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Development of risk-based indicators for the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area

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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 Hecate Strait/Queen Charlotte Sound (HS/QCS) Glass Sponge Reefs Complex is the latest Pacific Region Marine Protected Area (MPA) designated by the Government of Canada in February 2017. This work proposes suites of risk-based indicators to monitor the biodiversity in the HS/QCS MPA, selected using an ecological risk-based indicator selection framework. An ecological risk assessment framework was applied to determine the relative risk to the MPA ecosystem from anthropogenic activities. Using the outputs of an ecological risk assessment process (based on the Pacific Region Ecological Risk Assessment Framework; O et al. 2015), an ecological risk-based indicator selection framework was then applied to the MPA to select and prioritize ecological risk-based indicators. These indicators can be used to monitor the risk of harm to Significant Ecosystem Components (SECs) from anthropogenic activities and associated stressors. This work proposes separate suites of risk-based indicators for current snapshot stressors (predictable, and occurring most years) and potential stressors (unpredictable, and occurring infrequently), and both incorporated SEC specific, stressor specific, and SEC-stressor interaction indicators. Measures of abundance are commonly proposed across the indicator suites, highlighting the need to establish baselines of information as a priority. Both current snapshot and potential stressor indicator suites should be considered when developing monitoring strategies and plans, using a combination of SEC-specific, stressor-specific, and SEC-stressor interaction indicators. Due to the remote access and associated cost of monitoring indicators at the HS/QCS MPA, many of the suggested indicators may be measured using visual surveys and, due to the overlapping distribution of several SECs, multiple indicators may be measured or sampled during the same survey operations period. As data are collected through the monitoring of indicators, this information may be fed back into the adaptive management framework for future iterations of risk assessments, evaluation of selected indicators, selection of new indicators, and refinement of monitoring plans.

1 INTRODUCTION

1.1 CONTEXT

The Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Complex (HS/QCS) were designated a Marine Protected Area (MPA) under Canada's *Oceans* in February 2017 (Canada Gazette 2017). The designation as an MPA provides comprehensive protection from human activities that could negatively impact the reefs. Fisheries and Oceans Canada (DFO) has overall responsibility for the MPA performance measurement and evaluation as the lead authority for the MPA. The effectiveness of management measures in the MPA is determined by the achievement of the conservation objective(s), assessed by monitoring ecological indicators and associated impact thresholds developed using a risk-based approach. To date, a broad conservation objective has been set for the HS/QCS MPA "to conserve the biological diversity, structural habitat, and ecosystem function of the glass sponge reefs", and an Ecological Risk Assessment Framework (ERAF; O et al. 2015) has been applied to the HS/QCS MPA to assess the risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors (Hannah et al. 2019). The next step in the adaptive management framework for Pacific Region MPAs (Figure 1) is to select ecological risk-based indicators that will be used to develop research and monitoring strategies, refine conservation objectives further into operational objectives, and develop monitoring plans. As data are collected through the monitoring of indicators, this information may be fed back into the adaptive management framework for future iterations of risk assessments, evaluation of selected indicators, selection of new indicators, and refinement of monitoring plans (Figure 1).

This work proposes suites of risk-based indicators to monitor biodiversity in the HS/QCS MPA, selected using an ecological risk-based indicator selection framework (Thornborough et al. 2016A, 2016B). This framework has been evaluated by applying it to two Pacific Region MPAs: Endeavour Hydrothermal Vents and SG̲aan K̲inghlas-Bowie Seamount MPAs (Thornborough et al. 2016A, 2016B). Here, it is applied to the HS/QCS MPA using the outputs of the ERAF application (Hannah et al. 2019) The scoping and scoring for this ERAF application was originally undertaken in 2014-2015, prior to MPA designation, and the selection of risk-based indicators for HS/QCS MPA was originally developed in 2015-2016. Both have incorporated significant updates, particularly in the scoring and selection processes to incorporate the new MPA regulations. However, due to the rapidly growing body of publications on the HS/QCS MPA in recent years there may be gaps in the literature that should be addressed in future iterations of this work. Indicators and their measureable components (i.e. how to measure the indicator) identified in this paper focus on ecological SECs (not social or economic), and are not intended to evaluate compliance with regulations, licenses, or other management measures, though it is recognized that these factors may influence the final choice of indicators for monitoring.

This work proposes suites of risk-based indicators to monitor the biodiversity in the HS/QCS MPA, selected based on the risk to SECs from anthropogenic stressors. Suites of indicators, rather than one or two, are provided to ensure a better understanding of ecosystem structure and function and the risk of harm from anthropogenic stressors. This understanding enables future development of indicator thresholds and appropriate management actions.

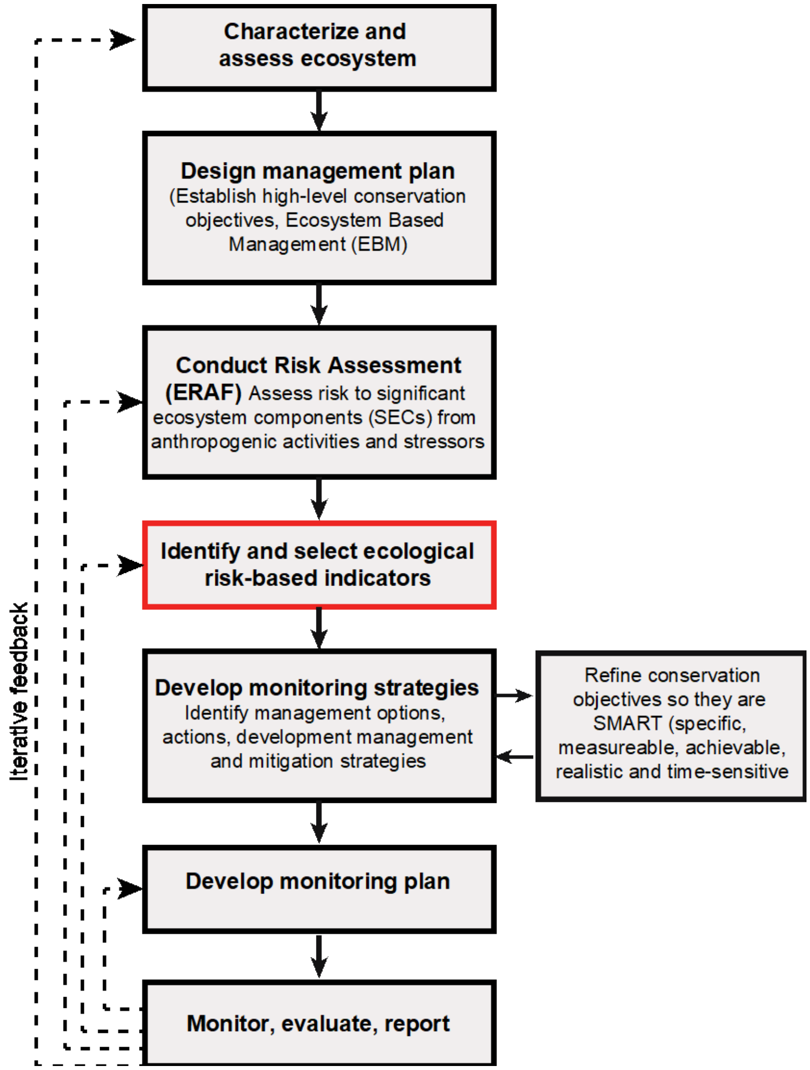

Figure 1. Overview of DFO Oceans – Pacific Region adaptive management framework (adapted from O et al. 2015). This process is iterative, and any information gathered during monitoring can be fed back into the framework.

1.2 INDICATORS

An ecological indicator is a specific measurable component of an ecosystem used for monitoring, assessing, and understanding ecosystem status, impacts of anthropogenic activities, and effectiveness of management measures in achieving objectives (adapted from Rice and Rochet 2005). The most effective indicators are sensitive, responsive to change, have specificity to a management action, and are relatively simple measurements that can be used to represent a more complex situation (Rice and Rochet 2005). The selection of appropriate indicators is an integral part of DFO Oceans – Pacific Region adaptive management framework (Figure 1), as indicator selection leads to the development of monitoring strategies, that in turn feed into the refinement of broad conservation objectives into operational objectives that are specific, measureable, achievable, realistic, and time-sensitive (SMART). Two types of indicators may be used in this adaptive management framework: risk-based and ecosystem indicators. Risk-based indicators are developed and discussed in this paper.

Risk-based indicators are selected based on outputs of an ERAF applied to the specific area, and include SECs, stressors, and SEC-stressor interactions ranked by relative risk. Uncertainties associated with the calculated relative risk help to identify knowledge gaps, and the division of stressors into current snapshot (predictable, and occurring most years) and potential (unpredictable, and occurring infrequently) allow for differentiation in the approach to monitoring indicators at different time scales (i.e., single event or time series). By selecting indicators for SEC-stressor interactions based on risk, we can provide targeted science advice to managers and increase the effectiveness of monitoring strategies developed.

1.3 REGIONAL SETTING

The HS/QCS MPA is located between Haida Gwaii and the mainland of British Columbia (Figure 2) within the Pacific North Coast Integrated Management Area (PNCIMA) and Northern Shelf Bioregion. The MPA covers an area of 2,410 km^2 and captures four discrete reefs that form a discontinuous band covering 390 km^2 at a depth of 165-240 m (Conway et al. 2004) within three areas: the Northern Reef, two Central Reefs, and the Southern Reef (Figure 2). The MPA bounds include the reefs, water column, surrounding waters, and the seabed and subsoil (Boutillier et al. 2013). The reefs are composed of large colonies of Hexactinellid (glass) sponges (DFO 2015) sitting atop of dead sponges that have been continually buried for 6000-9000 years old (Conway et al. 2001).

The HS/QSC Glass Sponge Reefs were discovered by the Geological Survey of Canada between 1987 and 1988 (DFO 2000) and were the first and only discovered living examples of the large glass sponge reefs that were analogous to those reefs abundant during the Jurassic Period (DFO 2015). While glass sponge reefs have been discovered elsewhere in the northeast Pacific, the size and extent of the HS/QCS reefs make them unique and globally significant. The glass sponge reefs have been identified as an Ecologically and Biologically Significant Area (EBSA) of the North Coast Integrated Management Area (PNCIMA), and obtained the highest uniqueness rating (Clarke and Jamieson 2006).

The living sponges are 1-2 m tall and sit atop buried skeletal mounds on average 5-8 m high (but can be up to 30 m) (Conway et al. 2007; Stone et al. 2014). Each sponge colony may live for over 200 years (DFO 2011), with data suggesting that they grow 1-5 cm per annum (Dunham et al. 2015). It is this slow growth rate combined with the fragility of the sponges that make these reefs particularly vulnerable to disturbance, since their recovery may take tens to several hundreds of years. After the living sponge tissue dies, the rigid structure left behind allows juveniles to settle on the exposed skeleton, building the reef upwards. The base of the skeletons is filled with sediment, locking them into a rigid reef structure and continuing the growth and productivity of the reef (Conway et al. 1991; Conway et al. 2001; Krautter et al. 2001; Conway et al. 2005; Leys et al. 2007). The sponge reefs provide refuge, habitat, and nursery ground for other aquatic species, including rockfish species and other finfish and shellfish species (Conway 1999; DFO 2011), and also provide an important ecosystem service as a water filtration mechanism (Chu and Leys 2010; Chu et al. 2011; DFO 2011; Kahn et al. 2015).

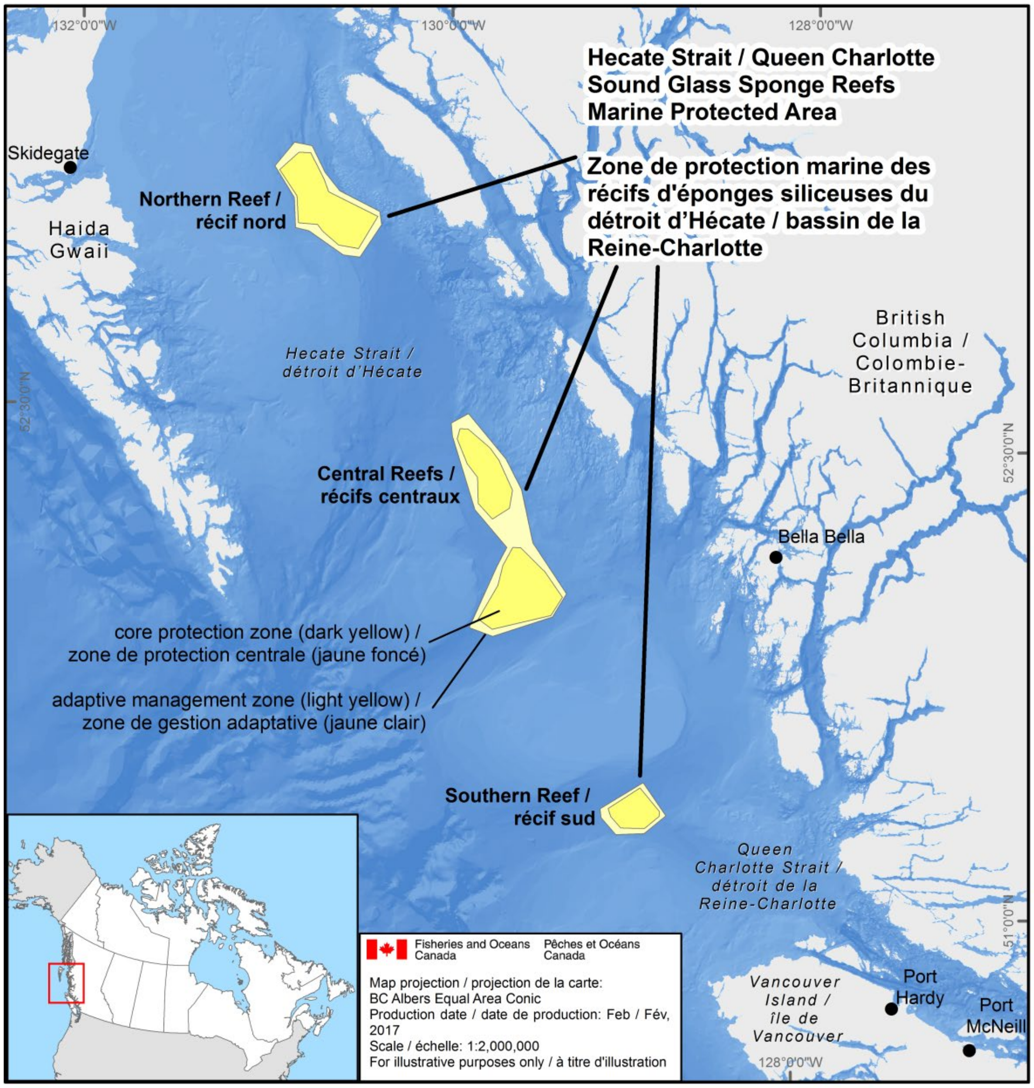

Figure 2. Location of the Hecate Strait/Queen Charlotte Sound Glass Sponge Reef Marine Protected Area.

1.4 CONSERVATION OBJECTIVE

The HS/QCS MPA conservation objective is "*to conserve the biological diversity, structural habitat, and ecosystem function of the glass sponge reefs*" (Canada Gazette 2017). An MPA management plan is currently under development to guide day to day management and reporting, governance, and monitoring of the MPA. As a result, more detailed conservation objectives and operational objectives are yet to be developed.

The Pacific Region Cold-water Coral and Sponge Conservation Strategy (DFO 2010A) identifies key objectives, strategies and actions for cold-water coral and sponge conservation to guide DFO managers which apply to the HS/QCS MPA. The strategy is intended to support DFO's mandate to develop and implement policies and programs in support of Canada's scientific, ecological, social and economic interests in oceans and fresh waters.

The overarching goal of the strategy is aligned with the HS/QCS MPA conservation objective:

Conserve the health and integrity of Canada's Pacific Ocean cold-water coral and sponge species, communities and their habitats as integral components of a healthy and productive ecosystem providing for economic and ecological value and sustainable use.

The Cold-water Coral and Sponge Conservation Strategy strives to meet three objectives:

1. Conservation Objective: To conserve the health, composition and function of cold-water coral and sponge species, communities and habitats in support of a healthy ecosystem.
2. Management Objective: To manage human activities with impacts on cold-water coral and sponge communities efficiently and effectively in support of a healthy ecosystem and sustained economic benefits, within a risk assessment framework.
3. Research Objective: To support decision making through the provision of scientifically based peer-reviewed advice on human caused impacts on cold-water corals and sponges; and, the health and integrity of cold-water corals and sponges and their contributions to the conservation of a healthy ecosystem.

Both the conservation strategy and objective are broad, and more specific operational objectives have not been defined at this time. The lack of clearly defined objectives inhibits the ability to identify and defend specific monitoring requirements without appearing to be an arbitrary selection (Davies et al. 2011). The refinement of 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.

1.5 CURRENT ACTIVITIES AND MANAGEMENT

MPA designation provides comprehensive and long-term management and protection for the reefs, and allows DFO to effectively manage the broad range of activities that could damage the ecosystem. As the lead federal authority for the MPA, DFO has the overall responsibility for ensuring compliance with, and enforcement of, the regulations. The HS/QCS MPA is regulated under the Oceans Act (SOR/2008-124).

Each of the three reef areas, northern, central, and southern reefs (Figure 2) have three protective internal management zones: Core Protection Zone (CPZ), Adaptive Management Zone (AMZ), and Vertical Adaptive Management Zone (VAMZ). The CPZ contains the sponge reefs and is designed to mitigate the risks of direct impacts to the reefs by prohibiting bottom contact activities. The CPZ includes seabed, the subsoil to a depth of 20 m, and the water column above the seabed to a specified depth below the sea surface (the depth is specific to each reef complex). The VAMZ consists of the water column that extends above the CPZ to the sea surface. The AMZ consists of the seabed, subsoil to a depth of 20 m and waters above each reef complex within the MPA that are not part of the CPZ or VAMZ.

Due to the remote location and depth, there is little anthropogenic activity in and around the vicinity of the HS/QCS MPA. The primary use of the area has been commercial fisheries, including prawn and shrimp traps, bottom long-line and trawling for groundfishes, and for midwater trawling for hake. In 2002, the four reefs were closed to groundfish trawl under the *Fisheries Act*, and the closures were expanded in 2006 to provide more comprehensive protection for the reefs. Crab trapping occurs in the waters surrounding the proposed MPA boundaries, and effort in these areas has increased significantly since 2010 (Canada Gazette 2017). No fishing of any kind (commercial, recreational, or Aboriginal) is permitted in the CPZ. The VAMZ and AMZ are currently closed to all commercial bottom contact fishing activities for prawn, shrimp, crab, and groundfish, as well as for midwater trawl for hake, but some types of fishing are allowed in the AMZ and VAMZ, and may be subject to review and modification over time. Midwater trawl is currently banned, but may be allowed in the VAMZ (above the CPZ) in future.

Pacific Region glass sponge reefs are the subject of increasing scientific study. To date, the scientific research conducted at the HS/QCS MPA has been minimally invasive. While there is interest from both renewable and non-renewable energy sectors to undertake projects within the proposed MPA boundaries (e.g. cable routes installations), there is currently no production underway. Given the federal and provincial moratorium on offshore oil and gas production activities in British Columbia, it is unlikely that any offshore petroleum extraction would occur in the foreseeable future (Canada Gazette 2017). There are no current commercial marine tourist activities operating in the vicinity of the reefs (Canada Gazette 2017).

MPA Regulations prohibit: carrying out any activity that disturbs, damages, destroys or removes any living marine organism or any part of its habitat or is likely to do so; or carrying out any scientific research or monitoring, or an educational activity, unless it is part of an activity plan that has been approved by the Minister.

1.6 CURRENT STATE OF MONITORING AND RESEARCH ACTIVITIES

Since the discovery of the reefs using seismic profilers in 1987 there have been a number of research cruises visiting the HS/QCS MPA. These cruises have resulted in geological and biological datasets including sidescan sonar, high resolution seismic records, core samples, sponge samples, grab samples and still and moving images (Chu and Leys 2010; Conway et al. 2001; Conway et al. 2005; DFO 2010A; Dunham et al. 2018; Krautter et al. 2001; Leys 2013). The low frequency of research cruises in the area is attributed to several obstacles, including remote location, limited availability of suitable vessels, difficulty performing research in open waters, (potentially harsh wave and weather conditions), and limited research funding.

There is no current ongoing scientific monitoring program at the HS/QCS MPA, and community composition and population baselines are still being established, as well as information baselines on activities and anthropogenic stressors (particularly for the exposure of the ecosystem to stressors). Scientific research conducted at the HS/QCS MPA has focused on geology, ecology, biology, oceanography, and fisheries research, aiming to fill existing knowledge gaps. Data collection methods have included measurements of the physical and chemical characteristics along the seabed, deploying time-series observation equipment, collection of sediment and biota samples, seismic and acoustic sampling, and capturing video footage from either submersible vehicles or fixed station cameras. Past surveys have provided preliminary information on species richness, biodiversity, and habitat and species coverage of the HS/QCS MPA (Dunham et al. 2018), but are not complete enough to be regarded as a baseline study. A comprehensive monitoring plan will be implemented once operational conservation and management objectives are defined in the management plan.

Commercial groundfish fisheries at the HS/QCS MPA are monitored through fishing logbooks, observers (either at-sea observers and/or electronic monitoring), port sampling, and dockside monitoring (DFO 2010B). Commercial groundfish harvesters are required to keep at-sea catch records through both logbooks and electronic monitoring to record vessel details, line/trap specifications, soak time, fishing location and retained and released catch by species (Davies et al. 2011). In April and September, groundfish fishers are required to take an at-sea fisheries observer on board to record length frequencies, sex ratios, and collect otoliths for age compositions. Electronic monitoring occurs on all other trips, and 10% of the video is reviewed for accuracy of catch documentation by an independent consultant (Davies et al. 2011). Port-samplers collect biological data from commercial landings whenever feasible, and third party monitoring verifies catches offloaded from vessels.

Other federal departments conduct additional monitoring activities in the vicinity of the HS/QCS MPA. Transport Canada monitors ballast water exchange of ocean-going vessels through the Canadian Ballast Water Program, and the National Aerial Surveillance Program monitors pollution due to oil spills (Davies et al. 2011). Environment Canada also monitors oil spills and other ocean surface anomalies through the Integrated Satellite Tracking of Pollution program.

1.7 ECOLOGICAL RISK ASSESSMENT FRAMEWORK APPLICATION

Prior to this study, the ERAF developed by the Pacific Region (O et al. 2015) was applied to the HS/QCS MPA (Hannah et al. 2019). The ERAF consists of two main phases: scoping, and risk assessment. The scoping phase identified significant ecosystem components (SECs) that appropriately represent the ecosystem and anthropogenic stressors with the potential to impact the HS/QCS MPA ecosystem. The risk assessment calculated the likelihood that a SEC may be negatively impacted due to exposure to one or more identified stressors. The results of the application of the ERAF to the HS/QCS MPA are presented in Hannah et al. (2019) and summarized below.

The SECS identified for the HS/QCS MPA included six species and two habitats (Table 1; definitions and selection justifications from Hannah et al. (2019) are presented in Appendix A. Pathways of Effects (PoE) models were developed for activities that may impact the HS/QCS MPA (provided by Oceans Management), identifying associated stressors and effects on the ecosystem (Table 2).

Table 1: Significant ecosystem components for the HS/QCS MPA.

SEC type	SEC
Species SECs	*Heterochone calyx* (Reef building glass sponge)
	Aphrocallistes vastus (Reef building glass sponge)
	Farrea occa (Reef building glass sponge)
	*Rhabdocalyptus dawsoni (*Rosselid/boot sponge)
	Munida quadrispina (Squat Lobster)
	*Sebastes paucispinis (*Bocaccio Rockfish)
Habitat SECs	Glass sponge skeleton matrix (and material contained within)
	Sponge gardens (non-reef building glass sponges and demosponges)

Table 2: Activities (provided by Oceans Management) and associated stressors (identified through the development of PoE models) for the HS/QCS MPA. Stressors found to result in ***acute*** *and/or* ***chronic*** *change are in bold.*

Activity	Associated stressors
Discharge	**Entrapment/entanglement**
	Introduction of aquatic invasive species
	Oil/contaminants
	Substrate disturbance (crushing)
	Substrate disturbance (foreign object)
Grounding	**Introduction of aquatic invasive species**
	Substrate disturbance (foreign object)
Movement underway	**Disturbance (noise)**

Activity	Associated stressors
Oil spill	**Oil/contaminants**
Seismic testing/air guns	Disturbance (seismic energy)
Submersible operations	**Disturbance (light)**
	Introduction of aquatic invasive species
	Oils/contaminants
	Substrate disturbance (crushing)
	Substrate disturbance (sediment resuspension)
Bottom trawl	**Introduction of aquatic invasive species**
	Substrate disturbance (sediment resuspension)
Demersal long line hooks	**Substrate disturbance (sediment resuspension)**
Long line traps	**Substrate disturbance (sediment resuspension)**
	Introduction of aquatic invasive species
Midwater trawl	Entrapment/entanglement
	Removal of biological material
	Strikes
	Substrate disturbance (crushing)
	Substrate disturbance (sediment resuspension)

The risk assessment examined the interaction between the SECs and anthropogenic stressors identified during scoping. This involved scoring **exposure** (percent overlap between SECs and stressors for area, depth, temporal scale, and the intensity (amount and frequency) of the stressor), **resilience** (**acute change** and **chronic change**), and **recovery** (based on SEC life history traits) for each SEC (c) stressor (s) interaction, then calculating the risk score by multiplying the terms together (Equation 1).

$$Risk_{sc} = Exposure_{sc} \times Resilience_{sc} \times Recovery_{sc} \qquad \text{(Equation 1)}$$

Uncertainty for each term of **exposure**, **resilience**, and **recovery** was scored using the method outlined in O et al. (2015) and incorporated into the final risk score using a modified version of the uncertainty incorporation method from O et al. (2015) as outlined in Hannah et al. (2019). Separate uncertainty scores were produced (10/90% quantiles of the final median risk array) and presented with the risk score. Cumulative (additive) risk was calculated using the method outlined in O et al. (2015) for SECs and stressors. The resulting outputs were risk scores for each SEC-stressor interaction, as well as SECs and stressors ranked by cumulative (additive) risk score.

