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Development of risk-based indicators for the SG̲aan K̲inghlas-Bowie Seamount 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

Fisheries and Oceans Canada (DFO) Science was asked to recommend scientifically defensible indicators to monitor the achievement of the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) conservation objective. In response, a framework was developed to select and prioritize ecological risk-based indicators based on the outputs of an ecological risk assessment conducted on the SK-B MPA. Risk-based indicators are a novel approach to selecting indicators to monitor the risk of harm to Significant Ecosystem Components (SECs) from anthropogenic activities and associated stressors. Measures of abundance were commonly proposed across all 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, stressor, and SEC-stressor interaction indicators. Due to the remote access and associated cost of monitoring indicators at the SK-B 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 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 the refinement of monitoring plans.

Élaboration d'indicateurs fondés sur les risques pour la zone de protection marine du mont sous-marin Bowie (SGaan Kinghlas)

RÉSUMÉ

On a demandé au Secteur des sciences de Pêches et Océans Canada (MPO) de recommander des indicateurs défendables sur le plan scientifique en vue de surveiller l'atteinte de l'objectif de conservation de la zone de protection marine du mont sous-marin Bowie (SGaan Kinghlas [ZPM SK-B]). En réponse à cette demande, un cadre a été élaboré pour sélectionner des indicateurs fondés sur les risques écologiques et les classer par priorité, en fonction des résultats d'une évaluation du risque écotoxicologique menée dans la ZPM SK-B. Il s'agit d'une nouvelle approche de sélection d'indicateurs servant à surveiller le risque de préjudice pour les composantes importantes de l'écosystème (CIE) découlant d'activités anthropiques et des agents de stress connexes. Des mesures de l'abondance figurent régulièrement parmi les ensembles d'indicateurs proposés, ce qui fait ressortir la nécessité d'établir prioritairement des données de référence. Pour élaborer des stratégies et des plans de surveillance, il convient de prendre en considération les séries d'indicateurs des agents de stress actuels et potentiels et d'utiliser une combinaison d'indicateurs des CIE, des agents de stress et des interactions entre les CIE et les agents de stress. Étant donné l'éloignement du site et le coût de la surveillance des indicateurs dans la ZMP SK-B, bon nombre des indicateurs proposés peuvent être mesurés par le biais de relevés visuels et, comme plusieurs CIE se chevauchent, différents indicateurs peuvent être mesurés ou échantillonnés durant la même période d'opération. Dans la mesure où les données sont recueillies par le biais de la surveillance des indicateurs, elles peuvent être réintégrées dans le cadre de gestion adaptative pour les prochaines évaluations des risques et de certains indicateurs, ainsi que pour la sélection de nouveaux indicateurs et le perfectionnement des plans de surveillance.

1. INTRODUCTION

1.1. CONTEXT

Fisheries and Oceans Canada (DFO) Science was asked to recommend scientifically defensible indicators to monitor the achievement of the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA) conservation objective (Section 1.5). This conservation objective is broad, and has yet to be refined into specific operational objectives. In response, Davies et al. (2011) proposed a risk-based approach whereby risk-based indicators would be selected and prioritized based on the outputs of an ecological risk assessment conducted on the SK-B MPA. DFO Science developed an ecological risk assessment framework (ERAF; O et al. 2015), creating a structured approach for assessing the potential risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors.

The ERAF provides a systematic and transparent process of gathering, evaluating, and recording information related to the risk of harm from anthropogenic activities on SECs. The output of the ERAF is a key information tool for focusing the management priorities in the SK-B MPA and informs the development of more specific conservation objectives, management strategies, and action plans including research and monitoring (O et al. 2015). With the completion of the ERAF application to SK-B MPA in 2015 (Rubidge et al.[1]), the process of identifying and prioritizing indicators can now proceed.

It is essential to establish the context of this work early in the process in order to develop suites of indicators that are meaningful and useful to decision makers. The indicators proposed in this paper are risk-based indicators, and are distinct from ecosystem indicators, as was the design of the indicator selection process for the SK-B MPA proposed by Davies et al. (2011). Indicators and their measureable components (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.

The selection of ecological risk-based indicators is a key step in the adaptive management (AM) framework for the SK-B MPA (Figure 1.1). 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 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 1.1).

This work proposes suites of risk-based indicators to monitor biodiversity in the SK-B MPA, selected based on the risk to SECs from anthropogenic stressors. Suites of indicators, rather than one or two, are required to provide 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.

[1] Rubidge, E., Thornborough, K., and O, M. (2016) Ecological Risk Assessment for the SGaan Kinghlas Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc (in preparation).

