IDENTIFICATION OF REPRESENTATIVE SEAMOUNT AREAS IN THE OFFSHORE PACIFIC BIOREGION, CANADA

Habitats and species associated with Canadian seamounts.(Image credit: Fisheries and Oceans Canada, S. Du Preez, C. Du Preez, Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners, Pacific Wild)

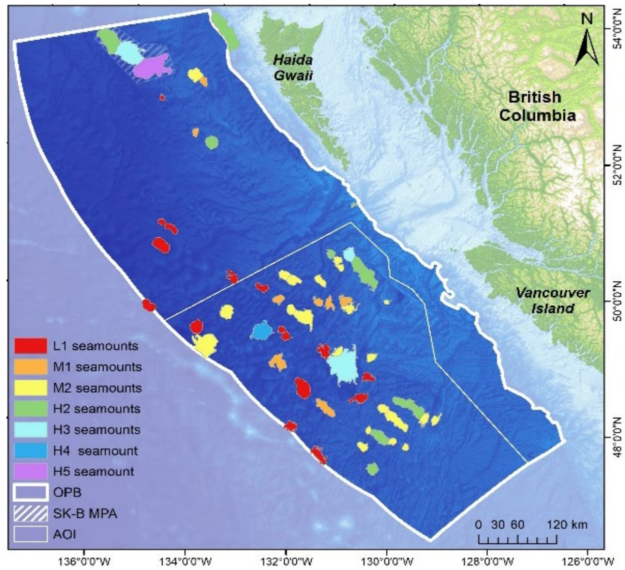


Figure 1. The Area of Interest (AOI) in the Offshore Pacific Bioregion (OPB). Also shown: 62 seamounts coloured by class and SGaan Kinghlas-Bowie Marine Protected Area.

Context:

In 2017, Fisheries and Oceans Canada (DFO) identified the southern portion of the Offshore Pacific Bioregion (OPB) as an Area of Interest (AOI) in anticipation of a proposed Marine Protected Area (MPA; Fig. 1). The proposed Offshore Pacific MPA would contribute to the protection and conservation of the region's unique seamounts and hydrothermal vents. These Ecologically and Biologically Significant Areas (EBSAs) occur nowhere else in Canada other than the OPB, with the majority located inside the AOI (DFO 2019).

DFO Oceans Management Branch has requested that Science Branch develop an evaluation, based on ecological criteria, to identify representative seamount areas in the Offshore Pacific AOI, to identify natural seamount boundaries, and to assess the ecological uniqueness and ecosystem functions provided by each seamount (above photo). Representative ecosystems are considered a collection of areas that captures examples of different biogeographic subdivisions that reasonably reflect the full range of ecosystems present at the scale of assessment, including the biotic and abiotic diversity of those ecosystems (CBD 2008; DFO 2013). This advice will guide management and monitoring decisions for seamount conservation and protection within the OPB and AOI, and will inform the future application of the Ecological Risk Assessment Framework (ERAF; similar to DFO 2015).

This Science Advisory Report is from the November 25-26, 2020 regional peer review on the Identification of Important Seamount Areas in the Offshore Pacific Bioregion, Canada. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Seamounts are Ecologically and Biologically Significant Areas (EBSAs) and Vulnerable Marine Ecosystems (VMEs) that are unique within Canada to the Offshore Pacific Bioregion (OPB).
- Compared to the surrounding deep seafloor, the relatively shallow habitat provided by all seamounts supports diverse and distinct species assemblages including habitat-forming cold-water corals, sponges, and hundreds of other benthic and pelagic species.
- There are 62 seamounts known or predicted to occur in the OPB, of which 43 were newly identified (not currently reported in the Canada Gazetteer; 29 from DFO 2019 and 14 from this process). The location and depth of 21 of these new seamounts have been ground-truthed. DFO Science is working in partnership with several First Nations to name these new seamounts.
- The Area of Interest (AOI) for the Offshore Pacific Marine Protected Area (MPA) contains the majority (47) of OPB seamounts. Three seamounts are in SGaan Kinghlas-Bowie Seamount (SK-B) MPA, and 12 are in the OPB outside conservation areas.
- Newly delineated seamount boundaries can be used for future spatial planning.
- The density of seamounts within the AOI and the OPB is notable (approximately 5 and 3 times the global average, respectively).
- A regional assessment of geography and oceanography (major currents), supported by biological observations, revealed no evidence of biogeographic boundaries (i.e., barriers to dispersal) among the OPB seamounts. Additional research, such as genetic analyses, is needed to assess connectivity among the seamounts.
- Depth zones on the OPB seamounts are delineated by light availability and oxygen concentration, and align with depths of documented biological community transition zones.
- The information for the global seamount classification system previously used to classify the OPB seamounts was updated to include new seamounts, improved depth data, and an additional criterion.
- OPB seamounts were assigned to one of seven biophysical classes using quantitative thresholds of export productivity (new to this iteration), summit depth, and dissolved oxygen concentration at the summit. Two additional criteria, biogeographic province and distance to nearest seamount, do not vary within the OPB and so do not differentiate any seamounts.
- Assemblages of cold-water corals, sponges, and other benthic species vary across seamount classes and depth zones, supporting the classifications as biologically relevant. Seamounts with shallower summits span multiple depth zones and support higher species richness. SK-B Seamount, the shallowest in the OPB, supports unique benthic assemblages not represented elsewhere in the OPB (e.g., shallow subtidal communities).
- The seamount classification system is regionally relevant, as its criterion thresholds align with oxygen concentrations and depth boundaries observed in the OPB, and it can be applied to undiscovered OPB seamounts or those outside of Canadian waters.
- Representativity of the seamount classes within the OPB was assessed. Five of the OPB seamounts are rare or unique (occurring in only a few locations or the only one of its kind): Dellwood, Hodgkins, Explorer, Union, and SK-B seamounts.

- OPB conservation areas cover at least one representative seamount of each class. Six of the seven classes occur in the AOI, and the only Class H5 seamount, SK-B, occurs in SK-B MPA.
- It is recommended that the methods presented here be used to update/reassess the seamount classifications (classes and zones) as new data becomes available (e.g., improved bathymetry, seamount morphology, substrate, pelagic data).
- Future applications of the classification could consider new non-depth related metrics. For example, differences in summit morphology may affect local currents, which in turn may influence the community structure of cold-water coral and sponge assemblages.
- Seamounts provide ecosystem functions that enhance regional productivity, biological diversity, resilience, and connectivity. In general, shallower seamounts are thought to provide more ecosystem functions than deeper ones.
- All OPB seamounts are anticipated to experience changes, now or in the near future, as a result human activities and changing ocean conditions. Shallower seamounts such as SK-B and Union seamounts are anticipated to experience more changes.
- The amount of existing baseline data by which to detect change varies among OPB seamounts. In general, more is known about shallow seamounts and those closer to shore.
- Information on the anticipated environmental changes and existing ecological data for the 62 seamounts are presented in a single “portfolio” summary, illustrating a degree of likelihood associated with detecting change if the seamount is monitored in the future. Representative seamount areas with a high degree of likelihood (i.e., reference sites) are identified for each seamount class and for each conservation area.
- To support the scoping stage of the Ecological Risk Assessment Framework (ERAF), an inventory of species known to occur on OPB seamounts was compiled and potential Significant Ecosystem Components were provided. Since the last assessment in 2015, the number of known taxa on OPB seamounts has quadrupled. With increased sampling and examination of voucher specimens, more species are likely to be identified.
- There is no evidence of endemism (i.e., species unique to any one seamount).
- The remote nature, vast size, and range of habitats in the OPB make gathering comprehensive and/or representative data a challenge. The analyses presented here are limited to discrete or static (“snapshot”) information, but the OPB is a dynamic system with multi-scale spatial and temporal variability.
- It is recommended that this information is suitable for a range of potential applications, such as the ERAF and the development of an MPA management plan, conservation objectives, a monitoring framework and plan, and future survey design and research development.

