Pacific Marine Habitat Classes for Cumulative Impact Mapping

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PACIFIC MARINE HABITAT CLASSES FOR CUMULATIVE IMPACT MAPPING

By

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Abstract

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Canada's oceans are made up of a diversity of habitats that support its productive ecosystems. In order to manage and protect Canada's marine ecosystems and the ecosystem services that depend upon them, an understanding of the location and condition of habitat is important. The marine habitats spatial dataset we describe here is a three-dimensional characterization of the inshore and offshore environments of Canada's Pacific Ocean. The habitat classification was selected to match the habitat classes used for assessing vulnerability scores in cumulative impact mapping modelling. The Pacific marine habitats dataset is compiled from various sources to depict the diversity of habitat types in the region, including biogenic habitats, pelagic habitats, and general bottom, or benthic, types classified by depth strata. Biogenic habitats are those where species or species assemblages provide three-dimensional habitat, including eelgrass meadows, kelp beds, and hexactinellid sponge reefs. Pelagic habitats are composed of the surface waters and water column. Benthic habitats are based on the seafloor and can be composed of different substrates, such as sand, mud, rock of various sizes and origins. All habitats are three-dimensional with latitude, longitude, and an associated depth range. A comprehensive map of marine habitats is a vital contribution to marine spatial planning efforts in Pacific Canada, in particular to support the development of cumulative impact mapping.

Résumé

Agbayani, S. and Murray, C.C. 2024. Pacific Marine Habitat Classes for Cumulative Impact Mapping. Can. Tech. Rep. Fish. Aquat. Sci. 3608: vii + 33 p.

Les océans du Canada sont constitués d'une variété d'habitats qui soutiennent ses écosystèmes productifs. Pour gérer et protéger les écosystèmes marins du Canada et les services écosystémiques qui en dépendent, il est important de comprendre l'emplacement et l'état des habitats. L'ensemble de données spatiales sur les habitats marins que nous décrivons ici constitue une caractérisation tridimensionnelle des environnements côtiers et hauturiers de l'océan Pacifique du Canada. On a choisi la classification des habitats de manière à ce qu'elle corresponde aux catégories d'habitats utilisées pour évaluer les cotes de vulnérabilité dans les modèles de cartographie des effets cumulatifs. L'ensemble de données sur les habitats marins du Pacifique est compilé à partir de diverses sources et permet de représenter la diversité des types d'habitats dans la région, y compris les habitats biogéniques et les habitats pélagiques, de même que les types généraux ou benthiques de fonds classés par strates de profondeur. Les habitats biogéniques sont ceux où des espèces ou des assemblages d'espèces fournissent un habitat tridimensionnel, y compris les herbiers de zostère, les lits de varech et les récifs d'éponges hexactinellides. Les habitats pélagiques se composent des eaux de surface et de la colonne d'eau. Les habitats benthiques reposent sur les fonds marins et peuvent être composés de différents substrats, comme le sable, la boue et les roches de tailles et d'origines diverses. Tous les habitats sont tridimensionnels avec une latitude, une longitude et une profondeur associées. Une carte complète des habitats marins constitue une contribution essentielle aux efforts de planification spatiale marine dans le Pacifique du Canada, en particulier pour soutenir le développement de la cartographie des effets cumulatifs.

Introduction

Canada’s oceans are made up of a diversity of habitats that house and support its productive ecosystems. From the eelgrass beds and rocky intertidal of the nearshore to the seamounts and hydrothermal vents of the deep sea, marine habitats offer the specific physical and ecological conditions required for their unique occupants. Each habitat type supports a distinctive community of species that interacts with the physical environment and each other.

In order to manage and protect Canada’s marine ecosystems and the ecosystem services that depend upon them, an understanding of the location and condition of habitat is important. Mapping Canada’s marine habitats can be essential for recovering Species at Risk, supporting fisheries, protecting spaces designated as Marine Protected Areas, and identifying zoning frameworks for Marine Spatial Planning efforts. Under Canada’s Marine Spatial Planning initiative led by the Department of Fisheries and Oceans Canada (DFO) (DFO 2023), there was a need to map marine habitats to expand our knowledge of the system in planning as well as in cumulative impact mapping efforts.

Cumulative impact mapping is one of seven key Knowledge Products for Marine Spatial Planning in Canada. It is a spatially-explicit model that requires detailed information on the location of habitats and human activities, as well as the relative impact of activities on habitats (Halpern 2008). The marine habitats spatial dataset we describe here fulfills the need for spatial information on habitats. The dataset is a generalized characterization of the inshore and offshore environments of Canada’s Pacific Ocean. First produced by Ban et al. (2010), updated in 2013 (Agbayani et al. 2015; Clarke Murray et al. 2015b) and then again starting in 2020 (described here), it is compiled from various sources to depict the diversity of habitat types in the region.

The Pacific marine habitats classes dataset includes biogenic habitats, pelagic habitats, and general bottom, or benthic, types (offshore and inshore) by depth strata. Biogenic habitats are those where species or species assemblages provide three-dimensional habitat. Examples in Pacific Canada include eelgrass meadows, kelp beds, and hexactinellid sponge reefs. Pelagic habitats are composed of the surface waters and water column while benthic habitats are based on the seafloor. Benthic habitats can be composed of sand, mud, rock of various sizes and origins. All habitats are three dimensional with latitude, longitude, and an associated depth. The current report describes in detail the methods used to develop the product as well as the applications and future directions. The complete spatial dataset is available for download on Open Data (Agbayani and Murray 2024).

Methods

We created an updated version of the Pacific marine habitat classes for use in the 2022-23 iteration of cumulative impact mapping following the methods used by Ban et al. (2010), Agbayani et al. (2015), and Murray et al. (2015a; 2015b) and including new and updated spatial datasets. New information was included in this dataset: (i) refined substrate data at finer scales and the addition of mixed substrates, (ii) updated eelgrass and sponge reef layers, (iii) updated seamount and canyon boundaries, and (iv) updated coastline including estuaries. The habitat classes produced were designed to be consistent with the habitat classification system defined by the vulnerability scoring framework used specifically for cumulative impact mapping analysis (Murray et al. 2024).

The habitat classes were created using four types of input data: bathymetry, substrate, special geomorphic features, and biogenic habitats. These four data types were combined to characterize the final habitat classes based on water column depth for pelagic habitats, and bathymetric depth and substrate type for benthic habitats, while including information on special areas dominated by unique geomorphic features and/or biogenic habitats. All analyses were run using ArcGIS Pro 2.9.8 (ESRI 2021).

Input datasets

The Pacific Marine Habitat Classes were compiled using four categories of input data: study area (coastline), bathymetry, substrate, special geomorphic features and biogenic habitats. The bathymetry and substrate datasets used in the analysis were compiled from multiple data sources of varying resolution. The geomorphic features and biogenic habitats data were available as completed datasets and used in their original form. A summary of the input datasets used, and their respective data sources are outlined in Table 1.

Table 1. Data sources and definitions for data used to compile the habitat classes. *Pelagic habitat classes were delineated using the same bathymetry datasets used for the benthic habitat classes.

Spatial data	Data category	Details	Sources
Fine scale Pacific Ocean polygon (Williams and Hashimoto 2021)	Study Area	Coastline polygons derived from various BC Terrain Resource Information Management (TRIM) datasets were combined with estuary polygons from the Pacific Estuary Conservation Program (PECP) and clipped to the Canadian Pacific Exclusive Economic Zone (EEZ) using an EEZ line dataset.	BC TRIM derived coastline dataset (Hashimoto 2019); PECP Estuaries (Pacific Habitats Joint Venture 2019); EEZ Canada (NRCan 2017)

Spatial data	Data category	Details	Sources
Seamounts	Special features	Special features were compiled using updated DFO seamount boundaries, and hills and knolls features from DFO Undersea Features.	DFO Seamount boundaries (Du Preez and Norgard 2022); DFO Undersea Features (Manson 2009)
Canyons	Special features	Canyons and valleys features were taken from the Seafloor Geomorphic Features Map (Harris et al. 2014) to include canyons beyond the shelf break.	Seafloor Geomorphic Features Map (Manson 2009)
Kelp	Biogenic classes	Canopy forming kelp features– Bull kelp and Giant kelp –were compiled from a variety of sources.	Bull kelp (*Nereocystis luetkeana*) polygons from BCMCA Atlas (2011); Giant kelp (*Macrocystis pyrifera*) polygons from BCMCA Atlas (2011)
Eelgrass	Biogenic classes	Eelgrass features were compiled from a variety of sources. We used survey polygon features and only buffered points/lines that did not overlap with survey polygons.	Eelgrass survey features and buffered points/lines (Proudfoot and Robb 2021)
Sponge reefs	Biogenic classes	Sponge reef features were compiled from data gathered by Natural Resources Canada (NRCan) and DFO. Substrates beneath sponge reefs are assumed soft.	Sponge Reefs (Dunham 2018)

Spatial data	Data category	Details	Sources
Bathymetry (100 m)*	Benthic classes	National Oceanic and Atmospheric Administration (NOAA) 80m is a mosaic of many different high resolution data sources – the BCMCA 100m bathymetry dataset was used to fill in gaps in the North and South, and the Global Multi-Resolution Topography (GMRT) v3 (250m) was used to fill a small gap in the Northwestern corner of the EEZ. Intertidal areas were identified using the intertidal polygons created from Canadian Hydrographic Service (CHS) nautical charts (Murfitt n.d.) and shallow areas were refined using kelp and eelgrass coverage.	NOAA 80m (Carignan et al. 2013) ; 100m bathymetry from BCMCA Atlas (2011); GMRT v3 (Ryan et al. 2009); Intertidal polygons (Murfitt n.d.); Eelgrass (Proudfoot and Robb 2021); Giant Kelp and Bull Kelp from BCMCA Atlas (2011).
Substrate	Benthic classes	The benthic substrates from the BCMCA benthic classes were refined using the RF 100m substrate model, and surficial geology information from Natural Resources Canada (NRCan) where available. Substrate information was for undefined intertidal areas were pulled from the intertidal polygons. Kelp, eelgrass and sponge reefs were also used to refine substrate information where present.	Surficial geology for Douglas Channel (Shaw and Lintern 2016); Surficial geology for Chatham Sound (Shaw and Lintern 2023); RF 100 m substrate model (Haggarty et al. 2018); Benthic classes from BCMCA Atlas (2011); Eelgrass (Proudfoot and Robb 2021); Giant Kelp and Bull Kelp from BCMCA Atlas (2011); Sponge reefs (Dunham 2018); Intertidal polygons (Murfitt n.d.).