During the analysis of the risk assessment results, anthropogenic stressors were divided into *current snapshot* and *potential* stressors. *Current snapshot* includes activities and stressors that are somewhat predictable and known to occur at the HS/QCS MPA. *Potential* activities and stressors include those that occur infrequently and/or at unpredictable intervals. *Potential* stressors identified in Hannah et al. (2019) included: *oil* (oil spill), grounding/sinking (all stressors), discharge (foreign object, entrapment/entanglement, crushing, sediment resuspension), and *aquatic invasive species (*discharge, grounding, submersible operations, bottom trawling, long-line traps). *Potential* stressors were more likely to be scored higher than *current snapshot* stressors, as resilience was scored on a worst-case scenario, aligning with a precautionary approach. For example, *aquatic invasive species* was scored as establishment of an aquatic invasive species (rather than exposure to propagule). This division of stressors is essential to ensure that monitoring programs are linked to current management, and the monitoring program is well-balanced and informative (i.e. they are not dominated by *potential* stressors).

Hannah et al. (2019) found that the living sponge SECs (sponge gardens, *Aphrocallistes vastus, Heterochone calyx, Farrea occa,* and *Rhabdocalyptus dawsoni)* had the highest cumulative risk with 15 stressors found to have a negative impact on **resilience**. The glass sponge skeleton matrix habitat SEC had the next highest cumulative risk, but with one less stressor interaction (14). The two mobile species SECS (*Sebastes paucispinis and Munida quadrispina*) had the lowest cumulative risk and only nine stressors impacting **resilience**.

The stressors with the highest *potency* scores (sum of all risk scores for a stressor) were *oil* (oil spill), *substrate disturbance (sediment resuspension)* (bottom trawl), *removal of biological material* (midwater trawl), *oils/contaminants* (discharge), *the introduction of aquatic invasive species* (grounding), *substrate disturbance (crushing)* (midwater trawl), and *substrate disturbance (sediment resuspension)* (midwater trawl). Hannah et al. (2019) found that the highest risk scores were associated with the highest uncertainty.

1.8 INFORMATION GAPS IDENTIFIED THROUGH THE ERAF APPLICATION

The application of the ERAF to the HS/QCS MPA identified information gaps that should be addressed in future monitoring programs. These gaps were related to the terms of **exposure**, **resilience**, and **recovery**.

Terms of **exposure** (area, depth and temporal overlap between SECs and stressors), and the stressor intensity (amount and frequency) identified knowledge gaps in both the distribution and abundance of SECs. There are currently no established population baselines for SECs at the HS/QCS MPA, and information on stressors is limited. *Potential* stressors were scored on the assumption of a worst-case scenario of high overlap with SECs for acute and chronic change, and this highlighted the need for established SEC baselines to more accurately calculate overlap. Uncertainty surrounding *current snapshot* stressors varied.

The **resilience** terms also highlighted the lack of existing population baselines for species SECs as an information gap, as well as the lack of information on the **acute change** (a change in population/habitat size) and **chronic change** (a change in population/habitat condition) to SECs resulting from impacts from stressors. Uncertainty was highest for *potential* stressors.

Scoring of **recovery** factors identified some knowledge gaps in the life history traits of SECs, which is an ongoing field of research.

2 METHODS: INDICATOR SELECTION AND PRIORITIZATION

In order to provide MPA managers with relevant science advice on which SEC-stressor interactions require further monitoring, appropriate indicators are selected using an ecological risk-based indicator selection framework (Thornborough et al. 2016A, 2016B), based on the outputs of the ERAF application (Hannah et al. 2019). The selection framework focuses on the SECs and stressors with the highest cumulative risk scores on the assumption that operational objectives would be based around those species and habitats most at risk as well as those stressors, both current snapshot and potential, with the greatest impact on the ecosystem.

2.1 GENERAL DESCRIPTION OF THE INDICATOR FRAMEWORK

The selection of risk-based indicators is based on risk scores and the determination of the variable driving that risk score and associated uncertainty, but also on validity and the best available scientific knowledge. Selection criteria developed from primary literature are used to choose appropriate indicators. The final product includes suites of indicators, rather than one or two, to provide a better understanding of SEC distribution and range and the impacts from anthropogenic stressors (Figure 3). The monitoring of these indicators may permit future development of thresholds and appropriate management actions.

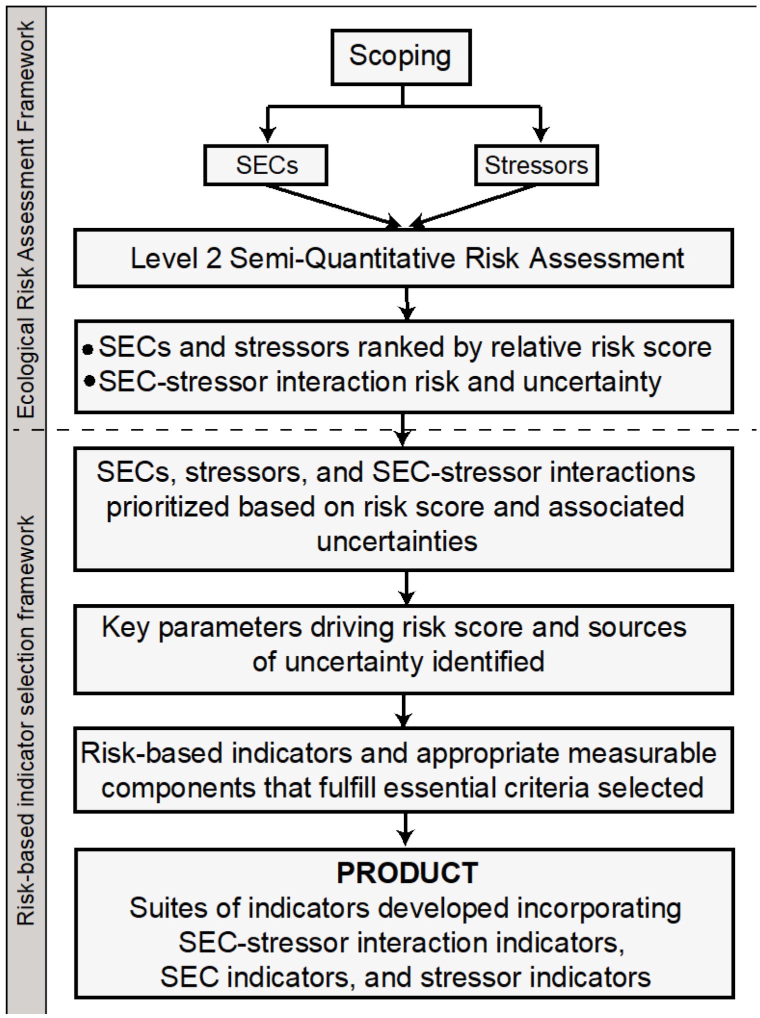

Figure 3. Overview of risk-based indicator selection framework (Thornborough et al. 2016A, 2016B), based on the outputs of the ERAF application.

2.2 SELECTION OF RISK-BASED INDICATORS FOR SECS AND STRESSORS

The risk-based indicator selection framework (Thornborough et al. 2016A, 2016B) can be summarized as three steps:

1. Prioritize SECs and stressors based on the outputs of the ERAF application (cumulative risk scores);
2. Determine the criteria that an indicator should fulfill; and,
3. Select indicators from available literature that fulfill these criteria.

SEC indicators were selected based on key attributes of population (or habitat) size and population (or habitat) condition. These attributes are linked directly from the resilience terms from the ERAF, where acute change and chronic change correspond to population/habitat size and condition, respectively. Stressor indicators were based on the exposure terms, including distribution (area/depth), seasonality (temporal), and scale and frequency of disturbance (intensity). Indicators were selected for all SECs and stressors. These indicators were incorporated into suites of indicators for current snapshot and potential SEC-stressor interactions where appropriate.

2.2.1 Prioritization of SECs/Stressors

Prioritization of SECs and stressors is based entirely on the outputs of the risk assessment of the HS/QSC MPA (Hannah et al. 2019). The application of the ERAF resulted in lists of SECs and anthropogenic stressors ranked by cumulative risk score and associated uncertainty (10/90% quantiles) on a relative scale within the MPA. These relative rankings were used to prioritize SECs and stressors prior to indicator selection, where high risk correlated with high priority, and low risk with low priority. The result is a list of all SECs and a list of all stressors prioritized by risk score; those deemed ‘low priority’ (based on low relative risk scores) were not removed from this process.

However, an additional filtering step was added to this work that was not included in previous applications of the risk-based indicator selection framework (Thornborough et al. 2016A, 2016B). Prior to prioritization, all SEC-stressor interactions with negligible effects on resilience (i.e. both acute and chronic change scored 0) were removed from the analysis. The filtering of these negligible resilience interactions was necessary to ensure that indicators are only selected for those interactions known to have an impact on population/habitat size and/or condition. The inclusion of negligible resilience interactions in the risk analysis is a modification in the HS/QCS MPA ERAF application (Hannah et al. 2019), and the ERAF analysis is based on these data. Previous applications of the ERAF (Rubidge et al. 2018; Thornborough et al. 2017) filtered out these interactions prior to the risk analysis and so were not included in the indicator selection process. The indicator selection process used the filtered risk results presented in Appendix L of Hannah et al. (2019).

2.2.2 Indicator Criteria

Each indicator should meet a set of essential and preferred criteria to ensure that the selected indicators provide useful measurements of the SECs, stressors, and SEC-stressor interactions. The criteria each indicator is required to meet are described in detail in the risk-based indicator framework (Thornborough et al. 2016A, 2016B), and include *theoretically sound, measureable/feasible, sensitive* (not applicable to stressor indicators), and *historical data available* (preferred but not essential). Full descriptions of criteria and additional considerations (developed for future iterations of indicator selection) are presented in Appendix B.

2.2.3 Selecting Indicators for SECs and Stressors

Indicators and their measurable components were selected from the scientific literature. If an appropriate indicator was not developed or could not be found for a specific SEC or stressor, a similar species/habitat or stressor was used, respectively. Each proposed indicator was required to fulfill all criteria/sub-criteria, with the exception of *historical data* criterion, which is preferred but not essential due to the limited availability of information in the HS/QCS MPA. This selection approach was used to ensure the scientific value of the indicators for monitoring, assessing, and understanding SEC status within the HS/QCS MPA, the impacts of stressors, and potentially the effectiveness of management measures in achieving conservation objectives. The *sensitive* criterion was not applied to stressor indicators, as stressors do not respond to changes in specific ecosystem attributes. Instead, greater importance was placed on *historical data* criterion. A consideration when selecting indicators was the lack of baseline information on

SECs at the HS/QCS MPA, meaning that indicators for SECs were preferred if they could provide information contributing to population baselines. It should be noted that while the selected indicators fulfill the *measureable/feasibility* criteria, some indicators may be difficult to measure with the current state of resources and access to developing technologies. This should be addressed when developing monitoring strategies.

SEC indicators were divided into two main categories: population/habitat size and population/habitat condition. Indicators were rejected if there was no operational (or near operational) technology capable of measuring the indicator or if no clear methods were available to interpret the monitoring data in a way that would provide useful information for policy and management decisions, as suggested by Jennings (2005).

Piet and Jansen (2005) recommended starting with a limited suite of indicators, as too many indicators can confound the selection process. Several considerations determined the number of selected indicators: the need for both SEC and stressor indicators (after Jennings 2005); the need for SEC-stressor specific indicators; and, the key attributes (population size and condition) for SECs and SEC-stressor interactions. The value of the selected indicators may be affected by measurement, process, and estimation error. Therefore, different indicators, and the same indicators measured at different spatial and temporal scales and in different ways (different measureable components), will provide confidence in the veracity of detected trends (Jennings 2005).

2.3 SELECTION OF RISK-BASED INDICATORS FOR SEC-STRESSOR INTERACTIONS

A total of 106 SEC-stressor interactions were identified as impacting the HS/QCS MPA. To provide relevant science advice, these SEC-stressor interactions were prioritized to reduce the number of listed interactions prior to the selection of indicators using the method outlined in the risk-based indicator selection framework (Thornborough et al. 2016A, 2016B). This process divided SEC-stressor interactions into *current snapshot* and *potential* interactions, then ranked the outputs of the risk assessment by risk score and uncertainty, dividing the interactions into high, moderate, and low priority. The resulting lists of interactions prioritized by risk and uncertainty scores are presented in Appendix F. Indicators are selected for only high and moderate priority interactions for *current snapshot* and *potential* interactions, as each highlight different information gaps and monitoring and management needs.

The division of *potential* and *current snapshot* interactions is essential to providing complete suites of indicators for monitoring. *Potential* stressors are almost impossible to measure at the time of occurrence and need to be identified and grouped together. While no commercial fishing is allowed within the MPA under current guidelines, there is potential for some fishing activities to be reintroduced in the future. Fishing activities are analyzed as *current snap-shot* stressors in the ERAF application (Hannah et al. 2019) and indicator selection to ensure that managers have this information available to them in the decision-making process. Future iterations of the ERAF and indicator selection framework applications will need to consider updated regulations within the MPA to determine what activities are included.

2.3.1 Determining the Measure Best Representing the SEC-Stressor Interaction

To determine if a measure of population size, population condition, or both was the most appropriate for each interaction, the original **resilience** (**acute change** and **chronic change**) scoring and justifications from Hannah et al. (2019) were examined. In the ERAF (O et al. 2015) **acute change** represented a change in population/habitat size, while **chronic change** represented a change in population/habitat condition. If **acute change** was scored as 0, only measures of population condition were selected, and vice versa for **chronic change** and population size. If scoring for **acute change** and **chronic change** were similar, indicators were selected for both.

2.3.2 Selection of Indicators for SEC-Stressor Interactions

Indicators and their measureable components were selected from available literature as described in Section 2.2.3. Each selected indicator was required to fulfill all essential criteria in Appendix B, and preferred criteria (available historical data) where applicable. Indicators were only selected for moderate-high prioritized SEC-stressor interactions, i.e., those interactions with priority rankings of 1-6 in Appendix F.

Suites of indicators where SECs are grouped by taxonomy and those with similar indicators for both *current snapshot* and *potential* interactions. Providing a suite rather than just one indicator provides options, and captures a greater range of ecological attributes. SEC and stressor indicators identified through the process outlined in Section 2.2 were incorporated into the indicator suites specific to the SEC-stressor interaction. This approach ensures that a range of attributes are measured, and provides alternative options for monitoring SEC-stressor interactions. The SEC and stressor specific indicators presented in the final suites of indicators went through an additional refinement process, where only indicators that may help to inform that SEC-stressor interaction were included.

3 RESULTS: SELECTION OF INDICATORS

3.1 INDICATOR IDENTIFICATION FOR SECS

3.1.1 Prioritization of SECs

Prioritization of SECs was derived from the relative rankings of SECs by risk score from Hannah et al. (2019) (see Appendix L in Hannah et al. 2019), where the highest and lowest cumulative risk scores correlate to the highest and lowest priority, respectively. SECs prioritized by risk are presented in Table 3; no SECs were removed during this process.

Table 3. SECs prioritized by cumulative risk scores (Appendix L in Hannah et al. 2019), including 10/90% quantiles (representing uncertainty).

SEC	Cumulative Risk	10% Q	90% Q
Aphrocallistes vastus	434.41	77.41	79.27
Rhabdocalyptus dawsoni	429.57	76.29	78.39
Farrea occa	407.88	73.21	74.98
Sponge Garden	403.67	76.71	78.73
Heterochone calyx	399.87	77.60	80.21
Glass Sponge Skeleton	390.89	78.88	82.89
Bocaccio Rockfish	329.96	63.46	64.91
Munida quadrispina	214.62	55.67	58.18

3.1.2 Proposed Indicators for SECs

Indicators were selected from available literature on ecosystem indicators, with particular focus on those indicators already employed by DFO, and studies on the Pacific Northwest (e.g., Andrews et al. 2013; Chu and Leys 2010; Curtis et al. 2012; Levin et al. 2010; Samhouri et al. 2009; Thornborough et al. 2016A, 2016B), as well as life history traits of SECs. Where an appropriate indicator could not be found for a specific SEC, a similar species or habitat was used. Each indicator selected fulfilled the essential criteria presented in Appendix B. Selected indicators and their measureable components for SECs are presented in Table 4.

Several indicators (average of three) were selected for each SEC, providing several alternatives. Suites of indicators for SECs are provided in Table 4 under two key parameters: population/habitat size; and, population/habitat condition. Several indicators were repeated for similar SEC types, and similar SEC types were grouped together. Justifications for indicator selections and how each of the criteria were fulfilled are presented in Appendix C and Appendix D, respectively.

Table 4. Summary table of proposed SEC indicators and measurable components.

SEC			Key parameter	Indicator	Measureable component
Species	Reef building glass sponges	*Heterochone calyx* *Farrea occa* *Aphrocallistes vastus*	Population size	Abundance (relative)	Oscula density (number of oscula per m^2); areal coverage (%); Patch area (m^2)
			Population condition	Biomass	Size structure; Weight/unit area (only to be used when sampling is already taking place or by-catch data is available)
				Health/condition related to disease and aquatic invasive species	Presence of disease, aquatic invasive species (e.g. desmacella spp. overgrowth); % of sampled colonies showing visible signs of stress (NB should be used in combination with other indicators and monitoring).
	Rosselid/ boot sponge	*Rhabdocalyptus dawsoni*		Health/condition related to physical damage	Proportion of colony or reef (%) damaged; evidence of scattered fragments of sponge skeletons; evidence of recovery.
				Genetic diversity	Allele frequency, polymorphic loci (applicable to demosponges and Rosselid sponges, and when comparing Hexactinellid sponges between areas).
	Bocaccio Rockfish	*Sebastes paucispinis*	Population size	Abundance	Size-frequency distribution, catch per unit effort (fishery log data).
				Biomass	Weight/unit area; catch per unit effort
			Population condition	Condition factor, k	E.g., weight/length, age, stomach contents, presence of disease or invasive species, parasitic load, size structure of population
				Genetic diversity of populations	Genetic delineation (allele frequency, polymorphism, etc.)
				Spatial distribution	Spatial distribution (home range) of the species within the MPA
	Squat Lobster	*Munida quadrispina*	Population size	Abundance/ species density	Average density/count of organisms within a given range
				Biomass	Weight/unit area
			Population condition	Health/ condition	Visible injury to organism or behavioral indicators (e.g. righting and feeding behavior, reflex actions)
				Species spatial distribution	Species range within the reef areas
Habitat	Physical habitat	Glass sponge skeleton matrix	Habitat size	Abundance (extent and distribution)	Areal coverage of sponge gardens (% cover, m^2)

SEC			Key parameter	Indicator	Measureable component
			Habitat condition	Health/condition related to physical damage	% of habitat modified or showing visible signs of damage
				Species richness and diversity	Diversity measures, alpha diversity (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness of associated biota) and beta diversity; *H. calyx* has the most robust skeleton (Krautter et al. 2001). It may be that the balance between these three reef building species can be used to indicate the degree to which a sponge reef area has been exposed to stressors, and the presence of a more fragile species such as *F. occa* could indicate a more pristine reef. A rapid decline of *F. occa* in a specific area could indicate a significant change in habitat condition. This indicator would need to be combined with baseline data and long-term trends.
	Biogenic habitat	Sponge gardens	Habitat size	Abundance (extent and distribution)	Areal coverage of sponge gardens (% cover, m^2)
			Habitat condition	Health/condition related to physical damage	% of habitat modified or showing visible signs of damage; changes in flow/hydrodynamics
				Species richness and diversity	Diversity measures (alpha and beta diversity); Density of juvenile sponges near live sponges and sponge skeletons. 3D surface area may indicate habitat diversity and availability (Santavy et al. 2013).

3.2 INDICATOR IDENTIFICATION FOR STRESSORS

3.2.1 Prioritization of Anthropogenic Stressors

Prioritization of stressors was derived from the relative rankings of stressors by risk produced as an output from the risk assessment (Appendix L in Hannah et al. 2019), where the highest cumulative risk score correlates with the highest priority, and the lowest cumulative risk correlates with lowest priority. The outputs were used to prioritize stressors only, and no stressors were removed using this process. Stressors prioritized by risk are presented in Table 5.

*Table 5. The HS/QCS MPA activities and associated sub-activities and stressors with risk scores (Hannah et al. 2019). * denotes potential stressors.*

Activity	Stressor	Risk (cumulative)	10% Q	90% Q
Oil spill	Oil*	943.95	118.79	121.83
Bottom trawl	Substrate disturbance (resuspension)	247.40	64.78	67.31
Midwater trawl	Removal of biological material*	235.50	52.58	55.80
Discharge	Oil/Contaminants	218.14	59.64	61.77
Midwater trawl	Substrate disturbance (crushing)*	197.40	52.07	54.96
Grounding	Introduction of aquatic invasive species*	184.70	58.50	61.87
Midwater trawl	Substrate disturbance (resuspension)	159.56	43.75	46.66
Long line traps	Substrate disturbance (resuspension)	127.97	37.70	39.12
Bottom trawl	Introduction of aquatic invasive species*	121.87	30.21	32.92
Discharge	Introduction of aquatic invasive species*	107.16	39.31	42.40
Grounding	Entrapment/entanglement*	103.59	39.60	42.66
Demersal long-line hooks	Substrate disturbance (resuspension)	102.57	30.57	32.46
Submersible operations	Introduction of aquatic invasive species*	68.07	24.28	25.71
Long line traps	Introduction of aquatic invasive species*	67.83	24.73	26.84
Submersible operations	Substrate disturbance (resuspension)	60.78	23.83	25.48
Midwater trawl	Strikes	27.08	17.23	18.11
Movement underway	Disturbance (noise)	25.26	23.48	25.25
Submersible operations	Disturbance (light)	12.03	10.27	11.57

3.2.2 Proposed Indicators for Anthropogenic Stressors

An average of three indicators per stressor were selected from available literature, and are presented in Table 6. Where an appropriate indicator could not be found for a specific stressor, a similar stressor was used as a surrogate. Each indicator selected fulfilled the essential criteria presented in Appendix B, and justifications are provided in Appendix E.1. Stressor Indicators scored against Indicator criteria Proposed indicators and their measureable components for stressors and descriptions of the criteria they filled are presented in Appendix E.1. Stressor Indicators scored against Indicator criteria.

*Table 6. Proposed indicators and measureable components for activities and associated stressors known to impact the HS/QCS MPA. * denotes potential stressors.*

Activity	Stressor	Indicator	Measureable component
Bottom trawl	Introduction of aquatic invasive species*	Frequency of potential exposure	Number of trawls per unit area
		Species richness of aquatic invasive species	Beta diversity measures
		Occurrence/abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; Number per m^2
	Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background
		Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background
		Substrate composition	e.g. % of substrate particles <6.35 mm
		Maximum potential exposure	Number of days per annum fishing is allowed
Demersal long-line hooks	Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background
		Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background
		Substrate composition	e.g. % of substrate particles <6.35 mm
Discharge	Introduction of aquatic invasive species*	Frequency of potential exposure	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell; Number of ballast water exchanges in vicinity of the HS/QCS MPA.
		Species richness of aquatic invasive species	Beta diversity measures
		Occurrence/abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; Number per m^2
		Biomass of aquatic invasive species	Weight/unit area
	Oil/contaminants	Frequency of potential exposure	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell; Number of ballast water exchanges in vicinity of the HS/QCS MPA.
		Discharge volume	Surface area x minimum thickness
		Proportion of water samples exceeding standards for water quality parameters of interest	e.g. CCME Water Quality Index
	Entrapment/ entanglement*	Relative abundance of debris	Frequency of occurrence (count/distance surveyed);

Activity	Stressor	Indicator	Measureable component
			weight/volume of recovered debris (from clean-up programs)
Grounding	Introduction of aquatic invasive species*	Frequency of potential exposure	Number of groundings within the bounds of HS/QCS MPA.
		Species richness of aquatic invasive species	Beta diversity measures around grounding site
		Occurrence/abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; number per m^2
		Biomass of aquatic invasive species	Weight/unit area
Long-line traps	Aquatic invasive species*	Frequency of potential exposure	Number of traps per unit area
		Species richness of aquatic invasive species	Beta diversity measures
		Occurrence/abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area/ number per m^2
		Biomass of aquatic invasive species	Weight/unit area
	Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background
		Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background
		Substrate composition	e.g. % of substrate particles <6.35 mm
Midwater trawl	Removal of biological material*	Catch per unit effort	Recorded catch and by-catch; Modeled catch/by-catch
		Maximum potential exposure	Number of days per annum fishing is allowed; Number of vessels x maximum allowable catch
	Strikes (to mobile species)	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further.	Number of incidences per trawl where mobile species are struck (partial sample using cameras attached to gear)
	Substrate disturbance (crushing)*	Crushed area	Proportion (%) of the area crushed/m^2
	Substrate disturbance (sediment resuspension)*	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background
		Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background
		Substrate composition	e.g. % of substrate particles <6.35 mm

Activity	Stressor	Indicator	Measureable component
Movement underway	Disturbance (noise)	Vessel density in vicinity of the HS/QCS MPA	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell
		Noise frequency at the HS/QCS MPA	Intensity of vessel sounds reaching benthos (kHz)
Oil spill	Oil/contaminants*	Vessel density in vicinity of the HS/QCS MPA	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell
		Oil spill volume	Surface area x minimum thickness
		Oil type	Determines surface, water column, or benthic coverage. E.g. bitumen – surface coverage of benthic habitats, petroleum – surface spill only
Submersible operations	Introduction of aquatic invasive species*	Frequency of potential exposure	Number of dive sites per cruise; Existence of cleaning/equipment flushing protocols between dive sites
		Species richness of aquatic invasive species	Beta diversity measures
		Occurrence/abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; Number per m^2
		Biomass of aquatic invasive species	Weight/unit area
	Disturbance (light)	Area exposed to artificial light from submersible	Areal coverage (%)
		Frequency of exposure	Number of submersible dives within a cruise or given period
	Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background
		Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background; Short-term measurement and would need to be measured in conjunction with other indicators of turbidity to be meaningful
		Frequency of exposure to potential collisions	Number of collision events

3.3 INDICATOR IDENTIFICATION FOR SEC-STRESSOR INTERACTIONS

3.3.1 Prioritization of SEC-Stressor Interactions

The process outlined in Section 3.3 was applied to both *potential* SEC-stressor interactions (included SECs impacted by *oil/contaminants (*oil spill*), aquatic invasive species* (all activities), and benthic midwater trawl stressors *(removal of biological material, substrate disturbance (crushing), substrate disturbance (resuspension))*, and *current snapshot* SEC-stressor interactions (all remaining interactions).