BACKGROUND

Canada's Oceans Act provides the legislative framework for an integrated ecosystem approach to manage oceans, particularly in areas considered ecologically or biologically significant. To guide efforts, in 2015, Canada adopted international and domestic 2020 Biodiversity Goals and Targets. The United Nations Convention on Biological Diversity (CBD) Aichi Biodiversity Target 11 (reformatted as Target 1 of the 2020 Biodiversity Goals and Targets for Canada) called for the conservation of 10% of coastal and marine areas by 2020 (CBD 2011, DFO 2016). The Government of Canada has since announced it will join the European Union Biodiversity Strategy for 2030, committing to protect 25% of its land and seas by 2025 and 30% by 2030. Under the Oceans Act, Fisheries and Oceans Canada (DFO) is legislated to provide protection to areas of the oceans and coasts through the establishment of Marine Protected Areas (MPAs), where the identification of an Area of Interest (AOI) is the first step in this process.

In 2017, DFO identified the southern portion of the Offshore Pacific Bioregion (OPB) as an AOI, in anticipation of a proposed MPA (Fig. 2). The proposed Offshore Pacific MPA would contribute to the protection and conservation of the region's unique seamounts and hydrothermal vents. These features are Ecologically and Biologically Significant Areas (EBSAs) and Vulnerable Marine Ecosystems (VMEs; Ban et al. 2016 and references therein) that are unique within Canada to the OPB, with the majority located inside the AOI (DFO 2019).

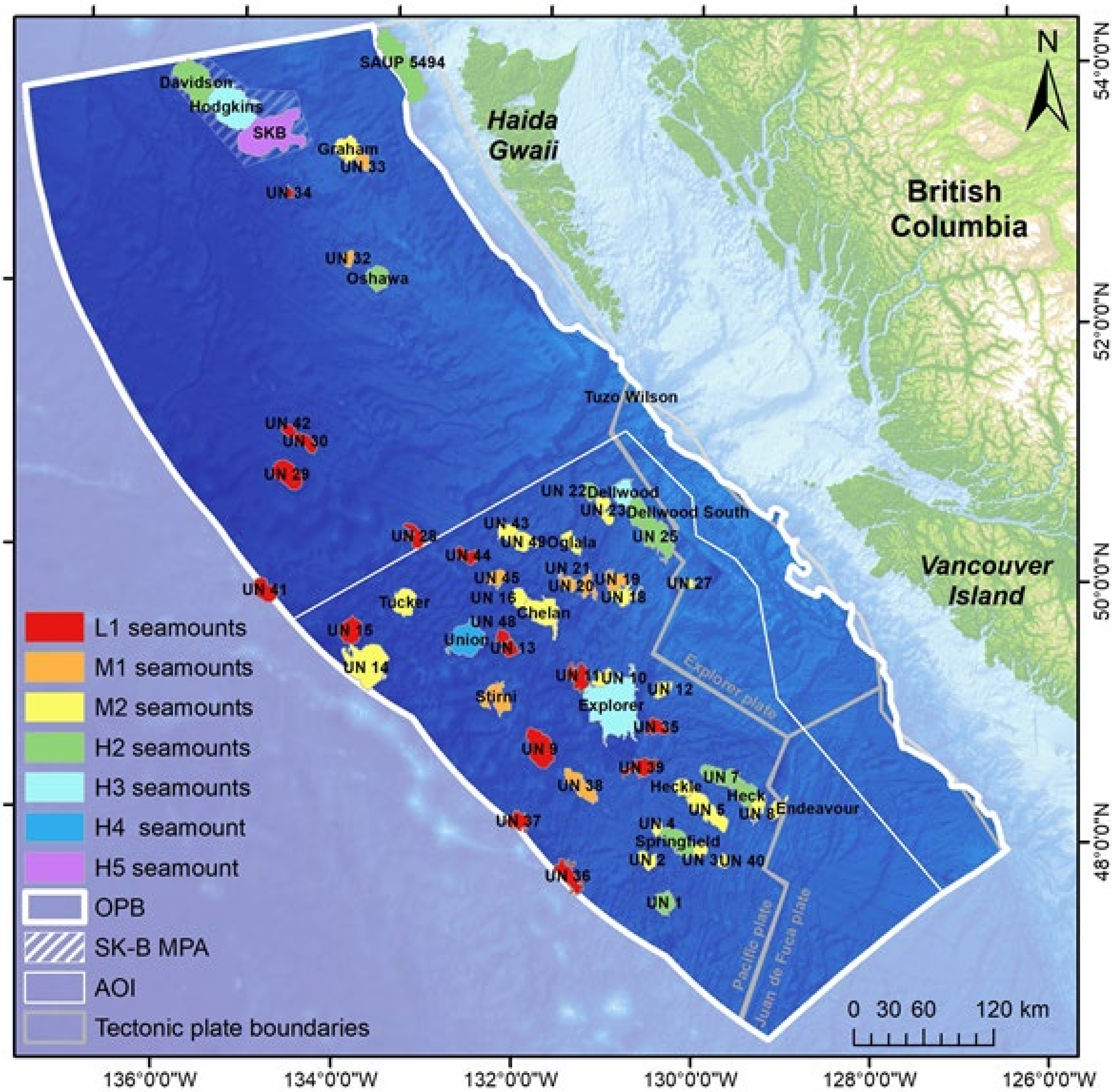


Figure 2. The 62 seamounts in the Offshore Pacific Bioregion (OPB), coloured by seamount class (see text for details). AOI: Area of Interest; SK-B MPA: SGaan Kinghlas-Bowie Marine Protected Area.

Seamounts are underwater volcanic mountains that rise abruptly ≥1,000 m above the deep abyssal and bathyal plains, dramatically altering environmental conditions. The OPB seamounts are uniquely shallow habitats offshore and are known to provide important habitat and food for species of conservation concern, as well as socially, culturally, and commercially valuable species, including cold-water corals and sponges, rockfish, halibut, whales, and seabirds (Ban et al. 2016; DFO 2019). Although the ecological importance of seamounts has long been recognized, the current state of knowledge on the OPB seamounts presented herein is from emerging and ongoing science.

Representative ecosystems are considered a collection of areas that capture examples of different biogeographic subdivisions that reasonably reflect the full range of ecosystems present at the scale of assessment, including the biotic and abiotic diversity of those ecosystems (CBD 2008; DFO 2013). EBSA management and monitoring places particular emphasis on the role of representativity in protecting sites of high biodiversity value, such as seamounts (DFO 2013).To assess the representation of ecosystems in protected areas, accurate and informative spatial baseline information is essential (DFO 2013).

Objectives

The purpose of the Research Document is to evaluate the representative seamount areas in the OPB, with a focus on the AOI for the proposed Offshore Pacific MPA.

For this Science Advisory Report (SAR) and the accompanying Research Document, the objectives presented in the Terms of Reference were reworded and reorganized for clarity (Table 1). In particular, the original Objective 1 was split in two, and Objective 4 was reworded to clarify the use of the term “important seamount area” (see Scope section below).

Scope

The working paper:

- Assesses all 62 known Canadian seamounts, including those in the AOI, SK-B MPA, and those in the OPB but outside conservation areas.
- Focuses on benthic ecosystems and their associated species, such as large cold-water corals and sponges.
- Does not address the concept of “Important Areas” under the EBSA framework (Clarke et al. 2006). “Important Areas” is a DFO term used to communicate a specific concept under the EBSA framework (i.e., important areas are considered those with regionally rare, significant, or functionally important species; Clarke et al. 2006) and that the similar wording of “important seamount areas” had inadvertently misrepresented the working paper. The terminology used was changed from “important seamount areas” in the Science Request and Terms of Reference to “representative seamount areas” in all subsequent documents.

Table 1. The wording of the Terms of Reference objectives, reworded for presentation in the Science Advisory Report (SAR) and Research Document.