Study Area and Coastline

The extent of the Pacific Marine Habitat Classes spans the entire area of the Canadian Pacific Exclusive Economic Zone (EEZ), with an outer boundary that lies 200 nautical miles offshore (Figure 1). The study area was delineated using an Ocean polygon spanning the entirety of the Pacific Canada EEZ (Williams and Hashimoto 2021). Coastline polygons derived from various BC TRIM datasets (Hashimoto 2019) to represent the British Columbia (BC) coastline were combined with estuary polygons (PCEP 2019) to ensure intertidal areas around estuaries that are underwater during highest high water were included in the study area.

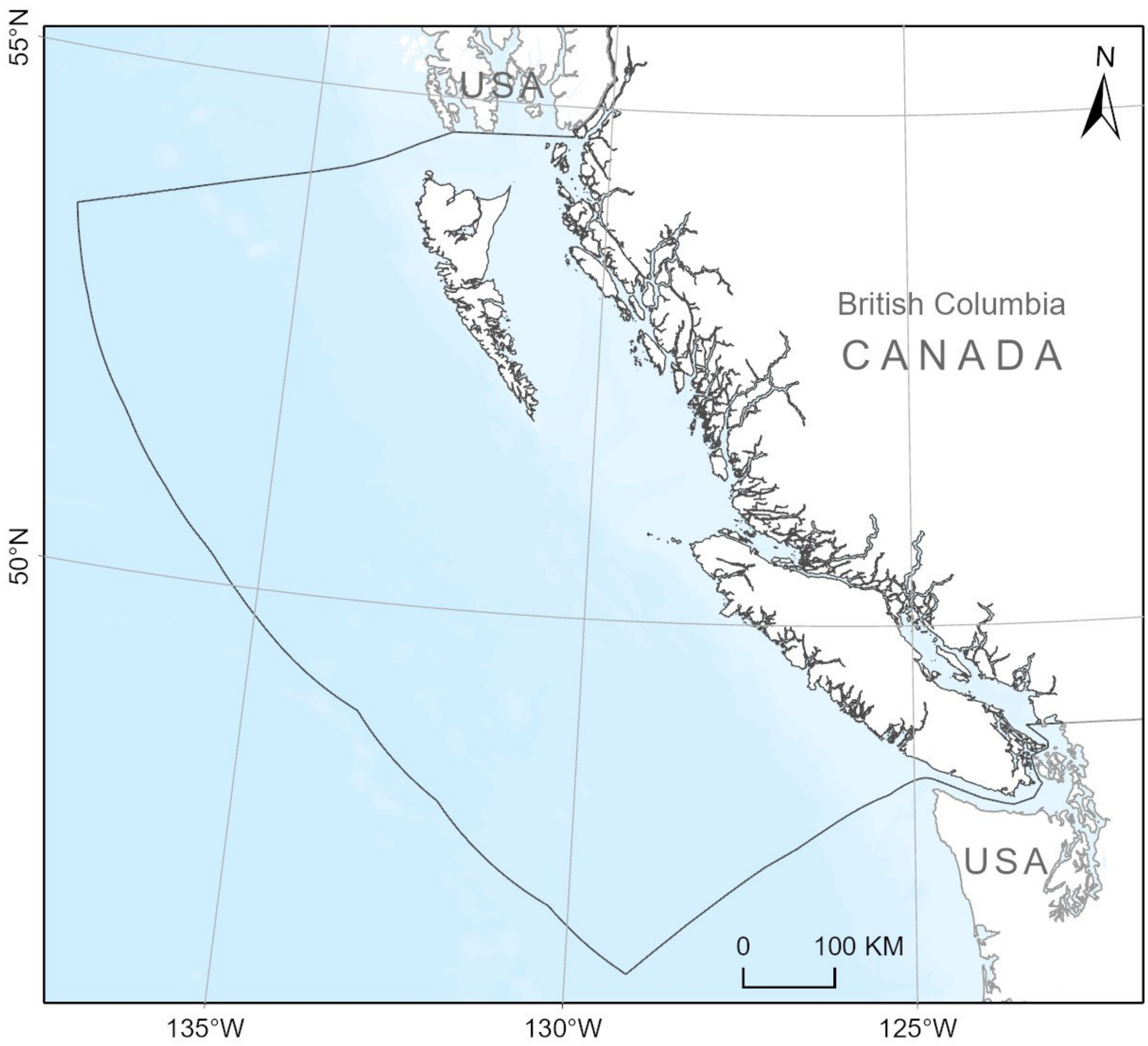

Figure 1. Study area representing the Pacific Canada Exclusive Economic Zone and the British Columbia coastline. Service layer credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada.

Bathymetry

We compiled a bathymetry dataset using the 3-arc second (~80m) bathymetric Digital Elevation Model (DEM) from the National Oceanic and Atmospheric Administration (NOAA) (Carignan et al. 2013), the 100m bathymetry dataset from the British Columbia Marine Conservation Analysis (BCMCA) (2011), and a 250m resolution subset of the GMRT v3 global bathymetric dataset (Ryan et al. 2009). The NOAA dataset was the best in terms of quality and resolution because the dataset was compiled from multiple data sources including the Canadian Hydrographic Service (CHS) multibeam sonar swaths from 1996-2012 and the BCMCA bathymetric digital elevation model (DEM). However the extent of the published dataset did not cover the full study area. The BCMCA dataset was the second-best dataset in terms of quality and resolution and was used to fill the gaps in coverage from the NOAA dataset. The GMRT v3 dataset was the coarsest resolution at 250m and was used to fill in offshore areas at the edge of the EEZ where the BCMCA extent did not match the EEZ boundary.

All three datasets were projected to BC Albers NAD 83, clipped to a box slightly bigger than the BC EEZ and resampled to 80m. The data were then combined using the ArcGIS Spatial Analyst Con (conditional) tool and Raster Calculator (ESRI 2023a) to mosaic the datasets together, so that the NOAA 80m overwrites the BCMCA dataset, which in turn overwrites GMRTv3. Once the three datasets were combined, the mosaic was resampled to 100m to reduce any sharp edges between the source layers. A Canadian Pacific EEZ feature class was buffered by 100m, and this final 100m mosaic was then clipped to the buffered Canadian Pacific EEZ feature class using the ArcGIS Extract by Mask Spatial Analyst Tool (ESRI 2023b) and reclassified to create five depth classes: intertidal ~0m, shallow <30m, shelf 30m-200m, slope 200m-2000m, deep >2000m) (Figure 2).

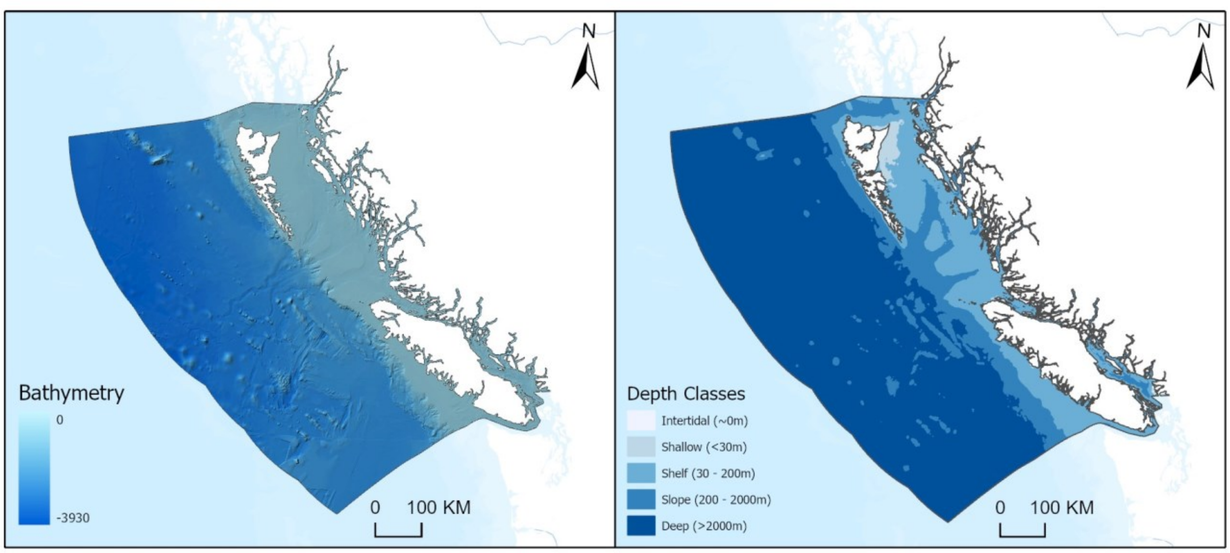

Figure 2. Composite bathymetry dataset (left panel) used to derive the five depth classes: (intertidal ~0m, shallow <30m, shelf 30m-200m, slope 200m-2000m, deep >2000m) (right panel). Service layer credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada.

Benthic Substrates

Information on benthic substrates were limited and were therefore compiled from a combination of survey observations and model outputs. The benthic substrate dataset was compiled using the BCMCA benthic classes (2011), the DFO 100m substrate model (Haggarty et al. 2018), the Natural Resources Canada (NRCan) surficial geology polygons for Kitimat and Douglas Channel (Shaw and Lintern 2016), intertidal polygons based on CHS charts (Murfitt n.d.), and data on the distributions of kelp and eelgrass (BCMCA 2011; Proudfoot and Robb 2021). The biogenic habitats were then used to refine substrate information in nearshore areas at finer scales, while substrate models were used to add information over large areas on the continental shelf where survey data such as the NRCan surficial geology data were not available. However, the substrate models did not extend past the continental shelf into offshore areas and a large area offshore remains undefined.

The 100m substrate model was reclassified to three substrate classes: Soft, Mixed and Hard substrates, and converted to polygons. In order to smooth out the edges of the zones, the raster was resampled to a higher resolution of 50m and run through the Spatial Analyst Boundary Clean Tool (ESRI 2023c). Mixed substrates were generally smaller in area, so the Spatial Analyst Expand tool (ESRI 2023d) was applied, increasing Mixed substrate zones by 2 cells to ensure that these smaller zones did not disappear into the larger zones on conversion to polygons. The raster was then converted to polygons (not simplified) using the Raster to Polygon tool (ESRI 2023e), and smoothed using the Smooth Shared Edges tool (ESRI 2023f) with the PAEK smoothing algorithm and a smoothing tolerance of 1000m.