The application of the prioritization method reduced the number of SEC-stressor interactions in order to select indicators for only those with moderate to high priority. Of the 59 *potential* SEC-stressor interactions, 51 were categorized as low priority and were removed from this process, leaving 8 *potential* interactions. Of the 47 *current snapshot* interactions, all but 21 interactions fell into the low bin and were removed. Full lists of all interactions and the results of the application of the prioritization method are presented in Appendix F. The resulting SEC-stressor interactions of moderate-high priority are presented in Table 7 and Table 8

Table 7. Current snapshot SEC-stressor interactions remaining after low-priority interactions were removed, presented with the median risk score and 10/90% quantiles for each interaction (Appendix L in Hannah et al. 2019).

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Bocaccio Rockfish	Midwater trawl	Removal of biological material	54.71	12.36	14.04
Glass sponge skeleton matrix	Bottom trawl	Substrate disturbance (sediment resuspension)	32.80	26.82	33.49
Sponge gardens	Bottom trawl	Substrate disturbance (sediment resuspension)	31.19	25.17	31.82
Heterochone calyx	Bottom trawl	Substrate disturbance (sediment resuspension)	30.98	20.84	25.37
Glass sponge skeleton matrix	Midwater trawl	Substrate disturbance (crushing)	29.17	18.57	24.94
Sponge gardens	Midwater trawl	Substrate disturbance (crushing)	29.15	18.55	24.29
Aphrocallistes vastus	Bottom trawl	Substrate disturbance (sediment resuspension)	29.04	15.04	17.92
Farrea occa	Bottom trawl	Substrate disturbance (sediment resuspension)	28.99	19.79	22.96
Heterochone calyx	Midwater trawl	Substrate disturbance (crushing)	28.86	18.60	24.51
Rhabdocalyptus dawsoni	Bottom trawl	Substrate disturbance (sediment resuspension)	28.85	14.89	17.65
Aphrocallistes vastus	Midwater trawl	Substrate disturbance (crushing)	28.75	17.90	24.64
Bocaccio Rockfish	Bottom trawl	Substrate disturbance (sediment resuspension)	28.60	23.74	27.79
Sponge gardens	Discharge	Oil/Contaminants	28.42	23.10	28.63
Glass sponge skeleton matrix	Discharge	Oil/Contaminants	28.21	23.46	29.78
Rhabdocalyptus dawsoni	Midwater trawl	Substrate disturbance (crushing)	28.20	17.98	24.81
Heterochone calyx	Discharge	Oil/Contaminants	26.87	18.63	23.12
Farrea occa	Midwater trawl	Substrate disturbance (crushing)	26.82	17.09	22.38
Aphrocallistes vastus	Discharge	Oil/Contaminants	26.41	18.23	22.73
Rhabdocalyptus dawsoni	Midwater trawl	Removal of biological material	26.25	17.66	25.12
Bocaccio Rockfish	Midwater trawl	Strikes	26.20	16.35	18.99
Heterochone calyx	Midwater trawl	Removal of biological material	26.16	17.54	24.59
Glass sponge skeleton matrix	Midwater trawl	Removal of biological material	26.00	16.82	23.58
Rhabdocalyptus dawsoni	Discharge	Oil/Contaminants	25.97	17.89	22.76
Sponge gardens	Midwater trawl	Removal of biological material	25.94	16.56	22.19
Aphrocallistes vastus	Midwater trawl	Removal of biological material	25.87	17.45	24.68
Heterochone calyx	Midwater trawl	Substrate disturbance (sediment resuspension)	25.59	16.12	22.42

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Aphrocallistes vastus	Midwater trawl	Substrate disturbance (sediment resuspension)	25.40	15.22	20.14
Sponge gardens	Midwater trawl	Substrate disturbance (sediment resuspension)	25.06	15.93	21.22
Rhabdocalyptus dawsoni	Midwater trawl	Substrate disturbance (sediment resuspension)	24.88	14.68	20.54
Farrea occa	Discharge	Oil/Contaminants	24.84	17.14	21.21
Glass sponge skeleton matrix	Midwater trawl	Substrate disturbance (sediment resuspension)	24.72	15.54	21.34
Farrea occa	Midwater trawl	Removal of biological material	24.50	16.76	22.68
Munida quadrispina	Bottom trawl	Substrate disturbance (sediment resuspension)	24.49	19.94	25.65

Table 8. Potential SEC-stressor interactions remaining after low-priority interactions were removed, presented with the median risk score and 10/90% quantiles for each interaction (Appendix L in Hannah et al. 2019).

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Aphrocallistes vastus	Oil spill	Oil/contaminants	136.96	41.32	52.19
Rhabdocalyptus dawsoni	Oil spill	Oil/contaminants	135.83	42.37	51.89
Sponge gardens	Oil spill	Oil/contaminants	134.28	41.80	49.95
Farrea occa	Oil spill	Oil/contaminants	128.31	38.70	46.85
Bocaccio Rockfish	Oil spill	Oil/contaminants	118.54	35.01	41.06
Heterochone calyx	Oil spill	Oil/contaminants	98.27	36.06	46.59
Glass sponge skeleton matrix	Oil spill	Oil/contaminants	98.06	35.35	46.82
Munida quadrispina	Oil spill	Oil/contaminants	72.07	30.70	40.88

3.3.2 Proposed Indicators for SEC-Stressor Interactions

Once interactions were prioritized and low priority SEC-stressor interactions removed, each remaining interaction was examined to determine both the key parameter driving risk (population size or condition), and gain detailed information regarding the impact on the SEC-stressor interaction based on the original scoring in the ERAF application (Hannah et al. 2019). SECs with similar taxonomic groups and impacting stressors were grouped together, with indicators and measureable components selected for each group, presented in Appendix G. Summaries of impacts of stressors on these SECs, as well as analysis on types of indicators that may be appropriate are displayed in Appendix H.

3.4 SUITES OF INDICATORS

Suites of indicators are provided for both *current snapshot* (Table 9) and *potential* (Table 10) SEC-stressor interactions, that incorporate indicators selected for SECs and stressors (Table 4 and Table 6 respectively). See Appendices C-I for associated measureable components and selection justifications.

Table 9. Indicator suites for current snapshot SEC-stressor interactions, presented roughly in order of the prioritization results.

Activity	Stressor	SEC Grouping	SEC	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Midwater trawl	Removal of biological material	Bocaccio Rockfish	Bocaccio Rockfish	Abundance/population density; biomass of removed organisms	Abundance; genetic diversity; species richness and diversity	Catch per unit effort; maximum potential exposure
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx* *Farrea occa* *Aphrocallistes vastus* *Rhabdocalyptus dawsoni*	Abundance (areal extent) of habitat removal scar; community structure; biomass of removed sponges (by-catch data)	Abundance (areal coverage);	By-catch per unit effort; maximum potential exposure
		Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent) of habitat removal scar; biomass of removed material/type (by-catch data)	Abundance (areal coverage)	By-catch per unit effort; maximum potential exposure
		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent) of habitat removal scar; biomass of removed sponges (by-catch data)	Abundance (areal coverage); community structure	By-catch per unit effort; maximum potential exposure
	Strikes	Bocaccio Rockfish	Bocaccio Rockfish	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further.	Proportion of species exhibiting visible injury.	Maximum potential exposure; proportion of trawl where mobile species are struck (partial sample using cameras attached to gear); incidents of lost gear
	Substrate disturbance (resuspension)	Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx* *Farrea occa* *Aphrocallistes vastus* *Rhabdocalyptus dawsoni*	Abundance (relative) of colonies showing visible signs of smothering	Abundance (areal coverage); genetic diversity between reefs	Maximum induced increase in suspended sediments; maximum increase in turbidity

Activity	Stressor	SEC Grouping	SEC	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Midwater trawl	Substrate disturbance (resuspension)	Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent) of habitat showing signs of smothering/stress; community structure	Species richness and diversity of assemblage; condition	Maximum induced increase in suspended sediments; maximum increase in turbidity
Midwater trawl	Substrate disturbance (resuspension)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent) of habitat showing signs of smothering/stress	Abundance (areal coverage)	Maximum induced increase in suspended sediments; maximum increase in turbidity
Midwater trawl	Substrate disturbance (crushing)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent) of habitat showing signs of crushing	Abundance (areal coverage)	Frequency of potential exposure; incidents of collisions
Midwater trawl	Substrate disturbance (crushing)	Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent) of habitat showing signs of crushing; community structure	Abundance (areal coverage); Species richness and diversity of assemblage; condition	Frequency of potential exposure; incidents of collisions
Midwater trawl	Substrate disturbance (crushing)	Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx*	Abundance (relative) of colonies showing visible signs of crushing	Health/condition; abundance	Frequency of potential exposure; incidents of collisions
			Farrea occa			
			Aphrocallistes vastus			
			Rhabdocalyptus dawsoni			
Bottom trawl	Substrate disturbance (resuspension)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent/proportion) of habitat showing signs of smothering	Abundance (extent and distribution); Species richness and diversity associated with the skeleton.	Maximum induced increase in suspended sediments; Maximum increase in turbidity; Substrate composition; Maximum potential exposure
Bottom trawl	Substrate disturbance (resuspension)	Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent) of habitat showing signs of smothering/stress	Abundance (extent and distribution); Health/condition related to physical smothering; Species richness and diversity	Maximum induced increase in suspended sediments; Maximum increase in turbidity; Substrate composition;

Activity	Stressor	SEC Grouping	SEC	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
					of associated community	Maximum potential exposure
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx* *Aphrocallistes vastus* *Farrea occa* *Rhabdocalyptus dawsoni*	Abundance of colonies showing signs of smothering; number of colonies showing signs of smothering (health and visible smothering)	Health/condition; abundance	Maximum induced increase in suspended sediments; maximum increase in turbidity
		Bocaccio Rockfish	Bocaccio Rockfish	Change in condition/ sub-lethal effects of smothering on Bocaccio Rockfish as a proportion of the population at the reefs	Abundance; biomass; Condition factor, k;	Maximum induced increase in suspended sediments; Maximum increase in turbidity;
		Squat Lobster	*Munida quadrispina*	Change in condition/ sub-lethal effects of smothering on *M. quadrispina* as a proportion of the population at the reefs	Abundance/ species density; biomass; Health/ condition; Species spatial distribution	Maximum induced increase in suspended sediments; Maximum increase in turbidity;
Discharge	Oil/ Contaminants	Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Abundance (areal extent/proportion) of habitat showing visible signs of reduced condition or smothering; species richness and diversity of organisms associated with the habitat	Abundance (extent and distribution); Health/condition related to physical damage; Species richness and diversity	Frequency of potential exposure; Discharge volume; Proportion of water samples exceeding standards for water quality parameters of interest
		Physical habitat	Glass sponge skeleton matrix (and material contained within)	Abundance (areal extent/proportion) of habitat smothered by oils; persistence of oils on habitat	Abundance (extent and distribution); Species richness and diversity of associated biota	Frequency of potential exposure; Discharge volume; Proportion of water samples exceeding standards for water quality parameters of interest

Activity	Stressor	SEC Grouping	SEC	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx* *Aphrocallistes vastus* *Farrea occa* *Rhabdocalyptus dawsoni*	Abundance of colonies with visible damage/ dead (proportion); change in condition/ sub-lethal effects	Health/condition; abundance; species richness	Frequency of potential exposure; discharge volume; proportion of water samples exceeding standards for water quality parameters of interest

Table 10. Indicator suites for potential SEC-stressor interactions, presented roughly in order of the prioritization results.

Activity	Stressor	SEC Grouping	SEC	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Oil spill	Oil/contaminants	Reef building glass sponges and Rosselid/boot sponge	*Heterochone calyx* *Aphrocallistes vastus* *Farrea occa* *Rhabdocalyptus dawsoni*	Abundance of colonies with visible damage/dead; change in condition/ sub-lethal effects; change in genetic diversity	Health/condition; abundance; species richness	Vessel density in vicinity of the HS/QCS MPA; oil spill volume; oil type
		Biogenic habitat	Sponge gardens	Abundance, species richness/presence of disease	Health/condition; abundance; species richness	Vessel density in vicinity of the HS/QCS MPA; oil spill volume; oil type
		Bocaccio Rockfish	Bocaccio rockfish	Change in condition/ sub-lethal effects; reduced abundance.	Abundance; genetic diversity and structure; species richness and diversity	Vessel density in vicinity of the HS/QCS MPA; oil spill volume; oil type
		Physical habitat	Glass sponge skeleton matrix	Proportion of the habitat showing visible signs of smothering by oil.	Health/condition; abundance, species richness.	Vessel density in vicinity of the HS/QCS MPA; oil spill volume; oil type
		Squat Lobster	*Munida quadrispina*	Abundance of organisms displaying symptoms of stress; sub-lethal effects	Abundance/ density; size structure; spatial distribution; health/condition	Vessel density in vicinity of the HS/QCS MPA; oil spill volume; oil type

4 DISCUSSION

The selection of appropriate ecological indicators is a key step in the adaptive management of the HS/QCS MPA (Figure 1). By selecting risk-based indicators, monitoring plans may be developed to measure those components identified as crucial to the functioning of the ecosystem and those at risk from anthropogenic stressors. This paper presents risk-based indicators for SECs, stressors, and SEC-stressor interactions. SEC-stressor interactions were divided into *current snapsho*t and *potential* interactions. Table 9 and Table 10 present suites of indicators representing *current snapshot* and *potential* interactions, respectively. These tables display the relevant SEC-stressor interaction indicator(s), as well as the indicator(s) specific to SECs and stressors (independent of one another) that would provide data relevant to that interaction. Suites of indicators are proposed, as no single indicator provides a complete picture of ecosystem state. Suites of indicators focus on different key parameters (population/habitat size and condition), using different types and sources of data, to provide information on changes within the ecosystem.

4.1 SUITES OF INDICATORS FOR MONITORING

SEC-stressor interaction indicators are those most specific to measuring the impact of a particular stressor on a SEC or group of SECs. The inclusion of SEC and stressor specific indicators with SEC-stressor interaction indicators in the suites serves two purposes: to provide alternate options if interaction-specific indicators cannot be measured; and information collected by monitoring SEC and stressor specific indicators help establish baselines of information and would complement existing datasets. The order of presentation of the indicator suite tables (Table 9 and Table 10; *current snapshot*, then *potential* indicators) does not reflect any prioritization of *current snapshot* over *potential* indicators, as each represents a different type of risk, state of knowledge, and management approach. When developing monitoring strategies and plans, both *current snapshot* and *potential* stressor indicator suites should be considered using a combination of SEC, stressor, and SEC-stressor interaction indicators.

The indicators presented in the *current snapshot* suite largely measure the SEC-stressor interaction directly and can be monitored at the same time as collecting general information to establish population baselines. For example, while conducting visual surveys to establish population baselines of *Heterochone calyx*, the proportion of *H. calyx* and/or other species SECs from the same assemblages (e.g. *Farrea occa, Aphrocallistes vastus*) displaying signs of disturbance can be measured concurrently. The most informative indicators for *current snapshot* interactions are SEC-stressor indicators, followed by SEC and stressor indicators. Managers should note that by using only SEC or stressor indicators, the level of uncertainty surrounding the specificity of a measurement to an interaction increases. The monitoring of *current snapshot* stressor indicators should use a combination of SEC-stressor interaction, SEC, and stressor indicators to establish baselines and measure disturbances concurrently.

The indicators presented in the *potential* suite of indicators, are generally less specific to the SEC-stressor interaction, relying more on ways to measure the stressor or impacted SEC separately. This lack of specificity is due to the unpredictable nature of the stressors (there is high uncertainty around the exposure and consequence of such interactions), and the lack of established baselines measurements. A different approach needs to be taken to monitor *potential* indicator suites, as the SEC-stressor specific indicators can often only be monitored if/when that stressor occurs. If a *potential* stressor does occur, baselines need to already be established in order to measure the impact of the disturbance. For this reason, SEC indicators are more closely linked to measures of abundance (to establish population baselines), and stressor indicators measure the possible exposure of the stressor and/or exposure of the stressor once the event has occurred (for example, oil spill, where the density/frequency of vessels or the volume of spilled oil can be monitored). The monitoring of *potential* stressor indicator suites should occur in two steps:

1. Establish baselines of information using SEC and stressor specific indicators; and,
2. If/when the *potential* stressor occurs, use SEC-stressor interaction indicators to measure the disturbance and compare with population baselines established in Step 1.

In terms of the timing of monitoring, indicators may be divided into two data collection streams: time series; and, single event. Time series monitoring (repeated measurements of an event over a given period) should be used to monitor highly ranked SEC-stressor interactions, SECs, and stressors and to collect baseline data for *potential* stressors. Single event monitoring should be used to collect data to resolve sources of high uncertainties and collect data to determine unknown impacts of stressors. Indicators specific to SECs may be affected by measurement, process, and estimation error (related to errors in the estimated quantities). Therefore, different indicators, and the same indicators measured at different scales and in different ways, will detect true trends on different timescales (Jennings 2005).

Johannes (1998) noted that when resources are very limited, stressor indicators are easier and more cost-effective to use than SEC indicators. However, information baselines for SECs are still required in the longer term, as it is unlikely that further restrictions on activities within the HS/QCS MPA bounds would be accepted without evidence that the proposed restrictions would help to meet operational objectives (i.e., status of SECs). Additionally, given the difficulties associated with measuring short-term changes in SEC population size and condition, it is likely that stressor indicators will be relied upon for annual reporting or assessments, with SECs being measured less frequently to determine the overall effectiveness of the MPA (Jennings 2005). However, while it is more cost effective and easier to measure the stressor indicators in most cases, a balance must be achieved between monitoring both SEC and stressor indicators as the ultimate success of the MPA management will be judged based on the achievement of conservation objectives related to ecosystem state, and therefore the state of SECs (Jennings 2005).

4.2 DATA COLLECTION AND ADDRESSING KNOWLEDGE GAPS

Indicators related to measures of abundance are suggested in most indicator suites, highlighting the need to establish baseline levels of abundance for all SECs as a priority at the HS/QCS MPA. Once these baselines are established, changes in population/habitat size and condition can be measured and monitored, and may be linked to both natural and anthropogenic stressors. This approach is particularly crucial for potential SEC-stressor interactions, as monitoring the impacts from these unpredictable stressor interactions is not possible until the event occurs, e.g. oil spill.

Indicators were selected with consideration given to the limitations of research and monitoring at the HS/QCS MPA. Such limitations include the remote location and depth of the reefs, and the associated high cost of access. As a result, monitoring is heavily reliant on the use of submersibles and remote cameras (e.g. drop cameras), the sampling/monitoring techniques available to each submersible, existing datasets (e.g., scientific studies, previous submersible video, vessel density, dive logs, etc.). With many indicators requiring visual surveys as a measurement technique and the overlapping distribution of several SECs (e.g. the three glass sponge species SECs), multiple indicators may be measured or sampled during the same operations period. However, it should be noted that at this time, the required tools and resources to measure several of the selected indicators are not currently available at HS/QCS

MPA and monitoring will likely be heavily reliant on visual survey techniques. As research technologies develop and baselines are established, monitoring may be able to extend beyond visual surveys and limited sampling programs. The use of visual surveys to monitor multiple indicators reduces the incidence of destructive sampling/measurements, which is particularly important for sensitive ecosystems like the HS/QCS MPA with low recovery rates.

The suites of indicators selected in this process will likely evolve over time as further resources and information become available (Jennings 2005). As more information on monitored SECs and stressors is collected and monitoring methods improve, indicators may be removed or additional indicators may be incorporated into the monitoring plan for the HS/QCS MPA. These changes may include indicators suggested in the SEC and stressor indicators tables (Appendix C and Appendix E) that were not included in the suites of indicators, or new indicators. Any new indicator should fulfill the criteria described in Section 3.2.2 and be scored against the more detailed criteria presented in Appendix B.

While indicators were selected based on the best available knowledge of indicator selection and monitoring (e.g. appropriate selection criteria, current state of knowledge at the time the review was undertaken, etc.), the effectiveness of the indicators in measuring changes to SECs resulting from interactions with stressors at the HS/QCS MPA will not be fully realized until after data collection has commenced, smaller scale impact experiments undertaken, and time series data have been analyzed (under 'monitor, evaluate, and report' in adaptive management framework; Figure 1). The effectiveness of current snapshot interaction indicators can be reassessed sooner than potential SEC-stressor interaction indicators, which cannot be evaluated until the stressor occurs at the HS/QCS MPA. Any monitoring plan will need to include an indicator reevaluation process once data collection has begun to determine the most effective indicators and which indicators will be monitored long-term. Indicator performance testing will need to employ a formal evaluation method, e.g., retrospective tests based on signal detection theory (proposed by Rice and Rochet 2005), or rule-based management with monitoring and feedback controls (also proposed by Rochet and Rice (2003)). The performance of indicators should be assessed in terms of the indicators capacity to track properties of interest (in this case, impacts from stressors, and establish population baselines for SECs), provide insights into the strength of the stressor-response relationship, and their ability to detect or predict trends in the measured attributes (Jennings 2005).

The next step in the adaptive management framework (Figure 1) is to develop monitoring strategies, which will typically include specifications for data collection, budgets and limitations for monitoring actions, data processing and analysis, the use of analytical outputs in assessment, how the assessment determines any decision rules, and how decisions may be implemented (Jennings 2005). Logistical constraints will likely dictate which indicators can be incorporated into monitoring strategies. Ultimately, indicators should be linked to reference points for SECs that, if exceeded, trigger management actions. Given the current state of knowledge of communities at the HS/QCS MPA, specific reference points have not been considered. Shin et al. (2010) concluded that the scientific community is still far from able to determine reference points for ecosystem indicators, and the same conclusion is applicable for risk-based indicators. At this stage, linking reference points to risk-based indicators is aspirational, but should not hinder the collection of data through monitoring programs.

4.3 LIMITATIONS AND FUTURE DEVELOPMENT OF THIS WORK

Indicators are subject to the limitations of available or existing data, and sampling design and tools (Kenchington et al. 2010). The need to establish information baselines is crucial in determining the effectiveness of management measures, and of the indicators themselves. For remote, difficult to access areas like the HS/QCS MPA, the sampling design and tools required to collect information on relevant indicators is limited to available technology, funds, and time. There are limitations in each method to measure indicators, however, the suites of indicators are designed so that, as more information is collected, several different methods (measurable components) will be used to validate existing datasets. The development of new sampling tools in the future will further add to these datasets.

4.3.1 Conservation Objectives

The HS/QCS MPA conservation objective "*to conserve the biological diversity, structural habitat, and ecosystem function of the glass sponge reefs*" is broad and more specific operational objectives had not yet been defined. Davies et al. (2011) stated in their risk-based indicator selection recommendations that the refinement of the conservation objective into SMART operational objectives is essential to the development of a monitoring plan that will measure ecosystem parameters that are useful and relevant for the management of anthropogenic stressors at Pacific Region MPAs. While it would have been preferable to have the full management plan and refined conservation objectives to link to selected indicators and use as potential selection criteria throughout this process, the lack of specific operational objectives and management plan did not inhibit the selection of proposed indicators that are appropriate for the current state of knowledge in the HS/QCS MPA ecosystem.

4.3.2 Ecosystem Indicators

This work proposed risk-based indicators, based on the outputs of the application of the ERAF to the HS/QCS MPA. The scoping phase of the ERAF identified several community SECs that could not be included in the risk analysis (Hannah et al. 2019). These included: glass sponge reef skeleton community; sponge garden community; rockfish community; glass sponge reef (living) benthic community; glacial surfaces and topographic enhancement of reef function; bacteria and picoplankton/incoming water flows/currents; and, living function of the reef - filtration. These are a combination of communities and ecosystem properties/functions. Development of ecosystem indicators should consider indicators that would appropriately monitor these potential SECs.

4.3.3 Stressors

The scoping phase of the ERAF identified anthropogenic stressors impacting the HS/QCS MPA through the development of PoE models. The selection of risk-based indicators is based on the interaction of these identified stressors with SECs. While these stressors were deemed appropriate in Hannah et al. 2019, future iterations of this work may include the further development of the stressors. For example, submersible operations may be divided by submersible type and size.

Long-range stressors were not included in this work, as this work was based directly on the outputs of the ERAF application. For future iterations of this work, the indicator selection criteria (Section 2.2.2; additional criteria in Appendix B) could be used to select appropriate indicators for impacts associated with long-range transport of atmospheric contamination (persistent organic pollutants), and stressors related to climate change (e.g., ocean acidification, species range changes, and temperature changes). However, indicators for these long-range impacts may not be sensitive to changes in the ecosystem, and would be reliant on stressor specific indicators and established population baselines.

Natural stressors were not included in the ERAF application to the HS/QCS MPA, and therefore were not included in this selection of risk-based indicators. The impact of these natural stressors may confound the results of monitoring plans designed to detect effects of anthropogenic stressors, and possibly exacerbate the impact of the anthropogenic stressors identified in the ERAF. Any future selection of ecosystem indicators should take into consideration natural drivers and pressures (including climate change), particularly when including community properties and ecosystem services.

Legacy impacts on SECs resulting from historical stressors that may no longer be present in the HS/QCS MPA should be considered in the development of future indicator suites and the selection of ecosystem indicators. For example, the current state of degradation of some glass sponge reef areas as the result of historical trawling may skew population baselines for monitoring or inhibit the recovery of associated species. Legacy impacts should be clearly identified in future applications of the ERAF and incorporated into indicator suites.

5 CONCLUSIONS AND RECOMMENDATIONS

The selection of ecological risk-based indicators is a key step in the adaptive management (AM) framework for the HS/QCS MPA. Suites of indicators were proposed for *current snapshot* stressors (predictable, and occurring most years) and *potential* stressors (unpredictable, and occurring infrequently), and both incorporated SEC specific, stressor specific, and SEC-stressor interaction indicators. The indicators selected during this process will be used to develop monitoring strategies, refine conservation objectives further into operational objectives, and develop monitoring plans. As data is collected through the monitoring of indicators, this information may be fed back into the adaptive management framework for future iterations of risk assessments, evaluation of selected indicators, selection of new indicators, and the refinement of the monitoring plans.

