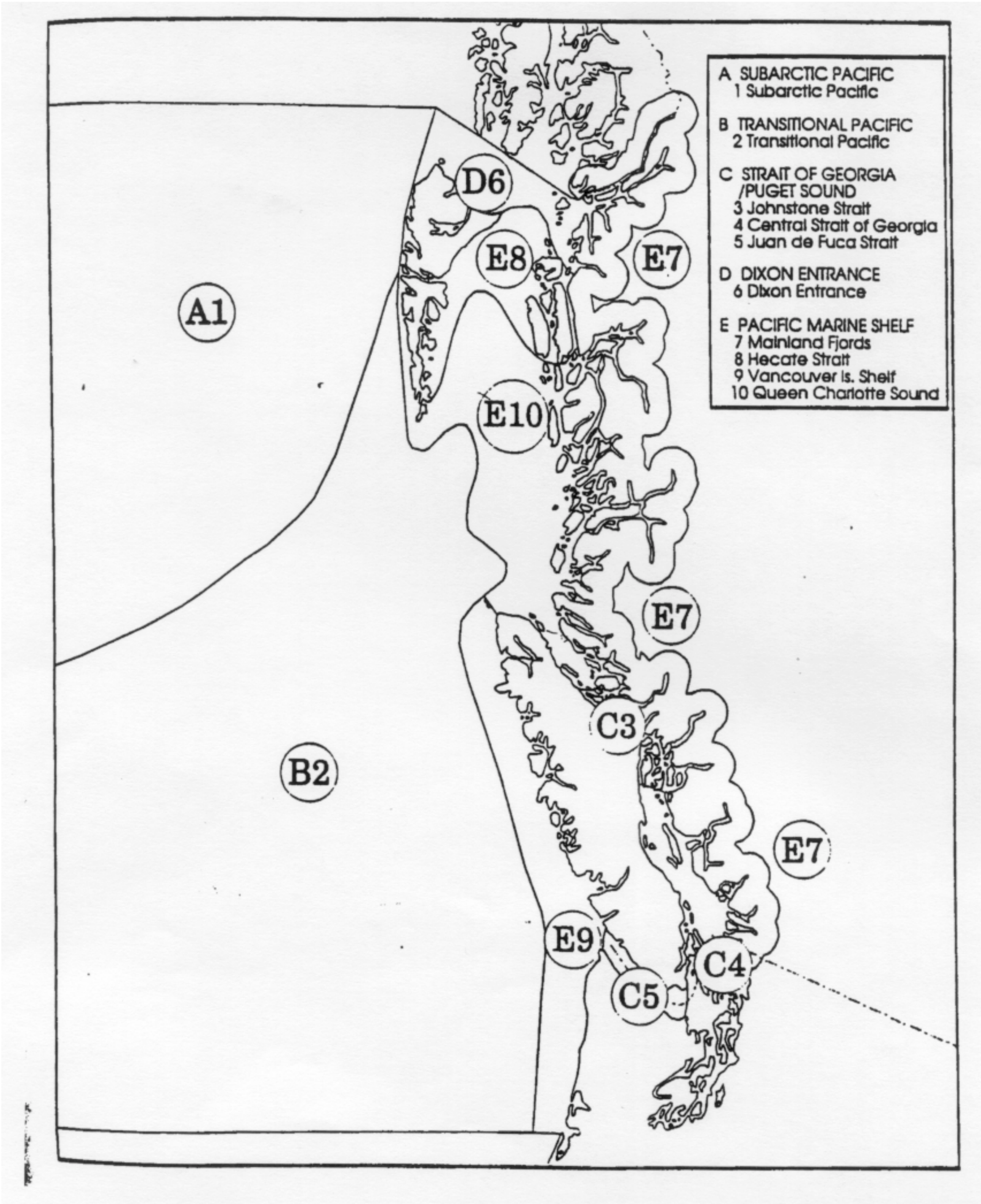

Figure 7. Revised names and boundaries of the ecodistricts (Harper et al. 1993).

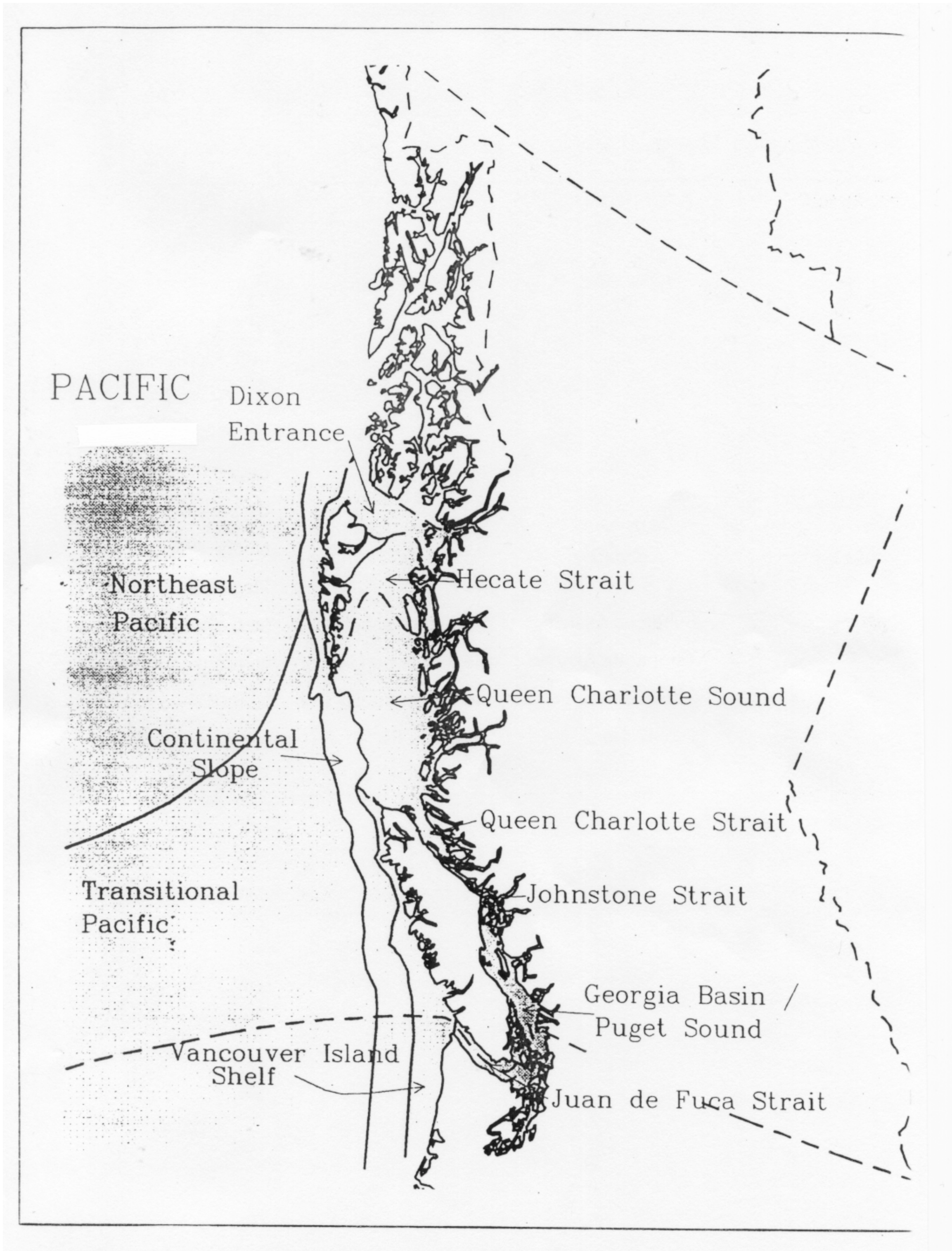

Figure 8. Further boundary and name modifications to the ecodistricts (Harding and Hirvonen 1996 based on Harding et al. 1994).

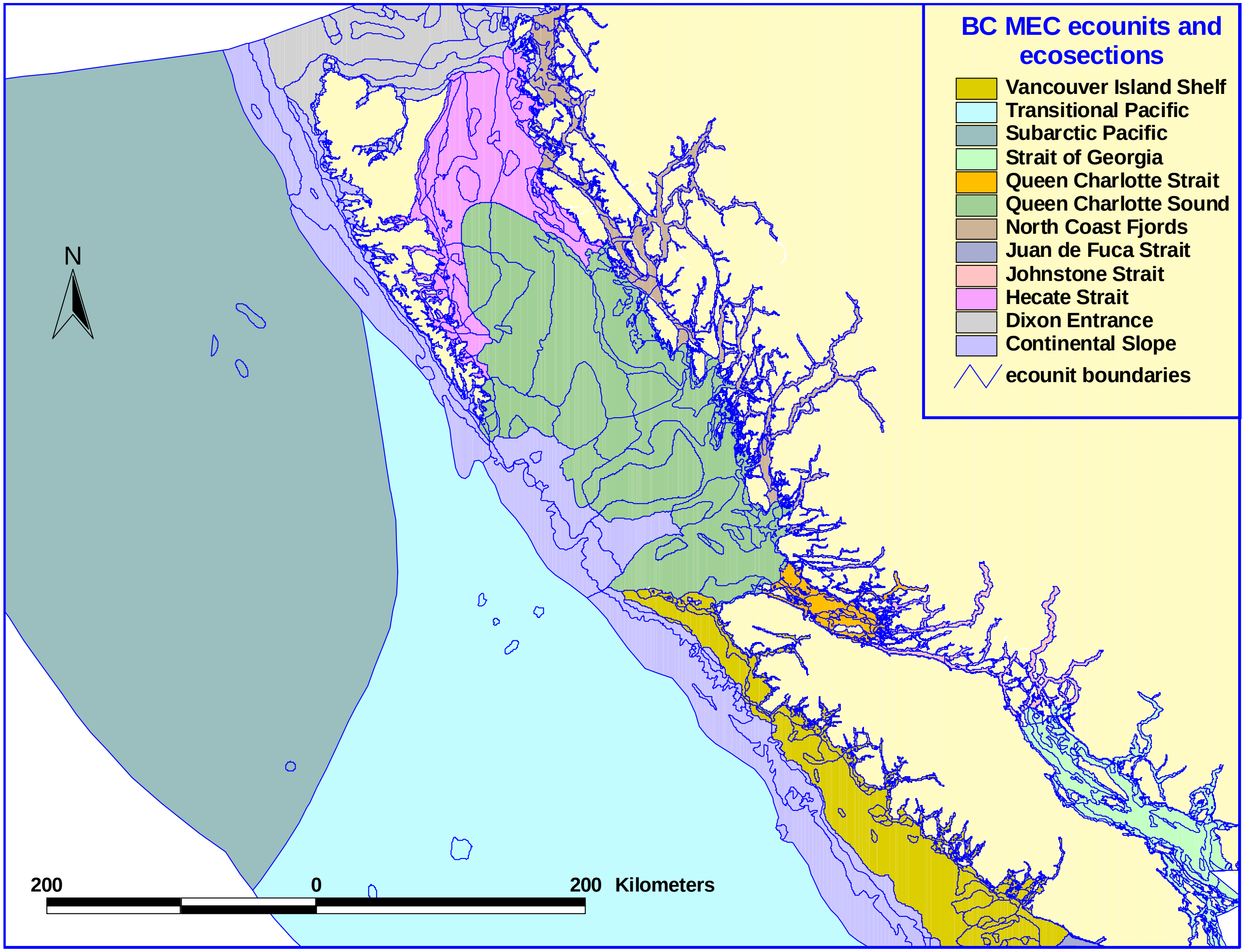

Figure 9. Map of the BC MEC ecosections and ecounits (Howes et al. 1997, data – LUCO 1998).

