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BRITISH COLUMBIA MARINE ECOLOGICAL CLASSIFICATION UPDATE

Final Report

Submitted to:

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TABLE OF CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

In 1994, the Ministry of Sustainable Resource Management (MSRM) (then the Land Use Coordination Office) developed the BC Marine Ecological Classification (BCMEC) system to assist in the conservation, management, and planning of coastal and marine resources. The smallest unit of this hierarchical classification system is the ecounit previously defined by: current, depth, substrate, relief, and wave exposure, and comprising 619 ecounits representing 65 unique classes, or combinations of the above variables.

The BCMEC has been updated at the ecounit level to include salinity, temperature, stratification, slope and by revising depth with new data and modeling relief. In addition, two types of ecounits are distinguished, namely benthic, describing the seabed and foreshore, and pelagic, describing the sea surface and water column (Figure 1).

This Final Report describes the methodology followed for each of the new data layers and for the creation of benthic and pelagic ecounits. 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 includng oceanographers, marine ecologists and marine park specialists from provincial, federal and U.S. agencies. The 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.

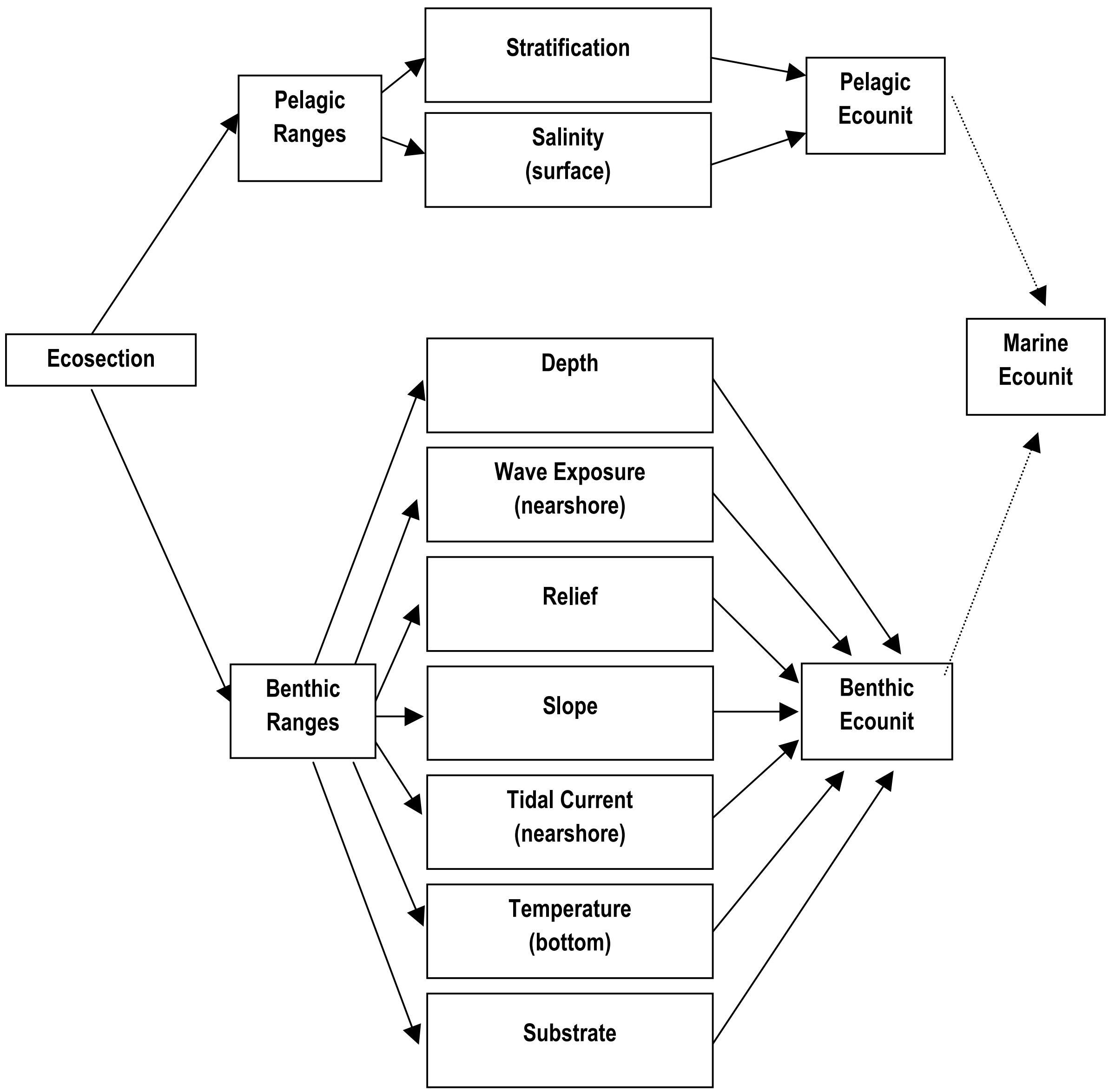

Figure 1. Methodological Framework

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 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 that 15 km^2 (to be consistent with the existing BCMEC) and dissolving neighbouring 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

File name: Depth

Class	Depth range	Attribute[1] 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