Objectives in the Terms Of Reference	Objectives in SAR and Research Document
1. Update information for the nomenclature, location and systematic classification of seamounts in the OPB	1. Update information for the nomenclature and location of OPB seamounts
2. Identify natural boundaries or zones within the OPB	2. Identify natural boundaries or zones within the OPB
	3. Update information for the systematic classification of OPB seamounts
3. Assess the uniqueness and ecosystem functions provided by each seamount within the OPB	4. Assess the uniqueness and ecosystem functions provided by each OPB seamount
4. Identify important seamount areas within the OPB, focusing on the AOI related to the proposed Offshore Pacific MPA	5. Identify representative seamount areas to detect changes within the OPB
5. Inform the future application of the Ecological Risk Assessment Framework (ERAF)	6. Inform the future application of the ERAF to the AOI
6. Examine and identify uncertainties in the data and methods	7. Examine and identify uncertainties in the data and methods

ASSESSMENT

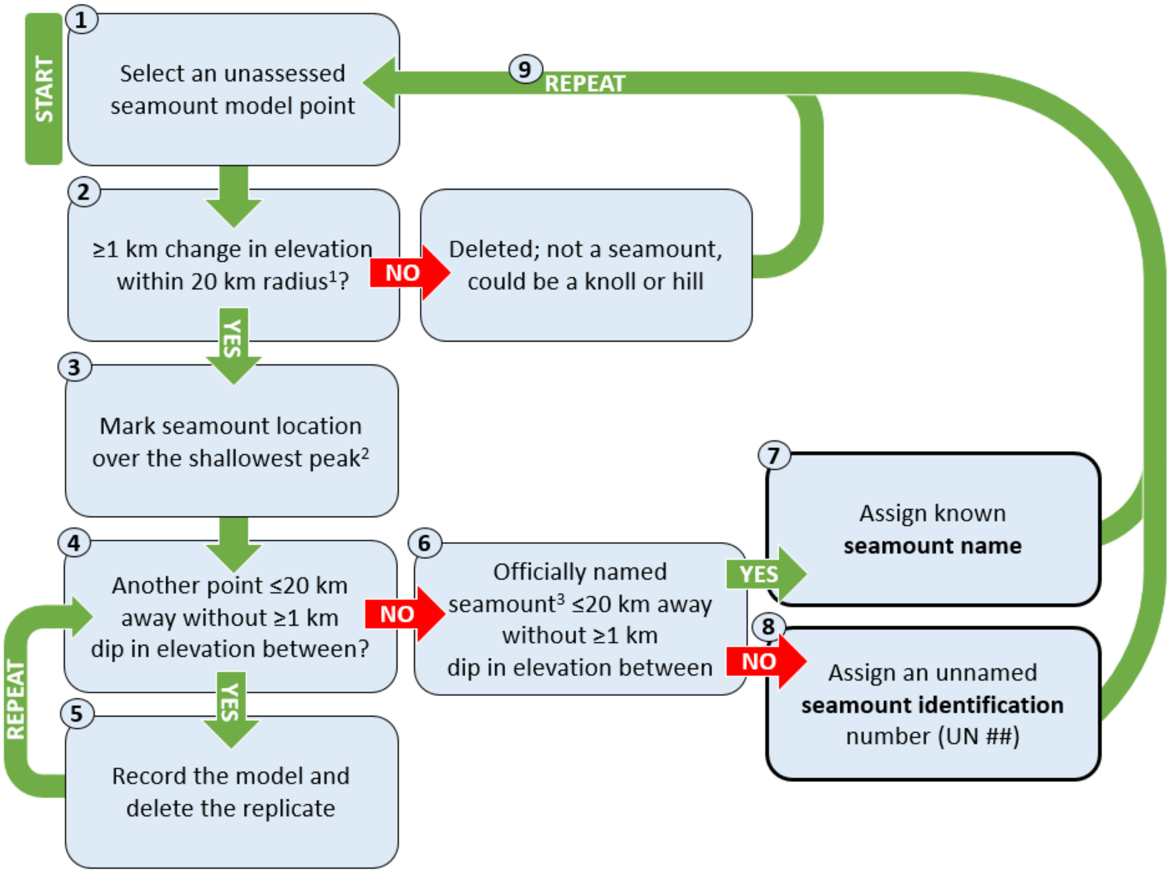
Objective 1: Seamount Identification and Naming

The Offshore Pacific Bioregion (OPB) seamounts were identified using published locations of seamounts (e.g., Canadian Gazetteer, NRC 2015; Ban et al. 2016), a systematic review of six seamount models (five listed in DFO 2019, plus Yesson et al. 2020), a compilation of bathymetric maps (e.g., new data from research cruises), and geophysical criteria (Fig. 3). Boundaries for the OPB seamounts were defined and produced using geoprocessing analyses in ArcMap.

There are now 62 seamounts known or predicted to occur in the OPB (Fig. 2; Table A1), of which 43 are newly identified and unnamed (UN)—ten more since the last inventory: four seamounts listed in DFO 2019 were removed from the inventory (for various reasons) and 14 new UN seamounts were discovered (denoted with * in Table A1). To mark the significance of seamounts as part of our geographical and cultural environment, DFO Science is working in partnership with the 17 coastal First Nations (Nuu-chah-nulth, Quatsino, Haida, and Pacheedaht First Nations) to name the new discoveries and update the Canadian Gazetteer (interim nomenclature: “UN” followed by two digits). The locations and depths of seamounts were determined using available databases and bathymetry models, which have varying degrees of accuracy. Using recently collected bathymetry (single- and multi-beam), the location and depth of 34 seamounts (21 newly identified) have been confirmed.

Forty-seven seamounts are in the Area of Interest (AOI; 76%), three are in the SGaan Kinghlas-Bowie Marine Protected Area (SK-B MPA; 5%), and 12 seamounts are outside of the conservation areas (19%). Thirty-six of the 47 AOI seamounts are currently protected by a fisheries closure. There are additionally hundreds to thousands more seamount-like knolls and hills in the OPB that do not meet the seamount criteria of ≥1 km elevation (e.g., Seminole "seamount"; DFO 2019).

Seamounts cover vast areas and vary in shapes and sizes, but these characteristics can be overlooked when seamounts are mapped as summit-point locations. Based on the newly defined feature boundaries (the outer 3° degree slope contour), seamounts cover 6.5% of the OPB and 11.2% of the AOI, indicating OPB and AOI seamounts are remarkably dense (global mean: 2.2%). Over half of the OPB seamounts share boundaries, forming seamount chains. Several of the seamounts around the edges of the OPB cross into the Northern Shelf Bioregion (SAUP 5494) and the High Seas (UN 41, 14, 36, and 37). There is almost a 50-fold difference in area between Tuzo Wilson and Explorer, the smallest and largest OPB seamounts, respectively (refer to Fig. 2).



[1] ≥1 km elevation between pinnacle-to-base distance (DFO 2019). [2] Seamount location recorded as the latitude, longitude, and depth of the shallowest peak. [3] Official names as listed in the Canadian Gazetteer (CG) or GEBCO (General Bathymetric Chart of the Oceans).

Figure 3. Steps for systematically assessing and consolidating six previously published seamount models. These steps were repeated until the prediction locations of seamounts from all six models were assessed to be a known seamount, an unnamed seamount, or deleted as a knoll, hill, or replicate.

Objective 2: Natural Boundaries

Natural boundaries within the OPB were assessed by reviewing the regional geography (tectonic plate boundaries, oceanographic zones, and spatial clustering and proximities) and by assessing regional depth zonation and ecological bathymetric trends on the seamounts.

There are three oceanic tectonic plates within the OPB. Currently, there is no evidence that the tectonic plates are ecologically significant boundaries. The majority of OPB seamounts are located within one plate, the Pacific (Fig. 2); two occur at junctions between the Pacific and Explorer plates, and there are none on the Juan de Fuca plate.

There are five major oceanographic features identified within the OPB: (1) the offshore Alaska current, (2) an offshore bifurcation zone, (3-4) coastal upwelling and downwelling zones with (5) a transition zone in-between, as well as large-scale eddies (e.g., Haida eddies).

We resolved four geographic clusters (zones) of seamounts based on spatial distribution. These clusters represent horizontal zonation. All seamounts are in close proximity to another seamount or the continental slope (≤100 km; Clark et al. 2011), with all but one seamount within a mean dispersal distance resolved for deep-sea fauna (≤33 km; Baco et al. 2016). There is no evidence of dispersal boundaries or endemism within the OPB, only variations in species relative abundances (e.g., dominant species).