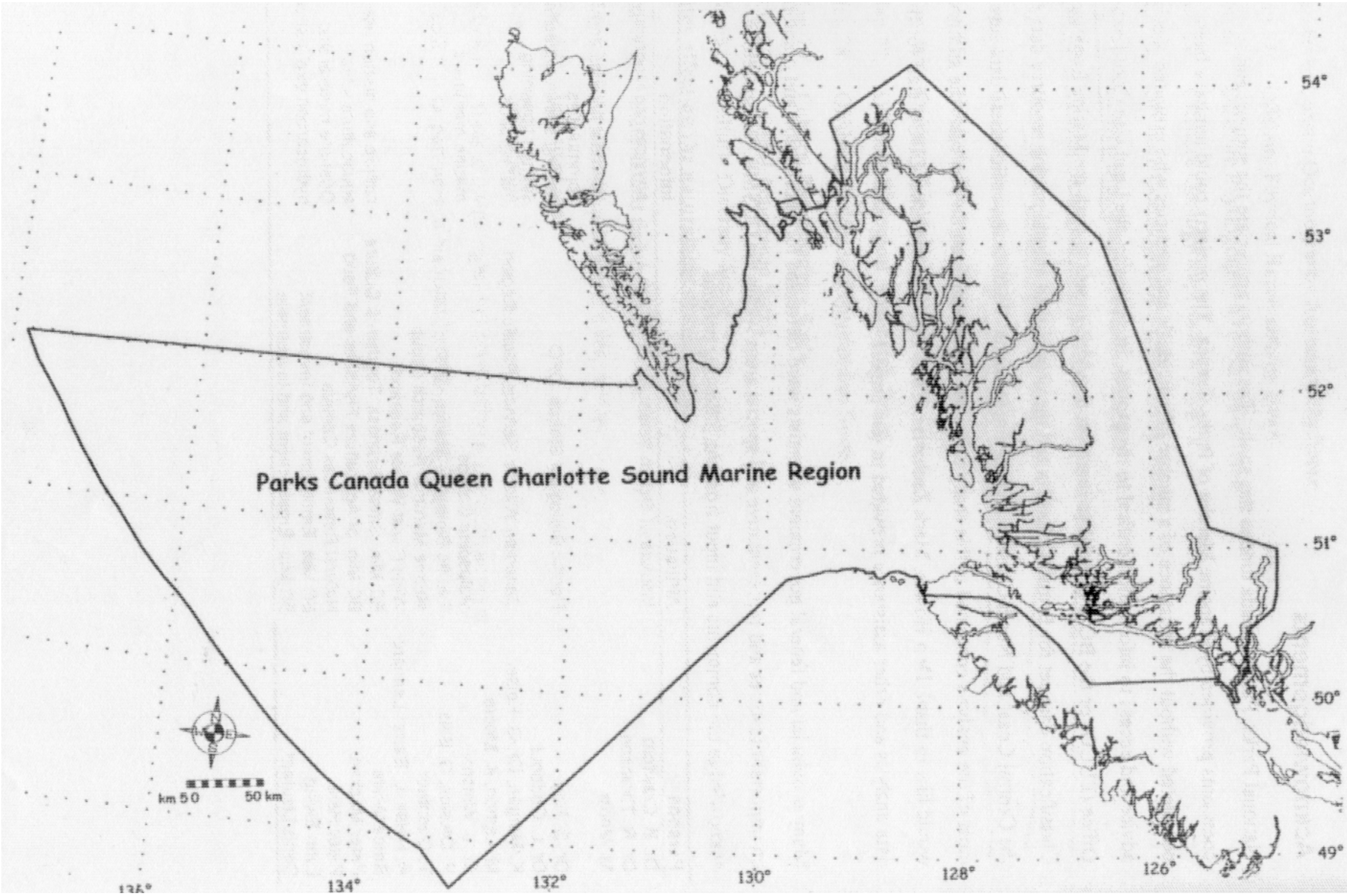

Figure 10. The Queen Charlotte Sound Marine Region of Parks Canada defined by Booth et al. (1998) largely using the ecounits of Howes et al. (1997).

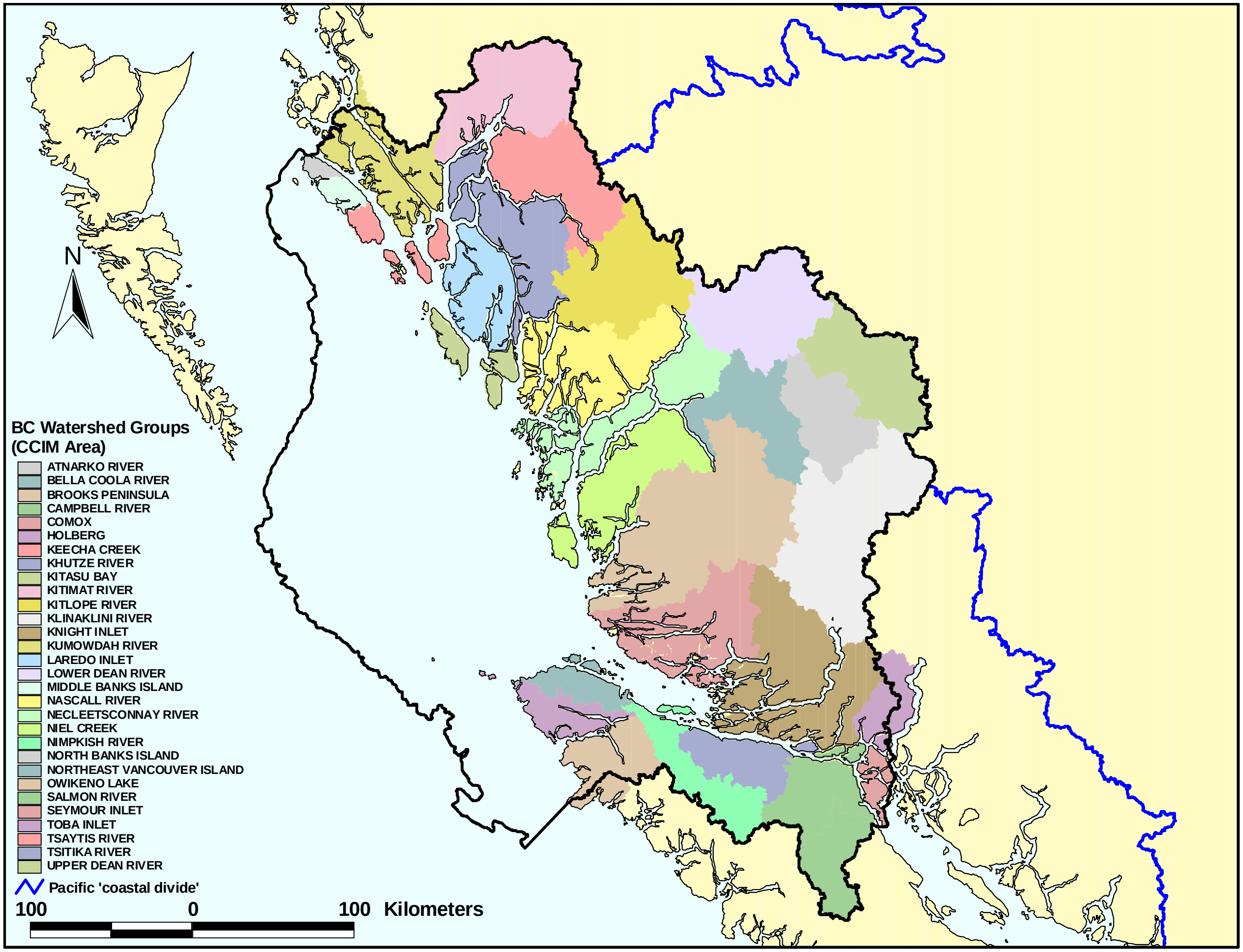

Figure 11. BC Watershed Groups for the central coast and the Pacific ‘coastal divide’ (data – MSRM 1998).