[1]Attribute = '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

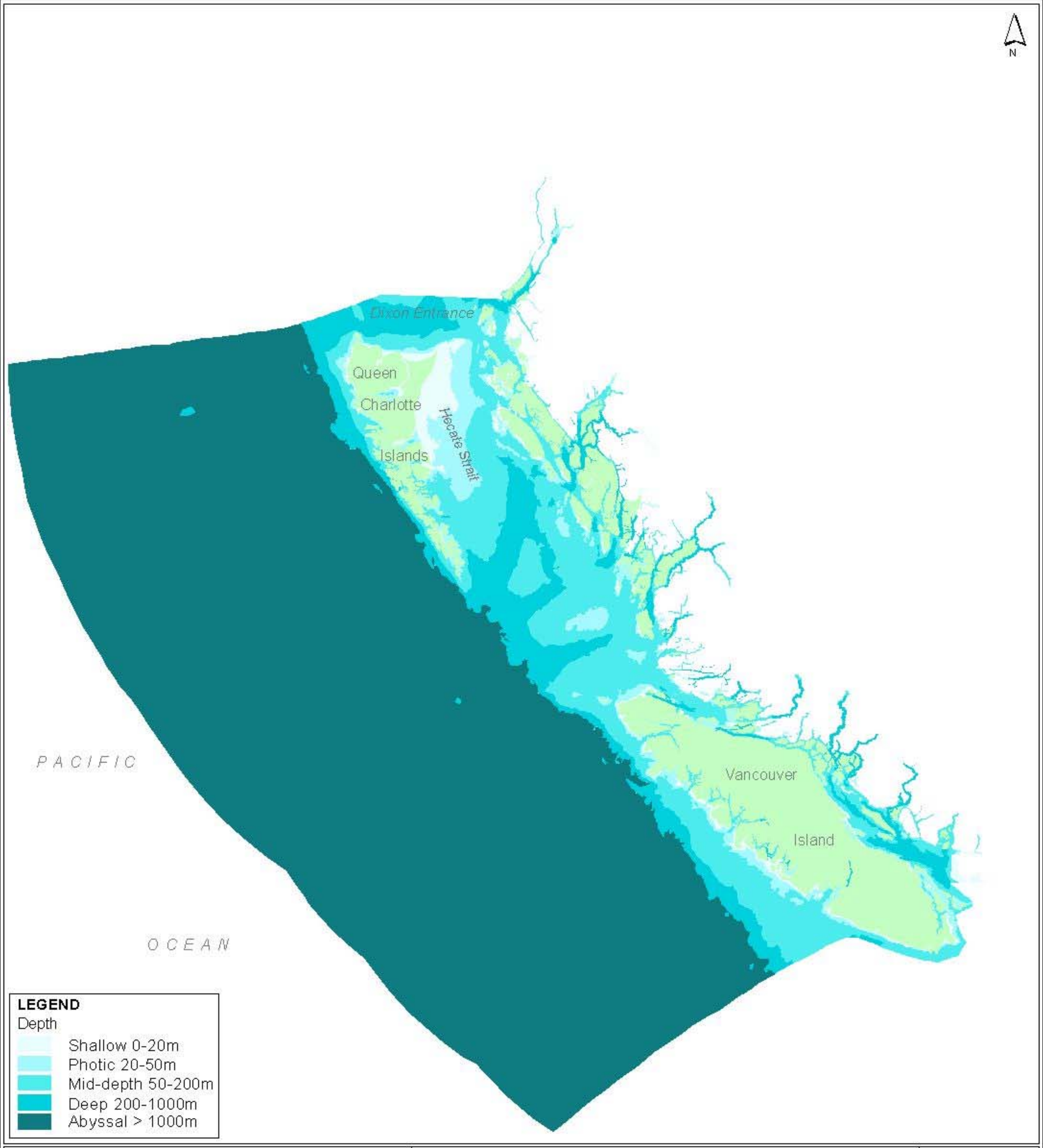

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Figure 2. Depth

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from Bathymetric points provided by Canadian Hydrographic Service

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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	Attribute[1] value
Flat	0-5%	F
Sloping	5-20%	S
Steep	>20%	T

[1]Attribute = 'Slope';
Attribute values: 'X' = land; 'U' = undefined

Results

A total of 84 polygons was 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

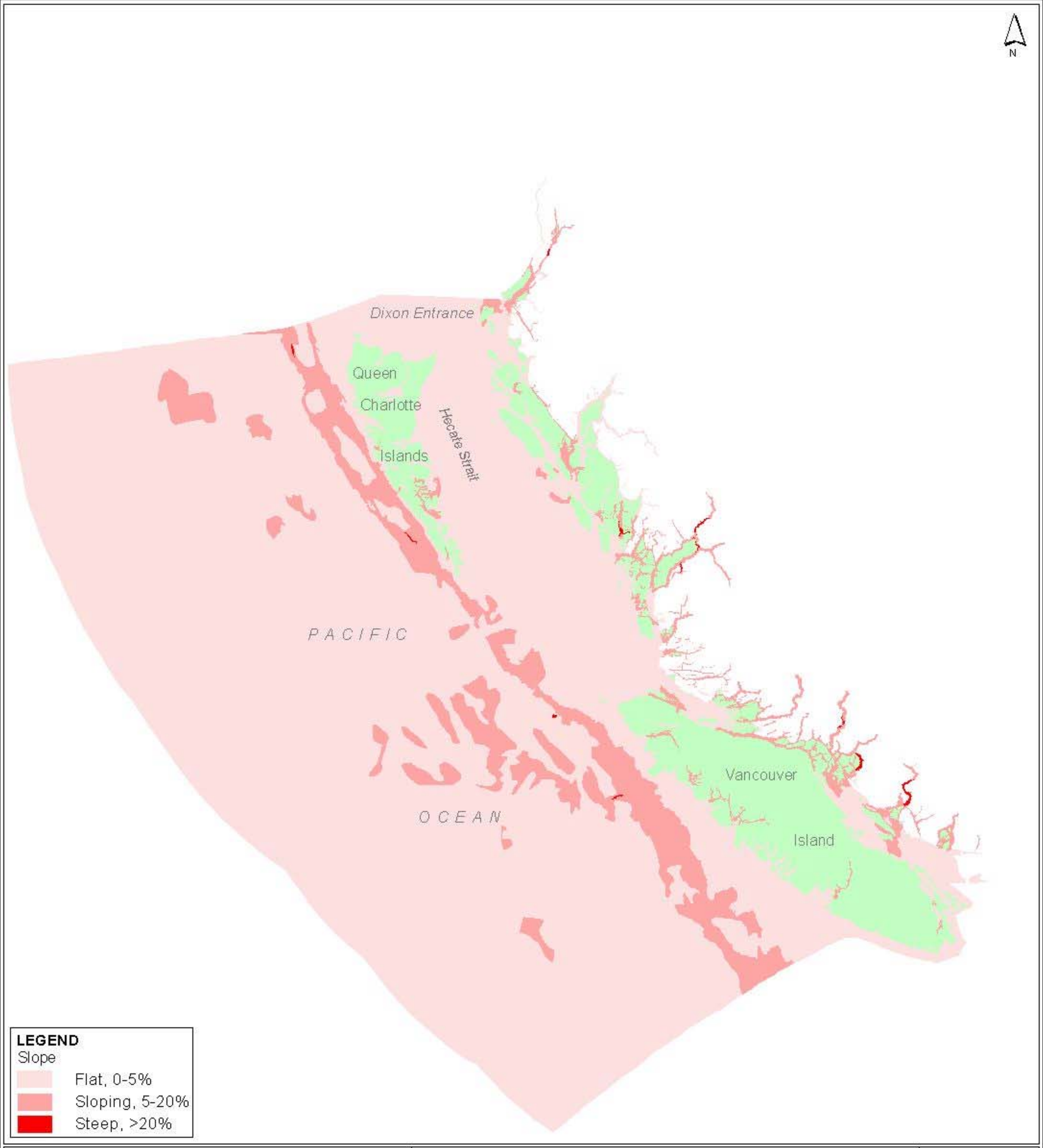

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Figure 3. Slope

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from bathymetric data points
Provided by Canadian Hydrographic Service

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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.

Figure 4. Relief Calculation

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.

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 km^2 to less than 2 samples per km^2 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 7).