The NRCan surficial polygons were classified as soft/mixed/hard based on text descriptions provided and used to refine the substrate model (Table 2 and Table 3; see Appendix Table 2 and Appendix Table 3 for additional details). In areas where substrate was undefined in the NRCan surficial polygons (e.g. dredged areas and bioherms), the data from the DFO 100m substrate model was prioritized.

The intertidal data (Murfitt n.d.) were also classified as soft/mixed/hard based on FCODES (see Table 4) and used to define substrate for areas not covered by the NRCan surficial morphology polygons. Biogenic features such as kelp, eelgrass, and sponge reefs were also used to refine substrate information. Areas where kelp were present were assumed to be hard substrate, while areas with eelgrass and sponge reefs present were assumed to be soft substrate. Areas where eelgrass and kelp were found to overlap were assumed to be mixed substrate.

Table 2. Surficial geology codes from the NRCan Douglas Channel dataset (Shaw and Lintern 2016) and associated substrate classes. Please see Appendix Table 2 for more details on the surficial geology definitions.

Code	Surficial geology	Seascape	Benthic habitat substrate class
S1	Fiord sidewall - bedrock	Fiords	Hard / Rock
S2	Fiord sidewall - unconsolidated	Fiords	Mixed

Code	Surficial geology	Seascape	Benthic habitat substrate class
F1	Fiord floor - postglacial mud	Fiords	Soft (Sand/Mud)
F2	Fiord floor - winnowed/scoured	Fiords	Mixed
M	Moraine	Fiords	Mixed
D1	Delta	Fiords	Mixed
D2	Fan delta	Fiords	Mixed
Mt1	Mass transport complex	Fiords	Mixed
Mt2	Debris flows / translational slide	Fiords	Mixed
Mt3	Bedrock slump / rock avalanche	Fiords	Mixed
Mt4	Bedrock creep	Fiords	Hard / Rock
B	Bioherm	Fiords	Mixed
A	Dredged area	Continental Shelf	Undefined
O1	Bedrock	Continental Shelf	Hard / Rock
O2	Moraine	Continental Shelf	Rocky
O3	Streamlined ridge	Continental Shelf	Rocky
O4	Glaciomarine sediment	Continental Shelf	Mixed
O5	Postglacial mud / sandy mud	Continental Shelf	Soft (Sand/Mud)
O6	Winnowed / scoured seafloor	Continental Shelf	Hard / Rock
O7	Bioherm	Continental Shelf	Mixed

Table 3.Surficial geology codes from the NRCan Chatham Sound dataset (Shaw and Lintern 2023) and associated substrate classes. Please see Appendix Table 3 for more details on the surficial geology definitions.

Code	Surficial geology	Substrate Types	Benthic habitat substrate class
B	Bedrock	Bedrock Substrates	Hard
G	Glacial sediment	Glacial Substrates	Mixed
Gm2	Glaciomarine sediment	Glacial Substrates	Mixed
S1	Postglacial sand, muddy sand	Postglacial Substrates	Soft
S2	Bedform field	Postglacial Substrates	Soft
S3	Starved bedforms	Postglacial Substrates	Mixed
S4	Bank	Postglacial Substrates	Soft
M	Post-glacial mud/sandy mud	Postglacial Substrates	Soft
D1	Delta foreslope	Postglacial Substrates	Soft
D2	Lowstand delta	Postglacial Substrates	Soft
T	Tidal delta	Postglacial Substrates	Mixed
Mt	Mass transport terrain	Postglacial Substrates	Mixed
R	Sponge reef	Biogenic Substrates	Soft

Table 4. Feature Codes from the intertidal polygons (Murfitt n.d.) and the associated depth and substrate classes in the benthic habitat classes.

FCODE	FCODE interpretation	Benthic Depth Class	Benthic Substrate Type
<=0	Depths <=0 m	Intertidal	Undefined
ITDARE	Intertidal area	Intertidal	Undefined
ITDGRAV	Intertidal gravel	Intertidal	Rocky
ITDMUD	Intertidal mud	Intertidal	Mudflats (Soft)
ITDRCK	Intertidal rock(y)	Intertidal	Rocky
ITDSAND	Intertidal sand	Intertidal	Beach
ITDSM	Intertidal sand/mud	Intertidal	Sand/Mud (Soft)
ITDSTON	Intertidal stony	Intertidal	Rocky
ITDRK	Intertidal rock(y)	Intertidal	Rocky

Once the DFO 100m substrates were converted into smoothed polygons, the dataset was combined with substrate information from the BCMCA benthic classes, the NRCan surficial polygons, and substrate information from the intertidal polygons (Figure 3).

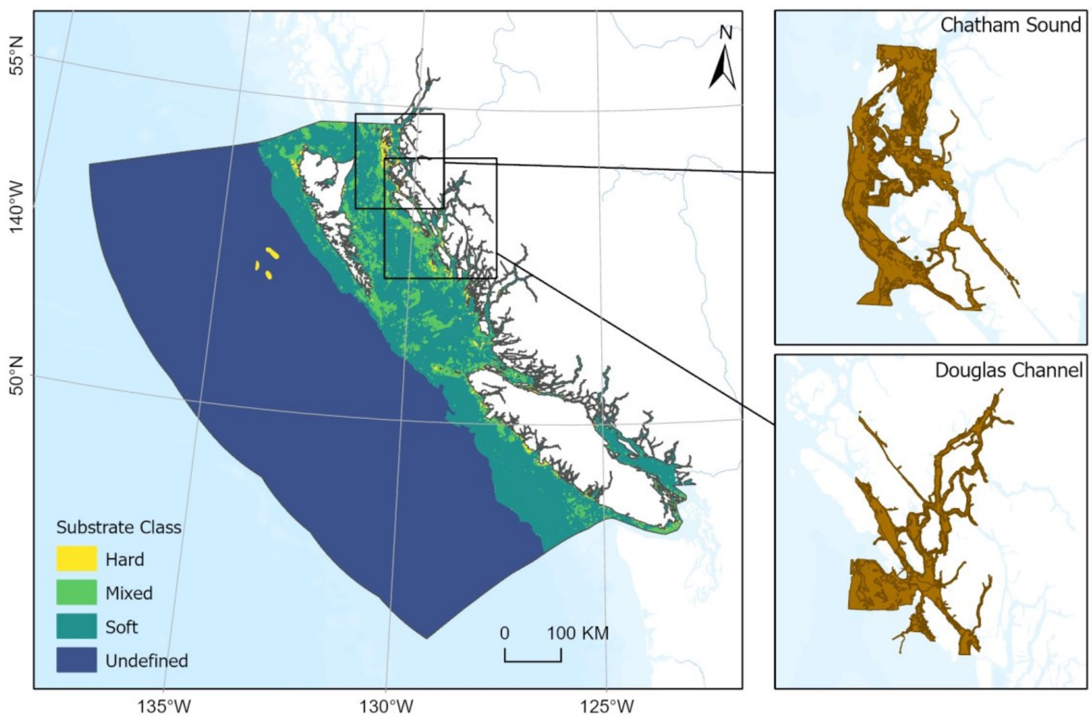

Figure 3. Map of substrate classes used to define the benthic habitat classes with inset maps indicating the extents of the surficial polygon datasets from Chatham Sound and Douglas Channel. Service layer credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada.

Special Geomorphic Features

Seamounts and underwater ridges, hills, and knolls

The data on seamount and other deep-sea features were available from two datasets generated by DFO: Identification of Representative Seamount Areas in the Offshore Pacific Bioregion, Canada (Du Preez and Norgard 2022) and the DFO Underwater Features dataset (Manson 2009). The polygon boundaries from the latest seamount modeling were from Du Preez and Norgard (2022), in which seamounts were delineated as underwater mountains with peaks >1km above the base. The seamount features from the global dataset produced by Harris et al. (2014) were not used in this dataset because we chose the more recent DFO dataset (Du Preez and Norgard 2022) reviewed by the Canadian Science Advisory Secretariat (CSAS) as the authoritative dataset for seamount boundaries in Canadian Pacific waters.

Underwater ridges, hills, and knolls were features taken from the DFO Underwater Features dataset (Manson 2009). These features were identified as areas higher than the surrounding area with a Bathymetric Positioning Index (BPI) value of > 100, and a slope >3°, including areas surrounded by a slope of >3° (Manson 2009). Hills and knolls were reclassified using the following classifications for height above the seafloor – Knolls: 500m-100m, Hills: <500m (Cherisse Du Preez, DFO, pers. comms.). One exception was the Dellwood Knolls, which were classified in gazetteer as Knolls even though the recorded height in the dataset was > 1000 m. Elongated features which were several times longer in length than width was identified as Ridges in the DFO Underwater Features dataset (Manson 2009) and were kept as Ridges. Underwater ridges, hills, and knolls were added to the dataset as distinct habitats of note because the variation in slope provides habitat similar to that of seamounts (Cherisse Du Preez, DFO, pers. comms.).

Canyons

The canyon features were taken from the global geomorphic features dataset generated by Harris et al. (2014). All canyon features (blind, and shelf-incising) within the Pacific EEZ boundary were included in the dataset. The canyon features from the DFO Underwater Features dataset (Manson 2009) were not used because those features included only canyons at the shelf break, and not beyond.

Biogenic features

Biogenic habitats occur where living organisms form three-dimensional structures providing habitats for other species (Loh et al. 2019). In this dataset, we included data for canopy-forming kelp, eelgrass, and hexactinellid glass sponge reefs.

Kelp

Canopy forming kelp – Bull Kelp (*Nereocystis luetkeana*) and Giant Kelp (*Macrocystis pyrifera*) – features were obtained from the BCMCA (2011). These were compiled from various sources from 1897-2008. Survey effort was not consistent across the entire study area. Some areas may be over/underrepresented and some areas with no data may not have been surveyed. Areas where kelp beds were present are assumed to be shallow (<30m deep) and have hard substrates.