Specific recommendations arising from the development of the risk-based indicator selection framework and application to the HS/QCS MPA include:

- Information baselines need to be established as a priority. This was highlighted by the proposal of measures of abundance across all indicator suites;
- When developing monitoring strategies and plans, both *current snapshot* and *potential* stressor indicator suites should be considered using a combination of SEC, stressor, and SEC-stressor interaction indicators;
- *Current snapshot* indicator suites should be monitored at the same time as collecting general information to establish baselines and measure disturbances using SEC and stressor indicators;
- *Potential* indicator suites should be monitored in two steps: establish baselines of information using SEC and stressor indicators; and if/when the potential stressor occurs, use SEC-stressor interaction indicators to measure the disturbance and compare with population baselines;
- Indicators should be measured using non-destructive methods where possible, such as visual surveys and existing datasets/samples. Multiple indicators may be measured or sampled during the same operations period using visual surveys;
- The effectiveness of the proposed indicators in measuring changes to SECs resulting from interactions with stressors will not be fully realized until after monitoring has commenced. The performance of indicators should be assessed in terms of the indicators' capacity to track properties of interest (in this case, impacts from stressors, and establish population baselines for SECs) and their ability to detect or predict trends in attributes. This

assessment process may result the indicators being added or discarded from monitoring plans.

6 REFERENCES CITED

Andrews, K.S., Harvey, C.J., and Levin, P.S. 2013. Conceptual models and indicator selection process for Washington State's Marine Spatial Planning Process. Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service. NOAA. 120 p. (Accessed December 21, 2018)

Boutillier, J., Masson, D., Fain, I., Conway, K., Lintern, G., O, M., Davies, S., Mahaux, P., Olsen, N., Nguyen, H., and Rutherford, K. 2013. The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/075. viii + 76 p. (Accessed December 21, 2018)

Canada Gazette. 2017. Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Areas Regulations. (SOR/2017-15) P.C. 2017-110, February 13, 2017, 151:4.

Chu, J.W. and Leys, S.P., 2010. High resolution mapping of community structure in three glass sponge reefs (Porifera, Hexactinellida). Mar. Ecol. Prog. Ser., 417: 97-113.

Chu, J.W., Maldonado, M., Yahel, G., and Leys, S.P. 2011. Glass sponge reefs as a silicon sink. Mar. Ecol. Prog. Ser., 441:1-14.

Clarke, C.L., and Jamieson, G.S. 2006. Identification of ecologically and biologically significant areas in the Pacific North Coast Integrated Management Area: Phase II – Final Report. Can. Tech. Rep. Fish. Aquat. Sci. 2686: v + 25 p.

Conway, K.W. 1999. Hexactinellid sponge reefs on the British Columbia continental shelf: Geological and biological structure with perspective on their role in the shelf ecosystem. Canadian Stock Assessment Secretariat Research Document 99/192. Fisheries and Oceans Canada. 20 p. (Accessed December 21, 2018)

Conway, K.W., Krautter, M., Barrie, J.V., and Neuweiler, M. 2001. Hexactinellid sponge reefs on the Canadian continental shelf: A unique “Living Fossil.” Geosci. Can., 28(2): 71–78.

Conway, K.W., Barrie, J.V., Austin, W.C., and Luternauer, J.L. 1991. Holocene sponge bioherms on the western Canadian continental shelf. Cont. Shelf Res., 11(8-10): 771-790.

Conway, K.W., Barrie, V.J., and Krautter, M. 2004. Modern siliceous sponge reefs in a turbid, siliciclastic setting: Fraser River delta, British Columbia, Canada. Neues Jahrb. Geol. P., 6: 335–350.

Conway, K.W., Barrie, J.V., and Krautter, M. 2007. Complex deep shelf habitat: sponge reefs in the Pacific Northwest, p. 259–269. In B. J. Todd and H. G. Greene (eds.), Mapping the Seafloor for Habitat Characterization. Geol. Assoc. Can., Special Paper 47.

Conway, K.W., Krautter, M., Barrie, J.V., Whitney, F., Thomson, R., Reiswig, H., Lehnert, H., Mungov, G., and Bertram, M. 2005. Sponge reefs in the Queen Charlotte Basin , Canada: controls on distribution, growth and development. Erlangen Earth Conf., 605–621.

Curtis, J.M.R., Poppe, K., and Wood, C.C. 2012. Indicators, impacts and recovery of temperate deepwater marine ecosystems following fishing disturbance. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/125. v + 37 p. (Accessed December 21, 2018)

Davies, S.C., O, M., and Boutillier, J. 2011. Recommendations for indicator selection for Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/068. vi + 24 p. (Accessed December 21, 2018)

DFO. 2000. Report of the PSARC Habitat Subcommittee meeting December 7-8, 1999. DFO Can. Sci. Advis. Sec. Proceed. Ser. 1999/035. 24p. (Accessed December 21, 2018)

DFO. 2010A. Pacific Region Cold-Water Coral and Sponge Conservation Strategy 2010-2015. DFO/2010-1663. (Accessed December 21, 2018)

DFO. 2010B. Occurrence, sensitivity to fishing, and ecological function of corals, sponges, and hydrothermal vents in Canadian waters. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/041. (Accessed December 21, 2018)

DFO. 2011. Socio-economic implications of the proposed glass sponge reef Marine Protected Area. (Accessed December 21, 2018)

DFO. 2015. Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Areas Regulations. Canada Gazette. Vol. 149, No. 26.

Dunham, A., Pegg, J., Carolsfeld, W., Davies, S., Murfitt, I., and Boutillier, J. 2015. Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community. Mar. Environ. Res. 107: 50-60.

Dunham, A., Mossman, J., Archer, S., Pegg, J., Davies, S., and E. Archer. 2018. Glass Sponge Reefs in the Strait of Georgia and Howe Sound: Status assessment and ecological monitoring advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/010. (Accessed December 21, 2018)

Hannah, L., Thornborough, K., and Thiess, M.E. 2019. Ecological Risk Assessment for the Hecate Strait/Queen Charlotte Sound Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/048. vi + 140.

Jennings, S. 2005. Indicators to support an ecosystem approach to fisheries. Fish Fish., 6: 212–232.

Johannes, R.E. 1998. The case for data-less marine resource management: examples from tropical near- shore fin fisheries. Trends Ecol. Evol., 13: 243–246.

Kenchington, E., Lirette, C., Cogswell, A., Archambault, D., Archambault, P., Benoit, H., Bernier, D., Brodie, B., Fuller, S., Gilkinson, K., Lévesque, M., Power, D., Siferd, T., Treble, M., and Wareham, V. 2010. Delineating Coral and Sponge Concentrations in the Biogeographic Regions of the East Coast of Canada Using Spatial Analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/041. vi + 202 pp. (Accessed December 21, 2018)

Kahn, A.S., Yahel, G., Chu, J.W., Tunnicliffe, V., and Leys, S.P. 2015. Benthic grazing and carbon sequestration by deep-water glass sponge reefs. Limnol. Oceanog., 60:78-88.

Krautter, M., Conway, K., and Barrie, J.V. 2001. Discovery of a “Living Dinosaur”: Globally unique modern hexactinellid sponge reefs off British Columbia, Canada. Facies, 44(1): 265–282.

Levin, P., Damon, M., and Samhouri, J. 2010. Developing meaningful marine ecosystem indicators in the face of a changing climate. Stanf. J. Law Sci. Policy, (March): 36–48.

Leys, S.P. 2013. Effects of sediment on glass sponges (Porifera, Hexactinellida) and projected effects on glass sponge reefs. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/074. vi + 23 p. (Accessed December 21, 2018).

Leys, S.P., Mackie, G.O., and Reiswig, H.M. 2007. The biology of glass sponges. Advances in Mar. Biol., 52: 1-145.

Matabos, M., Tunnicliffe, V., Juniper, S.K., and Dean, C. 2012. A Year in Hypoxia: Epibenthic Community Responses to Severe Oxygen Deficit at a Subsea Observatory in a Coastal Inlet. PLOS ONE, 7(9): 1–15.

O, M., Martone R., Hannah, L., Grieg, L., Boutillier, J., and Patton, S. 2015. An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/072.vii + 59 p. (Accessed December 21, 2018)

Piet, G.J., and Jansen, H.M. 2005. Evaluating potential indicators for an ecosystem approach to fishery management in European waters. ICES J. Mar. Sci., 65: 1449–1455.

Rice, J.C., and Rochet, M.J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES J. Mar. Sci., 62: 516-527.

Rochet, M.J., and Rice, J.C. 2005. Do explicit criteria help in selecting indicators for ecosystem-based fisheries management? ICES J. Mar. Sci., 62: 528–539.

Rubidge, E., Thornborough, K., and O, M. 2018. Ecological Risk Assessment for the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc 2018/012. (Accessed December 21, 2018)

Samhouri, J.F., Levin, P.S., and Harvey, C.J. 2009. Quantitative evaluation of marine ecosystem indicator performance using food web models. Ecosystems, 12: 1283–1298.

Santavy, D.L., Courtney, L.A., Fisher, W.S., Quarles, R.L., and Jordan, S.J. 2013. Estimating surface area of sponges and gorgonians as indicators of habitat availability on Caribbean coral reefs. Hydrobiologia, 707(1): 1-16.

Shin, Y.J., Bundy, A., Shannon, L. J., Simier, M., Coll, M., Fulton, E. A., Link, J. S., Jouffre, D., Ojaveer, H., Mackinson, S., Heymans, J. J., and Raid, T. 2010. Can simple be useful and reliable? Using ecological indicators to represent and compare the states of marine ecosystems. ICES J. Mar. Sci., 67: 717–731.

Stone, R.P., Conway, K., Csepp, D.J., and Barrie, J.V. 2014. The Boundary Reefs: Glass Sponge (Porifera: Hexactinellidae) Reefs on the International Border Between Canada and the United States. NOAA Technical Memorandum NMFS-AFSC-264.

Thornborough, K., Rubidge E., and O., M. 2017. Ecological Risk Assessment for the Effects of Human Activities at Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/068. (Accessed December 21, 2018)

Thornborough, K., Dunham, J., and O, M. 2016A. Development of risk-based indicators for the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/027 vii + 120 p. (Accessed December 21, 2018)

Thornborough, K., Dunham, J., and O, M. 2016B. Development of risk-based indicators for the Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/028 vii + 124 p. (Accessed December 21, 2018)

7 GLOSSARY AND ACRONYMS

Abundance - is an ecological concept referring to the relative representation of a species in a particular ecosystem. It is usually measured as the number of individuals found per sample.

Activity - An action that may impose one or more stressors on the ecosystem being assessed.

Acute change (ERAF) – The percent change in the population-wide mortality rate of a species SEC when exposed to a given stressor, the loss of area and productive capacity of habitat SECs, and the percentage of species impacted for community/ecosystem SECs. This term corresponds to a change in population size.

Biodiversity - The full range of variety and variability within and among living organisms and the ecological complexes in which they occur. Encompasses variation at the ecosystem, community, species, and genetic levels and the interaction of these components. Biodiversity includes the number of species and their abundance (species richness is the number of species, whereas species abundance is a measure of how common the species is in that environment).

Biogenic habitat - habitat created by a living organism, e.g. Coral, Sponge, Kelp.

Chronic change (ERAF) - The percent change in the long-term fitness (including condition and genetic diversity) of a species SEC, the percent change in structural integrity, condition, or loss of productive capacity of habitat SECs, and the percentage of functional groups impacted for community/ecosystem SECs. Chronic change corresponds with a change in population condition.

Community - a group of actually or potentially interacting species living in the same place. A community is bound together by the network of interactions that species have with one another.

COSEWIC - The Committee on the Status of Endangered Wildlife in Canada - a committee of experts that assesses and designates which wildlife species are in some danger of disappearing from Canada.

Cumulative impacts - The combined total of incremental effects that multiple human activities through space and time can have on an environment.

Cumulative risk ($CRisk_c$; ERAF) - Estimation of $CRisk_c$ across SECs enables evaluation of the relative risk ($Risk_{sc}$) to SECs within the area assessed. This is calculated by summing the risk scores of all stressors that impact a SEC.

***Current snapshot* stressors (ERAF)** - represents activities that are known to currently occur at the MPA, are predictable, and manageable at the MPA scale.

Ecological Risk Assessment Framework (ERAF) – Framework developed by the Pacific Region (O et al. 2015) in order to evaluate and prioritize the single and cumulative threats from multiple anthropogenic activities and their associated stressors to SECs. The key elements of this framework consist of an initial scoping phase followed by the risk assessment. Scoping includes: (1) the identification of species, habitat, and community SECs; and (2) the identification of anthropogenic activities and stressors that have the potential to affect these. The risk assessment consists of evaluating the risk of harm to each SEC from each activity and associated stressor using criteria and scoring methods described in O et al. (2015).

Ecosystem – A dynamic complex of plant, animal, and microorganism communities, climatic factors and physiography, all influenced by natural disturbance events and interacting as a functional unit.

Ecosystem-based Management (EBM) - An integrated approach to making decisions about ocean-based activities, which considers the environmental impact of an activity on the whole ecosystem, not only the specific resource targeted. Ecosystem-based management also takes into account the cumulative impact of all human activities on the ecosystem within that area.

Ecosystem components – Elements of an ecosystem identified as representative of that ecosystem.

Ecosystem component groups - Used to represent the ecosystem, three categories are considered in this process: Species, Habitats and Community/Ecosystem properties.

Ecosystem function - the physical, chemical, and biological processes or attributes that contribute to the self-maintenance of the ecosystem, for example nutrient cycling.

Ecosystem indicator - Indicators selected with the aim to reflect key ecosystem processes and serve as signals that something more basic or complicated is happening than what is actually measured. Sometimes referred to as 'state of the ecosystem' indicators. Ecosystem indicators cover a broad spectrum of ecosystem components and range from individual species to ecosystem services under the categories: environmental, species-based, size-based, and trophodynamics indicators.

Endangered - Species facing imminent extirpation or extinction (Species At Risk Act).

Endemic species - A species unique to a defined geographic area and only existing in that location.

Exposure (ERAF) - The estimated magnitude of interaction between the stressor(s) and SEC(s). Sub-terms: area overlap, depth overlap, temporal overlap, intensity (amount), and intensity (frequency).

Functional groups - a way to group organisms in an ecosystem by their role, usually mode of feeding, for example grazers, filter feeders, deposit feeders, and trophic level.

Habitat - "place where an organism lives". Habitats not only represent the fundamental ecological unit in which species interact, but it is the matrix of physical, chemical, and biological interactions that supports an essential range of ecological processes.

Indicator - 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.

Keystone species – A species that exerts control on the abundance of others by altering community or habitat structure, usually through predation or grazing, and usually to much greater extent than might be surmised from its abundance.

Nutrient importing/exporting species - Species which play a crucial role in maintaining ecosystem structure and function through the transfer of energy or nutrients that would otherwise be limiting to an ecosystem, into that system from sources outside the spatial boundaries of the ecosystem.

Pathways of Effects (PoE) model - A PoE model is a representation of cause-and-effect relationships between human activities, their associated sources of effects (stressors or pressures), and their impact on specific ecosystem components. These models illustrate cause-effect relationships and identify the mechanisms by which stressors ultimately lead to effects in the environment.

Population - Group of individuals of the same species that live in the same place and that (potentially) interact with one another to influence each other's reproductive success.

Potency (*$Potency_s$*; ERAF) - The ***$Potency_s$*** of each stressor was calculated by summing the ***$Risk_{sc}$*** scores of that stressor for each SEC the stressor interacted with

***Potential* stressors (ERAF)** - *Potential* stressors include those that occur infrequently and/or unpredictably.

Productivity - A measure of a habitat's current yield of biological material (DFO) - Species richness and abundance have been hypothesized to increase with ecosystem productivity.

Recovery (ERAF) - The time for the SEC to return to pre-stress level once the stressor is removed. Based on life-history traits of the SEC.

Resilience (ERAF) - The percent change of the SEC in response to stressors (acute and chronic). Sub-terms: acute change and chronic change

Risk (ecological risk) - A measure of the probability that adverse ecological effects may occur, or are occurring, as a result of the exposure to one or more stressors.

Risk – (*$Risk_{sc}$;* ERAF) - the likelihood that a Significant Ecosystem Component will experience unacceptable adverse consequences due to exposure to one or more identified stressors

Risk-based indicator - Risk-based indicators are a novel approach to selecting indicators to specifically monitor the risk of harm to SECs from anthropogenic activities and associated stressors.

SARA, Species at Risk Act - The Species at Risk Act was adopted by the Canadian Parliament in 2002 to provide legal protection to wildlife species at risk in Canada. SARA specifically aims to prevent wildlife species in Canada from disappearing, to provide for the recovery of wildlife species that are extirpated (no longer exist in the wild in Canada), endangered, or threatened as a result of human activity, and to manage species of special concern to prevent them from becoming endangered or threatened.

Significant Ecosystem Component (SEC) - Ecosystem components deemed to have particular importance due to fulfilling specific criteria or roles. Though SECs can be ecological, socioeconomic, or cultural in nature, the focus in this process is only on those of ecological significance, which include biological, oceanographic and physical components important to the ecosystem.

Species richness - The number of different species represented in an ecological community, landscape or region. Species richness is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions.

Species at Risk - An extirpated, endangered or threatened species or a species of special concern (formerly called vulnerable).

Species of special concern - Species particularly sensitive to human activities or natural events but not necessarily endangered or threatened as identified by COSEWIC (Committee on the Status of Endangered Wildlife in Canada). A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats). Special Concern was formerly referred to as Vulnerable.

Stressor - Any physical, chemical, or biological means that, at some given level of intensity, has the potential to affect an ecosystem.

Taxonomic distinctness - A univariate biodiversity index which, in its simplest form, calculates the average ‘distance’ between all pairs of species in a community sample, where this distance is defined as the path length through a standard Linnean or phylogenetlc tree connecting these species. It attempts to capture phylogenetic diversity rather than simple species richness and is more closely linked to functional diversity; it is robust to variation in sampling effort and there exists a statistical framework for assessing its departure from ‘expectation’; in its simplest form it utilizes only simple species lists (presence/absence data).

Target species - Primary species captured by a fishery in the MPA.

Uncertainty (ERAF) - Uncertainty associated with risk scores generated during ERAF application based on lack of available information or conflicting opinion. Uncertainty was scored during the application of the ERAF, and is expressed as 10/90% quantiles (array around the median risk score) in the results.

APPENDIX A: HECATE STRAIT/QUEEN CHARLOTTE SOUND GLASS SPONGE REEFS MARINE PROTECTED AREA SIGNIFICANT ECOSYSTEM COMPONENTS AND THEIR SELECTION JUSTIFICATIONS (HANNAH ET AL. 2019)

Table A.1. Species SECs identified in ERAF Application (Hannah et al. 2019)

Species SEC1: *Heterochone calyx* **Species SEC2: *Aphrocallistes vastus*** **Species SEC3: *Farrea occa***	
The three species of reef-building glass sponge were selected as individual species SECs which together also comprise the sponge reef habitat. Few distinctions between the species are known at present though *A. vastus* has been more extensively studied.	
These SECs met all 6 original ERAF criteria:	
Nutrient Importer/Exporter	The species comprising the glass sponge reefs are highly significant nutrient importers/exporters consuming large amounts of bacteria and picoplankton from the water column.
Specialized or keystone role in food web	These reef-building sponge species are the foundation species for the ecosystem and upon which the food web is based.
Structural habitat creating species	These three species create a complex three-dimensional structural habitat.
Rare, unique, or endemic species	Though present in other areas, the presence of these three species together is rare, and only a handful of similar reefs have been found. In particular, this area is one of the few where *F. occa* is observed.
Sensitive species	Glass sponge species are known to be sensitive to mechanical impacts and sediment input.
Depleted species	All the reefs have suffered considerable damage from fishing activities – this indicates that these species are depleted.
These SECs also fulfilled all 6 additional considerations for this ecosystem and analysis:	
Resident	These sessile species are resident in the area year-round.
Dependent	These species are dependent on the reef structure for their survival, including the sponge skeleton.
Abundant	These species are abundant within the area of study.
Observed on reef	ROV surveys found these species to comprise the reef.
Simple to monitor	It is expected that these sessile species comprising the reef should be relatively simple to observe and monitor.
Well studied	There has been study on these species, more on *A. vastus* than the other two, with new research ongoing.

Species SEC4: *Rhabdocalyptus dawsoni*	
This non-reef-building ‘boot’ type rossellid glass sponge is found within and on the periphery of the HS/QCS glass sponge reefs. They have also been found in glass sponge reefs in other areas in BC including the Strait of Georgia and the Boundary Reefs in Northern BC (Stone et al. 2014; Cook 2005; Cook et al. 2008).	
This SEC met 4 of the 6 original ERAF criteria:	
Nutrient Importer/Exporter	Sponges are nutrient importers/exporters consuming bacteria and plankton from the water column.
Specialized/keystone role in food web	This species may have a specialized role as it’s coating of spicules acts as a unique microhabitat (Boyd 1981).
Structural habitat creating species	This sponge creates structural habitat and microhabitat in the spicule ‘jungle’ it is covered with (Boyd 1981) as well as structural habitat or refuge for animals such as fish.

Species SEC4: *Rhabdocalyptus dawsoni*	
Sensitive species	Glass sponge species are sensitive to mechanical impacts and sediment input.
This SEC also fulfilled all 6 additional considerations for this ecosystem and dataset:	
Resident	This sessile species is resident in the area year-round.
Dependent	This species lives within and on the periphery of the sponge reefs and is likely to be dependent on the proximity of the reefs for protection, e.g. against water currents.
Abundant	This species has been observed by ROV to be abundant.
Observed on reef	This species has been observed within and on the periphery of the sponge reefs.
Simple to monitor	It is expected that these sessile, easy to identify species are simple to monitor.
Well studied	There has been a fair amount of research done on this species, comparable to *A. vastus.*

Species SEC 5: *Munida quadrispina*	
This species fulfills only two of six ERAF criteria so was not initially selected as a species SEC. However, it was strongly suggested for inclusion by a subject matter expert (S. Leys, U. Alberta) who considered it to have an important role in the ecosystem due to the following factors: i: likely to be an important link between sponges and fish; ii. 'rare' or 'sensitive' species may not exist in their absence; iii. a good representative of mobile decapods, which are abundant on the reef; iv. their abundance likely plays a key role in nutrient cycling (they decrease in abundance from live reef to dead reef in the HS/QCS (Cook 2005), and are also occur in greater abundance in the presence of glass sponge in Strait of Georgia reefs (Chu 2010)); vi. though present in many places, it is unusual to find them in the type of mud bottom around the sponge reef so they may be an indicator of habitat with potential for monitoring.	
This species met 2 of the original criteria:	
Nutrient Importer/Exporter	Expected to be an important link between reef and fish (as a prey item), and between the soft sediment community and the reef (as a predator).
Specialised or keystone role in food web	The role of this abundant species is expected to be important in the food web, particularly as a link between the reef and fish.
This species met all 6 of the additional considerations:	
Resident	Expected to reside on the reefs year round.
Dependent	Dependent on the reef for habitat/refuge/food.
Abundant	Observed in abundance on all reefs.
Observed on reef	Observed on all reefs in ROV surveys.
Simple to monitor	Their defensive nature means that when disturbed, they stay in place bearing their claws which may simplify monitoring.
Well studied	This species has been well studied in other areas.

Species SEC 6: Bocaccio Rockfish (*Sebastes paucispinis*)	
The rockfish assemblage was unable to be included as a community SEC in this iteration, so Bocaccio Rockfish was selected to represent rockfish in the risk assessment as a Species SEC. This species was selected as it was deemed the most sensitive rockfish on our list and so would be scored with the most precaution. This species is one of the few fish species with COSEWIC Endangered designation in the Queen Charlotte Basin (COSEWIC 2013). Bocaccio Rockfish also have commercial value and were caught in fishing trawls on the reefs prior to fishing closures (Jamieson and Chew 2002). At present, we do not know how closely this species is associated with the benthic sponge reef, but it is assumed to be representative of sponge reef-associated rockfish.	
This species met 4 of the original 6 ERAF criteria:	
Nutrient Importer/Exporter	Rockfish use the sponge reef as a significant source for food and are expected to feed upon decapods in the reef, and organisms such as worms in the soft sediment skeleton community.
Specialised/keystone role in food web	Rockfish are expected to be influential top predators in this ecosystem.
Sensitive species	COSEWIC Endangered species listing.
Depleted species	In continuous decline in Canada for 60 years, with 28% decline in the 10-year period since COSEWIC assessment. Recent declines are in areas of highest biomass (west coast of Vancouver Island and in Queen Charlotte Sound). Fishery bycatch is the main threat to the population.
This species met 5 of the 6 additional considerations:	
Resident	It is assumed that this species of rockfish spends a significant part of its life history on the reef.
Dependent	It is assumed that there may be a sponge reef specific population of this species, which is to some degree dependent upon the food and shelter provided by the sponge reef.
Abundant	Caught on three of the four reefs, and adjacent to the fourth according to DFO catch data (Jamieson and Chew 2002).
Simple to monitor	Though mobile species, rockfish are relatively simple to identify and get population data on.
Well studied	As a commercial species this species has been well studied and basic life history data is available (Love et al. 1990).

Table A.2. Habitats selected as SECs for the HS/QCS Glass Sponge Reef MPA identified in ERAF Application (Hannah et al. 2019)

Glass Sponge Reef Skeleton Matrix (and material within)

Consideration	Justification
Formed by biogenic species	Though formed from dead reef-building sponges, it was created by living organisms, so is biogenic.
Rare or unique habitat	There are few examples of the extensive glass sponge skeleton habitat that is an integral part of the glass sponge reefs.
Sensitive or have low tolerance to disturbance and impairment or loss may result in direct impact to species, communities and ecosystem structure and function	Sponge skeletons are fragile with low tolerance to physical disturbance. Older and lower parts of the skeleton may be less fragile once they become infilled with sediment. They support the entire glass sponge reef ecosystem so their damage/loss would severely impact the ecosystem structure and function.
Critical in supporting species of conservation concern (threatened/depleted), sensitive and/or endemic or rare species	The glass sponge skeleton is critical for the survival and support of the living glass sponge reef, a sensitive ecosystem which is of conservation concern. The sediment contained within the skeleton contains species **rare** for the

Consideration	Justification
	sponge reef such as worms and bivalves. The large community of polychaete worms living in the sediment provide food for fish living on the reef, such as rockfish, some of which are threatened. The skeleton-associated foraminiferal community also contains some species thought to be unique to this ecosystem or even reef (Guilbault et al. 2006).
Provide critical ecosystem functions or services	Critical for reef preservation and are the basis for the entire sponge reef ecosystem. Similar to live sponges, dead sponge skeletons are also are an important part of the Silica cycle (Chu et al. 2011).
As in coral reefs, the largest part of the sponge reef is not the living sponges, but the sediment-in filled skeleton forming the basis of the reef (Stone et al. 2014). Sediments that fill the skeleton cavities provides support for the growing reef framework and slow the silica dissolution of the skeletons (Whitney et al. 2005). More recent findings of iron oxide crusts on sponge skeletons (in reefs in Northern BC) may also play a role in preserving the reefs as the siliceous skeletons dissolve more slowly when coated with oxide (Stone et al. 2014).	