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

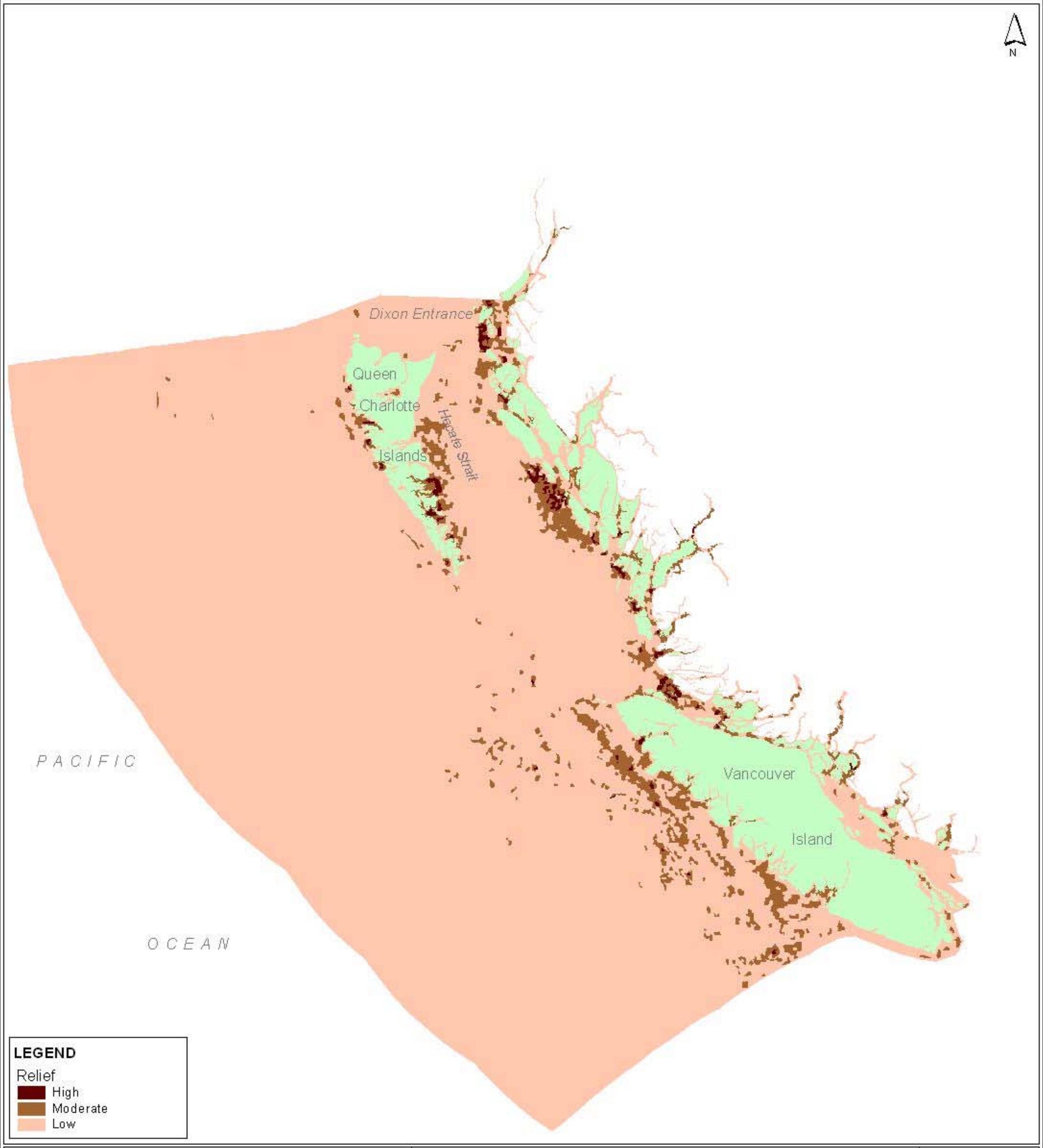

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Figure 5. Relief

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from Bathymetric points provided by Canadian Hydrographic Service

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2.4 Temperature

Data Source

Three datasets covering nearshore fjords and bays (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 ecounits. 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 ecosections 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	Attribute[1] value
Warm	9-15 °C	W
Cold	< 9 °C	C

[1]Attribute = '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

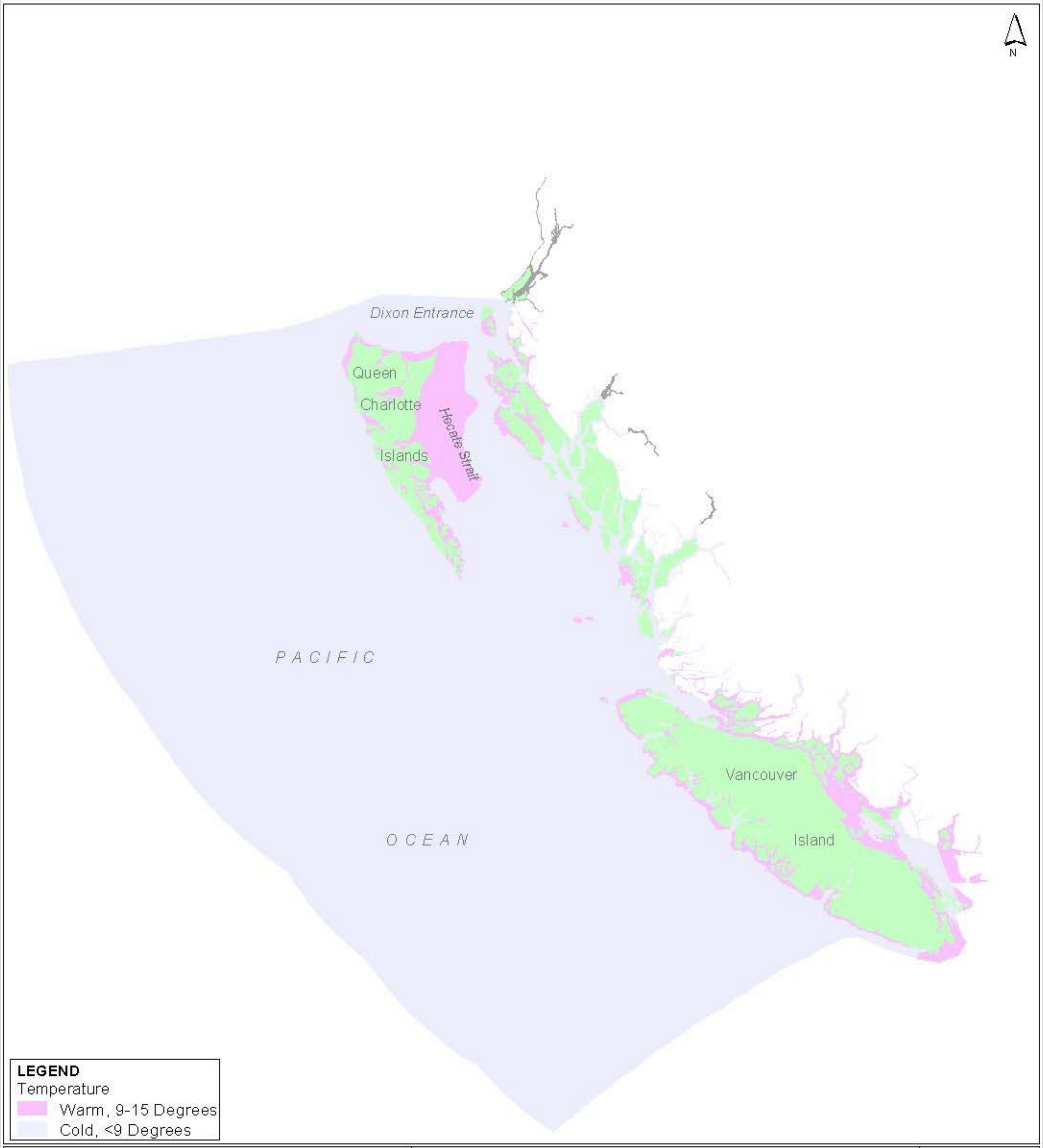

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Figure 6. Temperature

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from data provided by Institute of Ocean Sciences, DFO and BC Ministry of Fisheries

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2.5 Benthic Ecounits

Methodology

Six variables (depth, slope, temperature, current, exposure and substrate) were overlaid to create benthic ecounits. All resulting polygons less that 15 km^2 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