Eelgrass

Eelgrass features (*Zostera marina*) were obtained from a dataset representing eelgrass beds in the Pacific Region compiled from various sources ranging from the 1940s to the present (Proudfoot and Robb 2021). The eelgrass beds feature class originally contained survey features and buffer polygons of different sizes to represent eelgrass areas where only point and line data were available. In some areas, there was a significant amount of overlap between survey polygons and buffer polygons.

To preserve the higher-level detail where survey polygons were available, we first used the features representing survey polygons and included only buffer polygons that did not overlap with survey polygons (Figure 4). This dataset was built on prior efforts to compile a coastwide eelgrass dataset (BCMCA 2011) and includes data from various studies and surveys. As a result, survey effort is not consistent across the entire study area and some areas may be over/underrepresented and some areas with no data may not have been surveyed. Areas where eelgrass was present are assumed to be shallow (<30m deep) and have soft substrates.

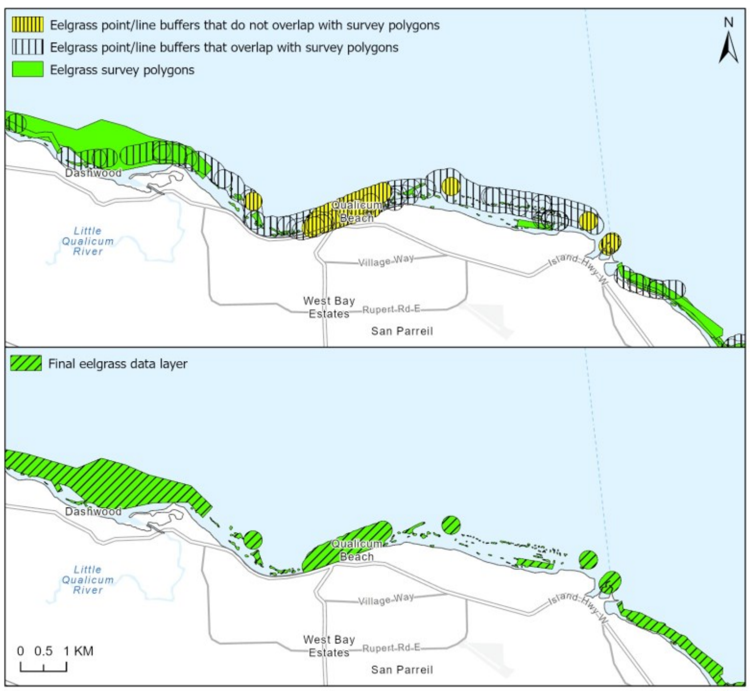

Figure 4. Example of the eelgrass features compiled from a variety of source data and available in the Pacific Region feature class (Proudfoot and Robb 2021). The top panel shows eelgrass survey polygons and point/line buffers. Point/line buffers that do not overlap with survey polygons were kept and dissolved to eliminate area overlap in areas where refined polygon observations were available. Point/line buffers that overlapped with eelgrass survey polygons were removed. The bottom panel shows the final features kept in the eelgrass habitat layer. Service layer credits: Esri Canada, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, USDA, NRCan, Parks Canada.

Sponge Reefs

The hexactinellid glass sponge reef features were compiled by Dunham (2018) from features mapped by NRCan and DFO. Sponge reefs are known to trap fine sediments, forming large bioherms or reef mounds over the span of centuries (Dunham 2018); therefore, sponge reef areas were assumed to be located upon soft substrate.

Spatial Analysis Methods

The spatial analyses used to combine the input datasets were conducted using ArcGIS Pro 2.8.8 and varied with the different habitat class types (pelagic, biogenic, and benthic). The primary methods that were used to overlay the input datasets were Union, Intersect, Identity, and Clip.

Pelagic Habitat Classes

The pelagic habitat classes were separated into two depth zones: deep pelagic and shallow pelagic. We created the deep pelagic class by reclassifying the composite bathymetry dataset to identify areas deeper than 200 m to represent the aphotic mesopelagic, bathypelagic, and abyssalpelagic zones (Kingsford 2010). Shallow pelagic was characterized using a feature class spanning the entirety of the study area to represent all surface waters up to 200 m deep, i.e. the photic or epipelagic zone down to the depth limit of where light can penetrate into the water column (Kingsford 2010). The three-dimensional nature of the pelagic zone is taken into account where shallow pelagic features overlap with deep pelagic features (Figure 5).

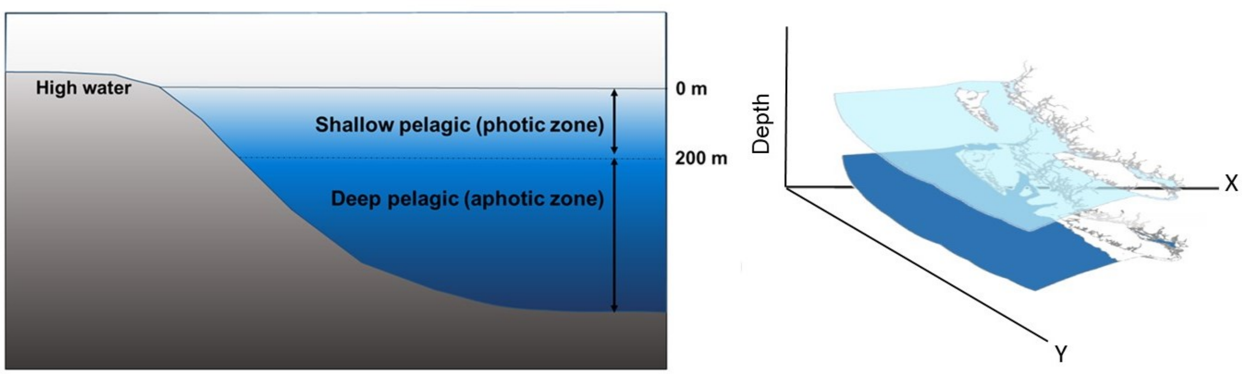

Figure 5. Pelagic habitat classes categorized by depth into “deep” and “shallow”. The deep pelagic class lies beneath the shallow pelagic habitat class to represent the three-dimensional nature of the pelagic zone.

Benthic Habitat Classes

We combined depth classes, substrate classes, and geomorphic features to create a single spatially-explicit benthic habitat classes feature class. Once the 100m bathymetry mosaic described above was reclassified into five different categories (intertidal ~0m, shallow <30m, shelf 30m-200m, slope 200m-2000m, deep >2000m), the classes were converted into polygons (Figure 2). Polygons representing the area between the high-water line and the low water line created from CHS charts were used to refine the delineation of intertidal areas (FCODES “<=0” and “ITD” prefix) along the coast (see Appendix Table 1 for details). The final polygon dataset was then clipped with the Pacific Ocean polygon feature class to limit the dataset to the Canadian EEZ.

Special geomorphic features such as canyons and seamounts were incorporated into the depth classes using the Identity tool in ArcGIS Pro (ESRI 2023g). Special geomorphic features replaced depth classes wherever they were present because the geomorphic features were characterized with varying depths, e.g., seamounts are underwater landforms of varying heights from the seafloor from base to peak and may exist at varying depths across the study area. We then combined the depth/geomorphic features layer with the substrate classes (soft, mixed, hard, and undefined) to derive a total of 33 benthic habitat classes (Table 6).

Results

The Pacific marine habitat classes were compiled into a geodatabase comprising 38 habitat classes represented in six feature classes (or layers) with seven fields (Table 5). Each habitat layer contained spatially-exclusive features occurring on the same plane, e.g., all benthic habitat classes occur on the seafloor, while all biogenic features occur on top of the seafloor.

Each habitat feature class was dissolved by habitat code and intersected with a 1×1 km planning unit grid to align with data inputs required for cumulative impact mapping. Habitat area was calculated using the geometric shape area of each feature by HabitatCODE, and a habitat area weight per planning unit was calculated by dividing the area of the habitat by the marine area within the planning unit.

The full list of habitat classes and their definitions are presented in Table 6. Maps of the resulting habitat classes are shown in Figures 6 to 10.

Table 5. Descriptions for fields within the habitat feature classes.Units for area are based the spatial projection of the dataset: NAD 83 BC Albers (EPSG 3005).

Field Name	Field Description	Data Type	Units
UNIT_ID	Planning Unit ID for 1x1 km grid	INT	N/A
Realm	Land/Marine	TEXT	N/A
MarineAREA	Marine Area within the Planning Unit	FLOAT	Square metres
Habitat	Name of Habitat Class	TEXT	N/A
HabitatCODE	Code for Habitat Class	TEXT	N/A
HabAREA	Area of Habitat within the Planning Unit	FLOAT	Square metres
HabAREA_WT	Proportion of the Habitat Area to the Marine Area within the Planning Unit. HabAREA_WT = HabAREA/MarineAREA	FLOAT	N/A

Table 6. Detailed description of the habitat classes, including habitat codes and their associated depth ranges. Substrate information was obtained from a combined substrate model described earlier in this document. Undefined substrate areas are areas where no substrate data or models were available. *HabitatCODEs marked with an asterisk did not occur in the spatial dataset, but definitions are included here for the sake of completion.

Habitat CODE	Habitat Class	Habitat Type	Depth range	Other Details (sources)
SEAG	Eelgrass	Biogenic	Intertidal (~0m)	Assumed soft substrates
KELP	Kelp	Biogenic	Intertidal (~0m)	Assumed hard substrates
SREEF	Sponge Reefs	Biogenic	On-shelf (30-200m)	Assumed soft substrates Sponge reef features (Dunham, 2018)
SITDL	Soft intertidal	Benthic	Intertidal (~0m)	Assumed to be at sea level, between the low water line, and the high-water line
MITDL	Mixed Intertidal	Benthic	Intertidal (~0m)	Assumed to be at sea level, between the low water line, and the high-water line
HITDL	Hard intertidal	Benthic	Intertidal (~0m)	Assumed to be at sea level, between the low water line, and the high-water line
UITDL	Undefined intertidal	Benthic	Intertidal (~0m)	Substrate undefined
SSHLW	Soft Shallow	Benthic	Shallow (<30m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
MSHLW	Mixed Shallow	Benthic	Shallow (<30m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
HSHLW	Hard Shallow	Benthic	Shallow (<30m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
USHLW	Undefined Shallow	Benthic	Shallow (<30m)	Substrate undefined
SSHLF	Soft Shelf	Benthic	Shelf (30-200m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
MSHLF	Mixed Shelf	Benthic	Shelf (30-200m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.

