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A Monitoring Framework for SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area, British Columbia, Canada

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area (SK̲-B MPA) is co-managed by the Haida Nation (as represented by the Council of the Haida Nation, CHN) and the Government of Canada (as represented by the Minister of Fisheries and Oceans Canada, DFO) to conserve and protect the unique biodiversity and biological productivity of the area. In 2019, the SK̲-B MPA Management Board published the management plan detailing the ecological conservation goals of the MPA. In this research document, we provide an ecosystem review and list indicators (ecosystem components and metrics), protocols (e.g., tools), and strategies related to monitoring the SK̲-B MPA conservation objectives. Indicator ecosystem component groupings were generated for biological, environmental, and stressor ecosystem components, incorporating anticipated changes (e.g., climate change, recovery from fisheries) and specific indicator species where appropriate. Metrics for ecosystem component groupings were described, then linked to standard protocols and strategies used in the respective scientific fields (e.g., ecology, geology, oceanography). Information and best practices for designing a monitoring program, such as existing baseline data, statistics, sampling design, feasibility, and data management were also discussed. Ecosystem function and trophic structure were examined through a conceptual food web model. The proposed monitoring framework was then evaluated against the ecological conservation objectives to support adaptive and iterative re-evaluation of plans as an essential part of the MPA management process. A key result of the monitoring framework is connecting the four major components (i.e., the ecological objectives and the monitoring indicators, protocols, and strategies). Priorities and combinations are recommended to address the six ecological operational objectives, with the caveat that some information is unknowable at this time and that new or improved information (e.g., resolved through monitoring) should feed back into the frameworks and plans. The information in this paper was presented in support of a Canadian Science Advisory process (peer-reviewed May 3–5, 2022) and will be used by practitioners and managers to develop an appropriate and effective monitoring plan for the SK̲-B MPA. This monitoring framework covers a great deal of generally and regionally relevant information and may support the development of monitoring frameworks and plans for other protected areas, especially in the case of the proposed Tang.ɢ̲wan – ḥačxʷiqak – Tsig̲is (TḥT) MPA to the south.

1. INTRODUCTION

1.1. CONTEXT

1.1.1. Cooperative Management and Science Advice

In recognition of their cultural and ecological significance, SGáan Kínghlas[1]-Bowie (SK-B), Hodgkins, and Davidson/Pierce Seamounts, along with the surrounding area, have been designated by both the Haida Nation, as represented by the Council of the Haida Nation (CHN), and the Government of Canada, as represented by the Ministry of Fisheries and Oceans (DFO), as a protected area. In 1997, the Haida Nation designated the area as a **Xaads síigee tl'a dám.án tl'a kíng gíigangs** *Haida Marine Protected Area*[2] (direct translation: "the ocean they will always take care of"). In 1998, under Canada's *Oceans Act*, the SK-B Seamount was identified as an Area of Interest. In April 2007, the Haida Nation and the Government of Canada signed a Memorandum of Understanding that established a management board to facilitate the cooperative management and planning of the protected area. On April 17, 2008, the area was designated as a Marine Protected Area (MPA) under Canada's *Oceans Act*. The SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA) is now co-managed through the SK-B MPA Management Board by the Haida Nation, as represented by the Council of the Haida Nation (CHN), and the Government of Canada, as represented by the DFO, to conserve and protect its unique biodiversity and biological productivity (e.g., seamount populations of cold-water corals, sponges, other invertebrates, fishes, algae). All SK-B MPA processes and decision-making are co-managed. Support for the SK-B MPA Management Board is provided by a CHN and DFO technical team. In 2019, the SK-B MPA Management Board published the SK-B **Ginn síigee tl'a dám.án kínggangs ginn k'áalaagangs** *MPA management plan* (CHN and DFO 2019) (Figure 1).

[1] Please note the updated spelling (as of March 2024) of SGáan Kínghlas as part of on-going Xaad kíl language revitalization and reclamation efforts. This updated spelling now reflects the pronunciation described in the management plan as "SAH-aawn KING-thlus" with the first part of the words starting with a high tone, and ending low. Tone markers (shown as accents over certain letters) are becoming more common in Gaw Tlagée Xaad kíl for learning purposes and to support correct pronunciation.

[2] Xaad kíl, the northern dialect of the Haida language, is used throughout this document since SGáan Kínghlas is in the northern part of Haida territory. Formatting for Haida language: Xaad kíl in **bold**, followed by English term in *italics* (Council of the Haida Nation, Communications Program: Communications Protocol, March 2022). This document should not be used as a language reference. All inquiries should be directed to the appropriate language authority of Xaad Kíl Née.

Figure 1. The SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA) logo was designed by Haida artist Wayne Edenshaw. The logo depicts the seamounts as Waaxaas, a Supernatural Being that is depicted as half wolf and half killer whale and has the ability to move on both land and in the sea. "In our old oral traditions, we have many supernatural beings that have settled all throughout Haida Gwaii that our ancestors, our kuuniisii, have told us about. And we know of Supernatural Beings that live under mountains and at creeks and under certain rocks and other important landmarks. And SGáan Kínghlas is one of our important Supernatural Beings who resides under this ancient volcano." ***Gaagwiis*** *Jason Alsop, President of the Haida Nation.*

The MPA management plan is guided by the SK-B principles of **Yahgudáng** *respect* (the precautionary principle and approach), **K'uláagée** *responsibility* (consultation and collaboration, shared responsibilities, etc.), **Ginn 'wáadluwaan gud .ahl kwáagíidang** *interconnectedness (everything depends on everything else)* (ecosystem approach, integrated management, etc.), **Agan t'ats'gang** *balance* (sustainable use and development), **Ginn Gán ga únsids kíl tla gudáng'wa** *seeking wise council* (knowledge based, adaptive management, management effectiveness), **'isda isgyaan diigaa isdii** *giving and receiving* (equitable sharing). The complete list of linkages between the SK-B principles and Canada's MPA and ecosystem-based management principles is provided in the management plan (CHN and DFO 2019).

On behalf of the SK-B MPA Management Board, DFO Oceans Management branch (i.e., Marine Planning and Conservation) requested that DFO Science branch develop a monitoring framework with science advice related to indicators, protocols, and strategies. The framework objectives are to (i) provide an ecosystem review, (ii) identify the ecological conservation objectives, (iii) propose monitoring indicators, protocols, and strategies, (iv) incorporate anticipated changes (e.g., climate change and post-fishing recovery), existing data sources, and feasibility, (v) evaluate the framework against the ecological conservation objectives, and (vi) examine uncertainties and limitations. This science advice will be provided to the SK-B MPA Management Board to guide the future development of a monitoring plan and management for the area in support of the SK-B MPA conservation objectives Goal 1 (i.e., the unique biodiversity, structural habitat and ecosystem function of the SK-B MPA are protected and conserved; CHN and DFO 2019). This monitoring framework was co-created and co-authored by scientists from CHN and DFO.

1.1.2. Statement of Positionality

Collectively, the co-authors represent unique backgrounds and experiences but share values of understanding, conservation, and sharing knowledge of ecosystems to benefit present and future generations. The co-authors acknowledge that, while absolute scientific objectivity is the ideal standard of research, the reality is that research carries the biases of the people and institutions who work on it. The co-authors also acknowledge the power and history of these intrinsically valuable seamounts and respectfully recognize the cultural and spiritual significance of SK̲-B and neighboring seamounts to the Haida Nation, past, present, and future. The lead co-authors state positionality and perspectives to work towards co-creating the best possible science.

"My name is Cherisse Du Preez. I am of European descent, born in South Africa, now living on Vancouver Island on the traditional territory of the Cowichan Tribes. What defines me most is my relationship with the sea. My childhood was spent in or below the waves. My parents and grandparents fostered an innate sense in me to do right by the ocean and sparked my dreams to explore its depths. I have earned a PhD in marine biology, specializing in deep-sea exploration, and I am currently the Head of the DFO Deep-Sea Ecology Program. I would describe my field of expertise as 'where deep-sea life and human beings meet.'"

"**Skil Jáada hánuu díi kyá'aang, Jaas K̲'iiygangaa hánuu díi 'aww kyá'aang, Sandra Adams hánuu díi náa.n kya'aagan. G̲aw Tlagée aa.uu Hl náagang, ga yaalas guusd uu díi K'waalaagang, díi uu Yahgu'jaanaas gaagang.** *My name is Skil Jáada, my mom is Sonia Rice and my naan was Sandra Adams. I live in Old Massett and I am Yahgujaanaas Raven clan.* I'm a **X̲aadáa** *Haida* scientist whose worldview was shaped by growing up in G̲aw Tlagée, **X̲aadáa Gwáay** *Haida Gwaii* and learning place-based Haida laws from matriarchs on how to relate to beings, land, and sea. As a means to understand interconnectedness, I've also become scientifically trained in ecology and oceanography, and I attempt to infuse both worldviews as CHN Marine Biologist/Planner."

"My name is Heidi Gartner and I am descendent of settlers and immigrants living on the traditional territories of the W̱SÁNEĆ Peoples. I grew up in Ontario with a strong love of animals and nature. I dreamt of becoming a marine biologist without truly knowing what it meant. To my absolute surprise and delight, being a marine biologist is more fascinating, exciting, and rewarding than I could have imagined! My personal goal is to use science based information to protect the biodiversity and health of our ecosystems to benefit the generations to come."

"My name is Laís Chaves. I was born and raised in Brazil and descend mostly (like many other Brazilians) from Indigenous Peoples and Portuguese colonizers. There, I concluded my formal education in Marine Sciences and obtained a PhD in Oceanography. I migrated to Canada in 2014 and live today with my family in the ancestral territory of the Haida people. Working with the Council of the Haida Nation since 2016, I had the opportunity not only to support the development of the SK̲-B MPA management plan but also to gain a deep understanding of Canadian history. This experience has been a conduit for continued personal and professional growth, as it had brought me great awareness of the colonial system initiated 500+ years ago and is still very much engrained in my country of origin."

1.1.3. SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area

The SK̲-B SG̲áan K̲ínghlas-Bowie MPA is located ~180 km west of **X̲aadáa Gwáay** *Haida Gwaii*, British Columbia (BC), in the Offshore Pacific Bioregion (OPB) (Figure 2A). The total area of the MPA is 6,131 km^2 and encompasses SK̲-B Seamount, the adjacent Hodgkins and Davidson/Pierce Seamounts, and their surrounding waters, seabed, and subsoil (CHN and DFO 2019). Three MPA zones were initially designated (DFO 2016; for the purpose of managing fishing activities): Zone 1 included SK-B Seamount from 457 m depth to the summit, Zone 2 encompassed the rest of SK-B Seamount and permitted bottom-contact fishing, and Zone 3 included both Davidson/Pierce and Hodgkins (Figure 2B). In 2018, the SK-B MPA Management Board closed the entire MPA to bottom-contact fishing to align with the conservation goals of the MPA and protect sensitive benthic habitats (SBH).

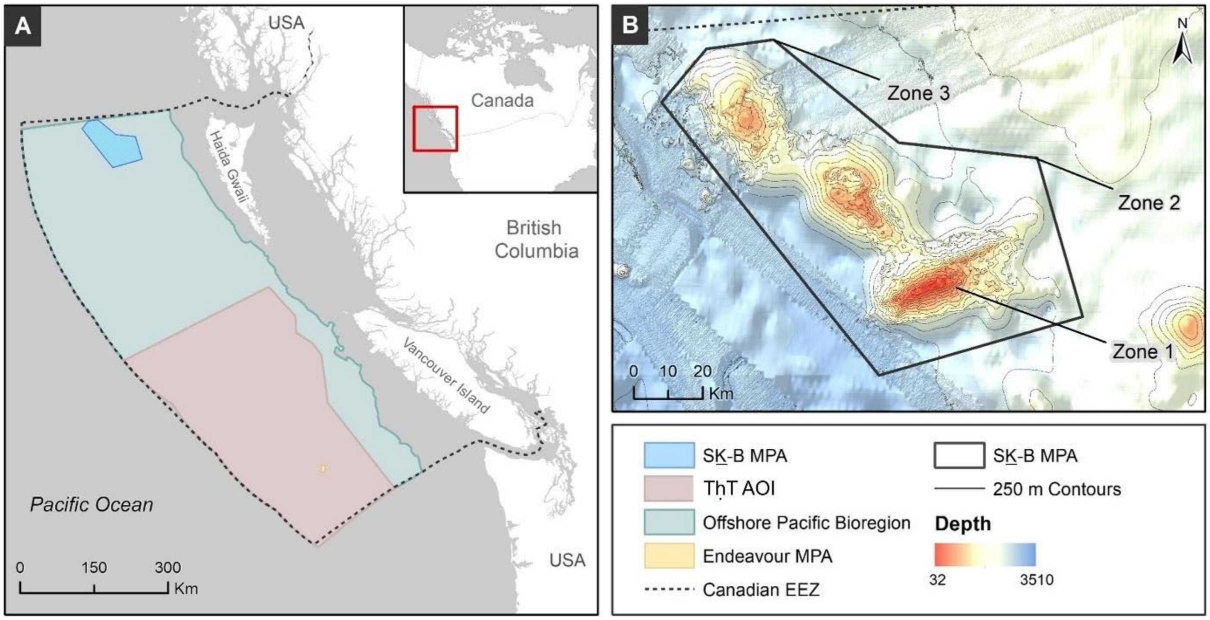

Figure 2. (A) The SGáan Kínghlas-Bowie Marine Protected Area (SK-B MPA) located 180 km from the coast of Haida Gwaii in the Offshore Pacific Bioregions. (B) While they no longer exist, historic management of the MPA included three zones with differing restrictions (see text). From south to north: SK-B Seamount (in zone 1 and 2), Hodgkins Seamount, and Davidson/Pierce Seamount (in zone 3). Note: the "Offshore Pacific" Area of Interest (AOI) was recently named as the proposed Tang.gwan – ḥačxʷiqak – Tsigis (TḥT) MPA. Map created by Georgia Clyde, Institute of Ocean Sciences.

The area has long held historical, spiritual, and cultural significance to the Haida Nation; the MPA's namesake seamount is home to the Supernatural Being, SGáan Kínghlas. In **Gaw Tlagée Xaad kíl**, *the Old Massett dialect of the Haida language* (the dialect used throughout this document), **SGáan Kínghlas** means *Supernatural Being looking outwards* (CHN and DFO 2019).

As the shallowest seamount in the Northeast Pacific, the summit of SK-B Seamount is just 24 m below the surface, within the photic zone (Canessa et al. 2003). High water clarity permits the sunlight to reach depths over 100 m below the waves; consequently, the seamount is associated with abundant algal growth at unusual depth and distance from the continental shelf (Gale et al. 2017; CHN and DFO 2019). The cold, nutrient-rich waters, rugged and complex substrates, and strong currents that prevail at shallower depths also support rich assemblages of marine invertebrates (McDaniel et al. 2003; Gale et al. 2017). These diverse communities on the seamount's summit and flanks also include resident and transient vertebrate species of cultural, conservation, commercial, and recreational interest.

1.1.4. What is a Monitoring Framework?

A monitoring framework is not a monitoring plan. A framework comes first and supports the development of an effective plan. A monitoring framework is like a roadmap, providing a broad and high-level summary of selected suitable options for monitoring the ecological conservation objectives. These options are prioritized where appropriate (e.g., most suitable, practical, or effective). The framework supports the future development of a monitoring plan, which will provide prescriptive details for the selected monitoring pathways. For example, a recent national Canadian Science Advisory Secretariat (CSAS) process developed a monitoring framework for cold-water coral and sponge area-based conservation measures (Neves et al. in prep[3] [Science Advisory Report available: DFO 2021a]). In the case of the SK-B MPA, the ecological conservation goal includes cold-water corals and sponges, as well as invertebrates, fishes, algae, sensitive benthic habitats (SBHs), and the pelagic and sea surface for an ecosystem known for its high habitat diversity and high community turnover. In addition to covering the current conservation goals, the framework will also support adaptive management and future re-examination of the management and monitoring plans.

While this research document can be read from start to finish, to facilitate its intended use as a reference tool, see the flowchart of the monitoring framework provided (Figure 3). The research document divides the monitoring framework into four major components: the objectives, indicators, protocols, and strategies. These can be simplified into “why”, “what”, “how”, and “ways” questions.

[3] Neves, B.M., Faille, G., Murillo, F.J., Dinn, C., Pućko, M., Dudas, S., Devanney, A., and Allen, P. In prep. A National Monitoring Framework for Coral and Sponge Areas Identified as Other Effective Area-Based Conservation Measures. DFO Can. Sci. Advis. Sec. Res. Doc.

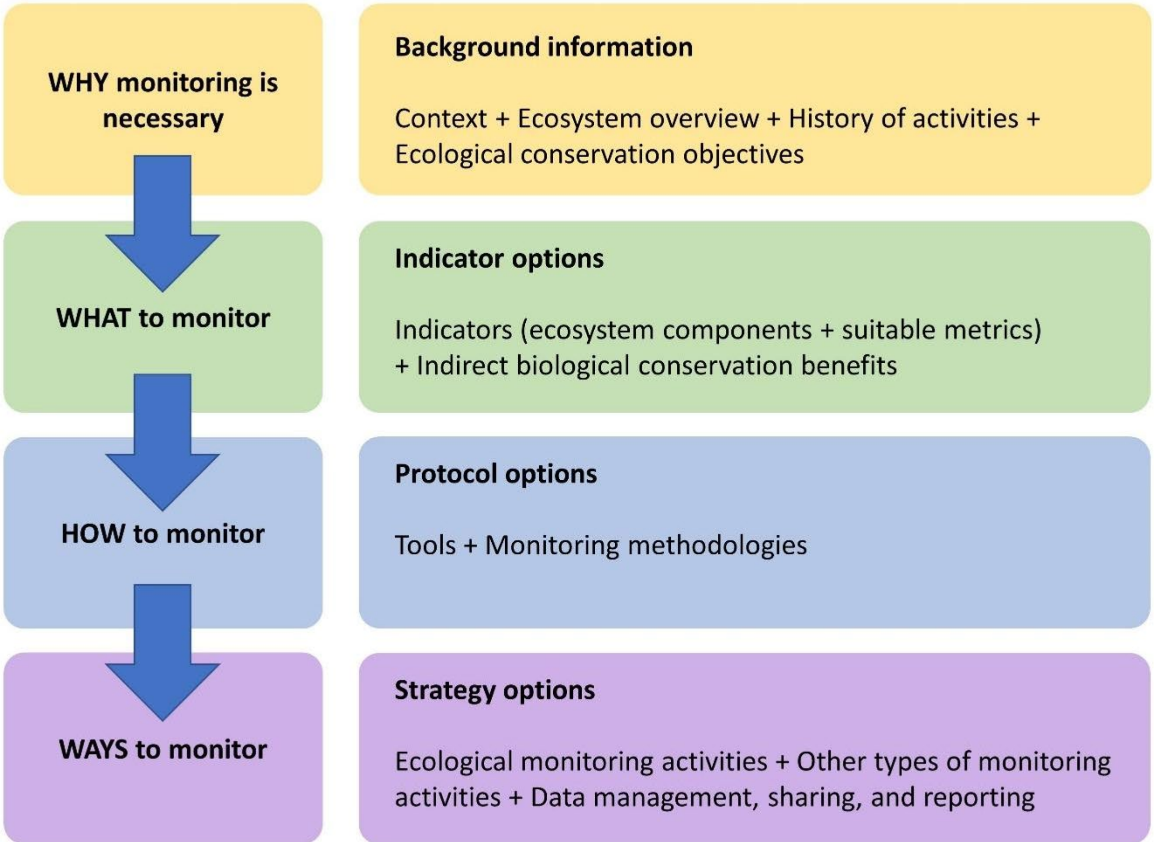

Figure 3. Flowchart illustrating the main components of this monitoring framework. A monitoring framework provides the full high-level spectrum of known options for monitoring the success of the conservation objectives; therefore, what to monitor (indicator ecosystem components and metrics), how to monitor (protocols), and ways to monitor (strategies). The framework supports the development of a monitoring plan and adaptive management.

Monitoring of biological, environmental, and stressor indicators is essential for: 1) incorporating an ecological component into broader MPA monitoring 'frameworks,' 'plans,' or 'programs'; 2) tracking status, condition, and trends to determine if MPAs are effective in achieving their conservation objectives; 3) aiding managers in the adjustment of MPA management plans to achieve conservation objectives; and 4) supporting the development of a reporting strategy to the Haida Nation, the Government of Canada, and Canadians.

This is the first monitoring framework developed for the SK̲-B MPA, a **X̲aads síigee tl'a dám.áan tl'a k̲íng gíigangs** *Haida Marine Protected Area*, and an *Oceans Act* MPA in the Pacific Region. The SK̲-B MPA monitoring framework will likely support the development of monitoring frameworks and plans for other protected areas, especially in the case of the proposed Tang.ɢwan – ḥačxʷiqak – Tsig̲is (TḥT) MPA to the south (contains at least 47 seamounts and 35 hydrothermal vents) (note: each MPA will have different decision-makers and not necessarily a management board). The need for monitoring plans and supporting documents will only grow following the unprecedented establishment of protected areas currently underway. There are differences in the processes used by different regions and practitioners within Canada and the processes (and use of terms) are changing over time. An effort to standardize practices where appropriate—while still promoting development and innovations—is likely to be a positive way forward. A working definition used herein is provided in the Glossary section.

This research document builds on the development of monitoring frameworks in other Canadian jurisdictions (e.g., Cooper et al. 2011; Lewis et al. 2016) and most closely aligns with the format and contents recently developed for the national monitoring framework for coral and sponge areas identified as other effective area-based conservation measures[3].

This research document also benefits significantly from previous region-specific research. For example, an Ecological Risk Assessment Framework (ERAF) for ecosystem-based oceans management was developed in the Pacific Region (O et al. 2015). An ERAF provides “a systematic, science-based and defensible risk-based decision-making structure needed to help guide the transition from high-level aspirational principles and goals to more tangible and pragmatic objectives, strategies and actions that could be implemented”. An ERAF includes a scoping phase where significant ecosystem components (SEC) are identified as well as activities, and their associated stressors, that have the potential to affect the SECs. The ERAF then includes a risk assessment phase where the harm to each SEC from each activity and stressors are scored. In 2015, DFO Science estimated the cumulative and relative risk posed by human activities to SECs (e.g., cold-water corals, sponges, rockfishes) by applying the ERAF to the SK̲-B context (Rubidge et al. 2018 [Science Advisory Report available: DFO 2015a]). For SECs, stressors, and stressor-SEC interactions associated with higher risk in the ERAF outputs, DFO Science proposed monitoring indicators, measurable indicator components, and data collection methods (Thornborough et al. 2016). The application of the ERAF to the SK̲-B MPA helped guide the transition from high-level goals to specific operational objectives in the management plan (CHN and DFO 2019).

The dramatic increase of seamount and deep-sea exploration in the OPB also greatly benefits this research document. The biophysical and ecological characteristics of OPB seamounts were reviewed (DFO 2019a), with a focus on those in the TḥT Area of Interest (AOI) (formerly known to as the “Offshore Pacific” AOI) (Figure 2A). Most recently, seamount species inventories, species distributions, and ecosystem functions (in terms of first order ecological services; Convention on Biological Diversity [CBD] 2008) were explored in detail for all three MPA seamounts as special (representative) seamount areas within the OPB (Du Preez and Norgard 2022; [Science Advisory Report available: DFO 2021b]).

1.1.5. Climate Change: Protection and Conservation in a Changing Ocean

Climate change is arguably the defining issue of our time but was not included in detail in the SK̲-B MPA management plan (CHN and DFO 2019) or the ERAF (DFO 2015a), likely in part because it is an unmanageable change with regard to the MPA spatial management scope. Given the unprecedented climate-related changes across all regions, monitoring indicators, protocols, and strategies that consider climate change should be a priority (Intergovernmental Panel on Climate Change [IPCC] 2021). In general, climate change is causing the ocean to become warmer, more acidic, and lose oxygen (Gruber 2011). It has and will continue to impact the environmental conditions and life of all OPB seamounts, including those within the SK̲-B MPA (Ross et al. 2020). Ocean basin-scale surface heat waves have started to appear and reappear for years at a time in the Pacific Northeast (e.g., ‘the blob’; Freeland and Whitney 2014). Ocean acidification within the region is another significant concern with the shoaling of the aragonite and calcite horizons (Ross et al. 2020). Deoxygenation may warrant special consideration, given that the Northeast Pacific contains some of the lowest oxygen levels in the global ocean (Paulmier and Ruiz-Pino 2009; Ross et al. 2020). Other key ocean climate variables within the region include salinity, currents, and multi-decadal variability, such as the Pacific Decadal Oscillations (e.g., Garcia-Soto et al. 2021). It is highly likely that changing climate variables have, are, and will continue to affect all SK̲-B MPA ecosystem components, either directly or indirectly.

For MPAs to be effective under a changing ocean, practitioners and managers need to be able to evaluate the risk and risk tolerance of meeting MPA objectives given direct or indirect climate influences on achieving those objectives (Karen Hunter, DFO, Nanaimo, BC, pers. comm.). However, climate variables that are changing and that are themselves MPA objectives (e.g., trying to conserve temperature, oxygen, or acidity) are unrealistic, and climate variables that are changing and that have direct or indirect impacts on the MPA objectives are realistically only managed via mitigation efforts. Therefore the impacts of the 'unmanageable' climate stressor can be monitored, assessed, and understood, but ultimately it is other human activities in the ocean that we can manage that must be considered in order to limit the likelihood of failing to meet MPA objectives within the context of climate impacts (Karen Hunter, DFO, Nanaimo, BC, pers. comm.).

1.2. SG̲ÁAN K̲ÍNGHLAS-BOWIE MARINE PROTECTED AREA

Seamounts are ancient underwater volcanoes that rise over 1,000 m. Their complex geology and oceanographic conditions support an amazing array of biological diversity. In Canada, seamounts are identified as Ecologically and Biologically Significant Areas (EBSAs) (Ban et al. 2016) and Vulnerable Marine Ecosystems (VMEs) (reviewed in Du Preez and Norgard 2022). The following ecosystem review summarizes the geological, oceanographic, and biological features found within the SK̲-B MPA.

1.2.1. Geology

The geology of the SK̲-B MPA has previously been described by Canessa et al. (2003), Chaytor et al. (2007), Gale et al. (2017), DFO (2021b), and Du Preez and Norgard (2022), and is summarized below.

The SK̲-B MPA lies on the Pacific Plate, at the southern end of the Kodiak-Bowie seamount chain. This chain of seamounts extends northwestward over 900 km, from SK̲-B Seamount to Kodiak Seamount on the Aleutian trench. The Kodiak-Bowie chain seamounts generally decrease in age from north to south, from approximately 24 million years old to less than 1 million years old (Turner et al. 1980), which would suggest they were formed by a volcanic 'hotspot' somewhere in the vicinity of the youngest seamount, SK̲-B. However, some seamounts in the chain are estimated to be much older than their position in the chain predicts under the hotspot model of formation (Turner et al. 1980; Chaytor et al. 2007). Additionally, dredged basalt samples from SK̲-B Seamount are isotopically similar to those of mid-ocean ridges, such as the Juan de Fuca ridge (Canessa et al. 2003), which originate in the upper mantle (i.e., not via hotspots from deep in the mantle). Thus, the geological processes which formed the three seamounts within the SK̲-B MPA are not firmly established and are subject to additional research.

While some evidence from the summit of SK̲-B Seamount suggests it was volcanically active as few as 18,000 years ago (Herzer 1971), the majority of the seamount is at least 75,000 to 720,000 years old (Turner et al. 1980; Chaytor et al. 2007). The shallow, terraced summit and accompanying rounded beach rocks suggest the seamount was once an offshore island – most likely during the Pleistocene epoch, when sea levels were much lower than present day (Herzer 1971). Additionally, Haida oral history describes a lengthy journey to an offshore island believed to be SK̲-B Seamount (CHN and DFO 2019). Even today, the 24 m depth of the summit makes SK̲-B Seamount a substantial marine hazard; deep wave troughs associated with heavy weather systems could theoretically expose the summit.

The SK̲-B Seamount itself is oblong and ridge-like, and is oriented in the southwest to northeast direction (Chaytor et al. 2007) (Figure 2B). The flanks average 10 to 20° in slope, but are generally much steeper and more rugged on the northeast and southwest sides of the main edifice (Chaytor et al. 2007). The seamount is ~3,200 m tall, rises from a basin depth of 3,224 m to 24 m below sea level, and covers 1,411 km^2 (Du Preez and Norgard 2022).

A 2,300 m deep ridge connects SK-B Seamount to neighbouring Hodgkins Seamount (Figure 2B). Hodgkins Seamount is roughly perpendicular to SK-B Seamount, to the northwest, and is much deeper—the shallowest summit is 611 m below the sea surface (DFO 2021; Du Preez and Norgard 2022) (previously reported as 596 m; Canessa et al. 2003). The top of Hodgkins is also characterized by multiple pinnacles (at least 10 are readily visible from any orientation; Canessa et al. 2003), while the flanks rise less steeply from the base than those of SK-B Seamount. Hodgkins Seamount is ~2,704 m tall, rises from a basin depth of 3,315 m, and covers 1,143 km^2 (Du Preez and Norgard 2022).

Davidson/Pierce Seamount, located to the northwest of Hodgkins Seamount, is the least surveyed of the three seamounts in the MPA (Figure 2B). Previously, summit depth was estimated to be between 1,100 and 1,500 m (Canessa et al. 2003; Manson 2009). In 2018, high-resolution bathymetry data were collected which confirmed a summit depth of 1,079 m and provided a more detailed impression of the seamount (Gartner et al. 2022). Davidson/Pierce Seamount is ~2,231 m tall, rises from a basin depth of 3,310 m, and covers 889 km^2 (Du Preez and Norgard 2022).

1.2.2. Oceanography

The physical oceanography of the SK-B MPA is highly dynamic because the area is within a major transition zone. The MPA is on the fringe of the large-scale circulation of the North Pacific, where it is located on the eastern edge of the Subpolar Gyre, a counterclockwise circulation that moves water around the northern North Pacific (Figure 4: the eastward flowing Subarctic Current is the southern limb of the Subpolar Gyre). It is embedded in the Alaskan Current, which is the eastern limb of both the Alaska Gyre and the larger Subpolar Gyre. Using Argo float data, Cummins and Masson (2018) showed that in the broad oceanic region adjacent to the North American coast, the temperature and salinity in the upper 1,000 m were highly correlated with the Pacific Decadal Oscillation (PDO), whereas the temperature and salinity at Station Papa (at approximately 50º N 145°W; see Strategies section on Line P) are uncorrelated with the PDO. They also showed that there are eastward-moving temperature and salinity anomalies advected with the Subarctic Current that pass through Station P on their way to the vicinity of the SK-B MPA. In addition, the California Undercurrent (CUC; not shown in Figure 4) brings warm, salty, low oxygen water from the south along the upper continental slope at depths of 100–300 m (Thomson and Krassovski 2010), which likely contributes to the water properties on the SK-B MPA. Along the continental slope off British Columbia and Alaska the ocean circulation is dominated by eddies (Thomson and Gower 1998; Crawford 2002; Ladd et al. 2009); as a result the water properties (temperature, salinity, dissolved oxygen, nutrients) in the water between the continental shelf and the deep ocean gyres are a complicated mixture of water from the shelf, the California Undercurrent, and the two deep ocean gyres (subpolar and subtropical gyres represented in Figure 4 by the Subarctic Current and the North Pacific Current, respectively) (Whitney et al. 2005). One recurring family of eddies are the Haida Eddies which are spawned off Cape St. James at the southern end of Haida Gwaii and sometimes bring water from Hecate Strait and Queen Charlotte Sound to the SK-B MPA before moving off to the southwest (e.g. Crawford et al. 2002; Canessa et al. 2003).

The Haida Eddies bring iron (an important micronutrient) from the shelf waters into the open North Pacific which is deficient in iron (Ladd et al. 2009). Cummins and Masson (2018) argue that the large variability in the vertical displacement of the density surfaces in the upper ocean in the vicinity of SK-B Seamount are a signature of the Haida Eddies. Dower and Fee (1999) suggested that Haida Eddies can become 'stuck' on shallow seamounts after observing a westward-moving Haida Eddie stalling over the SK-B MPA for approximately three months. In 2021, another stalled Haida Eddy was recorded over SK-B Seamount for three months (Tetjana Ross, DFO, Sidney, BC, pers. comm.) While the trajectory of Haida Eddies is unpredictable and many do not travel near the SK-B MPA, these eddies may function as a periodic offshore transport corridor for larval and juvenile rockfishes, plankton, and nutrients such as nitrate and iron (Thornborough et al. 2016).

Another explanation for the 'stuck' clockwise flow encircling SK-B Seamount is the presence of a Taylor cone (Canessa et al. 2003). Such a feature has been documented over Cobb Seamount (Dower and Fee 1999). A permanent or temporary Taylor cone over SK-B Seamount may also entrain passing eddies.

Using the satellite sea surface temperature (SST), Devred et al. (2021) found that the winter and summer temperatures have increased by about 1°C over the 40 years of satellite observations (equal to 2.5°C per century). This is much larger than the 0.75°C per century estimated by Cummins and Masson (2018) for annual anomalies of coastal SST at **K'íis Gwáay** *Langara Island* at the northwest corner of Haida Gwaii. Cummins and Ross (2020) report temperature trends of about 1.5°C per century in the upper 50 m at Station P. Therefore, work needs to be done to reconcile the trend estimates by accounting for the different time periods of the analysis (in the Northeast Pacific trend estimates are very sensitive to the choice of years used) and the difference between estimates from annual anomalies and those for particular seasons. Preliminary analysis of the sea surface chlorophyll concentrations from satellite ocean colour data did not reveal any evident trends (Charles Hannah, DFO, Sidney, BC, pers. comm.).

Given its location in the open North Pacific, the winds and waves are an important part of the environment of the SK-B MPA. While the winds are generally from the south, leading to northward mean surface currents in all seasons, storms can cause short-term currents from any direction and may occasionally transport water to the SK-B MPA from the north or shelf water from Dixon Entrance to the east.

The SK-B MPA is near the northern edges of two transition zones: the one between the southward-flowing California Current and the northward-flowing Alaska Current (Figure 4); and the one between the persistent downwelling regime along the Alaska coast and the summer upwelling regime from Vancouver Island to the south (Figure 4). As such, changes in the location of the boundary between the Subpolar and Subtropical Gyre may have implications for the SK-B MPA; the boundary does move north and south due to natural variability (Cummins and Freeland 2007).

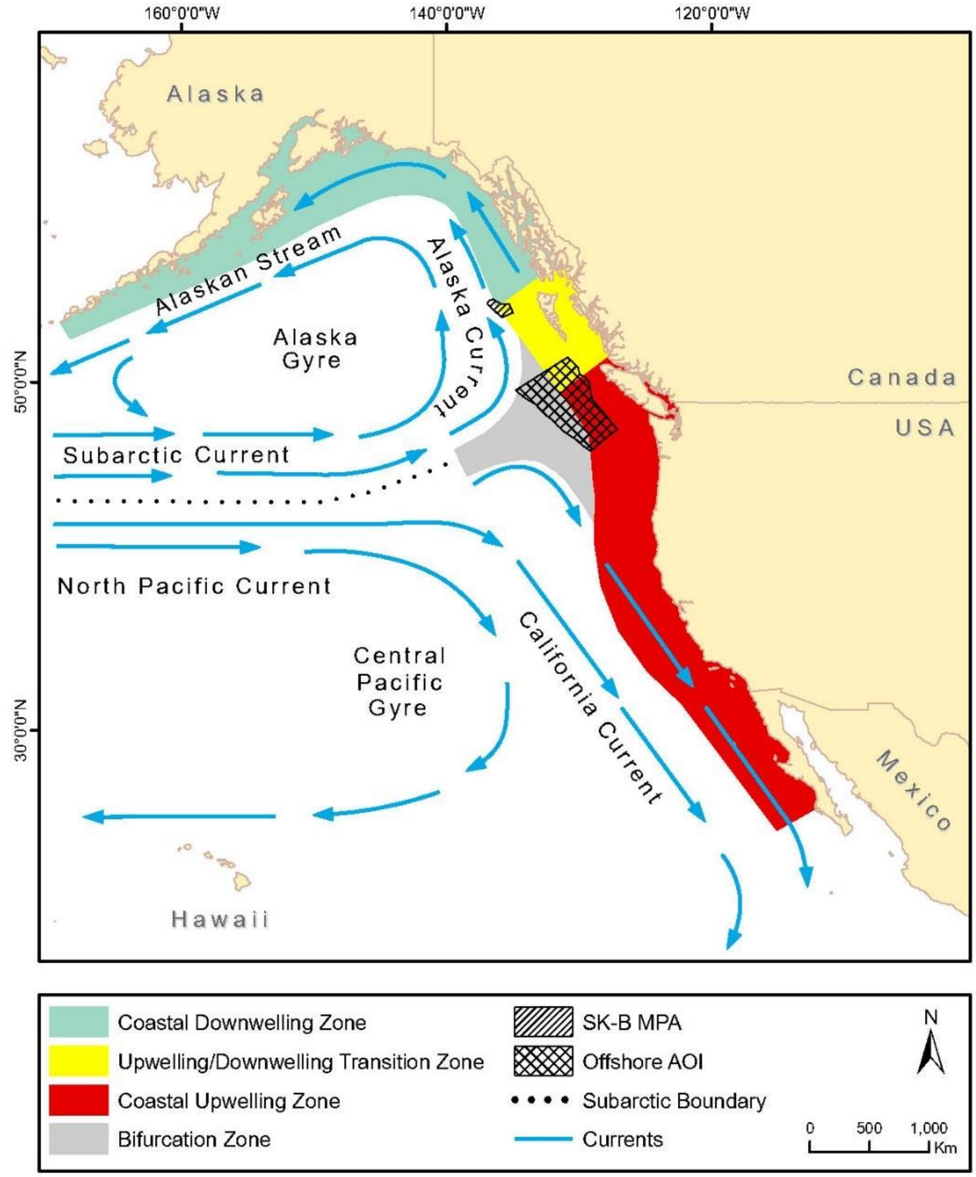

Figure 4. Schematic of the location of SG̲áan K̲ínghlas-Bowie Marine Protected Area (SK̲-B MPA) within the North Pacific circulation (created by Rick Thomson, published in Du Preez and Norgard 2022).

If the Subpolar Gyre expands and the boundary moves southward, one should expect an increased influence of subpolar water on the SK̲-B MPA, and if the Subtropical Gyre expands northward, then the influence of subtropical waters should increase. There is no consensus on the likely direction of future change. For example, Hristova et al. (2019) showed that there has been an increasing trend in the transport of the Alaska Gyre in the northeast Pacific over the period 1993–2017. However, IPCC (2021) reported that the intensification of the North Pacific Subpolar Gyre and northward expansion of the Subtropic Gyre since the 1990s ‘are likely predominantly due to interannual-to-decadal variability.’ There is, however, ‘medium confidence in a continued poleward shift of storms and their precipitation in the North Pacific.’ In addition, Rykaczewski et al. (2015) showed that the likely response to climate change along the west coast of North America was a poleward shift of the upwelling winds. In short, one should expect ongoing change and variability in the oceanographic and atmospheric environment surrounding the SK̲-B MPA.

The oxygen minimum zone (OMZ) is a dominant feature of the water properties in the Northeast Pacific; it exhibits hypoxic conditions between approximately 480 m and 1,700 m (Whitney et al. 2007; Cummins and Ross 2020; Ross et al. 2020). The OMZ is part of the oceanic environment at the SK̲-B MPA (Gale et al. 2017: Figure 8; Du Preez and Norgard 2022). Based on an analysis of in situ measurements and a global oxygen model, SK̲-B Seamount transects the entire OMZ and experiences 6.7 ml l^{-1} O_2 at its summit, Hodgkins Seamount transects the severely hypoxic zone of the OMZ (<0.5 ml l^{-1} O_2) and experiences 0.5 ml l^{-1} O_2 at its summit, and Davidson/Pierce Seamount transects the lower boundary of the OMZ (below the severely hypoxic zone) and experiences 0.5 ml l^{-1} O_2 at its summit (Du Preez and Norgard 2022).

There is important temporal and spatial variability in dissolved oxygen above the OMZ. Crawford and Peña (2016) showed that at Station P (in the Subpolar Gyre) the dissolved oxygen on the 26.9 kg m^{-3} isopycnal showed a declining trend with a strong 18.6-year cycle (likely caused by the lunar nodal modulation of tidal mixing in the Okhotsk Sea in the western Pacific). However, the trend was reduced and the 18.6-year cycle disappeared in the eddy-dominated region to the east (the Transition Zone). Over the upper continental slope (the 26.7 kg m^{-3} isopycnal, approximately 250 m depth) the temporal pattern was low values of dissolved oxygen in the 1950s, high values in the 1970–80s and declining values through 2012 when the analysis ended (Crawford and Peña 2016). This temporal pattern extends from California to BC and is a feature of the California Undercurrent. There is a need to monitor dissolved oxygen in the vicinity of the SK̲-B MPA to determine the temporal variability and to monitor for trends as oxygen values are declining below the surface mixed layer over the northeast Pacific (Cummins and Ross 2020; Ross et al. 2020).

Ross et al. (2020) provided a detailed examination of the oxygen and ocean acidification environment (calcite saturation horizon) within the TḥT AOI (Figure 2A). It is reasonable to assume that their conclusions hold for the SK̲-B MPA until monitoring provides evidence to the contrary. As such, one should expect that the bottom boundary of the OMZ on SK̲-B Seamount has been getting deeper at a rate of 3 m per year and that the calcite saturation horizon has been shoaling at a rate of about 1.7 m per year since the 1980s.

1.2.3. Ecology

The animals recorded within the SK̲-B MPA range from species common to coastal areas (though often at greater depths; Canessa et al. 2003), to open ocean species, and to rare and newly-discovered deep-sea species (e.g., Reiswig 2015; Gartner et al. 2022) (Figure 5). As EBSAs, seamounts are known to provide important habitats for many species of concern as well as socially, culturally, and commercially valuable species, including cold-water corals and sponges, **k̲'ats** *rockfish* species (*Sebastes* spp.), **x̲aguu** *Pacific Halibut* (*Hippoglossus stenolepsis*), **sk̲íl** *Sablefish* (*Anopoploma fimbria*), marine mammals, sea birds, and others (Ban et al. 2016; DFO 2019a; Du Preez and Norgard 2022). Lists of species for the SK̲-B MPA were generated by Canessa et al. (2003), updated for analysis by Rubidge et al. (2018), summarized by groupings for benthic species by Gauthier et al. (2018a–c), updated and summarized based on recent seamount expeditions (Du Preez and Norgard 2022), and provided here as an updated comprehensive species inventory with expanded information (Du Preez and Norgard 2022: Table A10: 771 taxa documented on OPB seamounts, 471 of which were documented within the SK̲-B MPA; includes information on taxa, age, generation time, depth range, reporting, and conservation status).

*Figure 5. Some of the biological diversity found within the SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area (SK̲-B MPA). The three seamounts rise steeply from the bathyal plains, transecting various ocean zones, until the shallowest, SK̲-B, reaches the sunlit waters just below the waves. This unique ecosystem is home to well-known shallow subtidal species, deep-sea animals new to science, and everything in between. From top-left to bottom-right: Black-footed Albatross (*Phoebastria nigripes*), Pom-pom Anemones (*Liponema brevicorne*), close-up of a brittle star (*Ophiuroidea*), massive Red Tree Coral* (Primnoa pacifica*) with many associated animals, pelagic school of Widow Rockfish (*Sebastes entomelas*) over SK̲-B pinnacle, Sunflower Sea Star* (Pycnopodia helianthoides*) surrounded by Crimson Anemones* (Cribrinopsis fernaldi*), Fin Whale (*Balaenoptera physalus*), SK̲-B pinnacle carpeted zoanthids, Blue Sharks (*Prionace glauca*), benthic and pelagic rockfishes (*Sebastes *spp.), Squat Lobsters (*Munida quadrispina*), Blob Sculpin (*Psychrolutes phrictus*), Deep-sea Octopus (*Graneledone boreopacifica*), Glass sponges (*Hexactinella*) surrounded by brittle stars, Dinner Plate Jellyfish (*Solmissus*), life on and around* Parastenella cf ramosa *coral, jellyfish, and a pair of crabs under large* Chonelasma oreia *glass sponge. Images from Fisheries and Oceans Canada, Shelton Du Preez, Pacific Wild, Ocean Exploration Trust, and the Northeast Pacific Seamount Expedition partners.*

The two most recent expeditions to the SK̲-B MPA were the first to visually survey Hodgkins and Davidson/Pierce seamounts (Gale et al. 2017: Pac2015-48 and Gartner et al. 2022: Pac2018-103). The 2018 surveys included sampling of the benthos (seafloor community) on all three seamounts, which has yielded multiple novel discoveries (Gartner et al. 2022) and valuable information about species that inhabit the SK̲-B MPA and Northeast Pacific seamounts in general. Obtaining good voucher specimens with associated imagery and tissue samples is imperative for a taxonomic study to determine species identification, including species new to science.

The following section highlights the biological diversity found within the MPA to date—with more discoveries anticipated on future expeditions. In addition to the most up-to-date information of the SK̲-B MPA, this document is populated with current knowledge of nearby seamount ecosystems, such as Cobb Seamount, which is located 500 km southwest of Vancouver Island. Cobb is similar to SK̲-B Seamount in many regards. Both seamounts are considered globally rare due to their extremely shallow summits. They represent the only two seamounts within the Northeast Pacific region that belong to seamount class H5—one of seven classes of seamount found in the OPB (Du Preez and Norgard 2022). Classes are based on ecologically significant seamount features and provide information on the species, communities, habitats, and ecosystem functions provided, among other characteristics. Of the 62 seamounts presently mapped in the OPB, SK̲-B Seamount is the only H5, Hodgkins Seamount is one of three rare H3 (i.e., likely similar to Dellwood and Explorer in the TḥT AOI), and Davidson/Pierce Seamount is one of nine H2 seamounts (Du Preez and Norgard 2022).

Due to the life history of SK̲-B MPA inhabitants (e.g., many can be hundreds of years old, Du Preez and Norgard 2022: Table A10) and the rapid rate of human-mediated impacts (e.g., bottom-contact fisheries), the seamount ecosystem and its species are vulnerable to disturbances (under the Food and Agriculture Organization of the United Nations, seamounts and their inhabitants are designated VMEs; reviewed in Du Preez and Norgard 2022). Considering resiliency and recovery of species and functional groups to different disturbances is crucial for monitoring changes within the communities of the SK̲-B seamounts. The resilience of systems (the ability to resist and recover from a disturbance) can manifest in a variety of disturbance responses during the recovery period and the new post-disturbance state. Potential responses include complete resistance, depletion and full recovery, compensation/depletion and partial recovery, recovery to an alternative state, and no recovery with the potential for continued degradation (Figure 6). Recovery time to stabilize into post-disturbance states varies greatly with the life history of each species, from short-lived invertebrates to centuries-old cold-water corals and rockfishes. Recovery time also needs to consider the lag time between the disturbance and response—for example, the cold-water corals around the Deepwater Horizon oil spill were still degrading a decade after the disturbance; the full extent of the impact unknowable for decades to centuries (Girard and Fisher 2018; Girard et al. 2018). Baseline monitoring is required to determine the type and details of a disturbance response.

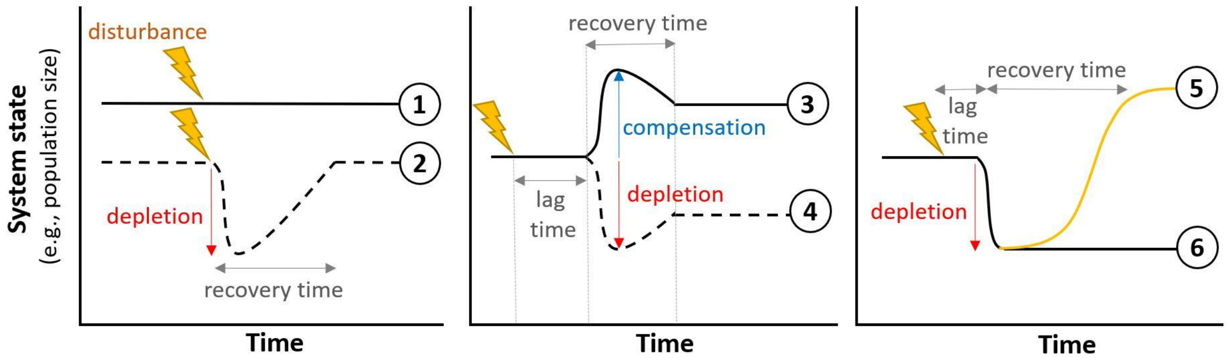

*Figure 6. Comparison between six disturbance responses and the elements of resilience. After a disturbance, the system state (e.g., size of the population) changes according to the initial state, tipping point, response (e.g., depletion or compensation), etc., creating a range of possible system states and defining the resistance to being disturbed. The time between the disturbance and response establishes lag time. The time needed to settle into one of the multiple possible post-disturbance state outcomes establishes the recovery time. Post-disturbance system states include: **(1)** same initial pre-disturbance state (resistant), **(2)** full recovery to initial state, **(3)** partial recovery to a compensation state**, (4)** partial recovery to a reduced state, **(5)** recovery to an alternative state (e.g., different composition), and **(6)** no recovery with potential continued degradation.*

1.2.3.1. Invertebrates

Invertebrates are a diverse group of animals from over 30 phyla, characterized as not having a backbone (Brusca and Brusca 1990). On seamounts these animals range from microscopic crustaceans inhabiting any small space available (e.g., amphipods in sediment, rock crevices), to mats of detritus- and suspension-feeding brittle stars, to large predators such as octopods. The species composition in an area on a seamount is influenced by substrate/habitat available, depth (and corresponding abiotic features), and food availability (e.g., Morgan et al. 2019). Invertebrate species fill many ecological niches and may occupy different trophic levels, though primarily, invertebrate communities connect the primary production of an area up the trophic chain to the larger (and often migratory) predators such as large fishes, sharks, and marine mammals. Assemblages of invertebrates define the majority of rare or unique areas discovered within the SK-B MPA and on other Northeast Pacific seamounts (Figure 7) (Du Preez and Norgard 2022).

There are 578 taxa of invertebrates identified on OPB seamounts, 350 of which are documented within the SK-B MPA (Du Preez and Norgard 2022: Table A10). In 2015 an ERAF (O et al. 2015) was applied to known species for the SK-B MPA (Thornborough et al. 2016; Rubidge et al. 2018) and identified the following important invertebrate SECs (highest risk scores): *Isidella tentaculum, Primnoa* sp., the benthic invertebrate community (including the squat lobster *Munida quadrispina*), coral habitat, and sponge habitat (Figure 7). More details on these SEC groups are provided below.

Cold-water corals and sponges

Cold-water coral and sponges are animals from the phyla Cnidaria and Porifera, respectively. Both are primary consumers; coral colonies of small polyps pick out food from the surrounding water column, and sponges pump and filter the surrounding water through their bodies (Brusca and Brusca 1990). Seamounts are environments where cold-water corals and sponges thrive as they provide hard substrates, such as bedrock and boulders, for invertebrates to settle and grow (Watling and Auster 2017). Additionally, the physical structure of seamounts is ideal for filter-feeders, such as cold-water corals and sponges, as flow is enhanced by the rugose topography and increased bottom flow (Genin et al. 1986). For example, on Cobb Seamount, rugosity was the second strongest environmental proxy of community-structuring processes (after depth, Du Preez et al. 2016).