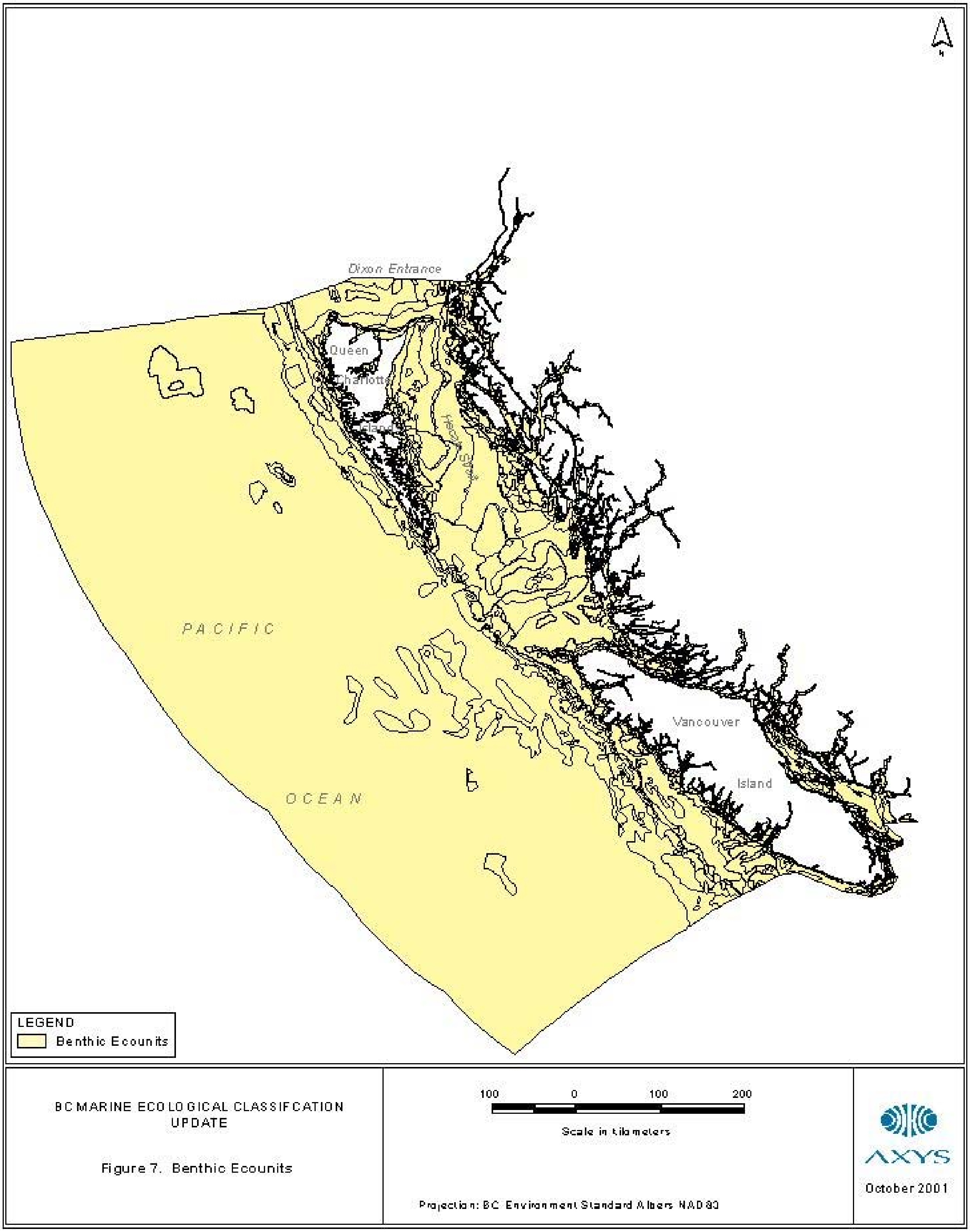

Figure 7. Benthic Ecounits

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 $^{0}/_{00}$) 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 *et al.*	Booth *et al.*	Laffoley & Hiscock
0	<.05 Fresh	Fresh	Dilute	Upper Estuary
5	Oligohaline	Oligohaline		Inner Estuary
10	Mesohaline	Mesohaline		Middle Estuary
15				
20	18ppt	Polyhaline	Estuarine	Lower Estuary
25	Polyhaline			
30		Marine		
35	Euhaline		Marine	Sea
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

[1]Attribute = '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

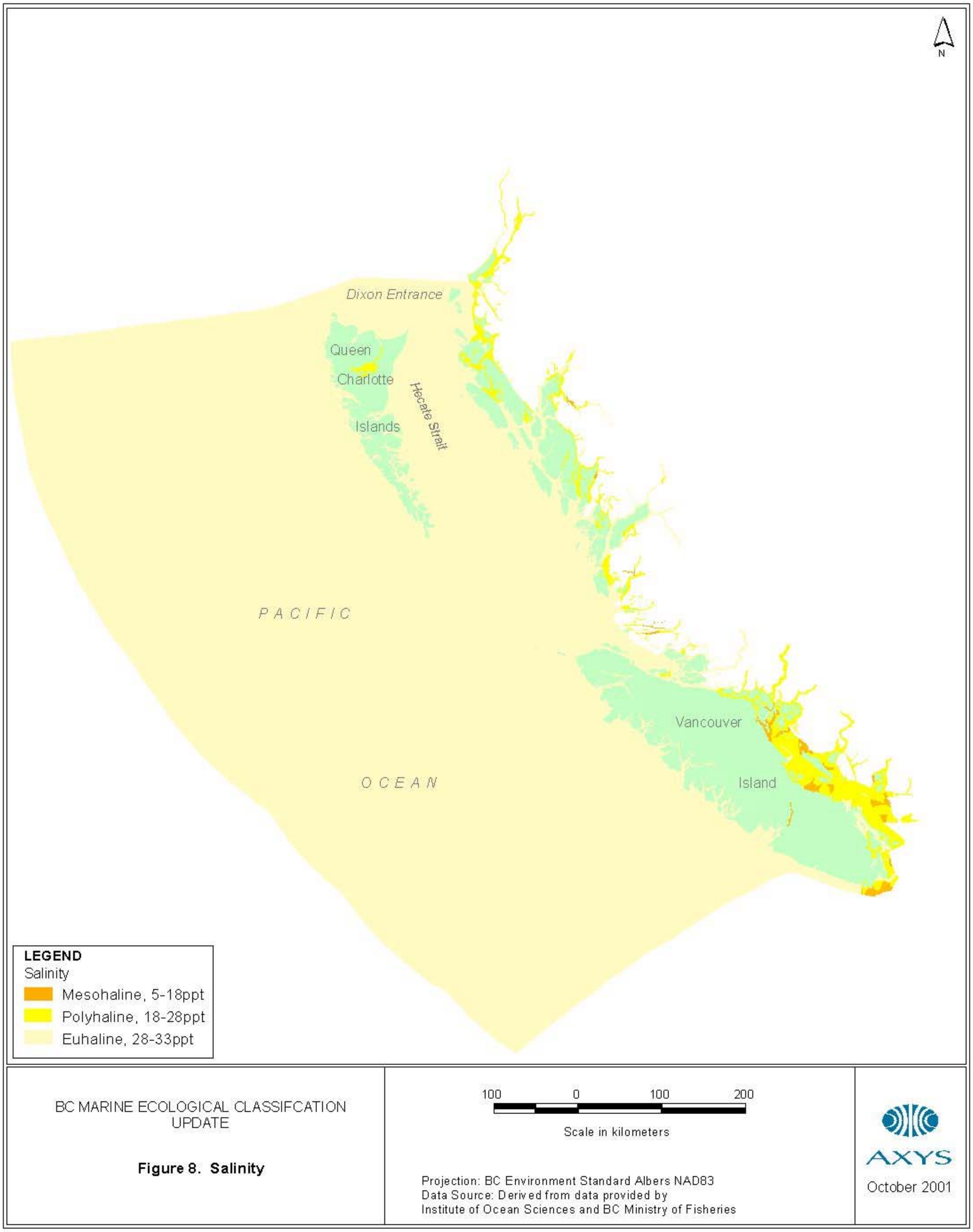

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Figure 8. Salinity

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from data provided by
Institute of Ocean Sciences and BC Ministry of Fisheries

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 ($\rho_{bottom} - \rho_{surface}$) 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 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	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