Sponge Gardens (non-reef-building glass sponges and demosponges)

Consideration	Justification
Formed by biogenic species	Comprised of non-reef-building glass sponges and demosponges.
Critical in supporting species of conservation concern (threatened/depleted), sensitive and/or endemic or rare species	Sponge gardens are important habitat on reef peripheries (Freese and Wing 2003; Marliave et al. 2009), they are also found within sponge reefs. Sponge reefs and sponge gardens together provide important habitat for different stages of juvenile rockfish (Marliave et al. 2009; Stone et al. 2014), and several species of conservation concern have been recorded from the area. For example, sponge gardens are an important habitat for newly recruited Quillback Rockfish—a COSEWIC Threatened species-- providing a combination of refuge and feeding opportunity (Marliave et al. 2009; Richards 1986). There are also studies indicating other potential sponge-fish associations may exist (Freese and Wing 2003). Sponge gardens are considered highly important habitat not only for fish but also for crustaceans (S. Leys, University of Alberta, pers. comm.).
Sensitive or have low tolerance to disturbance and impairment or loss may result in direct impact to species, communities and ecosystem structure and function	Sponges are fragile structural species with low tolerance to physical disturbance. Damage or loss would directly impact communities dependent on them.
Supporting critical life stages	Sponge gardens provide important nursery habitat for newly recruited juvenile rockfish, and provide the necessary food subsidy to young-of-year rockfish (Marliave et al. 2009). Several rockfish species found in this area are of conservation concern.
We define sponge gardens as assemblages of non-reef-building glass sponges and demosponges within or on the periphery of sponge reefs. In other work, the term sponge garden may have other definitions; for example, in Marliave et al. (2009), they are defined as 'colonies of individual cloud sponges, growing on rock'. Sponge reefs are essential fish habitat for later stages of juvenile rockfish, providing cover and prey species aggregations (Collie et al. 1997; Stone et al. 2014). In the Strait of Georgia and Howe Sound, newly recruited juvenile rockfish may prefer glass sponge gardens to sponge reef bioherms as nursery habitat because sponge gardens provide the necessary food subsidy and are more species-rich (Marliave et al. 2009).	

APPENDIX B: RISK-BASED INDICATOR SELECTION CRITERIA FOR FUTURE APPLICATIONS OF THE RISK-BASED INDICATOR SELECTION FRAMEWORK TO MARINE PROTECTED AREAS

Criteria	Sub-criteria	Description
Theoretically sound	Indicator and measureable component established in literature/monitoring programs	Scientific, peer-reviewed findings should demonstrate that indicators act as reliable surrogates for ecosystem components and stressors.
Measurable/ feasible	Quantifiable in real-world units (concreteness of measurement) (e.g. number of individuals per m^2, etc.); Measured using tools and methods that are scientifically sound; Directly measureable (opposed to interpretation through modeling); Operationally simple; Monitoring method allows for several indicators through a single program; Method should be repeatable over different time scales, and applied to different areas	The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible and repeatable. Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments. Due to the remote location, and therefore limited opportunities for monitoring, several indicators would preferably be monitored within the same program. Methods for monitoring at the HS/QCS MPA are largely restricted to remote methods (e.g. visual surveys by submersibles, box-grab sampling, etc.). Therefore, indicators should be able to be measured using feasible remote methods. Advice from the review process for Thornborough et al.(2016A, 2016B), recommended extending this definition to methods that may become available in the study area in the future.
Sensitive	Responds predictably and is sufficiently sensitive to changes in specific ecosystem key attribute(s)	Indicators should respond unambiguously to variation in the ecosystem key attribute(s) they are intended to measure, in a theoretically- or empirically-expected direction (not applicable to stressor indicators).
Historical data	Supported by scientific data and best practices; historical data or information is available	Indicators should preferably be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.
Related to MPA management	Linked to conservation objectives/operational objectives; relevant to management concerns	Indicators should be linked to operational objectives, and provide information related to specific management goals and strategies.
Other considerations (Kershner et al. 2011; Rice and Rochet 2005)	Understood by the public and policy makers	Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with technical definitions.
	History of public reporting	Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators
	Cost-effective	Ensures that measurement tools are widely available and inexpensive to use. Sampling, measuring, processing, and analyzing the indicator data should make effective use of limited financial resources.
	Anticipatory or leading indicator	A subset of indicators should signal changes in ecosystem attributes before they occur, and ideally with sufficient lead- time to allow for a management response

Criteria	Sub-criteria	Description
	Regionally/nationally/internationally compatible	Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status
	Complements existing indicators	This criterion is applicable in the selection of a suite of indicators, performed after the evaluation of individual indicators in a post-hoc analysis. Sets of indicators should be selected to avoid redundancy, increase the complementary of the information provided, and to ensure coverage of key attributes
	Linkable to scientifically-defined reference points and progress targets	It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.

APPENDIX C: SEC INDICATOR SELECTION JUSTIFICATIONS

Table C.1. Proposed indicators for Reef Building Glass Sponges (Aphrocallistes vastus, Heterochone calyx, Farrea occa), and Rosselid/boot sponge (Rhabdocalyptus dawsoni)

Proposed indicator	Measureable component	Justification
Population size		
Relative abundance	Oscula density per m^2; density measure; areal coverage (%)/patch area (m^2)	Commonly used metric for live reef building sponge abundance (Chu and Leys 2010; Dunham et al. 2018); Comparable across reef areas; Feasible, quantitative and repeatable. Visual approaches verified by spot collection; Relative abundance is suggested as the first measurement of abundance, and can be used as an index. As monitoring program collect more data absolute abundance may be estimated also. Relative abundance is suggested here for initial monitoring programs.
Population condition		
Health/condition related to disease and aquatic invasive species	Presence of disease/ aquatic invasive species. % of sampled colonies showing visible signs of stress (N.B. should be used in combination with other indicators and monitoring).	Existing data (visual surveys) may help to inform this indicator; Highly sensitive to sampling effort as well as the selectivity of the sampling device (if not visual)
Health/condition related to physical damage	Proportion of colony or reef (%) damaged, evidence of scattered fragments of sponge skeletons; evidence of recovery.	Commonly used metric (Dunham et al. 2018); Existing data (visual surveys) may help to inform this indicator, complimented by post-event surveys; Highly sensitive to sampling effort as well as the selectivity of the sampling device (if not visual); sponges are known to recover from small scale damage (e.g. mimicking bites by fish or nudibranchs) within a year but not from crushing from a large area (e.g. 1.5 x 2 m^2) after even three years (Kahn et al. 2015). Sponge “stumps” and abraded distal edges are signs of mechanical damage from trawling (Conway et al. 2001).
Genetic diversity	Allele frequency, polymorphic loci	Quantifiable and repeatable; Well-used index, comparable across ecosystems; Highly sensitive to sampling effort as well as the selectivity of the sampling device. “Genetic mixing” has been noted across the glass sponge reefs in the Strait of Georgia via widely dispersed larvae (Brown et al. 2017). While within a reef and across the Strait of Georgia Basin, genetic distance between individuals did not vary with geographic distance, populations between the reefs in the Strait of Georgia and Barkley Sound were genetically distinct (Brown et al. 2017). Therefore, genetic diversity may not be informative at the reef level for glass sponges. For demosponges, genetic diversity can be found within populations, and differentiation found

Proposed indicator	Measureable component	Justification
		among populations and among geographic regions (Blanquer and Uriz 2010).

Table C.2. Proposed indicators for Bocaccio Rockfish (Sebastes paucispinis)

Proposed indicator	Measureable component	Justification
Population size		
Abundance	Size-frequency distribution; Catch per unit effort (for target species)	Commonly used metrics; Comparable across ecosystems; Quantitative and repeatable; achievable by visual survey
Biomass	Weight/unit area; Catch per unit effort	Biomass is a commonly used indicator. Andrews et al. (2013) states that changes in biomass/individual over time may lead to misinterpretation and should be used in conjunction with abundance; May be determined using existing data; Quantitative and repeatable; Changes in biomass are detectable depending on the frequency of data collection; Biomass is subject to sampling gear selectivity
Population condition		
Condition factor, k	e.g. weight/length, age, stomach contents, presence of disease or invasive species, parasitic load, size structure of population	Commonly used metric for fish. Theoretically sound as condition of fish is directly related to growth and fecundity (Andrews et al. 2013; Hooff and Peterson 2006).
Spatial distribution	Spatial distribution of the species within the MPA	The species home range can be an indicator of fish condition (Kramer and Chapman 1999).
Genetic diversity of populations	Population or stock delineation	Strongly supported in the literature (Andrews et al. 2013); Genetic diversity is an important component to determine the health and success of a population

Table C.3. Proposed indicators for Squat Lobster (Munida quadrispina)

Proposed indicator	Measureable component	Justification
Population size		
Abundance/ species density	Average density/count of organisms within a given range	Commonly used metric; Comparable across area/reefs; Quantitative and repeatable; Achievable by visual survey
Population condition		
Biomass	Weight/unit area	Commonly used metric; Comparable across ecosystems; Quantitative and repeatable
Health/condition	Visible injury to organism or behavioral indicators (e.g. righting and feeding behavior, reflex actions)	Commonly used metric; Comparable across ecosystems; Quantitative and repeatable; Previously applied to Squat Lobsters
Species range	Spatial distribution	Changes in distribution are detectable depending on the frequency of data collection; Repeatable and quantitative; Determination of species range is directly related to the coverage of the sampling method; This indicator is fairly insensitive and is slow to respond after perturbation; often by the time significant changes are documented, usually any other ecological consequences have already occurred.

Table C.4. Proposed indicators for Glass sponge skeleton matrix

Proposed indicator	Measureable component	Justification
Habitat size/extent		
Abundance (extent and distribution)	Areal coverage of community (% cover, m^2)	Commonly used metric (Dunham et al. 2018); Comparable across ecosystems; Quantitative and repeatable
Habitat condition/function		
Physical damage	Proportion (%) of the skeleton matrix modified	Commonly used metric for other habitat types; Repeatable; Quantifiable
Species richness and diversity	Diversity measures (alpha and beta diversity); *H. calyx* has the most robust skeleton (Krautter et al. 2001). It may be that the balance between these three reef building species can be used to indicate the degree to which a sponge reef area has been exposed to stressors, and the presence of a more fragile species such as *F. occa* could indicate a more pristine reef. A rapid decline of *F. occa* in a specific area could indicate a significant change in habitat condition. This indicator would need to be combined with baseline data and long-term trends. The density/concentration of juvenile sponges (2-10 cm in osculum diameter) near live sponges and sponge skeletons (see Chu and Leys 2010).	Commonly used metric for other habitat types; Repeatable and quantifiable; Suggested in literature. The presence of juvenile sponges could be used as an indicator of appropriate settlement area (Kahn et al. 2015).

Table C.5. Proposed indicators for Sponge gardens

Proposed indicator	Measureable component	Justification
Habitat size		
Extent and distribution	Areal coverage of sponge gardens (% cover, m^2)	Establishing the current extent and distribution of habitats is necessary to establish a baseline. Commonly used metric for other habitats. Quantitative and repeatable. May not be sensitive to small-scale anthropogenic disturbances
Habitat condition		
Health/condition related to physical damage	Functional index (e.g. average trophic level); % of the population showing visible signs of stress/damage (NB should be used in combination with other indicators and monitoring).	Commonly used indicator biotic habitats
Species richness and diversity	Diversity measures (alpha and beta diversity). Density/concentration of juvenile sponges near living sponges and sponge skeletons.	Commonly used metric; Comparable across ecosystems; Quantitative and repeatable.

APPENDIX D: SEC INDICATOR CRITERIA SUMMARY

Table D.1. Species SEC Indicators scored against criteria

Population size

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/feasible	Sensitive	Historical data	
Abundance (relative)	Count per unit area (e.g. m^2)/density measure; Areal coverage (%); Patch area (m^2); extend and distribution	Commonly used metric	Quantifiable; Repeatable; Multiple measureable components; Areal coverage suitable for colonial, large species; Number/counts suitable for conspicuous and distinguishable taxa; Frequency of occurrence measurements are simple, provided the taxon can be distinguished; Species density estimates use numerical abundances of individual per unit area; Habitat suitability models may be used to predict presence and/or abundance in unsurveyed areas, but may be highly uncertain.	There may be issues related to sampling sensitivity between gear types (DFO 2010A); This indicator will primarily be measured using visual surveys, which are commonly used to estimate large scale changes in relation to stressors	No baselines have been established, but video surveys exist.	Good way to establish population baselines; Also related to habitat quality and community structure; There may be issues related to sampling sensitivity between gear types (DFO 2010A); Measurements repeatable, quantifiable, and comparable across reef areas; Data can be collected using visual surveys; Relative abundance is suggested as the first measurement of abundance, and can be used as an index. As monitoring program collect more data absolute abundance may be estimated also. Relative abundance is suggested here for initial monitoring programs.

Population condition

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/feasible	Sensitive	Historical data	
Biomass	Size structure; Weight/unit area (only to be used when sampling is already taking place or by-catch data is available)	Commonly used indicator for individual focal species (Blanchard et al. 2010; Large et al. 2014; Shin et al. 2010).	Quantifiable; Measurement can be achieved using existing data and extractive scientific sampling; Repeatable; Comparable within and among gear types; Changes in biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance.	Changes in biomass are detectable depending on the frequency of data collection (DFO 2010A); For assemblages: changes in a single group may or may not be indicative of the entire community (Andrews et al. 2013). Benthic inverts: Correlates well with ecosystem health; gradual change should show major community reorganization (Andrews et al. 2013)	Some data available based on scientific sampling and by-catch	Should be used in conjunction with other population size indicators, such as abundance; Cannot be achieved only using visual surveys, and needs to rely on existing data and extractive scientific sampling; Subject to sampling gear selectivity (DFO 2010A). Can also be used for population size in Boccacio Rockfish and Squat Lobster.
Condition factor, k	E.g., weight/length, age, stomach contents, presence of disease, size structure of population	Commonly used indicator. Changes in the attribute are not likely to vary with this indicator at any scale but the very smallest.	Measurement mostly reliant on extractive sampling; Quantifiable as a percentage of sampled organisms; Repeatable	Highly sensitive to sampling effort as well as the selectivity of the sampling device	Data on scientific samples exist	Highly sensitive to sampling effort as well as the selectivity of the sampling device.

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/feasible	Sensitive	Historical data	
Health/ condition related to disease and aquatic invasive species	Presence of disease, aquatic invasive species. % of sampled colonies showing visible signs of stress (NB should be used in combination with other indicators and monitoring).	May be related to condition, but changes in the attribute are not likely to vary with this indicator at any scale but the very smallest	Measurement likely reliant on extractive sampling (visual surveys may report condition, but not the source of the disease or invasive species); Quantifiable as a percentage of sampled organisms; Repeatable	Highly sensitive to sampling effort as well as the selectivity of the sampling device	Some published reports available and video data	Highly sensitive to sampling effort as well as the selectivity of the sampling device (if not visual)
Health/ condition related to physical damage	Proportion of colony or reef (%) damaged, evidence of scattered fragments of sponge skeletons.	May be related to condition, but changes in the attribute are not likely to vary with this indicator at any scale but the very smallest.	Visual surveys may report condition, but not the source of the disturbance; Quantifiable as a percentage of sampled organisms. Repeatable	Highly sensitive to sampling effort as well as the selectivity of the sampling device	Existing data (visual surveys) may help to inform this indicator, complimented by post-event surveys	Highly sensitive to survey effort
Genetic diversity of populations	Population delineation; Allele frequency; Polymorphic loci	Commonly used metric. Strongly supported by literature	Measurement mostly reliant on extractive sampling	Scientific sampling. Sensitive to sampling techniques	Published report available for some glass sponge species (Brown et al. 2017; Jensen 2011)	Genetic diversity is an important component in order to determine the health and success of a population

Table D.2. Habitat SEC Indicators scored against criteria

Habitat size

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
Abundance (extent and distribution)	Areal coverage of habitat (% cover, m^2)	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Frequency of occurrence measurements are simple	This is not a sensitive indicator at the scale of projected monitoring programs	Data exist for reef boundaries. Some data exists on the extent of sponge skeleton habitat	Related to hydrodynamic conditions and substrate; Measurements repeatable, quantifiable; Data can be collected using visual surveys

Habitat condition

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
Physical damage	Proportion (%) of the habitat modified	Commonly used for other habitat types	Quantifiable as a percentage of total reef area; Repeatable	Highly sensitive to sampling effort (visual surveys)	Data exist for occurrences of anthropogenic stressors causing damage (e.g. ROV video showing submersible collisions, sampling, installation, etc.)	Sensitive to survey effort
Health/ condition related to physical damage	Functional index; % of the habitat showing visible signs of stress/damage (NB should be used in combination with	Commonly used for biogenic habitat types	Quantifiable as a percentage of total reef area; Repeatable	Highly sensitive to sampling effort (visual surveys)	Data exist for occurrences of anthropogenic stressors causing damage (e.g. ROV video showing submersible collisions,	Visible damage may not be able to be linked to a specific stressor

Indicator	Measureable component	Indicator criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
	other indicators and monitoring.				sampling, installation, etc.)	
Species richness/ diversity	Diversity measures (alpha and beta diveristy)	Commonly used metric and is comparable across reefs	Quantifiable; Repeatable; Species richness measures are a dimension of biodiversity, but does not require estimates of abundance; Diversity measures the number and evenness among species	Sensitive to the different sampling methods (DFO 2010A); Highly sensitive to sampling effort as well as selectivity of sampling device (DFO 2010A); Species diversity may not be sensitive to disturbance; Species richness is sensitive to sampling effort	Part of this measurement can be informed using existing scientific sampling	Indicator of community structure; Metrics used are well established; Repeatable, quantifiable, and comparable across ecosystems

APPENDIX E: STRESSOR INDICATOR CRITERIA SUMMARY

*Table E.1. Stressor Indicators scored against Indicator criteria. * denotes potential stressor.*

Bottom trawl

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species*	Frequency of potential exposure	Number of trawls per unit area	Quantifiable	The frequency of trawls correlates with potential harmful species introductions	Part of this measurement can be informed using catch/by-catch data	
	Species richness of aquatic invasive species	Beta diversity measures	Commonly used metric	Quantifiable; Repeatable; Can't be calculated without biomass estimates, and it is limited by taxonomic resolution	Part of this measurement can be informed using catch/by-catch data	Metrics used are well established; Repeatable, quantifiable
	Occurrence/ abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; Number per m^2	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Areal coverage suitable for colonial, gregarious, large species; Number/counts suitable to conspicuous and distinguishable taxa; Frequency of occurrence measurements are simple, provided the	Catch data only exists for economically valuable species; Bycatch data are heavily influenced by fisher behaviour and management restrictions	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the viability and integrity of native species and natural biodiversity. This database is polled by region, serves as a baseline for invasion, but has been updated since its creation. (Andrews et al. 2013).

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				taxon can be distinguished; Species density estimates use numerical abundances of individual per unit area		
Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types; Would be difficult to measure at time of disturbance without cameras on trawls.
	Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method for measuring sediment resuspension.	Little to no data exist	May be difficult to measure at time of disturbance; Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Substrate composition	e.g. % of substrate particles <6.35 mm	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method for measuring sediment resuspension; Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types
	Maximum potential exposure	Number of days per annum fishing is allowed	Commonly used metric	Data is in real-world units; Time series has been established.	Records are available on vessel movements.	Fishery-dependent data is biased toward fisher behavior, fleet dynamics, and management restrictions. Only focuses on economically valuable species Andrews et al. 2013)

Demersal long-line hooks

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method for measuring sediment resuspension; Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types
	Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method for measuring sediment resuspension.	Little to no data exist	May be difficult to measure at time of disturbance; Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts
	Substrate composition	e.g. % of substrate particles <6.35 mm	Commonly used metric	May be difficult to measure at time of disturbance; Visual surveys (% of background) are the most realistic method	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications		

Discharge

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species*	Frequency of potential exposure	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell; Number of ballast water exchanges in vicinity of the HS/QCS MPA.	Established indicator (Andrews et al. 2013); Indicator tested well in (Andrews et al. 2013), and is a combination of indicators for commercial shipping activity and invasive species	Correlated with shipping activity. (Andrews et al. 2013) suggested that this indicator could be improved if the size of the vessel and transit mileage was added to quantify the vessel's footprint and pathway. Otherwise, the number of trips doesn't tell us anything about the extent of	Data is available on vessel movements in BC	Andrews et al. 2013 suggested that this indicator could be improved if the size of the vessel and transit mileage was added to quantify the vessel's footprint and pathway. Shipping is considered one of the key invasion pathways.

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				areas affected by these trips. The number of ports the vessels visit correlates with potential harmful species introductions in most regions globally.		
	Species richness of aquatic invasive species	Beta diversity measures	Commonly used metric	Quantifiable; Repeatable; Can't be calculated without biomass estimates, and it is limited by taxonomic resolution	Part of this measurement can be informed using catch/by-catch data	Metrics used are well established; Repeatable; Quantifiable
	Occurrence/ abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution); Areal coverage/patch area; Number per m^2	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Areal coverage suitable for colonial, gregarious, large species; Number/counts suitable to conspicuous and distinguishable taxa; Frequency of occurrence measurements are simple,	Catch data only exists for economically valuable species; Bycatch data are heavily influenced by fisher behaviour and management restrictions	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the viability and integrity of native species and natural biodiversity. This database is polled by region, serves as a baseline for invasion, but has been updated since its creation. (Andrews et al. 2013).

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				provided the taxon can be distinguished; Species density estimates use numerical abundances of individual per unit area		
	Biomass of aquatic invasive species	Weight/unit area	Commonly used indicator	Quantifiable; Measurement can be achieved using existing data (catch/by-catch), and extractive scientific sampling; Repeatable; Comparable within and among gear types; Changes in biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance	Some data is available for fish from catch records; Some data available for corals and sponges from by-catch records	Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling. Subject to sampling gear selectivity (DFO 2010A)
Entrapment/ entanglement*	Relative abundance of debris	Frequency of occurrence (count/distance surveyed); Mass	Theoretically feasible	Unknown and unpredictable stressor to be measured	No existing data	

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		of recovered debris (from clean-up programs)				
Oil/ contaminants	Frequency of potential exposure	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell; Number of ballast water exchanges in vicinity of the HS/QCS MPA.	Commonly used metric	Quantifiable; Repeatable; Not very specific to stressor	No/little data	
	Discharge volume	Surface area x minimum thickness	Currently used indicator in BC waters (DFO)	Measurement can be obtained by remote sensing/ imagery; Quantifiable in real world units	Data exists on remote sensing of discharged oils in BC. This data would be available during a spill (DFO)	Ocean-based pollution, including oil spills, was assumed to be primarily driven by vessel activities and port volume. This indicator evaluated well in most criteria and is a combination of indicators for commercial shipping activity and invasive species (Andrews et al. 2013).
	Proportion of water samples exceeding standards for water quality parameters of interest	e.g. CCME Water Quality Index	Established measurement	Requires time series data to be effective; Repeatable; Measurements are possible, but may be difficult to establish	Data exists on remote sensing of discharged oils in BC. This data would be available during a spill (DFO).	Measures of total inorganic pollutants discharged into the water will provide a relative measure over time of what is discharged into the water. However,

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				appropriate time series		variation in other variables (e.g. type of material discharged) will de-couple these measurements from observations as well as the impact on organisms (Andrews et al. 2013).

Grounding

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species*	Frequency of potential exposure	Number of groundings/ sunken vessels within the bounds of the MPA	Quantifiable	Potential exposure can be determined by easily obtained records.	Records exist of ship grounding/sinking in the Pacific Region, although none have been recorded within the HS/QCS MPA area.	This indicator only provides information on the potential exposure of aquatic invasive species to the MPA.
	Occurrence/ abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change in distribution). Areal coverage/ patch area; Number per m^2.	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Areal coverage suitable for colonial, gregarious, large species; Number/ counts suitable to conspicuous and distinguishable taxa; Frequency of occurrence measurements	Records exist of ship grounding/sinking in the Pacific Region, although none have been recorded within the HS/QCS MPA area.	As any establishment of aquatic invasive species would originate from a point source, it may be possible to link an outbreak to a specific grounded/sunken vessel.

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				are simple, provided the taxon can be distinguished; Species density estimates use numerical abundances of individual per unit area		

Long-line traps

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species*	Frequency of potential exposure	Number of traps per unit area	Quantifiable	The number of sites the traps are dropped correlates with potential harmful species introductions	Part of this measurement can be informed using catch/by-catch data	
	Species richness of aquatic invasive species	Beta diversity measures	Commonly used metric	Quantifiable; Repeatable; Can't be calculated without biomass estimates, and it is limited by taxonomic resolution	Part of this measurement can be informed using catch/by-catch data	Metrics used are well established. Repeatable, quantifiable
	Occurrence/ abundance of aquatic invasive species	Total count of non-native species with established breeding populations (and potential change	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Areal coverage suitable for	Catch data only exists for economically valuable species. Bycatch data are heavily influenced	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the viability and integrity of native

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		in distribution). Areal coverage/ patch area Number per m^2		colonial, gregarious, large species; Number/counts suitable to conspicuous and distinguishable taxa; Frequency of occurrence measurements are simple, provided the taxon can be distinguished; Species density estimates use numerical abundances of individual per unit area	by fisher behaviour and management restrictions	species and natural biodiversity. This database is polled by region, serves as a baseline for invasion, but has been updated since its creation. (Andrews et al. 2013).
	Biomass of aquatic invasive species	Weight/unit area	Commonly used indicator	Quantifiable; Measurement can be achieved using existing data (catch/by-catch), and extractive scientific sampling; Repeatable; Comparable within and among gear types; Changes in biomass over time may lead to misinterpretation (Andrews et al.	Some data is available for fish from catch records; Some data available for corals and sponges from by-catch records	Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling; Subject to sampling gear selectivity (DFO 2010A)

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				2013) and should be used in conjunction with other population size indicators, such as abundance		
Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	Limited habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types
	Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension.	Little to no data exist	May be difficult to measure at time of disturbance Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Substrate composition	e.g. % of substrate particles <6.35 mm	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Midwater trawl

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Removal of biological material*	Catch per unit effort/by-catch per unit effort	Recorded catch and by-catch; Modeled catch/by-catch	Commonly used metric	Data is in real-world units; Time series has been established; Landings represent the majority of removals for most species. This metric does not include discarded catch	Catch data will inform this for target species, and partially for non-target species	Fishery-dependent data is biased toward fisher behavior, fleet dynamics, and management restrictions. Only focuses on economically valuable species Andrews et al. 2013). NB: there is a potential to get false positives when using apparent absence data from trawls (due to the size of the gear) (Howell et al. 2016).
	Maximum potential exposure	Number of days per annum fishing is allowed; Number of vessels x maximum allowable catch	Commonly used metric	Data is in real-world units; Time series has been established.	Records are available on vessel movements.	Fishery-dependent data is biased toward fisher behavior, fleet dynamics, and management restrictions. Only focuses on economically valuable species Andrews et al. 2013)
Strikes (to mobile species)	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further.	Proportion of species exhibiting visible injury; proportion of trawl where mobile species are struck (partial sample using cameras	No existing metric for strikes on mobile species.	Extremely difficult to measure. Even video of the trawl won't show the damage to an individual (extent of injury), may not capture all incidents with the frame. Time	Strikes are known to occur on mobile species, but there is no available data for midwater trawl gear in the region.	Indicator is not recommended at this time, as does not appropriately fulfil criteria. The information gained will likely not be enough to justify the effort/expense of monitoring.