SK-B MPA cold-water corals records are from science surveys and fisheries bycatch records (e.g., Gautier et al. 2018a). SK-B MPA is home to all three coral orders considered Vulnerable Marine Ecosystem indicator species (Alcyonacea, Antipatharia, and Scleractinia; DFO 2019a). The 2018 SK-B MPA expedition identified more species and distributions for the seamounts and preliminary analyses indicate that there a potentially two new corals species to science (Merlin Best, DFO, Sidney, BC, pers. comm.; Garter et al. 2022).

The *Isidella tentaculum* is a member of the family Isididae, the deep-sea bamboo corals. Documented Isididae in BC waters include *I. tentaculum, Isidella* spp., *Keratosis* spp., and *Lepidis* spp (Wilborn et al. 2021; Du Preez and Norgard 2022: Table A10). *I. tentaculum* is a relatively new species to science that is characterized as large, abundant, and a conspicuous habitat former (Etnoyer 2008). *I. tentaculum* was determined to be an important SEC as its depth distribution put it at risk of the Sablefish fishery, it is a long-lived species, and it is sensitive to disturbances and stressors (Rubidge et al. 2018). *I. tentaculum* has been documented on the two shallowest SK-B MPA seamounts but not Davidson/Pierce (likely too deep) (Du Preez and Norgard 2022). There is a unique coral habitat of dense thickets of large *I. tentaculum* (1 to 2 m tall) on the eastern ridge summit break of SK-B Seamount, covering an area of hundreds of meters between 550–600 m depth (Du Preez and Norgard 2022) (Figure 7L).

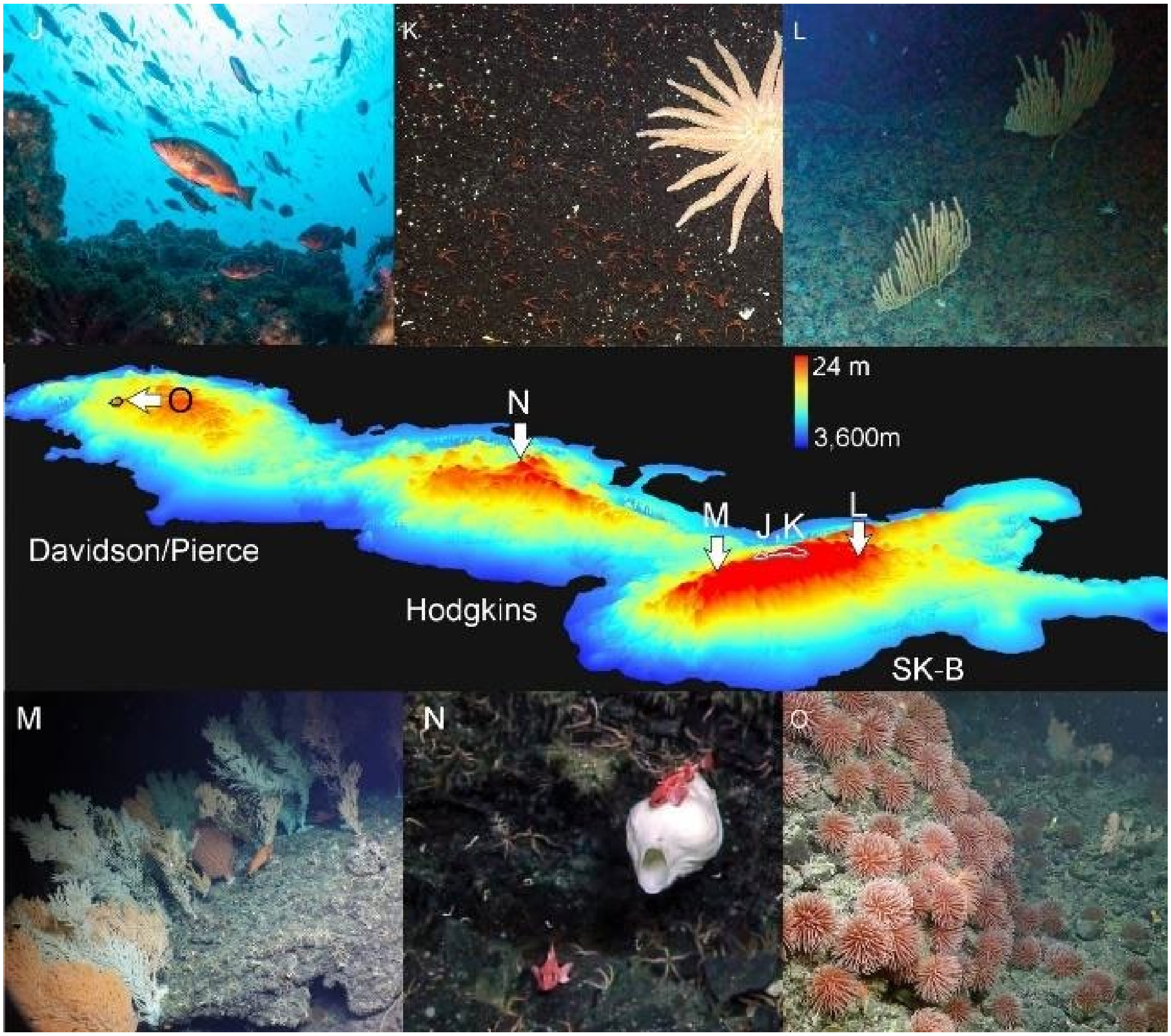

*Figure 7. Examples of species, habitats, and communities (defined by invertebrates) that are unique or rare within the Offshore Pacific Bioregion (OPB), which occur within SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA). (J) The sunlit summit of SK-B Seamount supports coastal animals above 130 m depth (white line) and (K) extensive and dense casts of squat lobsters (*Munida quadrispina*) above 190 m depth (grey line). It is also home to regionally rare deeper species and habitats, such as dense forests of the tall Gorgonian coral (L)* Isidella tentaculum *and (M) the red tree coral* Primnoa pacifica *between 550–600 and 230–450 m depth, respectively. Its two sister seamounts also support uncommon assemblages deep on their summits, including sponge gardens acting as possible nursery grounds for juvenile fishes (on Hodgkins summit, ~600 m) and (O) dense gardens of pom-pom anemones (*Liponema brevicorne*), black corals, and glass sponges (on Davidson/Pierce summit, ~1,180–1,500 m depth (black line). Figure from Du Preez and Norgard (2022).*

The genus *Primnoa* is a representative of the family Primonidae. The common names of most of the species in this family end in names like 'Sea Fan,' 'Sea Feather,' and 'Tree Coral' due to the characteristic branching nature that results in fan, bushy, or tree-shaped colonies. There are nine species of the Primnoidae family known from BC waters (Wilborn et al. 2021). Habitat-forming Primnoidae found in high abundances within SK-B MPA include species in the genera *Parastenella*, *Paragorgia*, and *Primnoa*—with representative species found of all three seamounts with the exception of *Primnoa* spp. on Hodgkins and Davidson/Pierce (Du Preez and

Norgard 2022). The *Primona* sp. listed as a SEC was referred to a ‘white *Primona*’ and was suspected of being endemic to SK-B MPA. Molecular work from samples collected in 2018 has determined that the white *Primnoa* sp. is a colour morph of the Red Tree Coral *P. pacifica* (unpublished data see Gartner et al. 2022: Appendix 5) (see white and red colour morphs in Figure 7M). This species SEC was partially chosen because it has many ecological similarities to *I. tentaculum,* but it occurs at high abundance on SK-B Seamount at shallower depths (above 457 m, in different management zone at the time; Rubidge et al. 2018). In 2018, an incredible forest of *P. pacific* was discovered on the western ridge summit break of SK-B Seamount, extending for over a kilometre of seafloor between 230–450 m depth (Du Preez and Norgard 2022) (Figure 7M). The forest was teeming with a high diversity of coral habitat-associated animals, including Rougheye/Blackspotted (REBS) Rockfish (*Sebastes aleutianus/ melanostichus*) finding refuge below and around the up to 3 metre tall and wide corals (similar to Du Preez and Tunnicliffe 2011).

There are at least 58 coral taxa on OPB seamounts, 30 of which have been documented within the SK-B MPA (many more than those listed, including several species of *Swiftia* spp., dense forests of the black coral *Chrysopathes* sp., a diverse assemblage of true soft corals, sea pens, cup corals, and hydrocorals) (Du Preez and Norgard 2022: Table A10). All these coral species may contribute to the coral habitat SEC. Additionally, habitat-forming sponges were identified as another habitat SEC, with the highest risk scores (Rubidge et al. 2018).

Cold-water corals and sponges are capable of altering the structure of the seafloor in ways that are used by other organisms. The importance of the structural habitat they contribute to ecosystem function has been documented in many studies and reviewed in Freiwald and Roberts (2005). Key functions of these bioengineers in creating physical habitat complexity include refuge from predation for small planktonic and benthic invertebrates and fishes (Figure 7N), foraging grounds for grazers and predators, resting sites from strong currents by altering current flow, and retaining nutrients and entraining plankton near the sediment (Tissot et al. 2006). Generally, they serve as aggregation features for marine life (Boutillier et al. 2010) and widely contribute to the local trophic web. Moreover, these functions combine to make these communities the most species-rich areas among marine ecosystems, representing biodiversity hotspots for invertebrates and commonly supporting a high abundance of fishes. In contrast to tropical reefs, the cold temperatures and inconstant food supply in the deep-sea implies that most of the cold-water corals have reduced growth rates and sporadic or low rates of recruitment. These life history characteristics and their longevity indicate that cold-water corals and sponges (Du Preez and Norgard 2022: Table A10) have a reduced capacity to recover from disturbance events, such as bottom-contact fisheries (Du Preez et al. 2020). The Sablefish fishery was known to primarily operate along the slopes of the SK-B Seamount perpendicular to contour lines at depths between 457 and 1,500 m and highly overlapped with the distribution of these habitat-forming coral species (Doherty and Cox 2017). The time necessary to detect such changes will be key to inform monitoring efforts (e.g., frequency, sample size).

For sponges, morphological forms such as thick encrustations, lumps, and branched, funnel- or fan-like bodies influence near-bottom current and sedimentation patterns. Although some of the siliceous spicules of non-reef-forming species dissolve quickly, there is a certain accumulation of shed spicules and spicules from dead sponges between and under the living ones. These spicules can form a thick sediment stabilizing mat, which constitutes a special bottom type and houses a rich fauna of small-sized species (International Council for the Exploration of the Sea [ICES] 2009). In low-flow habitats, non-reef-forming species skeletons can persist intact for so long that they serve as advantageous relief for other corals and sponges to grow (visual observations for 2018 expedition, Cherisse Du Preez).

Sponge taxonomy is quite complex and usually involves examining small structural morphological features, called spicules, under a microscope. It can be difficult to identify sponges from imagery alone as their gross morphology can change with habitat, current flow, etc. (Henry Reiswig, Royal BC Museum, Victoria, BC, pers. comm.) There are four classes of sponges based on their spicule composition: Demospongia and Homoscleromorpha have siliceous spicules, Calcarea have calcareous spicules, and Hexactinellida have spicules made of silica or glass. Representative species of all classes have been identified within the SK-B MPA (Du Preez and Norgard 2022: Table A10). Sponges provide habitat for other species, but in particular, the Hexactinellida (or glass sponges) are masters at building complex structures. Despite being made of glass, their spicules can grow large with strong structural patterns (that are species specific), and fuse in a way to make them extremely strong (e.g., Fernandes et al. 2021) (e.g., the tall funnel sponge *Pinulasma* sp. found on all three MPA seamounts; Clark 2022). These structures are so strong that individuals can grow metres in the water column (e.g., Wagner and Kelly 2016), and certain species can fuse to grow together to make reefs measuring up to hundreds of square kilometres (e.g., Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs; Conway et al. 2001).

There are at least 66 sponge taxa on OPB seamounts, 31 of which have been documented within the SK-B MPA, including the large habitat-forming species *Chonelasmsma oreia*, *Farrea* spp., *Tretrodictyum* n. sp., *Pinulasma* n. sp., and *Hexactinella* n. sp. (Du Preez and Norgard 2022: Table A10). Many are not resolved to species due to the need to examine spicules to confirm identifications and the immense amount of ongoing taxonomic work of sponges. Having voucher specimens is essential for determining biodiversity of the deep sea. In 2015, a new species of glass sponge was described via a sample recovered from the Sablefish trap fishery by-catch in the SK-B MPA. The species *Doconesthes dustinchiversi* was documented as the first member of the genus *Doconesthes* reported outside the North Atlantic Ocean and the first ever found in the Pacific Ocean (Reiswig 2015). The following year, two sponges collected in the same manner were identified as new species previously unknown to science (*Rhabdocalyptus trichotis* and *Pinulasma bowiensis*; Reiswig 2018). Samples collected during the 2018 expedition to the SK-B MPA revealed seven new species to science (unpublished descriptions by the late Henry Reiswig; Gartner et al. 2022: Appendix 5). These discoveries suggest that the MPA may support other species that are currently unknown to science in the North Pacific and highlights the importance of ongoing research and monitoring in the area.

Other benthic invertebrates

The benthic taxa of seamounts live in and on a variety of substrates ranging from unconsolidated sediment to pillowing basalt rock. Within the SK-B MPA these habitats range from depths of ~3,300 m to 24 m from the ocean's surface. Along this depth gradient there are a number of bathymetric boundaries whose number and characteristics determine the species turnover and assemblage structure (McClain et al. 2010). The different bathymetric zones support different inhabitants tolerant of the depth-related environmental gradients. For example, nutrients, oxygen, and ocean acidity directly or indirectly affect feeding, distribution, respiration, metabolism, growth, dissolution, behavior, reproduction, and, ultimately, survival (Ross et al. 2020).

The benthic invertebrate communities within the SK-B MPA were identified during the scoping phase of the ERAF but were not included in the risk assessment. These communities should be considered in any future application of the ERAF as well as the development of additional risk-based and ecosystem indicators (Thornborough et al. 2016). The cold-water coral and sponge species that contribute to these communities have been highlighted in the above section. The other benthic invertebrate species in these communities will be considered in the research document based on their habitat and mobility, as those factors affect how we monitor these species.

Infauna invertebrates inhabit any of the unconsolidated substrate within the MPA. Common infauna invertebrate species on seamounts are often nematodes, copepods, polychaetes, percaridids, and molluscs (Rogers 2018). Though studies within the SK-B MPA have not targeted infaunal specimens (e.g., 2018 push cores were used for nutrient and DNA (deoxyribonucleic acid) analyses; Gartner et al. 2022), many taxa have been recorded and are observed through imagery (e.g., Terebellidae; see Gauthier et al. 2018b). An example of targeted infaunal sampling was during the 2018 expedition within the SK-B MPA; specimens were collected of the genus *Chateopterus,* a tube-dwelling polychaete that can build its tube in sediment or attached to rocky habitat, to try to resolve taxonomic work on this genus (Gartner et al. 2022: Appendix 5). Infaunal species play an important role in bioturbation (e.g., Norling et al. 2007) and Yang et al. (2020) have demonstrated enhanced bioturbation around seamounts in the northwest Pacific.

Epifaunal invertebrates live on the substrate. Roughly 96 taxa were considered as SECs during the ERAF (Thornborough et al. 2016; Rubidge et al. 2018). The list clearly demonstrates the unique mix of common shallow coastal species, such as habitat-forming bryozoans (e.g., *Bugula* spp.), to deep-sea species, such as species of king crabs (e.g., *Paralithodes camtschaticus*). Invertebrates can be commonly described by their ability to move; sessile and sedentary animals are either attached to the substrate or have little motility to move from their location, whereas motile animals can move freely (Brusca and Brusca 1990). It is important to consider both of these motility lifestyles, both in the way in which you can study these animals but also in the way that they may respond to, and recover from, disturbance. For example, squat lobsters (*Munida quadrispina)* were identified as an important species SEC during the ERAF process but scored lower than other SECs as behaviourally it was able to respond and circumvent benthic impacts that are unavoidable to sessile invertebrates (Rubidge et al. 2018). A dense assemblage of *M. quadrispina* lives on the shallow gravel plateau of SK-B Seamount (Figure 7K). Based on its distribution and density, this population likely plays a significant role in seamount energy transfer, representing a large proportion of the local benthic productivity and biomass (Du Preez and Norgard 2022). Collections made in 2018 confirmed the identification of *M. quadrispina* as well as the presence of other members of the family Munidae within the MPA. In consultation with a taxonomic expert, the additional species were not resolved as there are currently worldwide taxonomic efforts on this family, particularly for the deep sea (Greg Jensen, University of Washington, Seattle, Washington, USA, pers. comm.; Gartner et al. 2022: Appendix 5).

The benthic invertebrate assemblage includes a diverse group of animals that have varying longevity, growth and recruitment rates. The diversity of these traits indicates that the benthic invertebrate assemblage may have different capacities to respond and recover from disturbances. In addition to those detailed above, there are two other notable occurrences of rare or unique invertebrate assemblages within the MPA recently documented from the 2018 expedition (Du Preez and Norgard 2022). The dense assemblage of Pom-pom Anemones (*Liponema brevicorne*) on the summit of Davidson/Pierce Seamount (~1.5 km^2 between 1,180–1,500 m; co-occurred with a dense forest of the black coral *Lillipathes* cf. *wingi* and glass sponge *Farrea* spp.) (Figure 7O) and the living mats of brittle stars on SK-B Seamount between approximately between 500–700 m depth (*Ophiacantha diplasia*, *Ophiacantha eurypoma*, *Ophiacantha rhachophora*, *Ophiopholis bakeri*, *Ophiopholus longispina*; likely other *Ophiopholus* and *Ophiacantha* spp.) (Figure 7L and M). Similar to the squat lobsters (although likely more so), the assemblage of brittle star species likely plays a significant role in seamount energy transfer, representing a massive proportion of the local benthic productivity and biomass (the topic of M.Sc. student thesis in prep, Pandora Gibbs). Preliminary analyses strongly suggest that oxygen concentration in the OMZ controls the lower distribution boundary of these species—suggesting climate change impacts to the OMZ may impact their distribution and, because they are mobile, their distribution may be useful as a biological indicator of ecologically meaningful oxygen levels. While they are considered a generalist species, crinoids are another abundant invertebrate within the MPA that are often examined in deep-sea ecosystems as a VME indicator species (mentioned as a potentially overlooked species SEC in Du Preez and Norgard 2022).

Additionally, invertebrates have complex life-history strategies that vary among the different taxa. However, most go through some sort of pelagic phase during their reproduction, where they may become part of the plankton community (discussed below). As such, invertebrate assemblages and recruitment are all greatly affected by conditions and factors in the water column as well.

1.2.3.2. Algae

As defined in the management plan for the SK-B MPA, sensitive benthic habitats (SBH) are "vulnerable to proposed or ongoing human activities. Vulnerability will be determined based on the level of harm that human activities may have on the benthic habitat by degrading the ecosystem functions provided or impairing productivity. Biogenic habitats, such as those created by cold-water corals and sponges, and complex physical seabed elements are common examples of SBH." Through the risk-based assessments of the SK-B MPA (O et al. 2015; Thornborough et al. 2016; Rubidge et al. 2018), four habitat groups were determined to be important SECs: cold-water coral, sponge, macroalgae, and coralline algae (the first two habitat SECs were covered in the Invertebrates section above).

SK-B Seamount is shallow and rises to within 24 m of the surface. This provides a unique opportunity for available substrate in the offshore within the photic zone. Algae are chlorophyll bearing organisms that photosynthesize and provide rare in situ primary production within marine food chains. Early studies (summarized in Canessa et al. 2003) described the summit of SK-B Seamount dominated by red, brown, and encrusting algae to a degree of species richness typically limited to shallow, moderate current or wave exposure regimes in coastal environments. In the OPB, 200 m marks the lower boundary of the euphotic zone, and algae have been observed growing at ≥160 m depth on SK-B Seamount (Gauthier et al. 2018a; Du Preez and Norgard 2022). The depths at which some taxa are found on SK-B are greater than those ever recorded for the species (Canessa et al. 2003). The summit area of SK-B confidently predicted to support kelps and seaweeds is 5 km^2 (<130 m depth) and creates a remote shallow marine island oasis for typically coastal species (Du Preez and Norgard 2022). There are at least 31 algae taxa on documented on SK-B Seamount, mostly brown and red algae (Du Preez and Norgard 2022: Table A10).

Macroalgae tends to be fleshy and grow tall, providing complex three-dimensional structure. It has been identified as important habitat for invertebrate and fish species to live in, spawning and nursery groups for fishes, and serves as a food source for many taxa (Thornborough et al. 2016). On SK-B Seamount there are brown, red, and green macroalgae (Du Preez and Norgard 2022: Table A10). Algae detritus is a large export of organic carbon and nutrients into deep-sea ecosystems; therefore, the presence of algae on the summit of SK-B Seamount may have a large seamount effect downslope, to its sister seamounts, and even enhance biomass on the surrounding bathyal plains (a unique ecosystem function provided by SK-B Seamount; Du Preez and Norgard 2022). On the summit of SK-B Seamount, *Desmarestia* sp. (flattened acid and stringy acid kelp) represents the dominant large algae (Rubidge et al. 2018).

Coralline (red) algae are hard, encrusting or branching, and provide structural habitat for other species on SK̲-B Seamount. Coralline algae was identified as a habitat SEC as it (1) plays a critical role in binding reef materials into sturdy structure; (2) provides two-dimensional structure for larval settlement; and (3) are vulnerable to ocean acidification so can act as a good indicator (Rubidge et al. 2018). Additionally, coralline algae are more sensitive to activities that cause sediment resuspension due to its encrusting nature (DFO 2015a).

In comparison to the other habitat SECs, algae are shorter-lived and can be very seasonal in abundance and distribution. As with all monitoring indicators, life-history traits of algae species will factor into any monitoring program that is developed in the future.

1.2.3.3. Fishes

Fishes are the most diverse group of vertebrates, with around 30,000 species, specialized to a multitude of aquatic environments (Burton and Burton 2017). Fishes are characterized morphologically by their fins and gills, and ecologically are commonly predators, with the capability for rapid movement and a complex sensory system, even in juvenile phases. Due to the long evolutionary history and niche adaptations of fishes, certain genera have high levels of speciation, including rockfishes (*Sebastes* spp.; Hyde and Vetter 2007).

There are 121 species of bony fishes, skates, and sharks on OPB Seamounts, 81 of which are documented within the SK̲-B MPA (Du Preez and Norgard 2022: Table A10). Those species listed as SECs includes Prowfish (*Zaprora silenus*), Wolfeel (*Anarrhichthys ocellatus*), Pacific Halibut, Sablefish, and Dover Sole (*Microstomus pacificus*) (Thornborough et al. 2016; Rubidge et al. 2018). There are 30 species of rockfishes and thornyheads (*Sebastes* spp. and *Sebastolobus* spp.) within the SK̲-B MPA (all part of a rockfish community SEC) including species SECs REBS Rockfish (*Sebastes aleutianus/melanostictus*), Yelloweye Rockfish (*Sebastes ruberrimus*), Widow Rockfish (*Sebastes entomelas*), and Bocaccio (*Sebastes paucispinis*). To date, eight species of sharks, including four pelagics (Great White Shark (*Carcharodon carcharias*), Basking Shark (*Cetorhinus maximus*), Salmon Shark (*Lamna ditropis*), and Blue Shark (*Prionace glauca*)), have been detected within the MPA (Rubidge et al. 2018).

While fisheries records and transect surveys have shed light on the diversity and relative abundance of pelagic fishes found in the MPA, the distribution and behaviours of those fishes (both within and beyond the MPA boundaries) require additional research. Some connectivity between MPA and coastal fish populations has been observed: Yamanaka et al. (2000) determined that Yelloweye Rockfish at SK̲-B seamount are not genetically distinct from those on the BC coast, and tagging data indicates that Sablefish can migrate from seamounts to the coast (and vice versa; Whitaker and McFarlane 1997); however, the frequency and phenology of these movements are not yet clear (e.g., Beamish et al. 2006). At the seamount-scale, the distribution of pelagic fishes is likely most strongly influenced by depth-dependent factors such as oxygen availability. For example, REBS Rockfish appear to be restricted to the upper-oxic zones of seamounts in Canada's OPB (i.e., less than 450 m depth), whereas Sablefish have been observed on seamounts at depths down to 1,538 m, and Pacific Halibut have been fished at depths down to 1,765 m (Du Preez and Norgard 2022).

In the case of benthic fishes, the age composition data from catches in the SK̲-B for Yelloweye Rockfish, indicate that demographic factors can operate a much smaller spatial scale (Canessa 2003), even though the genetic analyses provided evidence of a single stock for the outer Pacific coast (and one for Salish Sea) (Siegle et al. 2013; Andrew et al. 2018). Adult Yelloweye Rockfish reside over specific rocky habitats and move little from these areas. Hence, the combination of intrinsic biological traits (longevity and sedentary behavior) and fishery in the past have resulted in detectable changes for population parameters in this species, either offshore or closer to the coast (Canessa 2003; Frid et al. 2016). Heavily fished populations are characterized by a truncation of the size and age distribution as larger, older individuals are removed by fishing and not replenished rapidly by adult immigration or population growth (Kronlund and Yamanaka 2001; Levin et al. 2005; Audzijonyte et al. 2013). Thus, changes in size and age at maturity are expected to occur once fishery is closed and sufficient larval replenishment has occurred. It might take years or even decades before these effects are noticed, and this must also be considered in monitoring efforts.

1.2.3.4. Birds and Mammals

Seamounts are generally regarded as hotspots of pelagic diversity (e.g., Morato et al. 2010) that provide foraging opportunities, spawning habitat, and/or navigational waypoints for a wide variety of pelagic species (Rogers 2018). Shallow seamounts are often described as attractants for high aggregations of transient marine species, such as cetaceans, pinnipeds, sharks, turtles and large migratory fishes (Holland and Grubbs 2007; Litvinov 2007; Pitcher and Bulman 2007; Morato et al. 2008; Rogers 2018). A comprehensive list of known occurrences is provided in Du Preez and Norgard (2022: Table A10). The seamounts themselves may act as navigation landmarks, and are associated with higher food availability relative to surrounding areas (Holland and Grubbs 2007). For instance, seabirds may be attracted to the “seamount effect” of SK-B Seamount, in consequence of increased abundance of plankton promoted by particular local oceanographic conditions (e.g., Haida Eddies). Around Cobb Seamount, several species of seabirds were significantly more abundant than elsewhere in the region (Dower and Fee 1999). A similar effect is expected to occur in the SK-B MPA. Not surprisingly, the SK-B MPA has been identified as a Canadian Wildlife Service (CWS) Area Of Interest for Migratory Birds and SK-B seamount itself is a CWS confirmed area of importance to marine and coastal birds (Canessa 2003; CWS 2003). Because of the large sphere of influence seamounts are known to have on surrounding ocean ecosystem functions and services, seamount EBSAs are considered to include up to 30 km of the surrounding ocean (DFO 2019a; Du Preez and Norgard 2022).

In 2015, no clear patterns of birds with respect to proximity to the seamount pinnacle and/or water depth were found (Gale et al. 2017). However, a few generalizations could be made: (i) there was an apparent higher density of Fork-tailed Storm-Petrels (*Oceanodroma furcata*) within 50 km of the pinnacle, and over waters 200 m deep or less; (ii) an apparent higher density of Leach’s Storm-Petrels (*Oceanodroma leucorhoa*) over deep waters (i.e., more than 200 m deep), more than 50 km from SK-B Seamount; and (iii) fewer species over shallow waters, within 50 km of the pinnacle. It is unknown if lack of patterns were related to small sample sizes.

Little is known about the occurrence, abundance, or seasonal patterns of seabirds or marine mammals around the SK-B MPA (Gale et al. 2017). Earlier at-sea bird surveys in the vicinity of SK-B seamount in 1997, 1998, and 2000 (Ken Morgan, pers. comm. in Canessa et al. 2003) recorded 13 species of birds in summer and/or autumn, while the other two species were only seen during autumn and winter. The 2015 expedition recorded three new species for the area, although did not observe 6 species listed in earlier surveys.

During the 2018 expeditions, there were some opportunistic surveys resulting in 32 transects conducted over a 5-day period that included areas within the SK-B MPA (Gartner et al. 2022: Appendix 8). The birds observed were Leach’s Storm Petrel, Northern Fulmar (*Fulmarus glacialis*), Blackfooted Albatross (*Phoebastria nigripes*), unidentified alcids, and unidentified seabirds. In total, 22 seabirds have been documented over OPB seamounts, 15 of which were in the SK-B MPA (Du Preez and Norgard 2022: Table A10).

Sixteen marine mammals have been observed over OPB seamounts, 12 within the SK-B MPA (Du Preez and Norgard 2022: Table A10). Seven species of cetaceans were sighted during the 2015 survey (Gale et al. 2017): Blue Whales (*Balaenoptera musculus*), Fin Whales (*Balaenoptera physalus*), Humpback Whales (*Megaptera novaeangliae*), Orca (*Orcinus orca*), Dall's Porpoises (*Phocoenoides dalli*), Pacific White-sided Dolphins (*Lagenorhynchus obliquidens*), and Northern Right Whale Dolphins (*Lissodelphis borealis*). Marine mammal observations earlier than 2015 include Sperm Whales (*Physeter catodon)* and possibly Striped Dolphins (*Stenella coeruleoalba*) (Canessa et al. 2003; Yamanaka 2005). Other marine mammal sightings included Northern Fur Seals (*Callorhinus ursinus*), Northern Elephant Seals (*Mirounga angustirostris*), and Steller Sea Lions (*Eumetopias jubatus*) (Gale et al. 2017). Other species observed on OPB seamounts outside the SK-B MPA include Bottlenose Dolphins (*Tursiops truncatus*), Northern Minke Whale (*Balaenoptera acutorostrata*), False Killer Whale (*Pseudorca crassidens*), and Cuvier's Beaked Whale (*Ziphius cavirostris*).

1.2.3.5. Plankton

Plankton is a general term used to describe organisms that are unable to move against horizontal currents (Brusca and Brusca 1990). Plankton includes a wide range of organisms from bacteria, to photosynthetic algae (phytoplankton), and floating and drifting small marine animals (zooplankton), as well as the juvenile phases of certain marine animals (meroplankton).

Shallow seamounts generally are an area of cold, nutrient-rich water in the upper euphotic zone with upwelling and turbulent mixing of surface waters. In biological terms, these conditions would increase phytoplankton growth, thereby contributing to the highly productive communities that often exist on shallow seamounts (Morato et al. 2010). The degree to which this enhanced productivity is retained over the seamount (directly or indirectly affecting local productivity), or swept off-seamount downstream, is unknown. The concept of a "seamount effect" that causes enhanced local primary productivity has been documented in some regions (Leitner et al. 2020 and citations therein) but has not been demonstrated within the MPA region. It may be that higher abundances of plankton are caused (entirely or partially) by local currents advecting or retaining organic material (e.g., Haida Eddies and/or Taylor Cone) and deep-scattering layer trapping (see below).

Primary productivity of phytoplankton is higher through spring and summer (May to September; Du Preez and Norgard 2022: Appendix G by Andrea Hilborn, Institute of Ocean Sciences, DFO). The lengthy phytoplankton bloom is likely made possible by sustained nutrients that are never depleted and because micro-nutrients, such as iron, are readily available from the SK-B summit (Frank Whitney, DFO, Sidney, BC, pers. comm.).

Zooplankton communities are, in general, secondary producers and form a trophic link between primary producers and higher trophic levels. Zooplankton exerts significant influence on the vertical transport of carbon through the water column, a process known as the 'biological carbon pump' (Stefanoudis et al. 2019). The taxonomic composition of zooplankton communities is therefore very important to the balance of trophic webs and highly dependent on temperature and timing of primary productivity, as those indicate more or less availability of food for these communities.

A large proportion of zooplankton undergoes a daily migration known as the deep-scattering layer (surface at night and in the deep during the day). Within the OPB, the lower boundary of the deep scattering layer migration is ~800 m; therefore, both SK-B and Hodgkins receive direct delivery of zooplankton to their summits and shallow flanks daily, which can become trapped and consumed by benthic species (Du Preez and Norgard 2022). In addition to localized surface productivity, zooplankton exported from other locations through horizontal currents, often become trapped behind seamounts following diel vertical migrations. These trapped zooplankton support deep-sea productivity by providing an influx of prey for fishes; therefore, the dynamic currents around seamounts are an important aspect of seamount ecology. Zooplankton transport by ocean currents and Haida Eddies are likely also an important source of planktonic larvae for many invertebrate species that settle in the seamount benthic community.

Export productivity (i.e., particulate organic carbon or 'marine snow') has been calculated for all three SK-B MPA seamounts as a function of sea surface productivity and summit depth (i.e., milligrams of carbon per meter squared per day) (Du Preez and Norgard 2022). SK-B summit receives the highest export flux of any OPB seamount (581.2 mg C m^{-2} d^{-1}) whereas, in comparison, Hodgkins and Davidson/Pierce receive far less (33.1 and 18.8 mg C m^{-2} d^{-1}, representatively). While the latter two seamounts receive dramatically less than SK-B, all three are considered to experience "high" export flux in comparison to the other 59 OPB seamounts (Du Preez and Norgard 2022).

Very recently, off the coast of BC the warm water conditions in 2019 were reflected in higher abundances of gelatinous species (e.g., pyrosomes) and lower abundances of crustacean taxa in the zooplankton communities in the Eastern Pacific, as well as a dominance of small-sized copepod species (typical of southern latitudes) (Young and Galbraith 2020). Those conditions are persisting in recent years as heat waves are occurring more frequently than ever (Boldt et al. 2020b).

Planktonic organisms are generally short-lived and strongly affected by local conditions. Their responses to disturbances are usually immediate, and the recovery is affected by local conditions and recruitment. While plankton communities regularly experience fast responses to changing conditions, changes in surface productivity (primary, secondary, or otherwise) directly effect export flux and may therefore have a long-lasting effect on the health and/or distribution of deep-sea species (Du Preez and Norgard 2022). For example, the recent climate change-related shift in the OPB zooplankton to a pyrosome dominated community (*Pyrosoma atlanticum*) was documented to have a cascading effect on the deep-sea communities kilometres below the bloom itself (Archer et al. 2018).

1.2.3.6. Trophic Connections

In temperate oceans, such as the Northeast Pacific Ocean, food arrives in pulses, following the spring and late summer blooms of primary productivity (described in the Plankton section above). For this reason, deep-water benthic communities receive high-quality phytodetritus within a short temporal window following surface blooms (Witbaard et al. 2000; Dunlop et al. 2016). There is no photosynthetically derived primary production in the deep sea, and therefore, deep-water ecosystems are generally characterized by a limited food supply and are mostly heterotrophic (except cold seeps, hydrothermal vents, and deadfalls). Nonetheless, food can also be actively transported down by those animals that carry out vertical diel migrations through the water column or the occasional fall of animal carcasses and other organic debris (e.g., logs and kelp).

Seamount trophic webs are generally understudied or incomplete, focusing on certain linkages, such as the trophic ecology of commercially valuable fishes (Christiansen et al. 2009; Hirch and Christiansen 2010; Nishida et al. 2016; Laptikhovsky et al. 2020). A study on the Condor Seamount (North Atlantic) found that mesopelagic organisms provided a link between pelagic and benthic systems (Colaço et al. 2013), consistent with previous modelling and theory (van Denderen et al. 2021). The trophic relationships in the SK-B MPA are yet to be properly addressed, but have been previously mapped and described as simpler than the typical coastal ecosystems due to the apparent diminished presence of the small pelagic community on the seamount relative to the number of species at the highest trophic levels (Beamish and Neville 2003).

The SK-B MPA ecosystem is vulnerable to impacts from lost fishing gear, climate change (e.g., deoxygenation, ocean acidification, increased temperature), shipping traffic, debris, and many other anthropogenic stressors and activities (Thornborough et al. 2016; Rubidge et al. 2018; Du Preez and Norgard 2022). In addition, there may be recovery from fisheries following closures (albeit on the scale of decades to centuries). Further research is required to quantify the interactions between trophic functioning and these potential ecosystem changes. However, some predictions may be made for broad functional group responses to certain impacts, such as ocean acidification adversely affecting shellfish and their predators (Haigh et al. 2015). In another example, the effect of ocean acidification on shelled pteropods, a group of calcifying zooplankton, is a major concern for offshore food webs (e.g., Bednaršek et al. 2021). On the OPB seamounts, the future of cold-water corals, sponges, and other habitat-forming species in a more acidic ocean is of great concern, with the extirpation of some species predicted to occur in the next hundred years (Ross et al. 2020). Furthermore, temperature and nutrient changes from climate change or shifts in patterns of Haida Eddies would likely cause a trophic cascade by decreasing the primary producers (phytoplankton and kelp) with ripple effects moving up the food web to impact the high-level predators. Top-down effects are also anticipated as the rapid deoxygenation in the already naturally low OMZ causes the local extirpation or distribution shift of predators, such as rockfishes (Ross et al. 2020). These impacts are highly complex and difficult to identify, therefore highlighting the importance of baseline data to understand any major shifts in populations that can affect the trophic functioning of the ecosystem. A priority of baseline monitoring should be to understand the connections between key ecosystem components and oceanographic (climate) variables that are already changing (for more details, see the Climate Change Monitoring section).

SK-B Seamount is a highly biodiverse ecosystem, ranging from shallow to deep-sea environments, with the highest risk level for threats out of all OPB seamounts (Du Preez and Norgard 2022). While trophic relationships are complex and tightly coupled, in-depth research on multiple species and habitat components can reveal significant information on ecosystem functioning. Consistent monitoring of each of the major functional groups and how they respond to changes in the environment or as populations shift will illuminate predicted and unexpected relationships within the food web, and can allow for adaptive management to mitigate any negative impacts.

1.3. HISTORY OF SGÁAN KÍNGHLAS-BOWIE SEAMOUNTS

1.3.1. Ecological Timeline

The following section is illustrated in Figure 8.

SK-B and its sister seamounts started as small submarine volcanic mountains on the deep bathyal plains 3 km below the waves approximately 75,000 to 720,000 years ago (Chaytor et al. 2007) (for more details, see the Geology section above). At some point—likely during the last ice age when sea level was lower—the tallest of the volcanoes (i.e., SK-B Seamount) rose above sea level, becoming a volcanic island. Its last eruption was some 18,000 years ago, after which its natural disturbance regime became relatively stable (Chaytor et al. 2007). Since time immemorial, Haidas have inhabited their territory, and there is oral history of Haidas visiting the offshore island of SK-B (for more details, see the Context section above). While it's relatively safe to assume marine animals have been visiting and inhabiting the submarine habitats with varying degrees of success and succession since eruptions began, almost nothing is known about the occupation of the island by terrestrial animals. Haida traditional knowledge recounts an island with an abundance of **kwa.anaa** *puffins* (Figure 9), and it is likely marine mammals used the beach to haul out (e.g., sea lions). Haida fishing and gathering would have been sustainable and size-selective, and unlikely to have caused long-lasting impacts (Smythe 2018) (Figure 9).

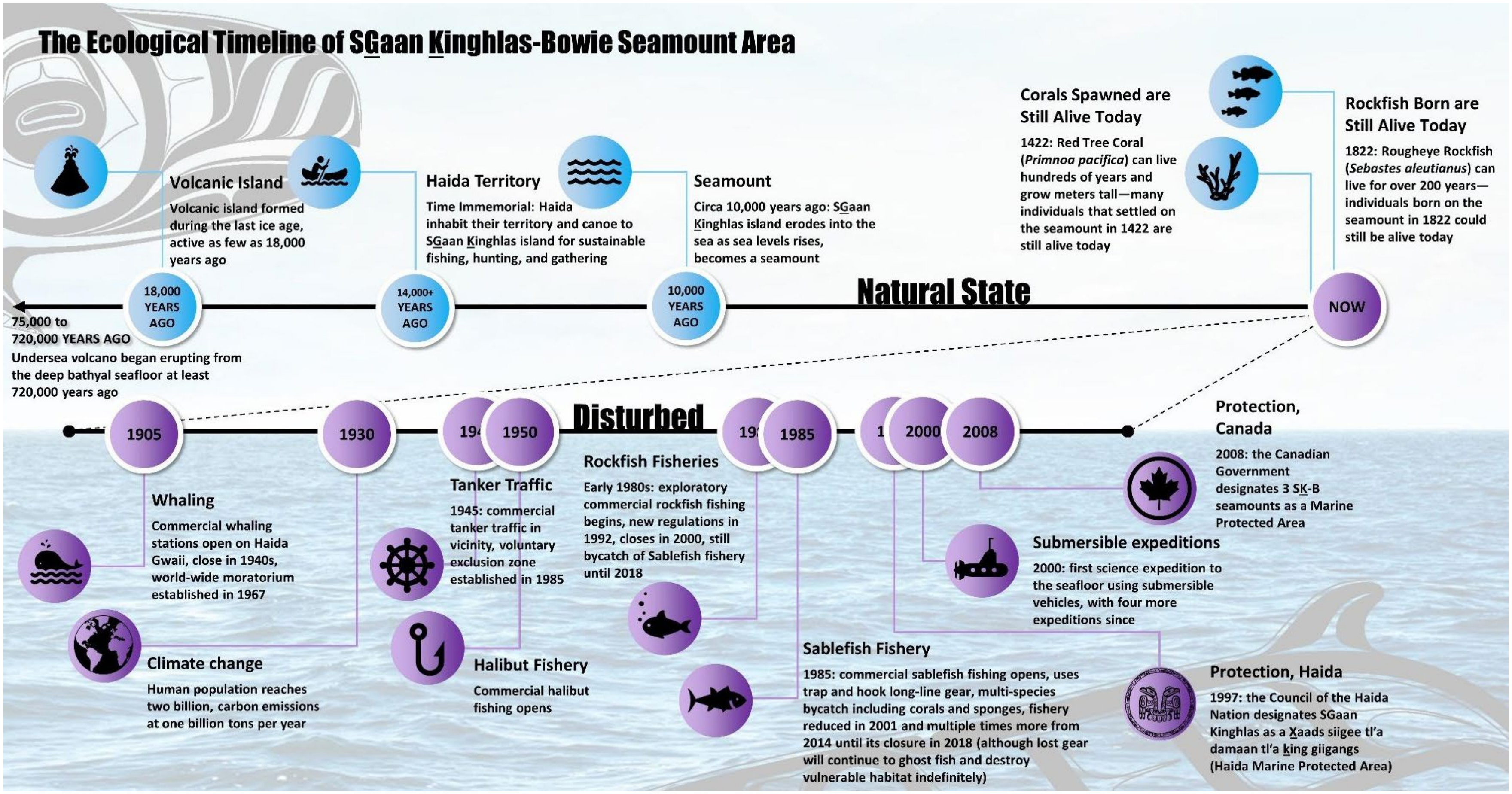

Figure 8. The ecological timeline of SG̲áan K̲ínghlas-Bowie (SK̲-B) Seamount area illustrates the long natural history and the comparatively short recent history of extraction, followed by protection and activities. See text for details on each event. The Haida art was shared by ***Iljuuwaas*** *Tyson Brown, from the SK̲-B Seamount Marine Protected Area (MPA) management plan (CHN and DFO 2019).*

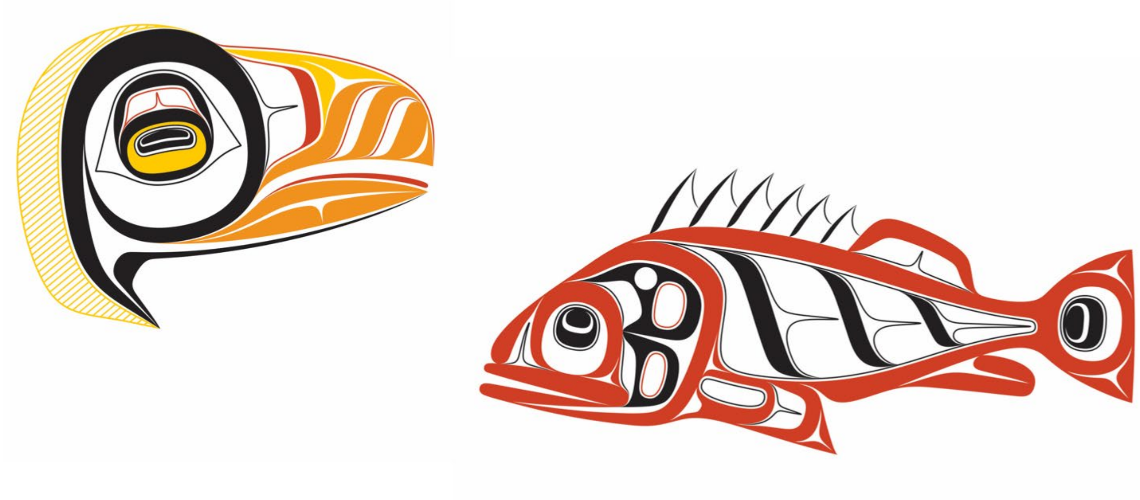

Figure 9. Traditional knowledge recounts Haida visiting an island with an abundance of ***kwa.anaa*** *puffins (left), where they fished, likely for* ***k'aalts'adaa*** *Rougheye/Blackspotted Rockfish (*Sebastes aleutianus/melanostictus*) and other* ***k'ats*** *rockfish species (*Sebastes *spp.). The Haida art was shared by* ***Iljuuwaas*** *Tyson Brown, from the SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA) management plan (CHN and DFO 2019).*

Circa 10,000 years ago, SK-B eroded back into the sea as water level rose, and the island became a seamount, its shallow summit becoming home to a diverse assemblage of species that are typically found in coastal habitats.

Many species within the SK-B MPA are slow-growing and long-lived—meaning that many animals alive today settled on the seamounts hundreds, potentially even thousands of years ago (e.g., cold-water corals and sponges). A **k'aalts'adaa** *Rougheye/Blackspotted Rockfish* (*S. aleutianus/melanostictus*) alive today could have been "mid-life" at 100 years old when whaling, the first extraction industry, began (circa 1905). Since then, the SK-B MPA ecosystem has suffered the cumulative impacts of multiple fisheries (detailed below), industrial revolution and climate change, commercial vessel traffic, and other human-induced environmental changes (e.g., ocean litter, noise pollution, ship strikes).

Over the last twenty-five years, modern human activities have slowly changed from purely resource extractive to protection and conservation. In 1997, the Haida Nation designated the area as a **Xaads síigee tl'a dám.án tl'a kíng gíigangs** *Haida Marine Protected Area.* Submersible science expeditions have been on the rise since 2000 (detailed below). In 2008, the area was designated as a MPA under Canada's *Oceans Act*. Through CHN and DFO co-management, the last of the operational fisheries was closed in 2018. While spatial management alone cannot alleviate all human impacts, the reduction or removal of some stressors will reduce the cumulative and compounding effects of those outside the scope of the MPA (e.g., climate change, pollution, etc.). The lag time of the full impacts of the last hundred years, followed by a recovery to a natural state, may take timelines on the order of generations (i.e., hundreds to thousands of years).

1.3.2. History of Monitoring and Activities in the SGáan Kínghlas-Bowie Marine Protected Area

There has been no historic ecological monitoring plan or program for the SK-B MPA. However, sporadic surveys and research initiatives have taken place in the SK-B MPA since the 1940s, for geological, biological, oceanographic, and naval purposes (see summaries in Canessa et al. 2013 and Gale et al. 2017). Data for target and non-target fish and non-target invertebrate species are also available from commercial fishery records, as well as SCUBA dive, submersible, and remotely operated vehicle (ROV) surveys (Canessa et al. 2003; Gauthier et al. 2018a–c; Gartner et al. 2022). Haidas have been visiting SK̲-B since time immemorial and have Marine Traditional Knowledge of the seamounts (CHN and DFO 2019). There has been some monitoring for human activities in the area (summary in Davies et al. 2011), most recently related to vessel traffic and associated noise pollution (e.g., Allen et al. 2018). Details on these activities have previously been reviewed multiple times (Canessa et al. 2003; Davies et al. 2011; Gale et al. 2017; Thornborough et al. 2016) and are summarized below, with updated unpublished information.

For more details on the ongoing science and fisheries surveys in and around the SK̲-B MPA, see the Strategies section below. For more details on the current monitoring of human activities in and around the SK̲-B MPA, see the Human Activity Monitoring section below.

1.3.2.1. Fisheries Activities

Haidas have fished SK̲-B Seamount for traditional (cultural, subsistence, and economic) purposes since time immemorial (CHN and DFO 2019). The traditional Haida fishery was mainly **x̲aguu tla danjuu isgyáan sk̲íl tla x̲awgang** *jigging for Halibut and fishing for Sablefish,* as well as rockfishes, using highly specialized hooks. Given the remote location and rough, open waters around SK̲-B, fishing endeavours have been limited to larger vessels of sufficient power capacity (Canessa et al. 2003).

It is very likely commercial whaling occurred in the vicinity of the SK̲-B MPA seamounts as there were two shore-based whaling stations on Haida Gwaii, Naden Harbour and Rose Harbour, which closed in 1941 and 1943 respectively (Nichol et al. 2002). Whaling began in BC in 1905 and continued until 1967, but earlier newspaper accounts describe commercial whaling in the Queen Charlotte Strait between 1866 and 1873 (Nichol et al. 2002). Some level of whaling likely lasted until banned in 1986 when the International Whaling Commission moratorium was imposed (Nichol et al. 2002).

The seamounts were commercially fished for Pacific Halibut as early as the 1950s, but the majority of documented commercial activity since that time has been part of directed rockfish and Sablefish fisheries (see Canessa et al. 2003 for a more detailed history; Rockfish: 1992 to 1999; Sablefish with rockfish bycatch: 1985 to 2018) (Figure 8). The commercial fishing methods on SK̲-B have primarily included mid-water trawls and bottom longlines with hooks or traps. Exploratory surveys to establish these fisheries and some catch data provide limited data on target and non-target fish and some non-target invertebrate species (see Canessa et al. 2003; Gauthier et al. 2018a–c). For example, the longest-running fishery was for Sablefish (for details on fishing gear, see Box 1), which was monitored through fishing logbooks, at-sea observation through either at sea observers or electronic monitoring (EM), port-sampling, and dockside monitoring (DFO 2010a). All harvesters were required to keep at-sea catch records using both fishing logbooks and EM to record vessel details, line/trap specifications, soak time, fishing location and retained and released catch by species (Davies et al. 2011).

Box 1. Sablefish fishing gear

The Sablefish fishery most commonly used circular cone-shaped traps,1.4 m wide base by 0.8 m wide top, with hundreds of traps attached to a long ground line, by rot cords and clips (Figure 10). The set line was dropped to depths between 800 and 1,200 m using 60 kilogram anchors (CHN 2018). The average longline string length for the fisheries was 2,915 ±25 m, with a footprint of 3,994 ±24 m^2 for trap longline gear, and additional buoyant lines and floats at both ends of the set that extended through the water column to the surface (Du Preez et al. 2020). Available data and trends were summarized in Canessa et al. (2003) and documented a decrease in catch per unit effort and total catch to 1993 suggested that fishing levels were not sustainable (Murie et al. 1996). While there is evidence the abundance of the Sablefish population in BC started to stabilize in the late 1990s and early 2000s, and potentially increased more recently (Lacko et al. 2021), research on the fishery itself determined that current, wind, and waves drag the traps along the seafloor and encounter and impact habitat-forming species such as corals and sponges (Doherty et al. 2018; Buchanan et al. 2018). The fishery was subsequently closed in 2018 (CHN and DFO 2019).