Habitat CODE	Habitat Class	Habitat Type	Depth range	Other Details (sources)
HSHLF	Hard Shelf	Benthic	Shelf (30-200m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
USHLF	Undefined Shelf	Benthic	Shelf (30-200m)	Substrate undefined
SCANYON	Soft Canyons	Benthic	Varying depths	Canyons from global geomorphic features dataset (Harris et al. 2014)
MCANYON	Mixed Canyons	Benthic	Varying depths	Canyons from global geomorphic features dataset (Harris et al. 2014)
HCANYON	Hard Canyons	Benthic	Varying depths	Canyons from global geomorphic features dataset (Harris et al. 2014)
UCANYON	Undefined Canyons	Benthic	Varying depths	Substrate undefined. Canyons from the global geomorphic features dataset (Harris et al. 2014)
SSLOPE	Soft Slope	Benthic	Slope (200-2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
MSLOPE	Mixed Slope	Benthic	Slope (200-2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
HSLOPE	Hard Slope	Benthic	Slope (200-2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
USLOPE	Undefined Slope	Benthic	Slope (200-2000m)	Substrate undefined
SDEEP	Soft Deep	Benthic	Deep (>2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
MDEEP	Mixed Deep	Benthic	Deep (>2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.
HDEEP	Hard Deep	Benthic	Deep (>2000m)	Substrates derived from compiled substrate model. Depths derived from compiled bathymetry dataset.

Habitat CODE	Habitat Class	Habitat Type	Depth range	Other Details (sources)
UDEEP	Undefined Deep	Benthic	Deep (>2000m)	Substrate undefined
SHILL*	Soft Hill	Benthic	Varying depths	Underwater hills with summits <500m above the seabed: features from DFO Undersea Features (Manson, 2009).
MHILL*	Mixed Hill	Benthic	Varying depths	Underwater hills with summits <500m above the seabed: features from DFO Undersea Features (Manson, 2009).
HHILL	Hard Hill	Benthic	Varying depths	Underwater hills with summits <500m above the seabed: features from DFO Undersea Features (Manson, 2009).
UHILL	Undefined Hill	Benthic	Varying depths	Undefined substrate. Underwater hills with summits <500m above the seabed: features from DFO Undersea Features (Manson, 2009).
SKNOLL*	Soft Knoll	Benthic	Varying depths	Underwater knolls 500m-1000m above seabed: features from DFO Undersea Features (Manson, 2009).
MKNOLL*	Mixed Knoll	Benthic	Varying depths	Underwater knolls 500m-1000m above seabed: features from DFO Undersea Features (Manson, 2009).
HKNOLL	Hard Knoll	Benthic	Varying depths	Underwater knolls 500m-1000m above seabed: features from DFO Undersea Features (Manson, 2009).
UKNOLL	Undefined Knoll	Benthic	Varying depths	Undefined substrate. Underwater knolls 500m-1000m above seabed: features from DFO Undersea Features (Manson, 2009).
SSEAMT	Soft Seamount	Benthic	Varying depths	Seamounts >1000m, above the seabed, features from Du Preez (DFO 2021).
MSEAMT	Mixed Seamount	Benthic	Varying depths	Seamounts >1000m, above the seabed, features from Du Preez (DFO 2021).

Habitat CODE	Habitat Class	Habitat Type	Depth range	Other Details (sources)
HSEAMT	Hard Seamount	Benthic	Varying depths	Seamounts >1000m, above the seabed, features from Du Preez (DFO 2021).
USEAMT	Undefined Seamount	Benthic	Varying depths	Undefined substrate. Seamounts >1000m, above the seabed, features from Du Preez (DFO 2021).
USEAMT	Undefined Seamount	Benthic	Varying depths	Undefined substrate. Seamounts >1000m, above the seabed, features from Du Preez (DFO 2021).
SPELAGIC	Shallow Pelagic	Pelagic	Shallow (<200m)	Shallow pelagic waters up to 200m deep represent the photic zone.
DPELAGIC	Deep Pelagic	Pelagic	Deep (>200m)	Deep pelagic waters deeper than 200m representing the aphotic and abyssal zones.

The following section is a collection of figures showing maps of the final benthic, biogenic, and pelagic classes.

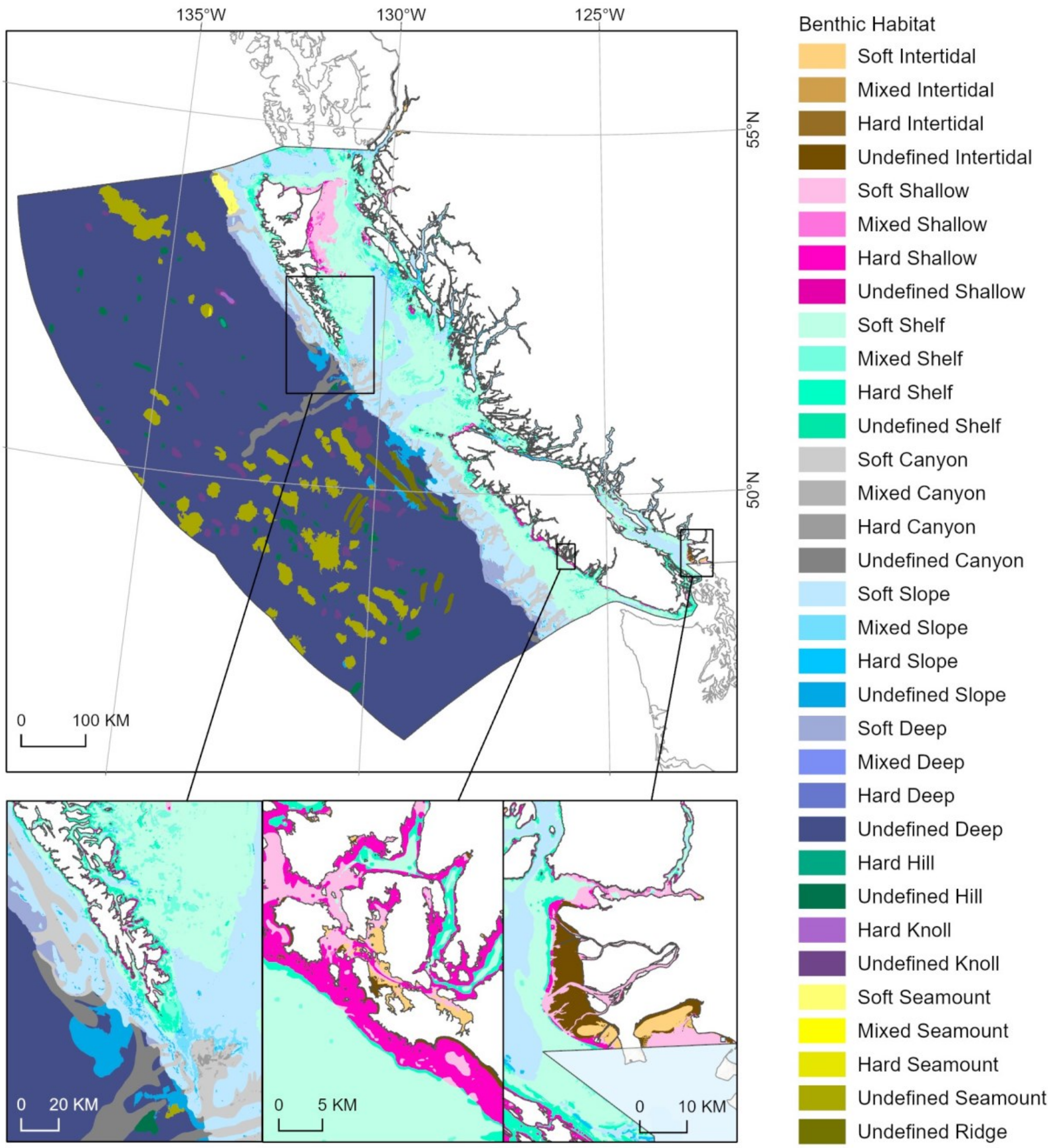

Figure 6. Map of benthic habitat classes, with inset maps zoomed in to show details along the coast. The 33 benthic classes were characterized by depth-substrate combinations, or geomorphic feature-substrate combinations. Service layer credits: Esri Canada, Esri, HERE, Garmin, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada, NASA, NGA, CGIAR, NOAA, State of Alaska, SafeGraph, NPS.

