
British Columbia Marine Ecological Classification

Marine Ecosections and Ecounits

Prepared by
Ministry of Sustainable Resource Management
Decision Support Services Branch
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Preface

This report is submitted to the Resource Information Standards Committee (RISC) by the Coastal Task Force. The Resource Information Standards Committee members are resource inventory specialists from a wide variety of professional disciplines representing provincial, federal, aboriginal and private sector agencies and other resource interests. RISC's objective is to develop a common set of standards and procedures for Provincial resource inventories.

The Coastal Task Force has identified a number of projects to develop a common set of inventory standards for the coastal environments of British Columbia. This manual documents the British Columbia Marine Ecological Classification (BCMEC), a hierarchical ecological mapping system for use in marine planning, conservation and protection. The classification identifies 12 Provincial marine ecosystems based on physical, oceanographic and biological characteristics, and a number of smaller ecosystems, based on depth, current, exposure, relief, salinity, slope, stratification, substrate, and temperature.

Abstract

The British Columbia Marine Ecological Classification (BCMEC) is a hierarchical classification that delineates Provincial marine areas into Ecozones, Ecoprovinces, Ecoregions and Ecosystems. The classification was developed from previous Federal and Provincial marine ecological classifications which were based on 1:2,000,000 scale information. The BCMEC has been developed for marine and coastal planning, resource management and a Provincial marine protected areas strategy. A new, smaller level of classification termed “ecosystems” developed using 1:250,000 scale depth, current, exposure, relief, salinity, slope, stratification, substrate, and temperature and was created to assist with conservation and management of provincial coastal resources as well as verify the larger ecosystems, and to delineate their boundaries.

Acknowledgments

The Government of British Columbia provides funding of the Resources Information Standards Committee work, including the preparation of this document. The Resources Information Standards Committee supports the effective, timely and integrated use of land and resource information for planning and decision making by developing and delivering focussed, cost-effective, common provincial standards and procedures for information collection, management and analysis. Representatives to the Committee and its Task Forces are drawn from the ministries and agencies of the Canadian and the British Columbia governments, including academic, industry and First Nations involvement.

The Resources Information Standards Committee evolved from the Resources Inventory Committee which received funding from the Canada-British Columbia Partnership Agreement of Forest Resource Development (FRDA II), the Corporate Resource Inventory Initiative (CRII) and by Forest Renewal BC (FRBC), and addressed concerns of the 1991 Forest Resources Commission.

For further information about the Resources Information Standards Committee, please access the RISC website at: <http://srmwww.gov.bc.ca/risc/>.

The project team for this project included Mr. Don Howes and Dr. Mark Zacharias of the Ministry of Sustainable Resource Management, Dr. Rosaline Canessa of AXYS Environmental Research, Dr. John Roff of the University of Guelph, and Dr. Ellen Hines of San Francisco State University. The authors would like to thank workshop participants and others who contributed to this standard.

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1. INTRODUCTION

Several Canadian ecosystem classifications have been developed over the past 30 years for preservation, planning and resource management purposes (Harper et al. 1983, Harper et al. 1993, Hirvonen et al. 1995, Howes et al., 1996). In the 1970's and 1980's some early attempts at classifying the marine environment of British Columbia were undertaken by Environment Canada for marine emergency (Owens 1977) and Parks Canada for conservation (Harper et al. 1983).

In the early 1990's, Environment Canada initiated the development of a Marine Status and Trends Monitoring Network for environmental quality and assessment. Part of this mandate was the development of an ecological classification to serve as a framework for this program. The resulting *Classification of the Marine Regions of Canada* was developed from the systematic application of physical criteria that were deemed significant in controlling regional ecological processes (Harper et al. 1993, Hirvonen et al. 1995). Four levels of criteria were applied to define Ecozones (ice regimes and ocean basins), Ecoprovinces (ocean regimes and continental margins), Ecoregions (marginal seas) and Ecoregions (mixing and stratification) (Harper et al. 1993, Hirvonen et al. 1995).

Following the publication of the *Classification of the Marine Regions of Canada*, the Province in consultation with the Federal government added the Continental Slope and Queen Charlotte Strait ecoregions to the classification (Harper et al. 1993, Hirvonen et al. 1995). This modified classification was reviewed by the RIC Coastal Task Force (CTF) who initiated a study to evaluate the applicability of the proposed ecoregions and their boundaries for British Columbia marine management and protected areas planning.

In 1995, the CTF study developed a further subdivision of the BCMEC referred to as **ecoregions**. These ecoregions were developed in part, to evaluate the validity of the initial marine ecoregions and to delineate their boundaries. The ecoregions were derived using systematic provincial coverages for depth, current, subsurface relief, substrate and wave exposure mapped at a 1:250,000 scale. A total 619 ecoregions, representing 65 different combinations of themes were identified. Based on the results of this study, the RIC CTF worked with the RIC Terrestrial Task Force to develop a common ecosystem classification for the marine and terrestrial environments at the Zone, Province and Ecoregion levels (Zacharias & Howes 1998, Zacharias et al. 1998). The results of these efforts were reported in the *British Columbia Marine Ecological Classification* RIC Standard, Version 1.0.

In 2000, the BCMEC was updated at the ecoregion level to include salinity, temperature, stratification, slope and by revising depth with new data and modeling relief. In addition, two types of ecoregions are distinguished, namely benthic, describing the seabed and foreshore, and pelagic, describing the sea surface and water column. These updates were made possible by the consolidation of oceanographic and physiographic data sets by Fisheries and Oceans Canada which were unavailable in 1995, and experiences with similar classifications piloted by World Wildlife Fund Canada in the Scotian Shelf region.

An earlier report (AXYS 2000) provides extensive description of data sources and method options for each of the variables. These were presented at a workshop on 7 November 2000 in Victoria to a group of local and regional scientists including oceanographers, marine ecologists and marine park specialists from provincial, federal and U.S. agencies. The

Marine Ecosections and Ecounits

objective of the workshop was to present methodological research to date and to reach agreement, through discussion, on ecologically-relevant classifications of temperature and salinity, methods to derive and classify stratification and relief, and a framework to incorporate additional variables to derive meaningful marine ecounits. The results of the workshop provided guidance in developing the final methodology described in this report.

The purpose of this report is to provide an update on how the new BCMEC ecounits were created, and how this work integrates into other provincial and non-provincial marine classification efforts. This Final Report describes the methodology followed for each of the new data layers and for the creation of benthic and pelagic ecounits.

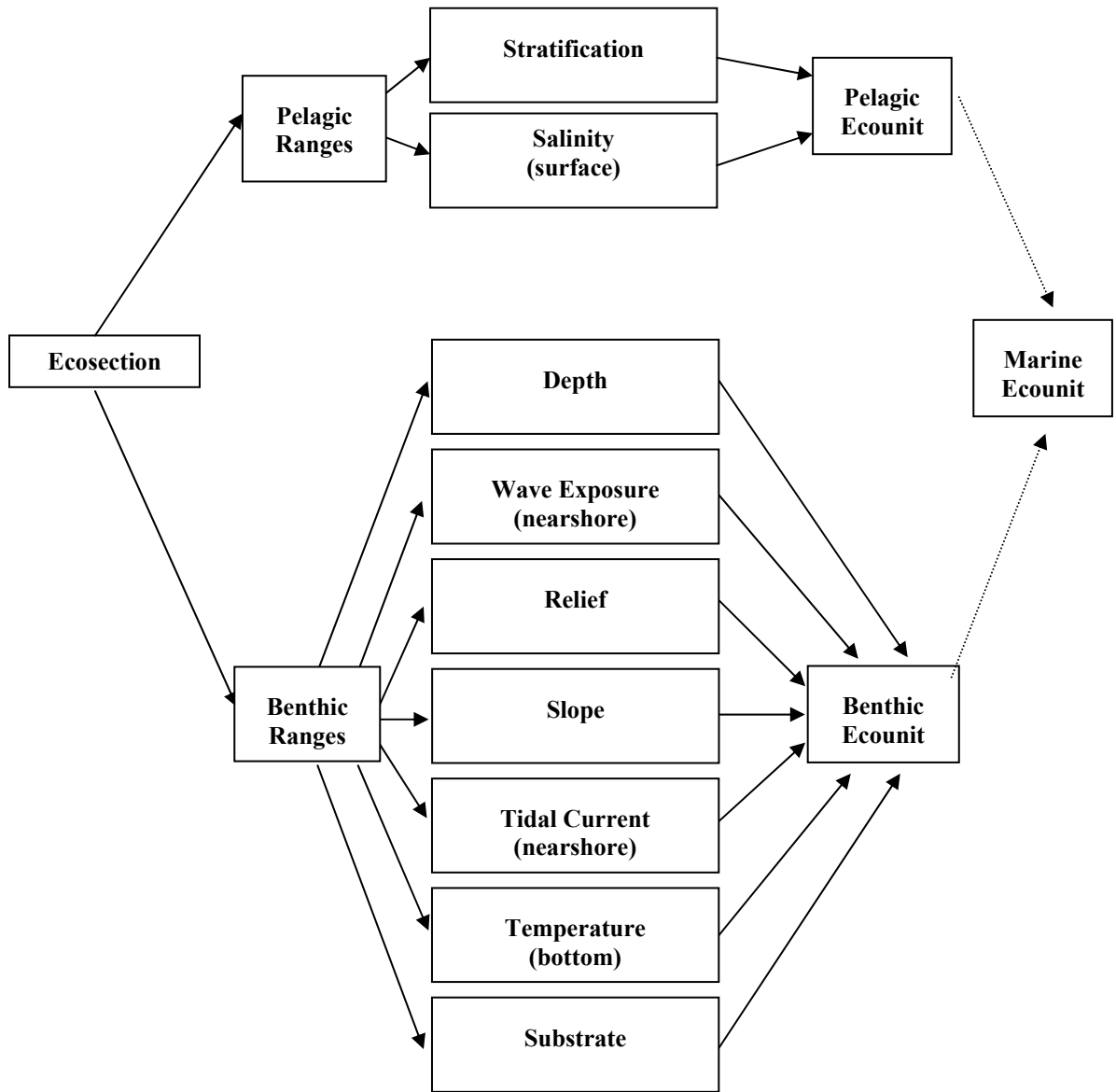


Figure 1. Methodological Framework

2. BENTHIC ECOUNITS

Benthic ecounits are intended to describe the sea bed and nearshore. Seven variables were selected to derive benthic ecounits:

1. Depth
2. Slope
3. Relief
4. Temperature
5. Exposure
6. Current
7. Substrate

Exposure, current, substrate and depth are already incorporated into the BCMEC. The following sections describe the methods for deriving slope, relief and temperature. In addition, because an improved bathymetric data source was acquired, a revised depth layer was developed.