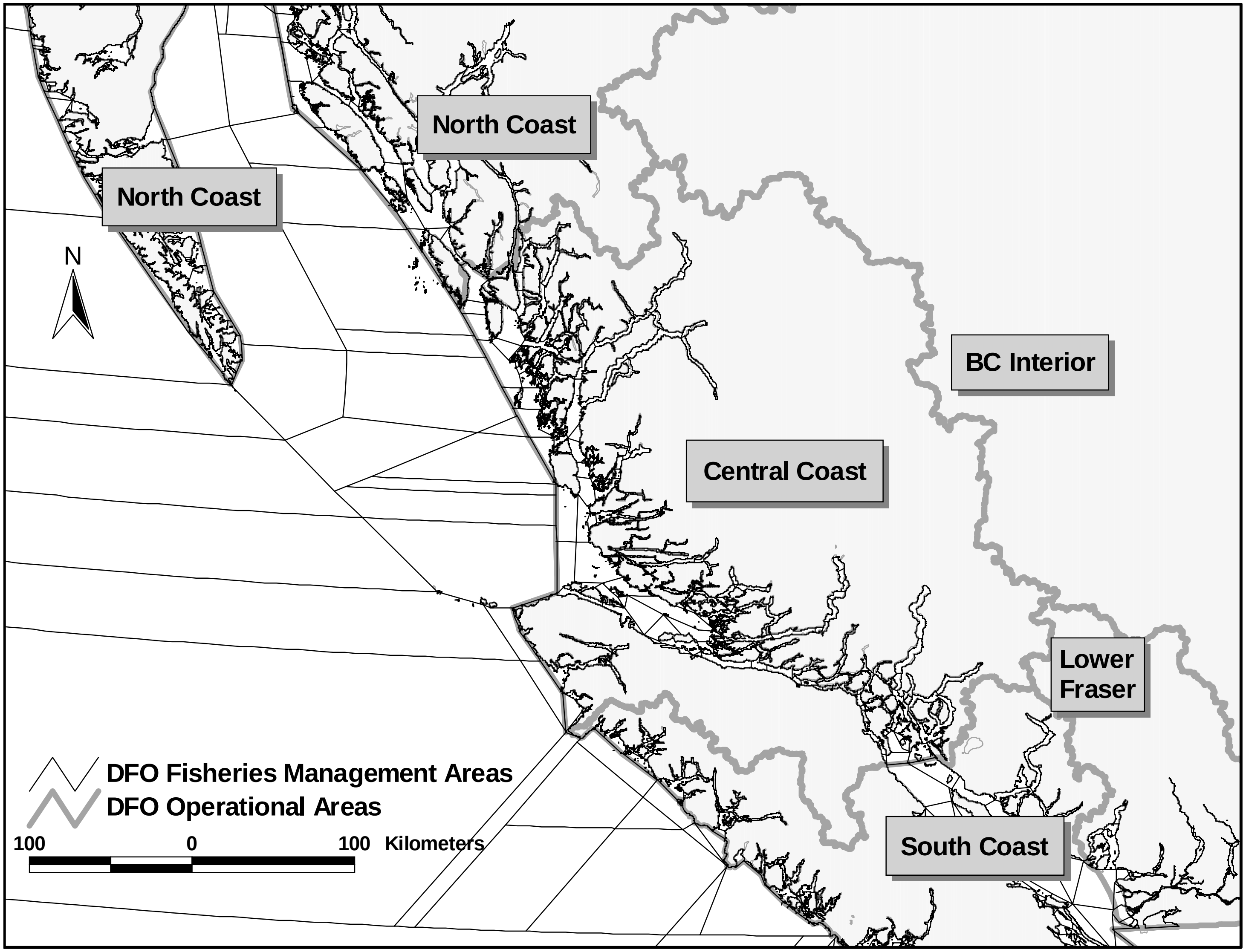

Figure 12. Boundaries of the DFO Operational Areas and the Fisheries Management Areas (data - Fisheries and Oceans Canada 1999a,b).

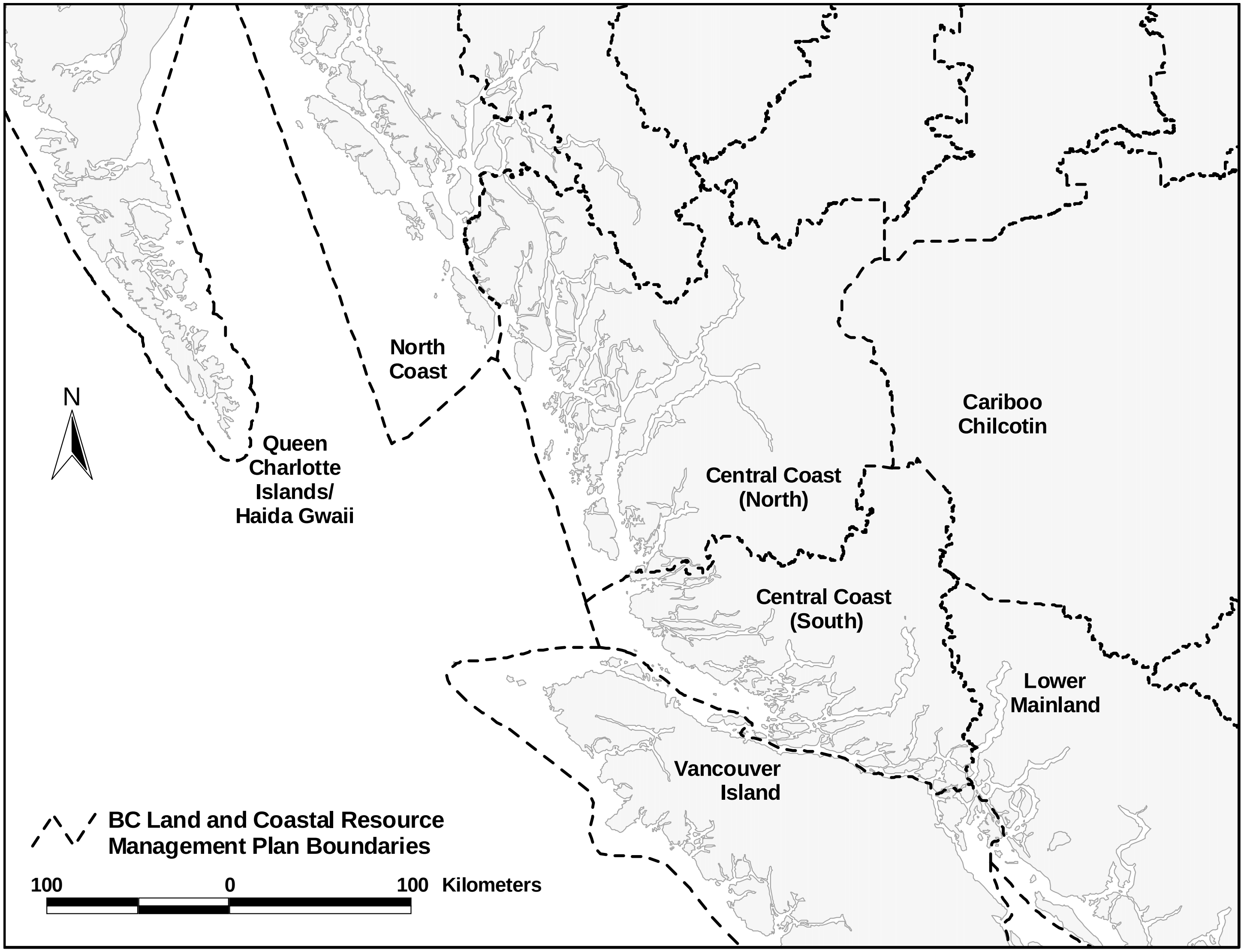

Figure 13. Boundaries of the Land and Coastal Resource Management Plan Areas (data - LUCO 1999).

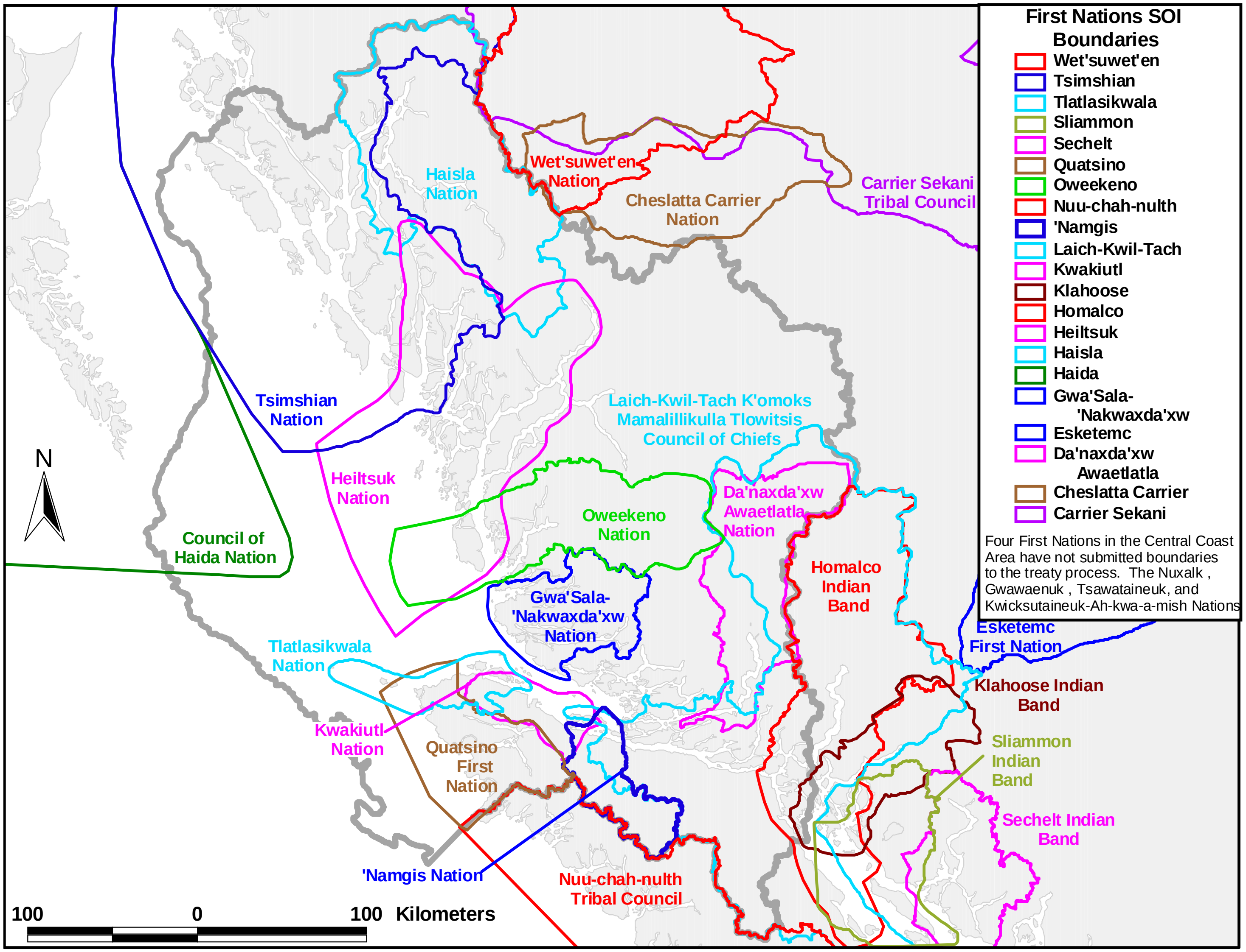

Figure 14. The boundaries of First Nations traditional territories in the Central Coast as defined in the First Nations Statements of Intent (data - Indian and Northern Affairs 2001).