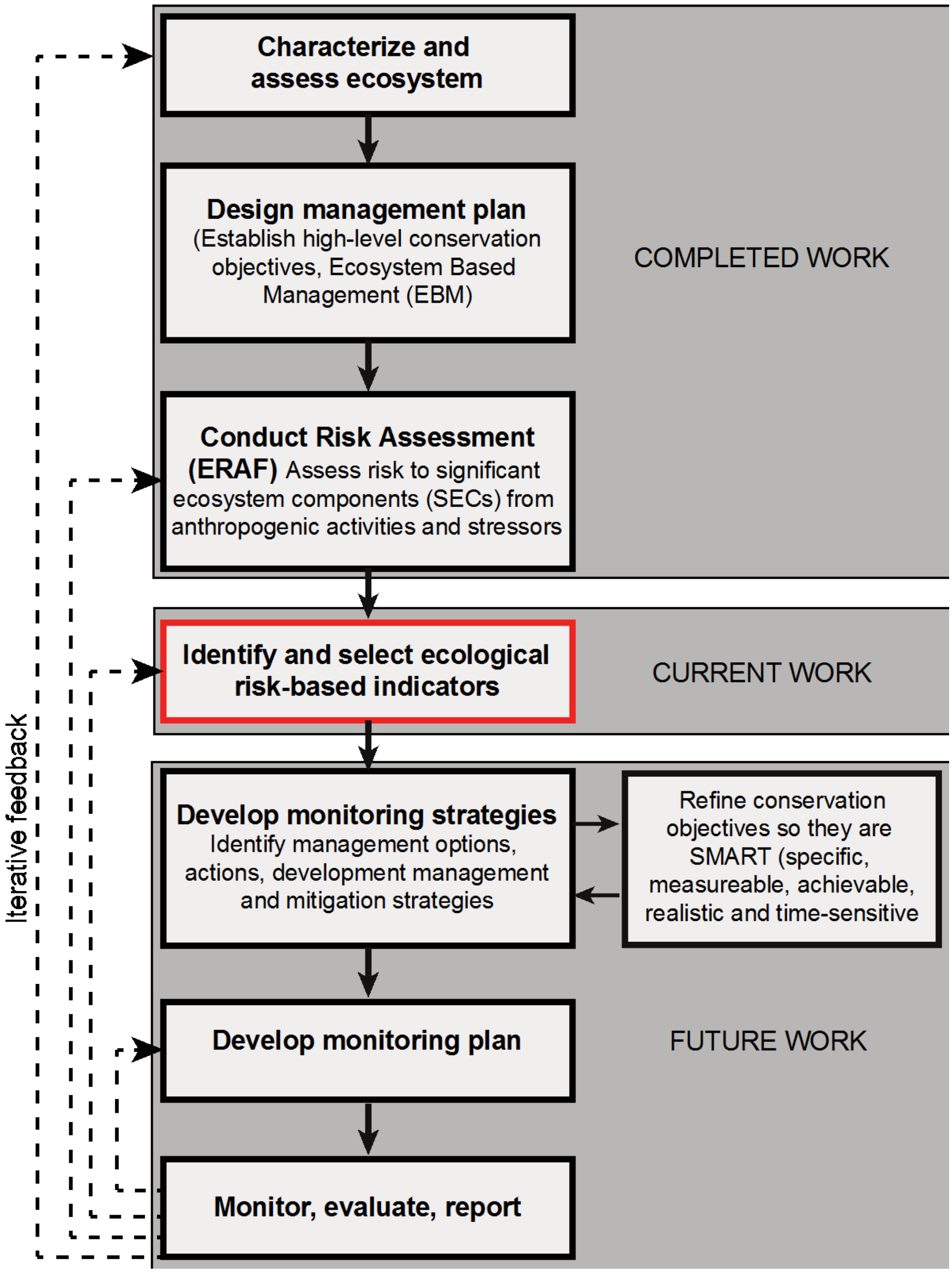

Figure 1.1: Overview of DFO Oceans – Pacific Region adaptive management (AM) framework (adapted from O et al. 2015). This process is iterative, and any information gathered during monitoring can be fed back into the framework.

1.2. INDICATORS

An ecological indicator is a specific measurable component of an ecosystem that is 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 particular 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 (AM) framework (Figure 1.1), 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 AM 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.

2. REGIONAL SETTING: SGAAN KINGHLAS-BOWIE MARINE PROTECTED AREA

2.1. DESCRIPTION OF SGAAN KINGHLAS-BOWIE MARINE PROTECTED AREA

The SK-B MPA is located in the North Pacific Ocean, 180 km west of Haida Gwaii. Bowie, Hodgkins and Davidson seamounts lie within its boundaries forming the southern end of the Kodiak-Bowie seamount chain. Rising steeply from the seabed, seamounts are known to support biologically rich, diverse and productive ecosystems. The Bowie Seamount, the largest in the SK-B MPA, rises from a depth of 3000 m to within 25 m of the surface photic zone, making it the shallowest submarine volcano in Canadian waters. This shallow offshore habitat is uncommon in the open ocean, and the combination of distance from the coast with upwelling and turbulent mixing water that is characteristic of seamounts has given rise to an ecologically isolated, yet biologically diverse and productive ecosystem containing both deep-water and coastal species (Davies et al. 2011). Davidson and Hodgkins seamounts are much deeper, rising to only 1146 m and 596 m below the surface (Canessa et al. 2003).