2.1 Depth

Data Source

The primary source of bathymetric data is a comprehensive dataset of spot soundings based on best scale charts, and surveys from the west coast of Vancouver Island and Queen Charlotte Sound supplemented with spot soundings from NAD27 charts developed by the Canadian Hydrographic Service (CHS) (Terry Curran pers. comm.) and purchased from NDI. This dataset has limitations primarily due to variations in data density (e.g., there are more sounding points in the southern portion of the study area than in the north, data coverage is sparse in remote inlets and deeper areas) (see Section 4.0 for a discussion on scale and accuracy). In addition, the dataset did not extend to the offshore study area boundary.

Methodology

The data were initially georeferenced to BC Environment Standard Albers NAD83. The bathymetric data were provided in two datasets covering a northern portion and a southern portion. The data were aggregated and cleaned to eliminate erroneous zero values, positive values on land and positive values falling within the water boundary. This yielded a depth point coverage for the study area comprising approximately 65,500 points. Due to the density of points, the dataset was divided and analysed by ecosections to increase processing efficiency. For each ecosection, a Triangulated Irregular Network (TIN) surface was interpolated from the bathymetric points using the coastline from the ecosection boundary as a hard clip polygon to establish the boundary between land and sea. The TIN was gridded into 250 m. The resulting cells were smoothed using a 9 x 9 cell window to eliminate sharp

edges emanating from the TIN and to eliminate gaps between the gridded coastline and the standard vector coastline. The grid was re-classified into five classes and converted into polygons. Polygon coverages for all the ecosections were compiled into a single province-wide coverage (Table 1). The classes correspond to the existing BCMEC depth classes with the exception of the additional class of 20-50 m to account for a potentially deeper photic zone in some areas. Using an iterative process of eliminating polygons less than 15 km² (to be consistent with the existing BCMEC) and dissolving neighboring polygons with similar attributes, all spurious polygons were removed. The available data did not cover the full offshore extent of the study area, but the data were extrapolated and classified as 'Abyssal'.

Table 1. Depth Classes

Class	Depth range	Attribute¹ value
Shallow	0-20 m	S
Photic	20-50 m	P
Mid-depth	50-200 m	M
Deep	200-1000 m	D
Abyssal	> 1000 m	A

¹Attribute = 'Depth';

Attribute value 'X' = land

Results

A total of 251 polygons were produced (Figure 2). Particular bathymetric features evident include the continental shelf, the bank to the northeast of the Queen Charlotte Islands, the finger-like trenches in Queen Charlotte Sound and the deep fjords and passages along the coast. Due to the offshore extent of the study area, the majority of the area falls into the abyssal range greater than 1000 m (Table 2).

Table 2. Depth Class Distribution by Area

Class	Total Area
Shallow, 0-20 m	7,400 km ²
Photic, 20-50 m	15,200 km ²
Mid-depth, 50-200 m	60,100 km ²
Deep, 200-1000 m	34,700 km ²
Abyssal, >1000 m	336,400 km ²

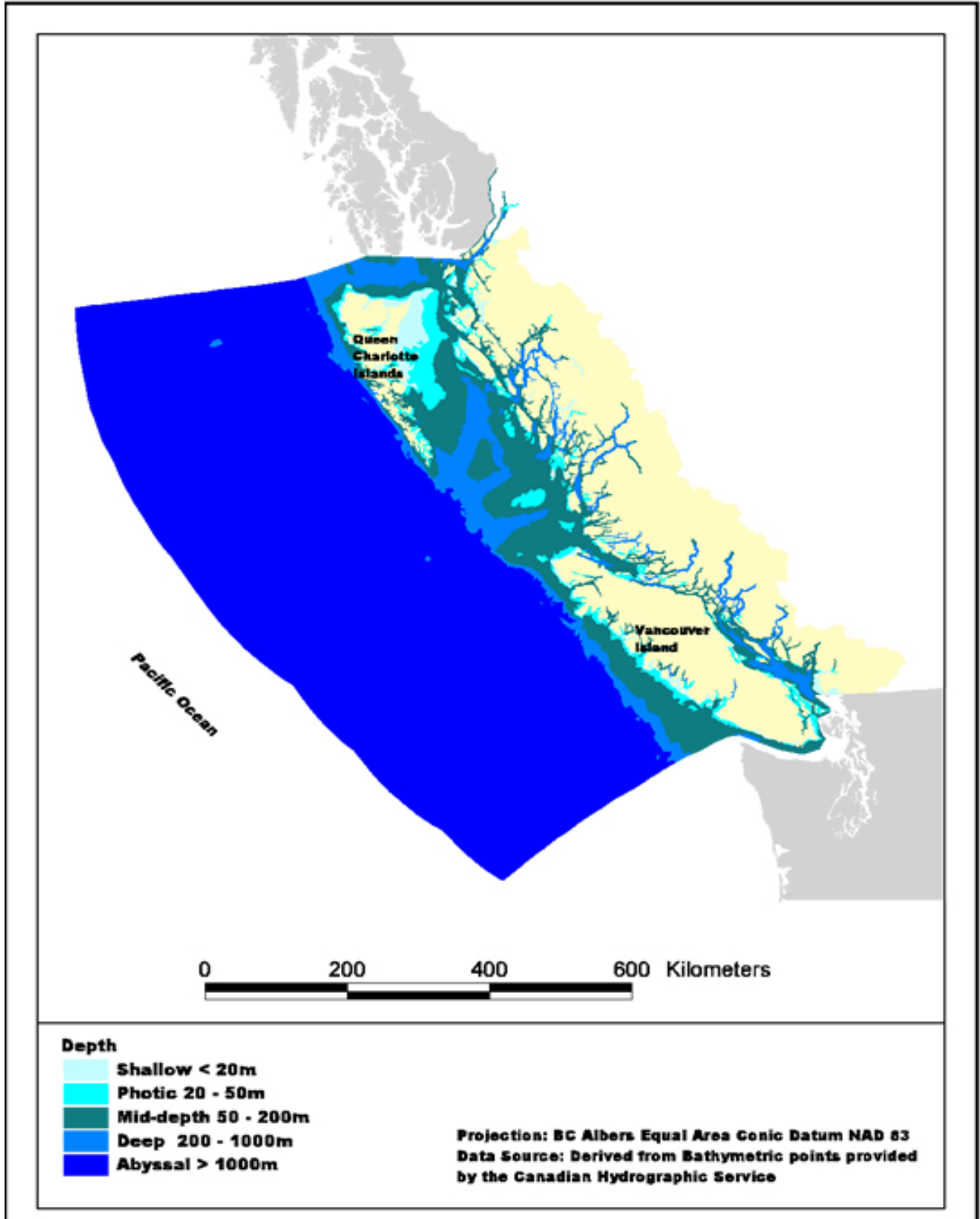


Figure 2 - Depth

2.2 Slope

Data Source

The bathymetric data set described above was used to derive slope.

Methodology

Slope (change in elevation) was derived for each triangular polygon in the bathymetric TIN described above. Based on discussions with marine ecologists and a survey of classification systems used, slope values were divided into three classes using the same method as described above for depth (Table 3). An additional class of greater than 45% was considered, but the size of the area was less than the minimum size, and therefore, was deleted in the elimination process.

Table 3. Slope Classes

Class	Slope range	Attribute¹ value
Flat	0-5%	F
Sloping	5-20%	S
Steep	>20%	T

¹Attribute = 'Slope';

Attribute values: 'X' = land; 'U' = undefined

Results

A total of 84 polygons were created (Figure 3). As expected, the predominant slope class is less than 5% (Table 4) with the steepest areas occurring in the fjords and some isolated occurrences at the edge of the continental shelf. Areas offshore beyond available data were extrapolated as flat, therefore particular features may not be represented.

Table 4. Slope Classes by Area

Class	Area
Flat, 0-5%	405,569 km ²
Sloping, 5-20%	4,737 km ²
Steep, >20%	427 km ²

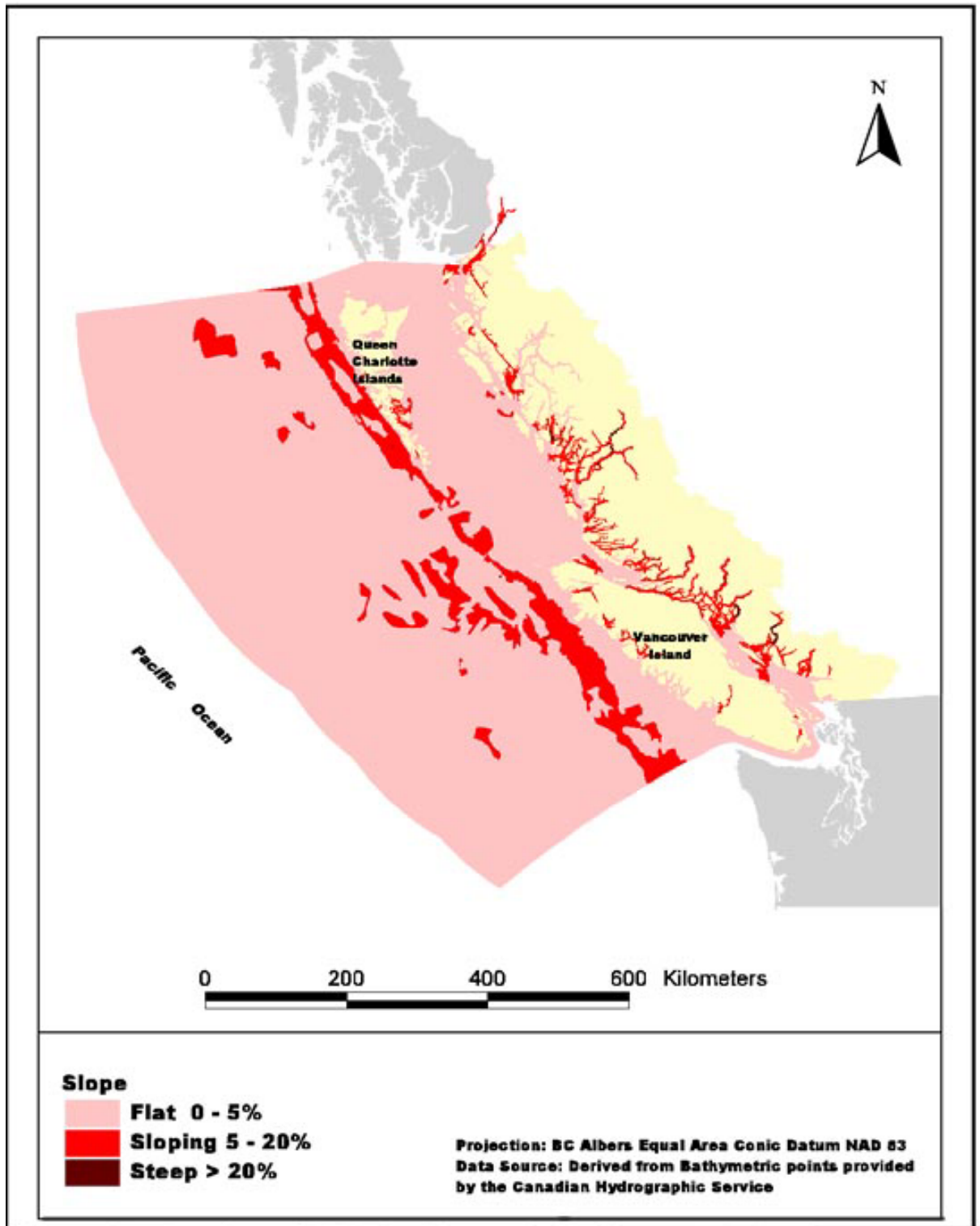


Figure 3 - Slope

2.3 Relief

Data Source

The bathymetric data set described above was used to derive relief.