While the seamount fisheries are closed, the lost and discarded fishing gear will remain entangled on the fished seamounts indefinitely—with no way to remove it and little to no degradation—similar to the hundreds of thousands of pieces of fishing gear on Cobb Seamount (Du Preez et al. 2020; Du Preez and Norgard 2022). During the 2018 expedition, long lines were observed on most dives on SK-B Seamount, from ~2,000 m to the sunlit pinnacles on the summit plateau (Figure 10) (Gartner et al. 2022; Du Preez and Norgard 2022) (note: well above the 800 m upper limit mentioned in Box 1). Perpetual impacts of lost gear include habitat alteration (e.g., damaging, crushing, removing cold-water corals and sponges) and ghost fishing (if rot cords were used, ghost fishing would stop once the trap breaks down) (Du Preez et al. 2020).

Figure 10. Lost or discarded fishing gear on the summit of SGáan Kínghlas-Bowie (SK-B) Seamount observed during the Pac2018-103 expedition (Gartner et al. 2022). Lost longlines litter the seamount; this piece is 79 m in depth, well within zone 1 (fishing prohibited since 2008). Credit: S. Du Preez, Northeast Pacific Seamount Expedition Partnership, Ocean Exploration Trust.

There is limited existing data available for the Albacore Tuna (*Thunnus alalunga*) fishery around SK-B (see Canessa et al. 2003), though Stocker et al. (2007) indicate catch reporting was unreliable prior to 1995. Tuna fishing activity is associated with warmer sea surface conditions (Nieto et al. 2017). The Albacore Tuna fishery uses trolling gear at depths near the surface and is not designed to contact bottom habitats (DFO 2020a).

1.3.2.2. Benthic science activities

In terms of existing data types, SK̲-B Seamount is the most well-studied seamount in the OPB, with Hodgkins and Davidson not too far behind (Du Preez and Norgard 2022). The first recorded images of life on the seamounts in the SK̲-B MPA were collected by SCUBA divers in 1969 (Scrimger and Bird 1969; Herlinveaux 1971). Subsequent benthic research was primarily driven by fisheries and their sampling methods, though a few sporadic SCUBA and remotely operated vehicle (ROV) research trips were conducted (Gale et al. 2017: Table 1). Starting in 2000, DFO and partners have conducted four targeted benthic scientific surveys using ROVs, submersibles, or tow cameras (Figure 11). In 2000, a multi-agency and multi-disciplinary research cruise was conducted that provided the first in situ survey methods using a submersible (PAC 2000-31; Yamanaka 2005). In 2011, a joint DFO and the National Atmosphere and Oceanic Organization (NOAA) survey utilized ROV and autonomous underwater vehicle (AUV) data to document habitat and species (PAC 2011-62; unpublished). In 2015, DFO led a research survey that utilized a new drop camera to study the benthic habitat and was the first to document life on Hodgkins Seamount (PAC 2015-48; Gale et al. 2017). In 2018, Northeast Pacific Seamount Expedition Partners (including CHN and DFO) conducted research on all three seamounts in the MPA using the Ocean Exploration Trust's state-of-the-art vessel, the Exploration Vessel *Nautilus*, equipped with a multi-beam echosounder used for seafloor mapping, oceanographic sampling tools, and two ROVs *Hercules* and *Argus* (DFO PAC 2018-103 and Nautilus NA097; Gartner et al. 2022). These surveys have provided insight and preliminary information on species richness and distribution of seamounts in the MPA but are not complete enough to be regarded as a baseline study (Davies et al. 2011). Monitoring sites were established during the 2018 expedition on all three seamounts (first time documenting Pierce/Davidson Seamount) as part of a seamount monitoring pilot study, in the hope of contributing to a long-term data set (Gartner et al. 2022: Table 3). Expeditions to the MPA have primarily occurred in summer, for example with one that occurred in June 2022.

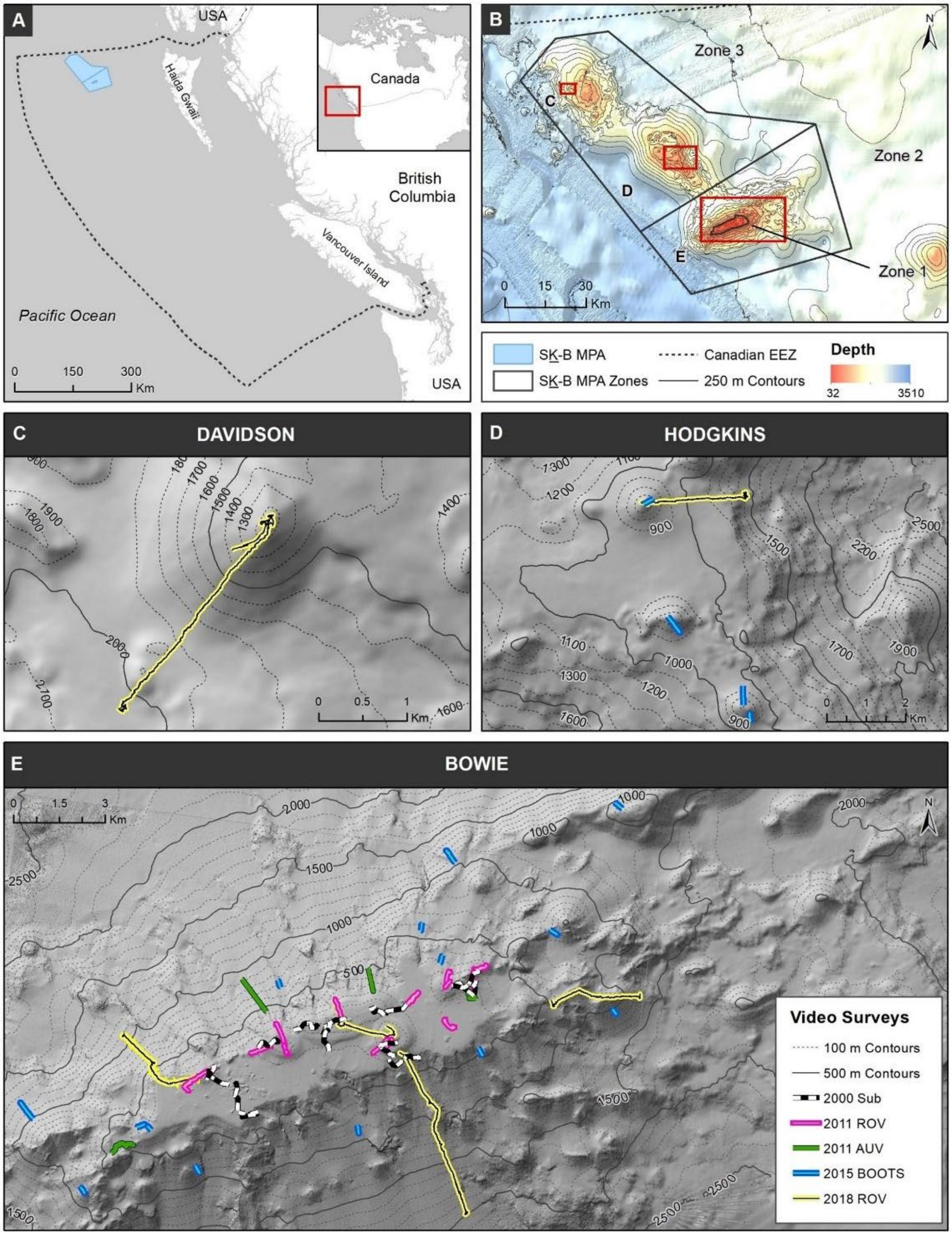

Figure 11. Location of the benthic science surveys within the SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area (SK̲-B MPA). Map created by Georgia Clyde, Institute of Ocean Sciences.

1.3.2.3. Oceanographic activities

Canessa et al. (2003) details the history of activities within the SK̲-B MPA, including oceanographic and sea surface data collected. Some notable activities include:

- 1969: a significant oceanographic component to the Herlinveaux survey (Herlinveaux 1971)
- 1974–1975: tide and temperature gauge moorings placed on SK-B Seamount (Crawford et al. 1981)
- 1998: oceanographic and high-sea salmon sampling near SK-B (David Welch, pers. comm. in Canessa et al. 2003)
- 2000: multibeam bathymetry of the SK-B and Hodgkin seamounts (Canessa et al. 2003)
- 2000: oceanographic sampling (CTD – conductivity, temperature, and depth and bongo nets), with seabird and marine mammal observations carried out during the science survey (Yamanaka 2005)
- 1998–2001: water property measurements and plankton community studies associated with mesoscale eddies (summarized in Canessa et al. 2003)
- 2015: a contrast of the planktonic community and chemical oceanography within and outside the boundaries of the SK-B MPA (Gale et al. 2017)
- 2016–2018: research on the underwater acoustic environment and anthropogenic noise (e.g., Riera et al. 2016; Allen et al. 2018)
- 2018: oceanographic sampling (bongo nets), oceanographic measurements (e.g., temperature, oxygen) taken in conjunction with ROV, and a more extensive, higher-resolution multibeam bathymetry and backscatter survey of all three seamounts (Gartner et al. 2022: Appendix 3)
- 2018: Pacific Region International Survey of Marine Megafauna (PRISMM) survey (Wright et al. 2021)

DFO uses some oceanographic programs to track trends for the North Pacific that inform or include conditions within the SK-B MPA. From Davies et al. (2011): “These include the free-drifting profiling floats for the Argo project that provide information on water temperature and salinity profiles, as well as satellite imagery from SeaWiFS (Sea-viewing Wide Field-of view Sensor) and MODIS (MODerate resolution Imaging Spectroradiometer) satellites that monitor phytoplankton and nitrate levels. In addition, sampling by the Continuous Plankton Recorder (CPR) for the Sir Alister Hardy Foundation for Ocean Science provides data on the seasonal cycle of total mesozooplankton biomass throughout the Pacific.” Long-term oceanographic data is available from stations along the Line P Program. There are 26 stations that extend from the mouth of the Strait of Juan de Fuca out to Station Papa in the offshore, with data collected at least three times annually since 1959 (Ross et al. 2020). The Program samples to depths of 2,500 m including some locations over or adjacent to seamounts. Lastly, starting in 2019, DFO has established a glider program with a ‘northern’ survey within the TḥT AOI (Figure 2A) with a second ‘southern’ survey line proposed. The glider program is again informative for the SK-B MPA as the surveys transect multiple seamounts, though they only go to a depth of 1,000 m (Canadian Pacific Robotic Ocean Observing Facility [C-PROOF] 2022). Quality controlled DFO collected oceanographic data is stored and accessible through its Water Properties Group website (login required). As previously mentioned, for more information on the ongoing surveys, see the Strategies section below.

1.3.2.4. Other activities

In addition to fishing and science, other human activities with management and monitoring measures within the SK-B MPA include marine tourism, non-renewable resource extraction activities (e.g., seamount seabed mining outside the MPA) (CHN and DFO 2019), oil spills, marine debris and litter, other discharge, equipment abandonment, equipment installation (DFO 2015a), changes in transient and/or migratory species (e.g., catch changes in Albacore Tuna, *Thunnus alalunga*; Canessa et al. 2003), and last but not least, vessel traffic (including ballast water), which is a component of most other human activities listed. In 1945 commercial tanker traffic started in the vicinity and continued without restriction until the voluntary exclusion zone around SK-B was established in 1985 (Transport Canada 2017). The Enhanced Maritime Situational Awareness Program, launched in 2019, is a partnership between Transport Canada, CHN, and 12 other coastal Indigenous Nations, and is another step towards improved marine safety, environmental monitoring, and protection within the region (Transport Canada 2022).

2. MARINE PROTECTED AREA OBJECTIVES AND BIOLOGICAL ECOSYSTEM COMPONENT GROUPINGS

2.1. CONSERVATION OPERATIONAL OBJECTIVES

The conservation objectives for the SK-B MPA are provided in the management plan (CHN and DFO 2019). There are five goals of the MPA related to the protection and conservation of the ecosystem, management measures, effective monitoring, cooperative management, and public awareness. The ecological operational objectives are encompassed in Goal 1: The unique biodiversity, structural habitat and ecosystem function of the SK-B MPA are protected and conserved (Table 1). There are aspects of the other goals that overlap with the objectives of Goal 1—these are identified and discussed in the research document when applicable (e.g., Operational Objective 3.2.d related to the monitoring of transient populations; see the section below on Monitoring for other conservation objectives relevant to ecological monitoring).

Table 1. The strategic objectives, and corresponding operational objectives, of Goal 1 of the management plan for the SGáan Kínghlas-Bowie Marine Protected Area (SK-B MPA) (CHN and DFO 2019).

Strategic Objectives	Operational Objectives
1.1 Populations of rare, localized, endemic and vulnerable species are protected and conserved.	a. The condition and abundance of cold-water coral and sponges are within a range of the natural state.
	b. The condition and abundance of other invertebrates are within a range of the natural state.
	c. The condition and abundance of fishes (e.g., REBS Rockfish, Bocaccio, Yelloweye Rockfish, Sablefish, Prowfish) are within a range of the natural state.
1.2 Habitats that are essential for life history phase of species with the MPA are protected and conserved.	a. Sensitive benthic habitats are within a range of the natural state.
	b. Pelagic and sea surface conditions are within a range of the natural state.
1.3 Ecosystem food webs are protected and conserved.	a. Ecosystem function and trophic structure are within a range of the natural state.

As pointed out by Thornborough et al. (2016): the refinement of specific, measurable, achievable, realistic, and time-sensitive (SMART) conservation objectives is essential to the development of a monitoring program. By adopting the adaptive management approach (Glossary (Use of Terms) section), the SK-B MPA Management Board may use outcomes of this monitoring framework to develop and implement management actions, including reexamining previous decisions, such as refining the operational objectives. For example, the interpretation of protecting and conserving such that an ecosystem component is "within a range of the natural state" requires thoughtful interpretation with regard to climate change. Herein we defined the term as the following: The natural variation of condition and extent, or range, of an ecosystem component (e.g., a species, ecological process, or environmental quality). In areas where human activity occurs, it implies that no measurable difference exists with or without such activity (DFO and CHN 2019). Therefore, with regard to climate change impacts, it implies that no measurable difference exists with or without the direct or indirect impacts of climate change. Future development of a common lexicon, including a working definition for "natural state", is required. For more information regarding changing ocean conditions and the operational objectives, see the Climate Change Monitoring and the Glossary (Use of Terms) sections.

2.2. GROUPING BIOLOGICAL INDICATOR ECOSYSTEM COMPONENTS

This section focuses on proposed groupings of potential biological indicator ecosystem components that will be monitored in order to evaluate the effectiveness of implementing the operational objectives (CHN and DFO 2019; Table 1). Similar to the challenges with the use and definition of the term "framework", the terms and definitions used to discuss "indicators" differ between regions and practitioners and have changed over time (see the Glossary section). For ease of understanding, the working definitions used herein are summarized below (Box 2).

Box 2. Terminology: Indicator = Ecosystem Component * Metric

An ecological indicator is a specific measurable component of an ecosystem that is used for monitoring, assessing, and understanding ecosystem status, impacts of anthropogenic activities, and effectiveness of management measures in achieving objectives (Thornborough et al. 2016). Therefore, throughout this document we discuss "indicators" in the context of two elements (components): (1) the "ecosystem component" and (2) the "metric." An "ecosystem component" is a fundamental element of the biological, physical or chemical environment that represents an explicit and tangible (i.e., measurable or observable) species, habitat, function, structure or other attributes (CHN and DFO 2019). A "metric" is the type of measurement or observation—it is the quantifiable data that can be either directly measured or calculated from other metrics (derived). Examples of potential ecological indicators relevant to the SK-B MPA operational objectives include:

- *Primnoa pacifica* coral [the biological ecosystem component] abundance [the metric],
- *Sebastes* spp. [the biological ecosystem component] diversity [the derived metric],
- surface water [the environmental ecosystem component] temperature [the metric],
- bottom trawls [the stressor ecosystem component] abundance [the metric].

Our intention of deliberately breaking apart the concept of the indicator, and distinguishing and defining the two elements, is to clarify the terminology in a way as to facilitate easy and intuitive use. As an example scenario, *P. pacifica* coral density may be an indicator of bottom-trawling activity whereas *P. pacifica* coral proportion of live and dead individuals may be an indicator of deoxygenation and climate change. While the ecosystem component is the same (i.e., *P. pacifica* coral), the metric changes the nature of what is indicated. Therefore, by specifying the two elements, an indicator can be directly related to a conservation priority.

In the context of deep-sea ecosystems, where the knowledge base for species identity, distribution, and behaviours is always growing and changing, grouping biological ecosystem components can facilitate moving forward with monitoring and adaptive management. Groupings allow researchers and practitioners to perform monitoring activities without the need to focus on individual species, unless warranted and possible[3]. Species-specific indicators will most likely be resolved during the baseline monitoring phase, based on regional assessments and needs and consideration of broader initiatives (e.g., network monitoring, national indicators, species of conservation concern). For the purpose of the SK-B MPA monitoring framework, species and habitat groups were defined based on phylogeny, morphology (e.g., body size, shape), life history traits, and habitat preferences, and follow the convention described in Gullage et al. (2022) as proposed in Neves et al. (in prep[3]) (Table 2).

The proposed biological ecosystem component groupings listed are not representative of all species and habitats found within the SK-B MPA. Instead, they are a subset of groups relevant to the ecological performance monitoring of Goal 1 in the management plan (described in the above section). The groupings are based on a list of species, community, and habitat SECs originally identified within the SK-B MPA ERAF (O et al. 2015; Thornborough et al. 2016; Rubidge et al. 2018). For example, the proposed groupings of fishes do not include bathyal demersal, bathyal pelagic, and pelagic species, all of which are found within the SK-B MPA. These groups are excluded because they are common throughout the region, transient, and/or inhabit large-scale continuous habitats (i.e., the pelagic waters or the bathyal to abyssal planes). Monitoring these groups is outside the current scope of "populations of rare, localized, endemic and vulnerable species" (Table 1: Strategic Objective 1.1). While not all species found within the SK-B MPA are captured within the proposed biological ecosystem component groupings, a comprehensive list of all species found within the SK-B MPA and other regional seamounts is provided in Du Preez and Norgard 2022 (Table A10).

It is not uncommon for the taxonomic identification of an organism to change owing to a misidentification, new specimen collections, improved identification techniques (e.g., DNA barcoding, high-resolution imagery), new discoveries for science, and/or changes in nomenclature. The species list provided in Du Preez and Norgard 2022 (Table A10) is a good baseline but it will require updating to stay accurate as monitoring and research within the MPA and surrounding regions continues. On that note, there are a couple of taxonomic identification updates required to the ERAF SEC list (Thornborough et al. 2016; Rubidge et al. 2018). Herein we refer to the Squat Lobster species SEC as *Munida quadrispina*—previously referred to as *Cervimunida princeps* and *Munida quadrispina*. Herein we refer to the Sponge habitat SEC as including all sponge species. Previous ERAF work mistakenly referred to all sponges within the MPA as Class Demospongiae (sponge diversity discussed in Ecology section above). Herein we refer to the Gorgonian habitat SEC—previously referred to as Deep Water Alcyonacea and Deep Water Gorgonian Corals. Herein we refer to *Primnoa pacific* SEC species. It was previously hypothesized that the white morphotype found on SK-B Seamount could be a different species, possibly endemic to the area, but DNA barcoding confirmed the different colour morphotypes observed on SK-B are all *P. pacifica* (based on expert taxonomic identification Merlin Best; BOLD DNA 100% COI-5P match for five *Primnoa* spp., including *P. pacifica*; Gartner et al. 2022: Appendix 5). Herein we refer to the REBS Rockfish (*Sebastes aleutianus/melanostichus*) – a species complex (Orr et al. 2008) previously referred to as either only the Rougheye Rockfish or the Blackspotted/Rougheye Rockfish.

The ERAF and identification of SECs directly informed the ecological conservation objectives within Goal 1 (e.g., all five of the fishes listed in Goal 1 are species SEC; Table 1). ERAF SECs can be easily organized into four high-level groupings: cold-water coral and sponges, invertebrates, fishes, and sensitive benthic habitats (SBH) to align with the operational objectives. A summary reference table is provided below, linking operational objectives with biological ecosystem component groupings, example species SEC, record notes, and SEC-stressors (Table 2).

Cold-water corals are classified into seven groups: gorgonians, soft corals, sea pens, black corals, reef-building corals, cup corals, and hydrocorals. These groups are from Neves et al. (in prep[3]), with one difference: we merged "small" and "large" gorgonians (originally eight groups). For the SK-B MPA region, and the purpose of this report, the monitoring information for the two gorgonian groups is the same. Note that reef-building corals are included despite no reef-building coral species having been documented to date within the SK-B MPA. It is possible that this is an artifact of survey effort—occasional surveys within the region, at similar depths to the shallow summit of SK-B Seamount, have documented rare *Lophelia pertusa* bioherms[4] (e.g., Cobb Seamount, Du Preez et al. 2015; central coast of BC). Molecular work has resulted in taxonomic revisions and *L. pertusa* now has the accepted name *Desmophyllum pertusum* (Hoeksema and Cairns 2022). Herein we still refer to *Lophelia* reefs for consistency with Neves et al. (in prep[3]). For details on the coral grouping process, see Neves et al. (in prep[3]).

Sponges are classified into two groups: glass sponge reef species and others (mixed species). Note that reef-building sponges are included despite no sponge reefs having been documented within the SK-B MPA to date. It is possible that this is an artifact of survey effort as the reef-forming species have all been documented on SK-B Seamount (i.e., Cloud Sponge (*Aphrocallistes vastus*), Goblet Sponge (*Heterochone calyx*), Lace Sponge *(Farrea occa[4]*); Du Preez and Norgard 2022: Table A10). These are the regionally relevant groups of the four original groups provided by Neves et al. (in prep[3]).

Benthic invertebrates other than cold-water corals and sponges are classified into three groups: infauna, sessile epifauna, and motile epifauna. These groups are outside the scope of Neves et al. (in prep[3]). The separations are based on habitat: infauna live within the substrate versus epifauna live on the substrate (e.g., Reiss et al. 2010). The epifauna were further separated based on mobility as it will affect the potential tools used to study these animals and their responses to stressors (Rubidge et al. 2018).

Benthic fishes are classified into three groups: benthopelagic fishes, shallow benthic fishes, and deep benthic fishes. These groups are outside the scope of Neves et al. (in prep[3]). The separations are based on mobility and depth, and represent standard groupings used by fisheries management in the region (DFO 2021c). As previously mentioned, for the purpose of this report, non-localized animals are excluded from this section (e.g., bathyaldemersal, bathyalpelagic, and pelagic fishes); however, non-localized species are discussed later under "ecosystem function and trophic structure" (Table 1: Operational Objective 1.3.a).

Sablefish are a non-localized exception to the fish groupings and are listed as an example species within Deep Benthic Fishes (Table 2). Sablefish are a species SEC (Thornborough et al. 2016; Rubidge et al. 2018) and an example fish species in the SK-B management plan conservation goals (Table 1: 1.1) but do not qualify as "localized". They are found deeper than the Deep Benthic Fishes group (>2,000 m depth) and they are highly migratory throughout their life history (DFO 2013a). In addition, the SK-B MPA Sablefish are, at a minimum, part of the population that extends from Vancouver Island to the Bering Sea (DFO 2013a). However,

[4] Du Preez et al. In prep. Discovery of *Lophelia pertusa* in Pacific Canada.

monitoring Sablefish is relevant to the monitoring of ecosystem function and trophic structure of the seamounts (Table 1: 1.3.a) and the monitoring of transient populations (under Operational Objective 3.2.d; CHN and DFO 2018)—especially considering their cultural and ecological importance, and ongoing commercial value (Box 3, Figure 12).

Box 3. Sk̲íl / Sablefish / Black Cod / *Anoplopoma fimbria*

Figure 12. The Haida art of ***Sk̲íl*** */ Sablefish / Black Cod /* Anoplopoma fimbria *was shared by* ***Iljuuwaas*** *Tyson Brown, from the SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area (SK̲-B MPA) management plan (CHN and DFO 2019).*

Sk̲íl / Sablefish / Black Cod / *Anoplopoma fimbria* are a unique and important fish in the context of the SK̲-B MPA. Sablefish undergo diel vertical migrations, consuming benthic and pelagic prey, connecting lower and higher trophic levels, and contribute to overall ecological functioning (Goetz et al. 2017). Documented in the Haida Marine Traditional Knowledge Study, “Black cod fishing is a Haida tradition. Long ago, fishermen made special hooks for black cod,” and “there is some evidence that Haidas travel to SG̲áan K̲ínghlas, or Bowie Seamount to fish” (Haida Marine Traditional Knowledge Study Participants et al. 2011a, 2011b). There were concerns around the commercial Sablefish fishery (1985–2018) regulations due to the non-selective gear that damaged benthic habitats with high bycatch rates. Thus, one of the main goals of the MPA was to protect the sensitive ecosystem from the fishery (CHN and DFO 2019). In 2018, the fishery was closed by direction from the SK̲-B MPA Management Board (CHN 2018), and therefore, it may be expected that the Sablefish population would eventually show signs of a recovery response. However, Sablefish adults are highly migratory, moving from seamounts to all along the coast and back again (DFO 2013a), causing difficulty in monitoring this culturally and ecologically important species. It will be important to keep in mind that, unlike localized species, any detected changes (or lack thereof) for Sablefish will be subject to conditions and stressors beyond the scope of area-based management measures within the SK̲-B MPA and that the population is still fished on the continental slope and shelf and on the seamounts outside the Canadian exclusive economic zone (e.g., Lacko et al. 2021). Spatial management of the Sablefish population requires a Pacific coast-wide approach with inter-governmental considerations (e.g., DFO 2013a). However, when the SK̲-B MPA habitat is healthy and productive, Sablefish could potentially spend more time in the area. Due to their broad range, any ecological metrics could not be attributed to the MPA management measures without robust control data from outside the MPA (for more information see the Sampling design section).

Sensitive Benthic Habitats are classified into four groups: coralline algae habitat, macroalgae habitat, cold-water coral habitat, and sponge habitat. The first two groups are outside the scope of Neves et al. (in prep[3]). These four habitat SECs were identified during the application of the ERAF to the SK̲-B MPA (Thornborough et al. 2016; Rubidge et al. 2018). The algae separations are based on taxonomy and growth forms that represent standard groupings (see Algae section above). The latter two circle back to the cold-water coral and sponge groups mentioned above. For the SK-B MPA region, and the purpose of this report, it is notable that cold-water coral and sponge habitats often spatially overlap, resulting in mixed gardens of both (Du Preez and Norgard 2022). Unlike the previous groupings, SHBs are defined as the physical seabed elements, which includes a combination of biological and environmental components (CHN and DFO 2019). Therefore, in addition to the cold-water coral, sponge, and algae ecosystem component groupings, SHBs should include geological oceanography (e.g., the surficial geology) as environmental ecosystem component groupings as well as stressors such as anthropogenic disturbance to the seafloor (both topics are covered in the Ecological Monitoring Indicator Ecosystem Components and Metrics section).

In total, we propose there are 19 biological indicator ecosystem component grouping: seven cold-water corals, two sponges, three other invertebrates, three fishes, and four SBHs (macroalgae, coralline algae, cold-water corals and sponges). Environmental (geological, biological, physical, and chemical oceanography) and stressor groupings are addressed later in the document.

*Table 2. Biological indicator ecosystem component groupings and examples of species found within the SGáan Kínghlas-Bowie Marine Protected Area (SK-B MPA) listed under their respective Operational Objective (1.1.a to 1.2.a): cold-water coral and sponges, invertebrates, fishes, and sensitive benthic habitats (SBH). Additional information includes record notes and significant ecosystem components (SECs) species, related stressors, current state (i.e., existing SEC-stressor = red; not existing but potential SEC-stressor = green), and expected current trend/responses (recovery post-disturbance = ▲; in decline = ▼; stable state = ▬; undetermined = **?**) (identified within the Ecological Risk Assessment Framework, ERAF; Thornborough et al. 2016; Rubidge et al. 2018; and Du Preez and Norgard 2022).*

	Grouping	Description	Species SECs[1] (bold) and other examples[2]	Record notes	SEC-stressors[3] and others
Cold-water coral and sponges (Operational Objective 1.1.a)	Gorgonian coral	Arborescent or fan-shaped corals in the order Alcyonacea with a proteinaceous and/or calcareous inner axis (skeleton).[4]	**Red Tree Coral (*Primnoa pacifica*), *Isidella tentaculum*, gorgonian habitat** (habitat SEC), Bubblegum Coral (*Paragorgia* spp.), *Parastenella* spp., *Keratoisis* spp., *Swiftia* spp., Bamboo coral (*Isidella* spp.), *Acanthogorgia* sp., *Callogorgia* sp.	Generally found attached to hard substrate. Large gorgonians can attain heights >2 m. Bycatch of the seamount Sablefish fishery[5]. Commonly observed during imagery surveys.[6]	▲ (red) Fishing (substrate disturbance: crushing and re-suspension; removal of biological material; aquatic invasive species), ▬ (green) Oil spill (oil), ▬ (green) Submersible operations and Discharge (aquatic invasive species),[3] ▼ (red) Lost fishing gear (substrate disturbance: crushing and re-suspension) (Du Preez et al. 2020), ▼ (red) Climate change (changes in temperature, oxygen, pH, saturation horizons, food web, species distributions) (Ross et al. 2020)
	Soft coral	Corals in the order Alcyonacea without an inner axis. They have a soft body supported by a hydrostatic skeleton and small $CaCO_3$ structures (i.e., sclerites) embedded in their tissue. This group is mainly represented by the families Nephtheidae and Alcyoniidae (mushroom corals), but includes delicate forms such the stoloniferous (creeping) *Clavularia* spp.[4]	*Gersemia* sp., *Heteropolypus* sp., *Clavularia* spp.	Generally found attached to hard substrate. Infrequently bycatch.[5] Observed during imagery surveys, although most individuals are small and/or encrusting.[6]	
	Sea pens	Corals in the order Pennatulacea. Include both quill pen (e.g., *Pennatula* spp.), and whip-like morphologies (e.g., *Halipteris* spp., *Protoptilum* spp.).[4]	*Umbellula lindahli, Anthoptilum grandiflorum, A.* cf *lithophilum, Halipteris* spp., Orange Sea Pen (*Ptilosarcus gurneyi*)	Mainly found on soft substrate (exception: *A.* cf *lithophilum*). They are permanently partly buried in the sediment (i.e., peduncle). Infrequently bycatch.[5] Observed during imagery surveys.[6]	No species SEC.

	Grouping	Description	Species SECs[1] (bold) and other examples[2]	Record notes	SEC-stressors[3] and others
	Black coral	Corals in the order Antipatharia. They have a wire-like organic skeleton composed of concentric layers of protein and chitin. Colonies range in shape from branching (e.g., *Stauropthes* sp.), to feather-like (e.g., *Bathypathes* sp.) or whip-like (e.g., *Stichopathes* sp.) morphologies. Some species can exceed 1 m in height, but most are < 50 cm.[4]	*Chrysopathes* spp., *Bathypathes patula*, *Stichopathes spiessi*, *Lillipathes wingi*, *Parantipathes* sp.	Mainly found attached to hard substrate. Infrequently bycatch (only *Parantipathes* sp.).[5] Observed during imagery surveys.[6] Some species are abundant (e.g., *Chrysopathes* spp.), while others are less commonly found.	No species SEC [not in SEC summary table]. Not determined to be SEC in 2015 ERAF.
	Reef-building coral	Corals in the order Scleractinia that form true reefs.[4]	*Desmophyllum pertusum* (***Lophelia pertusa***)	No observations within the SK-B MPA to date. Unlikely to be recovered as bycatch (small and brittle). Low occurrence on other North Pacific seamounts and adjacent continental shelf and slope.[6]	No species SEC.
	Cup coral	Solitary corals in the order Scleractinia. They have a $CaCO_3$ skeleton and can be found free-living (unattached) on soft bottoms or attached to hard substrates.[4]	***Desmophyllum dianthus, Balanophyllia elegans,*** Flabellidae	Individuals are small (usually < 5 cm in height), attached to hard substrate, can be rare and/or are found infrequently in aggregations. No bycatch records.[5] Observed during imagery surveys, although difficult to identify to species.[6]	No species SEC.
	Hydrocoral	Corals in the order Anthoathecata (class Hydrozoa). They have $CaCO_3$ skeletons and can have branching or encrusting morphologies, or form lamellate sheets. Colonies are usually branching.[4]	Stylasteridae	Species have a branching morphology, attached to hard substrate, and are <30 cm in height. No bycatch records.[5] Observed during imagery surveys, although difficult to identify to species.[6]	No species SEC.

	Grouping	Description	Species SECs[1] (bold) and other examples[2]	Record notes	SEC-stressors[3] and others
	Reef-building glass sponges	Globally unique. Formed through centuries of growth atop fused silicious sponge spicule framework which baffles sediment, forming large bioherms.[4]	**Sponge habitat** (habitat SEC), Cloud Sponge *(Aphrocallistes vastus),* Goblet Sponge *(Heterochone calyx),* Lace Sponge (*Farrea occa*)	Reefs are formed by three species of sponge, with several other non-reef forming sponges present on and near the reef structures. Rarely bycatch.[5] Commonly observed as part of sponge gardens within the SK-B MPA during imagery surveys.[6]	▲ Fishing (substrate disturbance: crushing and re-suspension; removal of biological material; aquatic invasive species), — Oil spill (oil), — Submersible operations and Discharge (aquatic invasive species).[3] ▼ Lost fishing gear (substrate disturbance: crushing and re-suspension) (Du Preez et al. 2020), —▼ Climate change (changes in temperature, oxygen, pH, saturation horizons, food web, species distributions) (Ross et al. 2020)
	Others: mixed sponges	Includes sponges not included in the previous group.[4]	**Sponge habitat** (habitat SEC), All other Hexactinellida and all other sponges; *Pinulasma* sp., *Chonelasma oreia*, *Farrea* spp., Boot Sponge (*Rhabdocalyptus dawsoni)*, *Auletta* sp., *Asbestopluma* spp., *Mycale* sp., *Penares cortius*	Bycatch[5] and commonly observed during imagery surveys[6] but most sponges are difficult to identify from imagery and identification from at-sea observations are at a low taxonomic resolution level. More sponge grouping will likely be defined in the future.	
Invertebrates (Operational Objective 1.1.b)	Infauna	Animals from diverse phyla that live within the substrate.	**Benthic invertebrate assemblage** (community SEC), nematodes, (some) small crustaceans, polychaetes, bivalves	Indirect evidence of presence (e.g., bioturbation) observed during imagery surveys. Rare high taxonomic records are from scientific samples (e.g., grabs).	No species SEC.
	Sessile and sedentary epifauna	Animals from diverse phyla that live on the substrate and have little to no ability to move around (not corals or sponges; covered above).	**Benthic invertebrate assemblage** (community SEC), hydroids, brachiopods, attached bivalves, stalked crinoids, bryozoans, tunicates	Observed during imagery surveys but many are difficult to resolve from imagery and identification are generally at a low taxonomic resolution level. Rare high taxonomic records are from scientific samples (e.g., grabs).	No species SEC.

	Grouping	Description	Species SECs[1] (bold) and other examples[2]	Record notes	SEC-stressors[3] and others
	Mobile epifauna	Animals from diverse phyla that live on the substrate and have the ability to move around (not fishes, covered below).	**Squat Lobster (*Munida quadrispina*), Benthic invertebrate assemblage** (community SEC), Brittle star mat complex (e.g., *Ophiacantha diplasia*), Sunflower Star (*Pycnopodia helianthoides*), Scarlet King Crab (*Lithodes couesi*), Giant Pacific Octopus (*Enteroctopus dofleini*), Giant California Sea Cucumber (*Apostichopus californicus*), Feather Star (*Florometra serratissima*)	Some species caught by seamount fishery (e.g., large crabs). Observed during imagery surveys.	Not completed for the species SEC.
Fishes (Operational Objective 1.1.c)	Bentho-pelagic fishes[7]	Rockfishes, mostly found in intermediate depths but range from 0-600 meters, adults live near the bottom, more likely to be schooling fish.[7]	**Widow Rockfish (*Sebastes entomelas*), Bocaccio *(Sebastes paucispinis)*, Rockfish assemblage** (community SEC), Greenstriped Rockfish (*Sebastes elongatus),* Harlequin Rockfish (*Sebastes variegatus*)	Caught by seamount fishery and observed during benthic imagery surveys but pelagic video shows much higher abundances off-bottom. Only present on SK-B Seamount (not Hodgkins or Davidson/ Pierce).	▲ Fishing (removal of biological material), ? Movement underway (noise disturbance), — Seismic surveys (seismic testing/air guns), — Oil spill (oil).[3] ▲ Fishing bycatch (removal of biological material) (Du Preez et al. 2020), ▲ Degradation of biogenic habitat (see Large gorgonians and soft corals) (DFO 2019a), ▼ Climate change (changes in oxygen, pH) (Ross et al. 2020)
	Shallow benthic fishes[7]	Rockfishes and others taxa, mostly found in shallow depths but range from 0-600 metres, adults live close to the bottom usually in rocky areas with high relief bottoms, some species like to hide in rocky crevices.[7]	**Prowfish (*Zaprora silenus*)**, **Yelloweye Rockfish (*Sebastes ruberrimus*)**[8], **Rockfish assemblage** (community SEC), China Rockfish (*Sebastes nebulosus*), Tiger Rockfish *(Sebastes nigrocinctus)*, Wolf Eel *(Anarrhichtys ocellatus)*	Caught by seamount fishery and observed during imagery surveys. Only present on SK-B Seamount.	
	Deep benthic fishes[7]	Rockfishes, flatfish and others taxa, mostly found in deeper depths but range from 100-2,000 meters, most species are red in colour, mixture of on-bottom, near-bottom and off-bottom schooling species.[7]	**REBS Rockfish *(S. aleutianus/ Sebastes melanostictusl)*, Pacific Halibut *(Hippoglossus stenolepis)*, Sablefish *(Anoplopoma fimbria)*, Rockfish assemalge** (community SEC), Pacific Ocean Perch *(Sebastes alutus)*, Rosethorn Rockfish *(Sebastes helvomaculatus)*, Shortspine and Longspine Thornyhead (*Sebastolobus alascanus* and *S. altivelis*), Dover Sole (*Microstomus pacificus*)	Caught by seamount fishery and observed during imagery surveys. Only present on SK-B Seamount.	

	Grouping	Description	Species SECs[1] (bold) and other examples[2]	Record notes	SEC-stressors[3] and others
Sensitive benthic habitats (Operational Objective 1.2.a)	Coralline algae habitat	Coralline algae in the family Corallinaceae, found in shallow depths above ~180 metres, mainly encrusting or low-relief morphologies, hard texture (deposits of calcium carbonate)	**Crustose coralline algae** (habitat SEC), unidentified (likely multiple species)	Observed during imagery surveys. Some encrusting patches cover extensive areas of cobble, boulder, and bedrock. Only present on SK-B Seamount.	Oil spill (oil), Submersible operations and Discharge (aquatic invasive species).[3]
	Macroalgae habitat	Brow algae in the class Phaeopyceae, found in shallow depths above ~40 m, structural flexiblity, bladed or filamentous	**Macroalgae** (habitat SEC), Flattened Acid Kelp (*Desmarestia ligulata*), Suction Cup Kelp (*Laminaria yezoensis*)	Observed during imagery surveys (mainly SCUBA). Some encrusting patches cover extensive areas of cobble, boulder, and bedrock. Can grow tens of centimeters high, creating complex biogenic habitats. Only present on the shallowest pinnacles of SK-B Seamount.	
	Cold-water coral habitat	See all coral groupings above.			
	Sponge habitat	See both sponge grouping above.			

[1]Species examples are from the SK-B ERAF SEC list (Thornborough et al. 2016; Rubidge et al. 2018). [2]Species examples are from Du Preez and Norgard 2022: Table A10. [3]Stressors are from Thornborough et al. 2018 (Tables 4.7 and 4.8: current and potential stressors) unless otherwise referenced. [4]Description from the National Monitoring Framework of Coral and Sponges Areas Research Document (Neves et al. in prep). [5]At-sea fishery observer records (e.g., Buchanann et al. 2015; Buchanann et al. 2017; Buchanan et al. 2018). [6]Du Preez and Best 2022. Marine Life of the Northeast Pacific. iNaturalist.[7] Groupings definitions and descriptions are from DFO with the names for two of the three groupings altered to seamount appropriate terms: 'midwater species' = 'benthopelagic species' and 'inshore benthic species' = 'shallow benthic species'. [8]Yelloweye Rockfish are categorized as 'deep benthic' by DFO but are listed here as 'shallow benthic' based on expert consultation (Danna Haggarty, DFO, Nanaimo, BC, pers. comm.).

3. INDIRECT BIODIVERSITY CONSERVATION BENEFITS

The biological indicator ecosystem component groupings described in the previous section focus on direct biodiversity conservation benefits (BCBs) of the SK-B MPA management measures. BCBs can be direct, meaning the species or habitat that are being targeted for protection, or indirect, which are the additional benefits occurring because of the protection measure[3]. Ecosystem functions provided by species are usually considered indirect BCB or "co-benefits" which can occur incidentally as a result of conservation measures implemented in the area[3]. That said, the protection and conservation of the seamount ecosystem function, as well as the trophic structure, of the SK-B MPA are an operational objective (Table 1: 1.3.a). Given the definitions provided by the management plan (DFO and CHN 2019), this operational objective can be interpreted as, "[The physical, chemical, and biological processes or attributes that contribute to the self-maintenance of the [living and non-living environmental components]] and [predation interactions] are within a range of the natural state."

The implication of developing an ecosystem-based operational objective is the need to (i) understand multi-scale dynamic processes and relationships and (ii) monitor an increased range of environmental conditions and ecological components. This would be a challenge in any marine ecosystem, but it is especially so with seamounts—which are located offshore, in the deep sea, and are known for having a large sphere of influence (30 kilometre buffer used to define the boundary of a seamount EBSA; DFO 2019a). In addition, the number of seamount ecosystem processes and attributes increases in number and strength with decreasing summit depth (DFO 2019a; Du Preez and Norgard 2022)—therefore, with its uniquely shallow summit, SK-B has the most of any seamount in the OPB. SK-B, Hodgkins, and Davidson/Pierce seamounts experience increased productivity, export productivity, habitat heterogeneity, refugia potential, and biodiversity (Du Preez and Norgard 2022).

While it is outside the practical limitations of any program to monitor all direct and indirect BCBs (i.e., all ecological components and environmental conditions), understanding interrelationships of prioritized indicators can help monitor ecosystem function and trophic structure and identify knowledge gaps and stressors for adaptive management interventions (e.g., identification of new monitoring indicators and potential pathways to detect change). The interrelationships between biological groupings—inclusive of indirect BCBs—is the topic of the Monitoring Ecosystem Function and Trophic Structure section.

4. ECOLOGICAL MONITORING INDICATOR ECOSYSTEM COMPONENTS AND METRICS

4.1. INTRODUCTION

Following the 2008 designation of the SK-B Seamount area as an *Oceans Act* MPA, DFO Science was asked to recommend scientifically defensible indicators to monitoring the achievement of the MPA. The identification of ecological indicators is one of the most important steps in monitoring planning[3]. However, with only broad conservation objectives and the operational objectives yet to be defined, Davies et al. (2011) recommended a risk-based approach using pathways of effects and ecological risk assessment methods. An ERAF was developed by the Pacific Region (O et al. 2015) to evaluate the single and cumulative threats from multiple anthropogenic activities and their associated stressors to SECs. The ERAF was further developed and improved through the pilot application to the SK-B MPA and Endeavour Hydrothermal Vents MPA (DFO 2015a) (Figure 2A). Utilizing the ERAF process, Thornborough et al. (2016) proceeded with the process of identifying and prioritizing indicators and Rubidge et al. (2018) determined the effects of human activities on SECs in the SK-B MPA. This risk-based assessment for the threats and indicator selection were progressed in the absence of specific conservation objectives. In 2019, the SK-B MPA Management Board released their management plan with clear conservation goals, strategic, and operational objectives (CHN and DFO 2019). This monitoring framework of indicators, protocols, and strategies will incorporate the previous ERAF work.

As previously mentioned, this will be the first monitoring framework for a Pacific MPA, but there are additional jurisdictions within Canada that have tackled the concepts of indicators and monitoring:

- In the Western Arctic Bioregion: (1) the Tarium Niryutait MPA has monitoring indicators (DFO 2010b; Loseto et al. 2010), a monitoring plan (DFO and Fisheries Joint Management Committee [FJMC] 2013), and monitoring protocols and strategies for selected indicators (DFO 2013b), as well as (2) the Anguniaqvia Niqiqyuam AOI has had potential monitoring indicators, protocols and strategies described (Schimnowski et al. 2017). There is also a research document describing the indicators for monitoring coral and sponge megafauna in the Eastern Arctic (Kenchington et al. 2012).
- In the Estuary and the Gulf of St. Lawrence Bioregion: (1) the Banc-des-Américains MPA has a review of indicators and ecological monitoring plans (Faille et al. 2019), (2) the Basin Head MPA had a community aquatic monitoring program from 2002 to 2008 (Thériault and Courtenay 2010), a monitoring plan with indicators and surveys (DFO 2019b), and a review of the plan's effectiveness (Joseph et al. 2021), and (3) there is an ecological monitoring plan for the St. Lawrence Estuary MPA (DFO 2012).
- In the Scotian Shelf Bioregion: (1) the Gully MPA has contaminants monitoring (DFO 2009a), recommendations for monitoring that include indicators, protocols, and strategies (Kenchington 2010), and held a CSAS meeting to review the MPA monitoring in 2021 (documents in prep), (2) the St. Anns Bank MPA had a monitoring framework developed while the area was an AOI (Kenchington 2014), and 3) the Musquash Estuary MPA has a monitoring framework (Cooper et al. 2011), reviewed the baseline for their monitoring indicators (Cooper et al. 2014), and implemented a monitoring plan (Oceans and Coastal Management Division 2015).
- In the Newfoundland-Labrador Shelves Bioregion: (1) Eastport MPA has monitoring indicators, protocols, and strategies to maintain a viable population of American Lobsters (DFO 2014; Lewis et al. 2017), (2) the Gilbert Bay MPA has had monitoring of the genetically distinct population of Northern Cod since 1998 and has since had a monitoring report (Janes et al. 2009), a review (DFO 2010c) and assessment (Morris and Green 2017) of monitoring indicators, protocols, and strategies, as well as an adaptive approach to the monitoring protocols and strategies (Morris and Green 2014; DFO 2017a), (3) the Laurentian Channel MPA had a monitoring framework (Lewis et al. 2016) as well as proposed indicators, protocols, and strategies (DFO 2015b) developed while the area was an AOI.

These monitoring resources developed for MPAs across Canadian jurisdictions were informative resources for the development of the SK-B monitoring framework. Additionally, DFO has provided guidance on the identification of indicators, monitoring protocols, and strategies for bioregional MPA networks (DFO 2013c) and approaches for marine bioregional network monitoring and evaluation (DFO 2020b) that provide relevant information despite SK-B not being part of a planned MPA network. However, a recently developed national monitoring framework for coral and sponge areas[3] provides the foundation for the development of our framework. The coral and sponge monitoring framework provides an effective format for highlighting (1) the ecological monitoring groupings, (2) the informative metrics of these groupings, (3) the tools, strategies, and methodologies to obtain the data on indicators, and (4) the limitations, benefits, and trade-offs of resources to monitor these indicators.

4.2. METHODS

4.2.1. How we Selected Indicator Ecosystem Component Groupings and Metrics

In this framework we identify indicator ecosystem component groupings and metrics appropriate to monitor for each ecological conservation objective of the SK-B MPA. We examined indicator ecosystem components and metrics described in the publications from other jurisdictions listed above, and resourced regional subject matter experts, but primarily align with the format and biological indicator ecosystem component grouping metrics (i.e., indicator states) used by Neves et al. (in prep[3]). That said, three of the operational objectives (Table 1: 1.1.a-c) specifically refer to two metrics with regard to the protection and conservation of populations of cold-water corals and sponges, invertebrates, fishes: abundance and condition.

National guidance for the selection of monitoring ecosystem indicator components and metrics are detailed in an eight step process (DFO 2013c). Similar to Neves et al. (in prep[3]), herein we follow the first four steps of the analysis (subsequent sections of this document). Steps 5–8 should come into play during the development of a monitoring plan.

4.2.1.1. Step 1. Identify conservation objectives

Fortunately, the SK-B MPA conservation goals, strategic objectives, and operational objectives are clearly stated in the management plan (CHN and DFO 2019; provided in Table 1). This is not always the case for MPAs or other effective conservation measures (OECMs) (e.g., Kenchington 2010).

There are six ecological conservation operational objectives within the SK-B MPA management plan related to the seamount populations of cold-water corals and sponges, other invertebrates, and fishes, sensitive benthic habitats, pelagic and sea surface conditions, ecosystem function, and trophic structure (CHN and DFO 2019: Goal 1) (Table 1). These objectives restrict what ecosystem components are relevant for monitoring the effectiveness of the management measures (Step 1 of 4 for indicator ecosystem components and metric selection).

4.2.1.2. Step 2. Identify suitable indicator ecosystem component groupings and metrics

We propose indicator groupings of ecosystem components (biological, environmental, and stressors) to address each operational objective within the ecological conservation goal (Table 1) by following Neves et al. (in prep[3]) for corals and sponges, our own groupings for the remaining biological indicator ecosystem components (see the Grouping Biological Indicator Ecosystem Components section above), and 2) determined groupings for environmental ecosystem components and relevant stressor ecosystem components (paired with metrics) from subject matter experts and other jurisdictions' publications. Within the scope of our biological indicator ecosystem component groupings, we highlight the important SECs determined from the applications of the ERAF to the SK-B MPA (O et al. 2015; Thornborough et al. 2016; Rubidge et al. 2018; Table 2: SECs and SEC-stressors).

With indicator ecosystem component groupings selected, we need to evaluate how we can monitor or measure change withing these groupings for the MPA. Neves et al. (in prep[3]) followed Kenchington et al. (2012) who suggested 12 metrics[5] for the monitoring of corals and sponges in the Eastern Canadian Arctic: abundance, biomass, distribution, diversity indices, size structure, live:dead ratio, percent zoanthid cover, patch area, patch density, patch isolation/proximity, patch connectivity, and patch dispersion. Dunham et al. (2018) also suggest indices specific to glass sponge reefs such as recovery potential, indicator taxa of live reef, and reef structure.

For environmental ecosystem component groupings and metrics we sourced information from monitoring frameworks that incorporated environmental parameters (e.g., Kenchington 2010; Kenchington 2014). We then shared the information with subject matter experts to refine and evaluate the indicators (see Appendix A: Table B1). Monitoring stressor as a first-order objective is outside the scope of Goal 1 (Table 1) and is covered under different goals within the management plan. However, in certain cases, stressors can be the most effective way to indirectly monitor a species, habitat, or condition. Key stressors relevant to the ecological conservation operational objectives are included in this framework (e.g., visual survey data identifying lost fishing gear of the seafloor), but any stressor monitoring could potentially be informative, providing important context for ecological patterns (or indirectly indicating status) (e.g., fisheries reported data on lost fishing gear collected as part of baseline monitoring under Goal 2.1.d—outside the scope of this framework—would be an indirect indicator of an impacted/disturbed seafloor habitat, potentially an SBH).