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		attached to gear); incidents of lost gear		consuming/ resource heavy.		
Substrate disturbance (crushing)*	Crushed area	Proportion (%) of the area crushed/m^2	Commonly used metric	Number of trawls relates to the amount of habitat disturbed and crushed areas will show different community characteristics. However, the magnitude of modification is dependent on the length of trawl, and habitat type.	Visual surveys in fished areas may inform this.	May be difficult to measure at time of disturbance. Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts
Substrate disturbance (sediment resuspension)*	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension.	Little to no data exist	May be difficult to measure at time of disturbance. Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts
	Substrate composition	e.g. % of substrate particles <6.35 mm	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Movement underway

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Disturbance (noise)	Vessel density in vicinity of the HS/QCS MPA	Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell	Theoretically feasible	Quantifiable; Directly relatable to measuring vessel noise	Data available on vessel movements	Long-range stressor
	Noise frequency at the HS/QCS MPA	Measure sound produced (e.g. hydrophones)	Established metric	Quantifiable; Repeatable; Ongoing monitoring possible	Hydrophones have recently been installed at the HS/QCS MPA	Long-range stressor.

Oil spill

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Oil/ contaminants*	Vessel density in vicinity of the HS/QCS MPA	Number of vessel movements per traffic reporting zone or per designated grid cell	Established indicator (Andrews et al. 2013)	Correlated with shipping activity. (Andrews et al. 2013) suggested that this indicator could be improved if the size of the vessel and transit mileage was added to quantify the vessel's footprint and pathway. Otherwise, the number of trips doesn't tell us anything about the extent of	No records of oil spills at the HS/QCS MPA. Vessel movement data available	Ocean-based pollution, including oil spills, was assumed to be primarily driven by vessel activities and port volume. This indicator evaluated well in most criteria and is a combination of indicators for commercial shipping activity and invasive species (*Andrews* et al. 2013).

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				areas affected by these trips.		
	Oil spill volume	Surface area *x* minimum thickness	Currently used indicator in BC waters (DFO)	Measurement can be obtained by remote sensing/imagery	Data exist on remote sensing of discharged oils in BC. These data would be available during a spill (DFO)	Oil volume determines the spatial overlap with SECs
	Oil type	Determines surface, water column, or benthic coverage. e.g. bitumen – surface coverage of benthic habitats, petroleum – surface spill only	Oil type is an effective indicator of the species/habitats impacted	Composition of transported material will provide an accurate indication of those components of the ecosystem impacted	Data should be available from vessel spilling oil	Oil type determines the components of the ecosystem impacted. The addition of dispersants may confound oil type as an indicator of potentially impacted components

Submersible operations

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species*	Frequency of potential exposure	Number of dives sites per cruise; Existence of cleaning/ equipment flushing protocols between dive sites	Commonly used metric when other information is not available	Quantifiable; Simple to obtain data and calculate	Data exist for previous samples, as well as video from submersibles	
	Species richness of aquatic invasive species	Diversity measures (beta diversity)	Commonly used metric	Quantifiable; Repeatable; Can't be calculated without biomass	No existing data on AIS at the HS/QCS MPA	Metrics used are well established; Repeatable, quantifiable

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				estimates, and it is limited by taxonomic resolution		
	Occurrence/ abundance of aquatic invasive species	Number per m^2; Total count of non-native species with established breeding populations (and potential change in distribution) Areal coverage/patch area	Commonly used metric	Quantifiable; Repeatable; Several different measureable components; Areal coverage suitable for colonial, gregarious, large species Number/ counts suitable to conspicuous and distinguishable taxa Frequency of occurrence measurements are simple, provided the taxon can be distinguished Species density estimates use numerical abundances of individuals per unit area	No existing data on AIS at the HS/QCS MPA	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the viability and integrity of native species and natural biodiversity (http://conserveonline.org/workspaces/global.invasive.assessment/). This database is polled by region, serves as a baseline for invasion, but has not been updated since its creation (Andrews 2013). This approach may be applied to the HS/QCS MPA.

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Biomass of aquatic invasive species	Weight/unit area	Commonly used indicator	Quantifiable; Measurement can be achieved using extractive scientific sampling; Repeatable; Comparable within and among gear types; Changes in biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance	No existing data on AIS at the HS/QCS MPA	Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling. Subject to sampling gear selectivity (DFO 2010A)
Disturbance (light)	Area exposed to artificial light from submersible	Areal coverage (%)	Theoretically sound	Quantifiable	Data is available	
	Frequency of exposure	Number of submersible dives within a cruise or given time period	Theoretically sound	Quantifiable (number of dives, length of dive, speed of submersible, etc.)	Data is available	
Substrate disturbance (sediment resuspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most	Little to no data exist	May be difficult to measure at time of disturbance. Visual surveys may not give the most accurate measurement, but are

Stressor	Indicator	Measureable component	Indicator criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				realistic method for measuring sediment resuspension.		realistically the best option for measuring impacts
	Frequency of exposure to potential collisions	Number of collision events	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment resuspension.	No habitat mapping or sediment characteristics known. Video data will help inform this	May be difficult to measure at time of disturbance. Visual surveys may not give the most accurate measurement, but are realistically the best option for measuring impacts

APPENDIX F: SEC-STRESSOR INTERACTIONS AND RESULTS OF THE PRIORITIZATION METHOD

Table F.1. Scoring system applied to risk and associated uncertainty scores

Cumulative Risk	Uncertainty	Order of Priority
High	Low	1
High	Moderate	2
High	High	3
Moderate	Low	4
Moderate	Moderate	5
Moderate	High	6
Low	High	7
Low	Moderate	8
Low	Low	9

Table F.2. Complete List of prioritized Current snapshot SEC-stressor interactions

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty grouping
Bocaccio Rockfish	Midwater trawl	Removal of biological material	54.71	High	12.36	14.04	13.20	Low
Glass sponge skeleton matrix	Bottom trawl	Substrate disturbance (resuspension)	32.80	Moderate	26.82	33.49	30.15	High
Sponge gardens	Bottom trawl	Substrate disturbance (resuspension)	31.19	Moderate	25.17	31.82	28.49	High
Heterochone calyx	Bottom trawl	Substrate disturbance (resuspension)	30.98	Moderate	20.84	25.37	23.11	High
Glass sponge skeleton matrix	Mid water trawl	Substrate disturbance (crushing)	29.17	Moderate	18.57	24.94	21.76	Moderate
Sponge gardens	Mid water trawl	Substrate disturbance (crushing)	29.15	Moderate	18.55	24.29	21.42	Moderate
Aphrocallistes vastus	Bottom trawl	Substrate disturbance (resuspension)	29.04	Moderate	15.04	17.92	16.48	Moderate
Farrea occa	Bottom trawl	Substrate disturbance (resuspension)	28.99	Moderate	19.79	22.96	21.38	Moderate
Heterochone calyx	Mid water trawl	Substrate disturbance (crushing)	28.86	Moderate	18.60	24.51	21.55	Moderate
Rhabdocalyptus dawsoni	Bottom trawl	Substrate disturbance (resuspension)	28.85	Moderate	14.89	17.65	16.27	Moderate

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty grouping
Aphrocallistes vastus	Mid water trawl	Substrate disturbance (crushing)	28.75	Moderate	17.90	24.64	21.27	Moderate
Bocaccio Rockfish	Bottom trawl	Substrate disturbance (resuspension)	28.60	Moderate	23.74	27.79	25.77	High
Sponge gardens	Discharge	Oil/Contaminants	28.42	Moderate	23.10	28.63	25.87	High
Glass sponge skeleton matrix	Discharge	Oil/Contaminants	28.21	Moderate	23.46	29.78	26.62	High
Rhabdocalyptus dawsoni	Mid water trawl	Substrate disturbance (crushing)	28.20	Moderate	17.98	24.81	21.40	Moderate
Heterochone calyx	Discharge	Oil/Contaminants	26.87	Moderate	18.63	23.12	20.88	Moderate
Farrea occa	Mid water trawl	Substrate disturbance (crushing)	26.82	Moderate	17.09	22.38	19.73	Moderate
Aphrocallistes vastus	Discharge	Oil/Contaminants	26.41	Moderate	18.23	22.73	20.48	Moderate
Rhabdocalyptus dawsoni	Mid water trawl	Removal of biological material	26.25	Moderate	17.66	25.12	21.39	Moderate
Bocaccio Rockfish	Mid water trawl	Strikes	26.20	Moderate	16.35	18.99	17.67	Moderate
Heterochone calyx	Mid water trawl	Removal of biological material	26.16	Moderate	17.54	24.59	21.07	Moderate
Glass sponge skeleton matrix	Mid water trawl	Removal of biological material	26.00	Moderate	16.82	23.58	20.20	Moderate
Rhabdocalyptus dawsoni	Discharge	Oil/Contaminants	25.97	Moderate	17.89	22.76	20.33	Moderate
Sponge gardens	Mid water trawl	Removal of biological material	25.94	Moderate	16.56	22.19	19.38	Moderate
Aphrocallistes vastus	Mid water trawl	Removal of biological material	25.87	Moderate	17.45	24.68	21.06	Moderate
Heterochone calyx	Mid water trawl	Substrate disturbance (resuspension)	25.59	Moderate	16.12	22.42	19.27	Moderate
Aphrocallistes vastus	Mid water trawl	Substrate disturbance (resuspension)	25.40	Moderate	15.22	20.14	17.68	Moderate
Sponge gardens	Mid water trawl	Substrate disturbance (resuspension)	25.06	Moderate	15.93	21.22	18.58	Moderate
Rhabdocalyptus dawsoni	Mid water trawl	Substrate disturbance (resuspension)	24.88	Moderate	14.68	20.54	17.61	Moderate
Farrea occa	Discharge	Oil/Contaminants	24.84	Moderate	17.14	21.21	19.18	Moderate
Glass sponge	Mid water trawl	Substrate disturbance	24.72	Moderate	15.54	21.34	18.44	Moderate

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty grouping
skeleton matrix		(resuspension)						
Farrea occa	Mid water trawl	Removal of biological material	24.50	Moderate	16.76	22.68	19.72	Moderate
Munida quadrispina	Bottom trawl	Substrate disturbance (resuspension)	24.49	Moderate	19.94	25.65	22.80	Moderate
Farrea occa	Mid water trawl	Substrate disturbance (resuspension)	23.87	Low	15.29	20.65	17.97	Moderate
Bocaccio Rockfish	Movement underway	Disturbance [noise]	23.34	Low	21.56	27.17	24.36	Moderate
Bocaccio Rockfish	Discharge	Oil/Contaminants	22.80	Low	15.60	19.39	17.50	Moderate
Munida quadrispina	Discharge	Oil/Contaminants	21.03	Low	17.05	22.93	19.99	Moderate
Sponge gardens	Long line traps	Substrate disturbance (resuspension)	16.06	Low	13.40	15.83	14.62	Low
Aphrocallistes vastus	Long line traps	Substrate disturbance (resuspension)	16.00	Low	13.01	16.52	14.77	Low
Heterochone calyx	Long line traps	Substrate disturbance (resuspension)	15.89	Low	13.38	16.66	15.02	Low
Glass sponge skeleton matrix	Long line traps	Substrate disturbance (resuspension)	15.81	Low	13.23	15.99	14.61	Low
Rhabdocalyptus dawsoni	Long line traps	Substrate disturbance (resuspension)	15.69	Low	12.90	16.17	14.53	Low
Farrea occa	Long line traps	Substrate disturbance (resuspension)	14.86	Low	12.25	15.42	13.84	Low
Munida quadrispina	Mid water trawl	Substrate disturbance (crushing)	13.81	Low	11.39	15.51	13.45	Low
Bocaccio Rockfish	Long line traps	Substrate disturbance (resuspension)	13.69	Low	11.12	14.43	12.77	Low
Aphrocallistes vastus	Long line hooks	Substrate disturbance (resuspension)	12.67	Low	10.34	13.51	11.92	Low
Glass sponge skeleton matrix	Long line hooks	Substrate disturbance (resuspension)	12.51	Low	10.07	13.60	11.83	Low
Sponge gardens	Long line hooks	Substrate disturbance (resuspension)	12.48	Low	10.46	13.47	11.97	Low
Heterochone calyx	Long line hooks	Substrate disturbance (resuspension)	12.47	Low	10.31	13.43	11.87	Low
Rhabdocalyptus dawsoni	Long line hooks	Substrate disturbance (resuspension)	12.25	Low	9.87	13.43	11.65	Low

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty grouping
Munida quadrispina	Mid water trawl	Removal of biological material	12.18	Low	10.14	13.53	11.83	Low
Farrea occa	Long line hooks	Substrate disturbance (resuspension)	11.61	Low	9.44	12.36	10.90	Low
Sponge gardens	Submersible operations	Substrate disturbance (resuspension)	11.34	Low	9.48	12.56	11.02	Low
Heterochone calyx	Submersible operations	Substrate disturbance (resuspension)	11.26	Low	9.32	12.46	10.89	Low
Munida quadrispina	Long line traps	Substrate disturbance (resuspension)	11.18	Low	9.35	11.80	10.57	Low
Aphrocallistes vastus	Submersible operations	Substrate disturbance (resuspension)	11.17	Low	9.51	12.61	11.06	Low
Bocaccio Rockfish	Long line hooks	Substrate disturbance (resuspension)	10.84	Low	9.04	11.37	10.21	Low
Rhabdocalyptus dawsoni	Submersible operations	Substrate disturbance (resuspension)	10.82	Low	9.03	12.47	10.75	Low
Munida quadrispina	Submersible operations	Disturbance (light)	10.61	Low	8.85	12.99	10.92	Low
Farrea occa	Submersible operations	Substrate disturbance (resuspension)	10.58	Low	8.85	11.62	10.23	Low
Munida quadrispina	Long line hooks	Substrate disturbance (resuspension)	9.18	Low	7.63	10.25	8.94	Low
		Max	54.71			Max	30.15	
		Min	9.18			Min	8.94	
		Mean	21.91			Mean	17.38	
		Median	24.72			Median	17.68	
		Range	45.53			Range	21.21	
		Range/3	15.18			Range/3	7.07	
		Low	24.35			Low	16.01	
		Medium	39.53			Medium	23.08	
		High	54.71			High	30.15	

Table F.3. Full prioritized list of Potential SEC-stressor interactions

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty Grouping
Aphrocallistes vastus	Oil spill	Oil/contaminants	136.96	High	41.32	52.19	46.76	High
Rhabdocalyptus dawsoni	Oil spill	Oil/contaminants	135.83	High	42.37	51.89	47.13	High
Sponge gardens	Oil spill	Oil/contaminants	134.28	High	41.80	49.95	45.88	High
Farrea occa	Oil spill	Oil/contaminants	128.31	High	38.70	46.85	42.78	High
Bocaccio rockfish	Oil spill	Oil/contaminants	118.54	High	35.01	41.06	38.03	High
Heterochone calyx	Oil spill	Oil/contaminants	98.27	High	36.06	46.59	41.33	High
Glass sponge skeleton matrix	Oil spill	Oil/contaminants	98.06	High	35.35	46.82	41.08	High
Munida quadrispina	Oil spill	Oil/contaminants	72.07	Moderate	30.70	40.88	35.79	High
Glass sponge skeleton matrix	Grounding	Introduction of aquatic invasive species	22.20	Low	18.33	25.66	22.00	Moderate
Heterochone calyx	Grounding	Introduction of aquatic invasive species	21.94	Low	18.24	25.59	21.92	Moderate
Sponge gardens	Grounding	Introduction of aquatic invasive species	21.94	Low	18.14	24.75	21.44	Moderate
Aphrocallistes vastus	Grounding	Introduction of aquatic invasive species	21.83	Low	17.82	24.99	21.40	Moderate
Rhabdocalyptus dawsoni	Grounding	Introduction of aquatic invasive species	21.68	Low	18.15	25.30	21.73	Moderate
Farrea occa	Grounding	Introduction of aquatic invasive species	20.66	Low	17.20	23.87	20.54	Low
Sponge gardens	Bottom trawl	Introduction of aquatic invasive species	19.29	Low	9.98	14.02	12.00	Low
Heterochone calyx	Bottom trawl	Introduction of aquatic invasive species	19.24	Low	9.89	15.04	12.47	Low
Bocaccio rockfish	Grounding	Introduction of aquatic invasive species	19.20	Low	18.11	24.68	21.40	Moderate
Glass sponge skeleton matrix	Bottom trawl	Introduction of aquatic invasive species	19.19	Low	10.06	14.07	12.06	Low
Aphrocallistes vastus	Bottom trawl	Introduction of aquatic invasive species	19.12	Low	10.05	14.66	12.35	Low
Aphrocallistes vastus	Discharge	Entrapment/ entanglement	19.01	Low	15.63	21.84	18.74	Low

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty Grouping
Heterochone calyx	Discharge	Entrapment/ entanglement	18.92	Low	15.63	21.86	18.74	Low
Rhabdocalyptus dawsoni	Bottom trawl	Introduction of aquatic invasive species	18.90	Low	10.10	14.13	12.11	Low
Glass sponge skeleton matrix	Discharge	Entrapment/ entanglement	18.80	Low	15.97	22.22	19.09	Low
Rhabdocalyptus dawsoni	Discharge	Entrapment/ entanglement	18.62	Low	15.53	21.54	18.54	Low
Farrea occa	Bottom trawl	Introduction of aquatic invasive species	18.08	Low	9.39	13.23	11.31	Low
Farrea occa	Discharge	Entrapment/ entanglement	17.60	Low	14.23	20.55	17.39	Low
Munida quadrispina	Grounding	Introduction of aquatic invasive species	16.09	Low	15.18	22.23	18.71	Low
Heterochone calyx	Discharge	Introduction of aquatic invasive species	16.00	Low	13.21	19.68	16.44	Low
Aphrocallistes vastus	Discharge	Introduction of aquatic invasive species	15.96	Low	13.37	19.55	16.46	Low
Sponge gardens	Discharge	Introduction of aquatic invasive species	15.86	Low	13.14	19.51	16.33	Low
Glass sponge skeleton matrix	Discharge	Introduction of aquatic invasive species	15.79	Low	12.92	20.77	16.84	Low
Rhabdocalyptus dawsoni	Discharge	Introduction of aquatic invasive species	15.53	Low	12.98	20.15	16.56	Low
Farrea occa	Discharge	Introduction of aquatic invasive species	14.71	Low	12.11	18.66	15.38	Low
Heterochone calyx	Long line traps	Introduction of aquatic invasive species	10.70	Low	8.77	12.67	10.72	Low
Aphrocallistes vastus	Long line traps	Introduction of aquatic invasive species	10.66	Low	8.81	12.52	10.67	Low
Rhabdocalyptus dawsoni	Long line traps	Introduction of aquatic invasive species	10.52	Low	8.61	12.36	10.49	Low
Glass sponge skeleton matrix	Long line traps	Introduction of aquatic invasive species	10.51	Low	8.66	12.80	10.73	Low
Heterochone calyx	Submersible operations	Introduction of aquatic invasive species	10.51	Low	8.65	11.99	10.32	Low

SEC	Activity	Stressor	Risk Score	Risk Grouping	10% Q	90% Q	Average Uncertainty	Uncertainty Grouping
Sponge gardens	Submersible operations	Introduction of aquatic invasive species	10.34	Low	8.46	11.92	10.19	Low
Aphrocallistes vastus	Submersible operations	Introduction of aquatic invasive species	10.33	Low	8.49	11.65	10.07	Low
Glass sponge skeleton matrix	Submersible operations	Introduction of aquatic invasive species	10.33	Low	8.45	11.65	10.05	Low
Rhabdocalyptus dawsoni	Submersible operations	Introduction of aquatic invasive species	10.13	Low	8.60	11.70	10.15	Low
Farrea occa	Long line traps	Introduction of aquatic invasive species	9.80	Low	8.24	11.70	9.97	Low
Farrea occa	Submersible operations	Introduction of aquatic invasive species	9.67	Low	8.05	11.24	9.64	Low
Munida quadrispina	Long line traps	Introduction of aquatic invasive species	7.83	Low	6.42	9.50	7.96	Low
		Max	136.96			Max	47.13	
		Min	7.83			Min	7.96	
		Mean	33.55			Mean	19.82	
		Median	18.80			Median	16.56	
		Range	129.13			Range	39.18	
		Range/3	43.04			Range/3	13.06	
		Low	50.88			Low	21.01	
		Medium	93.92			Medium	34.07	
		High	136.96			High	47.13	

APPENDIX G: SEC-STRESSOR INTERACTION INDICATORS AND MEASURABLE COMPONENTS

Table G.1. Current snapshot SEC-stressor interaction indicators and measurable components

Stressor		SEC Grouping	SEC	Key parameter	SEC-stressor interaction indicator	Measureable component	Data collection
Midwater trawl	Removal of biological material	Bocaccio Rockfish	Bocaccio Rockfish	Both	Abundance/population density; biomass of removed organisms	Count/size-frequency distribution	Visual survey; Stock assessment techniques; Catch data
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx*	Both	Abundance (areal extent) of habitat removal scar; community structure; biomass of removed sponges (by-catch data)	Size of the scar (m^2); change in areal extent of the species; biomass of removed sponges	By-catch data; visual survey; some baseline information required.
			Farrea occa	Both			
			Aphrocallistes vastus	Both			
			Rhabdocalyptus dawsoni	Both			
		Physical habitat	Glass sponge skeleton matrix (and material contained within)	Both	Abundance (areal extent) of habitat removal scar; biomass of removed material/type (by-catch data)	Size of the scar (m^2); biomass of removed sponge skeleton	By-catch data; visual survey; some baseline information required.
		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Both	Abundance (areal extent) of habitat removal scar; biomass of removed sponges (by-catch data)	Size of the scar (m^2); biomass of removed sponges	By-catch data; visual survey; some baseline information required.
	Strikes	Bocaccio Rockfish	Bocaccio Rockfish	Both	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further.	Number of incidents where rockfish are struck per trawl	Trawl video logs. Not recommended at this time. The cost of effort will not provide definitive, valuable information on this interaction
	Substrate disturbance (resuspension)	Reef building glass	*Heterochone calyx*	Both	Abundance (relative) of colonies showing	Proportion of sampled (visual; %) colonies in a set area	Visual surveys. Baseline data preferable.
			Farrea occa	Both			

	Stressor	SEC Grouping	SEC	Key parameter	SEC-stressor interaction indicator	Measureable component	Data collection
		sponges and Rosselid/ boot sponge	*Aphrocallistes vastus*	Both	visible signs of smothering	showing signs of smothering	
Midwater trawl			*Rhabdocalyptus dawsoni*	Both			
		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Both	Abundance (areal extent) of habitat showing signs of smothering/stress; community structure	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering.	Visual surveys. Baseline data preferable.
		Physical habitat	Glass sponge skeleton matrix (and material contained within)	Both	Abundance (areal extent) of habitat showing signs of smothering/stress	Change in abundance/proportion (%) of the habitat showing signs of smothering. Could include associated biota.	Visual surveys. Baseline data preferable.
	Substrate disturbance (crushing)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Both	Abundance (areal extent) of habitat showing signs of crushing	Proportion of sampled (visual; %) habitat in a set area showing signs of crushing	Visual survey; some baseline information required.
		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Both	Abundance (areal extent) of habitat showing signs of crushing; community structure	Proportion of sampled (visual; %) colonies in a set area showing signs of crushing	Visual survey; some baseline information required.
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx*	Both	Abundance (relative) of colonies showing visible signs of crushing	Proportion of sampled (visual; %) colonies in a set area showing signs of crushing	Visual survey; some baseline information required.
			Farrea occa	Both			
			Aphrocallistes vastus	Both			
			Rhabdocalyptus dawsoni	Both			

Stressor		SEC Grouping	SEC	Key parameter	SEC-stressor interaction indicator	Measureable component	Data collection
Bottom	Substrate disturbance (resuspension)	Physical habitat	Glass sponge skeleton matrix (and material contained within)	Condition	Abundance (areal extent/proportion) of habitat showing signs of smothering	Change in abundance/proportion (%) of the habitat showing signs of smothering.	Visual surveys. Baseline data preferable.
Bottom trawl		Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Condition	Abundance (areal extent) of habitat showing signs of smothering/stress	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering. Could include associated biota.	Visual surveys. Baseline data preferable.
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx*	Condition	Abundance of colonies showing signs of smothering (health and visible smothering)	Proportion of sampled (visual; %) colonies in a set area showing signs of smothering	Visual surveys. Baseline data preferable.
			Aphrocallistes vastus	Condition			
			Farrea occa	Condition			
			Rhabdocalyptus dawsoni	Condition			
		Bocaccio Rockfish	Bocaccio Rockfish	Condition	Change in condition/ sub-lethal effects of smothering on Bocaccio Rockfish as a proportion of the population at the reefs	Condition factor, k (e.g., weight/length, age, stomach contents, presence of disease or invasive species, parasitic load).	Visual survey; Stock assessment techniques; Catch data. Baseline data preferable.
		Squat Lobster	*Munida quadrispina*	Condition	Change in condition/ sub-lethal effects of smothering on *M. quadrispina* as a proportion of the population at the reefs	Visible injury to organism or behavioural indicators (e.g. feeding behaviour, reflex actions). Assessment of male versus female/juvenile (indicating recruitment)	Commonly used metric for other crustaceans; Comparable across ecosystems; Quantitative and repeatable using visual surveys; Previously applied to Squat Lobsters

Stressor		SEC Grouping	SEC	Key parameter	SEC-stressor interaction indicator	Measureable component	Data collection
							(Matabos et al. 2012)
Discharge	Oil/ Contaminants	Biotic habitat	Sponge gardens (non-reef building glass sponges and demosponges)	Condition	Abundance (areal extent/proportion) of habitat showing visible signs of reduced condition or smothering; species richness and diversity of organisms associated with the habitat	Proportion of sampled population (%) impacted. Tissue loss, covering by brown flocculent material (floc),	Visual surveys. Baseline data preferable. Some targeted sampling may be necessary. Needs to be combined with independent SEC and stressor indicators to link oil with SEC. Health of associated reef biota may help to inform indicator.
		Physical habitat	Glass sponge skeleton matrix (and material contained within)	Condition	Abundance (areal extent/proportion) of habitat smothered by oils; persistence of oils on habitat	Change in abundance/proportion (%) of the habitat showing signs of smothering.	Visual surveys. Baseline data preferable.
		Reef building glass sponges and Rosselid/ boot sponge	*Heterochone calyx*	Both	Abundance of colonies with visible damage/ dead (proportion); change in condition/ sub-lethal effects	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering. Could include associated biota.	Visual surveys. Baseline data preferable.
			Aphrocallistes vastus	Both			
			Rhabdocalyptus dawsoni	Both			
			Farrea occa	Both			

Table G.2. Potential SEC-stressor interaction indicators

Stressor		SEC Grouping	SEC	Key parameter	SEC-stressor interaction indicator	Measureable Component	Data collection
Oil spill	Oil/ contaminants	Reef building glass sponges and Rosselid/ boot sponge	*Aphrocallistes vastus*	Both	Abundance of colonies with visible damage/dead; change in condition/ sub-lethal effects; change in genetic diversity	Proportion of sampled population (%) impacted. Tissue loss, covering by brown flocculent material (floc),	Visual surveys. Baseline data preferable. Some targeted sampling may be necessary. Needs to be combined with independent SEC and stressor indicators to link oil with SEC. Health of associated reef biota may help to inform indicator.
			Rhabdocalyptus dawsoni	Both			
			Farrea occa	Both			
			Heterochone calyx	Both			
		Biogenic habitat	Sponge gardens	Both	Abundance, species richness/ presence of disease	Areal coverage of habitats; Diversity measures (alpha and beta diversity).	Visual surveys. Baseline data preferable. Visual surveys, stock assessment techniques, and catch data will help inform this.
		Bocaccio Rockfish	Bocaccio Rockfish	Both	Abundance; population density; size range; change in condition/sub-lethal effects; genetic diversity and structure	Size-frequency distribution; Age/size structure, count per area; Presence of disease, change in age/size structure	Requires baselines of populations; Visual surveys (ROV), Stock assessment techniques, and catch data will help inform this
		Physical habitat	Glass sponge skeleton matrix	Both	Abundance of the habitat showing visible signs of smothering by oil.	Proportion of habitat showing visible signs of smothering by oil; associated biota could also inform this interaction	Visual surveys. Baseline data preferable.
		Squat Lobster	*Munida quadrispina*	Both	Abundance of organisms displaying symptoms of stress; sub-lethal effects	Proportion of Squat Lobsters within a designated area showing visible signs of stress; Abundance of Squat Lobsters within a set area.	Population size indicator (abundance) requires baselines of populations; visible surveys and selective extractive sampling would inform for condition indicator.