Methodology

Much discussion ensued at the workshop regarding the definition and measurement of relief, particularly focused on describing the 'lay of the land' versus identifying specific features such as canyons and peaks. Various methods were presented to model relief including slope, slope derivative (change in slope) and variation in slope, all of which produced similar results (AXYS 2000). In determining an appropriate method, subsequent consideration was also given to developing a simpler approach based on the ratio of surface area to sea bottom area as a measure of the general 'lay of the land'; the assumption being that the higher the ratio, the more varied or undulating the terrain. It was also recognised that the slope variable itself was an informative measure of sea bottom morphology and was consistent with the national framework developed by Day and Roff (2000) (see Section 3.2).

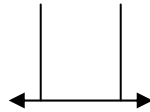
The selected concept for 'relief' was to combine the variability in aspect with the magnitude of slope. In this way, areas with a high variability in slope direction (*i.e.*, aspect) combined with a steep slope were identified as being the highest relief. The process is summarised in Figure 4, and discussed in detail below.

Prepare Slope:

- 250 m slope grid
- Mean of neighbouring values (smoothing)
- Reclassify to integer values of (0, 1, 2)

Prepare Aspect:

- 1 km aspect grid
- reclassify bearing
- determine variability of neighbouring values
- Mean of neighbouring values (smoothing)
- Reclassify to integer values of (0, 1, 2)



Combine Slope and Aspect:

- Overlay resulting Slope and Aspect using Sum (+)
- Reclassify resulting grid into H, M, L relief.

Figure 4. Relief Calculation

As with the individual slope layer, slope (change in elevation) was derived for each triangular polygon in the bathymetric TIN described above, using a 250 m raster grid. In order to smooth the resulting grid (and to amalgamate fragmented areas of similar slope), a neighbourhood analysis using the mean (assigning a cell value the mean of its neighbouring values) was used. Finally, the slope grid was assigned values of 0, 1 or 2 based on the same classification ranges used for the slope layer (Table 5).

Table 5. Slope Reclassification for Relief Calculation

Class	Slope range	Cell Value
Flat	0-5%	0
Sloping	5-20%	1
Steep	>20%	2

Aspect variability measures are sensitive to the density of sample points (*i.e.*, the density of triangles in the TIN) in that more densely sampled areas appear to have more variability in aspect. Depth sample point density for the study area is inconsistent, in many cases fluctuating from over 20 samples per km² to less than 2 samples per km² over a distance as small as 2 km (see Section 4.0 for a discussion on scale and accuracy). In order to reduce the bias toward highly sampled areas, it was decided to increase the grid cell size to 1 km for aspect.

The 1 km aspect grid was first reclassified to change bearings (0° – 359°) into bearing classes (a numeric equivalent to N, NW, W, etc.) (Table 6).

Table 6. Aspect Classes

Class	Aspect Range	Cell value
N	0° - 22.5°, 337.5° - 360°	1
NE	22.5° - 67.5°	2
E	67.5° - 112.5°	3
SE	112.5° - 157.5°	4
S	157.5° - 202.5°	5
SW	202.5° - 247.5°	6
W	247.5° - 292.5°	7
NW	292.5° - 337.5°	8

The second step is to determine the variability of neighbouring aspect cells. Variability in aspect cannot use measures such as range or standard deviation, since the values “1” and “8” (or 359° and 1°) are actually very similar in bearing, but mathematically very different. Consequently, the measure used was simply “Variety”, meaning a count of the number of different values present in the eight neighbouring cells. As with slope, a smoothing (mean) neighbour analysis was performed. Finally, in order to give aspect the same mathematical weight as slope, this resulting grid was reclassified into integer values of (0, 1, 2) (Table 6).

Table 7. Aspect Reclassification for Relief Calculation

Class	Aspect Variety Range	Cell Value
Not Variable	$0 - (\mu + 1\sigma)^1$	0
Variable	$(\mu + 1\sigma) - (\mu + 2\sigma)$	1
Highly Variable	$(\mu + 2\sigma) - \infty$	2

1. $(\mu + 1\sigma)$: Mean + one standard deviation

The resulting aspect grid was overlaid with the reclassified slope grid to produce a relief grid, with values ranging from zero to four. These values were then translated into High, Medium and Low Relief (Table 8). Areas beyond the extent of available data were extrapolated as 'Low'.

Table 8. Relief Classes

Class	Slope range	Attribute value
Low	0 – 1	L
Medium	2	M
High	3 – 4	H

Results

There were 508 relief polygons produced (Figure 5). As expected, the predominant class is Low relief (Table 9) with High relief 'hotspots' occurring near Dundas Island, Louise and Lyell islands in the Queen Charlotte Islands, Banks Island, and the northeast coast of Vancouver Island.

Table 9. Relief Classes by Area

Class	Area
Low	448,495 km ²
Medium	20,843 km ²
High	2061 km ²

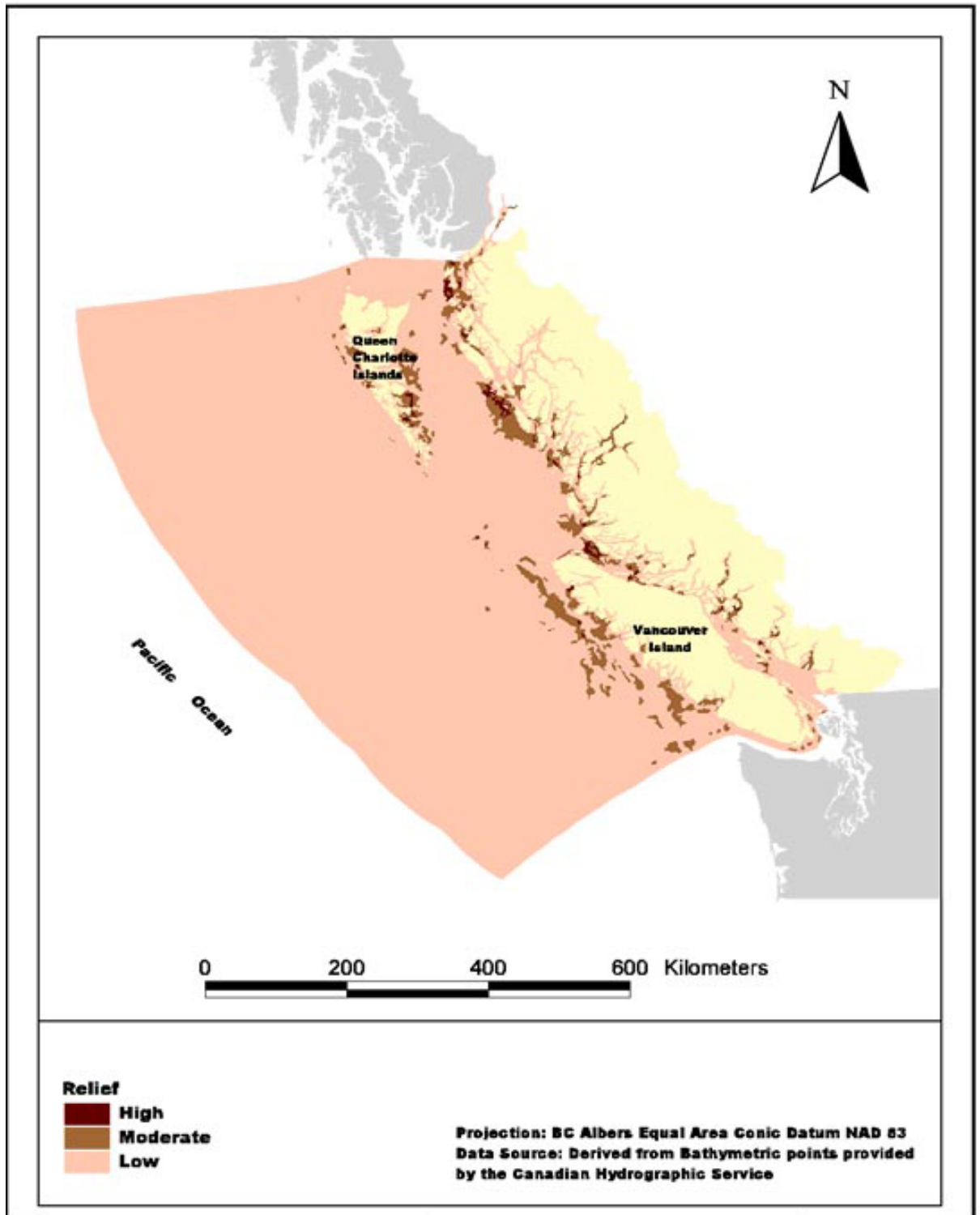


Figure 5 - Relief

2.4 Temperature

Data Source

Three datasets covering nearshore fjords and bays (BC Ministry of Fisheries), Strait of Georgia and Juan de Fuca (Crean/Ages dataset from the Institute of Oceans Sciences) and the remainder of the marine waters (already obtained by MSRM from the Institute of Oceans Sciences), were used to compile a comprehensive coverage of temperature (Table 10). This data set was also used for salinity and stratification.

The original temperature and salinity dataset obtained by MSRM from Bill Crawford at the Institute of Ocean Science reflected two depths, surface (3 metres), and bottom. Data at the same stations at additional depths were obtained from Bill Crawford and Ann Ballantyne to facilitate stratification calculations.