4.2.1.3. Step 3. Selection criteria for metrics

We use the National Guidance for selection criteria for indicators, inclusive of metrics (DFO 2012). The selection criteria to be considered for each indicator are:

- Theoretical basis – concepts are consistent with established theory;
- Measurement – data used to estimate indicators should be easily and accurately measured;
- Historical data – data from earlier time periods should be available, ideally with a time series of at least 10–20 years;
- Sensitivity – the amount of change in indicator value corresponds to a change in the pressure (e.g., fishing, pollution);
- Responsiveness – this includes the type of response (linear, non-linear, random) of the indicators to the pressure, the timeliness of the response and the signal to noise ratio, i.e., the data used to estimate the indicators should be measurable accurately enough that any change or trend in the indicator is greater than the variance in its measurement;
- Specificity – indicators may be influenced by more than one pressure (e.g., fishing and temperature). How specific is the indicator to the pressure of concern? Can it be disentangled from other pressure (i.e., it is critical to know why an indicator is changing)?
- Public awareness – should be easily understandable by non-scientists and clear to communicate; and,
- Cost-effectiveness – sampling, measuring, processing, analysing indicator data, and reporting assessment outcomes, should be feasible and within existing financial resources.

[5] Within this document we use the term ‘metrics’ to discuss the type of measurable component for monitoring indicators. Other terms previously used include ‘state indicators’[3] or ‘indicators’ (Thornborough et al. 2016).

4.2.1.4. Step 4. Evaluate metrics for ecosystem component groupings

Thornborough et al. (2016) applied the above selection criteria process to the SEC indicators for the SK-B MPA (e.g., see their Appendix D). Please note, Thornborough et al. (2016) provided context about excluding public awareness and cost-effectiveness from their analysis. Neves et al. (in prep[3]) also went through this selection criteria process (see their Table 4) and highlighted that the assessment is not a straightforward task, and in many cases, that are exceptions that make this evaluation difficult. However, they scored all 12 metrics from Kenchington et al. (2012) reasonably well to include them as indicators and added *Lophelia* reef extent, indicator taxa of live sponge reef, reef structure, recovery potential (from Dunham et al. 2018), and indirect BCBs to their metrics. We will build on the efforts of these two publications by utilizing their evaluated metrics for cold-water corals and sponge groupings, made reasonable deletions for other biological indicator ecosystem component groupings (e.g. removed reef context for fishes) and resourced subject matter experts for final lists of environmental metrics (e.g., physical oceanography).

4.3. RESULTS

4.3.1. Indicator Ecosystem Component Groupings and Metrics

For information on metrics for cold-water corals and sponges, we defer to Neves et al. (in prep[3]), which comprehensively describes metrics in terms of what each measures, how it *could be* and *is* measured, sampling design considerations, anticipated changes and cost-benefits. It is outside the practical limitations of this research document to replicate that level of detail for all biological and environmental ecosystem component groupings relevant to the SK-B MPA operational objectives and its indirect BCBs. Fortunately, Thornborough et al. (2016) provides similar information for SECs specific to the SK-B MPA (their Appendix C and D). As not to duplicate effort, we provide summary information for each metric and its suitability for each ecosystem component grouping. See below text for metric descriptions and tables for summaries of suitable metrics (Table 3: cold-water corals and sponges; Table 4: invertebrates; Table 5: fishes; Table 6: sensitive benthic habitats; Table 7: pelagic and sea surface habitats). Tables follow the Neves et al. (in prep[3]) format with a few notable differences: indirect BCBs are not included (covered in the Monitoring trophic structure section below), and environmental metrics are covered in the latter two tables.

We identify, describe, and examine the suitability of 15 biological metrics (components discussed in detail in previous section), 16 environmental components and metrics, and 5 stressor components and metrics. For biological metrics this included two priority metrics explicitly mentioned in the management plan: condition and abundance (CHN and DFO 2019: operational objectives 1.1.a–c).

4.3.1.1. Biological metrics

We've indicated whether the metrics are directly measured (measured) or created based on other metrics (e.g. derived).

Abundance – measured or derived

Abundance is specifically mentioned in the management plan as a metric for operational objectives addressing the protection and conservation of populations within specific assembles (i.e., cold-water corals and sponges, invertebrates, fishes; listed in Table 1) and should be considered a priority metric for monitoring related ecosystem component groupings. In its simplest form, abundance is the measure of the number of individuals/colonies (also relative abundance or density, coverage, and frequency) (Thornborough et al. 2016). Abundance can provide information on biodiversity, reproductive success, population size and structure. Direct abundance measurements can be non-extractive (e.g., imagery and acoustics) or extractive (e.g., fishery surveys). Derived data (indirect calculations) can be non-extractive (e.g., species distribution models) but require some direct measurements (ground-truthing). Limitations may be that abundance metrics can overlook or underestimate small and/or rare species (e.g., canopy cover of large organisms in imagery may obscure smaller organisms). Abundance estimates by imagery for mobile invertebrates and fishes may be underestimated due to avoidance and/or migration behaviours. Abundance estimates by fisheries and/or baited camera for fishes relative abundance is more representative of a catch per unit effort or maximum abundance for the area. A shift outside the natural state in abundance may result from a direct disturbance (e.g., fisheries), recovery post-disturbance (e.g., after the 2018 fisheries closure), abiotic conditions (e.g., climate change deoxygenation), or as part of a chain reaction (e.g., trophic cascades: prey items decrease as predators increase; for details, see the Monitoring Ecosystem Function and Trophic Structure section). Biological ecosystem component grouping-specific information is in Tables 3 to 6.

Biomass – measured or derived

Biomass is the measure of weight of organisms for a unit of area/volume (Thornborough et al. 2016). Biomass can provide information on productivity, reproductive success, population and trophic structure, metabolism and associated traits, and identification of biological hotspots. Direct biomass measurements require the removal of biological material from the ecosystem (i.e., destructive by nature; common metric used in fisheries and fish surveys). Derived data can be non-extractive (e.g., imagery or acoustics) but require reliable size-to-weight ratios. Interpretations of changes are similar to those mentioned above for ‘Abundance.’ Biological ecosystem component grouping-specific information is in Tables 3 to 6.

Distribution – derived

Distribution is the measure of where organisms are located (spatial range or extent, presence-absence, invasion or extirpation) (Thornborough et al. 2016; Neves et al. in prep[3]). Distribution can provide information on ecosystem resilience and genetic diversity. Distribution data requires the collection of high-resolution taxonomic and abundance data with spatial information. Robust baseline data are required to detect a shift in distribution (e.g., sufficient coverage of high-resolution spatial and taxonomic data to confidently detect latitudinal or depth-distribution shifts in response to climate change). Interpretations of changes are similar to those mentioned above for ‘Abundance.’ Biological grouping-specific information is in Tables 3 to 6.

Diversity indices – derived

Diversity indices measure how many different types there are in a set—and may consider proportions (i.e., richness, evenness, and diversity at scales ranging from genetic- to community-level). Diversity can provide information on community structure, ecosystem resilience, and genetic diversity. The calculation of diversity indices will follow the collection of abundance data for an assemblage and are dependent on the quality of abundance data and taxonomic resolution. Fishery surveys have limited contributions to diversity surveys as they are usually targeted fisheries (exception in bottom trawl, which is not advocated for use within the SK-B MPA). All physical samples collected should include tissue sampling to assess genetic diversity. An understanding of the assemblage composition, individual responses, and cascading effects is required to interpret changes in diversity. Biological grouping-specific information is in Table 3 to 6.

Size structure – measured

Size structure is the measure of the size-frequency of individuals/colonies in an assemblage (Thornborough et al. 2016). Size structure can provide information on population (e.g., age – life history stages and/or actual age for established size:age ratios) and trophic structure, reproductive stage and success. Direct size measurements can be non-extractive (e.g., imagery and acoustics, but not straightforward given the orientation of the sensor and organism) or extractive (e.g., fishery surveys with precise measurements ex situ). A shift outside the natural state in size structure may result from a size-related disturbance (e.g., gear bias for larger fishes), recovery post-disturbance (e.g., sizeable juvenile cohort following 2018 fisheries closure), or as part of a chain reaction (e.g., size-selective trophic cascades; for more details, see the Monitoring Ecosystem Function and Trophic Structure section). Biological grouping-specific information is in Tables 3 to 6.

Proportion of live and dead individuals – measured

The proportion of live and dead individuals is the measure of just that[3]. It can provide information on mortality rate, stressors, and—to an extent—historical abundance and distribution data, but it is limited to species that “leave a trace” fixed on the seafloor at a scale detectable by monitoring—such as cold-water corals and sponges that leave long-lasting intact skeletal structures (this metric was removed from subsequent biology tables). Direct measurements can be non-extractive (e.g., imagery) or extractive (e.g., fishery surveys). Given the long generation time of these taxonomic groups, the responsiveness of the ratio would depend on the direction of the shift (i.e., a die-off event could occur faster than a recovery event) and knowledge of the degradation rates. It is notable that some coral and sponge species have a naturally high dead-to-live ratio (e.g., reef-forming species and species with slow skeletal dissolution rates). Biological grouping-specific information is in Table 3.

Condition – measured or derived

Condition is specifically mentioned in the management plan as a metric for operational objectives addressing the protection and conservation of populations within specific assemblages (i.e., cold-water corals and sponges, invertebrates, fishes) and should be considered a priority metric for monitoring related ecosystem component groupings. Condition is the measure of the health of individuals/colonies and may relate to parasitic load (e.g., percent of corals with zoanthids), marine diseases (e.g., the sea star wasting disease), injury/damage, and behaviour (Thornborough et al. 2016). Condition provides information on physiological stress and resistance. Direct condition measurements can be non-extractive (e.g., high-resolution imagery of individuals) or extractive (e.g., fishery surveys or collections). Condition assessment from imagery may be opportunistic and limited by factors such as camera angle. In fisheries biology, there are established morphometric (e.g., weight/L^3), bioenergetic, and biochemical indices calculated that assess the ‘condition factor’ of a fish (e.g., Brosset et al. 2015; Getso et al. 2017). Although the lag time may be long (years to decades), the responsiveness of condition to environmental changes is likely to be faster than measurements to detect death. Biological grouping-specific information is in Tables 3 to 6.

Patch dynamics – derived

Ecological interactions of populations occur in environments that are spatially and temporally heterogeneous across a wide range of scales resulting in ‘patchy’ distributions of populations (Grünbaum 2012). Studying patch dynamics in large spatial scales, such as MPAs, provides more accurate context than in considering populations existing in a single point of space or time (e.g., Goode et al. 2021). Direct patch dynamic measurements can be non-extractive (e.g., high-resolution imagery of individuals) or extractive (e.g., plankton net hauls). Patchiness is to be considered over large spatial scales and direct measurements are generally used to inform theory and models. In fishery biology/ecology, they often use ‘patchiness’ in the context of habitat, prey, and/or larvae and then use the term (local) population to describe the resulting influence for the fauna (e.g., Jacobus and Webb 2005; Knutsen et al. 2021; Dupont et al. 2022). As we have defined how we are describing the patch concept (opening sentence of paragraph) we will apply the term across all fauna. A shift outside the natural state for patch dynamics may result from a direct disturbance (e.g., fisheries), recovery post-disturbance (e.g., after the 2018 fisheries closure), as response to abiotic conditions (e.g., oxygen) or as part of a chain reaction (e.g., trophic cascades: increased predation), with the responsiveness of the population corresponding to their mobility (e.g., mobile crab patches may change quickly versus sessile coral patches) and their generation time (e.g., short-lived plankton versus long-lived sponges).

Patch dynamics metrics:

- Patch area and density – measures the area of each patch and the density of the individuals within that given area. We would want to measure the changes in these metrics over time to provide information on the status of a population[3] so it is important to establish baseline data.
- Patch isolation/proximity – measures the distance from one patch to its nearest neighbour patch. Kenchington et al. (2012) suggests a calculation where this distance is considered in context of the mean nearest-neighbour distance over all patches for measure of relative isolation.
- Patch connectivity – measures the connectivity of the patches by gamete or larval dispersal range (Kenchington et al. 2012). This will be determined by the reproductive strategy of the population being studied (e.g., short and long lived planktonic phase), local oceanographic conditions (i.e., currents), and the distance between patches.
- Patch contagion index – measure the tendency for patches to be regularly or contagiously (i.e., clusters) distributed with respect to one another (Kenchington et al. 2012). High contagion results from areas with a few large, contiguous patches, while lower values generally characterize areas with many small patches. There are available formulas to calculate contagion index (Riitters et al. 1996).

Patch dynamic metrics need to be well defined relative to the populations being studied and should be informed by baseline studies within the SK-B MPA. Biological grouping-specific information for the four patch dynamic metrics are in Tables 3 to 6.

Reef dynamics – derived

The reef dynamics section in Neves et al. (in prep[3]) is based off the work of Dunham et al. (2018) for assessing and monitoring glass sponge reefs. However, for reef extent Neves et al. (in prep[3]) described reef extent only for Lophelia (coral reefs) while Dunham et al. (2018) focused solely on glass sponge reef. We diverge from both authors in that we attempt to consider reef dynamics for both reef-forming corals and sponges. These reef metrics were removed from subsequent biology tables as they do not contain reef-forming species.

Reefs are structured biogenic habitat that are formed by both the living and dead components of reef forming species. These dynamic structures provide habitat for other species and due to the insufficient understanding of glass reef ecology it can be difficult to quantify the ‘health’ of a reef (Dunham et al. 2018). Dunham et al. (2018) suggest several metrics to monitor and include a decision tree for how to adjust monitoring and management if changes are detected (Dunham et al. 2018: Figure 23). Many of the metrics are already covered (abundance, condition) but Neves et al. (in prep[3]) added a few of the categories not already covered (see reef dynamic metrics below). The following suggested reef dynamic metrics should be made with non-extractive tools (e.g., imagery and acoustic sensors). Changes in these metrics would indicate a response to biotic (e.g., predation – unlikely to create significant change), abiotic (e.g. sedimentation), or anthropogenic (e.g. bottom contact fishing) conditions. Given the long generation time of these taxonomic groups, the responsiveness may include some lag time but the Dunham et al. (2018) decision tree incorporates monitoring and management measures that may indicate the potential stressor (e.g., destruction from contact) and appropriate adaptive management.

Reef dynamic metrics:

- Reef extent – measures the area covered by the reef-forming species.
- Reef structure – measures the percentage of various reef structure habitat categories (no visible reef, dead reef, mixed reef, live reef).
- Indicator taxa – measures the presence and abundance of certain indicator taxa of live reef structures. For glass sponge reefs in the Salish Sea in the Northeast Pacific this includes *Chorilia longipes,* Sebastidae, *Rhabdocalyptus dawsoni, Pandalus platyceros,* and *Munida quadripina* (Dunham et al. 2018). However, these associations may vary locally and future studies should update and reconsider this list in the context of seamounts within the SK-B MPA. Additionally, *Lophelia pertusa* reefs are a new discovery to the Pacific coast[4] and at this time no indicator taxa exists and should be considered a component of future study.
- Recovery Potential – measures the percent of the reef structure that is dead or examines the visible reef structure habitat categories combined. This metric should be considered as a change over time highlighting the necessity of baseline data.

Biological grouping-specific information for the four reef dynamic metrics are in Table 3.

4.3.1.2. Environmental components and metrics

Whereas Neves et al. (in prep[3]) does not itemize proposed environmental indicators (i.e., components or metrics), the SK-B MPA management plan calls for a monitoring framework that considers the physical seafloor (related to SHBs), the pelagic and sea surface conditions (oceanographic quality such as biological, physical, and chemical characteristics) in addition to the state of benthic species of interest (DFO and CHN 2019). The below section describes metrics used to monitor geological, biological, physical, and chemical oceanographic conditions. These three environmental ecosystem component groupings are used for convenience and comprehension, but the groups are not intended to have any greater significance (similar to Kenchington et al. 2012).

Geological oceanography ecosystem components

Geological oceanography refers to the characteristics of planet Earth that are beneath the ocean—of particular interest to this work is the surficial geologic materials at the water-seafloor interface (i.e., benthic habitat). Metrics of surficial geology are directly applicable for monitoring SBH but are also indirectly informative for monitoring all benthic associated species (if used as an ecological proxy, lag time must be well understood through baseline monitoring). Metrics of surficial geology include substrate/grain size, sedimentation rate, and natural physical disturbance regime—which can provide information on species distributions and life history, fitness, and mortality. Direct surficial geology measurements can be non-extractive (e.g., imagery and acoustics) or extractive (e.g., grabs and dredges). Indirect calculations are non-extractive (e.g., distribution models) but require some direct measurements (ground-truthing). A shift outside the natural state in surficial geology may indicate a large-scale catastrophic event (e.g., earthquakes), changes in hydrology, and anthropogenic impacts (e.g., fishing gear drag marks). Environmental grouping-specific information is in Table 6.

Biological oceanography ecosystem components

Biological oceanography refers to the characteristics of the primary and secondary producers in the water column (mainly phytoplankton and zooplankton). Metrics of biological oceanography are directly applicable for monitoring the pelagic and sea surface conditions but are also indirectly informative for monitoring all benthic associated species and SBH (if used as an ecological proxy, lag time must be well understood through baseline monitoring). Metrics of biological oceanography include primary productivity (i.e., chlorophyll A, algae, seaweed, chemosynthetic bacteria, harmful algal blooms or HABs, fluorescence), secondary productivity (i.e., zooplankton), and particulate organic carbon (POC) flux (export)—which can provide information on energy and nutrients created within or entering an ecosystem, carbon sequestration, and species distributions. Direct biological oceanography measurements can be non-extractive (e.g., satellite imagery) but require some direct sampling (e.g., mid-water trawls). A shift outside the natural state in biological oceanography may indicate a large-scale catastrophic event (e.g., changes in trophic structure), changes in hydrology, change in source populations (e.g., Haida Gwaii), and anthropogenic impacts (e.g., climate change; for more details, see the Climate Change Monitoring section below). Environmental grouping-specific information is in Table 7.

Physical oceanography ecosystem components

Physical oceanography refers to the physical water conditions and processes. Metrics of physical oceanography are directly applicable for monitoring the pelagic and sea surface conditions but are also indirectly informative for monitoring all benthic associated species and SBH (if used as an ecological proxy, lag time must be well understood through baseline monitoring). Metrics of physical oceanography include temperature, current (speed and direction; e.g., major ocean currents, internal waves, surface waves, eddies, Taylor cones/columns), weather (e.g., wind, fetch, swell, sea state, light levels), turbidity (or sediment load), and marine noise (anthropogenic and natural)—which can provide information on productivity, light levels, sediment load, transport (of nutrients, productivity, larvae, and water masses), biological processes, and many other correlated factors. Direct physical oceanography measurements are non-extractive in general (e.g., sensors, water samples, satellite imagery). Often localized measurements are utilized to inform modelling of larger spatial scales. A shift outside the natural state in physical oceanography may indicate a large-scale natural (e.g., beyond the scope of our baseline data) or anthropogenic event (e.g., climate change). For example, a shift in water properties within the SK-B MPA influenced by a large-scale shift in dominant water mass source (i.e., North Pacific influences, subtropical influences, California Undercurrent, Haida Eddies, or other shelf and upper slope waters contribute in a meaningful way). Environmental grouping-specific information is in Table 7.

Chemical Oceanography ecosystem components

Chemical oceanography refers to the water chemistry of the ocean. Metrics of chemical oceanography are directly applicable for monitoring the pelagic and sea surface conditions but are also indirectly informative for monitoring all benthic associated species and SBH (if used as an ecological proxy, lag time must be well understood through baseline monitoring). Metrics of chemical oceanography include carbon saturation (or pH), dissolved inorganic carbon or total alkalinity (or DIC and TA; related to pH, calcite and aragonite saturation), partial pressure of carbon dioxide (pCO_2; related to pH and DIC), salinity, oxygen, and nutrients (e.g., silicate, silica, nitrate, nitrogen, phosphate, iron, calcium, carbon)—which can provide information on productivity, biological processes (e.g., range and physiological limits), and many other correlated factors. Direct chemical oceanography measurements are non-extractive in general (e.g., sensors, water samples, satellite imagery). Often localized measurements are utilized to inform modelling of larger spatial scales. Some chemical metrics have numerous ways they can be attained (e.g., sensor vs chemical analysis of water samples) and need considerations of standardization before comparing across time and spatial scales. A shift outside the natural state in chemical oceanography may indicate a large-scale natural event (e.g., beyond the scope of our baseline data) or anthropogenic event (e.g., climate change and eutrophication). For example, the shoaling of the calcite saturation horizon and deepening of the bottom boundary of the OMZ as described by Ross et al. (2020). Environmental grouping-specific information is in Table 7.

4.3.1.3. Stressor components and metrics

Anthropogenic disturbances refer to the interruption in ecological areas due to human-induced activities—which occur everywhere in the marine environment. Existing and anticipated stressors for OPB and SK-B MPA seamounts have been comprehensively assessed and/or reviewed (e.g., Thornborough et al. 2016; Rubidge et al. 2018; Du Preez and Norgard 2022). Metrics of anthropogenic disturbances herein are directly applicable for monitoring SBH and the pelagic and sea surface conditions but are also indirectly informative for monitoring all marine species (if used as an ecological proxy, lag time must be well understood through baseline monitoring) (e.g., Table 2: SEC-stressors). Metrics of anthropogenic disturbance stressors include measures of contaminants (e.g., oil spills, dispersant, toxins), microplastics, other anthropogenic debris, anthropogenic physical disturbances—which can provide information on species distributions and life history, fitness, and mortality. Direct measurements can be non-extractive (e.g., water samples, imagery, acoustics) or extractive (e.g., trawls and dredges). Indirect calculations can come from monitoring human activities (e.g., compliance; monitoring covered in Goal 2 of the management plan) but require some direct measurements to confirm (ground-truthing). The timing of an anthropogenic disturbance can be challenging to resolve as many disturbances are extremely long-lasting (e.g., drag marks) or essentially permanent (e.g., ghost fishing gear). Stressor grouping-specific information is in Tables 6 to 7.

Human-induced climate change has the potential to affect all facets of the seamount ecosystem (e.g., temperature, oxygen, species distribution, productivity) and should be a primary consideration in all aspects of the future monitoring plan, especially in interpreting the results of ecological monitoring (see the Human Activity Monitoring section below).

4.3.2. Summary Tables of Suitable Indicator Metrics

4.3.2.1. Cold-water corals and sponges

Table 3. Summary of suitable metrics to consider for indicator ecosystem component groups selected for monitoring the condition and abundance of cold-water corals and sponges within a range of the natural state (operational objective 1.1 a). Cold-water corals and sponges listed by indicator group. X = suitable. A dash = unsuitable. ? = unknown.

Metric (measured or derived)	Gorgonian corals	Soft corals	Sea pens	Black corals	Reef-building corals	Cup corals	Hydrocorals	Reef-building Glass sponges	Mixed sponges	Purpose/Strength	Limitations	Preferred tools
Abundance (measured)	X	X	X	X	X	X	X	X	X	- Biodiversity - Reproductive success - Population size and structure - Easy to measure (many options, e.g., count, % cover)	- Small and/or rare specimens might be overlooked or underestimated	- Submersible imagery surveys (with associated sampling where appropriate)
Biomass (measured or derived)	X	X	X	X	-	X	X	-	X	- Productivity - Reproductive success - Population structure - Predictor of metabolism and related traits - Identification of hotspots for diversity - Direct weight from physical samples	- Need calibration of size-weight relationships if using imagery - Biomass for glass sponges can be misleading, as they are very light	- Submersible imagery surveys (with associated sampling where appropriate)
Distribution (measured or derived)	X	X	X	X	X	X	X	X	X	- Ecosystem resilience - Genetic diversity - Can use historic bottom contact fishery bycatch data (presence only)	- Depends on good taxonomic resolution - Need large spatial sampling coverage (including depth) that can inform modelling	- Submersible imagery surveys (with associated sampling where appropriate)

Metric (measured or derived)	**Gorgonian corals**	**Soft corals**	**Sea pens**	**Black corals**	**Reef-building corals**	**Cup corals**	**Hydrocorals**	**Reef-building Glass sponges**	**Mixed sponges**	**Purpose/Strength**	**Limitations**	**Preferred tools**
Diversity indices (derived)	X	X	X	X	X	X	X	X	X	- Biodiversity - Community structure - Ecosystem resilience - Genetic diversity	- Depends on quality of abundance and richness data	- Submersible imagery surveys (with associated sampling where appropriate and genetic sampling)
Size structure (derived)	X	X	X	X	-	X	X	-	X	- Population structure - Reproductive success	- Best suited for organisms with linear growth - Difficult to measure from imagery - Small organisms might be missed in imagery data	- Submersible imagery surveys (with associated sampling where appropriate)
Live:dead ratio (measured)	X	-	-	X	X	X	-	X	-	- Mortality rate - Physiological stress	- Dependent on degradation rates (which are taxa specific and/or unknown for many species)	- Submersible imagery surveys (with associated sampling where appropriate)
Condition (measured or derived)	X	X	X	X	X	X	X	X	X	- Physiological stress	- Difficult to measure - Need target imagery	- Submersible imagery surveys (with associated sampling where appropriate)
Patch dynamics: area and density (derived)	X	X	X	X	X	X	X	X	X	- Biodiversity - Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys

Metric (measured or derived)	Gorgonian corals	Soft corals	Sea pens	Black corals	Reef-building corals	Cup corals	Hydrocorals	Reef-building Glass sponges	Mixed sponges	Purpose/Strength	Limitations	Preferred tools
Patch dynamics: isolation/proximity (derived)	X	X	X	X	X	X	X	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys
Patch dynamics: connectivity (derived)	X	X	X	X	X	X	X	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys (with associated sampling where appropriate and genetic sampling)
Patch dynamics: contagion index (derived)	X	X	X	X	X	X	X	X	X	- Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys (with associated sampling where appropriate and genetic sampling)
Reef dynamics: reef extent (measured or derived)	-	-	-	-	X	-	-	X	-	- Biodiversity - Reproductive success	- May need large spatial sampling for context of extent	- Submersible imagery surveys -Benthic acoustic surveys
Reef dynamics: reef structure categories (no visible reef, dead reef, mixed reef, live reef) (measured or derived)	-	-	-	-	X	-	-	X	-	- Relative proportions of these four habitat categories - Physiological stress	-	- Submersible imagery surveys

Metric (measured or derived)	Gorgonian corals	Soft corals	Sea pens	Black corals	Reef-building corals	Cup corals	Hydrocorals	Reef-building Glass sponges	Mixed sponges	Purpose/Strength	Limitations	Preferred tools
Indicator taxa of live sponge reef (measured)	-	-	-	-	?	-	-	X	-	- Certain taxa have significant associations with specific habitat types and their presence can indicate reef status	- Known associations may be region dependent	- Submersible imagery surveys (with associated sampling where appropriate and genetic sampling)
Reef indicators: Recovery potential (measured or derived)	-	-	-	-	X	-	-	X	-	- Recolonization and regrowth - Dead % cover - % visible habitat categories combined - Reef resilience	- Recruits can be difficult to visualize	- Submersible imagery surveys

4.3.2.2. Invertebrates

Table 4. Summary of suitable metrics to consider for indicator ecosystem component groups selected for monitoring the condition and abundance of other invertebrates are within a range of the natural state (operational objective 1.1 b). X = suitable. A dash = unsuitable. ? = unknown.

Metric (measured or derived)	Infauna	Sessile/Sedentary Epifauna	Mobile Epifauna	Purpose/Strength	Limitations	Preferred Tools
Abundance (measured)	X	X	X	- Biodiversity - Reproductive success - Population size and structure - Easy to measure (many options, e.g., count, % cover)	- Small and/or rare specimens might be overlooked or underestimated	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (mobile epifauna)
Biomass (measured or derived)	X	X	X	- Productivity - Reproductive success - Population structure - Predictor of metabolism and related traits - Identification of hotspots for diversity - Direct weight from physical samples	- Need calibration of size-weight relationships if using imagery (not possible for infauna)	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (mobile)
Distribution (measured or derived)	X	X	X	- Ecosystem resilience - Genetic diversity - Can use historic bottom contact fishery bycatch data (presence only)	- Depends on good taxonomic resolution - Need large spatial sampling coverage (including depth) that can inform modelling	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (mobile)
Diversity indices (derived)	X	X	X	- Biodiversity - Community structure - Ecosystem resilience - Genetic diversity	- Depends on quality of abundance and richness data	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (mobile)
Size structure (derived)	X	X	X	- Population structure - Reproductive success	- Best suited for organisms with linear growth - Difficult to measure from imagery - Small organisms might be missed in imagery data	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (motile)

Metric (measured or derived)	Infauna	Sessile/Sedentary Epifauna	Mobile Epifauna	Purpose/Strength	Limitations	Preferred Tools
Condition (measured or derived)	X	X	X	- Physiological stress	- Difficult to measure - Need target imagery	- Submersible imagery surveys (with associated sampling where appropriate) - Cores (infauna) - Traps (motile)
Patch dynamics: area and density (derived)	-	X	X	- Biodiversity - Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth) - Limited to mobile species without avoidance behaviours	- Submersible imagery surveys
Patch isolation/proximity (derived)	-	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches - Limited to mobile species without avoidance behaviours	- Submersible imagery surveys
Patch dynamics: connectivity (derived)	-	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches	- Submersible imagery surveys (with associated sampling where appropriate) - Settlement plates (sessile fauna)
Patch dynamics: contagion index (derived)	-	X	X	- Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches	- Submersible imagery surveys (with associated sampling where appropriate)

4.3.2.3. Fishes

Table 5. Summary of suitable metrics to consider for indicator ecosystem component groups selected for the monitoring the condition and abundance of fishes are within a range of the natural state (operational objective 1.1 c). X = suitable. A dash = unsuitable. ? = unknown.

Metric (measured or derived)	Shallow Benthic	Bentho-pelagic	Deep Benthic	Purpose/Strength	Limitations	Preferred Tools
Abundance (measured)	X	X	X	- Biodiversity - Reproductive success - Population size and structure	- Difficult to determine (underestimated) if biogenic or rocky obstructions (e.g., shallow benthic species hide in crevices) - Small and/or rare species may be overlooked - Avoidance and attraction behaviors in response to survey - Migrations (e.g., daily, seasonal)	- Submersible imagery surveys (including baited camera) - Fishing survey (e.g., hook and line)
Biomass (measured or derived)	X	X	X	- Productivity - Reproductive success - Population structure - Predictor of metabolism and related traits - Identification of hotspots for diversity - Direct weight from physical samples	- Need calibration of size-weight relationships if using imagery - Difficult to measure from imagery	- Pelagic acoustic survey - Fishing survey (e.g., hook and line) - Imagery surveys (including baited camera)
Distribution (measured or derived)	X	X	X	- Ecosystem resilience - Genetic diversity - Can use historic bottom contact fishery data (targeted and bycatch; presence only)	- Depends on good taxonomic resolution - Need large spatial sampling coverage (including depth) that can inform modelling	- Pelagic acoustic survey - Submersible imagery surveys (including baited camera) - Fishing survey (e.g., hook and line)
Diversity indices (derived)	X	X	X	- Biodiversity - Genetic diversity - Community structure - Ecosystem function - Ecosystem resilience	- Depends on quality of abundance and richness data	- Submersible imagery surveys (including baited camera) - Fishing survey (e.g., hook and line)

Metric (measured or derived)	Shallow Benthic	Bentho-pelagic	Deep Benthic	Purpose/Strength	Limitations	Preferred Tools
Size structure (derived)	X	X	X	- Population structure - Reproductive success - Recovery from fisheries	- Difficult to measure from imagery - Small organisms might be missed in imagery data - Trawl/net/hook size may be size-biased	- Submersible imagery surveys (including baited camera) - Fishing survey (e.g., hook and line)
Condition (measured or derived)	X	X	X	- Physiological stress	- Difficult to measure - Need extractive survey for fishes - Need targeted imagery	- Fishing survey (e.g., Fulton's K comparing lengths and weights) - Imagery surveys
Patch dynamics: area and density (derived)	X	X	X	- Biodiversity - Reproductive success	- Need clear definitions of patches/populations formed by each group - Need large spatial sampling coverage (including depth) - Challenged by mobility (Migrations, avoidance behaviours, etc.)	- Submersible imagery surveys (not baited) - Pelagic acoustic survey
Patch dynamics: isolation/ Proximity (derived)	X	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches/populations formed by each group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys (not baited) - Pelagic acoustic survey
Patch dynamics: connectivity (derived)	X	X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches/populations formed by each group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys (not baited) - Pelagic acoustic survey
Patch dynamics: contagion index (derived)	X	X	X	- Reproductive success	- Need clear definitions of patches/populations formed by each group - Need large spatial sampling coverage (including depth)	- Submersible imagery surveys (not baited) - Pelagic acoustic survey

4.3.2.4. Sensitive benthic habitats (SBHs)

Table 6. Summary of suitable metrics to consider for indicator ecosystem component groups selected for the monitoring that sensitive benthic habitats are within a range of the natural state (operational objective 1.2 a). X = suitable. A dash = unsuitable. ? = unknown.

Metric (measured or derived)	Coral	Sponge	Coralline algae	Macroalgae	Purpose/Strength	Limitations	Preferred Tools
Biotic							
Abundance (measured)	See Table 3		X	X	- Biodiversity - Reproductive success - Population size and structure - Easy to measure (many options, e.g., count, % cover)	- Small and/or rare specimens might be overlooked or underestimated	- Submersible imagery surveys (with associated sampling where appropriate)
Biomass (measured or derived)			-	X	- Productivity - Reproductive success - Population structure - Predictor of metabolism and related traits - Identification of hotspots for diversity - Direct weight from physical samples	- Need calibration of size-weight relationships	- Submersible imagery surveys (with associated sampling where appropriate)
Distribution (measured or derived)			X	X	- Ecosystem resilience - Genetic diversity	- Depends on good taxonomic resolution - Need large spatial sampling coverage (including depth) that can inform modelling	- Submersible imagery surveys (with associated sampling where appropriate)
Diversity indices (derived)			X	X	- Biodiversity - Community structure - Ecosystem resilience - Genetic diversity	- Depends on quality of abundance and richness data	- Submersible imagery surveys (with associated sampling where appropriate)
Size structure (derived)			-	X	- Population structure - Reproductive success	- Best suited for organisms with linear growth - Difficult to measure from imagery - Small organisms might be missed in imagery data	- Submersible imagery surveys (with associated sampling where appropriate)

Metric (measured or derived)	Coral	Sponge	Coralline algae	Macroalgae	Purpose/Strength	Limitations	Preferred Tools
Condition (measured or derived)			-	X	- Physiological stress	- Difficult to measure - Need target imagery	- Submersible imagery surveys (with associated sampling where appropriate)
Patch dynamics: area and density (derived)			X	X	- Biodiversity - Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling coverage (including depth) - Limited to mobile species without avoidance behaviours	- Submersible imagery surveys
Patch isolation/proximity (derived)			X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches - Limited to mobile species without avoidance behaviours	- Submersible imagery surveys
Patch dynamics: connectivity (derived)			X	X	- Reproductive success - Genetic diversity	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches	- Submersible imagery surveys (with associated sampling where appropriate) - Settlement plates
Patch dynamics: contagion index (derived)			X	X	- Reproductive success	- Need clear definitions of patches formed by each coral and sponge group - Need large spatial sampling for context of patches	- Submersible imagery surveys (with associated sampling where appropriate)

Metric	Coral	Sponge	Coralline algae	Macroalgae	Purpose/Strength	Limitations		Preferred Tools
Environmental and stressor								
Anthropogenic debris (e.g., plastics, lost fishing gear)	X				- Life history - Distribution - Fitness - Mortality	- Timing difficult to resolve - Physiological stress can continue (e.g., fishing gear not removed)	As an ecological proxy: the effect lag time must be well understood through baseline monitoring (e.g., Figure 6)	- Submersible imagery surveys (with associated sampling where appropriate)
Anthropogenic physical disturbance (e.g., trawl marks)	X				- Life history - Distribution - Fitness - Mortality	- Timing difficult to resolve - Requires ground truthing		- Submersible imagery surveys (with associated sampling where appropriate) - Benthic acoustic survey
Natural physical disturbance regime	X				- Life history - Distribution - Fitness - Mortality	- Timing difficult to resolve		- Submersible imagery surveys (with associated sampling where appropriate) - Benthic acoustic survey
Substrate/Grain size	X				- Life history - Distribution - Fitness - Mortality	-	-	- Imagery surveys (with associated sampling where appropriate) - Sediment sample
Sedimentation Rate	X				- Life history - Distribution - Fitness - Mortality	-	-	- Sediment trap

4.3.2.5. Pelagic and sea surface conditions

Table 7. Summary of suitable metrics to consider (grouped by biological, physical, and chemical oceanography, as well as stressors ecosystem components) for the monitoring that pelagic and sea surface condition are within a range of the natural state (operational objective 1.2 b).

Metric	Purpose/strengths	Limitations		Preferred tools
Biological oceanography components				
Primary productivity	- Productivity - Carbon sequestration - Species abundance distributions	- Relationship to phytoplankton concentration is species specific - Quenching in high light intensities	As an ecological proxy: the lag time must be well understood through baseline monitoring (e.g., Figure 6)	- Water samples (followed by filtration and spectrometry/ fluorometry) - Fluorescence sensors on tools (especially satellites)
Secondary productivity	- Productivity - Carbon sequestration - Species abundance, biomass, and distributions	- Identifying zooplankton time consuming and requires expertise		- Nets (e.g., bongo) - Continuous Plankton Counter - Underwater Vision Profiler
Physical oceanography components				
Temperature	- Physiological limit/range for species - Measure of climate change	-		- Sensors (e.g., CTD) - Ocean models
Current (speed and direction)	- Transport (nutrients, productivity, larvae, water masses)	-		- Deployed gear (e.g., current meters, floats) - Satellite data (e.g., sea surface height) - Ocean models
Weather	- Productivity - Stratification - Disturbance (e.g., stress)	-Difficult to get information in winter months (satellites - dependent on cloud cover)		- Satellite data - Weather stations (e.g., moorings) - Weather/climate models
Turbidity	- Light penetration and water clarity - Eutrophication, sediment load, productivity	-Multiple drivers		- Water sampling (with associated analysis) - Sensors (Optical backscatter)
Marine noise	- Wind, current, waves action (physical) - Organism activity (biological) - Disturbances (anthropogenic, e.g., vessel traffic) functional group is mammals	-Comparing noise levels between instruments requires calibration		- Hydrophones (moored, mounted, etc.)
Chemical oceanography components				

Metric	Purpose/strengths	Limitations	Preferred tools
pH	- Dissolution of unprotected calcium carbonate (carbonate saturation) - Physiological limit/range for species - Measure of climate change	- Sensors not readily used (e.g., labour intensive, calibration errors, costly) - Calculated (requires multiple measurements at the same time) - Diversity of measures (sensors vs calculation)	- Sensors - Calculations from other metrics (temperature, salinity, dissolved oxygen, partial carbon dioxide)
Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA)	- More robust measurement of carbonate saturation - Physiological limit/range for species - Measure of climate change	- Labour intensive - Calculated (requires multiple measurements at same time)	- Water sampling with calculations from other metrics (temperature, salinity, oxygen nutrients)
Partial pressure of carbon dioxide (pCO_2)	- Related to pH and DIC for fulsome scope carbon dioxide in water - Measure of climate change	- Calculated (requires multiple measurements at same time)	- Sensor/instruments can do measurement (e.g., on mooring or as part of the flow through on a vessel, best if measure temperature, salinity, oxygen, and pH at the same time)
Salinity	- Physiological limit/range for species (unlikely for microbes) - Measure of climate change	-	- Sensors (e.g., CTD) - Water sampling (with associated chemical analysis)
Oxygen	- Physiological limit/range for species - Measure of climate change - Proxy of physical oceanography (e.g., stratification) - Indirect proxy of eutrophication	- Calibration errors - Diversity of measures (sensors vs collection)	- Sensors - Water sampling (with associated chemical analysis)
Nutrients	- Physiological limit/range for species - Measure of eutrophication	-	- Water sampling (with associated chemical analysis)
POC	- Productivity flux - Indirect measure of nutrients	-	- Water sampling (with associated chemical analysis) - Sediment trap
Stressor components			
Contaminants	- Fitness of individuals/population - Mortality - Measure of anthropogenic activity	- Timing and extent can be difficult to resolve	- Water sampling (with associated chemical analysis)
Microplastics	- Fitness of individuals/population - Mortality - Measure of anthropogenic activity	- Timing and extent can be difficult to resolve	- Water sampling (with associated analysis)

5. PROTOCOLS

This section identifies, describes, and examines the suitability of potential tools, strategies, and methods currently available in the Pacific Region to address the monitoring of the proposed indicators (ecosystem components and metrics). This section is again adapted and expanded from Neves et al. (in prep[3]); please see their full text for details. We have indicated when we have summarized their information; however, most of the following section has been detailed for the Pacific context based on published literature and/or consultation with subject matter experts. The 30+ reviewed tools and sensors (which fall within five high-level groups: imagery and biological sampling, seafloor gear, acoustic, oceanographic, and online data) are those that could be used for monitoring the SK-B MPA with relevance to the ecological conservation objectives and within the context of existing equipment and expertise within the Pacific Region. We strategized how to implement monitoring by identifying and describing 14 previous or ongoing monitoring strategies within or outside the MPA with relevance to the ecological conservation objectives. Reviewed methodology focused on best practices when designing monitoring programs related to baseline data, frequency, volume (amount), and location. We identify the preferred tools for proposed indicator ecosystem components grouping and metric combination (e.g., cores are the preferred tool to measure the abundance and condition of infauna). The section is concluded with a description of data management and reporting considerations for the implementation of a monitoring plan.

5.1. TOOLS

The use of tools to obtain the appropriate data on our indicators is an important part of the monitoring process. The choice of tools can influence the resolution of the data; for example, Neves et al. (in prep[3]) highlight this with imagery tools where "detectability of certain taxa might differ between high-resolution still images and standard definition video (Althaus et al. 2015; Dunham et al. 2018). Also, the use of different gear can yield significant differences in terms of species richness, densities, or species composition (Sheehan et al. 2014). Therefore, careful consideration and, when possible, trials should be undertaken to make sure that the selected tools and the data they provide are well-aligned with conservation objectives and monitoring indicators."

The challenges associated with monitoring the SK-B MPA include that it is located 180 km offshore and in deep water, which imposes logistical constraints and the requirement of specific tools and platforms (e.g., relatively large ships and deep-sea submersible equipment). It is also an immensely large area (6,131 km^2) that represents challenges in the spatial distribution of data collection (including baseline data) and the implementation of appropriate monitoring measures. These challenges and limitations will need to be considered during the development of monitoring designs, which will need to follow best practices to ensure that data are collected to allow for meaningful analyses. Additionally, we have limited the discussion to focus on tools that do not do broad-scale, extractive surveys. This may be constraining for many of the indicators for fish species in the context of classical fisheries studies but does not violate any of the SK-B MPA regulations (CHN and DFO 2019). We have attempted to supplement the 'classical' fishing methods with new imagery technology (see the Submersibles section below) and more targeted fishing methods (see Fishing Surveys section below).

In this section, we describe the over 30 tools and sensors that could be used for monitoring the SK-B MPA with relevance to the ecological conservation objectives and within the context of existing equipment and expertise within the Pacific Region. This section of the document is not meant to provide a full review of these tools and sensors—or to provide specific protocols—but rather to list and briefly describe them as potential options for monitoring the SK-B MPA. We focus on equipment recently used in Canadian surveys. Similar to Neves et al. (in prep[3]), we try to detail the aspects of their data collection (Table 8) and provide some comparisons to consider for the usability of each (Table 9). Technological advances happen quickly and the tools available for monitoring are likely to change over time. As part of the iterative process of monitoring, MPA practitioners should revisit and consider the use of new tools to collect comparable monitoring data as technology advances. As such, we included a general description of the data streams garnered from each tool. However, the scope and details of a data management plan for the SK-B MPA will be an important final step of a monitoring plan once the anticipated types and volumes of data are determined. For more details, see the Data Management section.

5.1.1. Sensors

Many of our indicator metrics, particularly those relating to oceanography, can be acquired using sensors. Measuring water properties, and how they affect organisms, can be difficult as we are often limited by constraints such as depth and time. However, recent and rapid advances in technology, computing power, and sensor integration are fueling the development of a new generation of low-power, cost-effective, high-precision sensors that will withstand extended deployments in harsh environments and be able to relay data in real-time. What's more, these sensors can be mounted on an expanding variety of observatory platforms (Gallagar 2005). Below is a detailed (though not exhaustive) description of key metrics and their corresponding sensors. These sensors may be deployed on their own or on a variety of platforms (e.g., ROV, rosette).

A typical sensor data stream: instrument measurement in situ + timestamp (continuous time-series, ~1 hertz) → log raw data (often viewable in real-time) → processing (e.g., clean, correct, calibrate) and relating (e.g., to depth and spatial data) → store, share, assemble, analyze, create data products (e.g., depth profiles are a common output). The most common measurements are conductivity, temperature, pressure, and density. Below is a summary of how these water properties are measured using sensors adapted from the Ocean Networks Canada (ONC) website (ONC 2022a).

Conductivity sensors measure the water's ability to conduct electrical current. It is used to determine how much inorganic material is dissolved in the water and is measured using electrodes. Water passing between two electrodes will conduct a current based on the levels of dissolved inorganic ions, such as salt and other materials. Through calculations, salinity measurements can be derived from conductivity, temperature, and pressure of the water sample.

Temperature sensors are usually thermistors (also known as a resistance temperature detector). Thermistors measure temperature by detecting changes to the electrical resistance of a metal. Different metals will resist an electric current differently at different temperatures, so using conversion coefficients the resistance (change in resistance) can be used to calculate water temperature with an extremely high degree of accuracy.

Pressure is measured by a pressure gauge. Usually, a small coil of wire or tube of fluid that will compress or change shape depending on the external water pressure. In the ocean, pressure and depth are directly related, so the amount of pressure being exerted on the gauge can be used to determine the depth of the reading.

Table 8. Summary of potential tools for use in ecological monitoring of the SGáan Kínghlas-Bowie Marine Protected Area (SK-B MPA). Headers are defined as follows: Tool = tool name as listed in text. Data type = the type of data collected by the tool. Data target = abiotic or biotic features (e.g., ecosystem component). Data coverage = context of the spatial coverage of data acquisition. Environments = environments the tool is used in (i.e., benthic, pelagic, sea surface, or all). Conservation objective(s) = which ecological conservation objectives of the SK-B MPA may be informed by the use of this tool. Acronyms defined in text.

Tool	Data type	Data target	Spatial coverage[1]	Environments	Conservation objective(s)
Imagery and Biological Sampling					
ROV	- Imagery - Physical samples - Acoustic - Oceanographic sensors (e.g., CTD)	- Epifauna - Infauna (if push cores available) - Demersal nekton (including benthic fishes) - Seafloor - Water properties (chemical and biological)	Transect	All	All
Mini-ROV	- Imagery - Physical samples (limited) - Acoustic - Oceanographic sensors (e.g., CTD)	- Epifauna - Demersal nekton - Seafloor - Water properties (chemical and biological)	Transect	All (shallow)	All
HOV	- Imagery - Physical samples - Acoustic - Oceanographic sensors	- Epifauna - Infauna (if push cores available) - Demersal nekton - Seafloor - Water properties (chemical and biological)	Transect	All	All
AUV	- Imagery - Acoustic - Oceanographic sensors (e.g., CTD)	- Epifauna - Demersal nekton - Seafloor - Water properties (chemical and biological)	Transect	All	All
Drop camera	- Imagery - Oceanographic sensors (e.g., CTD)	- Epifauna - Demersal nekton - Water properties (chemical and biological)	Transect (or point)	All	All
TUVS	- Imagery	- Epifauna	Transect	Benthic (Flat-bottom areas, limited application within SK-B)	1.1a,b,c; 1.2a; 1.3a
BRUVS	- Imagery	- Motile Epifauna - Demersal nekton	Point	Benthic	1.1b,c; 1.3a

Tool	Data type	Data target	Spatial coverage[1]	Environments	Conservation objective(s)
SCUBA	- Imagery - Physical samples	- All organisms	Transect or Opportunistic	All	1.1a,b,c; 1.2a; 1.3a
Sea surface surveys	- Faunal counts, presence/absence, etc. - Imagery (if use camera)	- Birds - Mammals - Other surface nekton	Transect	Sea surface, Air-surface interface	1.3a
Drone	- Imagery	- Nekton - Marine birds	Transect or Opportunistic	Sea surface	1.3a
Fishing surveys					
Traps	- Physical Samples	- Motile epifauna - Demersal nekton	Point	Benthic	1.1b,c; 1.3a
Hook and line, gillnets, mid-water trawls	- Physical Samples	- Demersal nekton - Pelagic nekton	Point	All	1.1c; 1.3a
Seafloor gear					
Sediment samplers and traps	- Physical sample	- Infauna - Sediment (physical and chemical analysis possible)	Point	Benthic (Unconsolidated sediment)	1.1b; 1.2a; 1.3a
Settlement plates	- Physical samples	- Epifauna (recruitment)	Point	Benthic	1.1a,b; 1.2a; 1.3a
Acoustic					
Sonar	- Sound (interpreted from emission and reception)	- Bathymetry - Sub bottom profile - Nekton - Plankton	Transect	Benthic and pelagic	1.1c; 1.2b; 1.3a
Hydrophones	- Sound (reception)	- All fauna	Transect or Continuous (deployment dependent)	All	1.1a,b,c; 1.2a; 1.3a
Acoustic Doppler Current Profiler (ADCP)	- Sound (Doppler difference and time)	- Currents	Transect or Continuous (deployment dependent)	All	1.2b
Oceanographic					
Nets	- Physical samples (zooplankton) - Imagery (if UVP mounted) - Oceanographic sensors (if mounted)	- Plankton (small nekton possible)	Transect or Point (deployment dependent)	Pelagic (including sea surface)	1.2b; 1.3a

Tool	Data type	Data target	Spatial coverage[1]	Environments	Conservation objective(s)
Water sampling	- Physical samples	- Water (post collection analysis for biological, chemical, eDNA, etc.)	Point	Pelagic (including sea surface)	All
Underwater vision profiler	- Imagery	- Plankton and small detritus (small nekton possible)	Transect (vertical)	Pelagic (including sea surface)	1.2b; 1.3a
Gliders	- Oceanographic sensors	- Water properties (chemical and biological)	Transect	Pelagic (including sea surface)	1.2b; 1.3a
Floats and drifters	- Oceanographic sensors	- Water properties (chemical, biological, and physical)	Transect	Pelagic (including sea surface)	1.2b; 1.3a
Moorings, etc.	- Oceanographic sensors - Atmospheric sensors - Acoustic (e.g., hydrophone) - Physical samples	- Water properties (chemical, biological, and physical) - Atmospheric properties - Fauna (noise) and human activities - Sediment/Marine snow, Epifauna (recruitment)	Time series	All	All (sensor dependent)
Saildrones	- Oceanographic sensors - Atmospheric sensors - Acoustic (e.g., hydrophone)	- Water properties (chemical, biological, and physical) - Atmospheric properties - Fauna (noise) and human activities	Transect	All	All (with hydrophone)
Online					
Satellites	- Oceanographic and atmospheric sensors	- Water properties (chemical, biological, and physical) - Atmospheric properties	Broad	Pelagic	1.2b; 1.3a
Models	- Spatial maps	- All properties	Broad	All	All
Undersea cabled observatories	- Oceanographic sensors	- Water properties (chemical and physical)	Time series	Benthic	1.2b
Post-Processing					
Molecular/eDNA	- DNA sequences	- All fauna	Point	All	All

[1]Transect = data collection along a path; point = data collection from a discrete space and time; time series = data collection from discrete space but over long time; broad = data collection over large spatial and temporal scales.