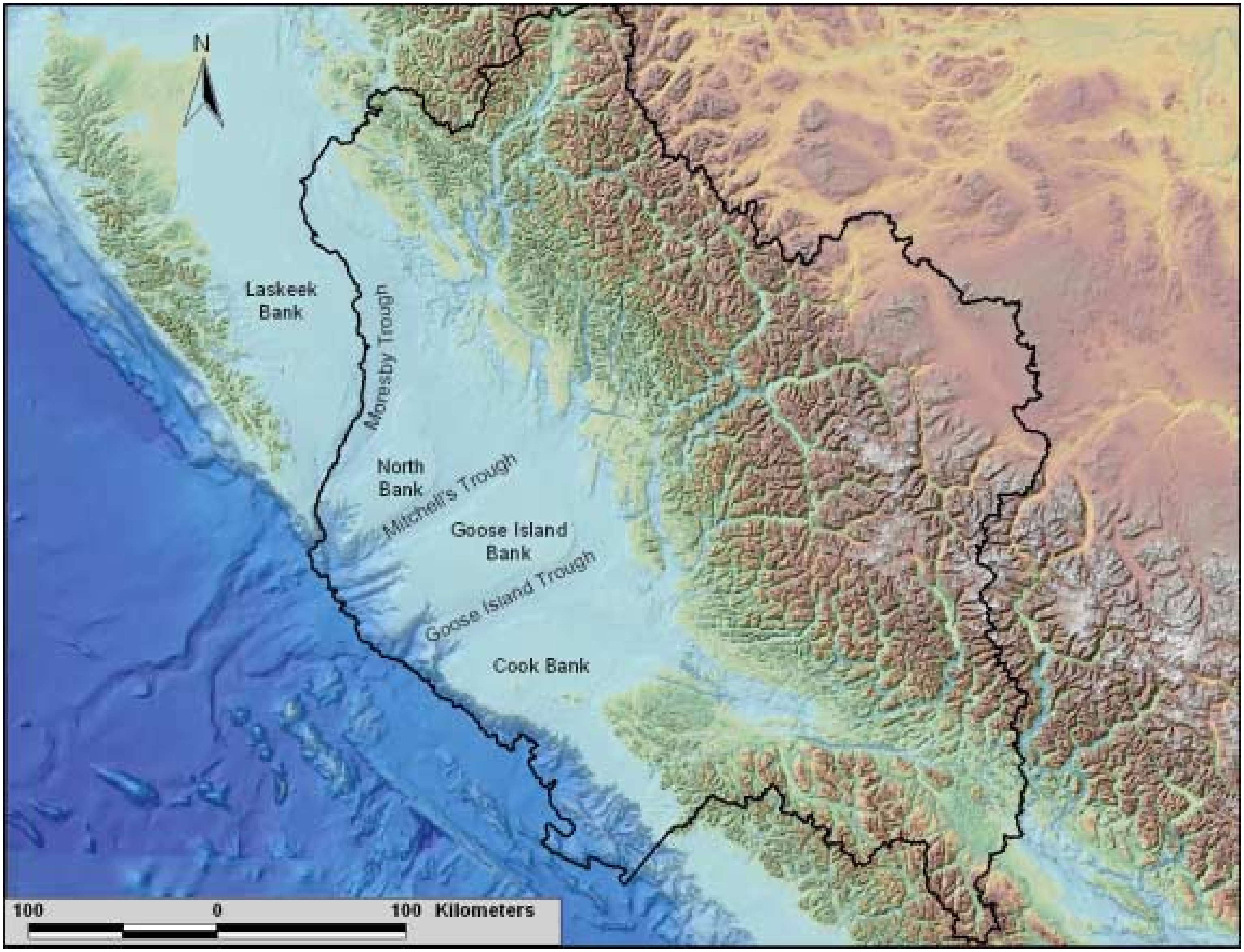

Figure 15. Proposed CCIM boundary with significant submarine features.

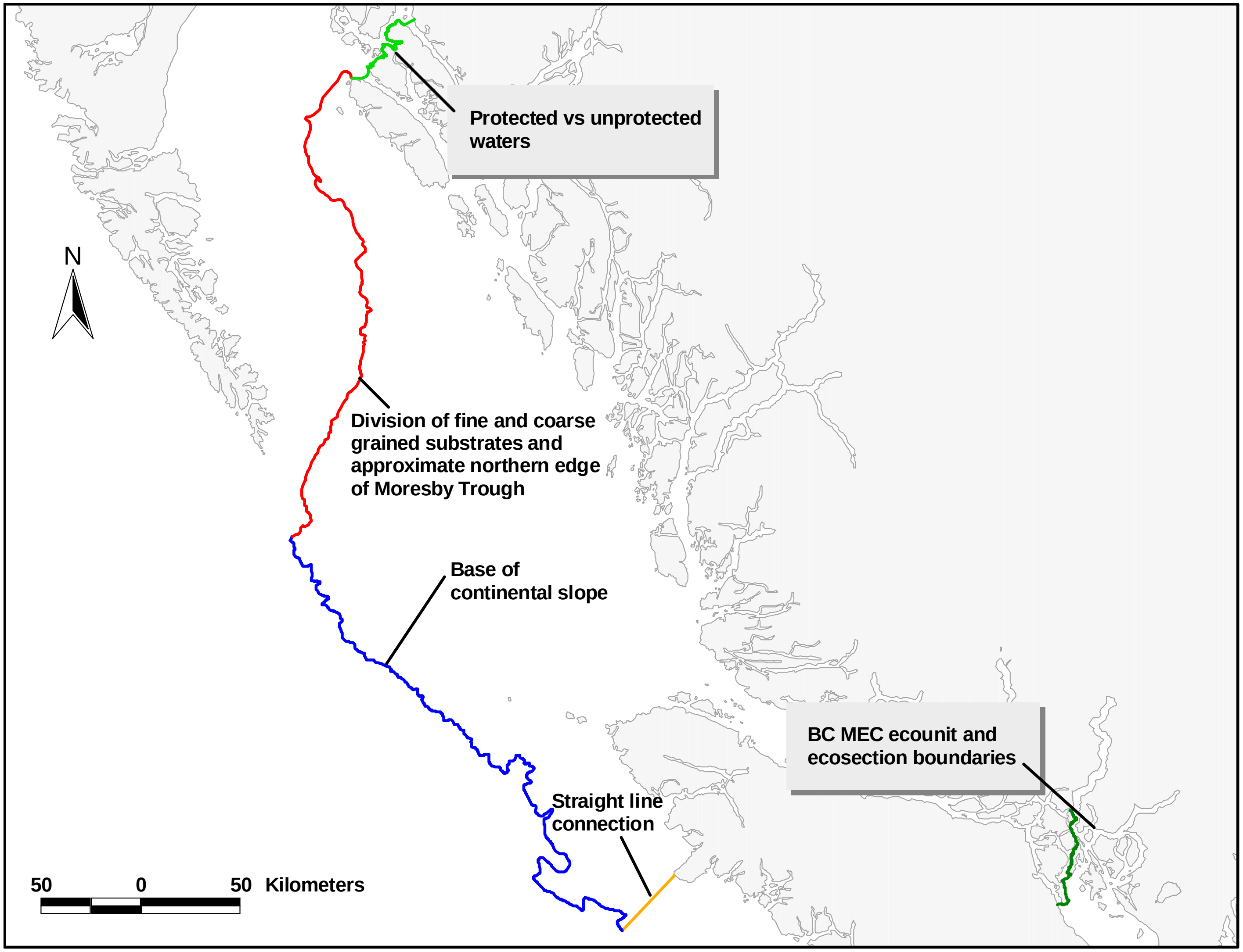

Figure 16. Information sources of marine boundaries used for the proposed CCIM boundary (Ardron 2003, LUCO 1998).

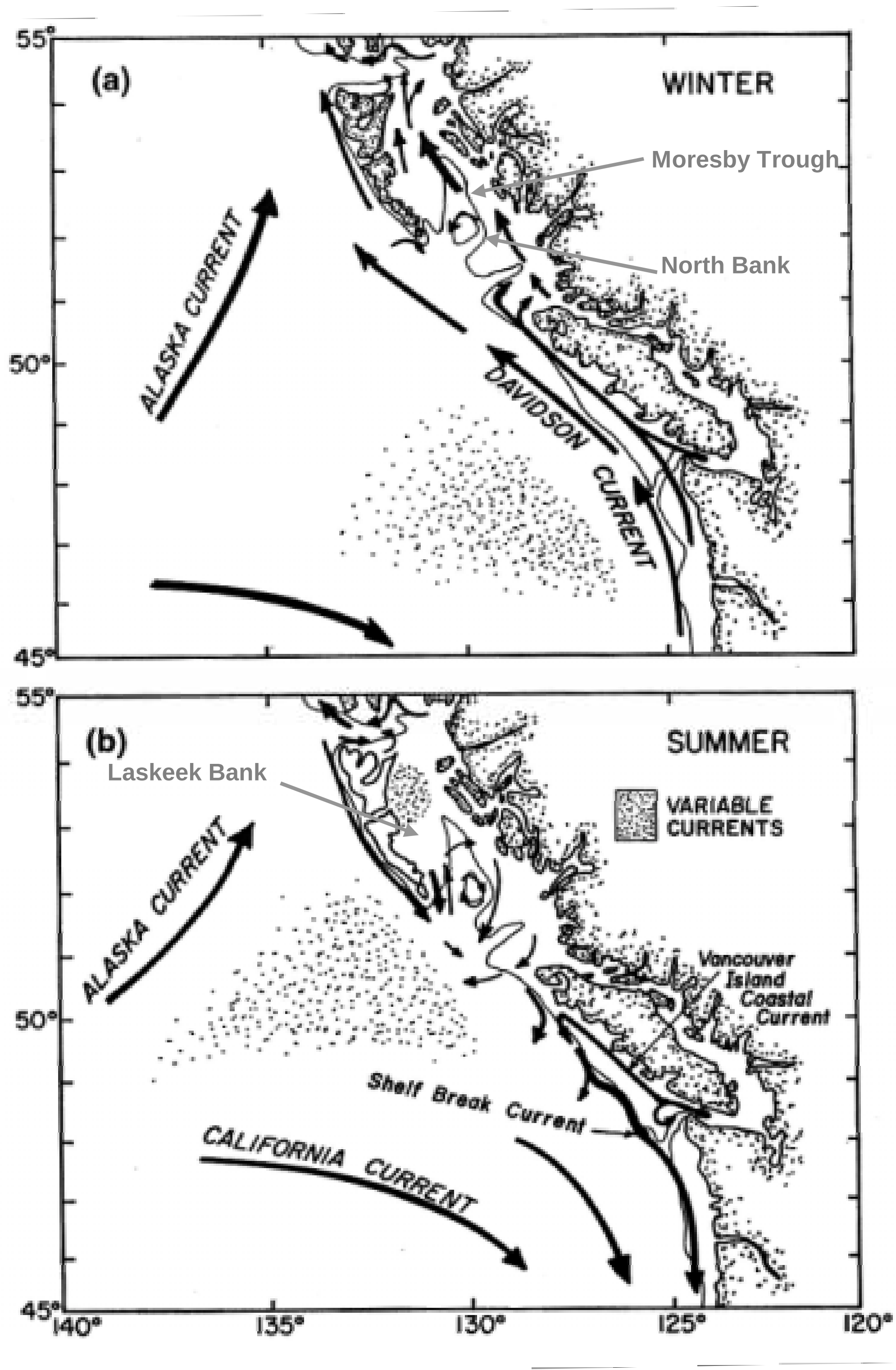

Figure 17. Surface circulation in summer and winter for the Northeast Pacific (deYoung *et al.* 1999).