The Ministry of Fisheries (MoF) data were compiled from CTD data collected by AXYS over a 6-year period for several study areas. For this project, the MOF depth ranges have been joined with the IOS data as follows: 0-5 m = surface (3 m), 5-20 m = 20 m, and 20-50 m = 50 m.

In consultation with Dr. Masson, the Crean/Ages information was the data set that was most closely related to the IOS data already available. The Crean/Ages data were collected in 1968 during cruises of the Strait of Georgia and the Juan de Fuca Strait (Crean and Ages 1971). The data were collected inclusively between December 1967 and December 1968, with information collected every month except June and September of 1968. This data set was made available through Dr. Diane Masson at IOS. Data gathered between mid-May and the end of October have been averaged as summer values, while other monthly data has been averaged as winter values (John Roff, pers. comm.). Depth values have been averaged and joined with the IOS data using the same method as the MOF data.

While each of these three data sets has differing sampling intervals in terms of the numbers of years, they were chosen because of the wide seasonal distribution of sampling times, their areas of spatial distribution, and their approximate 1 km resolution. Other data sets were available (e.g. BC Lighthouse data) which were not incorporated because the data were scattered too widely, or were from areas in which we already had a large amount of like data.

Methodology

It was concluded at the workshop that minimum summer sea bottom temperatures would be used to define benthic marine ecoregions. Of the three sources of data, only the original IOS data explicitly included a measurement of sea bottom temperature. Both the Ministry of Fisheries and Crean/Ages datasets provided temperature data down to a maximum of 50 m. Those data points at which the maximum depth was less than 50 m were assigned a bottom temperature equivalent to that of 50 m; the remainder were deleted from the dataset. The resulting dataset comprised 7467 points. As a result, there are no data for the upper reaches of some central coast and north coast fjords. In addition, data were extrapolated to cover the offshore extent of the study area.

Table 10. Temperature and Salinity Data Sets

Data source	Spatial Coverage	Depths	Seasons	Years	# of Data Points
Institute of Ocean Science (IOS)	Information in all ecoregions except for Juan de Fuca	3, 5, 10, 20, 50, 200 metres, and bottom	Winter and summer	Unknown (averaged over a number of years)	7414
Ministry of Fisheries	All fiord and inlet areas off mainland, Barkley and Clayoquot Sound	Depth averaged to: 0-5 metres 5-20 metres 20-50 metres	Winter and summer	1995-2000	920 (summer) 813 (winter)
Crean/Ages dataset	Strait of Georgia and Juan de Fuca	Depth averaged to: 0-5 metres 5-20 metres 20-50 metres	Monthly averaged to Winter and summer	1967-1968	935

A temperature 'surface' was created by interpolating a TIN from the data points. Using the same methodology as described above for bathymetry, temperature polygons were derived and classified into two classes primarily based on Booth *et al.* (1996) confirmed at the workshop (Table 11). Booth *et al.* (1996) chose a classification scheme for temperature distinguished at 9°C and 15°C as the most ecologically relevant for a subtidal habitat classification system for the British Columbia coast (There were no sea bottom temperatures greater than 15°C found in the BC MEC dataset). They considered that these values represent the most critical temperature divisions needed. They also recommended these same variables for the definition of small coastal units. It should be noted that participants at the workshop recognised that there is little scientific literature confirming ecologically-relevant temperature classes.

Table 11. Temperature Classes

Class	Temperature range	Attribute¹ value
Warm	9-15 °C	W
Cold	< 9 °C	C

¹Attribute = 'Temperature'; Attribute values: 'X' = land; 'U' = undefined

Results

A total of 69 temperature polygons were created (Figure 6). The vast majority of the area is classified as cold <9 °C (Table 12) with warmer waters evident nearshore surrounding Vancouver Island, and the northwest region of Hecate Strait.

Table 12. Temperature Classes by Area

Class	Area
Warm, 9-15 °C	24,400 km ²
Cold, <9 °C	482,200 km ²
Undefined	1,160 km ²

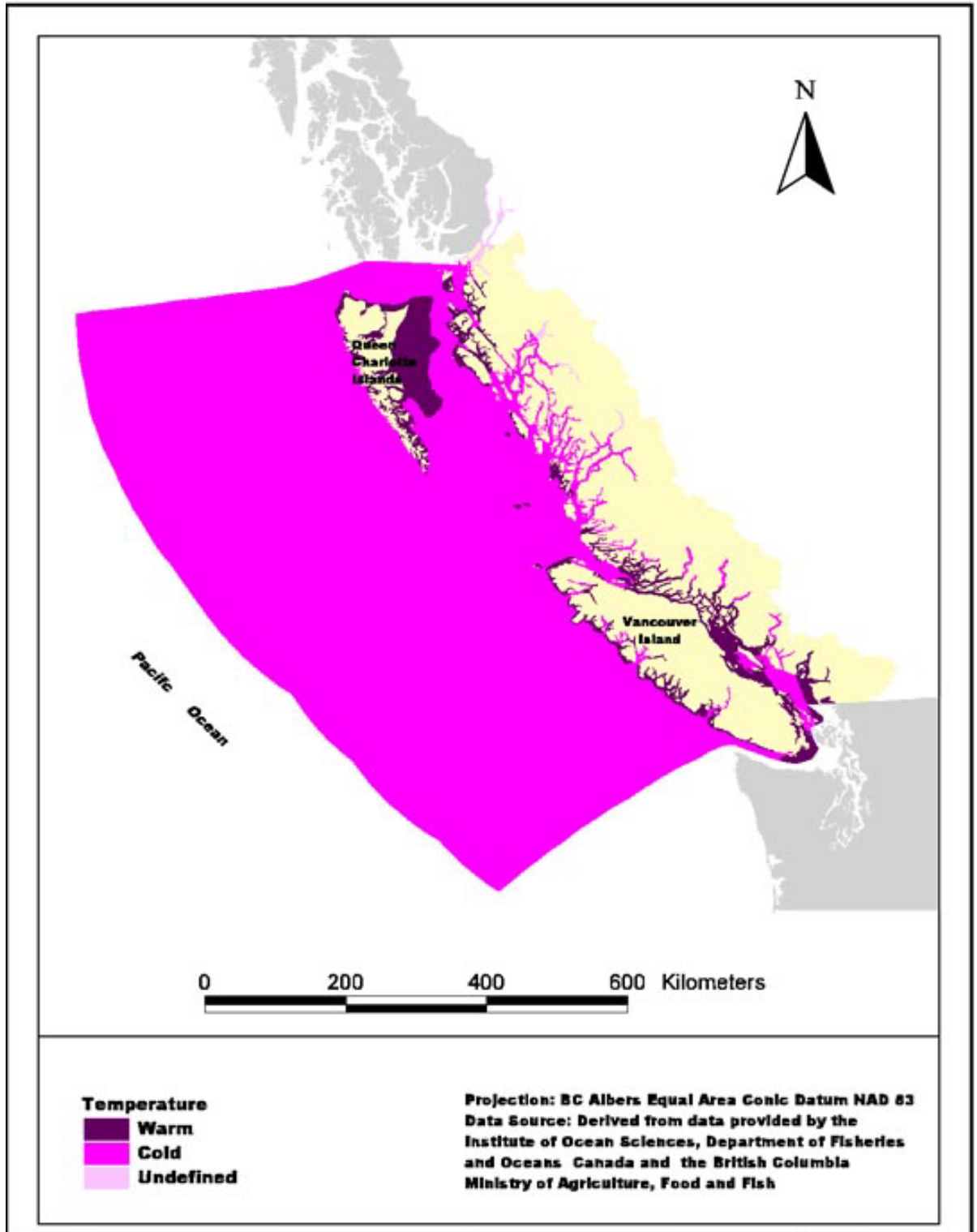


Figure 6 - Temperature

2.5 Benthic Ecounits

Methodology

Six variables (depth, slope, temperature, current, exposure and substrate) were overlaid to create benthic ecounits. All resulting polygons less than 15 km² were eliminated (merged with their largest neighbouring polygon). The relief layer was incorporated last and digitised to preserve existing ecounit boundaries as much as possible and minimize the creation of new ecounits.

Results

A total of 1201 benthic ecounits were created comprising 263 unique classes (*i.e.*, unique combination of attributes) (Figure 7). This compares with 619 ecounits and 65 unique classes in the initial marine ecounits. The largest marine ecounit class is the offshore area classified as Undefined Substrate, High Exposure, Low Current, Flat Slope, Abyssal Depth, Cold Temperature and Low Relief (Table 13). The smallest marine ecounit class was classified as Hard Substrate, Moderate Exposure, Low Current, Sloping Slope, Mid-depth, Warm Temperature and High Relief.

Table 13. Largest and Smallest Benthic Ecounit Classes

	Largest Area			Smallest Area		
Substrate	Undefined	Undefined	Sand	Hard	Sand	Hard
Exposure	High	High	High	Moderate	Moderate	High
Current	Low	Low	Low	Low	High	High
Slope	Flat	Sloping	Flat	Sloping	Flat	Sloping
Depth	Abyssal	Abyssal	Mid-depth	Mid-depth	Mid-depth	Mid-depth
Temperature	Cold	Cold	Cold	Warm	Warm	Cold
Relief	Low	Low	Low	High	High	Moderate