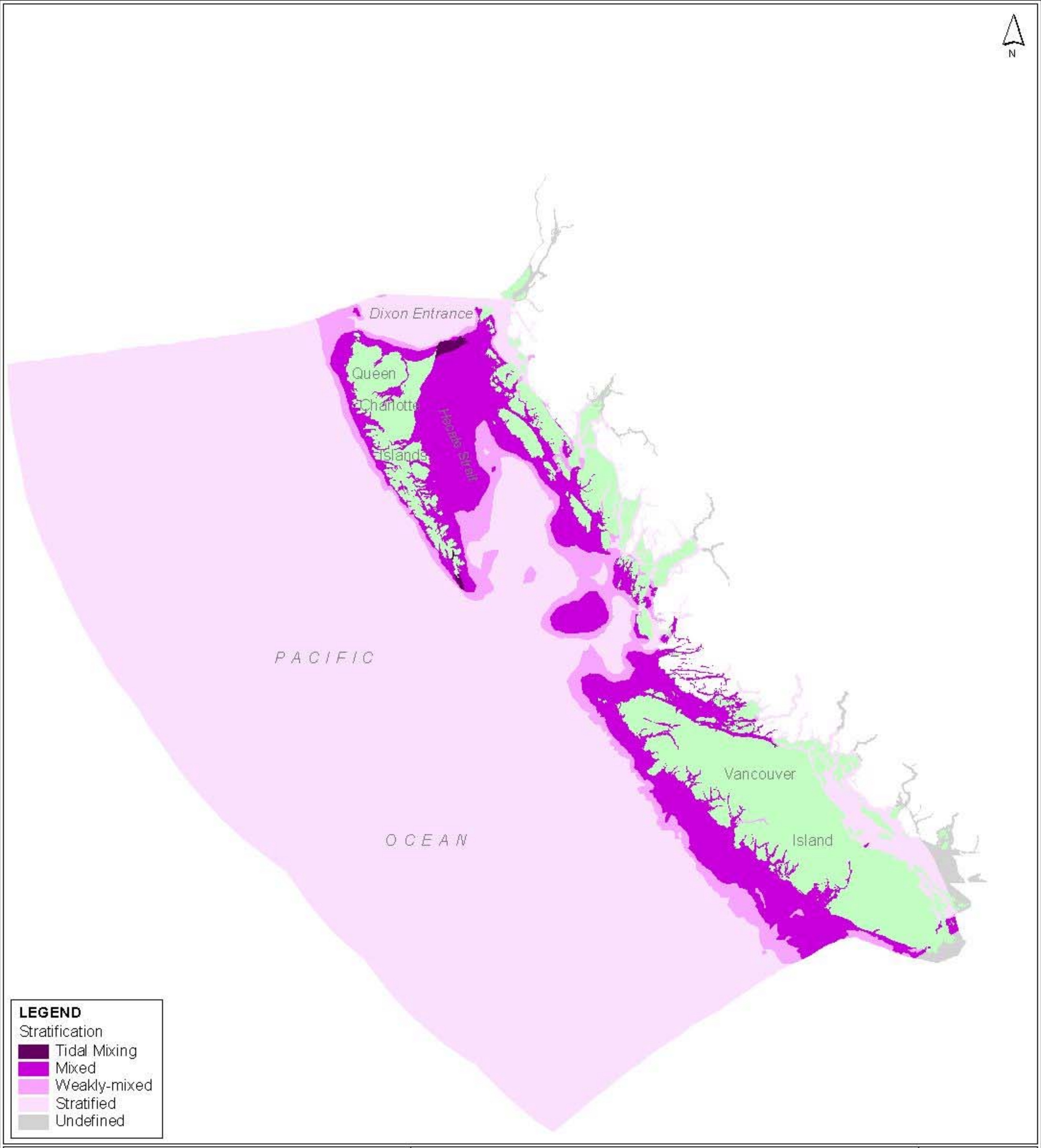
[1]Attribute = 'Stratification";
Attribute values: 'X' = land; 'U' = Undefined

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



BC MARINE ECOLOGICAL CLASSIFCATION UPDATE

Figure 9. Stratification

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD83
Data Source: Derived from (1) temperature and salinity data provided by Institute of Ocean Sciences, DFO and BC Ministry of Fisheries, and (2) tidal current data provided by Institute of Ocean Sciences, DFO

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3.3 Pelagic Ecounits

Methodology

Salinity and stratification were overlaid to create pelagic ecounits. All resulting polygons less that 15 km^2 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 CONCLUSION

BC MEC is a planning tool to be used for identifying marine conservation areas. 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 BC MEC 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 form 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 km^2) than offshore areas (generally less than two sample points within 10 km^2) (Figure 11). In fact, there are no data for much of the offshore area out to the 200 nm boundary of BC MEC, 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.