The seafloor of the OPB rises through nearly four vertical kilometres of water, transitioning through strong light- and oxygen-depth gradients (Fig. 4). Based on these environmental data, we resolved six bathymetric boundaries (representing vertical zonation): 0 m, 200 m, 480 m, 800 m, 1200 m, and 1700 m. The significance of these zones is supported by species turnover observed with benthic survey imagery (i.e., zones characterized by different assemblages; Fig. 4).

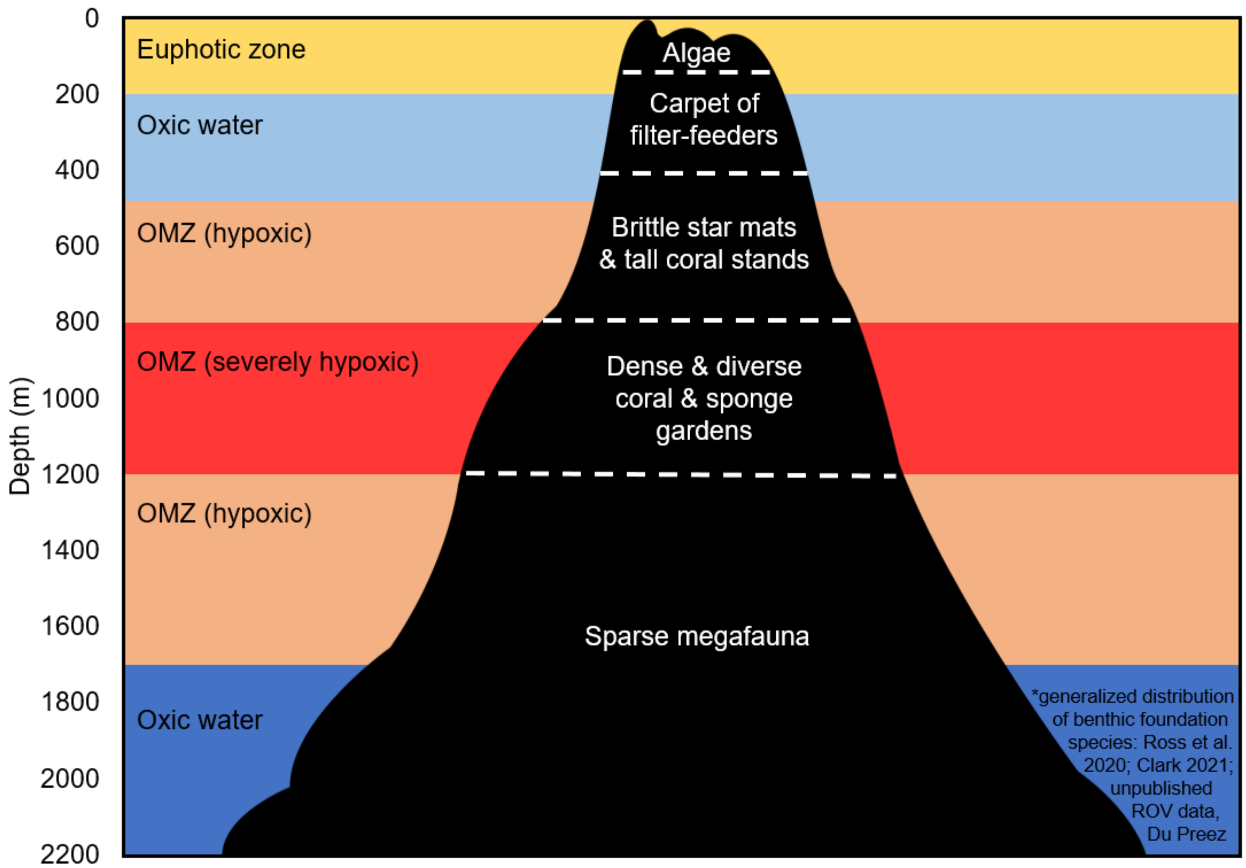


Figure 4. The spatial alignment of bathymetric boundaries (zones) and generalized distributions of benthic foundation species (Ross et al. 2020; Clark 2021; unpublished ROV data, Du Preez) on seamounts within the Offshore Pacific Bioregion.

Objective 3: Seamount Classification

OPB seamounts were classified based on physical and oceanographic characteristics using a global seamount classification system (Clark et al. 2011) and regional data. The seamount classification system was developed to aid the scientific design of MPAs (Clark et al. 2011) and was used to characterize OPB seamounts for an overview of the AOI (DFO 2019). This repeat analysis serves to update the previous classification by including an additional criterion (export productivity), new data (e.g., net primary productivity and better bathymetry), and newly discovered seamounts.

The classification system uses a decision tree to assign seamounts to classes based on the following ecologically important criteria:

1. biogeographic province;
2. export productivity (to summit);
3. summit depth;
4. dissolved oxygen concentration at summit; and
5. proximity (distance to nearest seamount).

Data were sourced or derived from:

1. lower bathyal global biogeographic provinces (Clark et al. 2011);
2. 19 years of sea surface net primary productivity (satellite-based data assembled and analyzed by Andrea Hilborn, Institute of Ocean Sciences), a carbon flux equation (Suess 1980), and summit depth;
3. best available bathymetry data for each seamount;
4. oxygen concentration from the World Ocean Atlas 2013 data (see DFO 2019 and references therein) and Line P (a long-term oceanographic time-series; Tetjana Ross, Institute of Ocean Sciences); and
5. distance to nearest seamount or continental slope (based on boundaries; Table A1).

In the OPB, criteria 1 and 5 are not informative since all seamounts occur in the “North Pacific” biogeographic province, and all occur within “close proximity” (≤100 km). The other three criteria are variable (Fig. 5). Seamount shape, listed as a potential consideration by Clark et al. (2011), was investigated as a possible sixth criterion but not included (see Objective 7: data limitations).

Seven classes of seamounts were identified in the OPB (Fig. 5): L1, M1, M2, H2, H3, H4, and H5; where the letters denote the export productivity categories (low, medium, high) and the numbers denote the summit depth and dissolved oxygen combination categories (comparable with the original five classes produced without considering export productivity; DFO 2019).

Ecological information derived from a subset of visual survey data collected from 2017-2019 was used to assess and ground-truth differences in species composition among the seamount classes. Presence-absence analyses of large habitat-forming octocorals support the biological meaningfulness of the seven seamount classes. Despite the low sample size (n = 11 of 62 seamounts), mean species richness (α-diversity) varied among classes, generally increasing with export productivity and increasing class number (i.e., decreasing summit depth), which aligns with the habitat-heterogeneity hypothesis (MacArthur and MacArthur 1961) that an increase in the number of different habitats can lead to an increase in species diversity (illustrated in Fig. 6). A (dis)similarity analysis further demonstrates that the species composition (β-diversity) also varies among classes; in general, seamounts in the same classes are more similar than seamounts in different classes. Exceptions to the trends mentioned above appear to be linked to high net primary productivity, suggesting the export productivity equation underestimates its ecological importance.