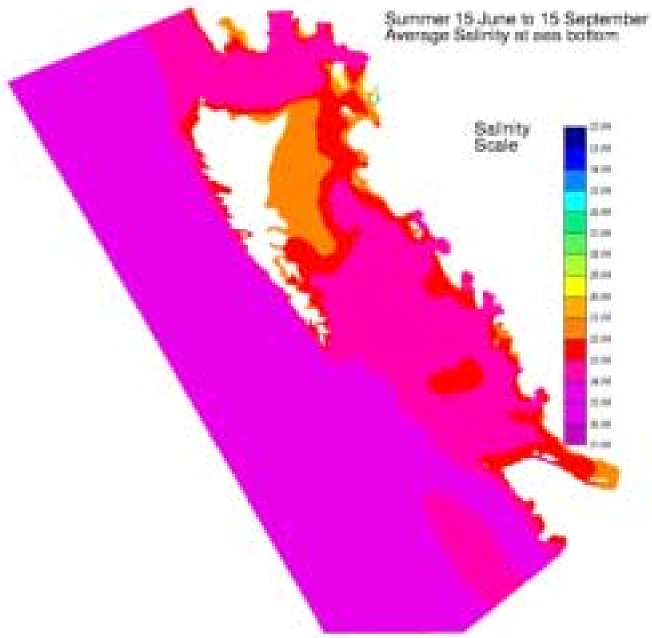

Figure 18. Average summertime bottom water salinity. Image from Crawford 2001.

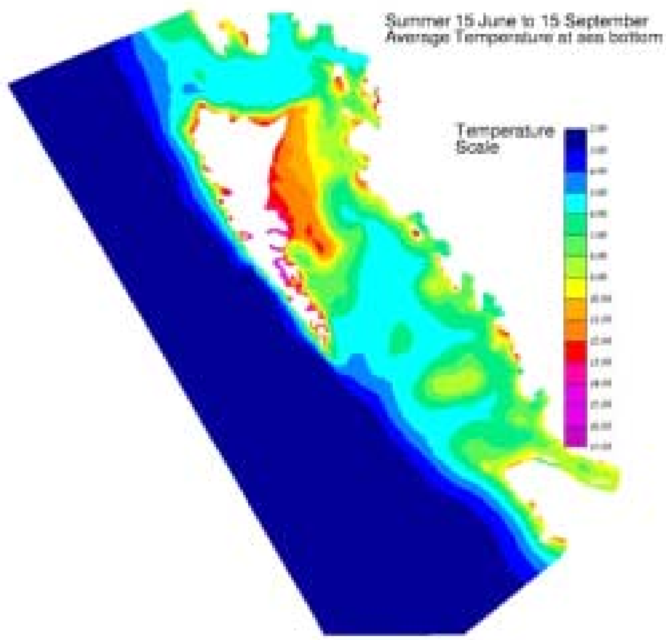

Figure 19. Average summertime bottom water temperature. Image from Crawford 2001.

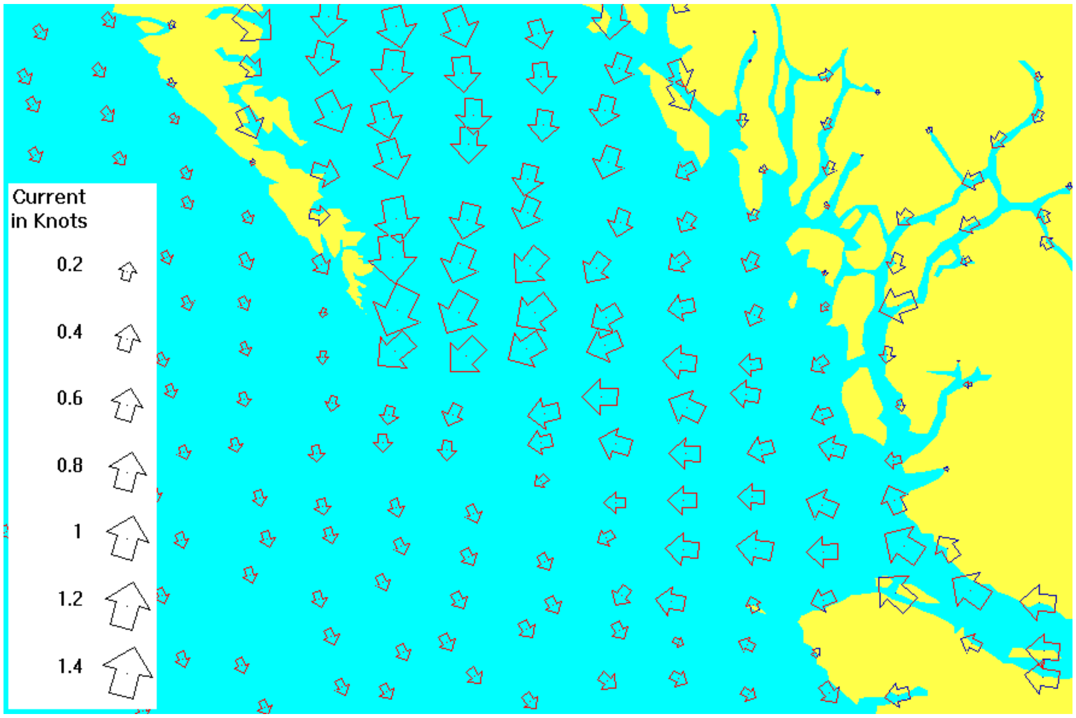

Figure 20. Tidal current speeds during peak ebb tide as modeled by Mike Foreman for June 16, 1999 (a time of strong tidal currents). Image from Crawford 2001.

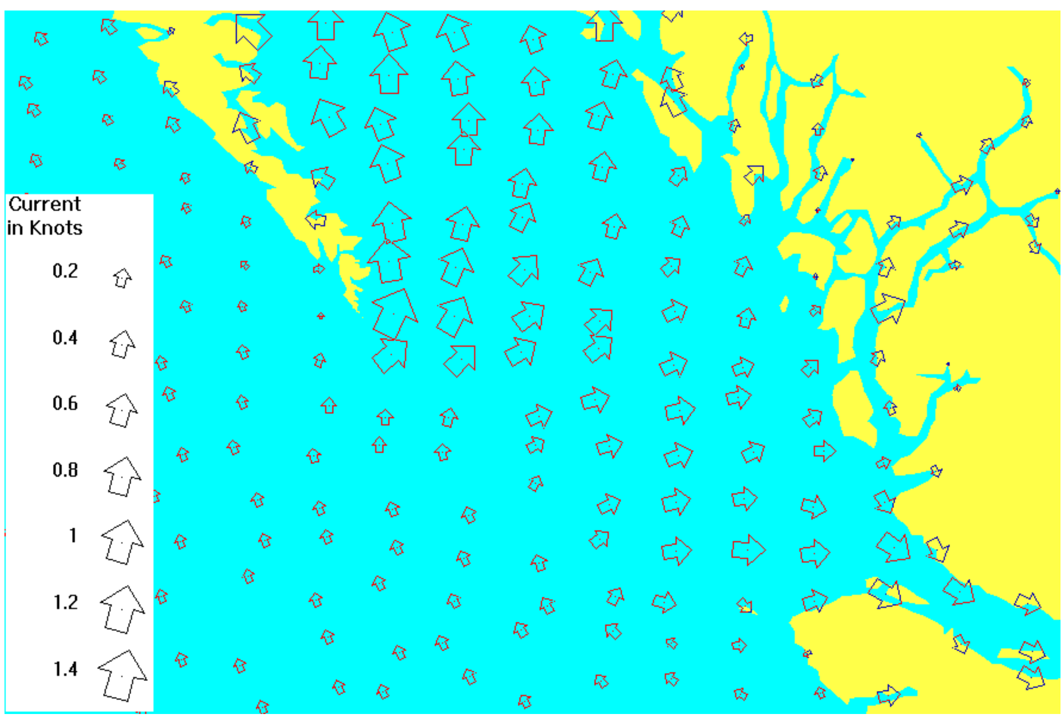

Figure 21. Tidal current speeds during peak flood tide as modeled by Mike Foreman for June 16, 1999 (a time of strong tidal currents). Image from Crawford 2001.

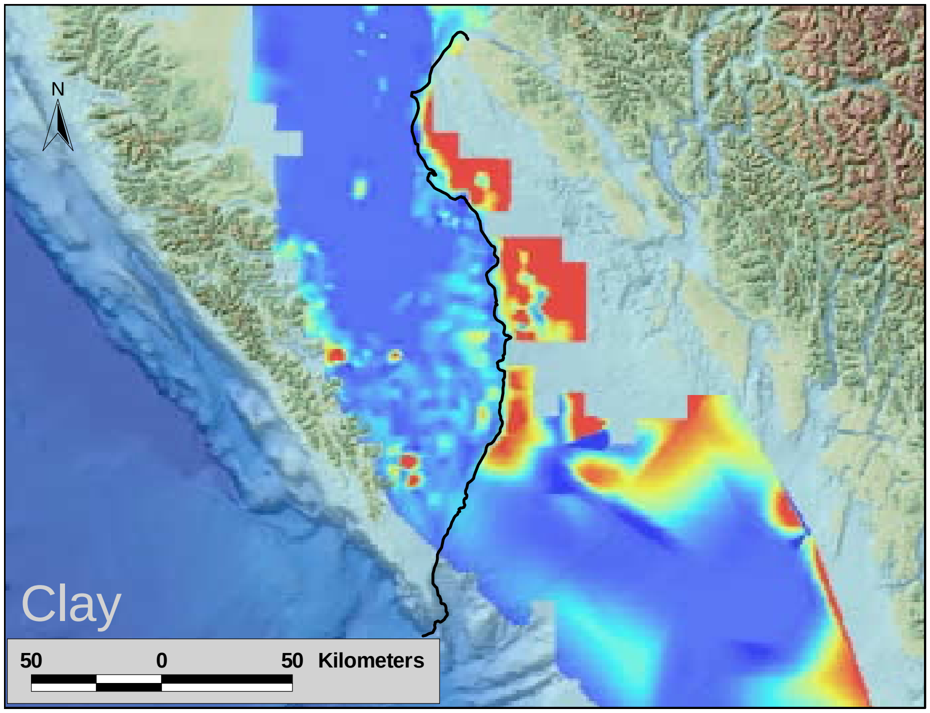

Figure 22. A map of the clay content of benthic sediments, red indicating high clay content, deep blue indicating low. Data from the Pacific Geoscience Centre.