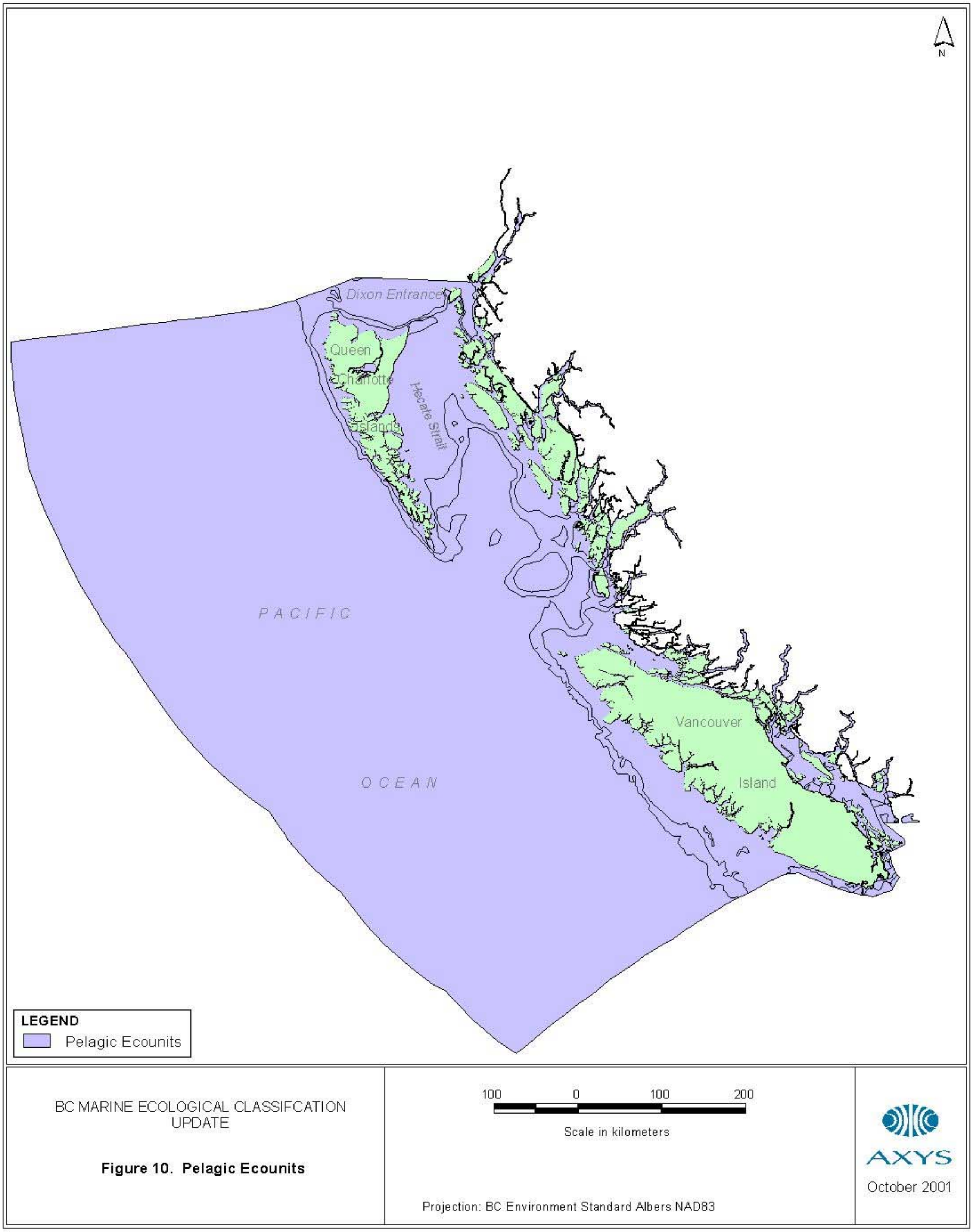
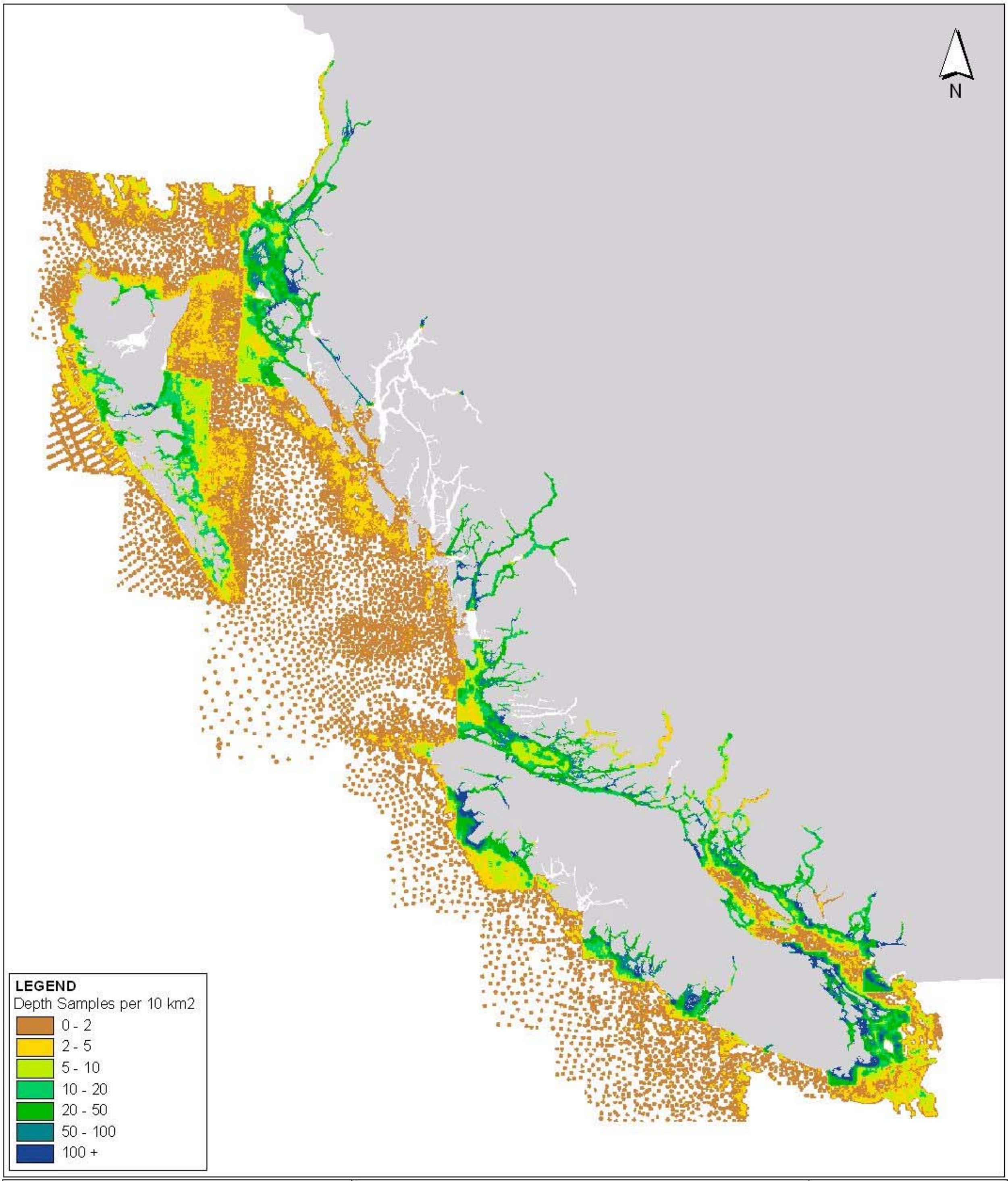


Figure 10. Pelagic Ecounits



BC MARINE ECOLOGICAL CLASSIFICATION UPDATE

Figure 11. Depth Samples per 10 km2

100 0 100 200

Scale in kilometers

Projection: BC Environment Standard Albers NAD 83

AXYS

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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 BC MEC (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:

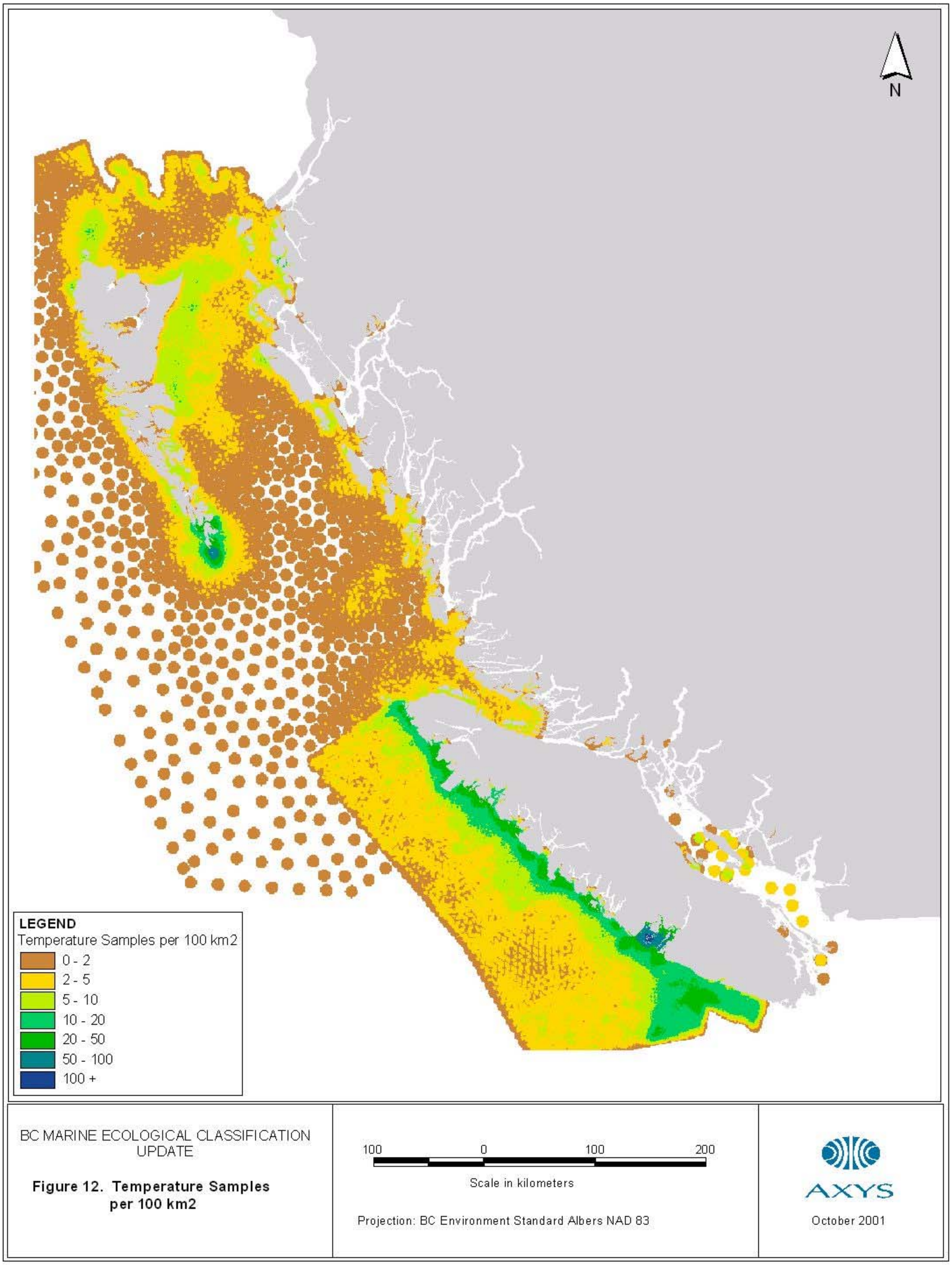
- Georeferencing;
- Interpolation;
- Extrapolation in offshore areas;
- Gridding at 250 m (accuracy of 125 m) (aspect from which relief was derived was gridded at 1 km to reduce variability bias due to point density;
- Smoothing using a 9 x 9 window (generalising to approximately +/- 1 km);
- Raster 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 were 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 km^2 (nominal accuracy approximately +/- 1km) in Barkley Sound and the southern tip of Queen Charlotte Islands, to less than two sample points in 100 km^2 (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 km^2 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.