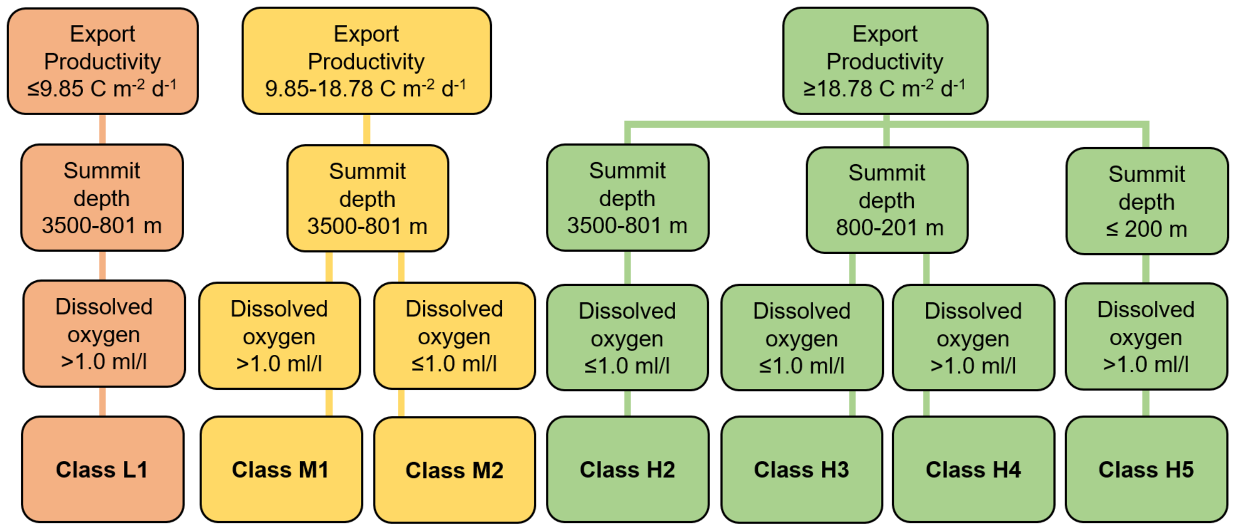


Figure 5. Organization chart of the hierarchical structure showing the seamount classification divisions for the seven combinations that exist in the Offshore Pacific Bioregion (OPB). Environmental conditions illustrated in Fig. 6. The significant figures provided for Export Productivity define the categories based on regional seamount conditions estimates and quartiles, and should not be interpreted as an indication of certainty or precision.

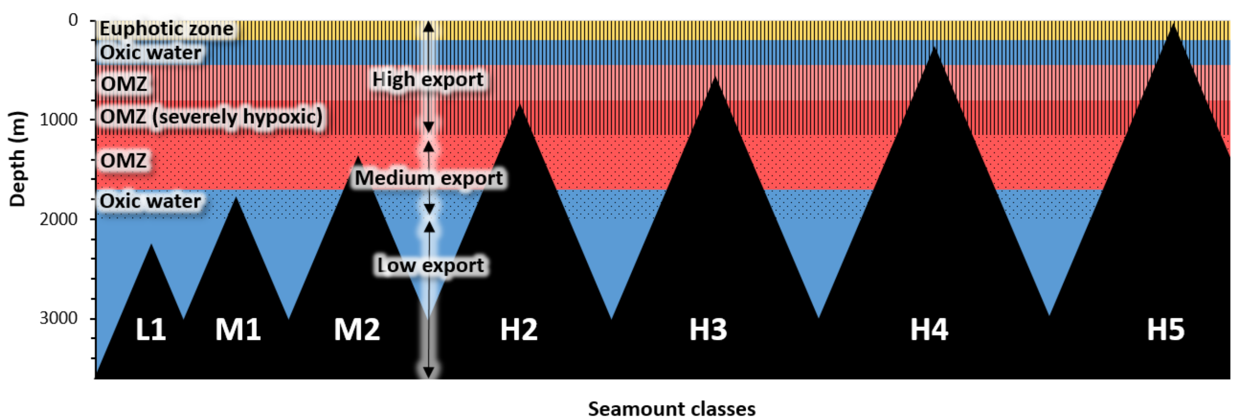


Figure 6. Illustration of the different depth-related environmental conditions (i.e., habitats) each of the seven seamount classes rise through: depth zones delineated by light availability (yellow: euphotic; aphotic below), oxygen concentration (blue: oxic; pink: hypoxic in the Oxygen Minimum Zone, OMZ; red: severely hypoxic in the OMZ), and export productivity from surface waters (vertical lines: high; dots: medium; black: low).

Objective 4: Uniqueness and Ecosystem Functions Provided by Seamounts

The uniqueness assessment is based on the CBD EBSA criteria definitions for *rare* (occurs in only a few locations) and *unique* (the only one of its kind) (CBD 2008). By default, *common* is neither *unique* nor *rare*. The ecosystem function assessment is based on the five biological CBD criteria for defining EBSAs as providing important services to one or more species, populations, or ecosystems, compared to other surrounding areas or areas of similar ecological characteristics (CBD 2008). Both assessments focus on the seamount classes.

Classes L1, M1, M2, and H2 are *common*, with >10% of the OPB seamounts in each (Table A2: *n* = 16, 8, 22, and 11, respectively), Class H3 seamounts are *rare* (Dellwood, Hodgkins, Explorer), and Classes H4 and H5 seamounts are *unique* (Union and SK-B, respectively). The AOI has at least one seamount from six of the seven classes (no Class H5), but the AOI and SK-B MPA combined cover all seven classes. Seamounts outside the conservation areas are deep and belong to well-represented *common* classes.

All seamounts provide ecosystem functions. Some functions are ubiquitous to all OPB seamounts (Table A2), such as providing relatively shallow benthic habitats which support diverse and distinct species assemblages of cold-water corals and sponges (i.e., rock as shallow as 24 m in comparison to the surrounding muddy basin at ~3 km). Other ecosystem functions apply to only a subset of seamounts (e.g., Class H5, higher biological productivity: macroalgae present). In general, the number of ecosystem functions provided by OPB seamounts increases with decreasing summit depth (i.e., Class H5 provides the most).

Objective 5: Representative Areas to Detect Change

Anticipated environmental changes within the OPB and a review of known existing ecological data for the 62 seamounts are combined in a single portfolio to offer valuable information for developing future management and monitoring plans.

Eleven possible changes were assessed, including those associated with closures to fishing (e.g., recovery), lost fishing gear (ghost fishing), ship traffic, exposure to ocean acidification (for calcite and aragonite) and deoxygenation (in four different water masses related to the mid-water oxygen minimum zone), and other environmental and biological effects of climate change. Twelve possible types of data were inventoried for each seamount: acoustic (bathymetry, pelagic, passive), benthic collections, fisheries, geological, monitoring sites, oceanographic (collections, sensors), visual benthic surveys (photo or video), satellite-based, and time-series.

This section also contains supplementary information on “control” seamounts (i.e., within the region but outside of conservation areas), and information on areas with regionally rare, significant, or functionally important species (identified based on opportune visual observations and expert opinion, limited to surveyed benthic areas on 12 OPB seamounts).

It is very likely all OPB seamounts will experience environmental change now or in the future. Of the 11 anticipated changes, those associated with climate change will probably impact the most seamounts, followed by fishing and ship traffic. Fifteen OPB seamounts are likely to experience change in six or more of the 11 categories considered.

Of the 12 existing data types, satellite and pelagic acoustic are the most readily available, while passive acoustic and geological surveys are the least. Only seven OPB seamounts have six or more types of existing data available. Benthic monitoring sites were established in 2018 at six OPB seamounts (positioned in particularly diverse/dense areas and bathymetric transition zones). The basic ecological data required for species distribution modeling (i.e., species presence and multibeam bathymetry) are available for roughly a quarter of the OPB seamounts. However, even on the best-studied seamounts that data is spatially and temporally limited.

The six shallowest seamounts score the highest with regards to anticipated changes and existing data (i.e., good candidate reference sites), have nearby control sites, and support regionally rare, significant, or functionally important species (Fig. 7). SK-B Seamount has the highest combined portfolio scores, suggesting it is a strong candidate to detect changes within the OPB and SK-B MPA. Dellwood Seamount has the highest combined portfolio scores within the AOI, but Union, the shallower seamount, is likely to experience more changes (may represent a knowledge gap).

The portfolio may be helpful for identifying representative seamount areas for monitoring. For example, for each seamount class: UN 35 for L1 (anticipated changes score = 3, existing data score = 4), UN 19 for M1 (5, 4), Endeavour for M2 (7, 4), Dellwood South for H2 (7, 9), Dellwood for H3 (8, 12), Union for H4 (9, 7), and SK-B for H5 (10, 12) (the latter three are labeled in Fig. 7).