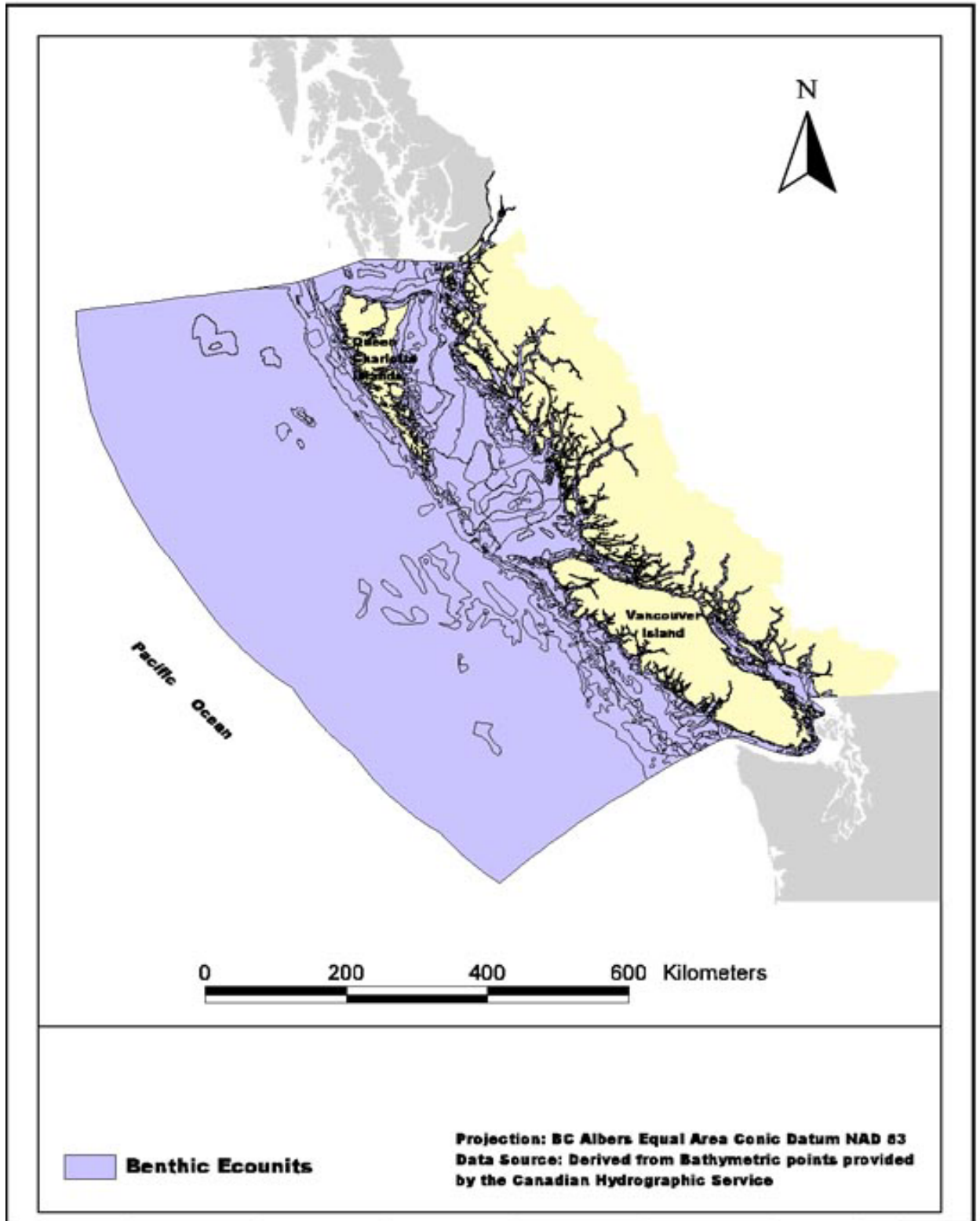


Figure 7 - Benthic Ecounits

3. PELAGIC ECOUNITS

Pelagic ecounits are intended to describe the sea surface and water column. Two variables were selected to derive pelagic ecounits:

1. Salinity
2. Stratification

3.1 Salinity

Data Source

The same dataset used for temperature contained measurements of salinity taken at various depths in summer and winter.

Methodology

It was concluded at the workshop that average summer and winter minimum surface salinity values would be incorporated into the pelagic ecounit. Therefore, surface salinity values for summer and winter were averaged to create a single value. In the event that a data point had a zero value for either summer or winter, the data point was deleted from the analysis. Data were extrapolated to cover the offshore extent of the study area.

In the national marine ecosystem classification system developed by Day and Roff (2000), salinity is used in Level 1 of the hierarchy to distinguish marine environments (>30 ‰) from other environment types, *e.g.*, freshwater lotic, freshwater lentic and estuarine, which are not included in the national classification system framework due to the scale of classification. Since the BCMEC system extends into less saline fjords and estuaries, a more refined salinity classification is required.

There are several salinity classification schemes that are potentially applicable (Table 14). The standard for the U.S. Department of Fish and Wildlife is the Cowardin system (Cowardin *et al.* 1976). Jane Watson, in her review of ecosystem classification for the Department of Fisheries and Oceans, recommends the Cowardin system as objective and uncomplicated in its required parameters. Levings and Thom (1994), and Booth *et al.* (1996) have problems with the use of this system for the British Columbia coast, as it was developed specifically for the Puget Sound, and is not designed to incorporate either pelagic areas or inlets.

As with the temperature data, a salinity ‘surface’ was created by interpolating a TIN from the data points. Using the same methodology as described above for bathymetry, salinity polygons were derived and classified into three classes confirmed at the workshop as being the most ecologically relevant (Table 15).

Table 14. Comparison of Various Salinity Classification Schemes

Salinity (0/00)	Cowardin	Bulgar <i>et al.</i>	Booth <i>et al.</i>	Laffoley & Hiscock
0	● <.05 Fresh ● Oligohaline	● Fresh	● Dilute	● Upper Estuary
5		● Oligohaline		● Inner Estuary
10	● Mesohaline	● Mesohaline	● Estuarine	● Middle Estuary
15	● 18pp	●		● Lower Estuary
20	● Polyhaline	● Polyhaline		● Sea
25	●	●	● Marine	
30	●	● Marine		
35	● Euhaline	●		
40	● Hyperhaline	●		

Table 15. Salinity Classes

Class	Salinity range	Attribute ¹ value
Mesohaline	5-18 ppt	M
Polyhaline	18-28 ppt	P
Euhaline	28-35 ppt	E

¹Attribute = 'Salinity'; Attribute values: 'X' = land;

Results

A total of 64 salinity polygons were created (Figure 8). The majority of the marine waters is classified as euhaline (Table 16) and the freshwater influences can be noted in the Strait of Georgia and the fjords.

Table 16. Salinity Classes by Area

Class	Area
Mesohaline, 5-18 ppt	1,500 km ²
Polyhaline, 18-28 ppt	12,800 km ²
Euhaline, 18-35 ppt	439,500 km ²

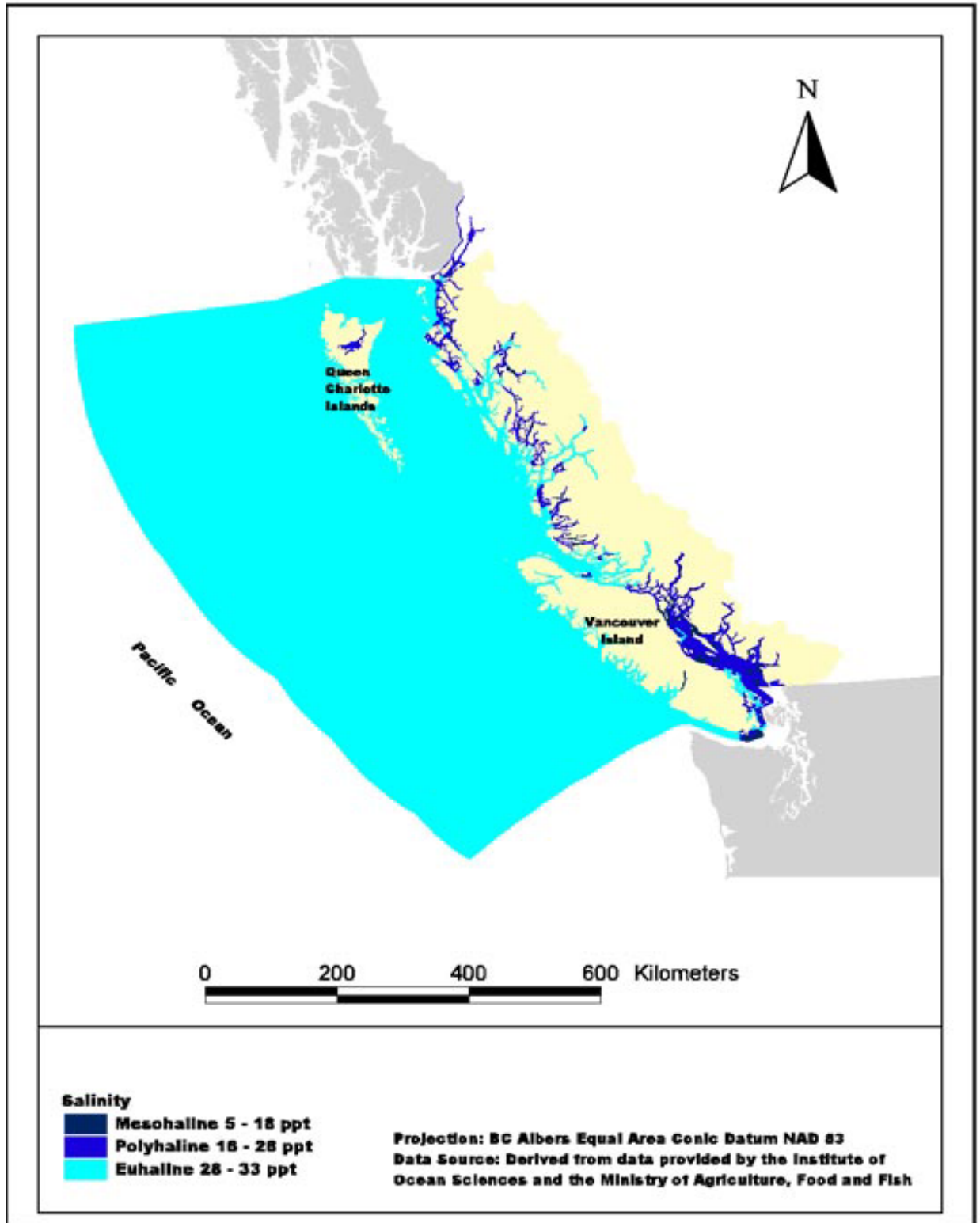


Figure 8 - Salinity

3.2 Stratification

Data Source

Temperature and salinity data described above was used to calculate stratification as the change in density over depth. Tidal current data obtained from the Institute of Ocean Sciences were used to calculate the Hunter- Simpson Stratification Index.

Methodology

Due to the freshwater influence in nearshore waters it was decided to model stratification as a density differential between surface and bottom waters ($\rho_{\text{bottom}} - \rho_{\text{surface}}$) using the standard UNESCO algorithm (UNESCO 1983). A differential of 25 units signifies complete freshwater/saltwater stratification. Initially a depth interval of 50 m was chosen, however this would skew the data for those areas less than 50 m deep. The density differential classes were chosen to reflect known stratification patterns in BC waters as confirmed by Dr. Bill Crawford of the Institute of Ocean Sciences (Table 17). The Hunter-Simpson Stratification Index (HSSI) was also used to further refine the results by identifying mixing areas due to tidal mixing. HSSI for those areas identified as mixed were calculated. Where $\text{HSSI} < 1$, these areas were classified as tidal mixing. Because the density differential method required sea bottom temperature and salinity measurements, complete coverage was not feasible for parts of the Strait of Georgia and upper reaches of fjords.