BC MARINE ECOLOGICAL CLASSIFICATION UPDATE

Figure 12. Temperature Samples per 100 km2

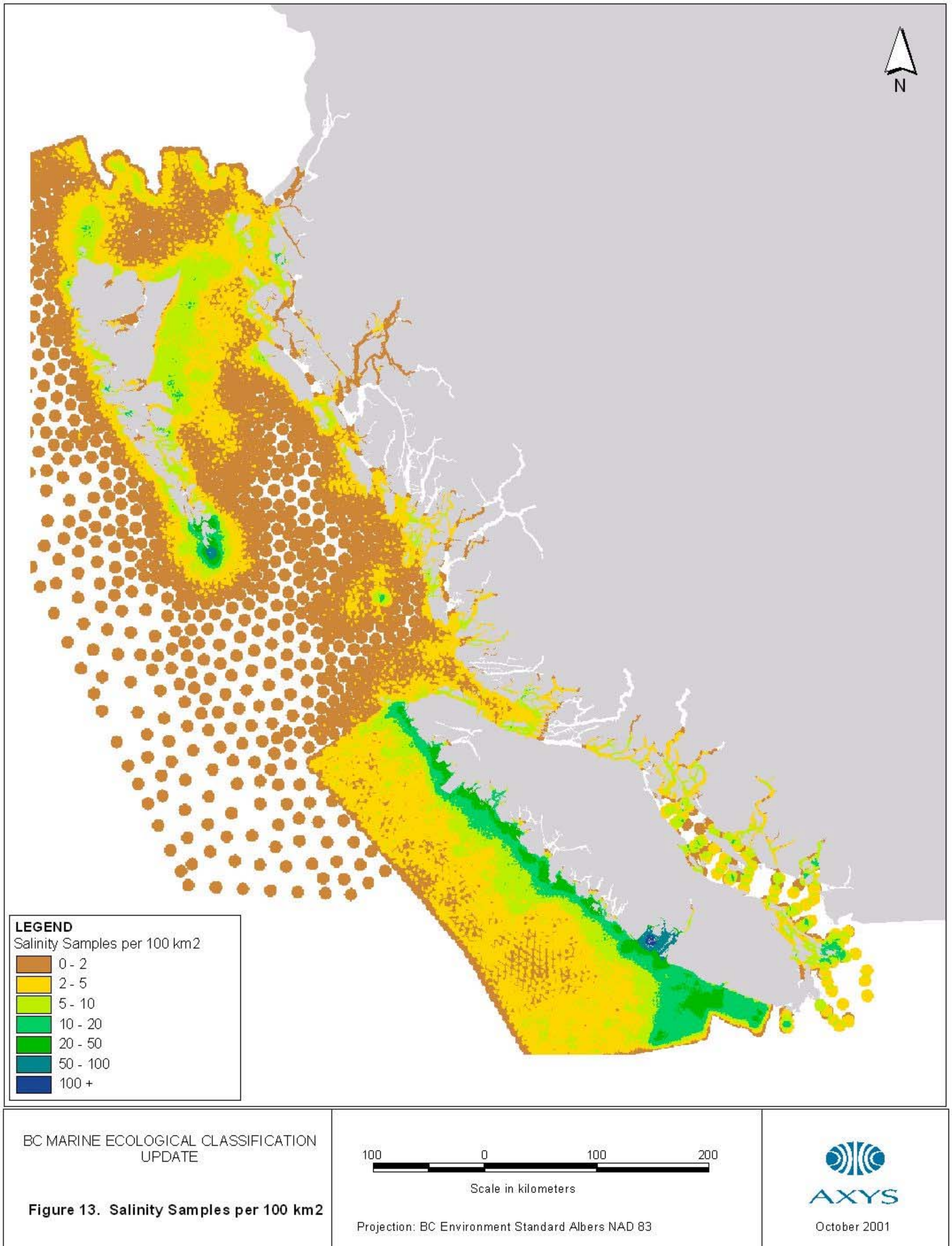


Figure 13. Salinity Samples per 100 km2

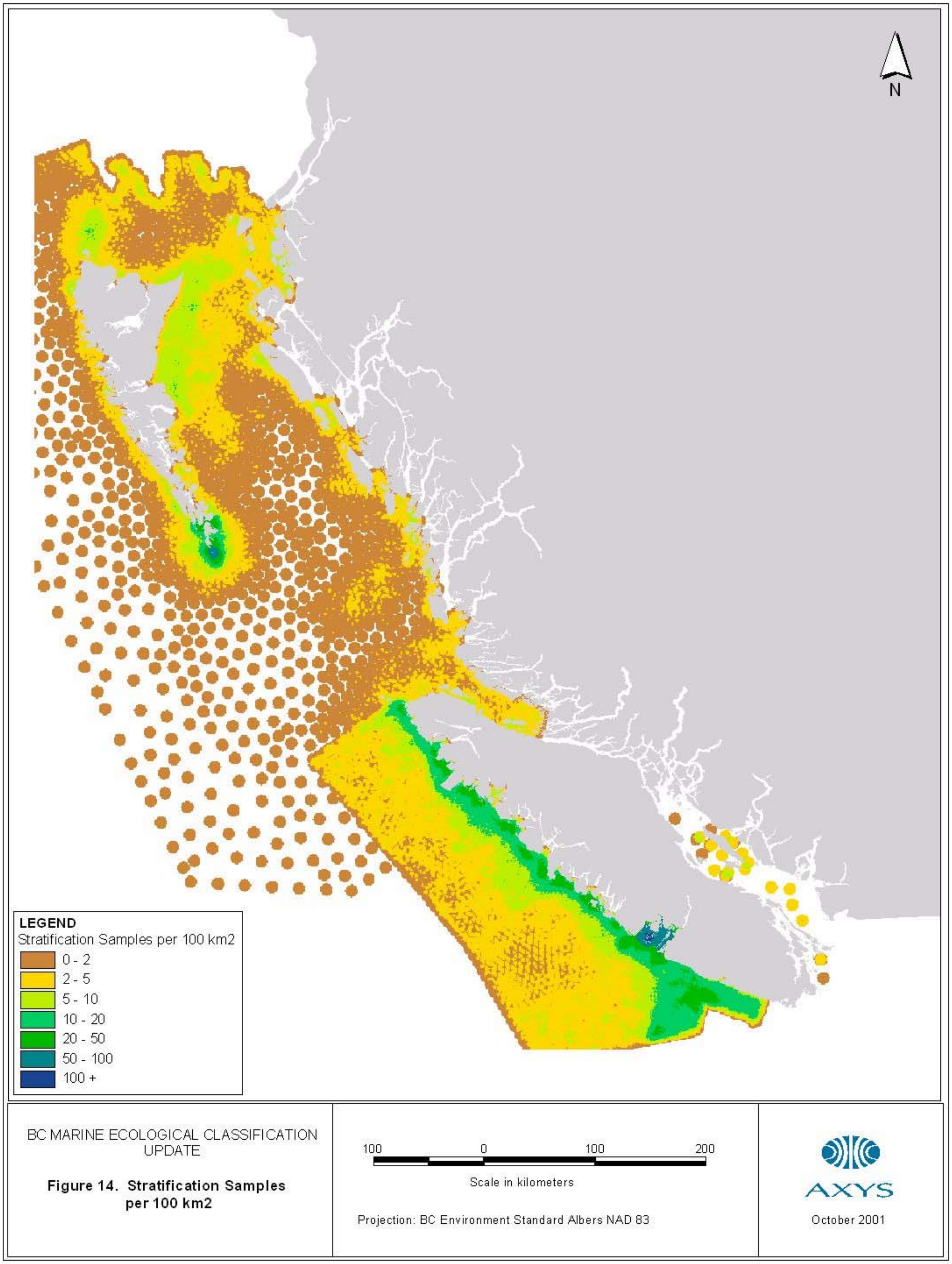


Figure 14. Stratification Samples per 100 km2

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 km^2 was used as a threshold to eliminate spurious polygons. This was consistent with the minimum area applied to the initial BC MEC. A 15 km^2 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 km^2 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.

5 BIBLIOGRAPHY

AXYS Environmental Consulting. 2000. *British Columbia Marine Ecological Classification Update – Method Options*. Prepared for Land Use Coordination Office, Government of British Columbia.

Berry, K., 2000. Map Analysis Helps Characterize Microterrain Features. *Geoworld.* Vol. 13(3):24-25

Booth, J., D. E. Hay, and J. Truscott. 1996. Standard methods for sampling resources and habitats in coastal

Bulgar, A. J., B. P. Hayden, M. E. Monaco, D. M. Nelson, and M. G. McCormick-Ray. 1993. Biologically-based

Canadian Technical Report of Fisheries and Aquatic Sciences 2118: viii + 53 p.

Carmack, E.C., R.W. Macdonald and J.E. Papadakis. (YEAR?) Water mass structure and boundaries in the Mackenzie shelf estuary. *Journal of Geophysical Research* **94**(c12):18,043-18,055.

Crean, P. B., and A. B. Ages. 1971. *Oceanographic records from twelve cruises in the Strait of Georgia and Juan de Fuca Strait, 1968.* Department of Energy, Mines and Resources, Marine Research Sciences Branch. Vol 1-5: 389 p.

Day, J.C., 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.

Diaz, J.V.M. 2000. *Analysis of Multibeam Sonar Data for the Characterization of Seafloor Habitats*. Master Thesis. University of New Brunswick. (DEPARTMENT?)

Dziak, R. P., H. Matsumoto, (OTHER AUTHORS?). 1993. Estimation of seafloor roughness spectral parameters from multi-beam sonar acoustic backscatter data: Axial Seamount, Juan de Fuca Ridge. *Geophys. Res. Lett.* 20(17): 1863-1866.

Estuarine salinity zones derived from a multivariate analysis. *Estuaries* 16(2):311-322.

Fox, C. G. 1996. Objective classification of oceanic ridge-crest terrains using two-dimensional spectral models of bathymetry: Application to the Juan de Fuca Ridge. *Mar. Geophys. Res.* **18**(6): 707-728.

Fox, C. G. and D. E. Hayes (1985). “Quantitative methods for analyzing the roughness of the seafloor.” *Rev. Geophys*. **23**(1): 1-48.

Harper, J.R., J. Christian, W.E. Cross, R. Firth, G. Searing, D. Thompson. 1993. A classification of the marine regions of Canada. Final Report to Environment Canada, Vancouver , B.C.