Table 9. Characteristics of the tools suitable for monitoring within the SG̲áan K̲ínghlas-Bowie Marine Protected Area. The occurrence of a certain characteristic is represented by an "X", unless non-applicable (NA), except for cost, where dollar signs were used to display relative costs ranging from low to high ($-$$$). Acronyms defined in text.

	Imagery and Biological Sampling										Fishery Surveys				Bottom-contact gear		Acoustic			Oceanographic							Online			Post-processing
Characteristics	**ROV**	**Mini-ROV**	**HOV**	**AUV**	**Drop camera**	**TUV**	**BRUV**	**SCUBA**	**Sea surface surveys**	**Drones**	**Traps**	**Hook and line**	**Gillnet**	**Mid-water trawl**	**Sedi. Samplers & traps**	**Settlement plates**	**Sonar**	**Hydrophones**	**ADCP**	**Oceanographic nets**	**Water sampling**	**UVP**	**Gliders**	**Floats and drifters**	**Moorings etc.**	**Saildrones**	**Satellites**	**Models**	**Cabled observatories**	**DNA (eDNA)[1]**
Continuous broad-scale spatial coverage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	X	-	-
Continuous fine-scale spatial coverage	X	X	X	X	X	-	-	X	X	X	-	-	-	-	-	-	-	X	X	-	-	-	X	X	X	X	-	-	X	-
Non-destructive[2]	X	X	X	X	X	X[3]	X	X	X	X	-	-	-	-	-	X	X	X	X	-	-	X	X	X	X	X	X	X	X	-
Repeatability[4]	X	-	X	X	-	-	-	-	-	X	-	-	-	-	X	X	X	X	-	-	-	-	-	-	X	-	X	-	X	X
Able to sample over a variety substrates	X	X	X	X	X	-	X	X	NA	NA	-	-	-	-	-	-	X	X	X	NA	NA	NA	NA	NA	X	NA	NA	X	X	NA
Species-level identification possible	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	X	-	X	X	X	-	-	X	-	-	X	X	X
Sample specimens	X	-	X	-	-	-	-	X	-	-	X	X	X	X	X	X	-	-	-	X	X	-	-	-	-	-	-	-	-	X
Behaviour observed	X	X	X	X	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Cryptofauna[5] observed	X	X	X	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Concurrent chemical/physical and biological data	X	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	X	-	X	X	X	X
Minimal technical expertise[6]	-	X	-	-	-	-	X	-	X	-	X	-	-	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Imagery and Biological Sampling										Fishery Surveys				Bottom-contact gear		Acoustic			Oceanographic							Online			Post-processing
Characteristics	**ROV**	**Mini-ROV**	**HOV**	**AUV**	**Drop camera**	**TUV**	**BRUV**	**SCUBA**	**Sea surface surveys**	**Drones**	**Traps**	**Hook and line**	**Gillnet**	**Mid-water trawl**	**Sedi. Samplers & traps**	**Settlement plates**	**Sonar**	**Hydrophones**	**ADCP**	**Oceanographic nets**	**Water sampling**	**UVP**	**Gliders**	**Floats and drifters**	**Moorings etc.**	**Saildrones**	**Satellites**	**Models**	**Cabled observatories**	**DNA (eDNA)[1]**
Access to equipment (easiness)	-	X	-	-	-	-	X	X	X	X	X	X	-	-	X	X	X	X	X	-	X	X	X	X	-	-	X[7]	X[7]	X[7]	X
Cost (not considering ship time)	$$$	$	$$$	$$$	$$	$$	$	$	$	$	$	$$	$$	$$	$	$	$$	$$	$$	$$	$	$$	$$	$-$$	$$-$$$	$$	$[7]	$[7]	$[7]	$$

[1]Option of DNA/eDNA post-processing for biological sampling and water sampling. [2]Non-destructive except for targeted small-scale sampling. [3]Constant contact with benthos indicates would be extractive in areas other than flat, soft-bottom habitats. [4]Repeating the survey/sample would get you the exact same result (e.g., zero spatial variability). [5]Organisms inhabiting protected and/or concealed habitats. [6]Equipment deployment/data collection only (no calibration or post-processing expertise considered). [7]Accessing online data only.

Density is calculated based on the salinity (calculated from conductivity), temperature, and pressure of the water, as these are the driving factors of density. As temperature decreases and salinity increases, the density of seawater will increase.

The sensors used for these four water properties can be deployed on their own but are most often grouped together as a unit called the **CTD** (Conductivity, Temperature, Depth). CTDs may be lowered from a research vessel or mounted on a variety of tools (e.g., rosettes, gliders, moorings, ROVs).

Determining how acidic or basic the ocean is requires measuring the hydrogen-ion concentration in a solution, also referred to as **pH.** There are many potential methods and sensors to measure pH; please see Rérolle et al. (2012) for a detailed description. Sensor systems for pH measurements have improved in recent years, and production costs have come down, but they remain complex and relatively expensive, particularly the optical components. To effectively study ocean acidification (low pH) it may be necessary to take water samples and do chemical analysis (see the Water sampling section below). Ocean acidification may also be measured by parameters other than pH. Alternate methods include calculating calcite horizons and measuring oxygen, salinity, temperature and partial pressure of carbon dioxide. This technique allows one to map the near-surface water properties as they relate to ocean acidification parameters.

Oxygen is measured to determine the dissolved oxygen and oxygen saturation levels in the water. The measurements are done using chemical titrations (see the Water sampling section below) or with the use of electrodes/optodes. From ONC (2022b), "Optodes, in very general terms, create their measurements by emitting light and measuring the luminescence (similar to a glow) given off by the oxygen in the water. To take a measurement, the optode emits a specific wavelength of light which excites the molecules of the substance being measured. These molecules then emit a slightly different wavelength of light in response to excitation, which the sensor detects. Using various calculations, the sensor then determines how much of the substance (in this case oxygen) is present in the water around the sensor."

To measure the primary productivity in the ocean scientists measure **chlorophyll-a** concentrations. Chlorophyll-a is the pigment that microscopic marine plants and plant-like organisms (collectively called phytoplankton) use to produce food. In-situ chlorophyll-a concentrations are usually measured using a sensor called fluorometer, which detects fluorescence. Fluorescence occurs when molecules absorb light of a wavelength, which excites the electrons, and then they emit light at a different wavelength. Chlorophyll-a absorbs blue light and emits, or fluoresces, red light. A cholophyll fluorometer transmits an excitation beam of light in the blue range and detects the fluorescent red light emitted. More molecules of cholorophyll-a correspond to more red light emitted (ONC 2023). Similarly, remote sensing, via satellite sensors, detects the wavelengths that leave the oceans (radiance) to calculate chlorophyll-a concentration. Using satellite technology, primary productivity can be measured on a large scale and over a long time period, but is very subject to cloud coverage in the Northeast Pacific (e.g., no satellite-based productivity data for BC in December over a 19 year period, Du Preez and Norgard 2022). (see the Satellites section below). Chlorophyll-a concentrations can also be determined from water samples (see the Water sampling section).

Acoustic sensors measure sounds as they travel through the water. The speed at which sound travels is different through water and solids, and can vary based on the temperature, salinity, and pressure. Scientists can use ocean acoustics to study ocean physics, chemistry, biology, and bathymetry (Woods Hole Oceanographic Institute [WHOI] 2022a). Acoustic sensors can be mounted on various tools (e.g., ROV, vessel mounted) or can deployed as a tool on its own (for example, see the Hydrophones section below).

5.1.2. Imagery and Biological Sampling

A typical imagery data stream: in situ images (video or photographs) + timestamp (continuous time-series, ~1 hertz) → record raw footage (often viewable in real-time) with or without embedded metadata (in overlay or filename) → processing (e.g., annotation, photogrammetry, mosaicing) and relating (e.g., to depth, spatial, environmental data) → store, share, assemble, analyze, create data products (e.g., species occurrence as first-order data, processed into density and/or diversity).

A typical biological sample data stream: collection of sample + metadata (including timestamp, location, depth) → processing (e.g., laboratory experiment, examine) → store, share, analyze, create data products.

5.1.2.1. Submersibles

Imagery tools and technologies have advanced such that they are incredibly effective tools for studying the marine environment (e.g., ROVs and drop cameras; Figure 13A,B). In this section we will describe some of the current imagery technologies with the potential to be used to monitor the SK-B MPA. While the majority of submersibles described below are intended to document the seafloor, some are versatile and can be used for pelagic surveys (e.g., ROVs; Quattrini et al. 2017), while some are designed explicitly for pelagic use only (e.g., pelagic BRUV; Heagney et al. 2007).

Remotely operated vehicles (ROVs)

A comprehensive section on ROVs in Neves et al. (in prep[3]) does a thorough job of describing the technology, advantages and disadvantages, and considerations. To summarize, ROVs are tethered, unoccupied underwater vehicles that can be equipped with sensors, cameras, oceanographic tools (e.g., Niskin bottles) and other equipment (e.g., manipulators, sampling boxes, sediment push-cores) (Figure 13A,C). ROVs provide a live-feed view to pilots and scientists aboard the vessel. The maneuverability and precision navigation ensures they can be used over a variety of substrates and return to specific locations with confidence. They collect transect data and are one of the least invasive ways to conduct biological and geological surveys of deep-water habitats. This is particularly helpful when surveying conservation areas, which support sensitive and/or vulnerable species.

ROVs collect quality imagery with transect speed, altitude, and distance determined by the scientists and pilots. This allows complete control over the type of imagery collected (e.g., close-ups to help with identification, mosaic grids). Additional cameras can also be mounted at different angles to collect complementary imagery. The still photographs and video imagery can be annotated in real-time (with highlight observations and identifications) and processed post-expedition (e.g., software programs such as BIIGLE) to address the metrics listed for our indicator ecosystem components. Having a pair (or more) of parallel laser points available in imagery is one of the most basic requirements associated with current imagery technologies. Parallel lasers have the main objective of providing a projected scale for size estimates. In addition to gathering imagery, ROVs have the added bonus of collecting complementary oceanographic data and physical samples. The versatility and non-destructive nature of ROVs make them a desirable survey tool.

Large ROVs with porches, boxes, triggers, and/or manipulators can also be used to deploy and retrieve tools (e.g., settlement plates, physical site markers). Large ROVs can also cover an incredible depth range, with many able to descend a few kilometres while recording geospatial data with a sub-metre level of precision.

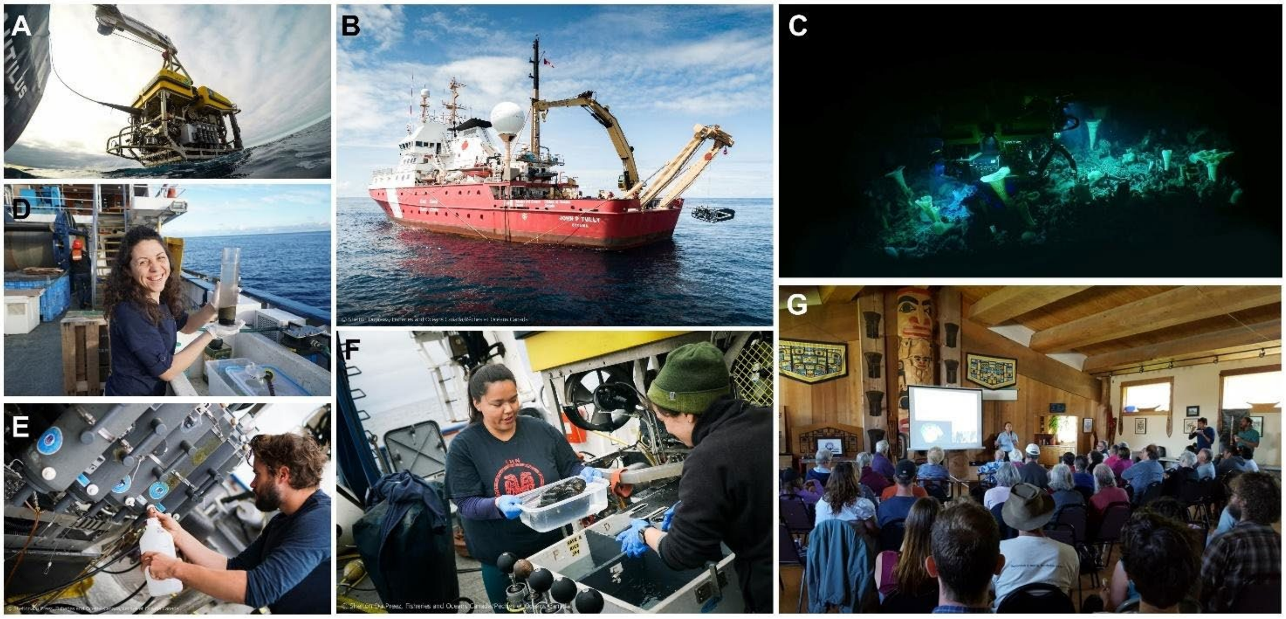

Figure 13. Capabilities of remotely operated vehicles (ROVs). (A) The ROV Hercules deployed from the exploration vessel Nautilus within the SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA). (B) The Fisheries and Oceans drop camera BOOTS deployed from the Canadian Coast Guard Ship John P. Tully. (C) The ROV Hercules surrounded by a forest of Pinulasma n. sp. Glass sponges. (D) Alessia Ciraolo (Memorial University student) with ROV collected sediment cores. (E) Brett Jameson (University of Victoria student) collected water samples from ROV-mounted Niskin bottles. (F) Jaasaljuus Yakgujanaas (Council of the Haida Nation) collecting specimens from the ROV biobox. (G) Offshore expedition live ship-to-shore event, from SK-B Seamount to Tluu Xaada Naay on Haida Gwaii. Photos are from Offshore Expeditions Pac2018-103 (one exception: B is from Pac2019-014). Credits: Fisheries and Oceans Canada, S. Du Preez, C. Du Preez, M. Clarkson, Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners.

There has been a history of ROV use in the SK-B MPA (summarized in Gale et al. 2017). The first ROV visit to SK-B Seamount was an exploration expedition led by National Geographic, which deployed an ROV to 150 m depth. A joint survey utilized Phantom ROV (DFO) and SeaBED (NOAA) autonomous underwater vehicle (AUV) data to document habitat and species (PAC 2011-62; unpublished). In 2018, a deep-sea expedition to the SK-B MPA was conducted with the ROVs Argus and Hercules from the exploration vessel *Nautilus* (Gartner et al. 2022). Dives were conducted on all three seamounts in the MPA, including the first imagery collected for Pearce/Davidson Seamount. The 2018 expedition highlights the capabilities of ROVs (Figure 13). During standard transects from the deep flanks to the seamount summits:

- multiple cameras were recording video and still images from different angles (Figure 13C);
- concurrent oceanographic measurements were collected from mounted sensors (e.g., temperature, depth, salinity);
- sediment samples were taken via ROV-manipulated push cores (Figure 13D);
- water samples were collected using mounted Niskin bottles (post-processing included eDNA) (Figure 13E);
- sonar provided piloting feedback and data on upcoming bathymetry and substrate;

- samples were collected during dive transects with a “Predator” seven-function; manipulator arm or a “slurp gun” suction sampler and stored in ROV bioboxes or slurp containers (Figure 13F);
- monitoring sites were established, markers deployed, and gridded surveys for mosaics run (post-processing included construction of 3D bathymetry data); and
- the imagery (and control room audio) was streamed live, online, across the world in real-time (feeds into Goal 5 of the management plan, public awareness and outreach; CHN and DFO 2019) (Figure 13G).

Having the ability to collect voucher specimens has implications for resolving difficult to identify species, new species to science, and contributing to genetic or isotope studies. The science team was working from a ‘wish list’ of specimen vouchers from colleagues and collaborators around the world. During the 2018 expedition, 570 specimen vouchers and tissue samples were collected (see Gartner et al. 2022).

Key points to consider for ROVs:

- The selection of ROVs and the tools/capabilities used depends on the different types of work, habitats, and metrics being collected.
- The quality of imagery and resulting data can vary greatly and needs to be linked to survey objectives and data requirements for monitoring.
- ROVs are versatile and can access locations where other traditional benthic gear cannot.
- ROVs can be the most efficient tool to collect both imagery and physical samples from targeted locations.
- ROV expeditions require technical teams (ROV pilots), vessels with dynamic position and launching/recovery systems (e.g., crane or A-frame) and are therefore quite costly.

Mini ROVs

Mini ROVs are emerging technology that are much smaller than traditional ROVs, relatively affordable, can be hand deployed, and are piloted using a simple tablet. However, they are usually limited to shallow-water operations (e.g., <100 m in Buscher et al. 2020), good conditions (limited thrust to fight currents), lack high-resolution geospatial capabilities, and require some user experience to properly deploy. Most are limited in power, lighting, and lack manipulator arms or have a single manipulator arm with limited carrying capacity. They are used to collect imagery (can have scaling lasers) and oceanographic data. Mini ROVs have not previously been used to study the SK-B MPA but more programs are buying these relatively affordable submersibles (e.g., DFO Pacific Region programs recently purchased a mini ROV capable of diving to 300 m depth).

Key points to consider for mini ROVs:

- Precision navigation with continuous imagery and limited oceanographic measurements.
- Limited to shallow water operations in good conditions.
- Limited or no physical sampling.
- Low costs (initial tool costs plus operations).

Human operated vehicles (HOVs)

Human operated vehicles (HOVs) operate in a similar manner to ROVs, except that they are untethered and the pilot(s) and scientist(s) are on board the submersible. Being submerged and surrounded by the deep-sea environment may allow for novel methods and observations (Liang et al. 2021). For details on HOVs, please see Neves et al. (in prep[3]). The benefits and drawbacks of using these tools are similar to ROVs (e.g., the precise and detailed data collection comes with high associated costs), but HOVs have the added disadvantages of limited bottom time and the associated potential risks to human life.

In 2000 the Delta submersible was utilized to develop stock assessment methods for benthic rockfishes (dive depths 53–306 m; Yamanaka 2005) and visited SK-B Seamount.

Key points to consider for HOVs:

- Similar to ROVs, HOVs are tools with precision navigation, high-quality imagery, mounted oceanographic and acoustic sensors, and sampling abilities.
- Allows scientists and pilots to examine the environment and animals in situ.
- Limitations include high associated costs related to technical needs, limited bottom times, and an elevated risk to human life.

Automated underwater vehicles (AUVs)

A comprehensive section on automated underwater vehicles (AUVs) in Neves et al. (in prep[3]) does a thorough job of describing the technology, its advantages and disadvantages, and their considerations. To summarize, AUVs are untethered underwater vehicles with autonomous navigation capabilities. They follow a pre-programmed track at set distances (altitude) above the seafloor to avoid habitat and species contact. AUVs can be equipped with cameras, oceanographic instruments (e.g., CTD) and sonar systems. AUVs require no pilot time and are not connected to the vessel, so can operate simultaneously to alternate field operations and can be deployed for long periods of time. The disadvantages include that there are no physical sampling capabilities and no ability to pause a transect to investigate notable areas opportunistically. The quality of imagery can vary and is largely determined by the pre-programmed altitude and speed (likely habitat complexity dependent). AUV altitude can be problematic when exceeding 2 m, as object detection and taxa identification might be compromised. This is especially challenging as AUVs are usually deployed at sites where fauna diversity is not well sampled or known. AUVs also rely on artificial intelligence for navigation and detection, and transecting at low altitudes increases the risk of running into and getting caught in complex seafloor and biological structures (e.g., AUV used on Cobb Seamount; Curtis et al. 2015). Because AUVs are untethered, finding and recovering them can be difficult, and AUVs can be harmed, destroyed, and/or lost (e.g., Curtis et al. 2015). With advances in technology, these tools can continue to improve in functionality in the future (Liang et al. 2021).

In 2011 the first deep imagery (1st past 300 m) of SK-B Seamount was collected using NOAA's SeaBED AUV (180-933 m; unpublished but summarized in Gale et al. 2017).

Key points to consider for AUVs:

- Pre-programmed path of continuous imagery, with oceanographic and acoustic sensors.
- Relies on artificial intelligence for navigation and detection (likely to keep improving with advances in technology).
- No pilot time and can run simultaneously with other field activities.
- Long deployment time with large spatial coverage possible.

- Image quality can vary and largely depends on altitude and speed set (and complexity of habitat).
- Risk of damage to the seafloor, including to fragile and vulnerable species, and risk of losing the vehicle higher than with tether submersibles.
- No physical sampling capabilities.

Drop camera systems

A comprehensive section on drop camera systems in Neves et al. (in prep[3]) does a thorough job of describing the technology, its advantages and disadvantages, and considerations. To summarize, drop camera units consist of a camera(s), lights, and sensors mounted to a cage. Some drop camera systems yield a real-time view to scientists and pilots who have limited control capabilities (generally can affect altitude) while other systems are deployed 'blindly' with no real-time view. These 'blind' drop cameras are lowered until they touch the seafloor, capture imagery, get hauled up, the ship moves, and the system is lowered again to repeat the process. This 'yo-yo' style drop camera system would not be recommended for the SK-B MPA as destruction and damage to the habitat and epifauna is likely.

Another style of drop camera is a "tow-cam," which is non-destructive and the type of drop camera owned by DFO Pacific Region. The Bathyal Ocean Observation and Televideo System (BOOTS; Figure 13B) captures and provides continuous real-time imagery to pilots and scientists aboard the vessel, is equipped with scanning sonar, and has the ability to move up and down on a winch system so that BOOTS can avoid contact with the seafloor and vulnerable animals. As with the other imagery tools, BOOTS is also equipped with scaling lasers to provide a scale for size and distance estimates. In 2015, BOOTS' inaugural dives were conducted in the SK-B MPA. Imagery was collected to depths of 1,246 m over 17 dives, including the first imagery collected on Hodgkins Seamount (Gale et al. 2017). Improvement in recent years has allowed BOOTS to be towed along continuous transects (fin added) and descend to depths over 2 km (i.e., deeper rating) (unpublished data Pac2021-036; see DFO Seamounts Expedition 2021-06 (Jun 2021) on Ocean Network Canada's SeaTube Pro website.

All drop camera systems rely on the movement of the boat for navigation and therefore are slow to control and respond. This also means they are affected by any other ship motion (e.g., rolling; although BOOTS has active heave compensation). Drop cameras are best used for random or haphazard sampling and take a lot of time to navigate to an exact location, although not impossible (e.g., BOOTS was used to relocate and resurvey monitoring sites on Dellwood Seamount in 2021 (unpublished data Pac2021-036).

Key points to consider for drop camera systems:

- 'Yo-yo' style drop cameras should not be used within the SK-B MPA as they make physical contact with the seafloor.
- Real-time view drop cameras collect continuous imagery, acoustic data, and oceanographic sensor data.
- Drop camera systems can be small and affordable (i.e., in comparison to ROVs and AUVs), facilitating their deployment from small-size vessels.
- Drop camera systems can be modified in "relatively simple ways" to increase capabilities.
- No physical sample collecting capabilities.

Towed underwater video systems (TUVS)

Towed underwater video systems (TUVS) differ from drop cameras in that they have continuous contact with the seafloor. A comprehensive section on TUVS in Neves et al. (in prep[3]) does a thorough job of describing the technology, its advantages and disadvantages, and considerations. To summarize, the most common TUVS are benthic sleds where a vessel pulls a metal frame, with a mounted camera, along the seafloor. This provides continuous imagery collection at a set height and distance (standardized data collection). However, because of the destructive nature of these sleds they are very limited in the benthic environments they can be used in. Sheehan et al. (2010, 2016) have also proposed the use of alternative "benthic-tending" TUVS, which are suspended versions of TUVS and only contact the seafloor via a small ground chain.

Given the complexity of the benthic habitat and the vulnerable benthic species on the seamounts within the SK-B MPA, the use of TUVS is not recommended until advancements in "benthic-tending" TUVS have been tested in VME and other deep-sea environments. Given the regulations of the SK-B MPA (CHN and DFO 2019), the destructive nature of TUVS in their current state limits the possibility of their use.

Key points to consider for TUVS:

- Current TUVS are destructive to habitat and habitat-forming species and are not recommended for use in the SK-B MPA.

Baited remote underwater video stations (BRUVS)

Baited remote underwater video stations (BRUVS) can be stationary platforms deployed in a benthic environment to assess metrics of motile species in the area or mid-water floating platforms (attached to a surface float or ship) to assess pelagic megafauna (e.g., Heagney et al. 2007). The designs of BRUVS can vary greatly but generally consist of a frame with mounted lights, cameras (to create stereo-video), and some sort of bait/attractant. Oceanographic sensors could be mounted to the frame to collect concurrent oceanographic measurements. To summarize from Neves et al. (in prep[3]), BRUVS are most commonly used to assess demersal fish diversity, distribution, and behaviours (e.g., Bailey et al. 2007; Espinoza et al. 2020; Schramm et al. 2020) but have also been used to assess benthic invertebrate diversity (Unsworth et al. 2014; Devine et al. 2019).

In addition to diversity and behaviour data, BRUVS can provide an estimate for relative abundance by standardizing the attractant (e.g., Heagney et al. 2007; Espinoza et al. 2020; Giddens et al. 2021) as a comparison metric between standardized deployments. However, interpretation of this relative abundance is not directly comparable to other common fish metrics such as catch per unit effort or population density within an area (Dana Haggarty, DFO, Nanaimo, BC, pers. comm.).

Key points to consider for BRUVS:

- Point observations of diversity, relative abundance, and behaviour or motile species (a good option for species potentially scared away by mobile imagery surveys).
- Frames could support oceanographic sensors.
- Deployment is limited by battery power and habitat (depends on size of BRUV).
- Standardization of attractants is made difficult by variable flow regimes.

Stereo cameras

The concept of using imaging systems with more than one camera to provide a three dimensional context to underwater biological photography is not novel (e.g., Cullen et al. 1965; Klimley and Brown 1983; van Rooij and Videler 1996) but has recently become a more competitive and emerging tool as they are non-lethal, can be used in areas where traditional fishing gear cannot, and with technological advances becoming more efficient and cost-effective (e.g., Costa et al. 2006; Rooper et al. 2010; Williams et al. 2010; Jones et al. 2012; Rooper et al. 2012). Boldt et al. (2018) field tested stereo camera technology to determine its success in Pacific waters for complementing traditional fishery acoustic-trawl sampling surveys for biomass/stock assessments. Though there are some challenges (in bullets below), they found the stereo camera system was a viable tool for acoustic target verification of fish species and measurements of fish lengths, with the advantages of additional information on specific fish depth, tilt, and yaw (Boldt et al. 2018).

Key points to consider for stereo cameras:

- Non-lethal (excellent application within MPAs) and can be used in habitats traditional fishery tools cannot.
- Can identify fish species and individual length, depth, tilt, and yaw.
- Limitations include smaller sample sizes and resource intensive processing of images.

SCUBA (self-contained underwater breathing apparatus)

Diving underwater for scientific research is possible when divers breathe using equipment to provide their air supply. This air supply unit is called a Self-Contained Underwater Breathing Apparatus (SCUBA). Recreational SCUBA diving can occur to depths of 40 m and with advanced training a diver can go even deeper.

The shallowest point in the SK-B MPA is only 24 m below the sea surface making it a reasonable depth for SCUBA dive surveys. McDaniel et al. (2003) summarize scientific SCUBA dives, with very limited data, dating back to August 1969, and more detailed data collected in 1996 to depths of 50 m (that was complimented with ROV imagery down to 150 m). McDaniel et al. (2003) returned in 2003 to compile a more comprehensive list of the marine taxa at SK-B Seamount.

SCUBA has the advantage that divers can take targeted biological samples (with the appropriate collecting permits) and complement their in situ observations with imagery (camera type and design depend on survey objectives). SK-B Seamount is the only seamount within the MPA that has summit depths within SCUBA range. It is unlikely that future studies and expeditions will focus on SCUBA surveys, given the short bottom time (usually <1 hr per dive) and depth limitations.

Key points to consider for SCUBA:

- In situ observations and decision making about sample collections and targeted imagery.
- Depth limited.
- Costly on its own but could compliment other expedition components.
- No longer necessary with advances in submersible cameras (which have the added benefit of no risk to human life).

Summary of imagery tools

Imagery tools effectively capture data on our indicators (ecosystem components and their metrics). In the context of MPAs, and their conservation goals, imagery technology has the added bonus of low/no habitat or VME destruction. It is noted that they are limiting for many of the indicator ecosystem components and metrics for fish species in the context of classical fisheries studies.

The choice of imagery tools, their specifications, and survey designs will need to be adapted for specific and predetermined survey objectives and in the context of available resources. It should be noted that post-processing (annotation) imagery can be resource-intensive, and there are many options and methods used. Neves et al. (in prep[3]) does an excellent job of highlighting some of the considerations, standardizations, and post-processing protocols to consider to obtain the best data. Finally, it should be noted that the ability to collect specimens greatly enhances the scientific value of a submersible (Figure 14).

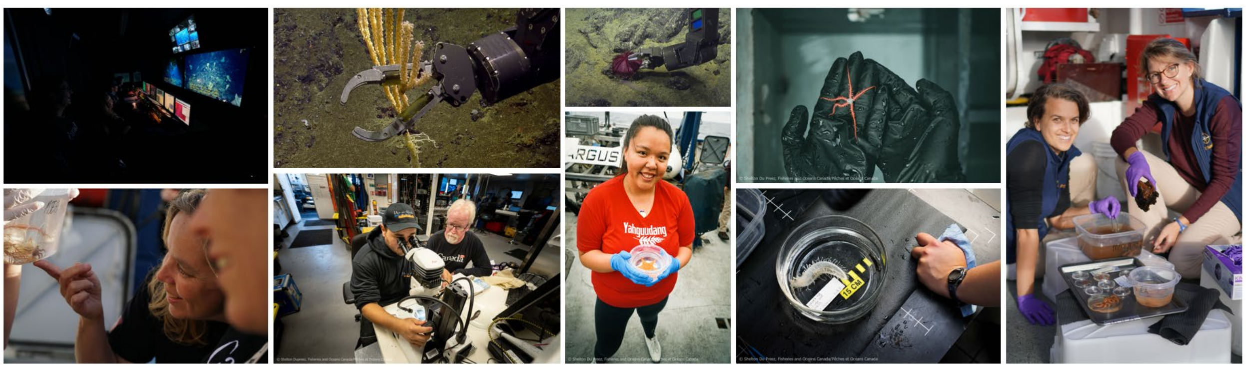

Figure 14. The process of collecting specimens using a remotely operated vehicles, from directly sampling in the ROV control room to processing collections onboard the ship. Photos are from Offshore Expeditions Pac2018-103 and Pac2019-014. Credits: Fisheries and Oceans Canada, S. Du Preez, Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners.

5.1.2.2. Above water visual surveys

Surface surveys (bird, mammal, and surface nekton)

Visual surface surveys can provide both opportunistic and standardized survey methods to observe the populations of animals at the air-surface interface. Though opportunistic records of observed taxa contribute to the knowledge of an area, standardized bird and mammal survey protocols exist to provide a more quantitative overview of an area. Typically, these surveys involve systematic scans made for set periods of time, aided by the use of binoculars and zoom photography. Seabird surveys tend to follow protocols similar to Tasker et al. (1984) and marine mammal surveys tend to follow DFO Cetacean Research Program (CRP) protocols. In 2018, the CRP attempted to establish more standardized transect patterns that included the offshore of BC and transects within the SK-B MPA (Wright et al. 2021).

For seabirds, Canessa et al. (2003) summarize data from two surveys (1997 and 1998) of Canadian Wildlife Surveys that identified the SK-B MPA as an AOI for migratory birds and SK-B Seamount itself as a confirmed area of importance to marine and coastal birds. Data is also available in Gale et al. (2017) of cruises conducted in 2001, 2003, and 2015. Limited data is available from the 2018 expedition to the area (Gartner et al. 2022).

For marine mammals and surface nekton, data is more limited and appears to be more opportunistic. Canessa et al. (2003) list species observed in the area without detailing the information or survey source. Gale et al. (2017) provide data from 2015 surveys, though they do mention limitations such as the speed while underway for benthic surveys, etc. Limited opportunistic observations have also been documented for the area (e.g., Gartner et al. 2022).

Key points to consider for surface surveys:

- Fills data gap on surface nekton and marine birds that may be attracted to seamounts.
- Would be expensive on its own but an inexpensive complement to other ship-based surveys.

Drones

Drones, also known as unoccupied aircraft systems/vehicles, are small flying robots that are remotely controlled. Their use in science is growing rapidly with recent advances in microelectronics, battery technology, and wireless communication that have made them more effective and efficient at lower costs (Johnston 2019). Limitations still exist, including training required to become a drone pilot and permits needed to fly in certain areas. However, drones are incredibly useful tools equipped with digital cameras, that can have a variety of sensors, and some have even been adapted to take remote samples (e.g., Hall 2016; Johnston 2019). Drones have allowed scientists to study more of the ocean, in areas they would not have been able to access, all while reducing human risk.

In the Pacific Region, DFO started developing a small drone fleet in 2020. Since then, DFO has been developing protocols for a wide range of remote sensing and mapping. During offshore surveys, drones have been used opportunistically to add to species inventories (e.g., Gartner et al. 2022), and document animals' behaviors (e.g., Du Preez et al. 2022). For monitoring the SK-B MPA, developing drone survey protocols that complement the traditional surface surveys would add value at a relatively low cost. However, drone technology does come with an associated sound pollution and would not be helpful in collecting data for many of the bird fauna observed at sea.

At the present time, data streams from drone work are primarily opportunistic imagery capture for species inventories and documenting unique behaviours.

Key points to consider for drones:

- Collects continuous imagery of the surface, but recent adaptations could allow for remote sample collection and sensing.
- Low cost.
- Noise pollution and avoidance behaviours by marine birds.

5.1.2.3. Fishing surveys

There are many tools that can be used to monitor fish populations living on or around seamounts (e.g., submersibles and acoustics). The following section will cover the fishing tools, with discussion limited to fishing methods commonly in place or with reasonable application in BC and within the SK-B MPA. For example, we will not be discussing destructive sampling tools such as benthic trawls—as, in addition to not providing targeted sampling, they can lead to the damage/removal of habitat and habitat-forming species. These fishery tools will not be reviewed as a monitoring option as they violate existing SK-B MPA regulations (CHN and DFO 2019).

The history of fishing within the SK-B MPA has been summarized in the Fisheries activities section above. The various tools for these fisheries and their potential for use for scientific monitoring are discussed below.

Traps

Mobile benthic fauna such as fish, crabs, and prawns may be scared away by the movement of some previous tools listed. Baited traps, out for set periods of time, can be used to obtain an estimate of relative abundance and diversity of these mobile taxa. Commercial style crab, fish, and prawn traps could effectively catch species, but their use within the SK-B MPA should be limited as they are destructive to benthic habitat and habitat-forming species (e.g., Du Preez and Norgard 2022).

Within the SK-B MPA, there was a bottom-contact longline trap (and occasionally hook) fishery that ran from 1985 to 2018 (see Fisheries activities section). The effects of trap fishing have been well summarized by Stevens (2021), which include impacts on benthic habitats during setting and retrieval, dragging along the seafloor, and entanglement and death of large motile species (e.g., marine mammals). Individual trap footprints may be small, but the overall footprint is increased by the lines connecting hundreds of traps along kilometres of line and the movement within the environment (at times dragging in excess of hundreds of meters; Du Preez et al. 2020 and references therein). The use of conventional trap fishing methods is not recommended for use within the SK-B MPA. Alternative trap methodologies could theoretically still be used in a limited capacity, such as bait traps on elevators (a platform that rises to the surface once triggered). This method was used to study deep-sea spider crabs in Alaska (NOAA 2010).

Hook and Line

A hook and line fishery is the broad term used to describe any of the fishing methods where hooks are attached to fishing line. As a monitoring tool, DFO utilizes hook and line surveys to monitor groundfish populations (DFO 2021d) and some pelagic species such as Albacore Tuna (DFO 2020a). Hook and line is also one of the fishing methods employed to catch salmon (DFO 2019c). There are four common methods among the hook and line gear: trolling, longlining, jigging, and pole and line fishing. Hook and line methods would be challenging to monitor benthic species in the SK-B MPA—in addition to removing fishes, there would be a risk of damaging or removing habitat and habitat-forming species (i.e., it would violate the SK-B MPA regulations; CHN and DFO 2019).

Trolling may be an effective means to monitor pelagic and/or transitory species. It is a method where hooks are attached to multiple lines and towed slowly behind a fishing vessel. Trolling typically occurs in the upper water column and has limited bycatch (DFO 2019c). Albacore Tuna fishing most commonly occurs along the west coast of Vancouver Island and Haida Gwaii, but also likely occurs in or near the SK-B MPA as depending on water conditions recreational fishing reports include encounters as far as 170 km from shore (summarized historic catches in MPA, see Canessa et al 2003; DFO 2020a). Pacific Fisheries Management Area Regulations (2007) allow fishing for salmon by trolling in the offshore area by the SK-B MPA. Information gathered this year by the 2022 International Year of the Salmon (IYS) Pan-Pacific Winter High Seas Expedition may be very informative for transient species around the SK-B MPA.

Longlining uses long main fishing lines with hooks set at depth intervals and follows a random depth-stratified design where sampling units are 2 x 2 km blocks (Lochead and Yamanaka 2004). In longline surveys to collect benthic species such as rockfishes, they are set on the bottom using a weighted (led) line with hooks or traps attached to this ground line. This type of fishery has been closed within the SK-B MPA following a study that demonstrated the impacts to long-lived species, such as coral and sponges, by landing on them during deployment or by being dragged during retrieval (Doherty et al. 2018). There is limited data available for some halibut and rockfish caught via longlining at SK-B (see Canessa et al. 2003). As summarized in Gale et al. (2017), “In 1980 and 1981, two exploratory fishing trips were conducted aboard the longliners *M/V Viking Star* and *M/V Star Wars II* to assess the potential for developing a [Rockfish] fishery at Bowie Seamount (Carter and Leaman 1981, 1982). The fishers deployed 46 (28 in 1980 and 18 in 1981) longlines at depths of 45–600 m... Fishing was hampered on both trips by lost and damaged gear due to weather and poor charts for the area... Between 1992 and 1999, there were occasional fishing trips to Bowie Seamount targeting rockfish with bottom longlines with hooks in the 200–500 m depth range (Beamish and Neville 2002, Canessa et al. 2003)." Additionally, in 2000 a longline research survey was conducted (Gauthier 2017).

Jigging uses a single hook on fishing lines that are sent down to a depth between 1–100 m and then mechanically 'jigged' back up to the surface and returned to a pre-determined depth (Canessa et al. 2003). In the early 1990s, exploratory surveys were conducted to assess establishing a squid fishery, some of which occurred near SK-B Seamount. Once a management plan was in place for the fishery, only two sets were conducted on SK-B Seamount with very low catches (Canessa et al. 203). This potential survey method targets squid species with a very low return and would likely not be worth the associated financial cost of running alone. Jigging is also another fishing methods for rockfishes and Lingcod (e.g., Starr and Haigh 2022).

In general, hook and line surveys are relatively inexpensive to perform and have the added benefit of collecting biological data such as sex, maturity, length, weight, age and stomach contents (Haggarty 2013). Some species can be released if not collecting data related to aging structures or trying to determine maturity (e.g., descending devices for rockfishes; Dana Haggarty, DFO, Nanaimo, BC, pers. comm.) However, the sampling methods are lethal for other species and should be utilized in limited means to inform data gaps not covered by other tools. As highlighted by Gale et al. (2017) and Doherty et al. (2018), in the paragraph above, longlining has the potential to damage habitat and habitat-forming species, so depth considerations should factor into any sampling design. Kuriyama et al. (2018) summarized the trade-offs of various fishery-independent tools for estimating fish populations. They analyzed the effectiveness of hook-and-line surveys and cautioned that their interpretation can be challenged by hyperstability and the competition amongst species.

Gillnet

Gillnets are curtains of netting that hang in the water column. They typically catch pelagic species and can be hung so that they do not intentionally contact the seabed. The mesh size of the netting can be selected to determine the size of fish caught. Unfortunately, there is a high incidence of bycatch, particularly of marine mammals (e.g., Reeves et al. 2013). Gillnets are one of the worst types of fishing gears for causing ongoing mortality when lost. For example, a gillnet recorded entangled on Cobb Seamount in 2012 had been actively ghost fishing for an estimated minimum of 35 years (Du Preez et al. 2020). In 1981, gillnets were deployed in the upper 100 m at SK-B Seamount (Canessa et al. 2003), but there have been no consistent research or gillnet fishery efforts around the SK-B MPA. Gillnets are used for part of the salmon fishery in BC (DFO 2019c), and catch data may provide context for some pelagic species.

Mid-water trawl

As highlighted previously, benthic trawls will not be discussed as they may be harmful to habitat and habitat-forming species in the SK-B MPA. However, mid-water trawls could be an effective way to determine fish and plankton populations in the water column. Typically, mid-water trawls are used in conjunction with acoustic technology to locate the position and depth of fish populations. Then a large, closed funnel-shaped net is passed through the water column. DFO's Integrated Pelagic Ecosystem Survey conduct broad-scale pelagic ecosystem surveys in the Pacific Region using a random, stratified survey design based on bathymetry and known ecosystem distinctions (for details see King et al. 2019 and Boldt et al. 2020a). In the SK-B MPA, there were some exploratory mid-water trawls that took place in the early 1980s, with limited success (Canessa et al. 2003). Hake surveys are an example of this integrated approach of acoustic and mid-water trawl tools (de Blois 2019). The issue is reduced when there is high-resolution mapping available, but mid-water commercial trawls (as well as gillnets) can and often do make physical contact with the seafloor (e.g., Tingley 2014; Salgado et al. 2018; Du Preez et al. 2020). Over a three-year study of an Antarctic fishery, 10 to 16% of mid-water trawls provided unequivocal evidence of trawling the seafloor (i.e., benthic animals caught; Tingley 2014). Scientific research studies with accurate high resolution maps, less intensive fishing (not profit driven, and with clear conservation directives within an MPA would be less likely to have such high contact with the seafloor.

Key points to consider for fishery surveys:

- Can obtain estimates of relative abundance, diversity, and distribution of species.
- Lethal sampling methods, so should be used only to fill in information gaps not covered by other tools.
- Issue of bycatch, particularly of concern for rare or endangered animals.
- Risk of benthic habitat destruction, whether gear is designed to make seafloor contact or not.
- Ability to obtain physical samples allows for studies on biomass, ageing (otolith measurements), growth (insulin; like growth factor (IGF1) and RNA:DNA ratios), stomach content analysis, DNA metabarcoding, isotope and fatty acid analysis (for more details, see the Monitoring Ecosystem Function and Trophic Structure section).

5.1.3. Seafloor Gear (non-imagery)

The use of bottom-contact gear is sometimes needed to obtain physical samples. Many of the large-scale sampling devices such as trawl, sleds, and dredges do not provide targeted sampling and can lead to the damage/removal of habitat and habitat-forming species. They are also often restricted to relatively soft-bottom habitats. These types of bottom contact tools will not be reviewed as a monitoring option as they would violate the regulations of the SK-B MPA (CHN and DFO 2019).

A typical geological sample data stream: collection of sample + metadata (including timestamp, location, depth) → processing (e.g., sorting, examining, testing) → store, share, analyze, create data products.

5.1.3.1. Sediment samplers (grabs and cores) and traps

Sediment samplers are used to obtain discrete and measurable samples of the soft benthic environment. A comprehensive section on sediment samplers in Neves et al. (in prep[3]) does a thorough job of describing these bottom contact tools. To summarize, sediment samplers collect sediment, infauna, and epifauna samples and allow for physical, chemical, and biological processing and characterization. If possible, sediment samplers should be deployed with acoustic beacons and deployed with associated cameras. Grabs and cores can be tools associated with ROVs and HOVs as part of the physical sampling protocols.

During the 2018 Northeast Pacific Expedition (Pac2018-103), fifteen successful push cores were collected, which included samples from within the SK-B MPA (Gartner et al. 2022). The push cores were collected for two Canadian Healthy Oceans Network (CHONe) graduate students. Alessia Ciraolo (Memorial University) incubated sediment for 24 hours in order to look at benthic nutrient fluxes and benthic community structure under hypoxic conditions (unpublished data) (Figure 13D). Brett Jameson (University of Victoria) used microsensors to measure dissolved oxygen and nitrous oxide profiles in the top few millimeters of the sediment to investigate how oxygen minimum zones affect benthic nitrous oxide 21 cycling (Figure 13E). Additionally, Brett sampled for nucleic acids (DNA/RNA) to get a snapshot of the microbial community dynamics (unpublished data).

Sediment traps collect particles falling toward the seafloor. This gives scientists an idea of sediment rates, the accumulation of marine snow, and essentially nutrient cycling in and to the deep sea (WHOI 2022b). They are basic structures that generally consist of a funnel with a collecting jar at the bottom. Sediment traps have been deployed as tools on the ONC cables but could also be placed on the seafloor as an individual deployment. Export productivity is a defining/distinguishing characteristic of seamount ecosystems within the OPB and the lack of in situ data represents a major knowledge gap (Du Preez and Norgard 2022).

Key points to consider for sediment samplers:

- Collects fauna not visible in most imagery surveys (infauna).
- Small footprint in soft sediment substrates means the tools have low impact to the deep-sea environment.
- Potentially address a key knowledge gap.

5.1.3.2. Settlement Plates

To examine recruitment to an area, scientists can use artificial settlement plates as a proxy for natural substrates to examine the settlement of invertebrates. Settlement plates can be made from a variety of substrates (e.g., ceramic tiles, petri dishes, plastic, brick) and are helpful tools as the researchers can measure the number of settled larvae/juveniles for a set area and time (known deployment and retrieval dates). Settlement plates have been used in invasion ecology (Marrafinni et al. 2017), coral recruitment studies (e.g., Harriott and Fisk 1987; Green and Edmunds 2011; Salinas-de-Leon 2011), and even in the deep-sea (Meyer-Kaiser et al. 2019).

Settlements plates are usually basic low-cost tools. However, the use of settlement plates could be considered costly as they would require a submersible with manipulators for deployment and retrieval. Pairing settlement plates with other activities, such as the deployment of long-term monitoring site markers, would make them low cost. They are also often components of mooring systems (see Moorings, buoys, benthic landers section below). Another factor to consider would be timing. Though settlement plates at the shallower depths on SK-B Seamount would likely be colonized more quickly, studies in the deep sea suggest that recruitment and colonization is a much slower process and that time scales of multiple years and decades may be more appropriate (Meyer-Kaiser et al. 2019). Therefore, size of plate area, substrate type, deployment timing, and length of deployment will factor into the use and comparison of datasets between areas and over time.

Key points to consider for settlement plates:

- Provides content of recruitment of epifauna to an area, including invasive species.
- Low cost and complexity tools, but would likely need to be deployed during ROV/HOV operations.

5.1.4. Acoustic Tools

The following section builds on the principles of the acoustic sensors described above and details the more significant tools to study acoustic specific research questions.

A typical active acoustic data stream: remote instrument measurement + timestamp (continuous spatial data) → log raw data (often viewable as a map or profile in real-time) → processing (e.g., clean, correct, calibrate) and relating → store, share, assemble, analyze, create data products (e.g., bathymetric maps, water column profiles).

A typical passive acoustic data stream: instrument measurement in situ + timestamp (continuous time-series) → log raw data → processing (e.g., clean, correct, calibrate) and relating (e.g., to depth and spatial data) → store, share, assemble, analyze, create data products (e.g., soundscape).

5.1.4.1. Sonar

Sonar is a method of sound navigation and ranging where a transducer produces an acoustic signal or pulse and then receives the returned sound signal as it travels through the water and reflects off objects. The timing between the sound emission and reception can determine the range and orientation of objects (NOAA 2022). A comprehensive section on sonar in Neves et al. (in prep[3]) does a thorough job of describing the use of the technology. To summarize, the most common types of sonar in use are single beam and multibeam echosounders as well as sidescan sonar. Sonar can be used for large-scale mapping of ocean bathymetry (seascape), backscatter (composition), identifying localized features such as reefs and trawling scars (though the latter should be ground-truthed with imagery data), and examining pelagic species. Sonar systems can be mounted to ships or platforms. For monitoring, ships-mounted systems are more applicable. Sonar systems can also be incorporated on ROVs, HOVS, and drop camera systems, but more so for navigational purposes.

Benthic

Mapping ocean bathymetry is an essential part of understanding our oceans. During the 2018 expedition, a hull-mounted Kongsberg EM 302 Multibeam Echosounder was used to map (bathymetry and backscatter) the flanks and summits of the SK-B MPA seamounts (Gartner et al. 2022). Sub-bottom profiles were also collected with a hull-mounted Knudsen 3260 sub-bottom profiler and echosounder. This echosounder operates at low frequencies to penetrate and reflect off of the layers of sediment, revealing a cross-section of the seafloor structure. The 2018 mapping resulted in more detailed multibeam data collected than ever before for SK-B and Hodgkins seamounts and the first multibeam data for Pierce/Davidson (see Gartner et al. 2022). It is unlikely that the geomorphology of the seamounts within the SK-B MPA will change at the resolution of mapping at any time in the near future (unless there is a major catastrophic event, e.g., eruption or landslide), so bathymetric mapping is unlikely to be a part of a long-term monitoring program.

Pelagic

Ship-based sonar is also an effective tool for examining pelagic biomass distributions of nekton and plankton within the water column. For example, the Pacific Plankton Program (DFO 2022a) and fisheries programs such as Hake surveys (Akash Sastri, DFO, Sidney, BC, pers. comm.) use sonar to determine the high-resolution vertical placement of zooplankton and fishes within the water column and to attain low-resolution biomass estimates. The Plankton Program then pairs the bioacoustic information with net sampling to obtain a biomass calibration coefficient to relate to the sonar data, as well as to deter the species and age classes with the biomass. Many Canadian Coast Guard Vessels run echosounders in transit (for example, the CCGS *Tully* has a long-term time series within its single beam echosounder; Akash Sastri, DFO, Sidney, BC, pers. comm.).

5.1.4.2. Passive acoustic monitoring

Hydrophones are a type of passive sonar that do not emit any sounds but only detect sound waves coming in. Usually, the data from hydrophones does not provide a context of the range of the subject, unless multiple devices are deployed to allow for a triangulation of sound source (NOAA 2022). Hydrophones can be used in monitoring ship movement (e.g., Merchant et al. 2012), transient species (such as whales; e.g., Rice et al. 2021), and even differing soundscapes of glass sponge reefs (Archer et al. 2018). Monitoring species and communities using hydrophones is a promising prospect, but the technology is still in its infancy.

Hydrophones can be deployed on many platforms such as moorings, ships, gliders, saildrones, or buoys. For the SK-B MPA, continuous hydrophone coverage could be possible using a fleet of 4–6 saildrones operating out of Masset (Charles Hannah, DFO, Sidney, BC, pers. comm.). It is important to note that instrument calibration is very important so that sound measurements are consistent from deployment to deployment. Between 2006 and 2019 the soundscape was recorded using hydrophone moorings within the SK-B MPA (documented in Du Preez and Norgard 2022).