DFO identified Bowie seamount as a pilot marine protected area in 1998. In the subsequent official designation as an MPA in 2008, the area of interest was expanded to include the neighbouring Hodgkins and Davidson seamounts. The SGaan Kinghlas Bowie Seamount is culturally significant to the Haida First Nation, and SGaan Kinghlas means “supernatural being looking outward”. DFO and the Council of Haida Nation (CHN) signed a memorandum of understanding for co-management in 2007 (Davies et al. 2011), allowing for cooperative management and planning and a DFO-Haida management board was established in 2009.

2.2. GEOLOGIC SETTING AND PHYSICAL DRIVERS

Formed by deep-sea volcanic eruptions along fissure lines, Bowie seamount is relatively young in geological terms. The base is believed to have formed less than one million years ago and the summit shows evidence of volcanic activity as recently as 18,000 years ago (Dower and Fee

1999). Bowie seamount is 55 km long and 24 km wide, with its flat-topped summit composed of weakly consolidated tephra. The summit consists of two distinct terraces at depths of 220-250 m and 65-100 m. The shallower terrace is dotted with steep-sided pinnacles, the largest rising to within 25 m of the surface (Dower and Fee 1999). Very little is known about Davidson and Hodgkins seamounts because their summits are well below the photic zone and they have not been the focus of commercial fishing activity (such as a commercial Sablefish trap fishery, unlike Bowie seamount.

SK-B MPA supports a rich biological community with a dynamic and productive ecosystem in an otherwise unproductive region of the ocean. The area is influenced periodically by regional eddies, known as the Haida Eddies, which form off Haida Gwaii during the winter and drift into the Gulf of Alaska (Davies et al. 2011). Haida Eddies are anticyclonic vortices that can be 200 km in diameter and are characterised by positive sea surface height anomalies, warmer sea surface temperatures than surrounding waters below the top 100 m and lower salinity than surrounding waters (Crawford 2002). Dower and Fee (1999) suggested that Haida Eddies can become ‘stuck’ on shallow seamounts after observing a westward moving Haida Eddie stalling over SK-B MPA for approximately three months. While the trajectory of Haida Eddies are unpredictable and many do not travel near SK-B MPA, these Eddies may function as a periodic offshore transport corridor for larval and juvenile rockfish, plankton and nutrients such as nitrate and iron.

Little scientific research has been conducted on the types of water flow phenomena that occur at or near Bowie, Hodgkins, and Davidson seamounts. However, Cobb seamount shares many characteristics with Bowie and has been studied extensively. There is evidence of a closed eddy and a Taylor cone (hydrodynamic spray processes) over Cobb seamount, so assuming similar flow phenomena occur at Bowie seamount, then there is a high probability of an area of cold nutrient rich water in the upper euphotic zone where a high level of mixing occurs (Rubidge et al.[1]).

It has been hypothesized that oceanographic drivers at the SK-B MPA support a large aggregation and rich diversity of fishes. Porteiro and Sutton (2007) summarize three hypotheses to explain this phenomenon. First, the high biomass of fish is the result of locally enhanced primary production and subsequent bottom-up transfer of this energy to higher trophic levels in the food chain (Boehlert and Genin 1987). Upwelling and Taylor cone formation can enhance nutrients in epipelagic waters and drive increased primary productivity (e.g., Genin and Boehlert 1985). Second, with the “feed-rest” hypothesis (Genin 2004) fish aggregations are sustained by the enhanced horizontal flux of pelagic prey organisms (via the strong currents on the upper slopes and summits of seamounts) past the seamount (Dower and Mackas 1996). Third, under the “topographic blockage” hypothesis (Genin 2004) seamount aggregations are maintained through predation on vertical migrants that are intercepted and trapped during the migration process (Isaacs and Schwatzose 1965; Genin et al. 1988, 1994). In other words, zooplankton migrate to photic zone at night to feed on phytoplankton; the current then carries them over the summit of the seamount where they are trapped on terraces during their descent, providing a concentration of forage species for visual predators such as fish during the day. There is evidence that food supplied to seamount communities via topographic trapping is as much as 40 times greater than local primary productivity (Isaacs and Scwartzlose 1965). If true, then the physical structure of Bowie seamount, including the two distinct terraces at depths of 220-250 m and 65-100 m, and the several steep sided pinnacles are key features maintaining the productivity of the SK-B MPA ecosystem (adapted from Rubidge et al.[1]).

2.3. CONSERVATION OBJECTIVE

The SK-B MPA was officially designated as an MPA in 2008 with a conservation objective to:

'Conserve and protect the unique biodiversity and biological productivity of the area's marine ecosystem, which includes the Bowie, Hodgkins and Davidson seamounts and the surrounding waters, seabed and subsoil'.