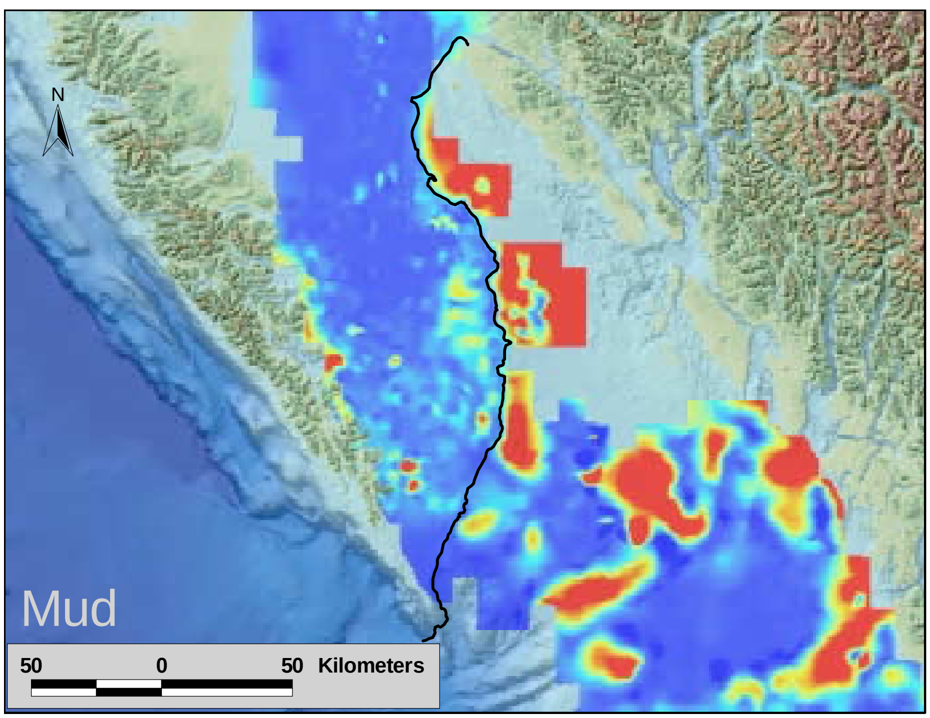

Figure 23. A map of the mud content of benthic sediments, red indicating high mud content, deep blue indicating low. Data from the Pacific Geoscience Centre.

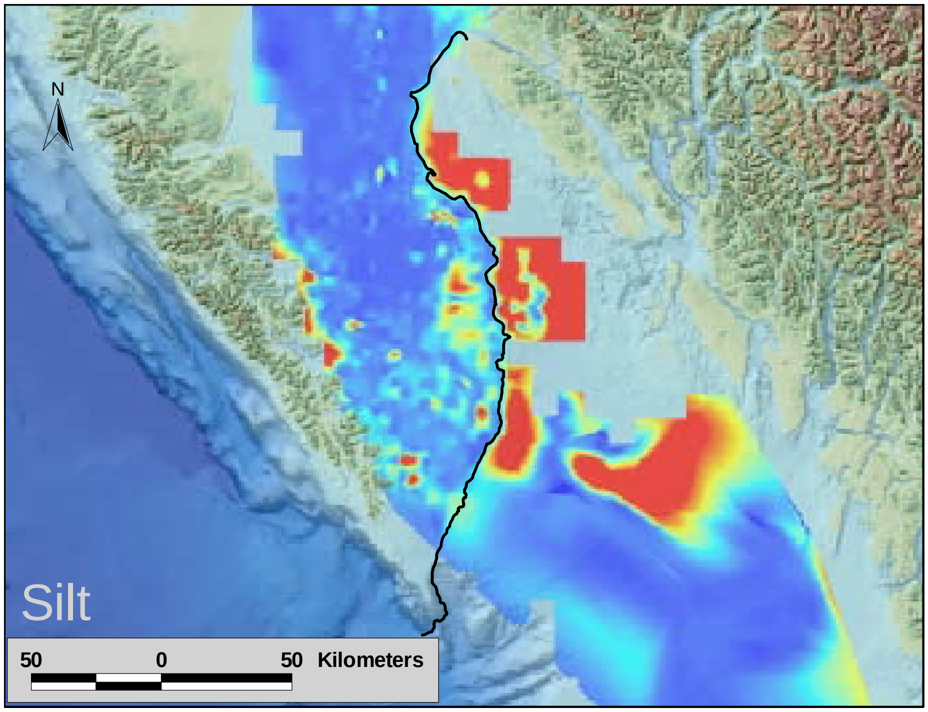

Figure 24. A map of the silt content of benthic sediments, red indicating high silt content, deep blue indicating low. Data from the Pacific Geoscience Centre.

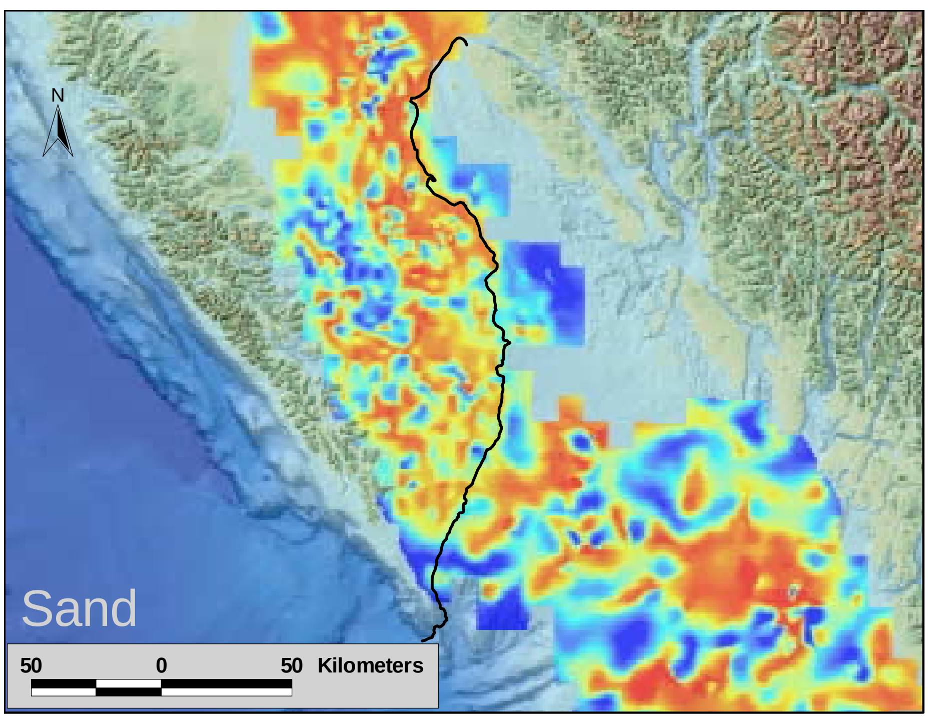

Figure 25. A map of the sand content of benthic sediments, red indicating high sand content, deep blue indicating low. Data from the Pacific Geoscience Centre.

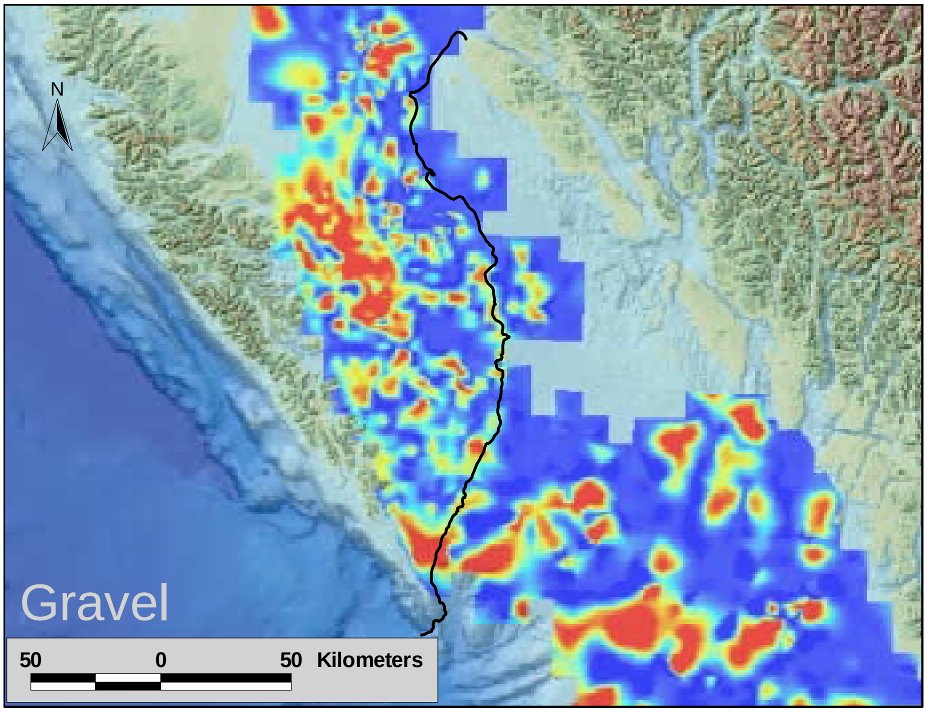

Figure 26. A map of the gravel content of benthic sediments, red indicating high gravel content, deep blue indicating low. Data from the Pacific Geoscience Centre.

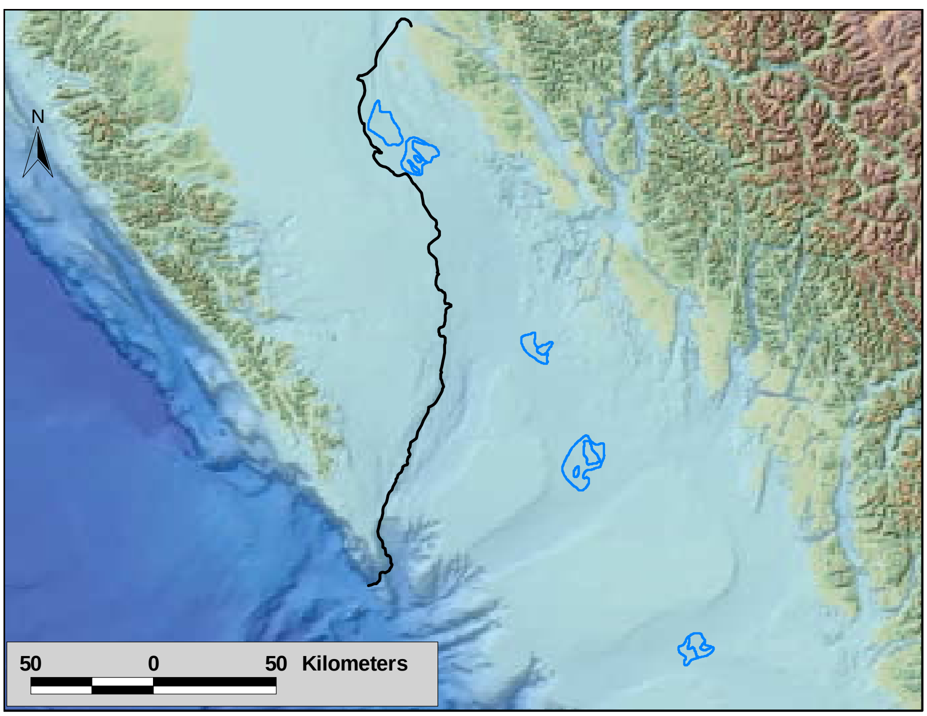

Figure 27. A map of the location of the known siliceous sponge reefs relative to the proposed northern boundary. Data from the Pacific Geoscience Centre.