5.1.4.3. Acoustic doppler current profiler (ADCP)

An acoustic doppler current profiler (ADCP) is a tool to measure how fast water is moving across an entire water column. When deployed on the seafloor, they can measure the current speed not just in the benthic environment but also at equal intervals all the way up to the surface. They can also be deployed on vessel hulls. The Woods Hole Oceanographic Institution (WHOI) website (2022c) does an excellent job of describing how ADCPs operate and what the advantages and disadvantages are of the tool. To summarize, ADCPs emit pings of sound at a constant frequency. The difference in frequency between the waves the profiler sends out and the waves it receives is used to calculate how fast the particles and the water around them are moving. By also measuring the time it takes for the waves to bounce back, the profiler can measure current speed at many different depths with each series of pings.

In the Pacific Region, ADCPs are becoming a more common oceanographic tool. They can be deployed on moorings (e.g., Dellwood Seamount ONC autonomous mooring with ADCP) and submersibles (e.g., Pac2021-036, ADCP mounted to BOOTS; Gartner et al. in prep[6]) or mounted on vessel hulls (e.g., CCGS *John P. Tully* now has a long-time series from their hull-mounted ADCP that they run when underway; Akash Sastri, DFO, Sidney, BC, pers. comm.). The Dellwood mooring ADCP had battery-power to gather continuous data on seawater properties and near-bottom currents for one year and has since been retrieved (Gartner et al. 2022; data is available on the ONC Oceans 3.0 Data Search website). The Line P Program (see Strategies section below) incorporates ADCP moorings in their program at Station Papa. Lastly, moored ADCP data archived at the Institute of Ocean Sciences database from 1998 to present (DFO 2022b).

Key points to consider for acoustic tools:

- Provide continuous measurements of the environment and water column biota.
- Acoustic tools are becoming more ubiquitous and can be mounted from vessel hulls, HOVs, ROVS, drop cameras, and moorings.
- The use of hydrophones to monitor biological indicators is promising, but it is an emerging option and should not replace standard practises of sampling methods at this time.

[6] Gartner, H.N. et al. In prep. Pacific Seamounts 2021 Expedition Report (PAC2021-036). Can. Tech. Rep. Fish. Aquat. Sci.

- Costs of the tools can be quite high.

5.1.5. Oceanographic Tools

A typical oceanographic sample data stream: collection of sample over a set distance or depth + metadata (including timestamp, location, depth) → processing (e.g., sorting, identifying, measuring) → store, share, analyze, create data products.

5.1.5.1. Sensors

Sensors are essential tools in oceanography and can be mounted to many other tools (e.g., ROVs, AUVs, deployed benthic equipment)—as such, they were described in the section above (in the Submersibles section).

5.1.5.2. Oceanographic nets

Oceanographic nets are utilized to study the communities living in the water column. The animals collected can be processed for identification (species or best taxonomic resolution), age classes, and limited information about biomass (DFO 2022a). The location and design of the sampling program with these nets can infer the distribution of zooplankton and micronekton in an area. Described below are a few of the sampling nets most commonly used in the Pacific Region Plankton Programs.

Bongo nets consist of two ring nets mounted next to each other (Figure 15A-B). The nets have a small width and a long funnel shape. The nets are towed from a set depth, through the water column, to the surface. Typically, half of the bongo samples can be preserved in formalin for future taxonomic analysis and the other half used for biomass analysis (Chelsea Stanley, DFO, Sidney, BC, pers. comm.) (Figure 15C-D). Bongos typically have CTD and oxygen sensors mounted on the net to gather complementary oceanographic details of cast. Recently the DFO Plankton Program has paired this type of sample collection with the use of an underwater vision profiler (UVP; see section below).

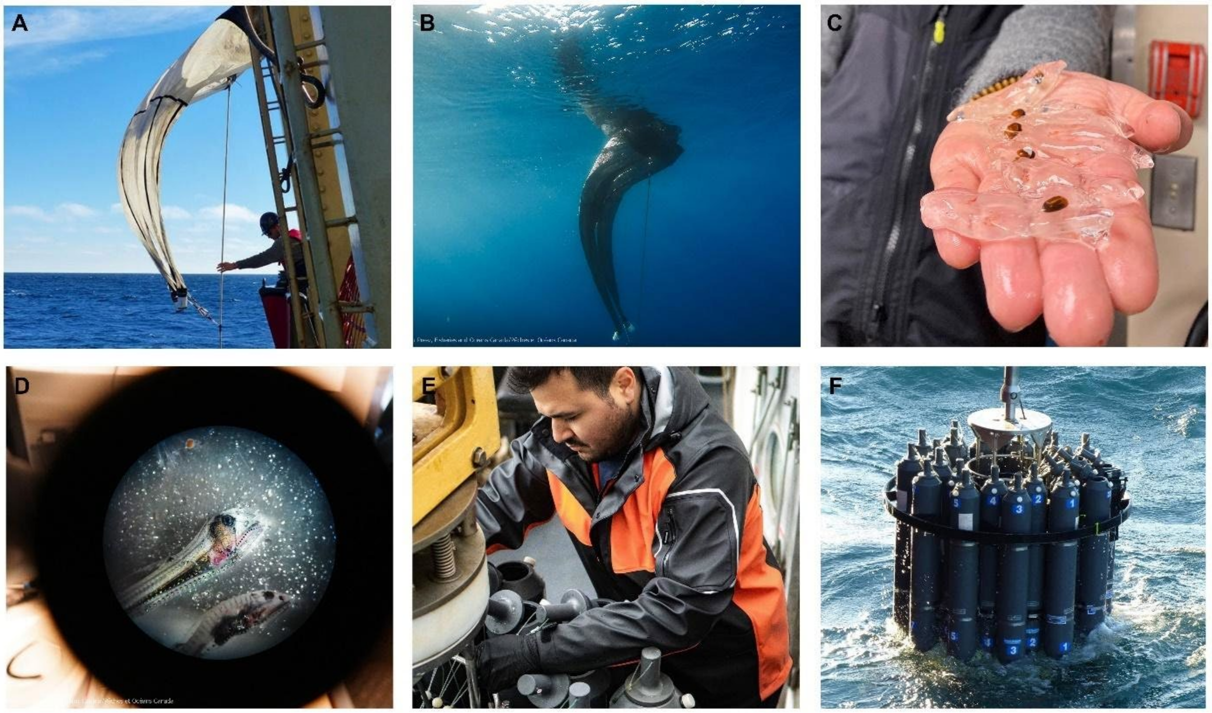

Figure 15. Examples of oceanographic tools and samples from Offshore Expeditions (Pac2018-103, Pac2019-014, Pac2021-036Pac202): (A) a bongo net above and (B) below water, (C) shallow-water zooplankton samples (salps), (D) deep-sea zooplankton samples under a microscope (Viper Fish), (E) opening the caps of Niskin bottles on a rosette, and (F) a rosette (with CTD) returning from a cast with its caps closed (and discrete water samples inside). Credit: Fisheries and Oceans Canada, S. Du Preez, C. Du Preez.

Multinets (e.g., the MOCNESS: Multiple Opening/Closing Net and Environmental Sensing System) and a HydroBios MultiNet Plankton Sampler are other styles of sampling net currently in use in the Pacific. These nets have one large opening but multiple nets that can be triggered to close remotely from a deck unit on the ship. By opening and closing the nets at specific depths, they allow for stratified zooplankton sampling of the water column (Chelsea Stanley, DFO, Sidney, BC, pers. comm.). This aids in the identification of organisms that are responsible for producing the backscattering layers observed on echosounders. These net types typically have CTD and oxygen sensors mounted to gather complementary oceanographic details of the casts.

The history of oceanographic studies conducted within the context of the SK-B MPA is detailed in Canessa (2003), Gale et al. (2017), and this research document (see the Oceanographic activities (history) section). Additionally informative for the SK-B MPA is the long-term data series along Line P, which includes seven established oceanographic nets sampling stations, the oceanographic components of the DFO lead Offshore Expeditions to other OPB seamounts (including the Pac2018-103, Gartner et al. 2022) (see the Strategies sections below for details).

Key points to consider for nets:

- Best method for looking at the zooplankton/small nekton community (identity, age class, relative abundance, limited biomass).
- Best when paired with acoustic information and CTD data (and increasingly UVP).
- High costs as requires ship time and many processing hours for the data.

5.1.5.3. Water sampling

Collecting discrete samples of water can be used to answer a wide range of physical, chemical, and biological investigations. Water sampling devices can range from buckets dropped into the water to larger sampling structures, with multiple bottles, sent thousands of meters below the surface. The most common sampling devices used in the Pacific for sampling in the open ocean/deep sea are known as CTD/rosettes (Figure 15E-F). Each rosette cast can collect continuous water chemistry readings from a SeaBird 9/11 CTD unit (described in the section above) as the twenty-four 10 L Niskin bottles of the rosette are triggered one at a time to collect discrete water samples at specific depths (Chelsea Stanley, DFO, Sidney, BC, pers. comm.). Water from each of these Niskin bottles can then be used to determine levels of dissolved oxygen, dissolved inorganic carbon (DIC), nutrients, salinity and for environmental (e)DNA. Sampling bottles, such as Niskins, can also be mounted on ROVs for discrete sampling at depth during benthic surveys.

The history of oceanographic studies conducted within the context of the SK-B MPA is detailed in Canessa (2003), Gale et al. (2017), and this research document (see the Oceanographic activities section). Additionally informative for the SK-B MPA, is the long-term data series along Line P (see Strategies sections below for details), that includes seven established oceanographic rosette sampling stations.

Niskins, or other sampling bottles, can be mounted on ROVs for discrete sampling at depth during benthic surveys—often with the objective to collect eDNA samples (see the Molecular analysis and environmental DNA (eDNA) section below). Additionally informative for the SK-B MPA, is the long-term data series along Line P (see Strategies sections below for details), that includes seven established oceanographic rosette sampling stations.

Water can also be sampled in situ. A tool that is useful in studying plankton communities is the continuous plankton recorder (CPR). The CPR is a vessel-mounted structure that filters plankton from the water over long distances. The plankton are captured on continuously moving bands of filter silk that can be removed from the mechanism back at the laboratory, and parceled to represent set distances within the vessel's travel (Marine Biological Association 2022). The first prototype was developed in 1927 and has had continued use and growth worldwide. However, data gaps existed in the Pacific until 1997. In 2003 DFO (Institute of Ocean Sciences) signed a collaborative agreement to service and unload CPRs locally. Plankton monitoring time series (2000-2021) now exists for the BC shelf and the offshore waters west of BC (North Pacific Marine Science Organization [PICES] 2022).

Another emerging, in situ, water sampling technology that is currently being tested in the Pacific Region is Ascension. It is a tethered vertical profiling tool that collects filtered microplastic samples through the water column. It is currently rated to 400 m depth and is envisioned to work for eDNA sampling (Ocean Diagnostics Inc. 2021).

Key points to consider for water sampling:

- Tools to collect parcels of water themselves are simple but require ship time.
- Samples can be processed on ship to answer specific research objectives and can be related to the plankton community, nutrients, dissolved oxygen, salinity, and eDNA.
- The use of eDNA to monitor biological indicators is promising, but it is an emerging option and should not replace standard practises of sampling methods at this time (see the Molecular analysis and environmental DNA (eDNA) section below).
- CPR and other emerging technologies allow for sampling in situ.

5.1.5.4. Underwater vision profiler (UVP)

Underwater vision profilers (UVP) are imagery systems designed specifically for large particulate matter and plankton. The latest two versions of this tool (Picheral et al. 2010, 2022) target particles greater than 100 µm and are so small and effective that they can be deployed and integrated within CTDs, AUVs, ROVs, and moorings. UVP are pressure-safe underwater cameras that are towed vertically through the water column. Objects are illuminated by the system's integrated pulsed lighting (Picheral et al. 2010, 2022) and shutter to allow for precision images that can be used for identification, individual measurements, and estimates of the small plankton vertical distribution and abundance in the water column.

UVP are a new tool, but are being increasingly integrated to the DFO Pacific Plankton Program. In 2021, during an expedition to OPB seamounts in the TḥT AOI (Figure 2A), fifteen casts were made with UVP, and paired with bongo casts, to 250 m (unpublished data; Gartner et al. in prep[6]). Currently, we do not have detailed Pacific Region-specific information on post-processing times and effectiveness in determining metrics compared to more traditional methods such as plankton tows.

Key points to consider:

- Imagery of particulate matter and plankton in situ.
- Improvements to the technology suggest it can be incorporated onto a number of platforms (e.g., moorings, AUVs).
- Emerging tool for the Pacific Region.

5.1.5.5. Deployed gear

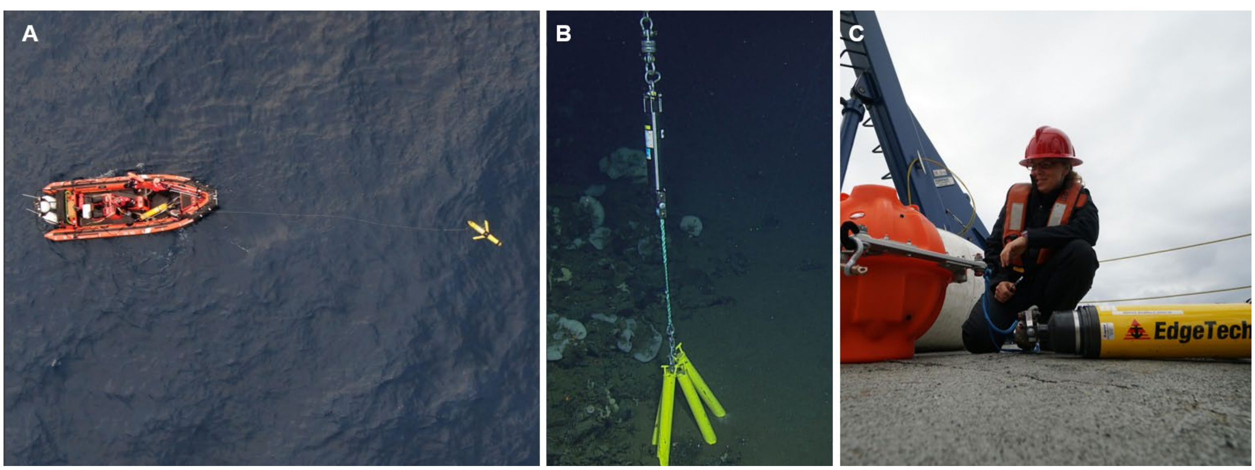

Figure 16. Examples of deployed scientific gear: (A) a C-PROOF glider, (B) an autonomous mooring with ADCP designed by Ocean Networks Canada, and (C) a mooring with hydrophone for the DFO Cetacean Research Program—all deployed during Offshore Expeditions (Pac2018-103 and Pac2019-014) over Dellwood Seamount (the second most well studied seamount in the Offshore Pacific Bioregion; SGáan Kínghlas-Bowie Seamount is the first (Du Preez and Norgard 2022). Credits: Fisheries and Oceans Canada, S. Du Preez, Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners.

Gliders

Gliders are oceanographic tools that can be used to collect data from remote locations, over a long time period, at a relatively low cost (Figure 16A). They are autonomous, unoccupied underwater robots that can be equipped with a variety of sensors. Gliders move along a pre-programmed track and move up and down through the water column using an internal pump to change its buoyancy. Data collected can be transmitted via satellite, and some gliders can even have their path altered via two-way satellite communications (Nation Oceanography Centre [NOC] 2022).

DFO gliders typically carry temperature, conductivity, pressure, oxygen, optical backscatter and fluorescence (chlorophyll and coloured dissolved organic matter) sensors. Using glider information helps creates a better picture of what is happening in the ocean, filling in depths and spatial scales scientists are unable to detect from satellites, which cover the surface only, or large research expeditions, which are broad scale and infrequent (Tetjana Ross, DFO, Sidney, BC, pers. comm.).

In the Pacific, there is a glider program through the Canadian Pacific Robotic Ocean Observing Facility (C-PROOF; for details, see the Strategies sections below). C-PROOF deploys autonomous ocean observing platforms, such as instrumented ocean gliders and profiling floats, to explore and monitor both BC coastal and offshore waters to track life, quantify turbulence, and measure ocean nutrients (C-PROOF Group 2022). In 2019, the glider 'Wall-e' successfully traveled to Station Papa offshore of BC tracking oceanographic measurements down to 1,000 m (Klymak 2019). This successful deployment marked the start of a repeated "northern" survey, which starts on the continental shelf and follows Line P out to the northwest corner of the TḥT AOI. A second, "southern" survey line is proposed, which would likely start in the same location (P4 on line P) but run to the southwest corner of the TḥT AOI (Du Preez and Norgard 2022). This data can be informative for the SK̲-B MPA; however, monitoring programs could consider adding an annual glider path to the SK̲-B MPA.

Gliders are similar to AUVs with drawbacks related to low responsiveness and higher risk of loss in comparison to tether equipment (e.g., a glider deployed on Dellwood Seamount in 2017 was lost at sea; unpublished data).

Key points to consider for gliders:

- Emerging tools equipped with sensors that cover large spatial and temporal scale.
- Initial costs of equipment are expensive, but relatively low cost when considering spatial and temporal coverage and the potential for repeated use.

Floats and drifters

One of the simplest concepts used in the study of physical oceanography (movement of currents and water parcels) involves simply dropping 'things' in the ocean and then tracking where they drift (WHOI 2022d). These simple concept sampling devices are referred to as floats or drifters. The historic 'message in a bottle' was the initial form of drift and is again being continued today by DFO scientists (see the Strategies sections below). Floats can be built to also rise and fall vertically through the water column. Modern advancements on floats and drifters include radio or satellite beacons and Global Positioning System (GPS) receivers to track their movements.

In the Pacific, the Institute of Ocean Sciences (IOS) has developed surface drift trackers, affectionately known as Sponge Bobs, due to the yellow and blue spongey material they are made from, to track ocean currents (Murray 2019). These buoy-like devices can be deployed anywhere in the ocean until they run aground or are collected. On each unit is a GPS satellite tracker. The information allows experts to build accurate modelling systems of the world's ocean surface currents. DFO also contributes to and analyzes information from the Intergovernmental Oceanographic Commission's Global Ocean Observing System (DFO 2022c; see the Strategies sections below). Some drifters may be equipped with sensors for measuring parameters such as temperature, barometric pressure, salinity, wind, and wave height.

Floats follow a similar concept, except that they can move up and down in the water column using simple mechanical pumps, bladders, and other devices. They change the buoyancy of the float, allowing it to bob between various depths. Modern floats are usually programmed to rise to the surface periodically in order to send data via satellite antenna to scientists on shore (WHOI 2022d).

In the Pacific, Argo floats are commonly used to profile the water column. Individual Argo floats could be targeted to study the SK-B MPA. DFO oceanographers participate in the global Argo float array. As summarized by Dr. Tetjana Ross (DFO, Sidney, BC, pers. comm.), Argo is a global array of about 4,000 free-drifting profiling floats that measure the temperature and salinity of the upper 2,000 m of the ocean. This allows continuous monitoring of the temperature, salinity, and velocity of the upper ocean, with all data being relayed and made publicly available within hours after collection (see the Strategies sections below). They are typically operated to collect one profile every ten days and drift at 1,000 m depth for the intervening time. The newer BGC-Argo floats also observe biogeochemical variables using oxygen, pH, nitrate, chlorophyll, optical backscatter and/or irradiance sensors. If individual Argo floats cannot be targeted to the SK-B MPA, online (publicly accessible) information from the global Argo array may inform baseline and monitoring data. Unfortunately, after its lifespan (usually five years), a float becomes marine debris.

Key points to consider for floats and drifters:

- Emerging tools equipped with sensors that cover large spatial and temporal scale.
- Initial costs of equipment are expensive (but relatively low cost when considering spatial and temporal coverage and the potential for repeated use).
- Argo floats are a global array and data are readily available online.

Moorings, buoys, benthic landers

Similar to the section above, these tools are equipment deployed and left at-sea. Scientific moorings are a term used for a collection of oceanographic instruments connected to a rope or wire, a floating unit, and anchored to the seafloor. Neves et al. (in prep[3]) has a section on moorings, and benthic lander technologies, their advantages and disadvantages, and considerations. To summarize, moorings are left underwater for a set period of time (limited by the battery life of instruments), and are usually recovered using an acoustic release (or a grappler if release fails). The data collected depends on the oceanographic instruments selected for the mooring (which also affects the cost). Moorings are large, heavy, and therefore have important logistics associated with their deployment and recovery.

The data collected by moorings is not generally collected in real-time and is dependent on the recovery of the mooring. Some modern advancements have enabled data to be communicated via satellites upon arrival at the surface (remote release). Moorings are one of the most effective ways of measuring near-bottom velocity profiles over the benthos and should be considered for use within the SK-B MPA. Moorings could also be complemented with the addition of settling plates (see the Seafloor Gear section above) to study recruitment to an area. Additionally, sediment traps can be added to collect particles falling toward the seafloor.

A recent success story for using moorings to study OPB seamounts was the autonomous mooring with ADCP developed by ONC that was deployed in 2018 on Dellwood Seamount (Figure 16B) (Gartner et al. 2022). A second mooring was deployed during the same expedition, this one with a hydrophone to record marine mammal and fish sounds (Figure 16C) (Gartner et al. 2022).

Some surface buoys are considered to be moorings. A Viking buoy is a moored surface float with a good atmospheric measuring package and an oceanographic profiling instrument (temperature, salinity, and oxygen). The data is logged internally as well as transmitted in near real-time via cellular or satellite modem. The standard package comes with pH sensor and a fluorometer fixed in the upper metre. Other instruments could be added, such as ADCPs, optical sensors or hydrophones. However, this type of gear is probably too light for an offshore location like the SK-B MPA. There are sixteen offshore weather buoys that are maintained by Environment Canada and DFO in association with Axys, that collect data on air pressure, air temperature, sea surface temperature (SST), wind observations, and wave height and are transmitted globally (DFO 2009b)

Another type of mooring is a benthic lander. To summarize Neves et al. (in prep[3]), these moorings can additionally host benthic chambers (that can be used for incubation experiments), carry cameras, have sediment traps and settlement plates, and sediment profiler systems. They are deployed through free fall but are equipped with buoyancy and ballast release systems, which allow them to sink slowly to the seabed, causing minimal seafloor disturbance before the chambers make contact with the sediment (Bagley et al. 2004; Gage and Bett 2005).

Key points to consider for mooring etc.:

- Detailed data collected for a set period of time in locations where data collection is usually finite.
- Equipment is expensive and can be costly to deploy.

Saildrones

Saildrones were first tested as research platforms off the west coast of Canada and the United States in the summer of 2018. They are autonomous platforms that collect a suite of geo-referenced acoustic, oceanographic and atmospheric data (Chu et al. 2019). These wind- and solar-powered robots were designed to monitor the weather but have been developed to add sensors to measure oceanographic conditions such as temperature, salinity, and carbon dioxide concentrations. They can also be equipped with acoustic sensors to collect data on biomass within the water column (Dimoff 2018).

Key points to consider for saildrones:

- Emerging tools equipped with sensors that cover large spatial and temporal scale.
- Initial costs of equipment are expensive (but relatively low cost when considering spatial and temporal coverage as well as the potential for repeated use).

5.1.6. Online Data

A typical online data stream: download data + metadata → processing (e.g., clean, correct, calibrate) and relating (e.g., to depth and spatial data) → analyze and create data products (e.g., maps).

5.1.6.1. Satellites

Satellites are machines that orbit the earth, sometimes several times a day. DFO oceanographer Tetjana Ross (DFO, Sidney, BC, pers. comm.) describes the use of these tools: “By placing instruments on a satellite, an oceanographer can obtain data from all over the world in a short amount of time. These instruments can tell us about ocean bathymetry, SST, sea level, the speed of the wind above the water, ocean colour, coral reefs, and sea and lake ice. For example, ocean colour data helps researchers determine the impact of floods along the coast, detect river plumes, and locate blooms of harmful algae that can contaminate shellfish and kill other fishes and marine mammals. Another important contribution of satellite sea level data is in assessing sea level rise due to climate change, which can cause inundation of coastal areas and islands, shoreline erosion, and destruction of important ecosystems such as wetlands and mangroves".

Oceanographers frequently look at satellite SST and ocean colour (a proxy for primary production as the primary product is chlorophyll-a biomass). An analysis by Devred et al. (2021) revealed a very important point, the Northeast Pacific is very cloudy and as a result, an individual 4 km pixel near SK-B yields data on a particular day between 1 and 10% of the time (low in winter and summer, high in spring and fall). As such spatial and temporal averaging is required to derive useful data sets, which places important limits on observing details of SK-B from satellites. The ocean colour satellites further do not acquire much data in the winter (Dec–Feb) because of the low sun angle. For example, December could not be included in a 19-year analysis based on satellite data for the OPB (Du Preez and Norgard 2022). There are derived products available that estimate the actual production rate of phytoplankton Net Primary Production (NPP). The spatial patterns of NPP can be very different from chlorophyll-a.

Particularly important for the SK-B MPA, is that there are also altimetric satellites that measure sea surface height. They can be used to track Haida Eddies, which are episodic, clockwise rotation ocean eddies that form during the winter off the coast of Haida Gwaii (DFO 2019d). These Haida Eddies bring nutrients and plankton, including potential larval recruits, to the SK-B MPA ecosystem, therefore, changes in the frequency of these Haida Eddies would likely impact the ecosystems of the SK-B MPA.

DFO contributes to and analyses data from National Satellite Programs, including (DFO 2021e; and see the Strategies section below):

- Advanced Very High Resolution Radiometer (AVHRR) remote sensing satellite
- Medium Resolution Imaging Spectrometer (MERIS) remote sensing satellite
- Moderate Resolution Imaging Spectroradiometer (MODIS) remote sensing satellite
- Operational Remote Sensing at Bedford Institute of Oceanography
- Sea-viewing Wide Field-of view Sensor (SeaWiFS) remote sensing satellite
- Virtual Centre for Ocean Satellite Salinity (VCOSS) remote sensing satellite

Satellites in themselves are expensive, exist in a harsh environment, and are difficult to maintain. However, there are many major institutions supporting their development and use and the data they collect are often shared online (for no or low fees). For example, organizations such as National Aeronautics and Space Administration (NASA) and NOAA make their data readily available. Therefore the cost of using satellite data to monitor the SK-B MPA is minimal. Though the measurements are only of sea surface properties, they can be informative and cover a large spatial area. They can provide insight into the SK-B MPA while providing context within the greater Pacific Ocean.

Key points to consider for satellites:

- Excellent spatial coverage of sea surface measurement within the MPA.
- Limitations, particularly in winter months, due to location and weather.
- Source data will determine the resolution of the data.
- Readily available data online for low or no cost.

5.1.6.2. Models

Ocean circulation models are powerful tools for predicting the state of the ocean. Environment and Climate Change Canada (ECCC) runs a coupled atmosphere-ocean prediction system for weather and ocean forecasting (e.g., Ocean Navigator 2024). It provides a 3-D description of the velocity, temperature and salinity fields at daily increments. The surface fields (including water level) are available at hourly increments. Holdsworth et al. (2021) used the same basic ocean model technology plus a biogeochemistry model to investigate changes in the ocean state under two climate change scenarios for the continental shelf of the Canadian Pacific coast.

One of the data sources to inform oceanographic modelling is the DFO resource called the BioChem database (DFO 2022d; Devine et al. 2014). BioChem is an archive of marine biological and chemical data maintained by DFO collected from department research initiatives and from areas of Canadian interest.

An example of using modelling is the collaborative efforts of DFO and NOAA to study ocean acidification in the North Pacific (DFO and NOAA 2018). DFO and NOAA want to connect their regional climate models across North America to better predict the impacts of climate change, specifically ocean acidification. For example, DFO and NOAA have separate models for the Northeast Pacific: one for Canadian waters off coastal British Columbia and another model for the Pacific Northwest coast in the US. These models could be connected with shared data to better understand regional dynamics of ocean acidification effects.

Modelling can also be applied to biological data where the computer algorithms utilize available data to predict the distribution of animals across a geographic space and time with known, extrapolated, or predicted environmental data (e.g., oxygen and temperature “at depth” used in DFO 2019a; Du Preez and Norgard 2022). Though there are limitations with having sparse data from the deep sea, species distribution mapping is an effective tool for seamount habitats and MPAs (e.g., Auscavitch et al. 2020). Within the SK-B MPA, baseline data could inform species distribution models that would facilitate long-term monitoring locations for our indicator species. Independent dataset for ground-truthing can dramatically increase the confidence and usability of a model.

Key points to consider for models:

- Excellent spatial coverage.
- Modelling has broad application as a tool.
- Model outputs are subject to the type and data used.
- Requires ground-truthing for confidence.

5.1.6.3. Undersea cabled observatories

Cabled observatories use fiber-optic communications systems and electric power cables to establish networks of sensors and tools on the seafloor and in the water column. The infrastructure established is usually remote, difficult to reach places and allows researchers to deploy and recover sensors and tools collecting data longer-term (usually more than a month) and even multi-year studies (WHOI 2022e).

There are currently no cabled observatories in the SK-B MPA. However, in the Pacific, ONC operates several ocean observatories (for details, see ONC website). The largest observatory is called the North East Pacific Time-series Underwater Networked Experiments (NEPTUNE), and spans a wide range of ocean environments, including deep-sea habitats, which may provide oceanographic context for the SK-B MPA. Two of the observatory nodes are near three seamount chains (Heck, Heckle, and Springfield; ~700 km south of the SK-B MPA). From ONC

(2022c): “In the Northeast Pacific Ocean, ONC is observing changes in the timing, intensity, and chemical properties of upwelled waters, nutrient availability, and primary production. To quantify these changes, ONC is committed to continuous, long-term recording of temperature, salinity, direction and intensity of water currents, dissolved oxygen distributions, pH and pCO_2 using sensors installed on the NEPTUNE observatory.” De Leo et al. (2018) do an excellent job of highlighting the variety of research and data acquisition accomplished using the NEPTUNE cabled observatory for Barkley Canyon over a span of almost a decade.

Though the NEPTUNE observatory provides context for the SK-B MPA, a cabled observatory within the SK-B MPA would greatly enhance monitoring strategies. Cabled observatories require large infrastructure and investment, given the location of the SK-B MPA, costs would likely be prohibitive.

Key points to consider cabled observatories:

- Established observatories in the Pacific can provide context for the SK-B MPA.
- It would be extremely costly to establish a node within the SK-B MPA.

5.1.7. Post-Processing Tools

Here we highlight some of the powerful tools that can be informative for monitoring that are processed post sample or data collection.

5.1.7.1. Molecular analysis and environmental DNA (eDNA)

Molecular analysis is a post-processing tool that allows scientists to sequence, or barcode, the genetic code for organisms from tissue samples. Modern taxonomy (the identification of species by their morphological traits) is complemented by molecular work, particularly for species from the deep sea, which are relatively unknown and not easily sampled. Many deep-sea species are difficult to identify based on gross morphology (particularly if they’ve never been encountered before). Even for species encountered more frequently, it can be difficult, for example, Neves et al. (in prep[3]) describe, “Even in cases where personnel are trained, species-level identifications can be difficult or impossible by sight alone. For example, inter-habitat morphological variation can occur in sponges (Hooper 2003), and in most cases, accurate species identification requires the use of microscopic and/or molecular methods.” By taking small snippets, or tissue samples, of an animal, we can better understand the identity and phylogenic relationships of deep-sea species.

During the 2018 deep-sea expedition within the SK-B MPA, specimens were collected for identification and molecular analysis. Many of these voucher specimens were rare or unique species, including seven new species of glass sponges (identified by the late Dr. Henry Reiswig), eight new species of demosponge (data in work by Bruce Ott), two new species of corals, and a parasitic zoanthid (Merlin Best working in collaboration with world experts for the Cnidarians) (see Gartner et al. 2022). Tissue samples of the vouchers were also collected. Much work is currently underway, but molecular analysis preliminary findings are helping to confirm species identifications, discover new species to science, provide phylogenetic context for the new species, and contribute to worldwide data/reference for species that are rarely sampled (Merlin Best, DFO, Sidney, BC, pers. comm.). Creating reference taxonomic (morphology), DNA, and eDNA libraries associated with deep-sea fauna facilitates species identifications and future research.

Environmental DNA (eDNA) is an emerging molecular tool. It allows for the identification of multiple taxonomic groups from a specific area based on a sample of the environment where those organisms lived or pass through (Loeza-Quintana et al. 2020). Neves et al. (in prep[3]) highlight the types of research that has been done on deep-sea fauna and summarize that eDNA is particularly useful for the identification of cryptic or rare species and can capture species presence not captured in other sampling tools. Water column samples can be collected via Niskin bottles (or other water sampling devices) and sediment samples can be collected via cores, grabs, or sediment traps.

In 2018, eDNA samples were collected from the SK-B MPA and are being worked up through a collaboration with scientists at NOAA (Dr. Meredith Everett, NOAA, Seattle, WA, pers. comm). It would be good to note here that, much like hydrophones, the use of eDNA is a promising prospect, but the technology and processing techniques are still very much in their infancy.

5.2. STRATEGIES

Monitoring strategies are those avenues employed to undertake the monitoring protocols (DFO 2012). Monitoring strategies for the SK-B MPA can be delivered through the programs listed below. These programs include one or more potential monitoring protocols/tools identified for the SK-B MPA. We have differentiated between spatial coverage within the SK-B MPA or just informative for the MPA. We have tried to indicate where it would be beneficial to expand current programs to include the SK-B MPA. The remoteness, depth range, and size of the SK-B MPA is a limitation influencing accessibility, spatial and temporal coverage, cost, and other feasibility considerations.

5.2.1. Strategies Within the SGáan Kínghlas-Bowie Marine Protected Area

Strategy Name:	**Offshore expeditions**

Description: DFO leads and designs multi-disciplinary expeditions with partners to the OPB to study deep-sea environments. The scale and location of each expedition are guided by science deliverables and available resources. Includes pilot study monitoring sites established within the SK-B MPA in 2018 (see Gartner et al. 2022) for potential long-term monitoring.

Protocols: When resources are not limited, the expeditions typically target mapping by echosounder, oceanographic studies (echosounders, rosettes, plankton nets), and benthic imagery surveys by ROV or BOOTS drop camera (e.g., see Gartner et al. 2022).

Implementation: Since 2017 (creation of Deep-Sea Ecology Program), these expeditions happen annually (COVID exception) in the OPB, including trips to the SK-B MPA. Historically (pre-2017), expeditions to study deep-sea environments have occurred but they were generally ad hoc. Targeted DFO-led and co-led expeditions to the SK-B MPA have happened five times in the past 21 years (see the Benthic science activities section above). The data collected from these expeditions are informative for all indicator groupings and metrics (biological, environmental, stressor).

Principal Investigator(s): DFO Deep-Sea Ecology Program (Cherisse Du Preez), usually in collaboration with other DFO programs (e.g., Integrated Conservation Monitoring Program - Tammy Norgard, and Plankton Group - Chelsea Stanley), Indigenous partners (CHN, Nuu-chah-nulth Tribal Council), and external partners (ONC, Oceana Canada).

Data produced: The benthic submersible dives are publicly available online through ONC's platform (video and audio with live annotation). Plankton studies shared through Plankton Program (see Plankton Program box below). Cruise reports (e.g., Gartner et al. 2022, and in prep) with mapping efforts shared.

Strategy Name:	**Offshore expeditions**

Data link: publicly available dive videos found on the ONC SeaTube Pro website, DFO (2018a), cruise reports and other open data types listed (e.g., Gartner et al. [2022] mapping) – all acoustic backscatter data, swath bathymetry, and navigation files were shared with the Marine Geoscience Data System (MGDS; NA097 – Marine Geoscience Data System), which provides free public access and feeds into other mapping initiatives such as General Bathymetric Chart of the Oceans (GEBCO). The NOAA Multibeam Data Report for NA097 is also available online.

Cost: $500,000–$1,000,000 for a two-week survey (survey costs are closer to $500,000 when using DFO equipment such as BOOTS drop camera and costs closer to $1,000,000 when renting ROV systems or entire vessels such as the *Nautilus*).

Strategy Name:	**Marine mammal surveys (Cetacean Research Program)**

Description: Systematic and opportunistic visual surveys occur annually with standardized survey methods, as well as hydrophone deployments (e.g., on SK-B Seamount; Allen et al. 2018). Observations in the OPB are often limited. The DFO Pacific Cetacean Research Program partnered with the Pacific Region International Survey of Marine Megafauna (PRISMM) survey in 2018 for the first extensive line-transect survey that included both visual and passive acoustic monitoring components. This was the first systematic survey of marine mammals in the OPB, including the SK-B MPA (Wright et al. 2021).

Protocols: Visual surface surveys and hydrophones.

Implementation: 2018 survey.

Principal Investigator(s): DFO (Sean MacConnachie).

Data produced: Distribution and density estimate maps, individual sightings.

Data link: Wright et al. 2021; GIS Hub data and maps available upon request (Thomas Doniol-Valcroze, DFO).

Cost: $0 (no additional costs with current programming).

Strategy Name:	**Haida Eddies monitoring**

Description: From February 1998 to September 2005, there were monitoring programs for Haida and Sitka Eddies in the Northeast Pacific. This monitoring program utilized satellites to measure sea surface elevations and chlorophyll-a concentrations. Satellite measurements were supplemented with ship-based Continuous Plankton Recorders (CPRS) and in one year by passing a transmissometer through the 1998 eddy. All relevant data was published in Studies in Oceanography Haida Eddies: Mesoscale Transport in the Northeast Pacific Volume 52, Numbers 7–8, 2005. Reinstating and comparing data from this monitoring program would be informative for the oceanographic conditions and larval supply to the MPA (e.g., Ross et al. In prep[7]).

Protocols: Satellite and Oceanography (sensors, plankton nets).

[7] Ross, T., Du Preez, C., and Ianson, D. In prep. Flow Around Aeamounts and Larval Retention: Revisiting the Taylor Cone.

Strategy Name:	**Haida Eddies monitoring**

Implementation: 1998–2005; could reinstate.

Principal Investigator(s): DFO (William R. Crawford and multiple co-authors during 1998–2005).

Data produced: Maps, time series.

Data link: DFO 2022e; DFO 2019d.

Cost: currently no program ($0), reinstating $45,000 annually (staff).

Strategy Name:	**Sea surface conditions monitoring**

Description: Oceanographers can use rapidly available satellite data from a variety of providers with no or low costs. The resolution of the data is dependent on the source provider. Examples of satellite data in use in the Pacific include oceanographers monitoring the 7-day mean SST (degrees Celsius) and anomalies and monthly mean SST and chlorophyll-a concentration for regions of interest, including the SK-B MPA (Hardy et al. 2021)

Protocols: Satellites.

Implementation: Dependent on dataset and processing but essentially, daily means possible (rare), in SK-B monthly more reliable. Provides context of the SK-B MPA within Pacific and global datasets.

Principal Investigator(s): DFO (Charles Hannah and Andrea Hilborn).

Data produced: Maps (e.g., Hannah and McKinnell 2016; Devred et al. 2021); monthly time series, climatology plots, seasonal trend summaries (Devred et al. 2021).

Data links: SOPhyE 2024; DFO 2021e; Hilborn et al. 2024.

Cost: $0 (no additional costs with current programming).

Strategy Name:	**Mooring Program**

Description: Historic deployment of pressure and temperature gauge on SK-B Seamount in 1974–75. Re-establishing a mooring program within the SK-B MPA would be informative of many oceanographic metrics. A basic mooring comes with 2 ADCPs, 4 CTDs, floatation and benthic release. Additions could include instruments for measuring pCO_2 and pH or deploying hydrophones for marine mammal detection/soundscape work.

Protocols: Moorings.

Implementation: Reinstate on suggested cycle (e.g., yearly).

Principal Investigator(s): DFO (no current lead).

Data produced: Sensor and equipment dependent. Typical salinity, temperature, depth, pressure, currents.

Data links: Crawford et al. 1981.

Cost: $310,000 per standard mooring unit for shallow water, more for deeper and more sensors.

5.2.2. Strategies Currently Outside the SGáan Kínghlas-Bowie Marine Protected Area

Existing monitoring strategies exist within the OPB but outside of the SK-B MPA that may be informative or potentially duplicated within (or expanded to include) the SK-B MPA. But how relevant is outside information? Do local processes over and around the SK-B MPA seamounts modify the water properties sufficiently such that the water over the seamount has different characteristics from the surrounding ocean? If so, does the modified water stay over the seamount long enough to affect the ecology (e.g., plankton populations)? Future research should explore the comparability of measurements inside and outside the SK-B MPA.

These are some of the primary questions that should be asked in order to understand the appropriate ways, and limitations to, relating outside data, trends, and/or events to the SK-B MPA.

Strategy Name:	**Line P**

Description: Ocean Station Papa situated at 50°N 145°W is the final station of a 26 station survey line that extends from the mouth of the Strait of Juan de Fuca (i.e., “near” to but not within the SK-B MPA). Since 1959, expeditions conduct oceanographic research along Line P with the recent trend being with three trips annually. The program samples to depths of 2,500 m. With regard to the monitoring of the SK-B MPA, Line P data provides appropriate information and trends on ocean acidification parameters and the oxygen minimum zone. *Profiles every year or two within the SK-B MPA would help resolve the relationship between Line P data and conditions within the SK-B MPA.*

Protocols: Oceanographic sampling (CTD, rosettes, bongo; for details, see the DFO Water Properties Group website).

Implementation: Up to three times annually (typically in February, June, and August).

Principal Investigator(s): DFO (Marie Robert).

Data produced: CTD data, Chemistry (rosette) data, Zooplankton data, Trace metal data, Drifter data, and thermosalinograph and loop data. The CTD, Rosette and Zooplankton data can either be downloaded by individual cast (one file), or by groups of casts (e.g., Deep casts, DMS casts, UBC casts, etc.). Data often summarized at State of the Ocean (e.g., Boldt et al. 2018).

Data link: Main Line P information and data source: DFO Water Properties Group website.

Cost: $0 (no additional costs with current programming).

Strategy Name:	**Plankton Program**

Description: The Pacific Plankton Program has zooplankton-related data for projects starting in the 1980s to present. Its database houses records for over 350,000 species from more than 9,500 oceanographic sampling stations between 42-65°N and 120-180°W. There are time series established, such as Line P and LaPerouse, that may be informative (e.g., see Young and Galbraith 2021). Plus ad hoc sampling has occurred in conjunction with Offshore Expeditions (see the Benthic science activities section for details). *A new time series sampling strategy to inform plankton processes in the SK-B MPA would add to and increase the value of the existing strategy.*

Strategy Name:	**Plankton Program**

Protocols: Biology oceanography (nets and samples), chemical oceanography (CTD and water sampling), and pelagic acoustic surveys.

Implementation: Projects in Plankton Program date back to 1980s, limited data within the SK-B MPA.

Principal Investigator(s): DFO (Moira Galbraith).

Data produced: Plankton diversity, abundance, and biomass

Data links: DFO 2018a.

Cost: $0 (no additional costs with current programming), establishing SK-B MPA specific $500,000 (this estimate includes ship costs, overtime, and full-time staff to analyze the samples).

Strategy Name:	**Canadian Pacific Robotic Ocean Observing Facility (C-PROOF) Glider Program**

Description: C-PROOF deploys autonomous ocean observing platforms, such as instrumented ocean gliders and profiling floats, to explore and monitor the BC coastal and offshore waters to track life, quantify turbulence, and measure ocean nutrients. Currently, there are two main glider tracks: (1) from Calvert Island, crossing Queen Charlotte Sound, out to the OPB, and (2) along Line P. *A new line to the SK-B MPA, with a deployment from Haida Gwaii, could include a partnership with CHN.*

Protocols: Gliders (current, plans to incorporate floats and moorings).

Implementation: A relatively new program with its first launch in 2018.

Principal Investigator(s): University of Victoria (Jody Klymak); DFO (Tetjana Ross); with many co-investigators (listed on the C-PROOF website).

Data produced: Sensor profiles (CTD, O2, Eco-puck backscattering and fluorescence measurements).

Data links: C-PROOF Glider Deployments webpage.

Cost: $0 (no additional costs with current programming), $400,000 if adding a new glider (Costs include glider, full-time person to maintain, travel to Haida Gwaii).

Strategy Name:	**Argo floats**

Description: Argo is the largest ocean climate monitoring system in the world. DFO has been a strong contributor and, since 2001, has launched over 400 Argo floats. The floats are free-drifting and collect data on temperature, salinity, and more (see the Floats and drifters section above). Argo data is publicly available online for free. *Though not targeted to the SK-B MPA, floats could theoretically travel within (or launches could be planned within) the MPA.*

Protocols: Floats.

Implementation: Started in 2001; each float's typical life span is five years.

Principal Investigator(s): DFO (Tetjana Ross for Pacific deployments).

Strategy Name:	**Argo floats**

Data produced: Positional data, salinity and temperature profiles, metadata (possibly more).

Data links: DFO 2019e.

Cost: $0 (no additional costs with current programming); $25, 000–$100, 000 per float (sensor dependent).

Strategy Name:	**ONC NEPTUNE (undersea cabled observatory)**

Description: In the Northeast Pacific ocean, ONC is observing changes in the timing, intensity, and chemical properties of upwelled waters, nutrient availability, and primary production. To quantify these changes, ONC is committed to continuous, long-term recording of temperature, salinity, direction and intensity of water currents, dissolved oxygen distributions, pH and pCO_2 using sensors installed on the North East Pacific Time-series Underwater Networked Experiments (NEPTUNE) observatory. The NEPTUNE shore station at Port Alberni on Vancouver Island sends the collected data from NEPTUNE via fibre optic cable to the University of Victoria. The NEPTUNE infrastructure is an 840 km loop of fibre optic cable with five nodes. Each node is instrumented with a diverse suite of sensors that enable researchers to study interactions among geological, chemical, physical, and biological processes that drive the dynamic earth-ocean system over a broad spectrum of oceanic environments. *Trends in oceanographic data may be informative for the SK-B MPA but costs are likely prohibitive to establishing a network within the MPA itself.*

Protocols: Undersea cabled observatory.

Implementation: Began in 2009.

Principal Investigator(s): Ocean Networks Canada (ONC) with many collaborating partners (including DFO).

Data produced: CTD, oxygen, ADCP, accelerometer, etc.

Data link: Data available publicly on the OCN's Oceans 3.0 Data portal; General information on the ONC Physical Infrastructure – Cabled Networks webpage.

Cost: $0 (no additional costs with current programming); Millions annually (install and maintain).

Strategy Name:	**Fish surveys and fisheries**

Description: Bottom-contact fishing (other than for recreational or traditional fishing) has not occurred within the SK-B MPA since 2018. Historic fishing catch and bycatch data may be quite informative of some historic/baseline data for the MPA (e.g., as examined in Du Preez and Norgard 2022; e.g., DFO PacHarv database). If non-destructive survey methods, such as imagery surveys, are insufficient for assessing fish populations, then fishing surveys may need to be considered in the future. Fisheries outside the MPA can also provide trends data and population data in the case of highly mobile species (e.g., Sablefish). Current Integrated Fisheries Management Plans identify objectives and requirements for groundfish, pelagic, and salmon species. Additionally, fisheries for transient, pelagic species, such as for salmon and Albacore Tuna, can be quite informative of the trophic web of the SK-B MPA. Catch reports are available for groundfish (DFO 2023a) and salmon (DFO 2023b), but co-authors could not find an equivalent catch statistic site for Albacore Tuna.

Protocols: Fishing surveys.

Implementation: 1950s to 2018.

Principal Investigator(s): DFO (Salmon - Mike Hawkshaw; Pelagics - Bryan Rusch; Groundfish - Danielle Scriven)

Data produced: Catch and weight data by species.

Data link: DFO reports: groundfish (DFO 2023a) and salmon (DFO 2023b).

Cost: Currently no program within the SK-B MPA, $500,000 to reinstate fishery targeted to inform monitoring within the MPA (cost of ship-time, equipment and staff).

Strategy Name:	**Ships of opportunities, Continuous Plankton Recorder (CPR)**

Description: The CPR is a vessel-mounted structure that filters plankton from the water over long distances. The plankton are captured on continuously moving bands of filter silk that can be removed from the mechanism back at the laboratory and parceled to represent set distances within the vessel's travel. Initiated in the UK, with now near-global reaching data collection. *On ships of opportunity that often travel in the vicinity of the SK-B MPA (voluntary exclusion zone).*

Protocols: Water sampling (Continuous Plankton Recorder technology).

Implementation: In the Pacific, we have time-series data from 2000. DFO (Institute of Ocean Sciences) has been in agreement to service and unload locally since 2003. The SK-B MPA falls within the dataset 'oceanic NE Pacific'. Potential future collaborations could collect/extract data specific to the MPA.

Principal Investigator(s): Marine Biological Association (Clare Ostle).

Data produced: Current year abundance data for four plankton variables (total diatom abundance, mesoplankton abundance, estimated mesozooplankton biomass, and average copepod community size) are presented as monthly means, superimposed on the long-term monthly mean and minimum/maximum monthly values found in the time series to date (for most regions since 2000).

Strategy Name:	**Ships of opportunities, Continuous Plankton Recorder (CPR)**

Data links: The North Pacific Marine Science Organization's web page on The Continutous Plankton Recorder Survey of the North Pacific; Marin Biological Association's web page on CPR Survey data philosophy).

Cost: $0 (no additional costs with current programming).

Strategy Name:	**Drifting buoys, Intergovernmental Oceanographic Commission's Global Ocean Observing System**

Description: Global distribution of drifters that report their positions while measuring air temperature, near-surface wind, sea surface salinity, surface air pressure, and SST. *Though not targeted to the SK-B MPA, could drift in the vicinity (or launches could be planned within the MPA), as well as data and models are informative for the area.*

Protocols: Drifters.

Implementation: Data available as early as 1978.

Principal Investigator(s): DFO and NOAA (in Northeast Pacific).

Data produced: The most comprehensive source for drifting buoy data is the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO). Positional data, sea surface salinity and temperature, near-surface weather conditions.

Data link: Integrated Ocean Observing System's web page on Provision of Data to the Global Telecommunications System (GTS); DFO 2017b; Data can be requested through the DFO Marine Environmental Data Program data request form.

Cost: $0 (no additional costs with current programming**),** $500 per drifter.

Strategy Name:	**The Drift Bottle Project**

Description: A drift bottle is a very simple piece of scientific equipment, made up of an empty glass bottle with a watertight lid and a note inside it. The note explains how to make contact with the research project. Project participants throw these bottles over the side of ocean-going ships and note the 'drop' location of each bottle. When a bottle is found and reported the location is added to our database for analysis. *Though not targeted to the SK-B MPA, could drift in vicinity, as well as data and models are informative for the area.*

Protocols: Drifters.

Implementation: Started in 2000.

Principal Investigator(s): DFO (Eddy Carmack, retired).

Data produced: Location data (deployed and recovery position) is used to calculate maximum travel time and minimum travel distance (contributes to current modelling).

Data links: DFO 2018b.

Cost: $0 (no additional costs with current programming).

5.3. MONITORING METHODOLOGIES

The topic of designing monitoring programs was comprehensively reviewed in Neves et al. (in prep[3]) and references therein (e.g., Noble-James et al. 2017 and Loh et al. 2019). Although their monitoring framework focuses on cold-water coral and sponge habitats, the information provided is broadly applicable to all elements of the SK-B MPA monitoring framework.