This conservation objective is 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 specific, measureable, achievable, realistic, and time-sensitive (SMART) conservation objectives are 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.

2.4. CURRENT ACTIVITIES AND MANAGEMENT

SK-B MPA is regulated under the *Oceans Act* (SOR/2008-124). Activities in the SK-B MPA are managed through specific exceptions to the general prohibitions (Davies et al. 2011). Exceptions include:

- Activities for the purpose of public safety, law enforcement, national security, national defense or emergency response are permitted to ensure the safety of Canadians;
- Scientific research for the conservation, protection and understanding of the area may be approved throughout the MPA under specific conditions;
- Fishing by Aboriginal Peoples in accordance with the Aboriginal Communal Fishing Licenses Regulations is permitted;
- Commercial fishing within the MPA is allowed as long as this is carried out in accordance with subsection 7(1) of the *Fisheries Act* (R.S.C. 1985) and is administered through the Integrated Fisheries Management Plan (IFMP), annual variation order, and license conditions. At present the only fishery in the SK-B MPA is a Sablefish trap fishery. The fishable area and number of vessels are restricted, with only one vessel allowed access per month (over a six-month period). Fishing is restricted to the use of trap gear only;
- Recreational fishing in accordance with the *Fisheries Act* and its regulations; and
- Travel or transport is permitted pursuant to the *Canada Shipping Act* (2001) and foreign vessel travel pursuant to the *Canada Shipping Act* (2001) and the *Coasting Trade Act* (S.C. 1992, c. 31).

2.5. CURRENT STATE OF MONITORING AND RESEARCH ACTIVITIES

Extensive oceanographic and biological research has been conducted at other seamounts in the northeast Pacific Ocean (e.g., Cobb seamount), but Bowie, Davidson, and Hodgkins seamounts have received less attention. The SK-B MPA is a relatively new research location and although interest to perform research exists, there are several obstacles impeding research activity. These obstacles include a remote location, limited availability of suitable vessels, difficulty performing research in open waters, (potentially harsh wave and weather conditions), and a lack of research funding (reviewed in Canessa et al. 2003). Since 2008, there have been four research trips to SK-B MPA (Rubidge et al.[1]), and there is no current ongoing monitoring program at the site.

Scientific research conducted at SK-B MPA has focused on geology, ecology, oceanography, and fisheries research to investigate the potential of rockfish and sablefish fisheries on or near Bowie Seamount. Past surveys have provided preliminary information on species richness and biodiversity of Bowie Seamount, but are not complete enough to be regarded as a baseline study (Davies et al. 2011). Measurements of the physical and chemical characteristics of the seabed have been obtained by capturing video footage from a submersible, hydroacoustic surveys, and exploratory fishing (trawl, hook and line, trap and jig) (Davies et al. 2011). Very little scientific research has focused on the Davidson and Hodgkins seamounts.

The Sablefish trap fishery at SK-B MPA is monitored through fishing logbooks, observers (either at-sea observers and/or electronic monitoring), port sampling, and dockside monitoring (DFO 2010). All fishers 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, 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 SK-B 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.

2.6. ECOLOGICAL RISK ASSESSMENT FRAMEWORK METHODS AND RESULTS

As part of the recommendations for selecting risk-based indicators (Davies et al. 2011), the ERAF (O et al. 2015) was applied to the SK-B MPA. The ERAF consists of two main phases: scoping, and risk assessment. The scoping phase identifies significant ecosystem components (SECs) and anthropogenic stressors with the potential to impact the SK-B MPA ecosystem. The risk assessment calculates 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 SK-B MPA are presented in Rubidge et al.[1], and are summarized below.

SECs that appropriately represent the SK-B MPA ecosystem were identified during the scoping phase of this risk assessment. These SECs consist of ten species, four habitats, and two communities (Table 2.1). Selected SECs were confined to components that could be managed at the MPA scale (which excludes highly transient species like marine mammals and birds) and to ensure that the unique nature of the seamount ecosystem (overlapping coastal and deep-water species) was captured. Due to limitations of the ERAF, community SECs were identified, but not included in the risk assessment. Descriptions of each SEC are presented in Appendix A. Pathways of Effects (PoE) models were developed for activities that may impact SECs in the SK-B MPA, identifying associated stressors and effects on the SK-B MPA ecosystem. The stressors identified as impacting SECs in the SK-B MPA through this process are presented in Table 2.2.

Table 2.1. Significant ecosystem components for the SK-B MPA.