Table 17. Stratification Classes

Class	Stratification range	Attribute ¹ value
Tidal mixing	$\text{HSSI} < 1$	T
Mixed	0.002-2.5 ($\Delta\rho$)	M
Weakly-mixed	2.5-3 ($\Delta\rho$)	W
Stratified	3-17.35 ($\Delta\rho$)	S

¹Attribute = 'Stratification';

Attribute values: 'X' = land; 'U' = Undefined

Results

Seventy-eight stratification polygons were created and the majority of the area was classified as stratified including Dixon Entrance and the Strait of Georgia (Figure 9; Table 18). Notable mixed areas including Hecate Strait, west, north and northeast coast of Vancouver Island, and

the bank in Queen Charlotte Sound. Tidal mixing is evident off the northeast and southern tips of the Queen Charlotte Islands and several narrow passages.

Table 18. Stratification Classes by Area

Class	Area
Tidal mixing	430 km ²
Mixed	49,300 km ²
Weakly-mixed	20,800 km ²
Stratified	378,200 km ²
Undefined	4,800 km ²

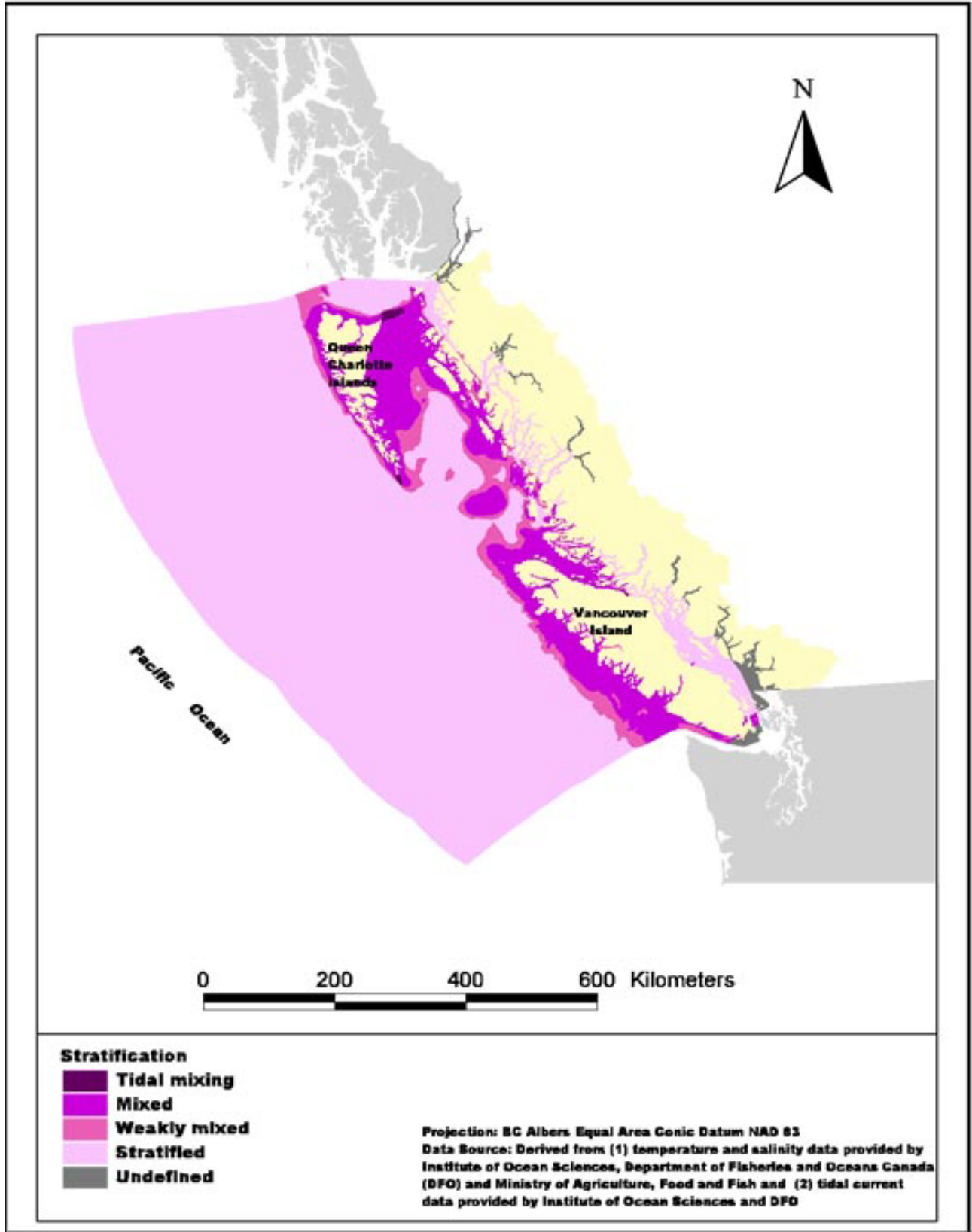


Figure 9 - Stratification

3.3 Pelagic Ecounits

Methodology

Salinity and stratification were overlaid to create pelagic ecounits. All resulting polygons less than 15 km² were eliminated (merged with their largest neighbouring polygon).

Results

A total of 155 pelagic ecounits were created comprising thirteen unique classes (*i.e.*, unique combination of attributes) (Figure 10). As with the benthic ecounits, the marine environment is fairly uniform offshore of the continental slope represented by one single ecounit. The largest marine ecounit class is the offshore area classified as Stratified and Euhaline (Table 19). The smallest marine ecounit class was classified as tidal mixed and polyhaline.

Table 19. Largest and Smallest Pelagic Ecounit Classes

	Largest Area			Smallest Area		
Stratification	Stratified	Mixed	Weakly-mixed	Tidal mixing	Mixed	Weakly mixed
Salinity	Euhaline	Euhaline	Euhaline	Polyhaline	Mesohaline	Polyhaline

4. DISCUSSION

Twelve distinct marine ecosystems have been identified for the British Columbia marine environment on the basis of this analysis (Table 4). They range in size from 1500 to 171,000 square kilometers. The Subarctic Pacific and Transitional Pacific Ecoregions are defined on ocean currents and circulation and have not been further subdivided at the ecosystem level for this classification. The remaining ecosystems display a unique combination of the physical themes used in this study.

The spatial location of these west coast ecosystems are presented on Figure 8 and their dominant physiographic, oceanographic and biological features are summarized on Table 5. The boundaries of these ecosystems have been defined according to the 1:250,000 thematic data and ecounits. Digital copies of the classification are available in ARC/INFO format.

Testing and verification of the British Columbia Marine Ecological Classification 'ecounits' continues to be developed by Decision Support Services Branch of the Ministry of Sustainable Resource Management, under the direction of a Marine Ecological Classification Working Group (Zacharias & Howes 1997).

Table 20 - Summary characteristics of the BC marine ecoregions

Marine Ecoregions	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rationale
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 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 slope 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 R. 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 Is Shelf
Queen Charlotte Strait	Predominantly shallow (< 200 m), 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

Marine Ecosystems and Ecounits

Marine Ecosystems	Physiographic Features	Oceanographic Features	Biological Features	Boundary Rationale
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 shelf break. 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 flow 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 shelf break. 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

5. CONCLUSION

BCMEC is a planning tool to be used for understanding coastal and marine environments, and identifying conservation and management issues. As with any planning tool, it is important to know the accuracy of the information upon which decisions are made as a measure of faith in the decision itself. Accuracy is informed by the inherent scale of the data and the processing or data manipulation steps which may introduce error or otherwise erode accuracy. The various data sources and data manipulation steps make it difficult to calculate a specific accuracy measure for the ecounits. However, discussion of several factors can inform on the reliability and constraints of using BCMEC as a planning tool.

There are two primary data sets which were used to derive six new layers: bathymetric data from which depth, slope and relief were derived; and temperature/salinity data from which temperature, salinity and stratification were derived. Each of the primary data sets itself was compiled from various data sets which in turn muddies the water with respect to estimating a definite accuracy of the ecounits.

The bathymetric data is a composition of various charts and oceanographic data sheets ranging in scale from 1:5,000 to 1:1,000,000. Few of the source data sets are at these extremes of scale and predominantly the data area at 10 km line spacing and 700 m along line (T. Curran, pers. comm.). In general, the resolution of coastal areas is higher (around 20 samples points per 10 km²) than offshore areas (generally less than two sample points within 10 km²) (Figure 11). In fact, there are no data for much of the offshore area out to the 200 nm boundary of BCMEC, nor for some of the northcoast fjords. Thus the inherent nominal accuracy of the bathymetric data ranges from 700m in nearshore areas, to +/- 3km throughout much of the area for which data are available. These accuracies correspond to scales of 1:700,000 and 1:3,000,000 respectively.