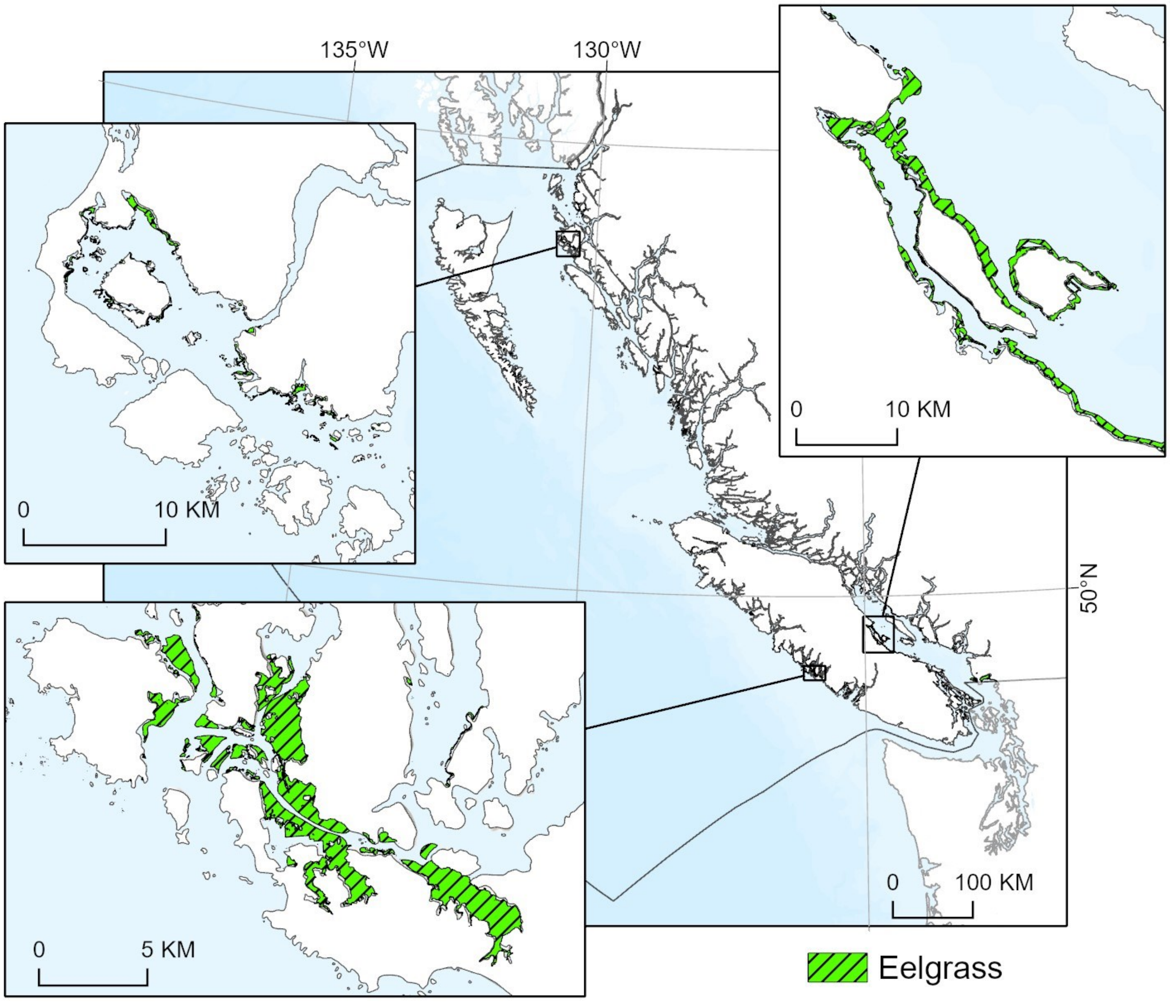

Figure 7. Map of eelgrass biogenic habitats, with inset maps to show details along the coast (Proudfoot and Robb 2021). Service layer credits: Esri Canada, Esri, HERE, Garmin, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada, NASA, NGA, CGIAR, NOAA, State of

Alaska, SafeGraph, NPS.

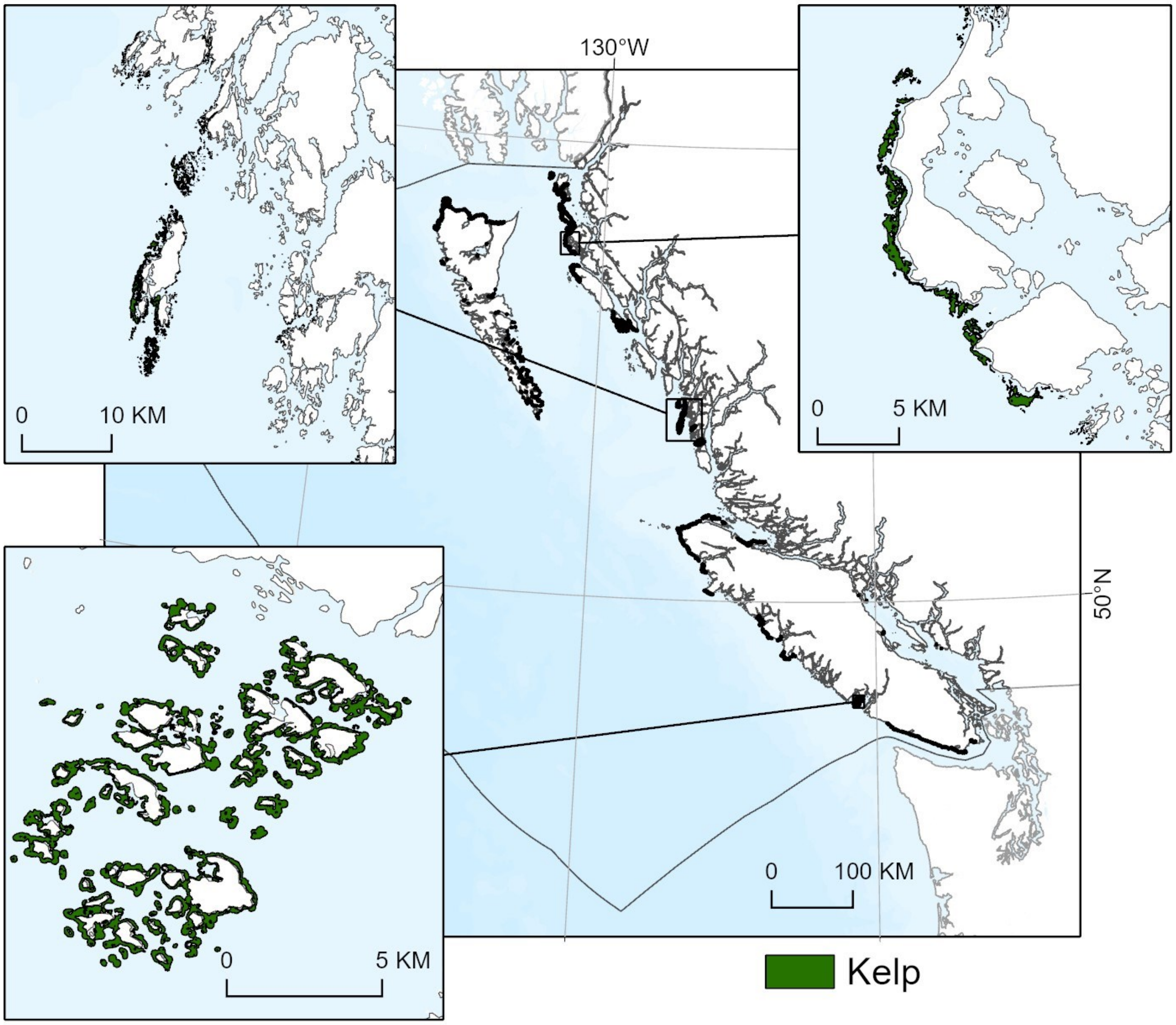

Figure 8. Map of canopy-forming kelp biogenic habitats, with inset maps to show details along the coast. Service layer credits: Esri Canada, Esri, HERE, Garmin, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada, NASA, NGA, CGIAR, NOAA, State of Alaska, SafeGraph, NPS.

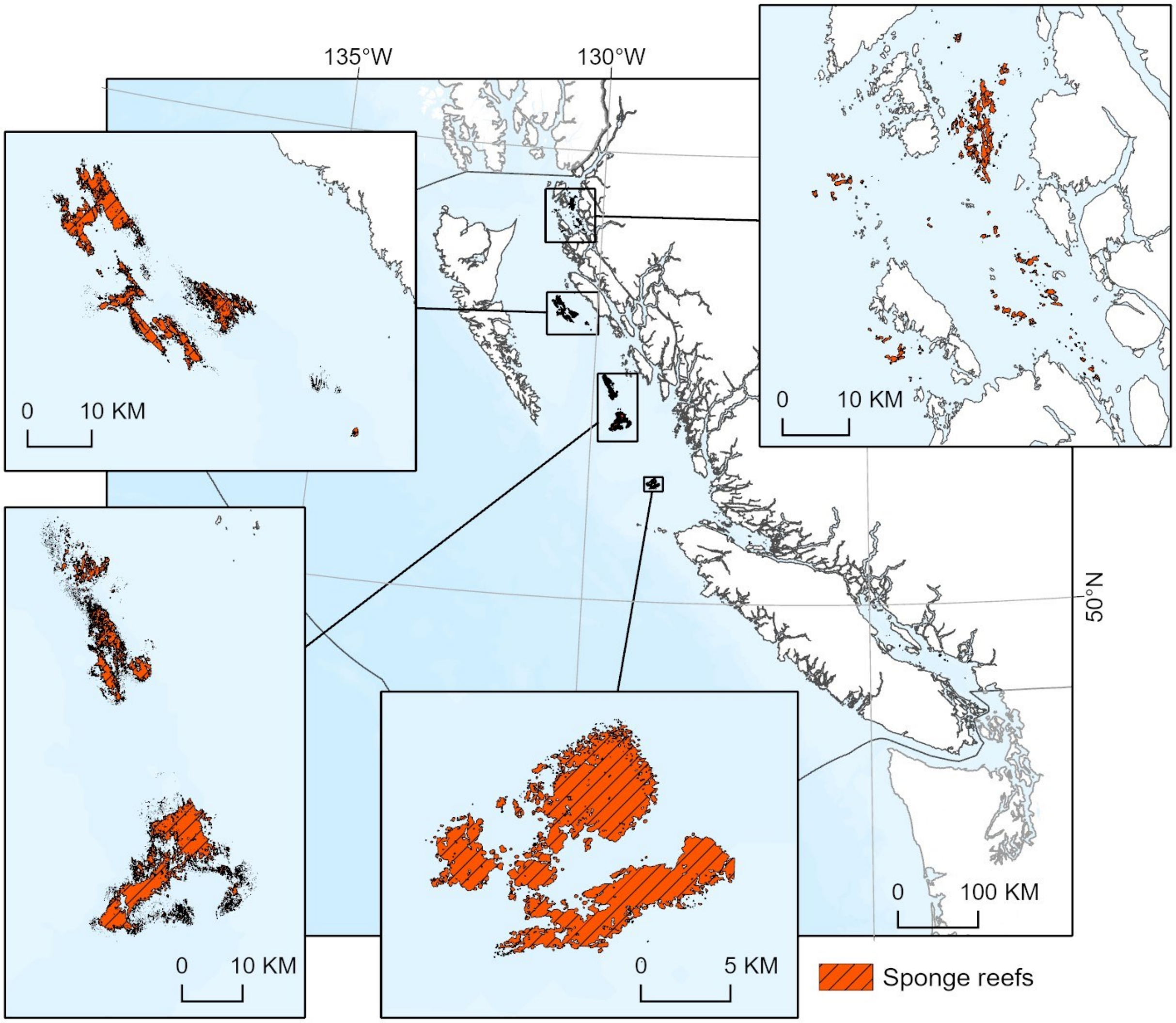

Figure 9. Map of sponge reef biogenic habitats (Dunham 2018), with inset maps to show greater detail in different areas. Service layer credits: Esri Canada, Esri, HERE, Garmin, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada, NASA, NGA, CGIAR, NOAA, State of Alaska, SafeGraph, NPS.