SEC type	SEC
Species SECs	Prowfish (*Zaprora silenus*) Sablefish (*Anoplopoma fimbria*) Pacific Halibut (*Hippoglossus stenolepis*) Bocaccio Rockfish (*Sebastes paucispinis*) Yelloweye Rockfish (*Sebastes ruberrimus*) Rougheye/Blackspotted Rockfish (*Sebastes aleutianus*) Widow Rockfish (*Sebastes entomelas*) Squat Lobster (*Cervimunida princeps*) *Isidella tentaculum* (Alcyonacea) *Primnoa* sp. (Alcyonacea)
Habitat SECs	Demosponges Deep Water Alcyonacea Macroalgae Coralline Algae
Community SECs	Benthic invertebrate assemblage Rockfish species assemblage

Table 2.2: Activities (provided by Oceans Management) and associated stressors (identified through the development of PoE models) for the SK-B MPA.

Activity	Associated Stressor
Movement underway	Noise Disturbance
	Substrate Disturbance (waves)
Oil spill	Oil
Discharge	Debris
	Aquatic invasive species
	Oils/contaminants
	Nutrients
Grounding	Substrate Disturbance (crushing)
	Substrate Disturbance (sediment re-suspension)
Equipment abandonment	Contaminants
Equipment installation	Substrate disturbance (crushing)
	Substrate disturbance (sediment re-suspension)
	Light disturbance
	Noise disturbance
Sampling	Substrate disturbance (crushing)
	Substrate disturbance (sediment re-suspension)
	Removal of organisms
Scuba diving	Light disturbance
	Noise disturbance
	Substrate disturbance (crushing)
	Substrate disturbance (sediment re-suspension)
Submersible operations	Aquatic invasive species
	Light disturbance
	Noise disturbance
	Substrate disturbance (crushing)
	Substrate disturbance (sediment re-suspension)

Activity	Associated Stressor
Trap/pot fishing	Aquatic invasive species
	Entrapment/entanglement
	Removal of biological material
	Substrate disturbance (crushing)
	Substrate disturbance (sediment re-suspension)
Seismic testing/air guns	Sound generation

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 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 also scored and incorporated into the final risk score using the method outlined in O et al. (2015). Separate uncertainty scores were produced (10/90% quantiles of the final median risk array) and presented with the risk score. 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 SK-B MPA (e.g., fishing). *Potential* activities and stressors include those that occur infrequently and/or unpredictable intervals. *Potential* stressors (activity) include: *oil (oil spill), debris (discharge), sound generation (seismic testing/air guns),* and *aquatic invasive species (submersible operations, trap/pot fishing, discharge)*. *Potential* stressors were more likely to be scored higher than *current snapshot* stressors as they were scored on a worst-case scenario. For example, *aquatic invasive species* was scored as establishment of an aquatic invasive species (rather than exposure to propagule), and *oil (oil spill)* was scored based on a large-scale tanker spill.

Isidella tentaculum, Alcyonacea coral habitat, and Sponge habitat SECs had the highest cumulative risk scores for the SK-B MPA. Rougheye Rockfish had the highest cumulative risk score of all fish SECs, but there was considerable overlap among fish SECs. *Potential* stressors in general had the highest cumulative risk scores, and included *oil (oil spills), sound generation (seismic testing/air guns),* and *aquatic invasive species (debris, submersible operations, and trap/pot fishing)*. The highest risk scores were associated with the highest uncertainty.

2.7. INFORMATION GAPS

The application of the ERAF to the SK-B 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 baseline data for SECs within the SK-B MPA, and information on stressors is limited. *Potential* stressors were scored on the assumption of a worst-case scenario of high overlap with SECs, and this highlighted the need for established SEC baselines to more accurately calculate overlap. Uncertainty surrounding *current snapshot* stressors varied. Stressors related to research activities (e.g., sampling, scuba, equipment installation, etc.) had lower uncertainty for terms of the exposure terms than stressors related to trap/pot fishing.

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 (defined in the ERAF (O et al. 2015) as a change in population size) and chronic change (a change in population condition) to SECs resulting from impacts from stressors. Uncertainty was highest for *potential* stressors and lowest relating to research activities.

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

3. METHOD: INDICATOR SELECTION AND PRIORITIZATION

Davies et al. (2011) recommended a process for the selection of risk-based indicators that includes: refinement of conservation objectives in measureable terms; identification of candidate indicators and protocols to monitor the impact of stressors from activities assessed or prioritized through the ERAF application that warrant monitoring (i.e., sufficient risk to the achievement of the conservation objectives); and, identification of candidate indicators and protocols for monitoring the ecosystem reference state to serve as baselines for comparison to indicators relevant to stressors. Although these recommendations were used as a guide in the development of this work, some changes were necessary because the potential outputs from the ERAF application were unknown when Davies et al. (2011) recommended this process, their recommendations are heavily based on Rice and Rochet (2005), who described a different process to select ecosystem indicators for fisheries management, and, there are no refined conservation objectives for the SK-B MPA at present.