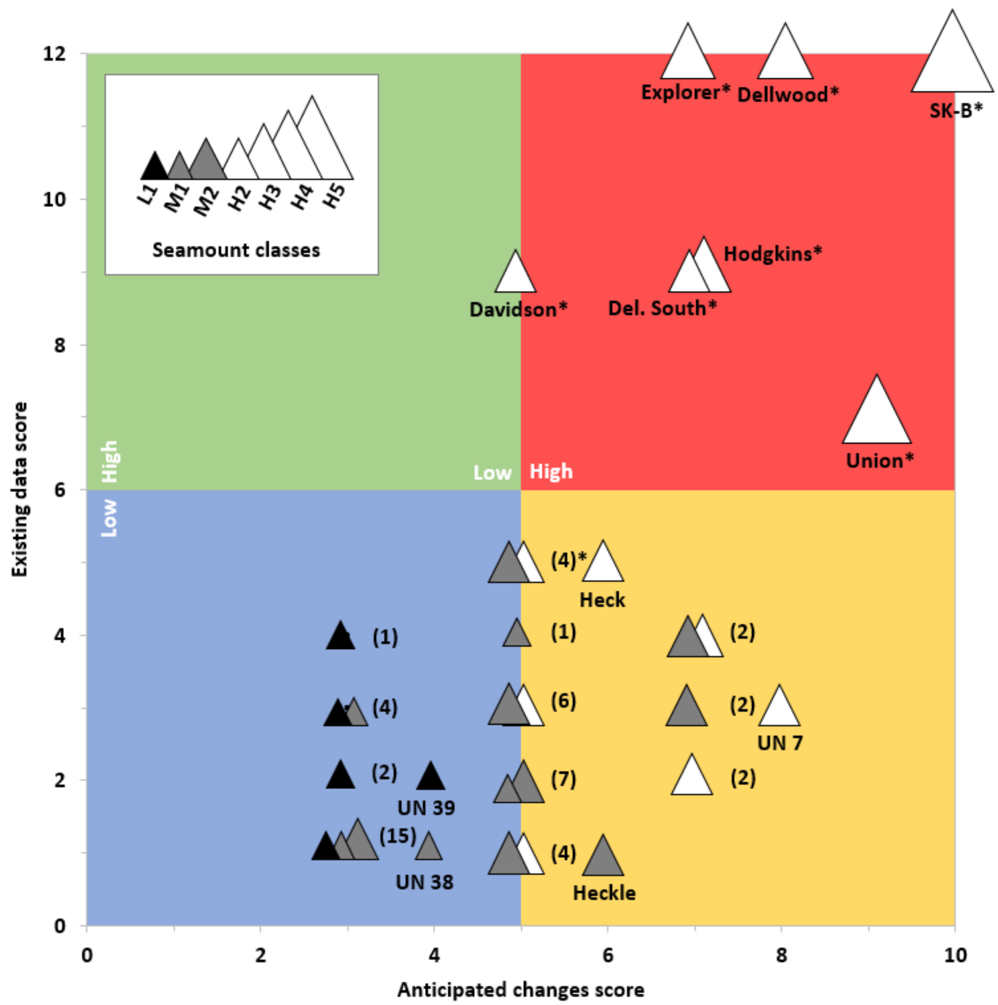


Figure 7. Seamount portfolio plot based on anticipated changes score and existing data score for the 62 seamounts in the Offshore Pacific Bioregion (OPB). The different colours represent four categories. Blue: few anticipated changes with low likelihood to detect (based on existing baseline data). Yellow: few anticipated changes with high likelihood to detect. Green: many anticipated changes with low likelihood to detect. Red: many anticipated changes with high likelihood to detect. If multiple seamounts share the same scores, the count (n) is provided in brackets, otherwise, the individual seamount name is provided. Asterisks denote seamounts with one or more observations of regionally rare, significant, or functionally important species.

Objective 6: Information for the Ecological Risk Assessment (ERAF)

The ERAF is a tool to identify and assess the risk of harm to significant ecological components (SECs) and to inform the development of indicators to monitor the impact of human activities on SECs and the achievement of conservation objectives (DFO 2015). There are two phases to an ERAF: scoping and risk assessment. To inform the scoping phase of the future application of the ERAF to the proposed Offshore Pacific MPA, the SK-B seamount component inventories (DFO 2015) were expanded to include new OPB seamount data.

By compiling observations collected over the past three years of surveys, an additional 580 taxa were added to the species inventory, quadrupling the number of taxa identified on OPB seamounts (from 191 to 771). Dozens of these species are confirmed new to science, collected during the Pac2018-103 expedition and identified by taxonomic experts and DNA barcoding. The seamount taxa represent 17 phyla, 46 classes, and 140 orders. The Research Document contains further information on habitat and community ecosystem components that may be relevant to the ERAF.

Objective 7: Limitations and Uncertainties

Limitations and uncertainties with the methods, data, and results were considered and discussed throughout the working paper and are summarized below.

Data

- The remote nature and vast size (area and volume) of the OPB make gathering comprehensive and/or representative data a challenge (e.g., technical and/or effort limitations).
- There may be more seamounts in the OPB than is presented in this analysis. Because the definition of a seamount is based on depth, the inventory and known summit depth of suspected seamounts may be revised depending on the quality, coverage, and resolution of bathymetry used. High-resolution multibeam bathymetry is preferred but is only available for a small portion of the OPB. The new seamounts were discovered by adding new high-resolution bathymetric maps to the compilation used in DFO 2019 and reassessing the geophysical criteria (as shown in Fig. 2).
- The coverage of existing benthic survey imagery is extremely limited and may not necessarily be representative of the seamount, zone, or class in which it was collected. Work is ongoing to determine the variation within and among OPB seamount classes, but preliminary analyses and research from other regions suggests within-seamount variability associated with differences in sedimentation, current directionality, flow speed, and other environmental variables is common (e.g., Morgan et al. 2019).
- The collection of voucher specimens to compare and validate imagery-based identifications is invaluable, but there are limited opportunities to collect such samples.
- Oceanographic data such as water and phyto- and zooplankton samples are limited within the OPB, and a lack of long-term data (e.g., time-series) makes it difficult to detect change. A notable exception is the DFO Line P Program, which provides a long-term oceanographic dataset at a series of fixed sites through the southern half of OPB (DFO 2017).

Analyses

- This assessment focused on the benthic habitats; work is ongoing to understand the pelagic realm and surface waters, which are important components of seamount ecosystems.
- Clark et al. (2011) list potential considerations for additional seamount classification criteria, which would result in a different seamount classification scheme. Seamount summit shape likely has biological relevance and should be considered in future iterations, but was not included here because of difficulties integrating bathymetry data of variable resolutions.

- The criterion thresholds used in the original seamount classification system were developed based on global conditions. The global thresholds for four of the five criteria were determined to be regionally relevant and were retained. Regional thresholds based on quartile breaks were used for Export Productivity, because the global thresholds were found to be too high to be informative.
- Variability in surface productivity is likely important and requires additional *in situ* data to explore.
- The results of the hierarchical cluster analyses (i.e., based on spatial distance, summit shape, and cold-water coral assemblages) in this assessment are likely sensitive to the algorithms to select the optimal number of clusters; alternate methods would likely produce different results.
- The assessment did not incorporate sensitivity analyses.
- Multiple analyses in this assessment focused on cold-water corals and sponges, or a specific group of corals (i.e., Alcyonacea). Sessile long-lived species serve as good proxies, but it is uncertain whether the observed ecological trends reflect patterns of other taxa.
- The portfolio scoring does not reflect the anticipated magnitude or duration of the environmental changes (e.g., is not weighted) nor the quantity or quality of the existing data. This will be incorporated into future applications of the ERAF.
- Some of the analyses are more qualitative than others. The level of information to include was sometimes based on subjective expert opinion (e.g., the level of detail included for species turnover with depth, ecosystem functions, anticipated changes, existing data types, the opportune observations of regionally rare, significant, or functionally important species, and the habitat and ecosystem component inventory suggestions for the future application of the ERAF).