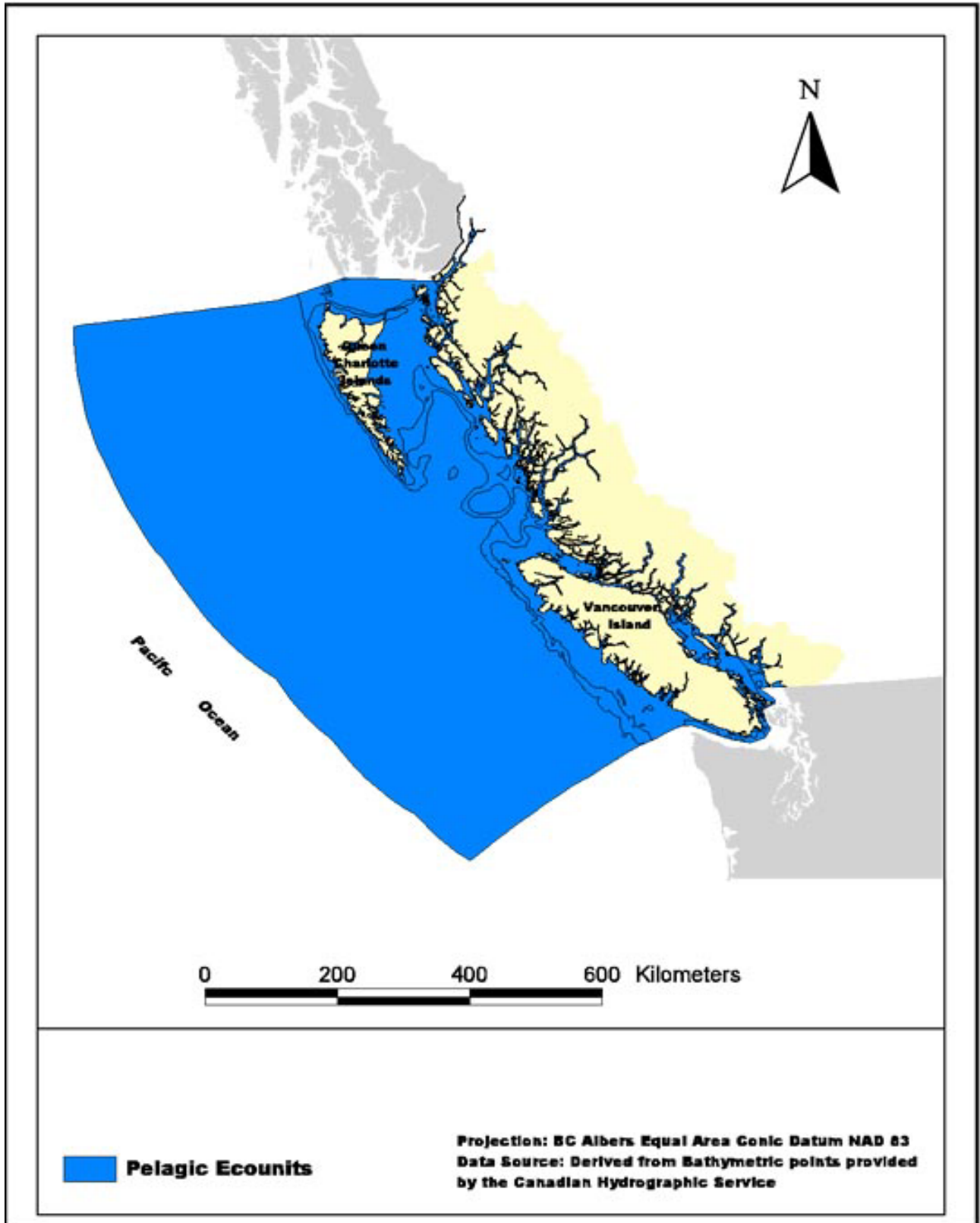


Figure 10 - Pelagic Ecouints

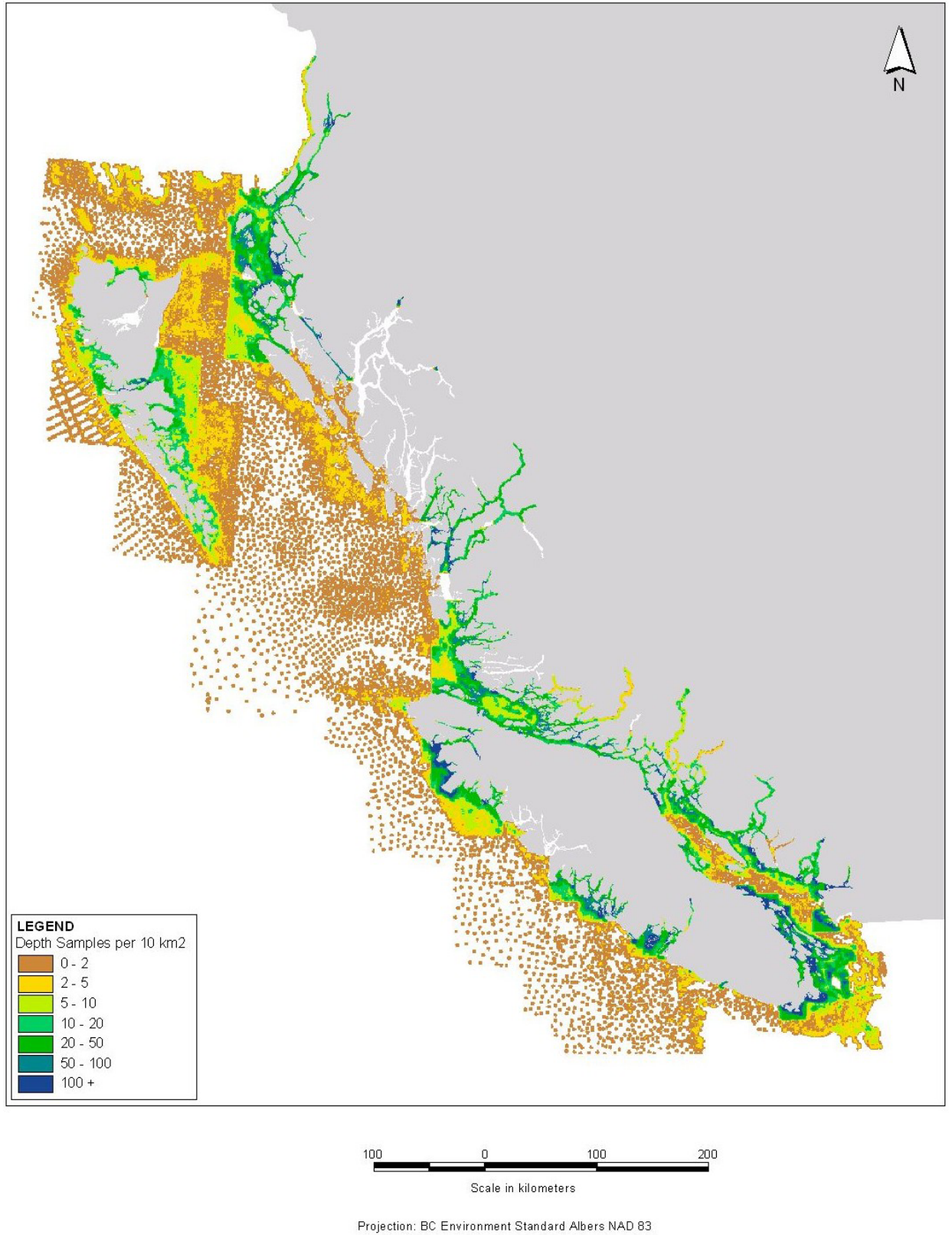


Figure 11 - Depth Samples per 10 km²

Marine Ecosections and Ecounits

It has been raised that another data set, the 1:250,000 Natural Resource Maps, is a better bathymetric data set. However, the NRM data are extracted, interpolated and/or generalised from the same data set used in BCMEC (T. Curran pers. comm.). Therefore, the reported 1:250,000 scale is not uniform and in some areas is likely to be larger than the nominal accuracy of the data.

The bathymetric data was used to derive depth, slope and relief. Each following similar steps comprising:

- Georeferencing;
- Interpolation;
- Extrapolation in offshore areas;
- Gridding at 250 m (accuracy of 125 m) (aspect from which relief was derived was gridded at 1 km to reduce variability bias due to point density);
- Smoothing using a 9 x 9 window (generalising to approximately +/- 1 km);
- Raster to vector conversion;
- Elimination of slivers;
- Splining of relief polygons to smooth the vector linework; and
- Manual editing of slope polygons to delete spikes generated by the TIN.

The processing decisions were based on:

- Producing a relatively smooth coverage rather than one with steps (from the grid) or spikes (from the TIN);
- Recognition that the resulting benthic ecounits would be formed by combining 7 layers and a need to produce a heretofore undefined “manageable” number of ecounits; and
- Desire to automate as much of the process as possible.

The result is that coastal areas which started as a scale as low as 1:5000 were generalised to the extent that there is little width variation in a fjord (the result of the 250 m grid). Conversely, offshore areas, particularly those where data were sparse or where there was no data at all, the implied accuracy is greater than the actual accuracy. This is not unexpected when modelling sea bottom for marine areas stretching from indented and complex coastlines, to a pronounced continental slope, to a large expanse of abyssal sea bottom.

The temperature and salinity data from which stratification was also derived was an amalgamation of the three data sources. The initial resolution of data points is as high as over 100 sample points in 100 km² (nominal accuracy approximately +/- 1km) in Barkley Sound and the southern tip of Queen Charlotte Islands, to less than two sample points in 100 km² (nominal accuracy approximately +/- 7km) in much of the offshore area except for offshore of Vancouver Island (Figures 12, 13 and 14). The mean sample density of approximately 4 samples per 100 km² translates to a scale of 1:5,000,000. There is a notable lack of data in many fjords and offshore areas out to the 200 nm limit. There is also a sparsity of data for the

Strait of Georgia in the data set acquired. The density of points used for temperature, salinity and stratification analysis are similar. However, the density of points in some areas is slightly less for temperature, which required data points with bottom temperature measurements. It is sparser yet for the stratification analysis, which required temperature and salinity data at two depths.