As described in Neves et al. (in prep[3]), this section aims to provide some consideration and best practices when designing monitoring programs. Once monitoring objectives have been clearly identified, indicators have been selected as described in the previous section (Ecological Monitoring Indicator Ecosystem Components and Metrics section), adequate tools chosen (Tools section), and monitoring strategies identified to achieve monitoring goals (Strategies section), a monitoring design needs to be developed (i.e., next steps within a management plan). Monitoring design will be directly linked to the availability of resources such as funding and access to tools and vessels. The monitoring design needs to be statistically robust and regionally-specific to allow conclusions to be drawn about the cause and direction of change observed and thus effectively be used to inform the management of conservation areas.

Some of the primary questions Neves et al. (in prep[3]) pose that should be asked in order to have a complete and robust monitoring design include:

- What are the baseline data available and how can we use them?
- When and how often should we sample?
- How much should we sample?
- Where should we sample?

The above questions were addressed in the following sections of Neves et al. (in prep[3]): Baseline data (section 5.3.1), Statistical considerations with subsections Size and replication (5.3.2.1), Sample size, power and significance (5.3.2.2), Statistical issues around data independence (5.3.2.3); and Sampling design with subsections Temporal consideration and frequency (5.3.3.1), Types of sampling design (5.3.3.2), and BACI design and reference sites (5.3.3.3).

As not to repeat their recent effort, the below sections provide bullet summary points of the review in Neves et al. (in prep[3]) and additional information where applicable (e.g., region-specific notes and/or points related to monitoring the pelagic and sea surface conditions).

5.3.1. Baseline Data

- While the ancient volcanoes themselves are relatively stable physical environments, the oceanographic environment—which determines what and how life thrives on the seamounts—changes on a variety of time scales from daily through to decadal and longer.
- Baseline data and data gaps exist for the SK-B MPA (summarized in Du Preez and Norgard 2022). However, SK-B Seamount has the most existing data types of all 62 OPB seamounts. Davidson and Hodgkins tie with Dellwood South Seamount in fourth.
- Existing baseline data require careful evaluation for suitability before use in the monitoring program (e.g., data comparability is a key aspect when considering temporal data)[3]. When using existing data as the first point in a monitoring time series, current monitoring practices should be aligned wherever possible (e.g., in terms of survey timing, operational methods, equipment, processing and analysis techniques)[3]. The seamount fisheries data is an example of when this is not possible (i.e., bottom-contact long-line fishing is prohibited within

the MPA). However, these time series and spatial data sets hold information on target and bycatch fish and invertebrate species, including Sablefish, rockfish, crabs, cold-water corals, and sponges (e.g., DFO PacHarv database and Buchanan et al. 2018). While direct comparisons with non-destructive survey techniques will be difficult (although not impossible), the linkage between the historic seamount fisheries data, ongoing coastal fisheries data, and future trends may be informative (especially in the case of Sablefish; see Box 3 above). Future research is recommended to address the comparability of these survey techniques.

- Bathymetric data and bottom type are key factors for the development and implementation of a good sampling design[3]. The upper flanks and summits of the SK-B MPA seamounts were recently mapped with high-resolution multibeam bathymetry and backscatter (Pac2018-103; Gartner et al. 2022). However, seafloor below ~2,000 m depth was not mapped and it should be a priority to do so in the future. These data are used to map the seafloor, essential spatial context for all other geospatial data, and is the foundation for an ongoing species distribution modelling project (DFO Deep-Sea Ecology program).
- Reference points or thresholds were not covered in Neves et al. (in prep[3]), likely for the same reasons these topics were not included in the above section on Ecological Monitoring Indicator Ecosystem Components and Metrics. Indicator-associated reference points (e.g., “the natural state”) or thresholds are unknowable at this time and should be determined through future assessments as baseline measurements are collected and/or become available. Monitoring practitioners should try to account for the uncertainty of the changing climate by reviewing and updating management objectives, reference levels and risk tolerances, so they remain consistent with potential consequences from human activity under new biological, ecological and socio-economic realities (Roux et al. 2022).
- A detected state or trend could be the result of various stressor effects, both positive and negative pressures. For example, while an overall ecological state may be “impacted” or trend may be “negative”, an existing management measure may be removing or reducing stressors and creating positive pressures. An anticipated scenario is that climate change impacts (unmanageable at the scale of the MPA) will drive overall negative trends while the mitigation of manageable stressors (e.g., fishing) will be essential positive pressures.
- Researchers are actively working to better understand the level of dependency and connectivity that exists between localized SK-B MPA species, populations, and communities and the adjacent coast by means of the Haida Eddies (Tetjana Ross, DFO, Sidney, BC, pers. comm.). For more information, see Box 4.
- When extractive surveys are done within the MPA, consideration should be taken to provide context to the trophic connections on the seamounts (e.g., isotope analysis; See Monitoring Ecosystem Function and Trophic Structure section below)
- Ensure baseline data informs adaptive management of the MPA. Monitoring plans need to be revisited as data is collected.

Box 4. Understanding the significance of the Haida Eddies

Haida Eddies are large-scale eddies which transport water (with temperature, salinity, and chemical profiles typical of coastal waters) and materials (e.g., nutrients, larvae, productivity) offshore (Ban et al. 2016) from Haida Gwaii. The Haida Eddies often pass through the MPA and occasionally become entrapped over SK-B Seamount for months at a time (Tetjana Ross, DFO, Sidney, BC, pers. comm.; John Dower, UVic, Victoria, BC, pers. comm.). It is unresolved if Haida Eddies make a meaningful contribution to the water properties and ecosystem within the SK-B MPA (i.e., they may simply be transient events with no long term impact). If these eddies make a significant contribution to the ecosystem structure within the MPA, a consequence of this connectivity may be that MPA populations are seeded by coastal populations (i.e., source populations are outside the MPA rather than self-recruiting/self-sustaining populations inside the MPA). Another consequence may be that productivity of the SK-B MPA depends on coastal conditions (e.g., allochthonous productivity is delivered and trapped at the SK-B MPA). In both cases, the continued formation and dynamics of Haida Eddies are essential to maintain the natural state of the SK-B MPA. Furthermore, it is important to note that conservation measures restricted to the spatial extent of the MPA may not be effective at protecting and conserving reproductive populations or productivity.

5.3.2. Statistical Considerations

5.3.2.1. Size and replication

- The size and type of the sampling unit should be related to the size and expected distribution of the indicator species or biological ecosystem component grouping[3].
- Replication within sampling units should be conducted where resources allow to reduce the effects of environmental 'noise' or random variation and to provide a more accurate and precise estimate[3].
- Reference sites should be used and their placement should be carefully evaluated[3]. Within the SK-B MPA, 17 long-term monitoring sites were established in 2018 (Table 3 in Gartner et al. 2022) and six were revisited in 2022. With the development of a monitoring plan, and in the context of species distribution modelling[8], the location and number of these monitoring sites should be considered and expanded.

5.3.2.2. Sample size, power and significance

- The optimal sample size is directly linked to the environment and indicators that are being monitored and the type of statistical analysis that will be required. The Joint Nature Conservation Committee (JNCC) developed a flexible framework which can be used to help define appropriate ratios and levels of power and significance related to benthic monitoring (Noble-James et al. 2017; as reported in Neves et al. in prep[3]).
- When existing data are available, power analysis should be conducted *a priori* to determine how large the sample (N) must be to detect change of a given magnitude at a given level of significance for each indicator. *Post hoc* power analysis should be conducted retrospectively to determine whether the sample was sufficiently large or if detectable changes would be possible for a specific indicator[3].
- Environmental parameters thought to strongly influence variation or add noise to the data should be measured so that they can be included as variables in statistical analyses[3].

5.3.3. Statistical Issues around Data Independence

- The choice of sampling locations must also consider the independence of data points. Autocorrelation within response variables in space and/or time is common in the marine environment, violating the statistical assumption of independence[3].

[8] Du Preez, C. et al. In prep. Species Distribution Modelling of Seamounts in Pacific Canada.

5.3.4. Sampling Design

5.3.4.1. Temporal consideration and frequency

- The frequency of sampling will depend on the taxa selected as a focus of each specific conservation objective (e.g., life history, such as generation time and lifespan, Du Preez and Norgard 2022: Table A10), temporal variation of the ecosystem (e.g., seasonality), the risk to human pressure (i.e., anticipated changes), and will also heavily depend on the resources available (including fieldwork, processing, and analyses)[3]. In the context of the conservation goals for the SK-B MPA we have indicator taxa that have life histories that are short-lived (e.g., plankton) to extremely long-lived (e.g., rockfish, corals, sponges). The frequency of sampling may not need to be consistent across all indicator species.
- Monitoring indicator metrics such as abundance need to be considered in light of the life history of the taxa of interest. In a monitoring context, detection of change in biological response can take from a few years to decades (i.e., lag time)[3].
- To achieve sentinel and investigative monitoring objectives in an efficient way, a long-term commitment to ongoing regular and consistent data collection is needed, and frequency should be revisited as the monitoring progresses and data on various trends are collected and analyzed[3].
- Positional specificity of sites will also need to be considered and alternative methods might be investigated if navigation poses a challenge (e.g., grid versus point sites)[3].

5.3.4.2. Types of sampling design

- Probabilistic sampling design ensures that data are randomized and are statistically robust designs best employed in well-known and environmentally homogenous areas or well-stratified areas[3].
- Fixed sites (non-probabilistic designs, judgment sampling) are useful in areas that are well-understood and resources are limited, for areas that are representative, or for rare species and habitats. Appropriate statistical techniques must be employed, and conclusions must be considered within the limitations of the bias created by this sampling design[3].
- For investigative monitoring, which aims to evaluate the effectiveness of measures**,** Before-After-Control-Impact (BACI) design is theoretically one of the more appropriate methods[3]; however, (i) the monitoring program for the SK-B MPA will be initiated years to decades after the management measures were put in effect, (ii) due to the unique ecosystem of the MPA there is no ideal reference site for the SK-B MPA ecosystem, and (iii) the used of the BACI design in the deep sea is almost certainly cost and time prohibited (more on BACI below).
- Baseline data collected before SK-B MPA management measures were put in effect can be extremely valuable, and should be leveraged if and when possible, even though it is unlikely the data were collected for the purpose of temporal (repeated) monitoring. If practitioners can continue collecting the same or comparable data, they can generate a continuous Before-After (BA) design to provide specific information for a conservation objective or question. Without a reference site and by using opportunistic historic data, a BA design is also considerably more feasible than a BACI design (Christie et al. 2019), especially in the deep sea.
- After design is generally statistically weaker than a BACI or BA design (Christie et al. 2019) but is likely the most common option since, as mentioned above, the monitoring program for

the SK-B MPA will be initiated years to decades after the management measures were put in effect (often the case).

- To increase confidence, a combination of sampling designs, for example, nested boxes, may be an ideal way to ensure data robustness while focusing on known areas of species distribution[3]. The three seamounts may be expected to change differently in response to the same stressors (e.g., three different ecological-relevant classes of seamounts; Du Preez and Norgard 2022). Constraining monitoring sites for representation on each seamount and within defined depth and aspect ranges is an example of a nested box design (e.g., Box 5), albeit an After design since the establishment of monitoring sites is post-impact (i.e., protection).

Box 5. Monitoring sites pilot study within the SK-B MPA (example of "After" design)

Monitoring sampling and survey designs should consider the spatial distribution of stressors and anticipated changes when appropriate (reported in Du Preez and Norgard 2022). The SK-B MPA bottom-contact fishing footprint or spatial management zones (i.e., zones 1, 2, and 3) could be used to identify sites for monitoring recovery and/or ongoing damage by lost fishing gear. Depth-specific anticipated changes in combination with high-resolution bathymetry maps could be used to identify spatial sites for monitoring climate change impacts (e.g., present-day depths of the upper and lower Oxygen Minimum Zone, 480 and 1,700 m, and the calcite and aragonite saturation horizons, approximately 340 and185 m). Future surveys could also attempt repeat transects to control for spatial variability and collect time-series data; however, repeat surveying in the deep sea based on positional data and visual cues alone can be difficult, if not impossible.

In 2018, scientists from DFO and CHN established 17 benthic survey sites (10 m by 10 m) within the SK-B MPA during a deep-sea expedition aboard the *E/V Nautilus* using the ROV Hercules (Gartner et al. 2022) (similar to the example in Figure 17). The objective was to initiate a pilot study to collect time-series data. Each site contains a physical marker with a unique identification number (Gartner et al. 2022), deployed specifically to facilitate relocation and repeat surveys. Sites were selected in locations and at depths of anticipated importance (e.g., inside and outside of the fishing footprint; at the upper and lower boundaries of the Oxygen Minimum Zone; within coral and sponge grounds; within or below the photic zone) and on different sides (aspects). Twelve sites were established on SK-B Seamount (between 1,807 and 63 m depth), four on Hodgkins Seamount (945 and 597 m), and one of Davidson/Pierce Seamount (1,165 m) (Du Preez et al. 2020). Sites were extensively surveyed over roughly one to two hours to collect high-resolution imagery (video and still) of the seafloor and benthic community (Gartner et al. 2022). The imagery processing into high-resolution 3-D models of the seafloor and image mosaics of the community is ongoing (Georgia Clyde, DFO, Sidney, BC, pers. comm.; e.g., Figure 17). Analyses for community composition and condition are ongoing. In addition to imagery, data collected during site surveys are from the ROV-mounted navigation system (latitude, longitude, depth, heading), CTD, oxygen sensor, water samplers (e.g., for eDNA), etc. (Gartner et al. 2022).

During the 2018 expedition, similar monitoring sites were also established on Dellwood and other seamounts inside the ThT AOI (south of the SK-B MPA) (Gartner et al. 2022). In 2021, scientists aboard the *CCGS John P. Tully* successfully used the DFO towed camera system BOOTS to repeat survey five of these Dellwood monitoring sites, providing the first intentional time-series data for the monitoring of benthic habitats on Canadian seamounts (Figure 17) (analyses in process[6]). We anticipate similar success in re-locating and re-surveying the SK-B MPA sites during future submersible expeditions to the region. Analyses for community composition and variability (e.g., abundance/density, condition) are in progress (Lindsay Clark, UVic, Victoria, BC, pers. comm.) but it is anticipated to yield data on abundance, distribution, biomass, condition, ratio or live-to-dead, community composition, diversity indices, and the occurrence (if any) of catastrophic events (mass die-off).

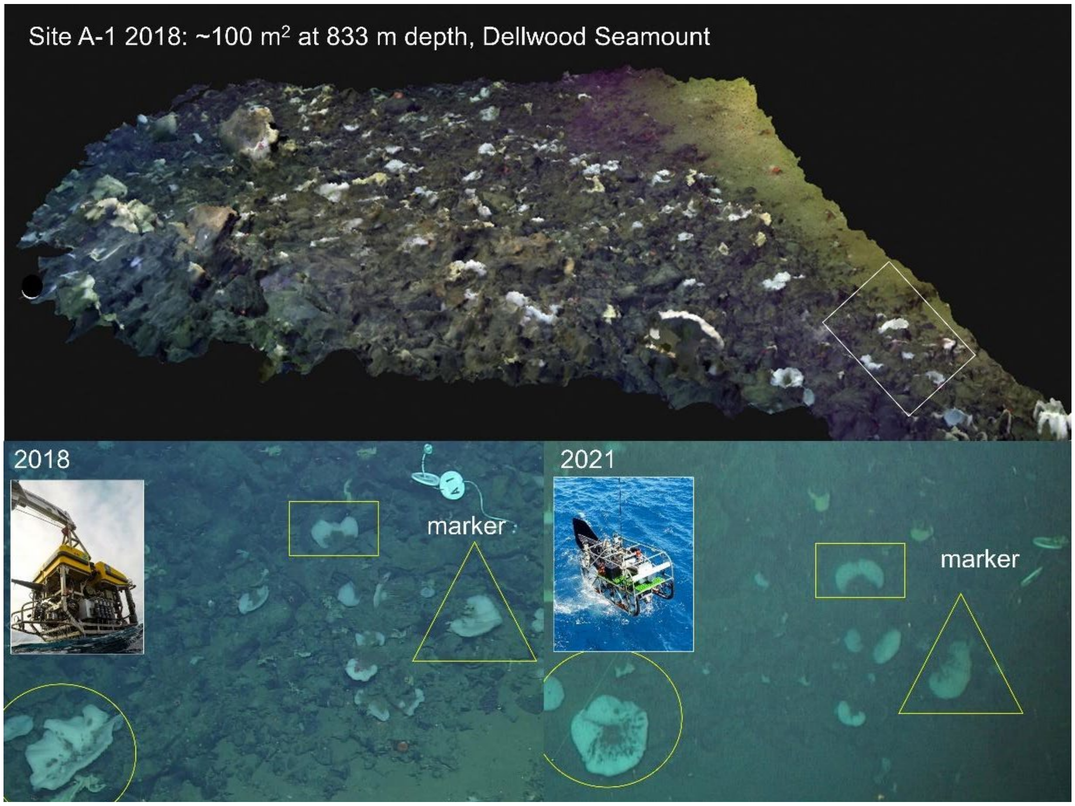

Figure 17. A high-resolution 3D photo-mosaic of the 10 m by 10 m monitoring site A-1 at 833 m depth on Dellwood Seamount (within the severely hypoxic zone, <0.5 ml/l O_2). The area is largely rock covered in dead sponges (dark brown) and patches of living glass sponges (white). Individual organisms, such as the glass sponge Tretodictyum n. sp. (within yellow shapes) can be tracked for changes over time. Imagery collected on the Pac2018-103 and Pac2021-036 Offshore Expeditions using the ROV Hercules and the DFO drop camera BOOTS. Mosaics were processed and provided by Georgia Clyde, Institute of Ocean Sciences.

5.3.4.3. The challenge of the Before-After-Control-Impact (BACI) design and reference sites

- The use of external reference sites is required for BACI or similar sampling designs. In general, the placement of BACI references sites should (i) be in relatively close proximity to the conservation area but not directly adjacent to it to avoid biological ‘overspill’ or edge effects; (ii) ideally have comparable environmental conditions to those of the conservation area and have the same type of substrates; and (iii) consider the distribution of pressures within and between reference sites and “impact sites” so they have similar historical levels[3].
- Potential reference sites for the SK-B MPA seamounts include the adjacent continental shelf and slopes offshore of Haida Gwaii and mainland British Columbia, and seamounts within the region that do not have the same management measures (e.g., Cobb, Warick, Brown Bear north, Eickelberg, and Eickelberg South seamounts; Du Preez and Norgard 2022). However, the SK-B MPA ecosystem is unique, and caution should be taken when inferences are made based on these other ecosystems. For example, SK-B and Cobb

seamounts share many of the same characteristics but support different rockfish communities (Du Preez et al. 2015; Gauthier et al. 2018c). SK-B essentially lacks comparable reference sites.

- The unique ecosystem of the MPA makes for a challenging sample design but can also be an opportunity to (i) elevate the value of other existing knowledge for baseline comparisons (e.g., baseline data from previous SK-B MPA science surveys (Gale et al. 2017) and Haida Marine Traditional Knowledge (Haida Marine Traditional Knowledge Study Participants et al. 2011a–c)), (ii) prompt exploration of new designs, and (iii) potentially pull from other data sources/surveys for comparisons with caution.
- Note: it is unlikely -there will be any “ambient monitoring” within the SK-B MPA (as defined by Dunham et al. 2020: to characterize the broader ecological system and is not guided by a priori hypotheses) as almost all measurable ecosystem components will fall under one of the broad ecological conservation objectives (CHN and DFO 2019).

5.4. DATA MANAGEMENT

Data management is essential for a successful monitoring program. Ultimately, it is a key component for evaluating the effectiveness of any marine protected area and informing the decision-making process within adaptive management. It is not uncommon, however, that monitoring programs generally allocate the largest portion of their budgets to data collection, while other, critical aspects of the program, such as scientific oversight, training, data management, quality assurance, and reporting, are neglected (Caughlan and Oakley 2001). The most likely situation in these cases is that data is collected, but never analyzed or reported upon, and therefore less relevant to management decisions. Moving into the planning and implementation phase of a monitoring program without careful evaluation of costs and benefits is risky—if costs are later found to exceed benefits, the program will fail (Caughlan and Oakley 2001). Experience from other programs shows that 25 to 30% of the monitoring program budget should be used for data management, assessment, and reporting (Caughlan and Oakley 2001). Therefore, realistic expectations of costs and benefits will help ensure the long-term monitoring program for the SK-B MPA survive the early, turbulent stages of development and the challenges posed by fluctuating budgets during implementation.

The requirements to effectively manage (and ultimately analyze, report, and share) monitoring data for the SK-B MPA is unknowable at this point. The scope and details of a data management plan for the SK- B MPA will be an important final step of a monitoring plan once the anticipated types and volumes of data are determined. There is an incredible effort to assemble and review information from various programs and data streams of the complex, multi-disciplinary monitoring required to achieve the conservation monitoring goals of this MPA. The steps of data collection and analysis need to be well-documented and archived to support repeatability and reproducibility over time. A documented approach to data management, summarized in a data management plan, establishes the data management procedures throughout the data life cycle. A comprehensive understanding of basic needs and workflows in advance of data acquisition is vital to ensuring co-management (CHN and DFO) can deliver adequate staffing, funding, and infrastructure to carry out the monitoring program and meet data management objectives (i.e., quality, completeness, availability, and usability for the long term) (Sutter et al. 2015). The data planning process should follow a process that is transparent, objective and documented. For the purposes of this framework, a data management plan will not be addressed, however, there are some initial recommendations about best practices for development of a long-term monitoring plan, including data management at different stages of data life cycle (Figure 18).

Figure 18. General steps of an ecological monitoring program that involve data management and the corresponding components. Adapted from Sutter et al. 2015.

Planning, data collection, and storge decisions for the development of the data management plan should include direct involvement of those who collect the data in large, spatial projects (e.g., see the Strategies section) as it is important not only to valorize the contribution of data collection and stimulate data sharing but above all to improve the quality and robustness of analyses performed and their interpretation. The monitoring of the SK-B MPA will involve the acquisition, interpretation, and management of data from biological, oceanographic, and atmospheric research components. The data may be gathered from different agency resources (e.g., DFO, NOAA, ONC) and potentially even within different programs of each agency (e.g., DFO Deep-sea Ecology Program, DFO Plankton Program). Even within DFO, different programs store, manage, and share their data through various portals (e.g., see data links in Strategies section). For example, to promote data and information sharing, in 2018 the DFO Deep-Sea Ecology Program launched an iNaturalist project (a photo-based inventory of seamounts species, including those within the SK-B MPA; titled Marine Life of the Northeast Pacific (Du Preez and Best 2022)). Additionally, to synthesize data for this framework we had to compile information from a wide variety of resources and source recommendations from numerous subject experts (see Appendices A and B).

The data management plan should adopt standards such as the FAIR (Findable, Accessible, Interoperable, and Reusable; Wilkinson et al. 2016) and CARE principles (Collective benefit, Authority to control, Responsibility, and Ethics; Carroll et al. 2020). Centralized and publicly available data resources are an emerging tenant in science and are a guiding principle within the Canadian government. To make government records and data more accessible to everyone, data and reports can be searched through the Open Government platform. Within

DFO, the development and utilization of emerging platforms such as the Canadian Integrated Ocean Observing System (CIOOS) contribute to the goals of centralized and publicly available data. CIOOS is a platform to integrate the large volumes of data of ocean observation by government (federal and international), academia, small business, not-for-profit organizations, Indigenous Nations, and research partners (Stewart et al. 2019) and would be informative for the SK-B MPA. To ensure successful adaptive management by the SK-B MPA Management Board (CHN and DFO) of the MPA, establishing a centralized data repository or contributing and sourcing data from publicly-accessible databases/portals is imperative.

A centralized SK-B MPA database for the data sourced and/or provided by the co-management team (CHN and DFO) and partners could store harmonized (i.e., normalized in format, structure, information content and terminology) and quality checked copies of the original data sets, integrated into a single, centralized platform where science partners from CHN and DFO can jointly analyze the combination of all available data. An example of a successful co-managed data platform is the Marine Plan Portal for the Marine Plan Partnership (MaPP) for the North Pacific Coast. The portal has more than 250 data layers to inform the co-operative management of the area by First Nations and the Province of British Columbia. Publicly-accessible, centralized data repositories are a standard goal for resource management and monitoring programs as a means of securing long-term data management, such that data accessibility and database design facilitate the sharing, assessment, and reporting of monitoring data relevant to the management of the MPA.

Considering the lessons learned from the California MPA Network process (Resources Legacy Fund 2020), an option that could be considerably less costly, more feasible, and more useful would be a tool to provide synthesized analysis and summaries on a regular basis. This approach may also better address the data privacy needs, such as the use of historical fishery and First Nations data along the BC coast. On that note, simple data visualization systems where select indicators are pre-programmed and viewed graphically, such as Seasketch, may address the vast majority of the SK-B Management Board, policymakers' and public outreach needs. A complementary approach would be to develop a simple communication tool for reporting the successes and failures of meeting conservation goals, determined through monitoring, using a reporting tool such as a 'report card'. The 'report card' style of communication could use a standardized colour scheme (e.g., green, yellow, red) for easy status reporting and could be adapted for monitoring programs across Canada. Report cards as communication tools of monitoring and/or management has been previously utilized for glass sponge reefs (Dunham et al. 2018), evaluation of ecosystem based fisheries management (Juan-Jorda et al. 2017), phytoplankton bloom status (Boyer et al. 2009), NOAA fishery stock assessments (e.g., NOAA Fisheries 2022) and area reports (e.g., Moon et al. 2021), and Parks Canada departmental results (e.g., Parks Canada Agency 2022).

Sharing and evaluation are important components in the data management cycle and considerations should be built in for sharing via publications (e.g., Du Preez et al. 2020; Ross et al. 2020; Gartner et al. 2022), presentations at scientific meetings and community events, and even through social media (e.g., see Media and Outreach in Gartner et al. 2022). The DFO-hosted State of the Pacific Ocean (SOPO) is an annual scientific meeting that provides updates to time series data relevant to the SK-B MPA (many listed in the Strategies section above) and should be considered an important reporting mechanism for the SK-B MPA (e.g., see Boldt et al. 2020b).

The next section discusses monitoring within the SK-B MPA for other conservation objectives relevant to ecological monitoring. A data management plan should attempt to centralize all data types under all conservation goals and include pathways to ensure relevant data reaches the appropriate monitoring practitioners. Timely data sharing, reporting, and communication between different monitoring practitioners will be essential for enabling adaptive options and accurate interpretation of detected changes. For example, it would be critical for a practitioner monitoring biological indicators to receive timely information related to changes in climate variables, compliance issues resulting in significant adverse impacts (e.g., anchoring or bottom-contact fishing), oil spills, lost container cargo, adjacent seabed mining activities, and so on.

6. MONITORING FOR OTHER CONSERVATION OBJECTIVES RELEVANT TO ECOLOGICAL MONITORING

The SK-B MPA management plan includes other types of monitoring outside the scope of the ecological conservation objectives as they are written in Goal 1 (Table 1). For example, Goals 2, 3, and 4 address human activity monitoring and cooperative monitoring (CHN and DFO 2019), aspects of which are inextricably linked to the aforementioned ecological conservation objectives. Monitoring these other conservation objectives can be used to directly inform the ecological data, support program evaluations, and assess the management of the MPA. The data should be readily available to the science teams and SK-B Management Board (see data management section for data sharing and management discussion).The following section describes the linkage between monitoring for Goal 1 and the proposed monitoring of fishing (2.1, 3.2.b), vessel traffic (2.2, 3.2.c), science activities (2.3, 3.2.b), marine tourism (2.4), non-renewable resource extraction activities outside the MPA (2.5), transient species (3.2.d), and proposed collaborations on broader initiatives such as climate change research (4.1.b).

6.1. HUMAN ACTIVITY MONITORING

Monitoring human activities and their impacts is an essential but undervalued type of monitoring (Dunham et al. 2020). It is fundamental for interpreting the results of ecological performance monitoring and evaluating MPA management effectiveness (Dunham et al. 2020). The false assumption of successful mitigation of human pressures (e.g., compliance, unrestricted activities, emerging activities) could lead to incorrect attribution of the causes of ecological changes, jeopardizing the management effectiveness evaluation and adaptive management (Dunham et al. 2020).

6.1.1. Fishing

All fishing gear is designed to remove biological material from the ecosystem. Bottom-contact fishing is the most relevant to the ecological conservation objectives of the SK-B MPA, but even gear types that are not intended to make contact with the seafloor, such as gill nets and mid-water trawls, can and often do (e.g., Tingley 2014; Salgado et al. 2018; Du Preez et al. 2020).

Baseline and monitoring data for fishing activities provide essential context and can be used as an indirect indicator of the state of ecosystem components. For example, with regard to cold-water coral and sponges SBHs (Figure 19), bottom contact fishing activity indicates the maximum potential crushed area and maximum induced increase in suspended sediments—which relates to abundance and health—and catch and by-catch—which relates to the removal in terms of abundance, biomass, genetic diversity, and species richness and diversity (Thornborough et al. 2016) (Table 2: SEC-stressor).

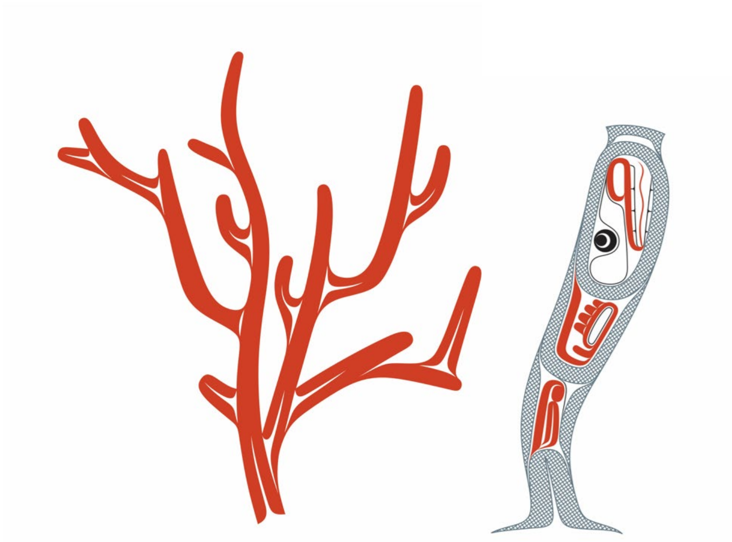

*Figure 19. Red tree coral (*Primnoa pacifica*) and **gin gii hlk'uuwaansdlagangs** glass sponges (Class Hexactinellidae) are abundant within the SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area (SK̲-B MPA)—they are foundation species, significant ecosystem components (SECs), sensitive benthic habitats (SBHs), and incredibly vulnerable to bottom-contact fishing gear. The Haida art was shared by **Iljuuwaas** Tyson Brown, from the SK̲-B MPA management plan (CHN and DFO 2019).*

DFO has baseline data of managed fisheries, groundfish surveys, and observations of lost fishing gear (existing data detailed in Du Preez and Norgard 2022). Monitoring programs for non-compliance involve remote sensing data and aerial surveillance, as detailed by Iacarella et al. (2020) and Burke et al. (2022) for Canadian marine conservation areas. Morgan and Baco (2021) used Automatic Identification System (AIS) data and algorithms of the publicly available Global Fishing Watch database to monitor fishing activities, fishing footprint, and compliance with closures for seamounts in the Northwest Pacific.

6.1.2. Vessel Traffic

The SK̲-B MPA is remote from land but is close to a busy vessel traffic route from the Alaska ports of Anchorage and Valdez, and the southern ports of Vancouver and Seattle. As mentioned above, vessel tracking for monitoring conservation effectiveness is accomplished with remote sensing data and aerial surveillance (Iacarella et al. 2020; Burke et al. 2022). Four data sources are particularly applicable to monitoring vessel traffic within the SK̲-B MPA: the Transport Canada National Aerial Surveillance Program flyover, RadarSat II, Conservation & Protection Aerial Surveillance Program flyovers, and AIS (Iacarella et al. 2020; Burke et al. 2022). Historically, these data have been difficult to access and use; however, a team of DFO Science Pacific Region scientists is working on methods to facilitate the creation of accessible and meaningful data products for the monitoring of vessel traffic in conservation areas (Burke et al. 2022).

Vessel-generated noise (i.e., marine noise pollution) is now another commonly recognized stressor, especially for acoustically sensitive marine organisms. An analysis of vessel AIS data and acoustic data on SK̲-B Seamount by Allen et al. (2018) showed that both nearby vessels and distant ones contribute to the ambient noise environment. An ongoing monitoring program with both in situ observations and tracking of vessels via AIS will be required to monitor and manage anthropogenic noise levels within the SK̲-B MPA. A model could be developed to estimate the noise levels on SK̲-B based on the AIS tracking data and vessel sound signatures, then validated with calibrated hydrophone deployments.

Other vessel-related stressors include groundings, anchoring, ship-strikes of marine animals, light pollution, debris (e.g., Box 6), oil spills, ballast discharge, dumping, and vessels as a vector of invasive species (hauls, equipment, and basalt discharge) (Box 7) (Thornborough et al. 2016).

Box 6. Vessel traffic and debris

As summarized by Frey and DeVogelaere 2014, the International Maritime Organization, governments, and marine insurers have estimated that up to 10,000 shipping containers may fall from cargo ships annually. This amounts to 41,500 tons of littered steel for the 20 by 40 foot containers plus 100,000 tons of substances in packaged form—many of which may be harmful. Lost containers are either washed ashore or sink to the seafloor where they persist for timelines that range to ‘indefinitely’. A recent and local example of such an event occurred when 109 containers (some containing hazardous materials) were lost from the *MV Zim Kingston* during a storm off the west coast of Vancouver Island on October 22, 2021. Only four containers washed ashore—the remaining 105 containers presumably sunk to the seafloor shortly after entering the water. Details of the accident are sourced from news outlets such as CBC[9].

Box 7. Vessel traffic and invasive species (and climate change)

Invasive species are expected to increase in Canadian Pacific MPAs because of vessel traffic and climate change (Iacarella et al. 2020). Preventing the introduction and spread of invasive species is mentioned multiple times in the MPA management plan in relation to fishing, vessel traffic, and scientific research (CHN and DFO 2019: 2.1.e, 2.2.c, and 2.3.d) but invasive species are not specifically mentioned within the ecological conservation objectives (Table 1). Invasive species were not assessed in the ERAF (marked for future iterations; Thornborough et al. 2016) but they can significantly alter that state of species, communities, and habitats by overgrowing, outcompeting, and replacing native species, modifying native habitat, and altering trophic structures (Iacarella et al. 2020). Early detection of invasive species requires an MPA species list of known native inhabitants (e.g., Appendix A), opportunistic surveying, and information sharing (e.g., lists of regional invasive species) with relevant agencies monitoring adjacent similar environments (e.g., protected areas around Haida Gwaii since the Haida Eddies effectively connect the shelf and slope environments and the seamounts). Early detection of invasive species appears to be a strong case for eDNA sampling within MPAs (Larson et al. 2020).

6.1.3. Science Activities

There is usually a science expedition to the SK̲-B MPA once every few years (see the History of Monitoring and Activities in the SG̲áan K̲ínghlas-Bowie Seamount Marine Protected Area section). Expedition leads are required to get planned activities reviewed and approved by the SK̲-B MPA Management Board. That process ensures science activities align with all conservation objectives outlined in the management plan (CHN and DFO 2019). Science activities that cause stressors require mitigations. All of the vessel traffic-related impacts mentioned above apply to science activities—the duration of which would depend on the length of the expedition but would be longer than a transiting vessel (that said, gliders and other

[9] CBC News. 2022, March 6. Debris from Cargo Ship Spill Last Fall Spreading along B.C. Coast, say Beach Cleaners.

remote sensing tools alleviate the need for a ship; see the Strategies section above). Ship-based science activities would also likely involve sampling, submersible operations, and possibly equipment installation, potentially resulting in the removal of organisms, introduction of aquatic invasive species, sub-surface light disturbances, substrate disturbances (sediment resuspension and crushing), and release of contaminants (Thornborough et al. 2016). The science activities application process further requests information on unintentional stressors. An example of a science accident in a Canadian Pacific MPA occurred recently, on August 26, 2021. The Ocean Exploration Trust science team lost communication with their ROVs within Endeavour Hydrothermal Vents MPA, ~750 km south of the SK-B MPA. The resulting impacts appear to be minimal, with the vehicles remaining stationary on the seafloor for a week, after which they were recovered. Monitoring of science activities is already accomplished through the science activities application process. In addition, science activities as cruise reports (e.g., Gartner et al. 2022: 2018 expedition), with the science published as reports and/or primary publications. As with any vessel-based activities, monitoring for compliance could involve remote sensing data and aerial surveillance.

In addition to monitoring science activities for their impacts, monitoring to facilitate data sharing could benefit ecological monitoring efforts.

6.1.4. Marine Tourism

Tourism and/or personal leisure trips to the SK-B MPA are uncommon but not unheard of events. In 2019, a team of SCUBA divers and photographers with Pacific Wild entered the MPA for an unauthorized five-day expedition to the summit of SK-B Seamount (Figure 20). In June 2020, a Transport Canada flyover documented a pusher tug on the pinnacle of SK-B Seamount (Burke et al. 2022). All of the vessel traffic-related impacts mentioned above apply to marine tourism—in some cases, more so. For example, the duration spent in the MPA would be longer if engaged in tourism in comparison to transit (i.e., more noise and light pollution), anchoring would be more likely to occur if the purpose is to visit the area (albeit prohibited), and sports gear—just as with vessel and science equipment (Thornborough et al. 2016)—could act as a vector for invasive species or marine diseases (e.g., SCUBA and camera equipment). SCUBA diving itself has associated stressors, including substrate disturbance of sediment (resuspension) and crushing (Thornborough et al. 2016). Like other human activities, monitoring marine tourism could involve remote sensing data and aerial surveillance.

In addition to monitoring marine tourism activities for their impacts, monitoring to facilitate all information and imagery (photos and videos) sharing could benefit ecological monitoring efforts.

Figure 20. Unauthorized SCUBA diver and equipment on the summit of SGáan Kínghlas-Bowie Seamount (SK-B) within the Marine Protected Area (MPA), 2019. Credit: Pacific Wild.

6.1.5. Non-Renewable Resource Extraction Activities Outside the Marine Protected Area

While non-renewable resource extraction activities are prohibited within the SK-B MPA (DFO 2023c), the three MPA 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 (ABNJ) (Du Preez and Norgard 2022). The activities occurring on these seamounts (or lack thereof, where conservation measures are in place) can affect conditions and the health of the SK-B MPA seamount ecosystem (Du Preez and Norgard 2022). For example, fishing and seabed mining impacts may indirectly influence the SK-B MPA seamounts through the migration and recruitment of species (Du Preez and Norgard 2022). Bottom-contact fishing of seamounts in the Pacific Northeast Areas Beyond National Jurisdiction is ongoing. While fishing activities have been discussed throughout this document, seabed mining has not.

The SK-B MPA ERAF research assessed seismic testing/air guns (for oil and gas extraction) as the second riskiest activity (first was oil spill) (Thornborough et al. 2016; Rubidge et al. 2018). At the time, seabed mining of seamounts and other deep-sea ecosystems was a lesser-known emerging activity and was not mentioned in the ERAF. In just a few short years, this prospect went from unknown to a real possibility—with licenses for commercial exploitation mining in ABNJ being approved as of June 2022[10]. Dozens of exploration licenses are already approved, and activities are underway, with contract sites including seamounts in the Northwest Pacific. No contracts have been awarded within the Northeast Pacific yet, but there are viable seamounts (Miller et al. 2018), and the SK-B MPA is just over 100 km away from the Northeast Pacific ABNJ.

Aside from the ecological linkages between seamount communities, the influence of mining activities on adjacent seamounts will be an essential consideration if mining occurs near the SK-B MPA (Du Preez and Norgard 2022). It is predicted that mining plumes will spread over

[10] International Seabed Authority. 2021, June 29. Press Release: Nauru requests the President of ISA Council to complete the adoption of rules, regulations and procedures necessary to facilitate the approval of plans of work for exploitation in the Area.

hundreds of kilometres from the mined sites, causing varying degrees of habitat alteration and reduced fitness and mortality for surface, pelagic, and benthic species (Drazen et al. 2019). In comparison, mined sites will suffer a catastrophic event with 100% mortality caused by the excavation activities and habitat alterations that will last millennia (e.g., Levin et al. 2016).

6.1.6. Other Human Activities Stressors

Additional human activities with known stressors applicable to the SK-B MPA but not explicitly mentioned in the management plan include accidents, other compliance issues, and large-scale ocean issues; for example, oil spills, marine debris and litter (e.g., plastics and other types of pollution), discharge (other than ballast water), equipment abandonment, and equipment installation (other than for science) (Thornborough et al. 2016).

6.2. TRANSIENT SPECIES MONITORING

As described above (in the Ecology section), many transient species are attracted to, use, and/or migrate through the SK-B MPA (e.g., whales, other marine mammals, and birds). While the protection and conservation of animals that live outside the management area are beyond the scope of any spatial management plan, monitoring them is helpful to broader initiatives (CHN and DFO 2019). Allen et al. (2018) used a hydrophone-based acoustic dataset of whale vocalizations to confirmed the presence of Fin Whales (*Balaenoptera physalus*; a species of high conservation concern) (Figure 21) and DFO's Cetacean Research Program surveys the region (for more details, see the Strategies within the SGáan Kínghlas-Bowie Marine Protected Area section). Such data could also provide feedback for ecological performance monitoring, providing information on ecosystem function, trophic structure (see Monitoring Ecosystem Function and Trophic Structure section) (Table 1: 1.3.a), and as a biological indicator of environmental conditions (e.g., pelagic and sea surface conditions; 1.2.b). There are large-scale reporting and data storage projects for monitoring transient oceanic species (e.g., the Happy Whale website), the authors are unaware of any contributions of data collected within the SK-B MPA (which should be considered in the monitoring plan).

Figure 21. Many whale species frequent the SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA), including ***Sgagúud*** *Fin Whales (*Balaenoptera physalus*). Fin Whale vocalization was recorded by a hydrophone deployed on SK-B Seamount by Allen et al. (2018). The Haida art was shared by* ***Iljuuwaas*** *Tyson Brown, from the SK-B MPA management plan (CHN and DFO 2019).*

6.3. CLIMATE CHANGE MONITORING

Climate change and its impacts on the SK-B MPA ecosystem, and by extension, its implications for the management and monitoring of the SK-B MPA, is covered in the Introduction of this research document (see the Context section). We will only reiterate the four main points here:

(i) climate change is impacting ecosystems within the Northeast Pacific, including the SK-B MPA, (ii) climate risk should be incorporated into the management and monitoring plans, (iii) monitoring climate change is essential as climate variables affect all SK-B MPA ecosystem components, either directly or indirectly (e.g., Box 7 and 8: invasive species and marine diseases), and (iv) managing climate variables within the MPA using spatial management measures is unrealistic (e.g., Table 1: 1.2.b: "Pelagic and sea surface conditions are within a range of the natural state") but managing impacts on other MPA objectives may be possible with mitigation efforts.

Ocean climate change increases the importance of MPA management and monitoring. Management plans can set strategies to consider how the MPA will respond to climate change and lay out the actions that can be taken to minimize manageable impacts on the objectives according to the risks each manageable impact presents (determined by ERAF) (Karen Hunter, DFO, Nanaimo, BC, pers. comm.). The first potential pathway to maintain a consistent risk to the MPA objectives that accounts for the short-term and longer-term impacts of a changing environment is to adjust the degree of exposure of human activities/pressures (e.g. climate conditioning; Roux et al. 2022). By conditioning activities within the control of spatial management measures, a management plan can account for the increased risk to the objectives introduced by climate change by minimizing the compounding effects of stressors that would otherwise exceed an ecological threshold. This requires that the management plan communicates ecological thresholds and the tolerance to changes to those thresholds to determine whether climate conditioning would be needed at all.

Box 8. Climate change and marine diseases

The introduction and spread of pathogens is another type of invasion that can have rapid and devastating effects (Davies 2021). Much like invasive species, marine diseases are expected to increase in line with climate change but are often overlooked in MPA management plans (Davies 2021). While marine diseases are not specifically mentioned within the ecological operational objectives of Goal 1, they can cause species and habitats to shift outside the range of the natural state by the decline or removal of a species, and its cascading effects. The sea star wasting disease that swept the Pacific Northeast (Hewson et al. 2014) is a local example of a marine disease that could have devastated the SK-B MPA. This disease affected dozens of keystone sea star species (e.g., caused a ~91% global decline of *Pycnopodia helianthoides*, now Critically Endangered; Gravem et al. 2021). Fortunately, the offshore location of the SK-B MPA appears to provide some aspects of a natural barrier since, as far as we know, the sea star-associated densovirus was not transmitted to the seamount populations. In moving forward, adaptive management actions triggered by opportunistic surveying (e.g., for changes in abundance, condition, size-structure) and information sharing with relevant agencies monitoring adjacent similar environments (e.g., presence, host species, description, transmission information) would support the detection of marine diseases.

With regard to the future monitoring plan, practitioners need to understand the risk and risk tolerance context and complexity added by the climate-related changing ocean to interpret changes detected during monitoring. For example, monitoring of some biological indicators can provide indirect evidence of climate change (e.g., poleward shifts in distribution, changes in depth distribution, changes in behaviour, reduced abundance or fitness)—assuming the mechanistic pathway, lag time, and additive and synergistic effects of multiple stressors are well understood. The second potential pathway to account for the short-term and longer-term impacts of a changing environment is to adjust the reference levels used to measure the "new/relative natural state" (i.e., maintain equivalent risk over time when objectives are no longer being met) (Roux et al. 2022).

Best practices require the SK-B MPA management plan, as part of its adaptive management approach, to incorporate climate change information and adaptation into future iterations (e.g., risk and/or vulnerability assessments; O'Regan et al. 2021; Roux et al. 2022).

7. MONITORING ECOSYSTEM FUNCTION AND TROPHIC STRUCTURE

7.1. INTRODUCTION

The biological ecosystem component groupings described in the sections above are connected through a seamount food web whose balance is dictated by biological interactions, oceanographic conditions, and human stressors. While these trophic and environmental interactions are difficult to quantify, food web models and conceptual diagrams are helpful tools to visualize connections and map potential pathways of cascading effect.

7.2. METHODS AND RESULTS

SK-B Seamount is inextricably linked to the BC coast through Haida Eddies and species migrations; therefore, it may be useful to compare with other studies on trophic linkages. However, recurring monitoring efforts on the BC Coast that focus on fish diets include species not found in the SK-B MPA, such as salmon, hake, herring and sardines (King et al. 2019; see Strategies section). Specific to SK-B Seamount, Beamish and Neville (2003) created an EcoPath food web model. While the data on trophic relationships is limited for the SK-B MPA, many species found at the seamount also exist in coastal environments, where the relatively well-studied systems can help fill data gaps. However, despite these similarities and linkages with the coast, SK-B Seamount is still incredibly unique from coastal and open ocean processes, where comparisons with other areas, even nearby seamounts, will not always have relevant information. Future research and next steps for trophic linkages are described in further detail in the section below.

The conceptual food web diagram presented here (Figure 22) was informed by Beamish and Neville's model (2003) and expanded from a fisheries-focus to also include corals and sponges, birds, and marine mammals based on well-known high-level interactions (see descriptions of trophic groups and ecosystem component groupings in the Ecology, Marine Protected Area Objectives and Biological Ecosystem Component Groupings, and Ecological Monitoring Indicator Ecosystem Components and Metrics sections). Further, the groups were combined if they filled similar ecological roles (e.g., functional groups) to better reflect the ecosystem component groupings. This food web model is presented with the best available high-level knowledge and is subject to change as more data collection and in-depth analyses are undertaken. This preliminary conceptual food web provides a foundation to be strengthened with baseline monitoring efforts, which will elucidate information on the trophic interactions, ecosystem functioning and response to any potential changes in ocean conditions.

Using the same method and format as with the ecological monitoring indicator ecosystem components and metrics, we evaluated stomach content and other trophic metrics for biological indicator groups for future work (monitoring or research) on the SK-B MPA trophic structure (Table 10). These studies could be implemented opportunistically on any physical samples collected to maximize information obtained from each specimen. Additionally, studies could potentially be expanded in the case in which monitoring of indicator ecosystem component groupings has suggested a shift in the food web, to further elucidate information on the trophic interactions.

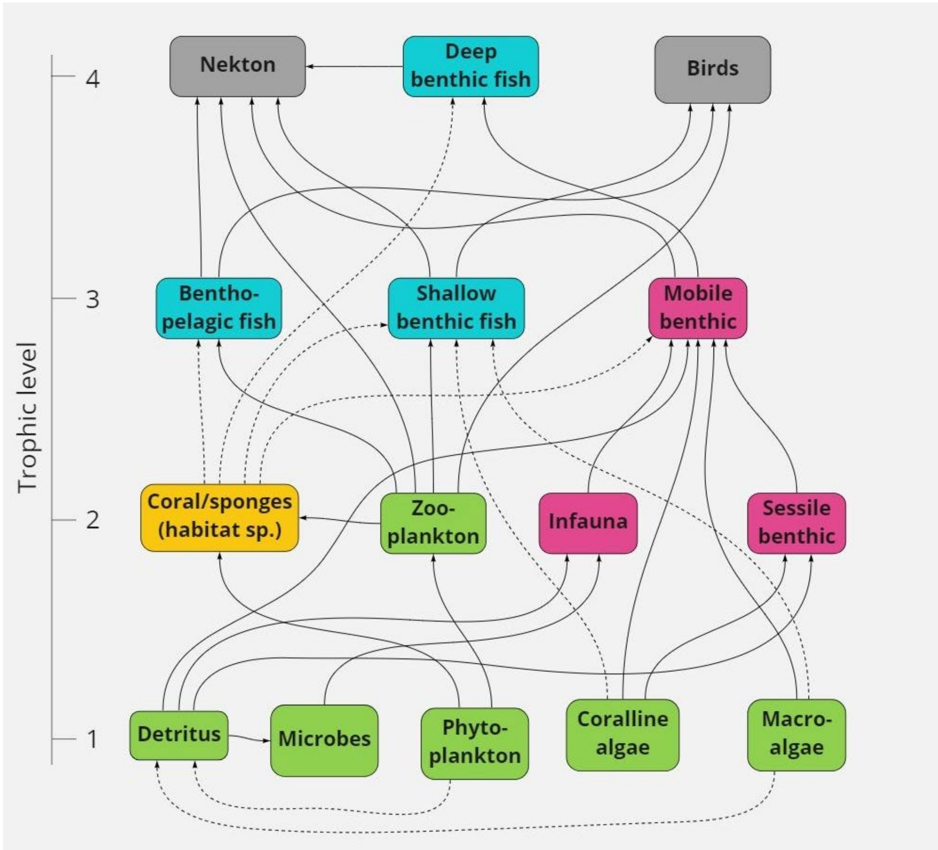

Figure 22. Conceptual simplified food web model depicting how functional groups (e.g., ecosystem component groupings) are connected. Solid lines indicate trophic relationships (arrow towards predators). Dotted lines indicate habitat usage or ecological process other than predation (e.g., macroalgae becomes detritus). Colors indicate broad groupings: grey for birds and large marine animals, blue for fish, pink for invertebrates, yellow for habitat forming species, and green for primary producers, small organisms and particles.