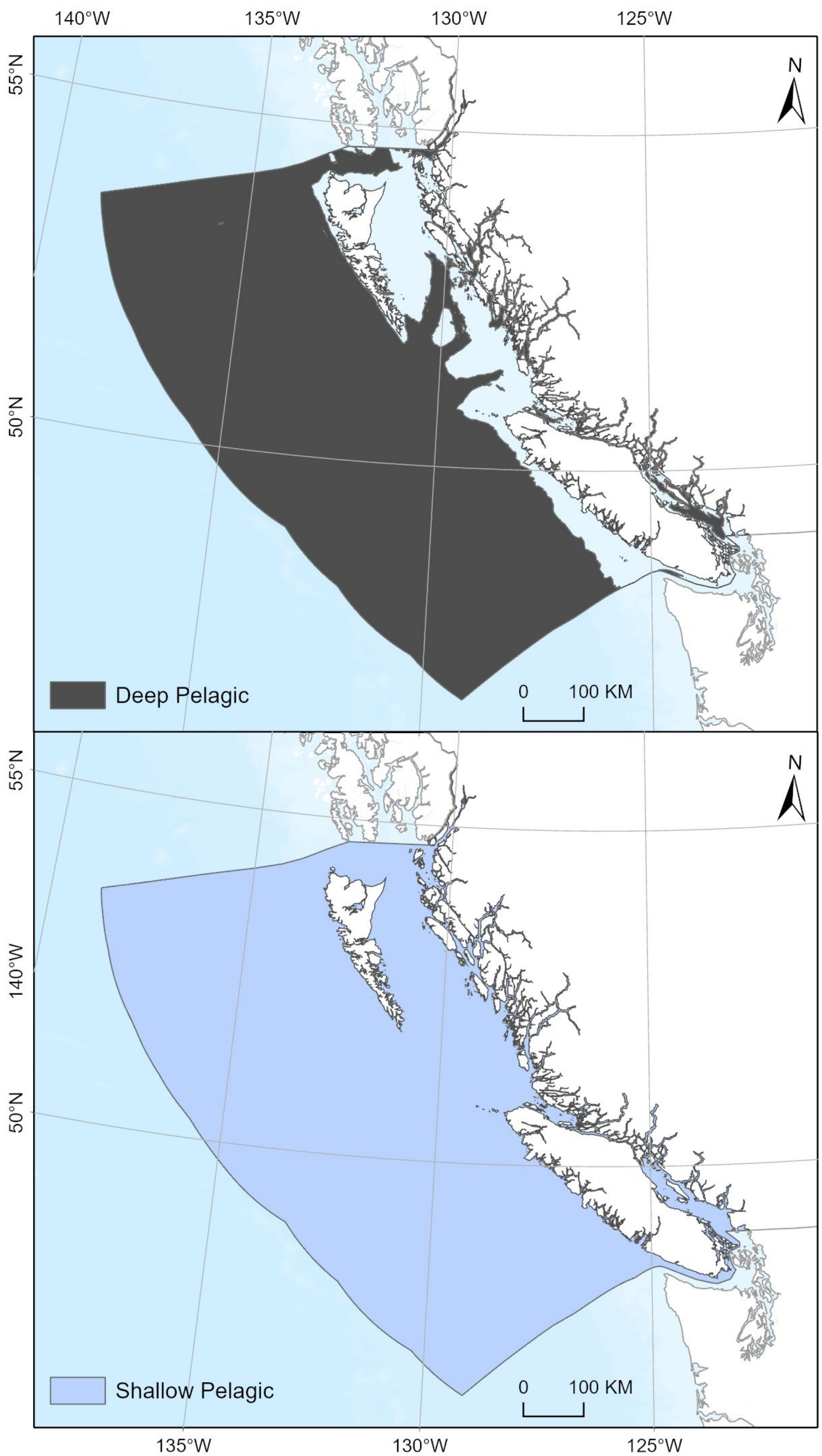

Figure 10. Maps of deep pelagic and shallow pelagic habitats. Service layer credits: Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada.

Discussion

The Pacific marine habitat classes were created for use as input data in cumulative impact mapping. In the cumulative impact mapping model, the habitat classes are the endpoints for the assessment of impacts from human activities and stressors. As such, the classes were specifically created to match the habitat classes used for assessing vulnerability scores (Murray et al. 2024) and have necessary differences from other habitat classification systems.

This dataset was created to match an existing habitat classification used in the expert elicitation process for habitat vulnerability scoring (Teck et al. 2010) and cumulative impact mapping in the Pacific region (Agbayani et al. 2015; Ban et al. 2010; Clarke Murray et al. 2015a; Clarke Murray et al. 2015b). We were unable to use existing spatial datasets developed for other habitat classifications for the Canadian Pacific (e.g., Gregr et al. 2016; Proudfoot and Robb 2022; Rubidge et al. 2016) because the methodologies for compiling them took into account different considerations and were produced for a different purpose. Gregr et al. (2016) modeled marine habitats based on the functional adaptation of organisms to ecological conditions. The Pacific Marine Ecological Classification System (PMECS) is a hierarchical classification for the Northern and Southern Shelf Bioregions of Pacific Canada produced by Rubidge et al. (2016). The PMECS layers include biophysical units which are areas of distinct physiographic and oceanographic conditions and processes that drive the composition of species in these areas at broad spatial extents, developed using cluster analyses on predicted species assemblages. The PMECS layers also include maps of geomorphic units (Proudfoot and Robb 2022; Rubidge et al. 2016), which are areas of discrete geomorphic structures that may be hundreds of kilometers in size and that are assumed to provide niches for distinct biological assemblages. The geomorphic units were developed using similar bathymetry datasets to this study and applied the benthic terrain modeler toolbox to look at changes in the slope of the seabed and were recently extended to include the Strait of Georgia Bioregion (Proudfoot and Robb 2022).

These various habitat classifications can be used in conjunction with each other to better inform models of habitat distribution in the Canadian Pacific. Habitat classifications like these are useful for informing various management processes such as marine spatial planning, marine protected area network design, and environmental impact assessments.

Assumptions and sources of uncertainty

Habitat classes are assumed to represent the vast majority of the habitat within a spatial feature, existing uniformly across each polygon. As a result, there may be overestimation of habitat area in areas where a habitat does not exist as indicated by spatial data, or possibe underestimation of habitat area where a habitat exists but was not captured by spatial data.

This dataset was created using the best available data at the time of compilation, from multiple data sources with varying scales and resolution for use at a coastwide scale. As a result, the accuracy and precision of the habitat classes differ across the study area, depending on the availability of spatial data across the region. The combination of multiple datasets at various scales and with varying levels of uncertainty make it challenging to quantify uncertainty within the layers. It is important to consider scale and overall uncertainties within the dataset when considering it for use in finer scale, localized analyses.

While this dataset covers the entire extent of the study area, data gaps remain for a large portion of Pacific Canada, particularly in deep offshore areas and remote, inaccessible portions of the coast. For example, substrate information was not available in the deepest offshore areas, and datasets such as the kelp and eelgrass, while extensive and the best data available, were not comprehensive for the whole coast. It is also important to note that this dataset does not capture changes through time. Habitat extents, particularly biogenic habitats, may shift with changing physical conditions and disturbance and therefore historical data may not reflect current extents. Ongoing efforts to develop methods to generate coastwide kelp data using remotely sensed imagery may help fill gaps in the future.

Future Directions

This dataset will be updated regularly with new and updated datasets as they become available. There are continued efforts by the Geological Survey of Canada to map the surficial geology of the sea floor along the floor, and further developments in habitat coastwide datasets such as ShoreZone (Harney et al. 2008) would be valuable for updating the dataset. There may also be opportunities to include additional habitat types as data become available. For example, the habitat classes for the Maritimes region include algal zones (intertidal habitats dominated by rockweed species) and salt marsh (Murray et al. 2024). These are habitats that exist in the Pacific region as well but spatial data were not readily available at the time of compilation. We aim to update the habitat classes dataset at regular intervals to incorporate new and/or improved datasets as they become available.

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Appendix

Appendix Table 1. List of other FCODES representing features in the intertidal dataset created from CHS nautical charts that were not used in the benthic classes (Murfitt n.d.). These FCODES were not used either because the code did not fit within the habitat classification we used or because the definition of the FCODE was unclear. Values and ranges of values listed are assumed to be in metres unless identified as fathoms (FA).

FCODES
<=0
>0
0-2
2-4
2-5
5-10
10-15
10-20
15-20
20-30
20-50
30-50
50-100
100-200

FCODES
200-300
300-400
400-500
500-600
600-1000
1000-2000
200+
1000+
2000+
3FA
6FA
10FA
20FA
30FA

FCODES
50FA
BUISGL
DAMCON
INLET
INSARE
UNSARE
LAGOON
FraserR
RIVERS
RUINSDR
SLCONS
Unlabeled
Unlabeled??
NULL

Appendix Table 2. Description of codes used in the NRCan surficial geology polygons for Kitimat and Douglas Channel (Shaw and Lintern 2016), and the substrate class they were assigned in the Cumulative Impact Mapping Pacific marine habitat classes.