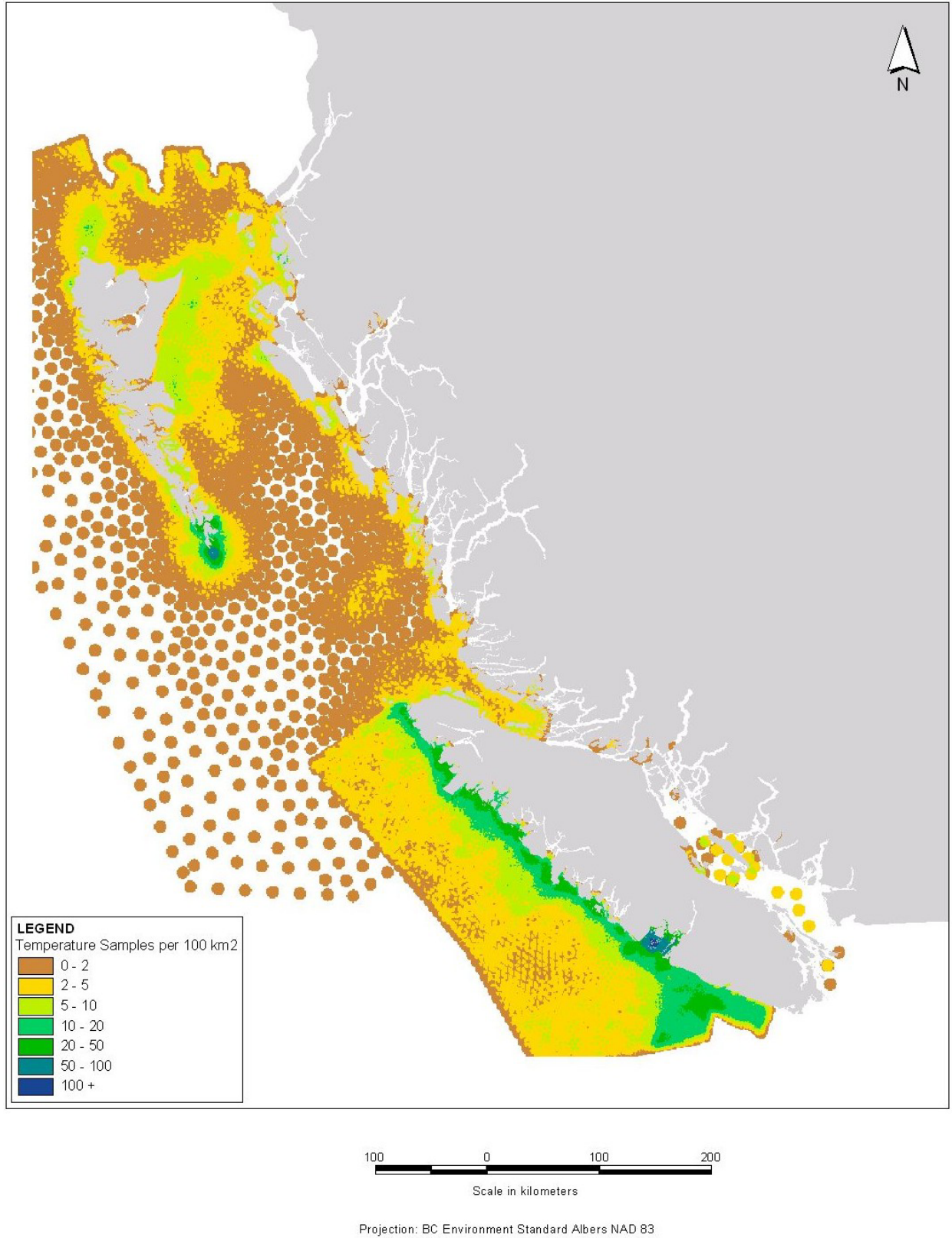


Figure 12 - Temperature Samples per 100 km²

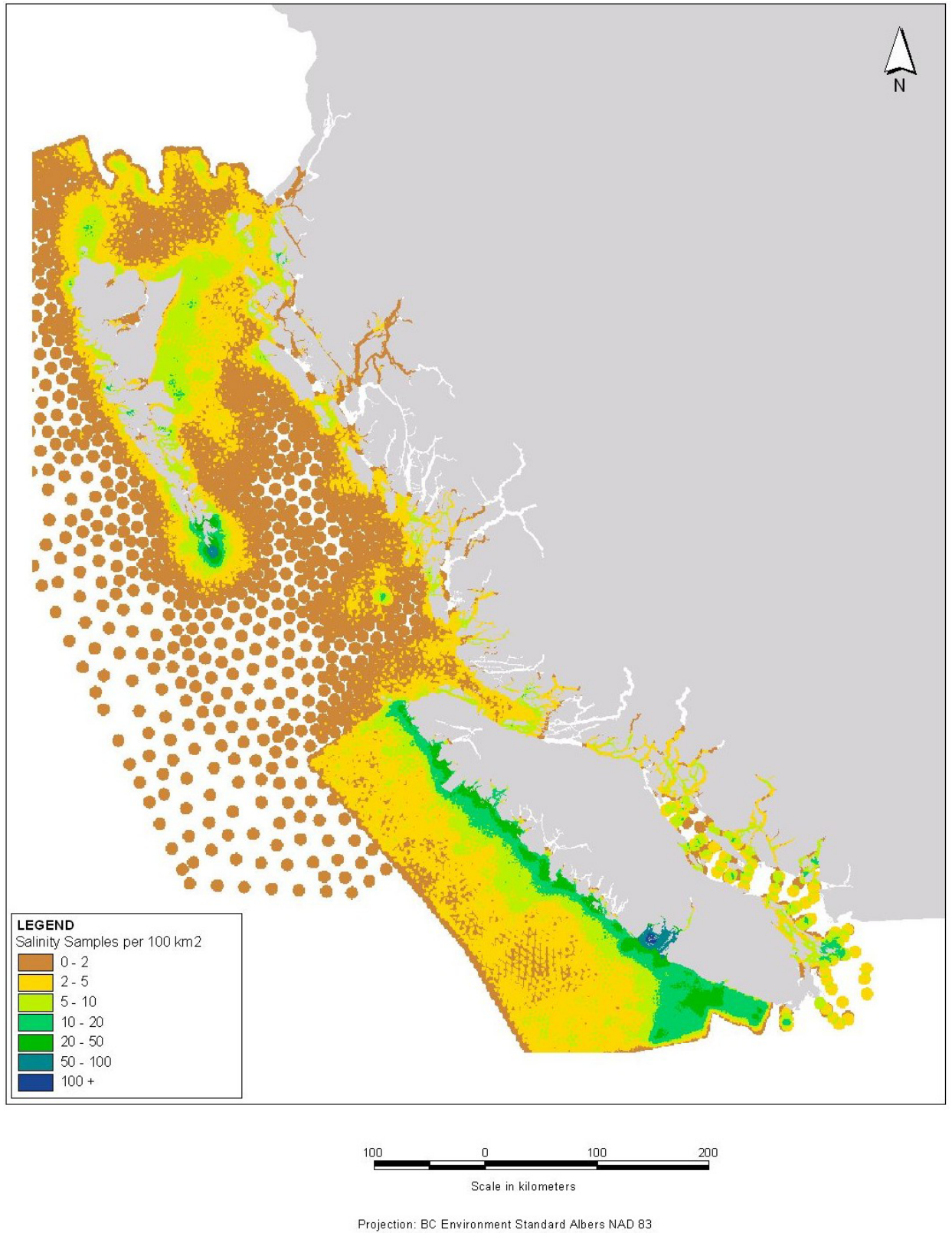


Figure 13 - Salinity Samples per 100 km²

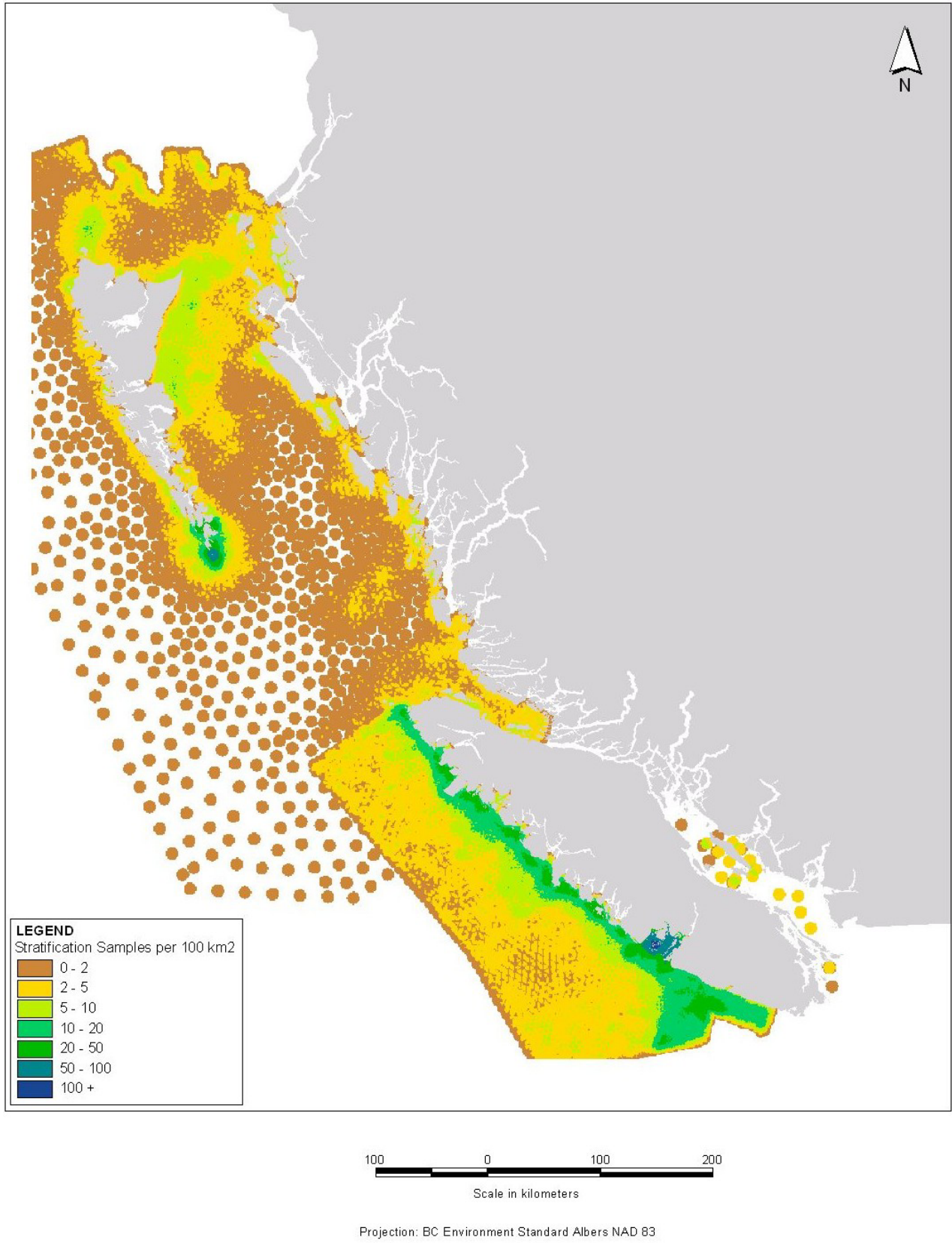


Figure 14 - Stratification Samples per 100 km²

Similar processing steps were applied to these data as were applied to bathymetry data.

Once each of the layers was prepared, six of the seven benthic layers (excluding relief) were overlaid and the two pelagic layers were overlaid. A minimum area of 15 km² was used as a threshold to eliminate spurious polygons. This was consistent with the minimum area applied to the initial BC MEC. A 15 km² minimum polygon size can be equated to +/- 4 km or a scale of 1:4,000,000. For coastal areas, this represents a marked generalisation and reduction in accuracy. For offshore areas, this represents a higher implied level of accuracy than is reflected in the data. However, with the exception of 'pockets' of slope and relief polygons, the offshore areas are more uniform in physical and oceanographic characteristics.

As was discussed previously, the relief layer was added last to the benthic ecounits and its delineation was guided by classifying existing ecounits and minimising the number of new ecounits. This hierarchical approach to adding relief implies less accuracy to relief in the benthic ecounits than other attributes, but not less accuracy in the individual relief layer.

The combination of more layers in the benthic ecounits than pelagic ecounits created more smaller polygons from the intersection of linework. Therefore, the elimination of polygons less than 15 km² would have a more pronounced effect on the benthic ecounits than the pelagic ecounits. Therefore, for more accurate characterisation of any specific variable is preferable to refer to the individual layer prior to the overlay.

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