At the time the Davies et al. (2011) recommendations were proposed, the ERAF had not yet been developed, and the capabilities and potential outputs of the risk assessment were not fully understood. The integration of the SEC and stressor identification as a key phase of the ERAF allowed for a more in-depth examination of the SK-B MPA than previously expected. In addition, the outputs of the risk assessment (relative rankings of risk by SEC and stressor) are specific enough to differentiate between stressor types (*current snapshot* and *potential*), and individual SEC-stressor interactions may be ranked by risk.

The conservation objective for the SK-B MPA is broad and lacks refined operational objectives. Davies et al. (2011) noted that if the conservation objectives are not measurable, then the identification of the stressors, their effects and the application of the ERAF can inform the development of measureable conservation objectives, otherwise known as operational objectives. In the absence of appropriate consultation and collaboration with MPA managers, the development of operational objectives is difficult and carries the risk that the objectives lack validity. This document 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.

In order to provide MPA managers with relevant science advice on which SEC-stressor interactions require further monitoring, a risk-based indicator selection framework was developed in order to select indicators for those SECs with the highest relative risk. This framework focuses primarily on the outputs of the application of the ERAF, incorporating sources of uncertainty and relevant literature as illustrated in Figure 3.1.

3.1. 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. Additional selection criteria suggested by Davies et al. (2011) (based on Rice and Rochet (2005)) as well as commonly suggested criteria for indicator selection from the primary literature were also incorporated into this method. 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 3.1). The monitoring of these indicators may permit future development of thresholds and appropriate management actions.

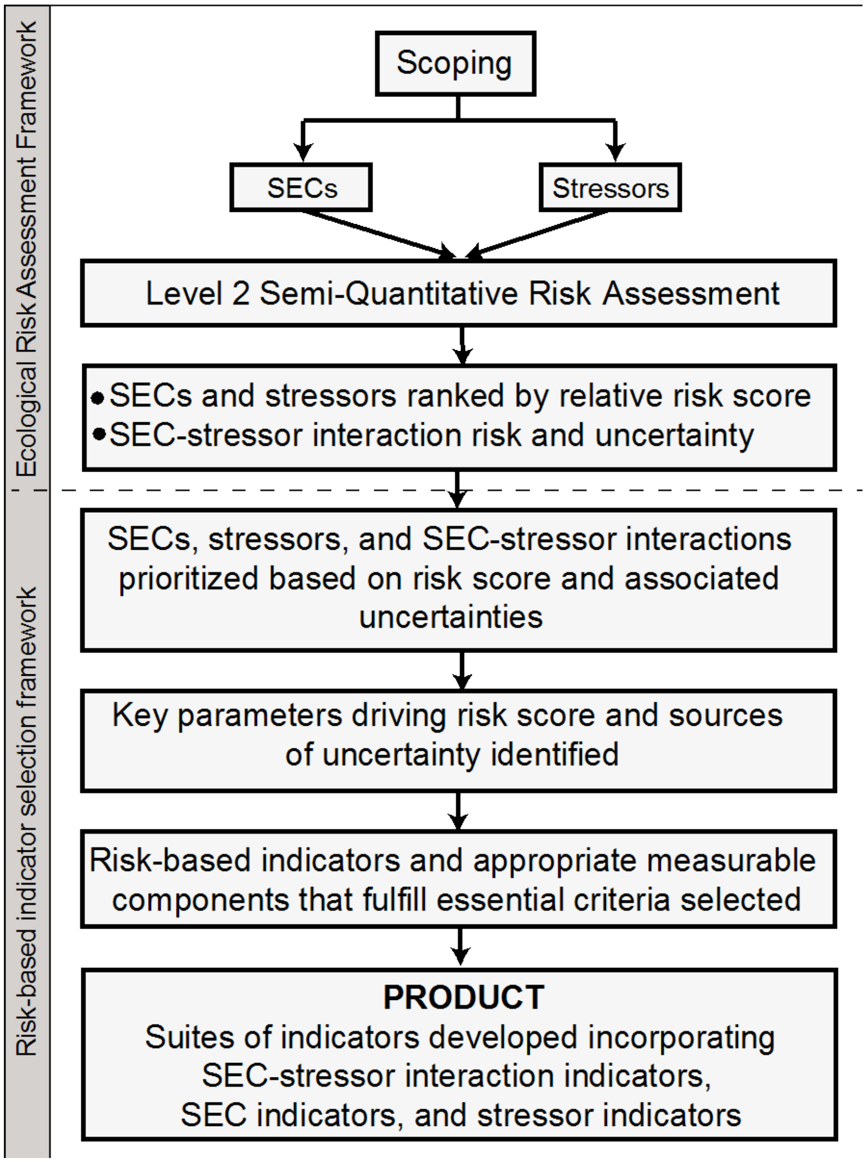

Figure 3.1: Overview of risk-based indicator selection framework, based on the outputs of the ERAF application.

3.2. SELECTION OF RISK-BASED INDICATORS FOR SECS AND STRESSORS

This process involved 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 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.