Knowledge gaps

- The analyses presented here are limited to discrete or static oceanographic and geomorphic information to classify seamounts, but the OPB is a dynamic system with multi-scale spatial and temporal variability. For example, there are intra-plate features (faults, spreading valleys and ridges), water bodies are known to be mobile, and new research shows fine-scale variability in water masses around seamounts (Clark 2021). Further research is required to determine if this variability translates into ecologically significant boundaries.
- There is uncertainty if and how seamounts directly or indirectly affect local productivity. The concept of a “seamount effect” that causes enhanced local primary productivity above the seamount has been documented in some regions but is still debated (Leitner et al. 2020 and citations therein); the increased local diversity and biomass observed at seamounts may be due to other seamount effects, such as providing shallow habitat in offshore areas, changes (acceleration) of currents over the bathymetry, local currents advecting or retaining organic material, etc.
- There is limited information on seamount connectivity. Additional research, such as genetic analyses, is needed to assess the movement/dispersal of organisms between seamounts.
- There is limited information about substrate, which is an important predictor of species distributions (Morgan et al. 2019). Work is ongoing to extract substrate information from existing imagery.

- There is little research on the ecological characteristics of hills and knolls (defined as features under 500 m and between 500 and 1000 m, respectively), but these features may support seamount-like ecosystems.
- Climate change poses multiple stresses to marine ecosystems, including deep-sea and oceanic habitats. Two components of climate change, ocean acidification and deoxygenation, were considered as part of the "anticipated changes", but other aspects such as rising temperature and changes to ocean circulation were not addressed in detail. Given the strong environmental gradients and resulting biological zonation observed at seamounts, the cumulative (potentially synergistic) effects of climate change can be expected to cause changes to species distributions and community structure on seamounts, which in turn will impact ecosystem function provision in ways not yet quantifiable.

CONCLUSIONS AND ADVICE

- There are 62 seamounts known or predicted to occur in the OPB, ten more than the 2019 inventory. It is highly likely others will be discovered as high-resolution mapping of the region continues.
- Compared to the surrounding deep seafloor, the relatively shallow habitat provided by all OPB seamounts supports diverse and distinct species assemblages including habitat-forming cold-water corals, sponges, and hundreds of other benthic and pelagic species.
- This assessment revealed no evidence of natural biogeographic boundaries (i.e., barriers to dispersal) among the OPB seamounts and no evidence of endemism. However, some seamount classes were assessed to be unique or rare.
- Depth zones on the OPB seamounts delineated by light availability (photic, aphotic) and oxygen concentration (oxic, hypoxic, severely hypoxic) are supported by biological observations of community transition zones.
- OPB seamounts were assigned to one of seven biophysical classes using quantitative thresholds of export productivity (new to this iteration), summit depth, and dissolved oxygen concentration at the summit.
- Assemblages of cold-water corals, sponges, and other benthic species vary across seamount classes and depth zones, supporting the classifications as being biologically relevant. Seamounts with shallower summits span multiple depth zones and support higher species richness. SK-B Seamount, the shallowest in the OPB, supports unique benthic assemblages not represented elsewhere in the OPB (e.g., shallow subtidal communities).
- OPB conservation areas cover at least one representative seamount of each class. Six of the seven classes occur in the AOI for the Offshore Pacific MPA, and the only Class H5 seamount, SK-B, occurs in SK-B MPA.
- Seamounts provide ecosystem functions that enhance regional productivity, biological diversity, resilience, and connectivity. In general, shallower seamounts are thought to provide more ecosystem functions than deeper ones.
- All OPB seamounts are anticipated to experience changes now and in the near future. The amount of existing baseline data by which to detect change varies between OPB seamounts, but, in general, more is known about the shallower seamounts and those closer to shore. SK-B and Dellwood seamounts (the shallowest seamounts in the SK-B MPA and AOI, respectively) are good candidates for representative seamount areas (i.e., reference sites) to detect changes.

- To support the scoping stage of the ERAF, an inventory of species known to occur on OPB seamounts was compiled and potential Significant Ecosystem Components were provided in the Research Document. Since the last assessment in 2015, the number of known taxa on OPB seamounts has quadrupled. With increased sampling and examination of voucher specimens, more species are likely to be identified.
- The remote nature, vast size, and range of habitats in the OPB make gathering comprehensive and/or representative data a challenge. The analyses presented here are limited to discrete or static ("snapshot") information, but the OPB is a dynamic system with multi-scale spatial and temporal variability.
- It is recommended that the methods presented here be used to update/reassess the seamount classifications (classes and zones) as new data becomes available (e.g., improved bathymetry, seamount morphology, substrate, pelagic data).
- It is recommended that this information is suitable for a range of potential applications, such as the ERAF and the development of an MPA management plan, conservation objectives, a monitoring framework and plan, and future survey design and research development.

OTHER CONSIDERATIONS

The OPB seamounts are part of a larger group of seamounts along the North American continent, ranging from southern Alaska to California and out into Areas Beyond National Jurisdiction. The activities occurring on these seamounts (or lack thereof, where conservation measures are in place) can affect conditions and the health of OPB seamount ecosystems. For example, fishing and deep-sea mining impacts may indirectly influence OPB seamounts through the migration and recruitment of species, and it is predicted that mining plumes will have large-scale direct effects, including reduced fitness and mortality for benthic, pelagic, and surface animals (e.g., Levin et al. 2016). The influence of activities on adjacent seamounts and other stressors, such as noise, light, physical, and chemical pollutions, are important considerations for seamount environmental management and monitoring but are beyond the scope of this report and will be addressed further in the ERAF.

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SOURCES OF INFORMATION

This Science Advisory Report is from the November 25-26, 2020 regional peer review on the Identification of Important Seamount Areas in the Offshore Pacific Bioregion, Canada. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX

Table A1. Seamount inventory: summary information for each of the 62 seamounts within the Offshore Pacific Bioregion (OPB). Seamounts included exceed 1 km elevation and are either listed in the Canadian Gazetteer (NRC 2015), predicted by one or more of six published models, mapped during recent expeditions (validated), or a combination thereof. Classes are based on a system by Clark et al. (2011), productivity export (low: ≤9.85 C m^{-2} d^{-1}, medium: 9.85-18.78 C m^{-2} d^{-1}, high: ≥18.78 C m^{-2} d^{-1}), summit depth (deep: 3500-801 m, medium: 800-201 m, shallow: ≤200 m), and dissolved oxygen concentration (high: >1 ml/l, low: ≤1 ml/l). Asterisks denote new seamounts (not identified in DFO 2019)[1]. Seamounts are listed by summit depth, from deepest to shallowest.

Seamount name	Class	Summit coordinates (in or out of conservation area)	Summit depth (m)	Export productivity	Summit depth	Oxygen conc.
UN 41*	L1	49.818072, -135.10177 (out)	2538	low	deep	high
UN 15	L1	49.532589, -134.12852 (in)	2472	low	deep	high
UN 29	L1	50.720553, -134.93982 (out)	2374	low	deep	high
UN 28	L1	50.322715, -133.37737 (out)	2282	low	deep	high
UN 42*	L1	51.069157, -135.03183 (out)	2268	low	deep	high
UN 30	L1	50.95286, -134.72759 (out)	2264	low	deep	high
UN 37*	L1	48.196964, -131.98435 (in)	2263	low	deep	high
UN 11	L1	49.323195, -131.30008 (in)	2238	low	deep	high
UN 36*	L1	47.729444, -131.36738 (in)	2232	low	deep	high
UN 44*	L1	50.193009, -132.70401 (in)	2198	low	deep	high
UN 9	L1	48.680612, -131.72344 (in)	2138	low	deep	high
UN 34	L1	52.90045, -135.24855 (out)	2103	low	deep	high
UN 35*	L1	48.961435, -130.48991 (in)	2091	low	deep	high
UN 39*	L1	48.627632, -130.56134 (in)	2064	low	deep	high
UN 48*	L1	49.573221, -132.2902 (in)	2057	low	deep	high
UN 13	L1	49.49516, -132.18185 (in)	2035	low	deep	high
UN 38*	M1	48.406989, -131.20749 (in)	1940	medium	deep	high
UN 21	M1	50.007095, -131.54815 (in)	1934	medium	deep	high