APPENDIX H: SEC-STRESSOR INTERACTION INDICATORS, MEASURABLE COMPONENTS, INTERACTION SUMMARY, DATA STATUS AND COLLECTION METHODS

Table H.1. SEC-stressor interaction indicators for Reef building glass sponges and Rosselid/boot sponge SECs: Heterochone calyx, Aphrocallistes vastus, Farrea occa, and Rhabdocalyptus dawsoni. Interaction justifications summarised from Hannah et al. 2019

Midwater trawl→ Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	% of dead reef building sponges and boot sponges showing signs of smothering.	Midwater trawls can touch bottom (Enticknap 2002; Donaldson et al. 2010) where they can temporarily resuspend bottom sediment (Leys 2013) and impact the sponge species in the reef (Boutiller et al. 2013). Acute mortality could occur where sponges become covered up and smothered by a large amount of sediment. Exposure scores indicates variable estimates of bottom interaction in this fishery that occurs 1.5% of the year.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration. Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of sediment suspended and future changes in frequency (level of impact).	Visual surveys; Requires some baseline information; NB: Due to the lack of data, unpredictable nature of the stressor, and the difficulty in determining the source/cause of the sediment this indicator should be used in conjunction with stressor indicators and with caution.
Population Condition	Colony health	% of reef building sponges within a reef showing visible signs of stress/disease/ smothering (NB should be used in combination with other indicators and monitoring).	Impact not necessarily localized. Trawling gear that makes contact with benthic sediments can temporarily resuspend bottom sediment (Leys 2013) and impact the sponge species in the reef (Boutiller et al. 2013). Acute mortality could occur where sponges become covered up and smothered by a large amount of sediment.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration.	Visual surveys and sampling events Requires some baseline information Will be difficult to tie accidental impact with midwater trawl

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
				Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of sediment suspended and future changes in frequency (level of impact).	

Midwater trawl→ Removal of biological material

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance (areal extent) of habitat removal scar; biomass of removed sponges (by-catch data)	Size of the scar (m2); change in areal extent of the species; biomass of removed sponges	Midwater trawls do touch bottom and when they do can damage fragile ecosystems within the path of a single bottom trawl, 1-8% of corals and 20-70% of sponges can be removed (DFO 2010A). If mid-water trawling is allowed again in the VAMZ (above the CPZ), bottom interaction would be expected to result in localised removal and mortality of this sponge SEC in the CPZ. Even infrequent bottom interactions within the reefs could cause a significant amount of removal and mortality to sponges.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration. Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of sediment suspended and future changes in frequency (level of impact).	By-catch data; visual survey; some baseline information required.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population Condition	Community structure	Diversity of associated species	Potential chronic effects on the remaining sponge population from removal of sponges from the population may result from changes in local water flow around sponges, loss of structural support, potential opening for disease, loss of larval settlement surfaces.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration. Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of sediment suspended and future changes in frequency (level of impact).	By-catch data; visual survey; some baseline information required.

Midwater trawl→ Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance (relative) of colonies showing visible signs of crushing	Proportion of sampled (visual; %) colonies in a set area showing signs of crushing	Midwater trawls can touch bottom (Donaldson, 2010) and crush sponges, even occasional contact with the sea floor can damage fragile ecosystems such as those containing corals and sponges (Donaldson et al, 2010). Within the path of a single bottom trawl, 1-8% of corals and 20-70% of sponges can be removed, with damage to much of those that remain (e.g. crushing, knocking over, severed parts) (DF0 2010A).	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration. Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of	Visual survey; some baseline information required.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
				sediment suspended and future changes in frequency (level of impact).	
Population Condition	Colony health	% of reef building sponges within a reef showing visible signs of stress/disease/ crushing (NB should be used in combination with other indicators and monitoring).	Midwater trawls can touch bottom where they can crush sponges. Even infrequent interactions with the sponge reefs could have chronic long term effects on this fragile, slow to recover sponge reef SEC.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Data for the Bering Sea Pollock fishery found that footropes of midwater trawls often contact the seafloor for up to 85% of tow duration. Uncertainty is due to lack of knowledge on the degree of bottom interaction of this fishery in this area, amount of sediment suspended and future changes in frequency (level of impact).	Visual survey; some baseline information required.

Bottom trawl→ Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Abundance of colonies showing signs of smothering (health and visible smothering)	% of the population showing visible signs of stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	Influxes of sediment drifting into the sponge area from areas trawled on the edges of the reef area could have chronic population effects as a result of reduced sponge feeding and clogging. Bottom trawl, close to or even far away (depending on the bottom currents) from the sponge reefs can disturb the reefs natural equilibrium with sediment having negative effects on the reef growth	Reefs have been mapped and video data exists. Data exists on bottom trawl areas and frequency (activity indicators).	Visual surveys and sampling events Requires some baseline information

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			(Leys et al. 2011). Too much sediment can also bury the sponges inhibiting new settlement (Leys et al. 2011). In demosponges, long term smothering by sediment causes increased respiration, decreases in oxygen consumption, and reduced reproductive ability and body weight with death occurring in 3-6 months (Leys 2013). In the glass sponge (Hexactinellid) *A. vastus*, no experiments have tested long-term effects of smothering by sediment but continued presence of >15-35 mg/L of sediment (grain size <25µm) causes complete and continued arrest of glass sponge pumping and filtration. Longer than 40 minutes exposure to 15-35 mg/L sediment causes clogging of sponge feeding tissues. Clogging by sediment reduces filtration in the glass reef sponge by 50-80% of normal levels (Leys 2013). Reduced feeding during maximum ambient current would deprive the reef sponges of 2/3 of their daily food intake, compromising growth and future reproductive ability (Leys 2013). If pumping stops for longer than 3 hours by ongoing sediment input, the sponge is in danger of starving and/or dying due to lack of nutrients and/or oxygen (Leys et al. 2011). Another study shows lower sponge recruitment on panels exposed to sediment deposition (Maughan 2001).		

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			When considering the potential proportion of the population that could suffer chronic effects from sediment resuspension, it is considered that sediment is only transported into the sponge area from the AMZ where trawling may be allowed under MPA regulations. Given that there are three separate reef areas that comprise the sponge reef MPA, a worst case scenario of trawling close to the CPZ the % chronic change would be expected to be low. For this stressor-activity interaction it would be important have knowledge on the population density of sponges around the reef edges as they may be actively expanding areas, given the way growth occurs (K. Conway pers. comm. in Hannah et al. 2019).		

Discharge→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/ dead (proportion)	Areal coverage of habitats, change in abundance/ proportion (%) of the habitat showing signs of stress or smothering. Could include associated biota.	Sessile filter-feeders are sensitive to both biotic and abiotic components of their environment, the population of this sponge SEC is expected to be sensitive and impacted by environmental stressors such as oil and contaminants (Zahn et al. 1981). Polycyclic aromatic hydrocarbons (PAHs), even in low concentrations, can have a deleterious effect on marine biota and sponges can accumulate contaminants such as	Some data available on discharge within the region, but limited. Two studies suggest there are only low levels in the area: sediment sampling in the Hecate Strait indicates low hydrocarbon concentrations (Yunker at al. 2014), and aerial surveys indicate low levels of chronic oily discharges by vessels in sponge reef areas (Bertazzon	The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended. Visual surveys. Needs to be combined with independent SEC and stressor

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			radionuclides, heavy metals and PCBs (Batista et al. 2013). Chronic releases of oil and contaminants by vessels not expected to cause immediate mortality to the population of this sponge species. It is speculated in Yunker et al. (2014) that the low hydrocarbons may mean than biota in these areas would be more sensitive to an oil spill.	et al. 2014). Requires baselines to measure against.	indicators to link oil with SEC.
Population condition	Abundance of change in population condition/ sub-lethal effects	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering. Could include associated biota.	Though there are no studies on the effects of oil /contaminants on glass sponges, long term chronic effects could be possible as benthic sessile filter feeding sponges are susceptible to oil pollution (Zahn et al. 1981). Examples of sub-lethal effects from exposure to petroleum hydrocarbons include: impairment of feeding mechanisms, growth rates, development rates, energetics, reproductive output, recruitment rates and increased susceptibility to disease (Capuzzo 1987). Unpublished research indicates adverse effects on demosponge tissue and genetic changes when exposed to traces of oil and dispersants (Dr. Jose Lopez pers. comm. In Hannah et al. 2019). Contaminants may act as irritants, triggering contraction and feeding cessation in sponges (e.g. the chemical stimulants glycine and glutamate) (Leys 2013). As sponges filter large volumes of water, they can have high uptake or accumulate pollutants such as radionuclides, heavy metals and PCBs (Batista et al.	Some data available on discharge within the region, but limited. Two studies suggest there are only low levels in the area: sediment sampling in the Hecate Strait indicates low hydrocarbon concentrations (Yunker at al., 2014), and aerial surveys indicate low levels of chronic oily discharges by vessels in sponge reef areas (Bertazzon et al. 2014). Requires baselines to measure against.	The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended. Visual surveys. Needs to be combined with independent SEC and stressor indicators to link oil with SEC.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			2013) and metals (Negri et. al. 2006). One effect of exposure to toxins may be an increased rate of abnormal and deformed spicules (Konnecker 2002). However, studies indicate at present low levels of hydrocarbons and oily discharges in the area (sediment sampling in the Hecate Strait (Yunker at al. 2014), and aerial surveys of oily discharges (Bertazzon et al. 2014), so it is expected that chronic oil/contaminant discharges would affect <10% of the population of this sponge SEC.		

Oil spill→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/dead	Proportion of sampled population (%) impacted. Tissue loss, covering by brown flocculent material (floc),	A catastrophic oil spill from a vessel accident could cause immediate mortality to a large proportion of the sponge population if it was able to reach the benthos from the surface. The acute effects of oil interacting with this species would likely be a result of smothering or relatively rapid toxic impact (Shigenaka 2011). Biological responses may range from immediate mortalities due to smothering and the acutely toxic effects of light petroleum hydrocarbon fractions to long-term and sub-lethal alterations in physiology, fecundity and community structure due to chronic but low level oil pollution (Samiullah 1985). Lethal and sub-	There are numerous studies on the negative impacts of oil on a range of marine organisms, though very few on sponges. No known instances of oil spill in vicinity of the HS/QCS MPA. Requires baselines to measure against.	The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended Visual surveys Needs to be combined with independent SEC and stressor indicators to link oil with SEC.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			lethal effects include individual mortality, alterations in population recruitment, growth, and reproduction, as well as changes in community structure. There are numerous studies on the negative impacts of oil on a range of marine organisms, though very few on sponges. Invertebrate communities respond to severe chronic oil pollution and/or acute catastrophic oil pollution in much the same way, initially with massive mortality (Suchanek 1993). Oil can alter the metabolic and feeding rate of benthic organisms (Elmgren et al. 1983; Gómez Gesteira and Dauvin 2000; US Fish & Wildlife Service 2004). Contact with oil hydrocarbons can damage respiratory organ tissues (e.g., filtration organs, gills) leading to increased mortality (Patin 1999). Some oil hydrocarbons can induce mutagenic (genetic damage) and carcinogenic effects in marine organisms, also leading to increased mortality (Patin 1999).		

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Abundance of organisms displaying symptoms of stress	% cover of stressed area as a proportion of overall abundance (extent). Extractive sampling and analysis. Diversity measures (alpha and beta diversity); change in genetic diversity	An oil spill could have severe long term fitness effects on this sponge species. Some of these are described under the acute change section. Sub-lethal effects include individual mortality, alterations in population recruitment, growth, and reproduction, as well as changes in community structure. There are numerous studies on the negative impacts of oil on a range of marine organisms, though very few on sponges. Oil can alter the metabolic and feeding rate of benthic organisms (Elmgren et al. 1983; Gómez Gesteira and Dauvin, 2000; US Fish & Wildlife Service, 2004). Sub-lethal impacts of oil on invertebrates are include physiological, carcinogenic and cytogenetic effects, at the population level there are changes in abundance, age structure, population genetic structure, reproduction and reduced recruitment potential (Suchanek 1993). The bacterial food source of this sponge species could be affected as bacterial chemoreception can be inhibited at low concentrations of exposure to petroleum hydrocarbons (Zahn et al. 1981). Sponges likely accumulate hydrocarbons and concentrations in one sponge species tested (*Tethya lyncurium*) were 40 times of the external concentration (Zahn et al. 1981).		Visual surveys. Baseline data preferable. Some targeted sampling may be necessary. Needs to be combined with independent SEC and stressor indicators to link oil with SEC. Health of associated reef biota may help to inform indicator.

Table H.2. SEC-stressor interaction indicators for Bocaccio rockfish. Interaction justifications summarised from Hannah et al. (2019)

Midwater trawl→ Removal of biological material

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance/ population density	Count/size-frequency distribution	Mortality of rockfish which are caught and released is very high due to barotrauma (expansion of the swim bladder).	DFO catch data (2007-2013) indicates that Bocaccio Rockfish were regularly caught in the midwater trawl Pacific Hake fishery, both in the AMZ and directly above the reefs (in the VAMZ); Catch data is available; Lack of data on the extent and nature of the Bocaccio Rockfish population in the sponge reef area (and therefore difficult to estimate population)	Visual survey; Stock assessment techniques; Catch data
Population condition	Biomass	Biomass of removed organisms.	In the Puget Sound, fishing practices were a major factor affecting the abundance and size structure of rockfish populations and Bocaccio Rockfish populations in that area were overfished to the point at which this species was not observed at all between 2001-2008 (NMFS 2008). DFO catch data (2007-2013) indicates that Bocaccio Rockfish are regularly caught in the midwater trawl Pacific Hake fishery in the sponge reef area, both in the Adaptive Management Zone (AMZ) and directly above the reefs (in the VAMZ) with an average of 15.3 midwater trawls/year in the VAMZ and AMZ from 2007-2013. Bocaccio was regularly recorded as part of the catch of this fishery from 2007-2013.	Lack of data on the composition of the sponge reef associated Bocaccio Rockfish population makes estimations of population impacts challenging, also there is a lack of knowledge on future changes in fishing frequency. Little is known on the extent or nature of the population of this species on the sponge reefs	Visual survey; Stock assessment techniques; Catch data

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			This regular removal of Bocaccio Rockfish from the population from midwater trawling over the around the sponge reefs has potential to have sub-lethal effects on the Bocaccio Rockfish population. As a threatened species, it may be that the population is small, in this case removals could have significant impacts on the structure and health of the remaining population, in these long living species, population recovery requires a long time once populations are at a low level. Bocaccio Rockfish have variable, episodic recruitment, with many years of failed recruitment being the norm (Tolimieri and Levin 2005) so a diverse age structure is important.		

Midwater trawl→ Strikes

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further and is explored here.	Number of incidents where rockfish are struck per trawl	Bocaccio Rockfish not captured could be hit by the midwater trawl gear during operation and suffer mortality.	Very little information is available on the current strike rate or impacts on Bocaccio Rockfish and fish in general. Some data may be available from cameras on trawl gear.	Not recommended at this time. The cost of effort will not provide definitive, valuable information on this interaction.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	No existing indicator will appropriately measure this stressor. The incidents of gear striking mobile species could be examined further.	Number of incidents where rockfish are struck per trawl	Bocaccio Rockfish not captured could be hit by the midwater trawl gear during operation and suffer sub-lethal effects, primarily injuries.	Very little information is available on the current strike rate or impacts on Bocaccio Rockfish and fish in general. Some data may be available from cameras on trawl gear.	Not recommended at this time. The cost of effort will not provide definitive, valuable information on this interaction

Bottom trawl→ Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Change in condition/ sub-lethal effects of smothering on Bocaccio Rockfish as a proportion of the population at the reefs	Condition factor, k (e.g., weight/length, age, stomach contents, presence of disease or invasive species, parasitic load).	Elevated levels of sediment (over background levels) may harm fish through sub-lethal effects, compromising well-being and survival (Birtwell 1999). Recent fishing data indicates approx. 11 bottom trawls per year in the Adaptive Management Zone (LY), though trawl frequency can change, so sediment suspended from bottom trawling outside the reef area and moving into the sponge reef habitat is expected to occur with relatively low frequency.	Data exists on bottom trawling areas and frequency (activity indicators). No documented impacts of sediment on Bocaccio Rockfish at HS/QCS MPA.	Visual survey; Stock assessment techniques; Catch data. Baseline data preferable.

Oil spill→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Size-frequency distribution	Oil has the potential to impact spawning success, as eggs and larvae of many fish species, including salmon, are highly sensitive to oil chemicals. Invertebrates likewise may suffer from smothering. Both crude oil and weathered oil byproducts are highly toxic to fish eggs and larvae (Incardona et al. 2004). Oil contamination may cause increased mortality of eggs and larvae even at low concentrations (Carls 1987; McGurk and Brown 1996). Exposure to oil and oil byproducts also leads to a range of sub lethal effects on fish eggs and larvae, including premature hatching (Carls et al. 1999), morphological malformations (Hose et al. 1996; Norcross et al., 1996) and genetic damage (Norcross et al. 1996). Mortality rates on malformed, premature or slow-growing larvae are likely to be extremely high (Carls et al. 1999; Rice et al. 1993). Demersal rockfish are the only fish species that have been found dead in significant numbers after a major oil spill, but the link between oil exposure and effect has not been well established. (Marty et al. 2003).	Requires baselines of information. Catch data may help inform this	Requires baselines of populations; Visual surveys (submersibles), Stock assessment techniques, and catch data will help inform this.
	Population density	Age/size structure, count per area	Oil can persist in habitats long after a spill has occurred, especially in areas sheltered from weathering (Elmgren et al. 1983). Exposure to oil and associated contaminants can have a	No known instances of oil spill in vicinity of the EHV MPA. Requires baselines to measure against.	Requires baselines of populations; Visual surveys (ROV), Stock assessment

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			range of chronic effects affecting feeding, migration, reproduction, and causing increased carcinogenesis (Zahn 1981). There can also be a number of sub-lethal effects on fish eggs and larvae, such as premature hatching (Carls et al. 1999); malformations (Hose et al. 1996; Norcross et al., 1996); increased mortality (Carls 1987; McGurk and Brown 1996); and genetic damage (Norcross et al. 1996). Low levels of dissolved oil hydrocarbons may also slow larval growth rates, and affect swimming and feeding behaviors (Tilseth et al. 1984). Mortality rates of malformed, premature or slow-growing larvae are likely to be high (Carls et al. 1999; Rice et al. 1993).		techniques, and catch data will help inform this
Population condition	Change in condition/ sub-lethal effects	Presence of disease, change in age/size structure	Oil can persist in habitats long after a spill has occurred, especially in areas sheltered from weathering (Elmgren et al. 1983). Exposure to oil and associated contaminants can have a range of chronic effects affecting feeding, migration, reproduction, and causing increased carcinogenesis (Zahn 1981). There can also be a number of sub-lethal effects on fish eggs and larvae, such as premature hatching (Carls et al. 1999); malformations (Hose et al. 1996; Norcross et al., 1996); increased mortality (Carls 1987; McGurk and Brown 1996); and genetic damage (Norcross et al. 1996). Low levels of	No known instances of oil spill in vicinity of the EHV MPA. Requires baselines to measure against.	Requires baselines of populations.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			dissolved oil hydrocarbons may also slow larval growth rates, and affect swimming and feeding behaviors (Tilseth et al. 1984). Mortality rates of malformed, premature or slow-growing larvae are likely to be high (Carls et al. 1999; Rice et al. 1993).		

Table H.3. SEC-stressor interaction indicators for Sponge gardens (non-reef building glass sponges and demosponges). Interaction justifications summarised from Hannah et al. (2019)

Midwater trawl → Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Change in abundance/ areal extent	Proportion (%) of the habitat/m^2	Suspended sediment may smother organisms or replace once colonized hard substrata with soft particles. Sediment could result in loss in area of this habitat through burial.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	Visual surveys Requires some baseline information Will need to be linked to the stressor indicator and timing of the activity and changes to the environment.
Habitat condition	Abundance (areal extent) of habitat showing signs of smothering/stress; community structure	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering. (NB should be used in combination with other indicators and monitoring.)	Sediment could result in impacts to condition and loss of productive capacity of the sponge garden habitat through surface smothering.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	Visual surveys and sampling events. Requires some baseline information

Midwater trawl → Removal of biological material

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance (areal extent) of habitat removal scar; biomass of removed sponges (by-catch data)	Size of the scar (m^2); biomass of removed skeleton	Parts of the sponge garden habitat may be removed when and if mid-water trawls touch bottom. A study has indicated that within the path of a single bottom trawl 20-70% of sponges can be removed (DFO 2010A). Even infrequent interactions with the seabed could cause a significant amount of removal and mortality to sponges.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	By-catch data; visual survey; some baseline information required.
Habitat condition	Abundance (areal extent/ proportion) of habitat showing visible signs of reduced condition or crushing; species richness and diversity of organisms associated with the habitat	Proportion of sampled population (%) impacted. Tissue loss	Parts of the sponge garden habitat may be removed when /if mid-water trawls touch bottom. Even infrequent interactions with the seabed could cause a significant amount of sponge removal as a study indicates a single bottom trawl can remove 20-70% of sponges and damage much of what is left (DF0, 2010). The removal of biological material from the habitat could impact structural integrity, condition and productive capacity of the remaining habitat.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	By-catch data; visual survey; some baseline information required.

Midwater trawl → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance (areal extent) of habitat showing signs of crushing	Proportion of sampled (visual; %) colonies in a set area showing signs of crushing	This fishery has been permitted above the CPZ (in the VAMZ) before MPA designation and may be permitted again. The fishery type can touch bottom potentially crushing and reducing the area of sponge garden habitat. Even occasional contact with the sea floor can damage the fragile sponges, studies indicate 20-70% of sponges can be removed within the path of a bottom trawl and most of those that remain are damaged (DFO 2010A).	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	Visual survey; some baseline information required.
Habitat condition	Abundance (areal extent/ proportion) of habitat showing visible signs of reduced condition or crushing; species richness and diversity of organisms associated with the habitat	Proportion of sampled population (%) impacted. Tissue loss	Even infrequent interactions with the sponge reefs could have chronic effects on the fragile sponge garden habitat impacting structural integrity, condition and productive capacity.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video data exists.	Visual survey; some baseline information required.

Bottom trawl → Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat condition	Abundance (areal extent) of habitat showing signs of smothering/ stress	Change in abundance/proportion (%) of the habitat showing signs of stress or smothering. Could include associated biota	Sediment settling on the sponge garden habitat could reduce the productive area of the habitat through smothering.	Sponge reefs have been mapped and video data exists. Some baseline information available.	Visual surveys and sampling events Requires some baseline information.