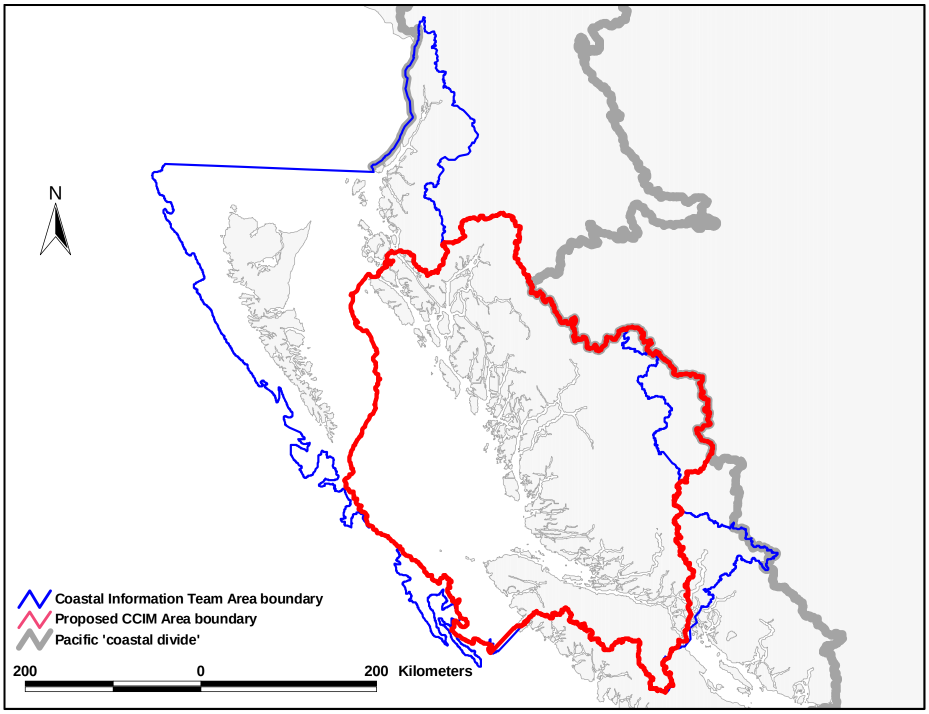

Figure 28. Coast Information Team (CIT) study area boundary (CIT 2002) with the Pacific 'coastal divide' (MSRM 1998).

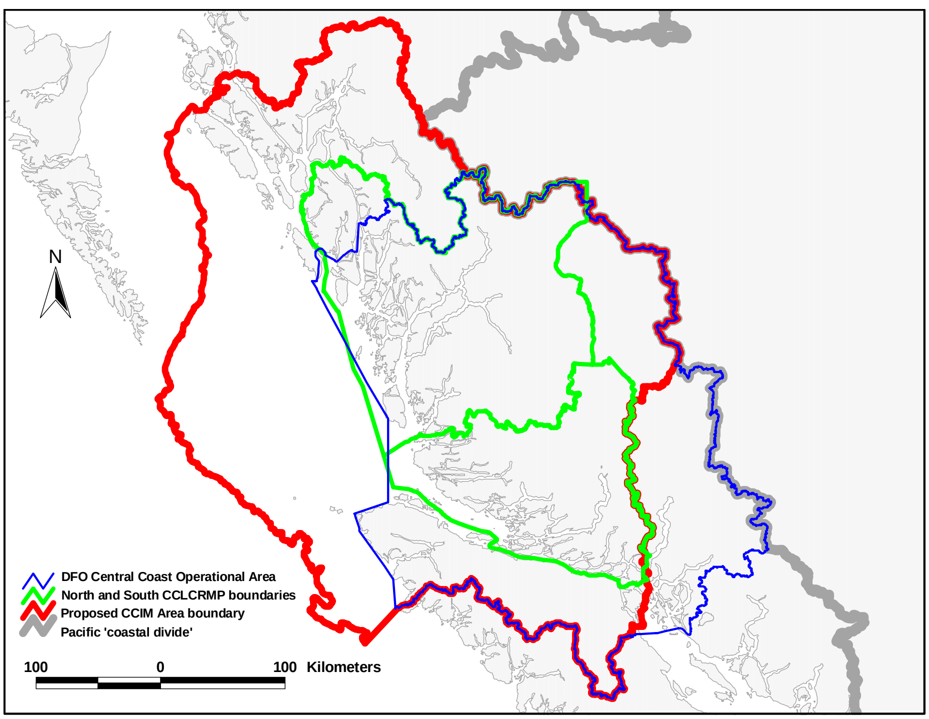

Figure 29. Proposed CCIM Area boundary compared to the DFO Central Coast Area and the North and South Central Coast LCRMP Areas (Fisheries and Oceans Canada 1999a, LUCO 1999).

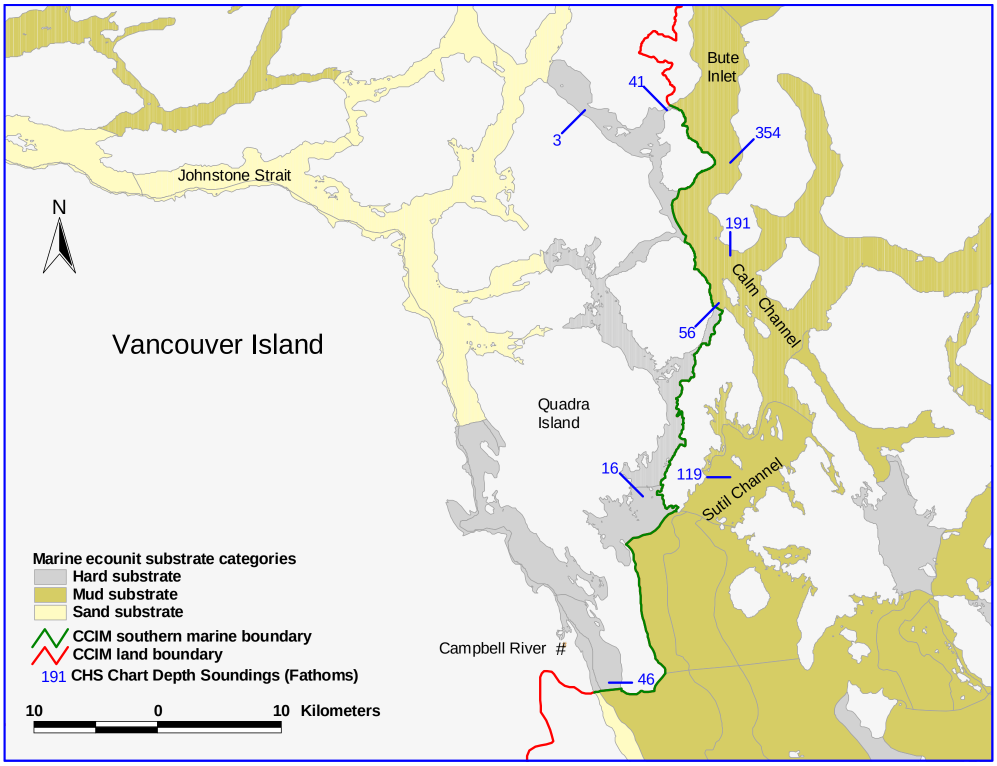

Figure 30. Detail of southern marine boundary showing ecounit substrate classification (LUCO 1998).

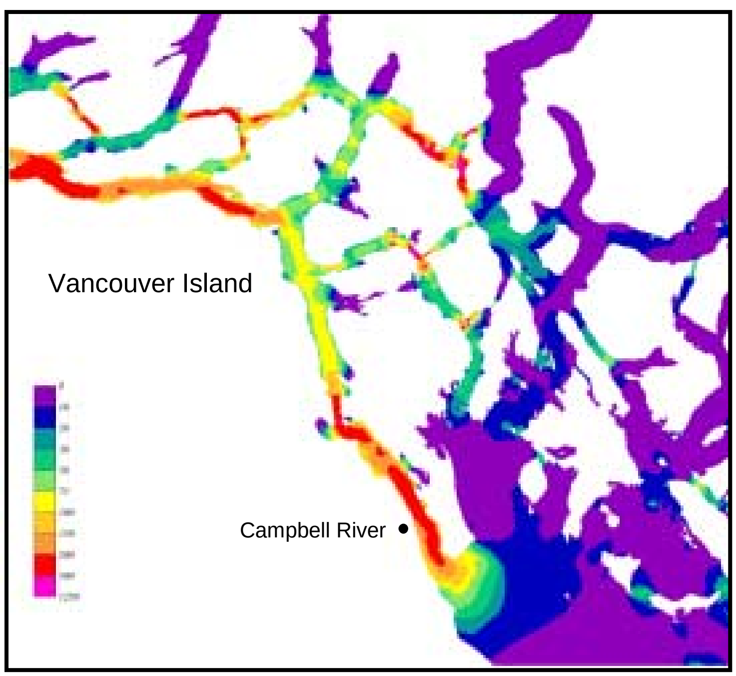

Figure 31. Map of the same area as above but here showing root mean square average tidal speeds (cm/s) from an updated model by Foreman et al (1993).