3.2.1. Prioritization of SECs/Stressors

Prioritization of SECs and stressors for this process was based entirely on the outputs of the risk assessment of the SK-B MPA (Rubidge et al.[1]). The application of the ERAF resulted in the ranking of SECs and anthropogenic stressors 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. All SECs and stressors included in the risk assessment phase of the ERAF were included in this process, and those deemed 'low priority' (based on low relative risk scores) were not removed from this process.

3.2.2. Indicator Criteria

To ensure that the selected indicators provide useful measurements of the SECs, stressors, and SEC-stressor interactions, each indicator should meet a set of essential and preferred criteria. Numerous criteria by which indicators may be evaluated have been published; however, they are generally similar (Rice and Rochet 2005) and may be summarized under the following broad criteria: *theoretically sound, measureable/feasible, sensitive, historical data available, cost-effective, public awareness of indicator*, and *linked to relevant management concerns/measures/targets (linked to conservation objectives).* Several of the listed criteria were not applied to this selection of risk-based indicators and are discussed below, including *cost-effectiveness, public awareness*, and *linked to management concerns/measures/targets*. The criteria for the selection of risk-based indicators was chosen from published lists, and summarized into key criteria and sub-criteria (Table 3.1).

Cost-effectiveness was excluded from this process in order to avoid incorrect assumptions regarding the available budget or resources for monitoring, and potential bias of indicator selection. Instead, the sub-criteria of *technically feasible*, *operationally simple*, and *monitoring method allows for several indicators through a single program* were used. *Public awareness* was excluded as it lacked relevance when selecting appropriate measureable indicators relating to specific ecological SECs, stressors, and SEC-stressor interactions. While this criterion is not a pathway for filtering potential ecological indicators, it may be relevant when selecting ecosystem indicators, particularly when the process includes indicators relevant to socio-economic factors. An example of a species that fulfills the public awareness criteria is the Killer Whale (*Orcinus orca*). *Linkages to management concerns/measures/ targets* were not included as essential criteria for this study as conservation targets have yet to be set for the SK-B MPA.

A longer, more detailed set of criteria was developed that includes the previously disqualified criteria (*cost-effectiveness, public awareness*, and *linked to management concerns/measures/targets*) and additional considerations from available literature, and is presented in Appendix B. This set of criteria was not developed for this risk-based indicator selection framework, but for future iterations of this work when more data become available and operational conservation objectives have been developed. These additional criteria may be used as a guide when selecting new indicators, refining existing indicators, and the development of ecosystem indicators. The additional criteria selected for any future applications should be linked to operational conservation objectives or the type of indicator being selected (e.g. socio-economic ecosystem indicator).

Table 3.1: Risk-based indicator selection criteria. Criteria and sub-criteria are deemed essential, with the exception of historical data (preferred), and sensitive (not applicable to stressor indicators).

Criteria	Sub-criteria	Description
Theoretically sound	Indicator and measureable component established in literature/monitoring programs	Scientific, peer-reviewed findings should demonstrate indicators act as reliable surrogates for ecosystem components and stressors.
Measurable/ feasible	- Technically feasible - Quantifiable in real-world units (concreteness of measurement) - 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 SK-B 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.
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 is available	Indicators should preferably be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.

3.2.3. 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. This selection approach was used to ensure the scientific value of the indicators for monitoring, assessing, and understanding SEC status within the 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 SK-B MPA, meaning that indicators for SECs were preferred if they could provide information contributing to population baselines.

SEC indicators were divided into two main categories: population size/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).

3.3. SELECTION OF RISK-BASED INDICATORS FOR SEC-STRESSOR INTERACTIONS

A total of 214 SEC-stressor interactions were identified at the SK-B MPA; 140 *current snapshot* and 74 *potential* interactions. In order to provide relevant science advice, these SEC-stressor interactions needed to be prioritized to reduce the number of listed interactions before indicator selection can occur. A method was developed using outputs from the risk assessment to prioritize SEC-stressor interactions by risk and uncertainty. This process ranked SEC-stressor interactions by both risk and uncertainty scores, divided the interactions into high, moderate, and low priority, and then indicators were selected for high and moderate priority interactions. The incorporation of both the risk score and uncertainty score into this prioritization process stems from the findings presented in Rubidge et al.[1] that uncertainty can drive the risk score, and is effective in identifying knowledge gaps. SEC-stressor interactions were divided into *current snapshot* and *potential* interactions prior to prioritization. This categorization was applied so that the final suite of indicators was not dominated by *potential* interactions. Both *current snapshot* and *potential* interactions are required for indicator selection, as each highlight different information gaps and monitoring and management needs.

3.3.1. Prioritization of SEC-Stressor Interactions

This process can be summarized in four steps:

1. 10 and 90% quantiles for each SEC-stressor interaction were averaged to give one score representing uncertainty for each interaction.