Discharge→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat condition	Abundance (areal extent/ proportion) of habitat showing visible signs of reduced condition or smothering; species richness and diversity of organisms associated with the habitat	Proportion of sampled population (%) impacted. Tissue loss, covering by brown flocculent material (floc)	This stressor would not impact the structural integrity of the sponge garden habitat but could affect condition and productive capacity through smothering/covering of the surface of the habitat or through contamination.	Lack of data on the impacts of oil to sponge habitats. Sponge reefs have been mapped and video data exists. Some baseline information available.	Visual surveys. Baseline data preferable. Some targeted sampling may be necessary. Needs to be combined with independent SEC and stressor indicators to link oil with SEC. Health of associated reef biota may help to inform indicator.

Oil spill→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Areal coverage of habitats	A catastrophic oil spill from a vessel accident could result in a large loss in area of the sponge garden habitat through smothering and contamination.	Lack of data on the impacts of oil to sponge habitats. Sponge reefs have been mapped and video data exists. Some baseline information available.	Requires baselines of populations. Needs to be combined with independent SEC and stressor indicators to link oil with SEC Visual surveys.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Species richness/ presence of disease/ stress	Diversity measures (alpha and beta diversity)	May impact one species within assemblage, and not others, having an indirect impact on SEC.	Some data available from literature. Lack of data on the impacts of oil to sponge habitats. Sponge reefs have been mapped and video data exists. Some baseline information available.	Requires baselines of populations. Needs to be combined with independent SEC and stressor indicators to link oil with SEC Visual surveys.

Table H.4. SEC-stressor interaction indicators for Glass sponge skeleton matrix (and material contained within). Interaction justifications summarised from Hannah et al. (2019)

Midwater trawl → Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance (areal extent)	Proportion (%) of of habitat showing signs of smothering/stress; community structure	This stressor could result in a loss in area of the sponge reef skeleton habitat through burial of the skeleton.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist. While currently not allowed within the bounds of the MPA, the location of the trawls when it does occur will be know.	Primarily video surveys. Baselines of information are required for this measurement.
Habitat condition	Signs of smothering	Proportion (%) of habitat showing visible signs of smothering or sediment resuspension. Associated biota may also inform this indicator.	Midwater trawls can touch bottom (Donaldson et al. 2010) where they can temporarily resuspend bottom sediment as in a bottom trawl (Leys 2013). Sediment could result in impacts to condition and loss of productive capacity of the sponge reef skeleton habitat through surface smothering or partial burial of the skeleton in the worst case. Though	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist.	Primarily video surveys. Baselines of information are required for this measurement.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			exposure indicates a low level of midwater trawls, there are significant unknowns regarding the proportion of time these trawls touch bottom.		

Midwater trawl → Removal of biological material

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance (areal extent) of habitat removal scar; biomass of removed material/type (by-catch data)	Size of the scar (m2); biomass of removed sponge skeleton	Parts of the glass sponge skeleton may be removed if mid-water trawls touch bottom. A study has indicated that within the path of a single bottom trawl 20-70% of sponges can be removed (DFO 2010A) and would be expected to also include removal of the sponge skeleton habitat resulting in a reduction in habitat area.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist.	By-catch data; visual survey; some baseline information required.
Habitat condition	Abundance (areal extent) of habitat showing signs of crushing/ removal	Change in abundance/proportion (%) of the habitat showing signs of crushing/ removal.	Parts of the glass sponge skeleton may be removed when mid-water trawls touch bottom. A study has indicated that within the path of a single bottom trawl 20-70% of sponges can be removed (DFO 2010A). Parts of the glass sponge skeleton may be removed when/if mid-water trawls touch bottom potentially reducing structural integrity, condition and productive capacity of this habitat of the remaining sponge reef skeleton habitat.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist.	By-catch data; visual survey; some baseline information required.

Midwater trawl → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance (areal extent) of habitat showing signs of crushing	Change in abundance/proportion (%) of the habitat showing signs of crushing.	Midwater trawls can touch bottom (Donaldson, 2010) and crush the skeleton habitat resulting in a loss of area. Even occasional contact with the sea floor could damage the fragile skeleton, and potentially result in an irreversible loss of habitat area. One study indicates 20-70% of sponges can be removed within the path of a bottom trawl and most of those that remain are damaged (DFO 2010A).	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist.	Visual survey; some baseline information required.
Habitat condition	Abundance (areal extent) of habitat showing signs of crushing	Change in abundance/proportion (%) of the habitat showing signs of crushing.	Even infrequent interactions with the sponge reefs could have chronic effects on the fragile skeleton habitat impacting structural integrity, condition and productive capacity.	There are no data on the impact of midwater trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al. 2008). Sponge reefs have been mapped and video surveys exist.	Visual survey; some baseline information required.

Bottom trawl → Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat condition	Abundance (areal extent/ proportion) of habitat showing signs of smothering	Change in abundance/proportion (%) of the habitat showing signs of smothering.	Sediment suspended from trawling on the edges of the reef area and entering the sponge reef area could result in impacts to condition and loss of productive capacity of the sponge reef skeleton habitat through surface smothering or partial burial of the skeleton in the worst case.	There is a lack of data on the amount of sediment that reaches the sponge reef area from bottom trawling. The impacts on the sponge skeleton is unknown, but assumed to reduce the functional capacity of this habitat.	Visual surveys. Baseline data preferable.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			This can reduce productive area which can reduce new sponge settlement, and sponge recruitment is lower on panels exposed to sediment deposition (Maughan 2001).		

Discharge→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat condition	Abundance (areal extent/proportion) of habitat smothered by oils; persistence of oils on habitat	Change in abundance/proportion (%) of the habitat showing signs of smothering.	This stressor could result in changes to condition and productive capacity due to smothering/covering of the skeleton surface or contamination of the sediment which infills the skeleton creating a soft sediment habitat.	No studies have examined impacts of oil to the sponge reef skeleton. Sponge reefs have been mapped and video surveys exist.	Visual surveys. Baseline data preferable.

Oil spill→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat size	Abundance of the habitat showing visible signs of smothering by oil.	Requires baselines for information – proportion of smothered habitat over time.	A catastrophic oil spill from a vessel accident could result in a large proportion of the sponge skeleton habitat losing productive capacity as a habitat (given oil was able to reach the benthos from the surface) through smothering by oil, both of the structure and of the sediments contained within.	Sponge reefs have been mapped and video surveys exist. No established baseline.	Visual surveys. Baseline data essential.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Habitat condition	Abundance of the habitat showing visible signs of smothering by oil.	Proportion of habitat showing visible signs of smothering by oil; associated biota could also inform this interaction	It is not known if contact with oil / contaminants can affect the structural integrity of the skeleton habitat through toxicity, but oil could potentially reduce the condition and productive capacity of the skeleton through smothering effects and the coating of the structure and sediments contained with oil.	Sponge reefs have been mapped and video surveys exist. No established baseline.	Visual surveys. Baseline data preferred.

Table H.5. SEC-stressor interaction indicators for Squat Lobster (Munida quadrispina). Interaction justifications summarised from Hannah et al. (2019)

Bottom trawl → Substrate disturbance (resuspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population conditions	Change in condition/ sub-lethal effects of smothering on *M. quadrispina* as a proportion of the population at the reefs	Visible injury to organism or behavioural indicators (e.g. feeding behaviour, reflex actions). Assessment of male versus female/juvenile (indicating recruitment)	Sediment can affect marine invertebrates through smothering, changes in behaviour, food limitation, reduced growth rates, recruitment and fertilization success, it can also affect early life stages by reducing larval survival and settlement and increasing abnormal larval development and mortality. However, studies on crabs indicate that they are frequently unaffected by increases in sedimentation and are able to move away from affected areas. Influxes of sediment drifting into the Squat Lobster habitat (sponge reef) from areas trawled on the edges of the reef area are expected to be relatively low if this fishery is re-permitted in the MPA. It	Population baselines of Squat Lobsters have not yet been established for the HS/QCS MPA. Some data could be extracted from existing video surveys.	Commonly used metric for other crustaceans; Comparable across ecosystems; Quantitative and repeatable using visual surveys; Previously applied to Squat Lobsters.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			is expected that sediment re-suspension (moving in from bottom trawling outside the area) has the potential to result in chronic effects to a low proportion of the Squat Lobster population.		

Oil spill→ Oil/Contaminants

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Count per unit area; Size-frequency distribution	A catastrophic oil spill from a vessel accident could cause immediate mortality to a large proportion of the Squat Lobster population if it spread to a large area of the benthos. Invertebrates respond to severe chronic oil pollution and/or acute catastrophic oil pollution in similar ways, initially with massive mortality (Suchanek 1993). The acute effects of oil interacting with this species would likely be a result of smothering or relatively rapid toxic impact (Shigenaka 2011). Lethal and sub-lethal effects include individual mortality, alterations in population recruitment, growth, and reproduction, as well as changes in community structure. Oil can alter the metabolic and feeding rate of benthic organisms (Elmgren et al. 1983; Gómez Gesteira and Dauvin 2000; US Fish	Population baselines of Squat Lobsters have not yet been established for the HS/QCS MPA. Some data could be extracted from existing video surveys. No recorded incidence of an oil spill within the MPA bounds.	Commonly used metric; Comparable across reef areas within the MPA; Quantitative and repeatable; Achievable by visual survey; Needs to be combined with independent SEC and stressor indicators to link oil with SEC.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			& Wildlife Service 2004). Contact with oil hydrocarbons can damage respiratory organ tissues (e.g., filtration organs, gills) leading to increased mortality and some oil hydrocarbons can induce mutagenic (genetic damage) and carcinogenic effects in marine organisms, also leading to increased mortality (Patin 1999).		
Population condition	Health/ condition	Visible injury to organism or behavioural indicators (e.g. feeding behaviour, reflex actions)	Sub-lethal impacts of oil on invertebrates include physiological, carcinogenic and cytogenetic effects. At the population level, there are changes in abundance, age structure, population genetic structure, reproduction and reduced recruitment potential (Suchanek 1993). Polycyclic aromatic hydrocarbons (PAHs) can result in: acute toxicity, carcinogenicity, mutagenicity, teratogenicity, and endocrine disrupting activity (Batista et al. 2013; Yamada et al. 2003). Crustaceans and marine invertebrates are known to accumulate (Zahn et al. 1981; Batista et al. 2013). For example, exposure of the kelp crab Pugettia to the water-soluble fraction of crude oil results in specific chemosensory induced brachycardia, affecting food searching abilities and suppresses	Population baselines of Squat Lobsters have not yet been established for the HS/QCS MPA. Some data could be extracted from existing video surveys. No recorded incidence of an oil spill within the MPA bounds.	Commonly used metric for Squat Lobsters and other crustaceans Comparable across ecosystems Quantitative and repeatable using visual surveys Needs to be combined with independent SEC and stressor indicators to link oil with SEC (will be difficult to specifically link the impacts of oil on this SEC without baseline monitoring and stressor-specific indicators).

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			chemoreception abilities (Case et al. 1987). Oil has been shown to affect reproduction and larval success in crustaceans (Suchanek 1993).		

APPENDIX REFERENCES

Andrews, K.S., Harvey, C.J., and Levin, P.S. 2013. Conceptual models and indicator selection process for Washington State's Marine Spatial Planning Process. Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service. NOAA. 120 p.

Batista, D., Tellini, K., Nudi, A.H., Massone, T.P., Scofield, A.D.L., and de LR Wagener, A. 2013. Marine sponges as bioindicators of oil and combustion derived PAH in coastal waters. Mar. Environ. Res., 92: 234-243.

Bertazzon, S., O'Hara, P.D., Barrett, O., and Serra-Sogas, N. 2014. Geospatial analysis of oil discharges observed by the National Aerial Surveillance Program in the Canadian Pacific Ocean. Appl. Geogr., 52: 78-89.

Birtwell, I.K. 1999. The effects of sediment on fish and their habitat. Fisheries and Oceans Canada. Canadian Stock Assessment Secretariat research document. Fs70-1/1999-139E-PDF. (Accessed December 21, 2018)

Blanchard, J.L., Coll, M., Trenkel, V.M., Vergnon, R., Yemane, D., Jouffre, D., Link, J.S., and Shin, Y-J. 2010. Trend analysis of indicators: a comparison of recent changes in the status of marine ecosystems around the world. ICES J. Mar. Sci., 67: 732–744.

Blanquer, A., and Uriz, M.J. 2010. Population genetics at three spatial scales of a rare sponge living in fragmented habitats. BMC Evol. Biol., 10:13.

Boutillier, J., Masson, D., Fain, I., Conway, K., Lintern, G., O, M., Davies, S., Mahaux, P., Olsen, N., Nguyen, H., and Rutherford, K. 2013. The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/075. viii + 76 p. (Accessed December 21, 2018)

Boyd, I. 1981. The spicule jungle of *Rhabdocalyptus dawsoni*: A unique microhabitat. B.Sc. Thesis. University of Victoria, British Columbia.

Brown, R.R., Davis, C.S., and Leys, S.P. 2017. Clones or clans: the genetic structure of a deep-sea sponge, *Aphrocallistes vastus*, in unique sponge reefs of British Columbia, Canada. Molecular Ecol., 26(4): 1045-1059.

Capuzzo, J.M. 1987. Biological effects of petroleum hydrocarbons: assessments from experimental results. London: Elsevier Applied Science; 343-410.

Carls, M. 1987. Effects of dietary and water-borne oil exposure on larval Pacific Herring (*Clupea harengus pallasi*). Mar. Environ. Res., 22: 253-270.

Carls, M.G., Rice, S.D., and Hose, J.E. 1999. Sensitivity of fish embryos to weathered crude oil: Part I. Low level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific herring (*Clupea pallasi*). Environ. Toxicol. Chem., 18: 481–493.

Chu, J.W.F. 2010. Biological patterns and processes of glass sponge reefs. MSc thesis, University of Alberta.

Chu, J.W. and Leys, S.P., 2010. High resolution mapping of community structure in three glass sponge reefs (Porifera, Hexactinellida). Mar. Ecol. Prog. Ser., 417: 97-113.

Chu, J., Maldonado, M., Yahel, G., and Leys, S. 2011. Glass sponge reefs as a silicon sink. Mar. Ecol. Prog. Ser., 441: 1–14.

Collie, J., Escanero, G., and Valentine, P. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Mar. Ecol. Prog. Ser., 155: 159–172.

Conway, K.W., Krautter, M., Barrie, J.V., and Neuweiler, M. 2001. Hexactinellid sponge reefs on the Canadian continental shelf: A unique "Living Fossil." Geosci. Can., 28(2): 71–78.

Cook, S.E. 2005. Ecology of the Hexactinellid Sponge Reefs on the Western Canadian Continental Shelf. Master's Thesis, Department of Biology, University of Victoria.

Cook, S.E., Conway, K.W., and Burd, B. 2008. Status of the glass sponge reefs in the Georgia Basin. Mar. Environ. Res., 66: S80-S86

COSEWIC (Committee on the Status of Endangered Wildlife in Canada), 2013. COSEWIC assessment and status report on the Bocaccio *Sebastes paucispinis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 49 pp. (Accessed December 21, 2018)

DFO. 2010A. Pacific Region Cold-Water Coral and Sponge Conservation Strategy. Pages 1-55. Fisheries and Oceans Canada: Oceans, Habitat, and Species at Risk Oceans Program, Ottawa, ON. (Accessed December 21, 2018)

DFO. 2010B. Monitoring indicators for the Tarium Niryutait Marine Protected Area (TNMPA). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/059. (Accessed December 21, 2018)

Donaldson, A., Gabriel, C., Harvey, B.J., and Carolsfeld, J. 2010. Impacts of Fishing Gears other than Bottom Trawls, Dredges, Gillnets and Longlines on Aquatic Biodiversity and Vulnerable Marine Ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/011. vi + 84 p. (Accessed December 21, 2018)

Dunham, A., Mossman, J., Archer, S., Pegg, J., Davies, S., and E. Archer. 2018. Glass Sponge Reefs in the Strait of Georgia and Howe Sound: Status assessment and ecological monitoring advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/010. (Accessed December 21, 2018)

Elmgren, R., Hansson, S., Larsson, U., Sundelin, B., and Boehm, P.D. 1983. The Tsesis oil spill: Acute and long-term impact on the benthos. Mar. Biol., 73(1): 51-65.

Enticknap, B. 2002. Trawling the North Pacific: understanding the effects of bottom trawl fisheries on Alaska's living seafloor. Alaska Marine Conservation Council.

Freese, J., and Wing, B. 2003. Juvenile Red Rockfish, *Sebastes sp*., Associations with Sponges in the Gulf of Alaska. Mar. Fish. Rev., 65(3): 38-43. (Accessed December 21, 2018)

Fuller, S.D., Picco, C., Ford, J., Tsao, C., Morgan, L.E., Hangaard, D., and Chuenpagdee, R. 2008. How we fish matters: addressing the ecological impacts of Canadian fishing gear. Ecological Action Centre, Living Oceans Society and Marine Conservation Biology Institute.

Gómez Gesteira, J.L., and Dauvin, J.C. 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. Mar. Poll. Bull., 40(11): 1017-1027.

Guilbault, J.P., Krautter, M., Conway, K.W., and Barrie, J.V. 2006. Modern foraminifera attached to hexactinellid sponge meshwork on the West Canadian Shelf: Comparison with Jurassic counterparts from Europe. Palaeontologia Elehowellctronica, 9(1): 7-12.

Howell, K.L., Piechaud, N., Downie, A.L., and Kenny, A. 2016. The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management. Deep Sea Res. PT1, 115: 309-320.

Hooff, R.C., and Peterson, W.T. 2006. Copepod biodiversity as an indicator of changes in ocean and climate conditions of the northern California current ecosystem. Limnol. Oceanogr., 51(6): 2607-2620.

Hose, J.E., McGurk, M.D., Marty, G.D., Hinton, D.E., Brown, E.D., and Baker, T.T. 1996. Sublethal effects of the (Exxon Valdez) oil spill on herring embryos and larvae: morphological, cytogenetic, and histopathological assessments, 1989 1991. Can. J. Fish. Aquat. Sci., 53(10): 2355-2365.

Incardona, J.P., Collier, T.K., and Scholz, N.L. 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicology and applied pharmacology, 196(2): 191-205.

Kahn, A.S., Yahel, G., Chu, J.W., Tunnicliffe, V., and Leys, S.P. 2015. Benthic grazing and carbon sequestration by deep-water glass sponge reefs. Limnol. Oceanog., 60:78-88.

Kershner, J., Samhouri, J.F., James C.A., and Levin P.S. 2011. Selecting Indicator Portfolios for Marine Species and Food Webs: A Puget Sound Case Study. PLOS ONE, 6(10): e25248.

Kramer, D.L., and Chapman, M.R. 1999. Implications of fish home range size and relocation for marine reserve function. Environ. Biol. Fish., 55(1-2): 65-79.

Krautter, M., Conway, K., and Barrie, J.V. 2001. Discovery of a "Living Dinosaur": Globally unique modern hexactinellid sponge reefs off British Columbia, Canada. Facies, 44(1): 265–282.

Konnecker, G. 2002. Sponge fields. Offshore Directory. Review of a selection of habitats, communities and species of the North-East Atlantic, pp.87-94.

Jamieson, G.S., and Chew, L. 2002. Hexactinellid Sponge Reefs : Areas of Interest as Marine Protected Areas in the North and Central Coast Areas. Can. Sci. Advis. Sec. Res. Doc. 2002/122. 78p. (Accessed December 21, 2018)

Jensen, E.L., 2011. Studying the genetic structure of sponge populations. Thesis. University of Alberta. Pp. 27.

Large, R.R., Halpin, J.A., Danyushevsky, L.V., Maslennikov, V.V., Bull, S.W., Long, J.A., Gregory, D.D., Lounejeva, E., Lyons, T.W., Sack, P.J., McGoldrick, P.J., and Calver, C.R. 2014. Trace element content of sedimentary pyrite as a new proxy for deep-time ocean–atmosphere evolution. Earth Plan. Sc. Lett., 389: 209-220.

Leys, S.P. 2013. Effects of sediment on glass sponges (Porifera, Hexactinellida) and projected effects on glass sponge reefs. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/074. vi + 23 p. (Accessed December 21, 2018)

Leys, S.P., Yahel, G., Reidenbach, M.A., Tunnicliffe, V., Shavit, U., and Reiswig, H.M. 2011. The sponge pump: the role of current induced flow in the design of the sponge body plan. PLOS ONE, 6(12): e27787.

Love, M., Morris, P., McCrae, M., and Collins, R. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NOAA Technical Report, 87(February).

Marliave, J.B., Conway, K.W., Gibbs, D.M., Lamb, A., and Gibbs, C. 2009. Biodiversity and rockfish recruitment in sponge gardens and bioherms of southern British Columbia, Canada. Mar. Biol., 156(11): 2247–2254.

Marty, G.D., Hoffmann, A., Okihiro, M.S., Hepler, K., and Hanes, D. 2003. Retrospective analysis: bile hydrocarbons and histopathology of demersal rockfish in Prince William Sound, Alaska, after the Exxon Valdez oil spill. Mar. Environ. Res., 56(5): 569-584.

Maughan, B.C. 2001. The effects of sedimentation and light on recruitment and development of a temperate, subtidal, epifaunal community. J. Exp. Mar. Biol. Ecol., 256(1): 59-71.

Matabos, M., Tunnicliffe, V., Juniper, S.K., and Dean, C. 2012. A Year in Hypoxia: Epibenthic Community Responses to Severe Oxygen Deficit at a Subsea Observatory in a Coastal Inlet. PLOS ONE, 7(9): 1–15.

McGurk, M.D., and Brown, E.D. 1996. Egg larval mortality of Pacific herring in Prince William Sound, Alaska, after the Exxon Valdez oil spill. Can. J. Fish. Aquat. Sci., 53(10): 2343-2354.

Negri, A., Burns, K., Boyle, S., Brinkman, D., and Webster, N. 2006. Contamination in sediments, bivalves and sponges of McMurdo Sound, Antarctica. Environ. Poll., 143(3): 456-467.

NMFS (National Marine Fisheries Service), 2008. Preliminary Scientific Conclusions of the Review of the Status of 5 Species of Rockfish: Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*Sebastes pinniger*), Yelloweye Rockfish (*Sebastes ruberrimus*), Greenstriped Rockfish (*Sebastes elongatus*) and Redstripe Rockfish (*Sebastes propriger*) in Puget Sound, Washington.

Norcross, B.L., Hose, J.E., Frandsen, M., and Brown, E.D. 1996. Distribution, abundance, morphological condition, and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the (Exxon Valdez) oil spill. Can. J. Fish. Aquat. Sci, 53(10): 2376-2387.

Patin, S. 1999. Environmental impact of the offshore oil and gas industry. EcoMonitor Publishing. East Northport, NY. 425 pp.

Rice, J.C., and Rochet, M.J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES J. Mar. Sci., 62: 516-527.

Rice, S.D., Wright, B.A., Short, J.W., and O'Clair, C.B. 1993. Subtidal oil contamination and biological impacts. Exxon Valdex Oil Spill Symposium. Trustee Council, Anchorage, Alaska. pp 23-26.

Richards, L.J. 1986. Depth and habitat distributions of three species of rockfish (Sebastes) in British Columbia: observations from the submersible PISCES IV. Environ. Biol. Fish., 17(1): 13–21.

Samiullah, Y. 1985. Biological effects of marine oil pollution. Oil Petrochem. Poll., 2(4): 235-264.

Shigenaka, G. 2011. Effects of oil in the environment. Oil Spill Science and Technology, edited by M. Fingas, pp.985-1024.

Shin, Y-J., Bundy, A., Shannon, L. J., Simier, M., Coll, M., Fulton, E. A., Link, J. S., Jouffre, D., Ojaveer, H., Mackinson, S., Heymans, J. J., and Raid, T. 2010. Can simple be useful and reliable? Using ecological indicators to represent and compare the states of marine ecosystems. ICES J. Mar. Sci., 67: 717–731.

Stone, R.P., Conway, K.W., Csepp, D.J. and Barrie, J.V. 2014. The Boundary Reefs: Glass Sponge (Porifera: Hexactinellidae) Reefs on the International Border Between Canada and the United States. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-AFSC-264, 31pp.

Suchanek, T.H. 1993. Oil impacts on marine invertebrate populations and communities. Am. Zool., 33(6): 510-523.

Tilseth, S., Solberg, T.S., and Westrheim, K. 1984. Sub-lethal effects of the water-soluble fraction of Ekofisk crude oil on the early larval stages of cod (*Gadus morhua L*.). Mar. Environ. Res., 11(1): 1-16.

Thornborough, K., Dunham, J., and O, M. 2016A. Development of risk-based indicators for the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/027 vii + 120 p. (Accessed December 21, 2018)

Thornborough, K., Dunham, J., and O, M. 2016B. Development of risk-based indicators for the Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/028 vii + 124 p. (Accessed December 21, 2018)

Tolimieri, N., and Levin, P.S. 2005. The roles of fishing and climate in the population dynamics of bocaccio rockfish. Ecol. Appl., 15(2): 458-468.

US Fish & Wildlife Service, 2004. Effects of Oils Spills on Wildlife and Habitat – Alaska Region. Accessed 8/05/13.

Whitney, F., Conway, K. W., Thomson, R., Barrie, V., Krautter, M., and Mungov, G. 2005. Oceanographic habitat of sponge reefs on the Western Canadian Continental Shelf. Cont. Shelf Res., 25(2): 211–226.

Yamada, M., Takada, H., Toyoda, K., Yoshida, A., Shibata, A., Nomura, H., Wada, M., Nishimura, M., Okamoto, K., and Ohwada, K. 2003. Study on the fate of petroleum-derived polycyclic aromatic hydrocarbons (PAHs) and the effect of chemical dispersant using an enclosed ecosystem, mesocosm. Mar. Poll. Bull., 47(1): 105-113.

Yunker, M.B., McLaughlin, F.A., Fowler, M.G., and Fowler, B.R. 2014. Source apportionment of the hydrocarbon background in sediment cores from Hecate Strait, a pristine sea on the west coast of British Columbia, Canada. Org. Geochem., 76: 235-258.

Zahn, R.K., Zahn, G., Müller, W.E.G., Kurelec, B., Rijavec, M., Batel, R., and Given, R. 1981. Assessing consequences of marine pollution by hydrocarbons using sponges as model organisms. Sci. Total Environ., 20(2): 147-169.