Seamount name	Class	Summit coordinates (in or out of conservation area)	Summit depth (m)	Export productivity	Summit depth	Oxygen conc.
UN 32	M1	52.426189, -134.42527 (out)	1878	medium	deep	high
UN 45*	M1	50.035884, -132.39638 (in)	1866	medium	deep	high
UN 33	M1	53.188725, -134.37533 (out)	1799	medium	deep	high
UN 19	M1	50.001045, -130.95969 (in)	1765	medium	deep	high
UN 20	M1	49.994295, -131.30997 (in)	1711	medium	deep	high
Stirni	M1	49.130001, -132.3 (in)	1710	medium	deep	high
UN 24	M2	50.537792, -131.07229 (in)	1659	medium	deep	low
UN 14	M2	49.329736, -133.82917 (in)	1600	medium	deep	low
UN 10	M2	49.262697, -131.13065 (in)	1599	medium	deep	low
UN 27	M2	50.046051, -130.07153 (in)	1597	medium	deep	low
Endeavour	M2	48.299028, -129.04386 (in)	1583	medium	deep	low
UN 18	M2	49.939332, -130.90524 (in)	1550	medium	deep	low
Oglala	M2	50.34853, -131.56642 (in)	1543	medium	deep	low
UN 3*	M2	47.980455, -129.92416 (in)	1542	medium	deep	low
UN 23	M2	50.635828, -131.13464 (in)	1541	medium	deep	low
UN 2	M2	47.89141, -130.51808 (in)	1529	medium	deep	low
UN 49*	M2	50.343684, -132.13711 (in)	1498	medium	deep	low
UN 5	M2	48.371081, -129.90449 (in)	1493	medium	deep	low
UN 43*	M2	50.389046, -132.25022 (in)	1486	medium	deep	low
UN 12	M2	49.188381, -130.42872 (in)	1465	medium	deep	low
Chelan	M2	49.794911, -131.77235 (in)	1459	medium	deep	low
UN 4	M2	48.137436, -130.41024 (in)	1426	medium	deep	low
Tuzo Wilson	H2	51.458095, -130.84638 (out)	1388	high	deep	low
UN 40*	M2	47.904917, -129.65888 (in)	1344	medium	deep	low
Heckle	M2	48.47019, -130.13644 (in)	1316	medium	deep	low
Tucker	M2	49.8044, -133.47484 (in)	1217	medium	deep	low
Graham	M2	53.263312, -134.54856 (out)	1201	medium	deep	low
UN 22	H2	50.725383, -131.28219 (in)	1170	high	deep	low
UN 8	M2	48.32499, -129.25247 (in)	1158	medium	deep	low
UN 16	M2	49.88355, -132.11363 (in)	1097	medium	deep	low
UN 25	H2	50.44943, -130.54107 (in)	1089	high	deep	low
Davidson (Pierce)	H2	53.66385, -136.58949 (in)	1079	high	deep	low
UN 7	H2	48.534491, -129.6396 (in)	1065	high	deep	low
Heck	H2	48.400701, -129.37674 (in)	1015	high	deep	low
Springfield	H2	48.06795, -130.19647 (in)	922	high	deep	low
SAUP 5494	H2	53.852354, -133.77998 (out)	902	high	deep	low
Oshawa	H2	52.285469, -134.03283 (out)	896	high	deep	low
UN 1	H2	47.567004, -130.30425 (in)	895	high	deep	low

Seamount name	Class	Summit coordinates (in or out of conservation area)	Summit depth (m)	Export productivity	Summit depth	Oxygen conc.
Dellwood South	H2	50.580251, -130.71313 (in)	821	high	deep	low
Explorer	H3	49.058736, -130.94218 (in)	795	high	medium	low
Hodgkins	H3	53.506186, -136.03632 (in)	611	high	medium	low
Dellwood	H3	50.748881, -130.89797 (in)	535	high	medium	low
Union	H4	49.546481, -132.70242 (in)	271	high	medium	high
SGaan Kinghlas-Bowie	H5	53.299792, -135.65106 (in)	24	high	shallow	high

[1]Fourteen seamounts are new, while four seamounts listed in DFO 2019 were removed from the inventory (UN 17, 26, 31 and Oglala west seamounts) for various reasons (e.g., recently collected bathymetric maps provided better resolution and indicated seamounts initially identified as two are likely one large seamount).

Table A2. Summary of the seven seamount classes identified for the Offshore Pacific Bioregion (OPB) and the five Ecologically and Biologically Significant Area (EBSA) biological criteria associated ecosystem functions provided by each seamount class. Seamount ecosystem functions listed for OPB by DFO (Ban et al. 2016) and North Pacific by CBD (CBD 2016) include five biological criteria and exclude two anthropogenic associated criteria ("vulnerability" and "naturalness").

Class: ***classification criteria*** • Biological EBSA criteria associated first-order ecosystem functions
L1 (*n* = 16): ***export productivity — low, summit depth — deep, oxygen concentration — high*** • Support unique or rare species, populations, communities, habitat, ecosystems, geomorphological, or oceanographic features; • provide special areas for life-history stages for a population to survive and thrive (i.e., fitness); • provide important areas containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species; • provide areas containing species, populations or communities with comparatively higher natural biological productivity; • provide areas containing comparatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity.
M1 (*n* = 8): ***export productivity — medium, summit depth — deep, oxygen concentration — high*** • All ecosystem functions listed above; • support higher biological productivity[1] (compared to surrounding abyssal waters and plains and other classes listed above): "medium" export productivity to the summits (particulate organic carbon or 'marine snow').
M2 (*n* = 22): ***export productivity — medium, summit depth — deep, oxygen concentration — low*** • All ecosystem functions listed above; • provide habitat for recovery of endangered, threatened, declining species: offshore refugia for continental slope species; • support higher diversity of habitats (compared to other classes listed above)
H2 (*n* = 11): ***export productivity — high, summit depth — deep, oxygen concentration — low*** • All ecosystem functions listed above; • support higher biological productivity (compared to surrounding abyssal waters and plains and other classes listed above): "high" export productivity to the summits.
H3 (*n* = 3): ***export productivity — high, summit depth — medium, oxygen concentration — low*** • All ecosystem functions listed above; • provide rare habitat: benthic habitat in the shallow hypoxic zone; • provide habitat for recovery of endangered, threatened, declining species: offshore refugia for continental shelf species. • support higher biological productivity (compared to surrounding abyssal waters and plains and other classes listed above): shallow; the most likely OPB seamounts to advect allochthonous matter and organisms and induce chlorophyll enhancement[1]; • support higher diversity of habitats (compared to other classes listed above): seamounts rise through an additional bathymetric zone; • provide unique geomorphology of Explorer Seamount: the largest seamount in the OPB (≥1,000 km^3), with the steepest pinnacle.

Class: *classification criteria*
• Biological EBSA criteria associated first-order ecosystem functions
H4 (Union): ***export productivity — high, summit depth — medium, oxygen concentration — high*** • All class-based ecosystem functions listed above; • provide rare habitat: benthic habitat in the shallow oxic zone; • provide habitat for recovery of endangered, threatened, declining species: offshore refugia for coastal species (continental shelf); • support higher diversity of habitats (compared to other classes listed above): seamount rises through an additional bathymetric zone.
H5 (SK-B): ***export productivity — high, summit depth — shallow, oxygen concentration — high*** • All class-based ecosystem functions listed above; • provide unique habitat: benthic habitat in the euphotic zone; • provide unique geomorphology: submarine beaches, gravel beds, pinnacles, and wave-cut terraces formed by subaerial history (once an island); • provide rare geomorphology: second largest OPB seamount; • provide unique oceanographic features: tallest and therefore most likely OPB seamount to alter local currents; • provide habitat for recovery of endangered, threatened, declining species: offshore refugia for shallow-water coastal species; • support higher biological productivity (compared to surrounding abyssal waters and plains and other OPB seamounts): macroalgae present; • support higher diversity of habitats: seamount rises through all bathymetric zones.

[1] There is uncertainty if and how seamounts directly or indirectly affect local productivity – see Knowledge Gaps.

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