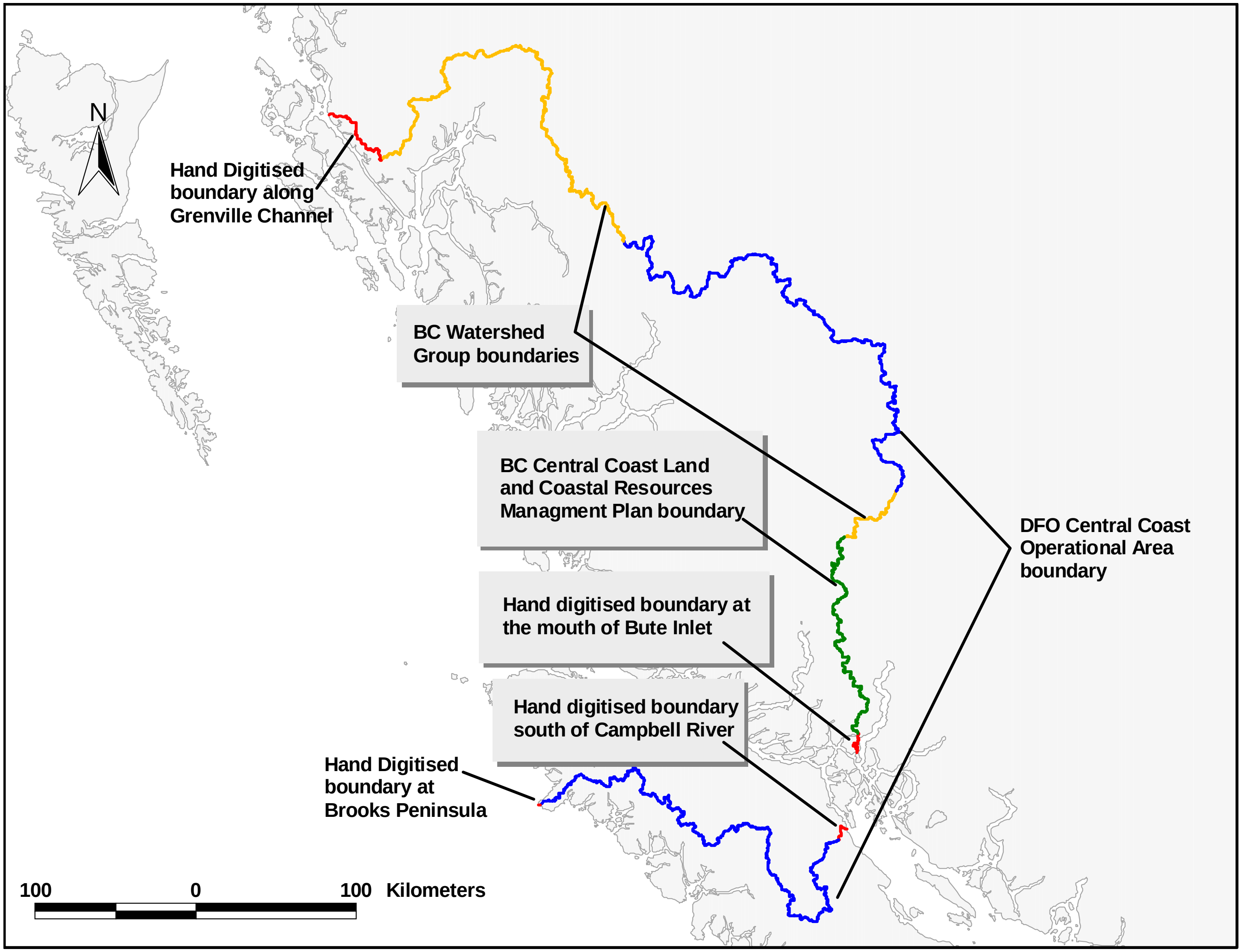

Figure 32. Information sources of land boundaries used for the proposed CCIM boundary (LUCO 1999, Fisheries and Oceans Canada 1999a, MSRM 1998).

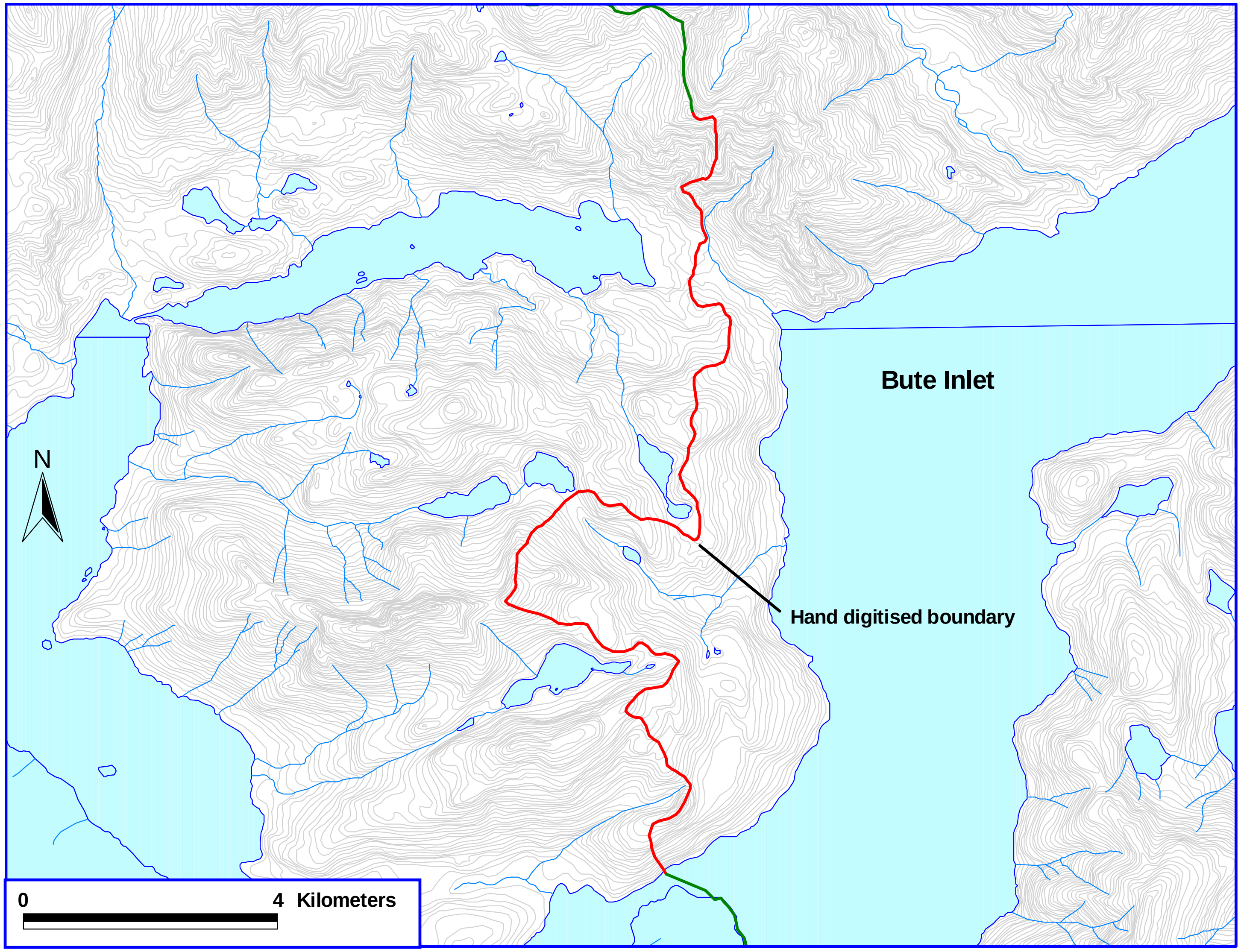

Figure 33. Detail of land boundary digitisation using 1:50 000 topography and hydrology for Bute Inlet (NRCAN 1960a, b).

Appendix 2

Methodology for the GIS Analysis used to produce the base of the continental slope line

Data Description: Base of Shelf Slope

Jeff Ardron, Marine Analyst, Living Oceans Society, July 31 2003.

GIS Datasets

Lines: Slopebase250k.shp; Slopebase1M.shp; Slopebase3M.shp

Overview

Living Oceans Society was contracted by Fisheries and Oceans Canada to perform a slope analysis to define the base of the continental shelf slope for the west coast of Canada. Three products were produced, of nominal scales: 1:250,000; 1:1,000,000; and 1:3,000,000. The latter two products are generalizations of the 1:250k line.

Methodology

Bathymetry

Prior to the contract, Living Oceans Society had purchased, cleaned, and merged NDI NRM 1:250,000 bathymetry for BC. These lines were broken into regularly spaced points (50m). These points were interpolated into 100m grid, using first power inverse distance weighting; i.e., linear interpolation, using a TIN. This raster formed the basis of the slope analysis.

Slope

A slope analysis was performed, again using a 100m grid. Exaggeration (z) values of 1 to 40 were explored. It was found that an exaggeration of 20x improved the visible extent of the shelf slope. However, the unexaggerated dataset (1x) was used to define the natural breaks. Generally, the base of the shelf slope was found to be delineated by a slope of about 2.7%. Slope of slope (second derivative) and slope of slope of slope (third derivative) analyses were performed to verify this break.

Creating Lines

In order to smooth the sometimes jagged break points, the slope break was snapped to the nearest bathymetry line. However, because the bathymetry varied over space, the resulting line was a conglomeration of many bathymetry line segments, and thus could not be said to represent any particular isobath. That is, the resulting 1:250k product is unique and cannot be “reverse engineered” back into bathymetry. The other 2 generalized lines do not match any isobaths at all.

Generalizing Lines

The 1:250,000 line was generalized in ArcInfo 8.2, using the “remove curves” function. A cut-off of 5,000 m was used for the …_1M dataset, and 10,000 m was used for the …_3M dataset. The stated scale of these two generalized lines is only to be used as a general guide, and has not been tested.

Depth Statistics

The depth of the base of the shelf was found to be generally about 2300m. Statistics, per 100m cell are as follows:

Minimum: 1743m
Maximum: 2900m
Range: 1157m
Median: 2355.5m
1^{st} Quartile: 1951
3^{rd} Quartile: 2602
Mean: 2309.2m
Standard Deviation: 363.79m
Skewness: 0.044684
Kurtosis: 1.5919

Depth Distribution

Depth was fairly evenly distributed, though was somewhat confounded by uneven bathymetry sampling (Figure 1) and was clearly influenced by geographic formations (Figure 2). While generally, the "low road" was chosen, whereby, the lowest slope break was deemed the base of the slope, this was deemed incorrect for the entrance of Queen Charlotte Sound, where the lowest breaks occurred very deep, and ten's of kilomtres westward of the rest of the line. In this case, the shallower breaks were chosen:

- The west coast of Haida Gwaii has two shelf breaks in rapid succession. The bottommost of these was chosen, which represented the deepest sections of the overall BC line.
- Due to its gullies and extensive crenulations, the entrance to Queen Charlotte Sound required visual interpretation. The "higher road" was chosen whereby the shallower plateau in line with the rest of the continental slope was deemed to determine the shelf slope, rather than the very deep gullies that begin about 60km westward of that. These represented the shallowest segments of the overall BC line.
- The west coast Vancouver Island represented a steady descent from the entrance to Queen Charlotte Sound, until the southern end, where depths began to decrease again.

Figure 1

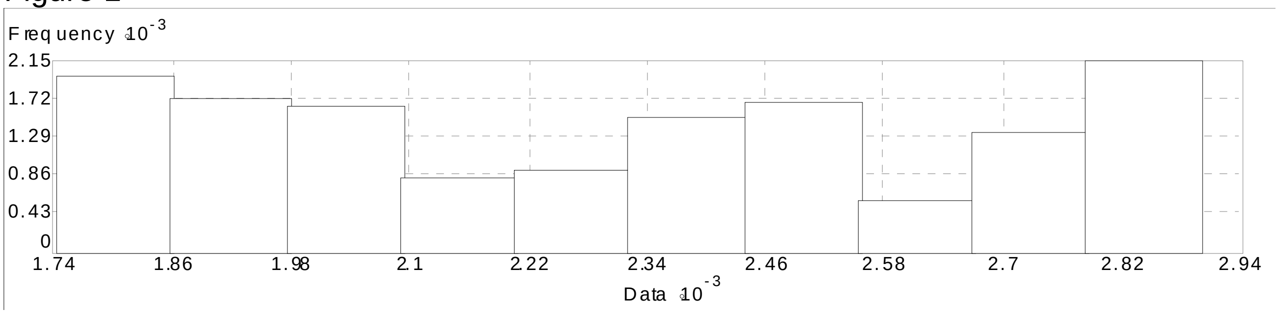

Figure 2