7.3. RECOMMENDATIONS FOR FUTURE WORK: TROPHIC METRICS

Trophic studies are crucial for understanding ecosystem functioning, as complex interactions within and between species respond to dynamic change in the environment with high variability. Ecosystem interactions can be quantified by diet studies and trophic biomarkers, such as fatty acid composition and isotopic signatures of $\delta^{13}C$ and $\delta^{15}N$ (for trophic niches and trophic level). Stomach content analyses can provide similar metrics as those described in Table 10, including relative abundance, biomass, and size of prey species, and predator diet diversity (Amundsen and Sánchez-Hernández 2019). Stomach content analysis is a frequently used tool in fish ecology studies (Brodeur 1990; Livingston et al. 2017). It is also used for invertebrate studies but can be problematic (Blankenship and Yayanos 2005), though there are successful studies particularly for certain taxa (e.g., crabs: Giddins et al. 1986; Wójcik-Fudalewska et al. 2016; Cordone et al. 2022). Abundance, biomass, frequency of occurrence, size, and general distribution of prey from diets of predators can also serve as a sampling technique for species that may be difficult to survey (e.g., epiphytic invertebrates). Trophic data provides a wealth of information on ecosystem productivity, competitive interactions, habitat or niche partitioning and how predator-prey interactions might shift with changing ocean conditions (Iken et al. 2001; Polunin et al. 2001). Therefore, in-depth feeding ecology data is needed for a better understanding of the food web interactions within the SK̲-B MPA and to monitor the conservation objective on healthy ecosystem functioning.

Stable isotopes and fatty acids provide valuable information on predator-prey interactions. The abundance and types of fatty acids isolated from predator muscle tissues (e.g., DHA and EPA) can reflect the types and quality of prey species consumed (Costalago et al. 2020), the overall health of the predator, and the level of ecosystem productivity. In turn, stable isotope analysis can indicate trophic niches through comparisons of $\delta^{13}C$ and $\delta^{15}N$ in consumer tissues (Post 2002). Examining the individual $\delta^{15}N$ or ^{15}N:^{14}N ratios among a group of organisms can indicate their relative trophic positions, because ^{15}N incorporation into muscle tissues increases with each trophic level, while ^{14}N remains relatively constant. The $\delta^{13}C$ (^{13}C:^{12}C) signatures of organisms, on the other hand, can reflect general foraging habitats. This isotope is associated with low trophic enrichment and can help to differentiate between systems such as benthic versus pelagic, marine versus terrestrial, or coastal versus marine (Hobson 1999). For example, Boyle et al. (2012) used $\delta^{13}C$ to differentiate between deep benthic fishes that fed on pelagic or benthic prey. Stable isotope analyses that capture both $\delta^{13}C$ and $\delta^{15}N$ can therefore be utilized to identify trophic niches of multiple species and to infer inter-specific competition for prey resources.

In recent decades, simultaneous use of different trophic markers and techniques (e.g., stable isotopes, fatty acids, gut contents, DNA metabarcoding) has provided a much more complete picture of trophic structure and dynamics (Parzanini et al. 2019). For instance, multiple tools were utilized to identify trophic niches of deep-sea asteroid species (Howell et al. 2003), as well as ontogenetic trophic niche broadening of deep-sea Vampire Squid (Golikov et al. 2019). Stable isotope analyses can also reveal novel environmental history of deep-sea ecosystems, such as an unusually large and rich sponge benthic community within the Central Arctic, found closely associated with an extinct seep community, utilizing fossil detritus (Morganti et al. 2022).

Trophic biomarkers and diet studies require destructive sampling methods such as stomach removal and muscle tissue collection from specimens captured via targeted fishing surveys or other methods which are not recommended at the SK̲-B MPA. Therefore, it is recommended that when removing samples for other purposes, practitioners should also gather isotopic data or stomach samples where possible (e.g., selective sampling using ROVs). Furthermore, these trophic methods are proposed for more in-depth analysis, in addition to the baseline monitoring, necessitated by any ecosystem component falling below the natural range. This adaptive management, triggered through monitoring major components of the food webs, would initiate trophic studies to investigate the causes of declines of a given species. Trophic studies don’t necessarily require removing samples of the species of concern, but instead their predators, prey, and competitors.

The ecosystem-level response to any stressor will depend not only on the nature of the stressor, but on the trophic relationships of the organisms present. Stressors that impact one trophic level disproportionately may have cascading or knock-on effects for their respective predators and/or prey. Whereas a decrease in predators or primary production may cause a trophic cascade (Pinnegar et al. 2000), or a mid-trophic level decrease affects both their predators and prey (“wasp waist” ecosystem response; Bakun 2006). Since ecosystems and stressors are highly dynamic, there may often be multiple and interacting effects co-occurring, therefore baseline ecosystem data is crucial to understand these changes.

Table 10. Summary of suitable stomach content and trophic biomarker metrics to consider for biological indicator ecosystem component groups—plus a pelagics category (e.g., birds and mammals)—proposed for monitoring the trophic structure (Table 1: Operational Objective 1.3.a).

Metric	Corals & sponges	Invertebrates	Fishes	Algae habitat	Pelagics (& nekton)	Purpose/Strength	Limitations	Preferred Tool
Stomach content analysis								
Relative abundance of prey consumed	-	X	X	-	-	Trophic structure	Time and expertise intensive	Fisheries surveys (with associated stomach content analysis)
Biomass of prey consumed	-	X	X	-	-	Trophic structure	Time and expertise intensive	Fisheries surveys (with associated stomach content analysis)
Distribution of prey consumed	-	X	X	X	-	Benthic/pelagic	Physical collection and processing required	Fisheries surveys (with associated carbon stable isotopes from muscle tissues)
Diversity indices of prey consumed	-	X	X	-	-	Trophic structure	Time and expertise intensive	Fisheries surveys (with associated stomach content analysis; DNA metabarcoding)
Size structure of prey consumed	-	X	X	-	-	Fish health	Time and expertise intensive	Fisheries surveys (with associated stomach content analysis)
Trophic biomarkers: Stable isotope and fatty acid analyses								
Condition (quality[1]) of prey consumed	-	X	X	-	X	Predator health	Physical collection and processing required	Fisheries surveys (with associated fatty acids from muscle tissues)
Trophic level of predator	X	X	X	X	X	Trophic structure	Physical collection and processing required	Fisheries surveys (with associated nitrogen stable isotopes from muscle tissues)
Trophic niche of predator	X	X	X	X	X	Trophic structure	Physical collection and processing required	Fisheries surveys (with associated C:N stable isotope ratios from muscle tissues)
Growth rates of predator	X	-	X	-	-	Prey quantity and quality, health and condition of predator	Physical collection and processing required	Fisheries surveys (with associated otoliths (fish), RNA:DNA ratios (proxy), Insulin-like growth factor 1 (IGF-1; fish))

[1]Condition = quality (not condition of individuals).

8. EVALUATION OF THE FRAMEWORK AGAINST THE ECOLOGICAL CONSERVATION OBJECTIVES

The exercise of developing a monitoring framework based on the current operational objectives called for us to critically examine and evaluate the operational objectives (summarized in Table 11). As pointed out by Thornborough et al. (2016): the refinement of specific, measurable, achievable, realistic, and time-sensitive (SMART) conservation objectives is essential to the development of a monitoring program to measure ecosystem parameters that are useful and relevant for the management of anthropogenic stressors in the MPA.

Based on the evaluation in Table 11 below, future iterations of the ecological conservation goals, strategies, and operational objectives will benefit from the following considerations:

- baseline data (i.e., baseline monitoring) is required to define “natural state”;
- baseline data will help determine if monitoring entire assemblages is possible and/or if monitoring indicator species is sufficient (or a combination of both using different metrics);
- baseline data is required to best select the metric(s) for the specific indicator ecosystem component(s);
- monitoring “condition and abundance” should be prioritized (that said, multiple other metrics are related and/or contribute);
- as currently defined/interpreted, some operational objectives are likely not achievable (e.g., high mobile non-localized species; climate change impacts); and
- timing/duration varies depending on the aspect of “conservation”: “protection and maintenance” could occur in real-time with the removal of a direct stressor (e.g., the bottom-contact fisheries closure), whereas “rehabilitation” (i.e., recovery) of some species known to be impacted could take centuries.

Table 11. Evaluation of the monitoring framework information against the ecological conservation objectives as described within the SGáan Kínghlas-Bowie Seamount Marine Protected Area (SK-B MPA) management plan (CHN and DFO 2019). Language used to describe a relative degree of certainty/confidence that the current spatial management measures of the SK-B MPA will be effective at achieving the species objectives as written: unlikely < possible < likely < very likely.

Strategic Objectives	Operational Objectives	Specific	Measurable	Achievable	Realistic	Time-sensitive
1.1 Populations of rare, localized, endemic and vulnerable species are protected and conserved.	A. The condition and abundance of cold-water **coral and sponges** are within a range of the natural state.	- indicator species vs assemblage (all species) - "natural state" TBD (requires baseline data and interpretation in relation to climate change)	- if indicator species: "condition and abundance" are priority metrics - in general: condition could be interpreted as biomass, size structure, ratio live-to-dead, etc. - if entire assemblage: condition and abundance could be interpreted in a variety of ways (e.g., diversity and distribution; patch or reef dynamics)	- **possible**	- main existing SEC-stressor (i.e., bottom contact fishing) manageable and removed - future stressor: TBD (e.g., climate change)	- protection and maintenance (e.g., stopping a trend of decline or supporting the current state): **very likely**, in real-time - rehabilitation (i.e., recovery): **possible** but could take decades to centuries
	b. The condition and abundance of other **invertebrates** are within a range of the natural state.	- same as above	- same as above	- **possible**	- main existing SEC-stressor (i.e., bottom contact fishing) manageable and removed - future stressor: TBD (e.g., climate change)	- protection and maintenance (e.g., stopping a trend of decline or supporting the current state): **very likely**, in real-time - rehabilitation (i.e., recovery): **possible** but could take years to decades
	c. The condition and abundance of **fishes** (e.g., REBS Rockfish, Bocaccio, Yelloweye Rockfish, Sablefish, Prowfish) are	- same as above	- same as above	- benthic and bentho-pelagic fish: **possible** - Sablefish population: **unlikely**	- main existing SEC-stressor (i.e., bottom contact fishing) manageable and removed -Sablefish: outside the scope of SK-B MPA spatial management measures	- protection and maintenance (e.g., stopping a trend of decline or supporting the current state): **very likely**, in real-time - rehabilitation (i.e., recovery): **possible**, but

Strategic Objectives	Operational Objectives	Specific	Measurable	Achievable	Realistic	Time-sensitive
	within a range of the natural state.					could take decades to centuries
1.2 Habitats that are essential for life history phase of species with the MPA are protected and conserved.	A. **Sensitive benthic habitats (SBH)** are within a range of the natural state.	- identification of SBHs TBD (e.g., as defined, "vulnerability based on human activities") (requires baseline ecological and stressor data) - "natural state" TBD	- same as above	- for coral and sponge habitats: **possible** - for algal habitats: **likely**	- for coral and sponge habitats: main existing SEC-stressor (i.e., bottom contact fishing) manageable and removed - for algal habitats: potential SEC-sensor manageable	- protection and maintenance (e.g., stopping a trend of decline or supporting the current state): **very likely**, in real-time - rehabilitation (i.e., recovery): **possible**, but could take decades to centuries
	b. **Pelagic and sea surface conditions** are within a range of the natural state.	- identification of specific "conditions" TBD (currently defined as "physical, chemical, and biological characteristics) - "natural state" TBD	- likely (there are existing tools and strategies)	- **unlikely** (as currently defined/ interpreted)	- spatial management can mitigate controllable adverse activities and manage risk - as an objective, though: outside the scope of spatial management measure (e.g., climate change: many metrics are climate variables or are influenced by climate variables)	- some climate change impacts are rapid (anomalous events, e.g., blob): **unlikely**, months to years - some climate change impacts are long-term trends (expansion of the OMZ): **unlikely**, years to decades
1.3 Ecosystem food webs are protected and conserved	A. **Ecosystem function and trophic structure** are within a range of the natural state.	- identification of specific "functioning" TBD - trophic structure TBD - "natural state" TBD	TBD	- **unlikely** (as currently defined/ interpreted)	- all points above	- **unlikely**, all points above

9. UNCERTAINTIES

The following are uncertainties and knowledge gaps pertaining to the current understanding of monitoring options for the SK-B MPA.

- The extent of current and future climate change impacts on the SK-B MPA ecosystem is uncertain. Baseline and future monitoring will help detect some of these impacts and resolve linkages between direct and indirect effects. As such, climate change considerations are incorporated into most aspects of the monitoring framework.
- The framework was developed based on the anticipated changes—unanticipated stresses may require monitoring beyond the scope covered.
- The species inventory for the MPA is incomplete and represents a knowledge gap (as evidenced by the rapid increase of known species as a function of survey effort within the SK-B MPA: documented SK-B MPA taxa was 191 in 2015 and 771 in 2021). In deep-sea ecosystems, the knowledge base for species identity, distribution, and behaviours are always growing and changing. By grouping biological ecosystem components, we facilitated moving forward with monitoring and adaptive management. The groupings are based on the ecological conservation objectives and the known current inventory of species. Groupings should be re-examined as further information becomes available and/or conservation goals are re-examined. Initial species indicators proposed in the ERAF were prioritized within groupings, but this list will also continue to be resolved during the baseline monitoring phase, based on regional assessments and needs and consideration of broader initiatives (e.g., network monitoring, national indicators, species of conservation concern).
- Indicator-associated reference points (e.g., the definition and quantitative measure of "the natural state"), thresholds, response lag time post-disturbance, recovery potential, etc., are all unknowable at this time and should be determined through future assessments as baseline measurements are collected and/or become available and are assessed.
- This framework reflects the best available current knowledge of the authors. However, the fields involved in studying deep-sea environments—such as seamounts—are cutting-edge sciences known for their innovations. There may be more options available currently in development that should be considered in the monitoring plan (i.e., new protocols and strategies).
- Innovations will undoubtedly help overcome the inherent challenges of monitoring a deep-sea MPA (e.g., SK-B MPA is ~180 km offshore, encircles over 6,000 km^2 of seafloor and over 3,000 m of water depths, and essentially lacks comparable reference sites).
- Quantifying trophic structure and ecosystem functioning requires sophisticated modelling and long-term time series data on a multitude of species and oceanographic conditions. While trophic modelling and determining whether it's "within a range of the natural state" is outside of the current scope of the monitoring framework, monitoring major indicator functional groups of the ecosystem is the first step to understanding a dynamic system. Once the future monitoring plan is established and more data becomes available, it is recommended to revisit and re-examine quantifying these trophic relationships, if possible.
- There is uncertainty regarding the achievability of the SK-B MPA ecological conservation objectives as written. This report evaluated the operational objectives against the monitoring framework focusing on whether the objectives met the criteria to be considered Specific, Measurable, Achievable, Realistic, and Time-sensitive (e.g., the pelagic and sea surface

conditions, and ecosystem function and trophic structure, operational objectives 1.2.b and 1.3.a).

10. SUMMARY, CONCLUDING REMARKS, AND RECOMMENDATIONS

10.1. SUMMARY

The monitoring framework is a summary of indicators (ecosystem components and metrics), protocols, and strategies options for monitoring the effectiveness of the MPA management measures against the ecological conservation objectives. By highlighting the connections between each monitoring component (see Tables 12 to 14), practitioners and managers can make strategic decisions for priorities during the next step of the process, which is developing the management plan (see summary Figure 23; Table 15). For example, based on current knowledge, monitoring of cold-water corals and sponges using ROVs during the offshore expeditions addresses the most operational objectives (Table 12 to14; Figure 23). The continued collection of baseline data will further help resolve which pathways are most effective.

Table 12. Connections between the major components of the monitoring framework: the operational objectives (6 columns) and monitoring indicator ecosystem component groupings (12 rows). Where 1 = the indicator ecosystem component provides information directly applicable to the objective, and a dash denotes it is not applicable. The count (total objectives covered) provides an idea of the versatility of the indicator to provide information. Linkages are illustrated in Figure 23.

Indicator ecosystem components ↓	**Objectives →**	1.1.a. The condition and abundance of cold-water coral and sponges…	1.1.b. The condition and abundance of other invertebrates…	1.1.c. The condition and abundance of fishes…	1.2.a. Sensitive benthic habitats…	1.2.b. Pelagic and sea surface conditions…	1.3.a. Ecosystem function and trophic structure…	**COUNT**
Corals and sponges		1	-	-	1	-	1	**3**
Invertebrates	Infauna	-	1	-	-	-	1	**2**
	Sessile and sedentary epifauna	-	1	-	-	-	1	**2**
	Mobile epifauna	-	1	-	-	-	1	**2**
Fish	Bentho-pelgaic fish	-	-	1	-	-	1	**2**
	Benthic fish	-	-	1	-	-	1	**2**
Algae habitat		-	-	-	1	-	1	**2**
Environmental	Geological oceanography	-	-	-	1	-	1	**2**
	Biological oceanography	-	-	-	-	1	1	**2**
	Physical oceanography	-	-	-	-	1	1	**2**
	Chemical oceanography	-	-	-	-	1	1	**2**
Stressor		-	-	-	1	1	1	**3**

Table 13. Connections between the major components of the monitoring framework: the indicator ecosystem component groupings (12 columns) and monitoring protocols tools (17 rows). Where 1 = the tool can be used to monitor the indicator ecosystem component, (1) = sometimes it can be used (i.e., potentially), and a dash denotes it is not used. The count (total indicator ecosystem components monitored) provides an idea of the versatility of the tool (potential indicators included in parentheses). Linkages are illustrated in Figure 23.

Indicator ecosystem components → / **Protocols ↓**			Invertebrates			Fish			Environmental					
		Corals and sponges	Infauna	Sessile and sedentary epifauna	Mobile epifauna	Bentho-pelagic fish	Benthic fish	Algae habitat	Geological oceanography	Biological oceanography	Physical oceanography	Chemical oceanography	Stressor	**COUNTS**
Imagery and biological sampling	Submersibles (benthic)[1]	1	1	1	1	1	1	1	1	(1)	(1)	(1)	1	**9 (+3)**
	Submersibles (pelagic)	-	-	-	-	1	-	-	-	-	-	-	1	**2**
	Sea surface surveys	-	-	-	-	-	-	-	-	-	-	-	1	**1**
	Fishing surveys	1	-	-	1	1	1	-	-	-	-	-	1	**5**
Seafloor	Sediment sampler	1	1	1	-	-	-	-	1	-	-	-	1	**5**
	Traps and plates	1	-	1	-	-	-	-	1	1	-	-	1	**5**
Acoustic	Sonar	-	-	-	-	1	-	-	1	1	-	-	1	**4**
	Hydrophones[2]	(1)	(1)	(1)	(1)	(1)	(1)	(1)	-	-	-	-	1	**1 (+7)**
	ADCP	-	-	-	-	-	-	-	-	-	1	-	1	**2**
Oceanographic	Sensors	-	-	-	-	-	-	-	-	1	1	1	1	**4**
	UVP	-	-	-	-	-	-	-	-	1	-	-	1	**2**
	Nets	-	-	-	-	-	-	-	-	1	-	-	1	**2**
	Water sampling[3]	(1)	(1)	(1)	(1)	(1)	(1)	(1)	-	1	1	1	1	**4 (+7)**
	Deployed equipment	-	-	-	-	-	-	-	-	1	1	1	1	**4**
Online	Satellites	-	-	-	-	-	-	-	1	1	1	1	1	**5**
	Models	-	-	-	-	-	-	-	1	1	1	1	1	**5**
	Cabled observatory[4]	-	-	-	-	-	-	-	-	(1)	(1)	1	1	**2 (+2)**

[1]Submersibles, like ROVs, can carry lots of mounted tools, such as water sampling bottles, ADCPs, and sensors—meaning it's possible ROVs can be used to measure all indicator ecosystem component groupings.[2,3] The use of hydrophones and eDNA water samples to monitor biological indicators is promising but both are emerging options and should not be used in place of standard sampling methods at this time.[4] In its current form, the ONC cabled observatory array can provide oceanographic information/context for the southern OPB, that can provide some information about conditions in the MPA, but there are no cabled nodes near the region.

Table 14. Connections between the major components of the monitoring framework: protocols tools (17 columns) and monitoring strategies (14 rows). Where 1 = the strategy uses the tool, (1) = sometimes it uses the tool (i.e., potentially), and a dash denotes it does not use the tool. The count (total tools used) provides an idea of the versatility of the strategy (potential tools included in parentheses). Linkages are illustrated in Figure 23.

	Protocols →	**Imagery and biological sampling**				**Seafloor**		**Acoustic**			**Oceanographic**					**Online**			
Strategies ↓		Submersibles (benthic)	Submersibles (pelagic)	Sea surface surveys	Fishing surveys	Sediment sampler	Traps and plates	Sonar	Hydrophones	ADCP	Sensors	UVP	Nets	Water sampling	Deployed equipment	Satellites	Models	Cabled observatory	**COUNTS**
Within the SK-B MPA	Offshore expeditions	1	(1)	1	-	1	(1)	1	1	1	1	1	1	1	1	-	-	-	**11 (+3)**
	Mammal surveys	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	**2**
	Eddy monitoring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	**2**
	Sea surface monitoring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	**1**
	Moorings	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	**1**
Outside the SK-B MPA	Line P	-	-	-	-	-	-	1	-	-	1	1	1	1	1	-	-	-	**6**
	Plankton program	-	-	-	-	-	-	-	-	-	1	1	1	1	1	-	-	-	**5**
	Glider program	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	**1**
	Argo floats	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	**2**
	ONC NEPTUNE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	**1**
	Fisheries	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	**2**
	Ships of opportunities	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	**1**
	Drifting buoys	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	**1**
	Drift bottle project	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	**1**

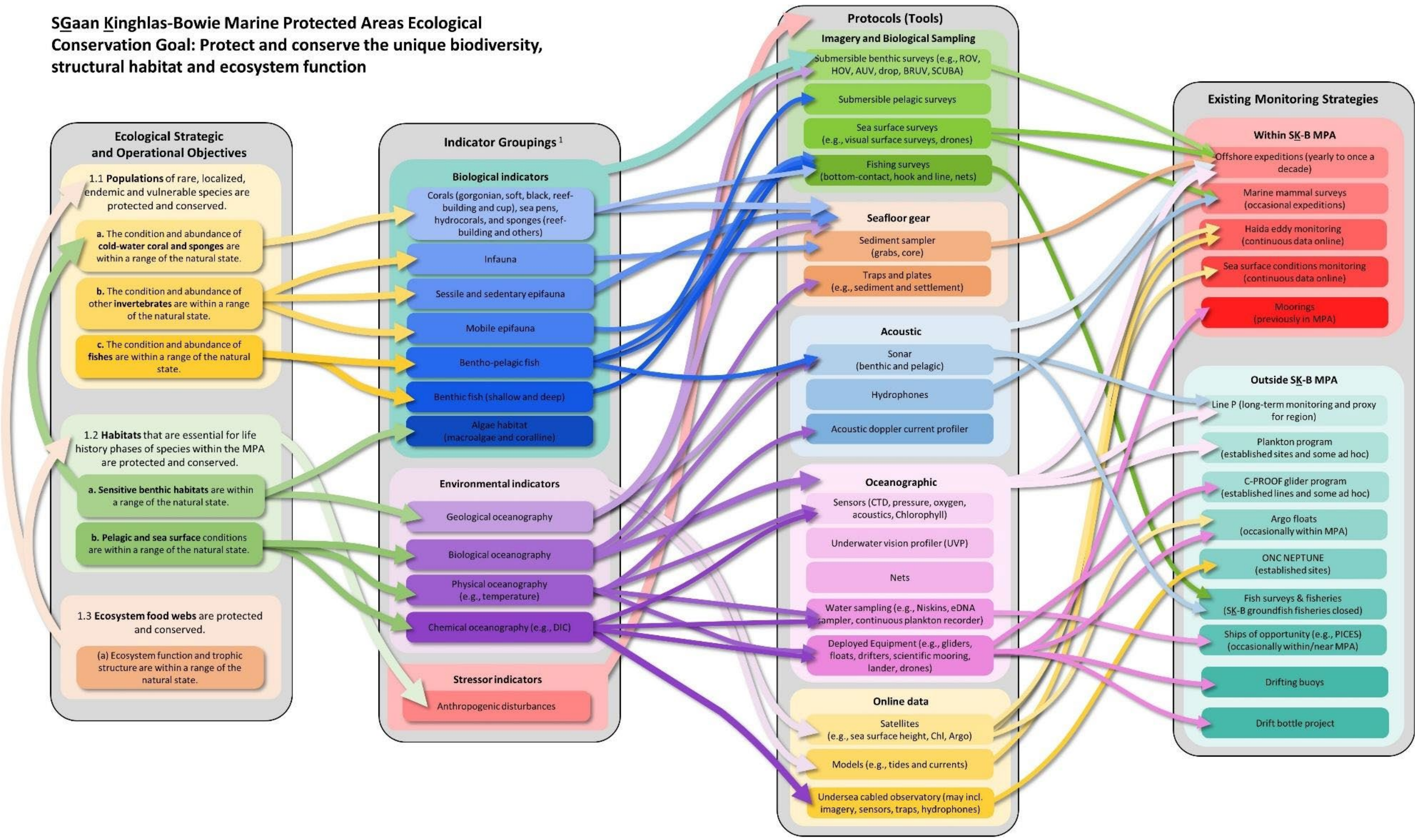

Figure 23. Connections between the four major components of the monitoring framework: the Ecological Strategic and Operational Objectives and the monitoring indicator ecosystem component groupings (metrics not shown), protocols (tools), and strategies. The graphic can be used in either direction to support the development of a monitoring plan. For example, (working left to right) most Operational Objectives and Indicator Groupings have multiple options of Tools for monitoring and (working from right to left) the Offshore Expeditions and Line P employ the highest number of those Tools. Details on preferred tool options are provided in summary tables Table 12 to 14. The specific tool selected for an indicator group will depend on the metric being measured.

10.2. CONCLUSIONS AND RECOMMENDATIONS

- This Research Document provides the basis for the essential next step in the management of the SK-B MPA, developing an ecological monitoring plan. We developed advice on monitoring indicators (ecosystem components and metrics), protocols (tools, methods, etc.), and strategies (programs) to guide the management and monitoring of the SK-B MPA. The framework provides a summary of options for monitoring the ecological conservation objectives outlined in the management plan, and includes specific recommendations when appropriate.
- Additional recommended next steps include:
  - monitoring practitioners and researchers integrate and report back on the information provided (part of the adaptive management framework),
  - a review of the operational objectives by the SK-B MPA Management Board (more information below; part of the adaptive management framework),
  - future monitoring and management documents and deliverables consider, use, and/or expand on the ways in which the SK-B MPA monitoring framework was co-created by the Nations that cooperatively manage it, CHN and the Government of Canada (e.g., integration of Haida traditional knowledge, Haida language and names, recognition of Haida cultural and ecological significance),
  - the MPA practitioner community develop a common lexicon (e.g., of what constitutes baseline information and working definitions for terms such as “natural state”), and
  - future site or regional monitoring frameworks or plans use or refer to applicable information provided herein, rather than duplicating the concerted effort to coalesce the knowledge and best practices in this research document.
- The proposed indicators, protocols, and strategies should be revisited, re-evaluated, and/or refined through the adaptive management framework as new data, methods (e.g., emerging technologies related to hydrophones and eDNA), information, and sampling opportunities become available.
- The ancient underwater volcanic mountains within the SK-B MPA have been relatively stable for tens of thousands of years. The disturbance of its natural state began over a hundred years ago with commercial whaling, followed by commercial fishing fifty years later.
- Existing and anticipated changes within the SK-B MPA related to the protection and conservation of its biodiversity, structural habitat, and ecosystem function include the recent prohibition of bottom-contact fishing and ongoing impacts of lost fishing gear, climate change, vessel traffic, and other human activities (e.g., non-renewable resource extraction outside the MPA, such as seabed mining). Ecological responses to changing conditions may occur immediately (e.g., the protection and maintenance afforded by prohibiting or managing an activity) or may take centuries or longer (e.g., the recovery of long-lived, slow-growing species such as cold-water corals and sponges). Monitoring plans should consider the indicator-specific timelines (e.g., generation time, response lag time) and disturbance/protection history when designing and implementing monitoring schedules.
- We recommend that future decisions on the SK-B MPA monitoring indicators use the proposed ecosystem component groupings (inclusive of cold-water corals, sponges, other invertebrates, fishes, sensitive benthic habitats, environmental conditions, and stressors groupings), metrics, and priorities (e.g., indicator species and condition and abundance measurements) provided in this research document.

- Of the proposed indicators, the monitoring of cold-water corals and sponges addresses the most operational objectives (Table 12).
- Many components (e.g., thresholds and reference points, response lag time, recovery potential, vulnerability) required to implement an effective long-term monitoring plan are unknowable at this time.
- We recommend that future decisions on the SK-B MPA monitoring consider the use of the proposed protocols (tools) provided in the research document. The options provided adequately cover the indicator ecosystem components and metrics proposed and are used in the region within existing strategies (programs).
- Of the proposed tools, submersibles are the most versatile, especially if the vehicle has mounted sensors and the capability to collect specimens and water samples (e.g., ROV), followed by water samples (and more if there is eDNA sampling) (Table 13).
- We recommend that future research examines the suitability of emerging technologies such as eDNA and hydrophones.
- All tools listed are available through at least one of the existing monitoring strategies (within or currently outside the SK-B MPA), with the exception of pelagic imagery specifically for monitoring bentho-pelagic fish (Table 1: 1.1.c) and settlement plates and sediment traps for monitoring biological and geological oceanographic processes in SBH (Table 1: 1.2.a)
- We recommend that future decisions on the SK-B MPA monitoring strategies consider the use of 14 previous and ongoing programs (including potential spatial expansion to encompass the SK-B MPA or extrapolation of information). The importance of a program's data and its availability on a shared platform is key.
- Of the existing strategies, the offshore expeditions are the most versatile regarding tools (which cascades into options for indicators), followed by Line P and the Plankton Program (Table 14). With the addition of online data resources, the combination of these existing strategies can potentially provide data to address at least one aspect of all six of the ecological conservation operational objectives (Figure 23).
- There are no permanent time-series monitoring strategies directly related to the SK-B MPA as of yet. While there are relevant repeated or long-term monitoring strategies outside the MPA, most of the existing 'within SK-B MPA' baseline data are from individual research projects (not intended time-series studies) and require careful evaluation for suitability before use in the monitoring program. However, there is a pilot study for long-term monitoring of benthic sites. In 2018, we established dozens of sites inside the SK-B MPA and the proposed TḥT MPA (Gartner et al. 2022). The first time-series data was successfully collected for Dellwood Seamount in 2021 and within the SK-B MPA in 2022.
- The SK-B MPA ecosystem is unique. Caution should be taken when inferences are made based on other ecosystems (e.g., other shallow seamounts and nearby coastal environments).
- Its uniqueness, limitations of existing data, and the resources required to execute certain methods may make developing sample designs challenging. For example, there is no ideal reference site for the SK-B MPA ecosystem.
- Conservation measures restricted to the spatial extent of the SK-B MPA may not be effective at protecting and conserving reproductive populations or productivity. Reproductive populations seeding the MPA may be on Haida Gwaii or elsewhere on the coast and delivered by way of Haida Eddies—an important future research topic.

- Monitoring human activities and their impacts is fundamental for interpreting the results of ecological performance monitoring and evaluating MPA management effectiveness. We recommend that the future SK-B MPA ecological monitoring plan incorporate data and information collected by all other SK-B MPA monitoring programs.
- Data sharing between all SK-B MPA monitoring practitioners will be essential for interpreting detected changes, or a lack thereof, in the context of cumulative effects and the effectiveness of management measures. A detected trend will be the result of various stressor effects, both positive and negative. For example, while an overall ecological trend may be "negative", the individual management measures may be effective at removing or reducing stressors and creating positive pressures. An anticipated scenario is that climate change impacts (unmanageable at the scale of the MPA) will drive overall negative trends while the mitigation of manageable stressors (e.g., fishing) will be essential positive pressures.
- We identify monitoring for other conservation objectives relevant to ecological monitoring. There are linkages between monitoring for the six major ecological conservation objectives within Goal 1 of the management plan (CHN and DFO 2019) and the proposed monitoring of fishing (2.1, 3.2.b), vessel traffic (2.2, 3.2.c), science activities (2.3, 3.2.b), marine tourism (2.4), non-renewable resource extraction activities outside the MPA (2.5), transient species (3.2.d), and proposed collaborations on broader initiatives such as climate change research (4.1.b).
- The management plan takes an ecosystem-based approach to its operational objectives; therefore, there is a need to (i) understand multi-scale dynamic processes and relationships and (ii) monitor an increased range of environmental conditions and ecological components. We propose a model trophic structure to provide context for linkages between ecosystem components of interest and potential cascading effects of detected changes.
- Trophic structure and ecosystem function were examined through a conceptual food web model, although direct data on trophic relationships within the SK-B MPA is limited. Metrics of gut content analysis and trophic biomarkers were proposed as additional methods for monitoring changes in trophic structure. Future research expanding on the previous ecosystem modelling of the SK-B MPA trophic structure and careful comparison with coastal environments is recommended to strengthen monitoring efforts.
- The use of non-destructive tools aligns with the management plan but has limitations, especially pertaining to research to resolve trophic interactions and ecosystem functioning. With regard to extractive sampling, there are advantages and disadvantages to consider when using targeted fisheries surveys to study these trophic relationships versus other sampling surveys (e.g., using remotely operated vehicles).
- When possible, protocols and strategies that are minimally invasive and collect data for multiple relevant ecosystem components should be prioritized.
- Baseline monitoring and research to fill identified knowledge gaps should be prioritized (e.g., high-resolution multibeam mapping and species distribution modelling, anticipated responses to climate change).
- The protection and conservation such that an ecosystem component is "within a range of the natural state" requires thoughtful interpretation, especially as it relates to climate change. The SK-B MPA management plan defines the term as: "The natural variation of condition and extent, or range, of an ecosystem component (e.g., a species, ecological

process, or environmental quality). In areas where human activity occurs, it implies that no measurable difference exists with or without such activity" (DFO and CHN 2019).

- A comprehensive data management plan was highlighted as an essential element of any future monitoring plan. The complexity of multi-disciplinary monitoring programs will necessitate substantial budget and human resources allocation to support the assembly, management and evaluation of collected data. Information and data streams should be well documented and openly available to support repeatability and reproducibility. The data management plan should adopt standards such as the FAIR (Findable, Accessible, Interoperable, and Reusable; Wilkinson et al. 2016) and CARE principles (Collective benefit, Authority to control, Responsibility, and Ethics; Carroll et al. 2020).
- Easy-to-read and comprehensible reporting on MPA management measure effectiveness should be used to communicate research findings of monitoring plans to management staff and the general public. One consideration is the use of a 'report' card concept—an effective tool which should be theoretically standardized across Canadian jurisdictions.
- The cooperative management of the MPA should be adaptive and responsive, and new information available through monitoring should feed back into an iterative process of re-examining the management and monitoring plans, for example: as baseline monitoring continues; as a common lexicon is developed; as climate change progresses; and in response to emerging threats (e.g., potentially deep-sea mining in adjacent waters).
- It is recommended that future decisions on the SK̲-B MPA management consider the evaluation of ecological conservation objectives provided in this research document, where components of four of the six operational objectives may be unachievable (i.e., as written, owing to climate change, or owing to time-sensitivity). For example, as written, climate change will make achieving some operational objectives highly unlikely. Managing climate variables (e.g., "Pelagic and sea surface conditions are within a range of the natural state") is unrealistic but managing impacts on other MPA objectives may be possible with mitigation efforts.
- Climate change is impacting Northeast Pacific seamount ecosystems (e.g., temperature, pH, oxygen, food web) and should be incorporated throughout the MPA management and monitoring plans (e.g., anticipated climate change impacts can be monitored directly or indirectly if lag time and mechanisms are understood).
- It was noted that the SK̲-B MPA monitoring framework may support the development of monitoring frameworks and plans for other protected areas or regions in general, especially in the case of the proposed TḥT MPA to the south (contains at least 47 seamounts and 35 hydrothermal vents). In general, there are differences in MPA monitoring processes and terms used by different regions and practitioners within Canada, and these are changing over time. An effort to standardize practices where appropriate while still promoting development and innovations is one option to move forward.
- Monitoring indicators, protocols, and strategies are interconnected, and baseline data will continue to help resolve the most effective pathways. Based on the best available information, our proposed monitoring recommendations are detailed in Table 15.

Table 15. Summary of proposed monitoring indicators (ecosystem components and metrics), protocols, and strategies to directly monitor populations of rare, localized, endemic and vulnerable species, habitats that are essential for life history phase of species within the SGáan Kinghlas-Bowie Marine Protected Area (SK-B MPA), and ecosystem food webs (CHN and DFO 2019: Strategic Objective 1.1 to 1.3). The information is listed in order of priority (primary, 1°, secondary 2°, tertiary 3°) or not if prioritization is still to be determined (TBD). Other monitoring efforts indirectly related and relevant to the ecological conservation objectives are included.

Operational Objectives	**Monitoring Indicators:** **Ecosystem Components**	**Metrics**	**Monitoring Protocol[1]**	**Monitoring Strategy[1,2]**	**Other Monitoring Efforts**
1.1.a. The condition and abundance of cold-water coral and sponges are within a range of the natural state	1° corals: *Primnoa pacifica* and *Isidella tentaculum* 2° corals: other Gorgonian corals[3] 3° corals: other known species of Soft, Black, Reef-building, and Cup Corals, Sea Pens, and Hydrocorals[3]	1°: abundance 1°: condition (i.e., health) 2°: other biological metrics (Table 3 to 6) 2°: other environmental and stressor metrics (indirect monitoring)	1°: submersible benthic imagery surveys (with associated sampling where appropriate) 2°: settlement plates Future possibility: eDNA water samples and hydrophones	1° Offshore expeditions	1° monitoring: climate change (same as Operational Objective 1.2.b) (relates to protection, maintenance, rehabilitation) 1° monitoring: fishing (e.g., non-compliance relates to protection) 2° monitoring: other human activities (e.g., vessel traffic, marine noise, and marine debris) 3° monitoring: transient species
	Known species of reef-building glass sponges and other sponges[3]				
1.1.b. The condition and abundance of other invertebrates are within a range of the natural state	1° invertebrates: *Munida quadrispina* (mobile epifauna) 2° invertebrates: brittle star mat complex (mobile epifauna) 3° invertebrates: other known species of infauna, sessile and sedentary epifauna, and mobile epifauna[3]				
1.1.c. The condition and abundance of fishes are within a range of the natural state	1° fishes: Widow Rockfish (*Sebastes entomelas*), Bocaccio (*Sebastes paucispinis*), Prowfish (*Zaprora silenus*), Yelloweye Rockfish (*Sebastes ruberrimus*), REBS Rockfish (*Sebastes melanostictus* / *S. aleutianus*), Pacific Halibut (*Hippoglossus stenolepis*), Sablefish (*Anoplopoma fimbria*) 2° fishes: other Rockfish (*Sebastes* spp. and *Sebastolobus* spp.) 3° fishes: other known species of benthopelagic, shallow benthic, and deep benthic fishes[3]		1° shallow and deep benthic fishes: submersible benthic imagery surveys 2° shallow and deep benthic fishes: fishing surveys (may provide valuable biological samples but violate existing regulations)		
			1° benthopelagic fishes: submersible pelagic imagery surveys 2° benthopelagic fishes: sonar 2° benthopelagic fishes: fishing surveys (may provide valuable biological samples but violate existing regulations)		

Operational Objectives	Monitoring Indicators: Ecosystem Components	Metrics	Monitoring Protocol[1]	Monitoring Strategy[1,2]	Other Monitoring Efforts
1.2.a. Sensitive benthic habitats (SBH) are within a range of the natural state	Habitat-forming coralline algae and macroalgae: known species[3]		1°: submersible benthic imagery surveys (with associated sampling where appropriate) Future possibility: eDNA water samples and hydrophones		
	Habitat-forming corals and sponges: same as Operational Objective 1.1.a				
	Geological, physical, chemical, and biological environmental and stressor ecosystem components	1° primary and secondary productivity, temperature, current, pH, oxygen (list primarily driven by climate change impacts) 2° other metrics[4]	1° remote sensing (relatively inexpensive and total coverage): satellite and model data 2° in situ: oceanographic sonar, sensors, nets, and water sampling (ship-based, deployed, or mounted on other tools)	1° remote sensing: eddy, sea surface, and mooring monitoring 2° remote sensing: other existing remote monitoring strategies[5]	
1.2.b. Pelagic and sea surface conditions are within a range of the natural state				1° in situ: Offshore expeditions 2° in situ: Line P, Plankton, Glider, Argo float programs 3° in situ: other existing strategies[5]	
1.3.a. Ecosystem function and trophic structure are within a range of the natural state	1° those ecosystem components already monitored/sampled (see above) 2° additional significant ecosystem components as they are identified	Stomach content and trophic biomarker metrics[6]	Guidance provided in text and Table 10 but specifics TBD through baseline monitoring (limited by the ability to collect biological samples)		

[1] The suitability of protocols (tools) and strategies (programs) will change in time (e.g., with changing techniques, technologies, and monitoring efforts). The lists provided are based on the best available current knowledge. Additional options and considerations are provided in the text.

[2] Guidance on methodologies provided in the text but specifics TBD through baseline monitoring and research and identification of specific indicators (ecosystem components and metrics), protocols, and strategies (e.g., sampling frequency may be influenced by cost and also needs to consider generation times and anticipated changes).

[3, 4, 5, 6] Listed in: Table 1 and Du Preez and Norgard 2022: Table A10; Table 6 and 7; Section 5.2 and Table 11; and Table 10, respectively.

11. ACRONYMS

ABNJ – Areas Beyond National Jurisdiction

ADCP – Acoustic Doppler Current Profiler

AIS – Automatic Identification System

AOI – Area of Interest

AUV – Autonomous Underwater Vehicle

AVHRR – Advanced Very High Resolution Radiometer

BACI – Before-After-Control-Impact

BC – British Columbia

BCB – Biodiversity Conservation Benefits

BOOTS – Bathyal Ocean Observation and Televideo System

BRUVS – Baited Remote Underwater Video Stations

C-PROOF – Canadian Pacific Robotic Ocean Observing Facility

CBD – Convention on Biological Diversity

CHN – Council of the Haida Nation

CIOOS – Canadian Integrated Ocean Observing System

CPR – Continuous Plankton Recorder

CRP – Cetacean Research Program

CSAS – Canadian Science Advisory Secretariat

CTD – Conductivity, Temperature, and Depth (instrument package)

CUC – California Under Current

CWS – Canadian Wildlife Service

DIC – Dissolved Inorganic Carbon

DFO – Fisheries and Oceans Canada

DNA – DeoxyriboNucleic Acid

EBSA – Ecologically and Biologically Significant Area

ECCC – Environment and Climate Change Canada

eDNA – Environmental DNA

ERAF – Ecological Risk Assessment Framework

GPS – Global Positioning System

HOV – Human Operated Vehicle

ICES – International Council for the Exploration of the Sea

IOS – Institute of Ocean Sciences

IPCC – Intergovernmental Panel on Climate Change

MaPP – Marine Plan Partnership

MERIS – Medium Resolution Imaging Spectrometer

MOCNESS – Multiple Opening/Closing Net and Environmental Sensing System

MODIS – Moderate Resolution Imaging Spectroradiometer

MPA – Marine Protected Area

NEPTUNE – North East Pacific Time-series Underwater Networked Experiments

NOAA – National Atmosphere and Oceanic Organization

NOC – Nation Oceanography Centre

OPB – Offshore Pacific Bioregion

ONC – Ocean Networks Canada

OMZ – Oxygen Minimum Zone

PDO – Pacific Decadal Oscillation

PICES – North Pacific Marine Science Organization

PRISMM – Pacific Region International Survey of Marine Megafauna

REBS – Rougheye/Blackspotted Rockfish complex

ROV – Remotely Operated Vehicle

SBH – Sensitive Benthic Habitat

SeaWiFS – Sea-viewing Wide Field-of view Sensor

SEC – Significant Ecosystem Component

SCUBA – Self-Contained Underwater Breathing Apparatus

SK-B – SGáan Kínghlas-Bowie

SMART – Specific, Measureable, Achievable, Realistic, and Time-sensitive

SOPO – State Of the Pacific Ocean

SST – Sea Surface Temperature

TUVS – Towed Underwater Video System

UVP – Underwater Vision Profiler

VME – Vulnerable Marine Ecosystem

WHOI – Woods Hole Oceanographic Institution

12. GLOSSARY (USE OF TERMS)

A challenge of working on a multi-disciplinary project is the use of terms and their meanings, and how these differ between fields. Below are terms and their definitions used in this report.

- **Adaptive Management –** A monitoring and management approach that assists in decision-making related to science-based processes. It is a prescriptive, formalized, systematic method that enables management to learn from the outcomes of implemented management actions.
- **Conservation –** The protection, maintenance and rehabilitation of living marine resources, their habitats and supporting ecosystems (CHN and DFO 2019).
- **Conservation Goal –** The highest, overarching or conceptual level description of the desired future state (supported by two hierarchical tiers: the Strategic Objectives and the Operational Objectives) (DFO 2012).
- **Distribution –** The range in space in which we observe a species/population.
- **Ecosystem –** A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.
- **Ecosystem component –** A fundamental element of the biological, physical or chemical environment that represents an explicit and tangible (i.e., measurable or observable) species, habitat, function, structure or other attributes (CHN and DFO 2019).
- **Ecosystem function –** The physical, chemical and biological processes or attributes that contribute to the self-maintenance of the ecosystem (CHN and DFO 2019).
- **Epifauna –** Benthic fauna living on the substrate but not burrowing into it.
- **Endemic species –** A species whose range is restricted to a limited geographical area (i.e., only found within the SK-B MPA).
- **Fitness –** An animal/species/population's ability to survive and reproduce in the environment.
- **Indicators –** An ecological indicator is a specific measurable component of an ecosystem that is used for monitoring, assessing, and understanding ecosystem status, impacts of anthropogenic activities, and effectiveness of management measures in achieving objectives (Thornborough et al. 2016). Therefore, throughout this document we discuss "indicators" in the context of two elements: (1) the "ecosystem component" and (2) the "metric."
- **Life history phases –** The sequence of development (stages) (e.g., settlement, growth, reproduction) that together comprise the life history strategy of an organism.
- **Localized species –** A species whose range is restricted to a particular geographical area (i.e., only found offshore of British Columbia).
- **Metric –** Quantifiable data that can be either directly measured or calculated (derived) from other metrics. Neves et al. (in prep[3]) used the term 'state indicators' and Thornborough et al. (2018) term 'indicator' (which had a 'measurable component'). Within this document we broke the concept of the indicator into (1) its ecosystem component and (2) its measurable component (metric) and found this terminology to clarify between the two.
- **Monitoring –** A continuous management activity that uses the systematic collection of data on selected indicators to provide managers and stakeholders with indicators that denote the

extent of progress toward the achievement of management goals and objectives (DFO and CHN 2019).

- **Monitoring framework –** A monitoring framework is like a roadmap, providing a broad and high-level summary of selected suitable options for monitoring the ecological conservation objectives (what to monitor [indicators], how to monitor [protocols], ways to monitor [strategies]). These options can be prioritized where appropriate (e.g., most suitable, practical, or effective). A monitoring framework supports the future development of a monitoring plan and is structured around an adaptive management approach so should consider existing and future needs and options (e.g., anticipates future opportunities to refine conservation objectives and/or revisit the framework and/or plan during/after monitoring and evaluations).
- **Monitoring plan –** A monitoring plan provides prescriptive details for the selected monitoring pathways (options) and enables consistent repeated monitoring of the success of the conservation objectives.
- **Nekton –** Living organisms that are able to move independent of currents. Includes benthic fish.
- **Operational Objectives –** Specific and measurable components of the Strategic Objectives which describe the outcomes expected if the MPA design and management are successful (DFO 2012).
- **Patch dynamics –** Considers the population as an interconnected assemblage over large spatial scales. Four patch interaction metrics are included in this research document: patch area and density, isolation/proximity, connectivity, and contagion.
- **Pelagic conditions –** The oceanographic qualities within the pelagic zone (e.g., physical, chemical, and biological characteristics).
- **Population –** A group of organisms of a species that interbreed and live in the same geographical area at the same time.
- **Protection –** Avoiding harm to fish, fish habitat or other natural resources from human activities through surveillance and enforcement, and management measures with the goal of compliance with relevant policies, plans and/or regulations (e.g., protection of species at risk).
- **Protocol –** Monitoring protocols describe the specific methodologies required for the monitoring activity such as equipment, techniques, quality control, timing, frequency, as well as analysis of data (DFO 2012).
- **Range of the natural state –** The natural variation of condition and extent, or range, of an ecosystem component (e.g., a species, ecological process, or environmental quality). In areas where human activity occurs, it implies that no measurable difference exists with or without such activity (DFO and CHN 2019). Therefore, with regard to climate change impacts, it implies that no measurable difference exists with or without the direct or indict impacts of climate change.
- **Rare species –** A species of organisms that occurs in only a few locations (CBD 2008), very uncommon, scarce, or infrequently encountered.
- **Reference points –** Values associated with specific indicators that management is either seeking to maintain, achieve, or avoid (DFO and CHN 2019). For example, the range of the natural state (or optimum habitat) is an ecological reference point. These values are to be

determined through baseline measurements/monitoring data collection and analyses (Cooper et al. 2011) (i.e., integrated part of the monitoring data streams and an adaptive monitoring plan). As stated in Kenchington 2014: cannot be defined in advance, after which a calculation can determine whether a threshold has been breached.

- **Sensitive benthic habitats –** Sensitive benthic areas are areas that are vulnerable to a proposed or ongoing fishing activity. Vulnerability will be determined based on the level of harm that fishing activity may have on the benthic area by degrading ecosystem functions or impairing productivity. [historically fishing but expanding to any human activity, including mining and climate change.]
- **Strategic Objectives –** Specific components of the Conservation Goal (supported by the Operational Objectives) (DFO 2012).
- **Strategies –** Monitoring strategies are those avenues employed to undertake the monitoring protocols (DFO 2012).
- **Transient population –** A population that occurs infrequently in an area over time as a result of dispersal from or between surrounding regions, and that does not maintain viable local populations.
- **Trophic structure –** The feeding relationships in an ecosystem that contribute to the routes of energy flow and the patterns of chemical cycling.
- **Threshold –** A point that when reached and/or exceeded triggers a reaction.
- **Voucher specimen –** a preserved specimen that serves as a verifiable and permanent record of a taxa.
- **Vulnerable species –** A species listed as such by a national or international governing body (e.g., SARA, ERAF SEC, VME, CITES lists).

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APPENDIX

Table A1. The list of subject matter experts who are not authors but who kindly contributed significantly to a section and/or topic of this research document.

Contributor	**Topic (field of expertise)**
Akash Sastri	Oceanography
Chelsea Stanley	Oceanography
Dana Haggarty	Fish ecology
Debby Ianson	Oceanography
Karen Hunter	Climate change
Lily Burke	Vessel traffic
Sheryl Murdock	Microbiology
Tetjana Ross	Oceanography