Laffoley, D., and K. Hiscock. 1993. The classification of benthic estuarine communities for nature conservation assessments in Great Britain. *Netherlands Journal of Aquatic Ecology* 27)2-4):181-187.

LeBlond, P.H. 1983. The Strait of Georgia functional anatomy of a coastal sea. *Can. J. Fish. Aquat. Sci*. 40:1033-1063.

Levings, C.D., J.D. Pringle and F. Aitkens (eds.). 1998. Approaches to Marine Ecosystem Delineation in the Strait of Georgia: Proceedings of a DFO Workshop, Sidney, B.C> , 4-5- November 1997.

Marine Environmental Quality Advisory Group (MEQAG). 1994. Marine Ecological Classification System for Canada. Environment Canada. Jan. 1994. 21pp.

McAllister, D.E. 2000. *A Model Frameowrk for a Marine Ecosystem Classification for Canada's West Coast.* A report prepared by Ocean Voice International for Marine Conervation, Wester Cnada Service Centre, Parks Canada, Vancouver,British Columbia.

Mitsch, W. J., and J. G. Gosselink, 1993, *Wetlands*, 2nd Edition, Van Nostrand Reinhold, New York, NY, USA.

Morris, M. C. 1996. Testing a nearshore biophysical classification system. M.Sc. Thesis. University of British Columbia, Department of Botany. 99 p.

Parks Canada. 1995. *Sea to Sea to Sea: Canada’s National Marine Conservation Areas System Plan*. Parks Canada, Department of Canadian Heritage, Ottawa.

Pickard, G.I. 1986. Oceanpgraphic Features of inlets in the British Columbia mainland coast. *J. Fish. Res. Bd. Canada,* 18(6):907-999.

Roff, J., and M. Taylor (In press). National frameworks for marine conservation - a hierarchical geophysical approach. Submitted to *Aquatic Conservation*.

Sotheran, I. S., R. L. Foster-Smith, and J. Davies, 1997. Mapping of marine benthic habitats using image processing techniques within a raster-based geographic information system. *Estuarine, Coastal and Shelf Science*, **44**(Suppl. A): 25-31.

subtidal regions of British Columbia: Part 1: Review of mapping with preliminary recommendations.

Thomson, R. 1998. Ecosystem classification of the Strait of Georgia: physical oceanographic delineation. *In* C.D. Levings, J.D. Pringle, and F. Aitkens (Eds.*) Approaches to Marine Ecosystem Delineation in the Strait of Georgia*. Proceedings of a DFO Workshop, Sidney, B.C., 4-5 November 1997.

UNESCO. 1983. *Algorithms for Computation of Fundamental Properties of Seawater.* UNESCO technical papers in marine science.

Watson, J. *A review of ecosystem classification: delineating the Strait of Georgia.* Report submitted to the Department of Fisheries and Oceans, North Vancouver, BC, Canada. 81 p.

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.