Code	Surficial geology	Seascapes	Description	Benthic habitat substrate class
S1	Fiord sidewall - bedrock	Fiord seascapes	Steeply sloping (>40deg) with bedrock outcrops separated by depressions containing gravelly sandy mud; attached fauna on exposed rock and infauna in depressions; high backscatter	Hard / Rock
S2	Fiord sidewall - unconsolidated	Fiord seascapes	Sloped >10deg, smooth surfaces or incised by gullies up to 10m deep; consists of glaciomarine sediment with surface lag or a veneer of postglacial mud; generally gravelly sandy mud at the seabed (high backscatter) but also sandy mud (low backscatter)	Mixed
F1	Fiord floor - postglacial mud	Fiord seascapes	Gentle relief (slopes <10deg) deposits of postglacial mud and sandy mud; commonly located in banks to either side of channel thalwegs; acoustically transparent or with moderate internal reflections; low backscatter; formed primarily by deposition of fluvial sediments, but also by reworking of glaciogenic sediments.	Soft (Sand/Mud)
F2	Fiord floor - winnowed/scoured	Fiord seascapes	Low-relief (<2deg) areas of non-deposition or erosion with glaciomarine mud exposed at the seafloor; some have a scalloped appearance with relief 0.6 to 2.0m; surficial lag of muddy sandy gravel overlies acoustically stratified glaciomarine sediments; high backscatter; formed where bottom currents are relatively strong	Mixed
M	Moraine	Fiord seascapes	High relief (>100m) transverse ridges; gullied in places; acoustically incoherent glacial diamict draped by acoustically stratified glaciomarine mud; surface veneer of muddy gravel; high backscatter; formed at former ice margins during the retreat of grounded ice.	Mixed

Code	Surficial geology	Seascapes	Description	Benthic habitat substrate class
D1	Delta	Fiord seascapes	Located where major rivers enter the fiords; stepped, concave profiles; slopes up to 15 deg; steeply-dipping internal reflections on acoustic records; chutes up to 15m deep; generally gravel to sand at the seafloor; high backscatter; formed by deposition of delta foresets and bottomsets.	Mixed
D2	Fan delta	Fiord seascapes	Fan-shaped deposits extending from sea level to depths of 300m; slopes of 10 deg to 30 deg; chutes up to 1m deep with transverse steps; generally course sediments (bouldery gravel to sand); high backscatter; small fan deltas may be separated from the coast by an area of bedrock (sediment bypassing); created by fluvial deposition where small to medium rivers enter the fiords.	Mixed
Mt1	Mass transport complex	Fiord seascapes	Large areas of seabed failure, with failure volume > 1km3 in Squally channel; irregular relief including escarpments, gullies, depositional zones, and residual 'mesas' composed of acoustically stratified glaciomarine sediments; surficial sediment is muddy sandy gravel; high backscatter, but low backscatter for small areas of post-failure sedimentation; created by failure of glaciomarine sediments draped over moraines, in the Late Glacial period. The area at Kitkiata may include failures by was more likely conditioned by an outburst flood.	Mixed

Code	Surficial geology	Seascapes	Description	Benthic habitat substrate class
Mt2	Debris flows / translational slide	Fiord seascapes	Submarine slide deposits of differing ages, including fine grained material and ranging up to boulders tens of metres in size; high backscatter except low backscatter where slides are buried by postglacial mud; the Kitimat slide (ca. 1970s) has complex morphology including remoulded debris, pressure ridges, depositional lobes, longitudinal shears; outrunner blocks; sand and muddy sand with some gravel; high backscatter; formed by failure of sediment on fiord sidewalls or delta fronts	Mixed
Mt3	Bedrock slump / rock avalanche	Fiord seascapes	Slump is a convex mass extending ~1km away from foot of bedrock slope irregular surface with relief `10m; total volume 0.3 km3; veneered by Quaternary sediments with high backscatter (muddy sandy gravel); rock avalanche includes irregular bedrock blocks mantled by sand.	Mixed
Mt4	Bedrock creep	Fiord seascapes	Blocks up to 5km long, detached from fiord sidewalls; rate of movement uncertain; may be equivalent to sackung (sagging bedrock on land); veneered by Quaternary sediments with gullies in places; high backscatter; formed by bedrock creep	Hard / Rock
B	Bioherm	Fiord seascapes	Ridges located on top of glacial deposits with relief commonly 5-10m; acoustically transparent with low backscatter; composed on glass sponges (Hexactinellida); also includes death assemblage of giant acorn barnacle (*Balanus nubilus*) in Devastation Channel; classified as bioherms (reefs of fossilized biological remains with some sediment)	Soft
A	Dredged area	Fiord seascapes	Area of Kitimat delta impacted by harbour activities; rectilinear dredge pits up to 6m deep; anchor drag marks	Undefined

Code	Surficial geology	Seascapes	Description	Benthic habitat substrate class
O1	Bedrock	Continental Shelf Seascapes	Bedrock ridges and knolls with relief up to 30m, separated by depressions containing glacial and postglacial sediments; high backscatter on outcrops, low backscatter in depressions.	Hard / Rock
O2	Moraine	Continental Shelf Seascapes	Lobate ridges 100m wide and 5-10m high; linear ridges 7km long and 30m high; composed of acoustically incoherent glacial diamict; bouldery gravel at the seafloor; high backscatter; formed at the margins of grounded glacial ice.	Rocky
O3	Streamlined ridge	Continental Shelf Seascapes	Ridges up to 10m high and 3km long, tapering to the southwest; composed of acoustically incoherent glacial diamict; bouldery gravel at the seabed; high backscatter; formed parallel to the flow of grounded glacial ice.	Rocky
O4	Glaciomarine sediment	Continental Shelf Seascapes	Areas of low relief imprinted by iceberg furrows and pits; surface lag of sandy muddy gravel overlies draped. Acoustically stratified, gravelly sandy mud; high backscatter; formed by deposition of reworked glacial meltwater plumes.	Mixed
O5	Postglacial mud / sandy mud	Continental Shelf Seascapes	Low-relief banks with weak acoustic stratification in a semi-ponded style; mud and sandy mud; low backscatter; formed by deposition of reworked glacial sediments and fluvial sediments	Soft (Sand/Mud)
O6	Winnowed / scoured seafloor	Continental Shelf Seascapes	Low relief, smooth seafloor; gravel lags; high backscatter; found where deposition of post glacial sediment is inhibited by currents.	Hard / Rock
O7	Bioherm	Continental Shelf Seascapes	Narrow ridges with relief of up to 5m, with low backscatter strength, located on top of glacial deposits, are tentatively identified as glass sponge (Hexactinellida) reefs.	Mixed

Appendix Table 3. Description of codes used in the NRCan surficial geology polygons for Chatham Sound (Shaw and Lintern 2023), and the substrate class they were assigned in the Cumulative Impact Mapping Pacific marine habitat classes.

Code	Surficial geology	Substrate Types	Description	Benthic habitat substrate class
B	Bedrock	Bedrock Substrates	Ridges and knolls with relief up to 30m, separated by depressions containing glacial and postglacial sediments; includes sidewall environments along the channels in the east of the map area; high backscatter on outcrops, low backscatter in depressions.	Hard
G	Glacial sediment	Glacial Substrates	Moderate to high relief and irregular morphology; high backscatter; acoustically incoherent; sandy gravel and bouldery gravel at the seafloor; composed of glacial diamict; the large north-south trending moraine in the west of the map area passes laterally into acoustically stratified glaciomarine sediment; includes one small area of De Geer moraines; may have a veneer of glaciomarine sediment; areas shallower than postglacial lowstand depth may have elongated, narrow, overstepped gravel beached and spillover wedges; formed in contact with grounded glacial ice.	Mixed
Gm2	Glaciomarine sediment	Glacial Substrates	Areas of moderate to low relief imprinted by iceberg furrows and pits; surface lag of sandy muddy gravel overlies draped, acoustically stratified, gravelly sandy mud; high backscatter, may overlie glacial diamicton. Gm1 has relatively low relief; Gm2 is an area of higher relief in Dixon Entrance and consists of a veneer over rugged bedrock terrain; formed by deposition from glacial meltwater plumes; the small area of glaciomarine sediment in Ogden Channel has no furrows and has been exposed by current scour.	Mixed
S1	Postglacial sand, muddy sand	Postglacial Substrates	Low-relief areas of mobile medium sand with increased mud component in some areas; low backscatter; acoustically incoherent or with no penetration; formed by reworking of glacial sediments; patches of gas masking in Browning Strait.	Soft

Code	Surficial geology	Substrate Types	Description	Benthic habitat substrate class
S2	Bedform field	Postglacial Substrates	Arrays of mobile sandy ridges with wavelengths 10 - 350 m, heights 0.2 - 10.0 m; medium sand; low backscatter; mobilized by tidal and storm driven current and action on Dogfish Bank; formed by reworking of glacial sediments.	Soft
S3	Starved bedforms	Postglacial Substrates	Series of ridges up to 5m high, commonly barchanoid in form; separated by a hard substrate; mobile medium sand; low backscatter; derived by reworking of glacial sediments by tidal currents in Hecate Trough.	Mixed
S4	Bank	Postglacial Substrates	Shallow platform with low relief and steep flanks bordering Hecate Trough; thick deposits of medium sand with low backscatter; bank tops area has bedforms up to 8 m high; in some areas the flanks consists of aggregated lobate ridges ~4m high, transverse to slope, extending to a depth of 112m in Hecate Trough. The platform is part of Dogfish Bank, while the lobate ridges are formed by transport off the bank top and down its flanks perhaps by gravity flows.	Soft
M	Post-glacial mud/sandy mud	Postglacial Substrates	Areas of low-relief located in depressions and areas sheltered from wave action; weak acoustic stratification in a semi-ponded style; gas masking in places; pockmarks and sedimentary furrows in some areas; mud and sandy mud; low backscatter, formed by deposition of reworked glacial sediments and by fluvial deposition.	Soft
D1	Delta foreslope	Postglacial Substrates	Located at the two principal outlets of the Skeena River (Telegraph Passage and Marcus Passage_; gently concave profiles with slopes of 1 degree; steeply dipping internal reflections on acoustic records; main channels up to 4m deep; birdsfoot pattern of distributary channels at the base of slope; sand at the seafloor; low backscatter; formed by construction of delta foreset beds.	Soft

Code	Surficial geology	Substrate Types	Description	Benthic habitat substrate class
D2	Lowstand delta	Postglacial Substrates	Low-relief platform in Hecate Trough with relatively steep face oriented towards the southeast; internal reflections show prograded clinoforms; coring shows silty sand; low backscatter; formed c. 11.5 ks when relative sea level was -95m.	Soft
T	Tidal delta	Postglacial Substrates	Flat-topped terrace with steep landward slope; located in channel near Prince Rupert; high backscatter; muddy gravel substrate; formed by tidal flow in narrow channel.	Mixed
Mt	Mass transport terrain	Postglacial Substrates	Erosional troughs adjacent to hummocky depositional zones; high backscatter; located off the port at Prince Rupert (recent deposits triggered by human activity) and in Victoria Channel (older deposits of unknown age).	Mixed
R	Sponge reef	Biogenic Substrates	Ridges typically located on top of deposits; with relief commonly 5-10 m but up to 25m; acoustically transparent with low backscatter; surface is muddy with groups of glass sponges (Hexactinellida); composition is mud and glass sponge remains; formed by growths of bioherms in postglacial time.	Soft