2. Score range was determined for all risk and uncertainty scores respectively, and then divided by 3, producing high, moderate, and low bins for both scores. This division of scores was confirmed to align with the natural division of the data by plotting raw scores.
3. SEC-stressor interactions were ranked using a combination of both risk and uncertainty, where high risk and low uncertainty was the highest priority, and low risk and low uncertainty was the lowest priority (see Table 3.2).
4. Low priority interactions are removed from this process, and only high and moderate interactions moved onto the next stage of indicator selection.

Table 3.2: 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

3.3.2. 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 measure for each interaction, the original resilience (acute change and chronic change) scoring and justifications from Rubidge et al.[1] were examined. In the ERAF (O et al. 2015) acute change represented a change in population size, whereas chronic change represented a change in population condition. If acute change was scored as 0, then only measures of population condition were selected, and vice versa for chronic change and population size. If scoring for acute and chronic change were similar, then indicators were selected for both.

3.3.3. Selection of Indicators for SEC-Stressor Interactions

Indicators and their measureable components were selected from available scientific literature as described in Section 3.2.3. Each selected indicator was required to fulfill all criteria deemed essential in Table 3.1, 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 Table 3.2.

Suites of indicators were then presented where SECs were 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 3.2 were incorporated into the indicator suites specific to the SEC-stressor interaction. This approach ensures that a range of attributes is 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.

4. RESULTS: SELECTION OF INDICATORS

4.1. INDICATOR IDENTIFICATION FOR SIGNIFICANT ECOSYSTEM COMPONENTS

4.1.1. Prioritization of Significant Ecosystem Components

Prioritization of SECs was derived from the relative rankings of SECs by risk produced as an output from the risk assessment (Rubidge et al.[1]), 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 SECs only, and no SECs were removed using this process. SECs prioritized by risk are presented in Table 4.1.

Table 4.1: SECs prioritized by cumulative risk (Rubidge et al.[1]), showing scores and 10/90% quantiles (representing uncertainty).

SEC	Risk (Cumulative)	10% Q	90% Q
Isidella tentaculum	679	579	782
Corals (habitat)	677	586	770
Sponges (habitat)	661	571	752
Rougheye Rockfish	474	398	554
Sablefish	432	361	506
Pacific Halibut	428	356	505
Coralline algae (habitat)	425	366	486
White Primnoa sp.	386	319	458
Widow Rockfish	380	315	448
Prowfish	375	311	443
Macroalgae (habitat)	374	315	436
Bocaccio Rockfish	373	314	435
Yelloweye Rockfish	364	302	428
Squat lobster	181	136	230

4.1.2. Proposed Indicators for Significant Ecosystem Components

Selected indicators and their measureable components for SECs are presented in Table 4.2. 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., Samhouri et al. 2009; Levin et al. 2010; Curtis et al. 2012; Andrews et al. 2013), 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 Table 3.1.

Several indicators (average of three for each SEC) were selected for each SEC, providing several choices. Suites of indicators for SECs are provided under two key parameters: population size; and, population condition. Several indicators were repeated for similar SEC types, for example abundance was repeated for *Isidella tentaculum* and White Primnoa sp., so similar SEC types were grouped together for presentation in Table 4.2. Justifications for indicator selections and how each of the criteria were fulfilled are presented in Appendix C and Appendix D, respectively.

*Table 4.2. Proposed indicators for SECs and measureable components. *Denotes indicators specific to habitat SECs only.*

SEC			Key parameter	Proposed Indicator	Measureable component
Invertebrates	Sessile, benthic	Corals: - *Isidella tentaculum* - Corals (habitat) - White Primnoa sp. Sponges: - Sponges (habitat) Algae: - Coralline Algae - Macroalgae (habitat)	Population size	Species richness*	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)
				Abundance	- Areal coverage (%) – (Macroalgae, coralline algae) - Patch area (m^2) - Number per m^2 (corals, sponges)
			Population condition	Biomass	Weight/unit area
				Health/ condition related to disease and aquatic invasive species	Presence of disease, aquatic invasive species
				Health/ condition related to physical damage	Proportion of colony/habitat (%) damaged
	Mobile, benthic	Crustaceans: - Squat Lobster	Population size	Abundance/ species density	Average density/count of organisms within a given range
			Population condition	Health/ condition	Visible injury to organism or behavioral indicators (e.g. righting and feeding behavior, reflex actions)
				Species spatial distribution	Range of species
Vertebrates (fish)	Pelagic	Rockfish: - Rougheye - Widow - Bocaccio - Yelloweye	Population size	Abundance	Size-frequency distribution
				Catch per unit effort	Weight/unit area
				Species richness and diversity	Population or stock delineation
	Demersal	Other fishes: - Sablefish - Pacific Halibut - Prowfish	Population condition	Condition factor, k	e.g., weight/length, age, stomach contents, presence of disease or invasive species, parasitic load
				Genetic diversity	Genetic delineation (allele frequency, polymorphism, etc.)

4.2. INDICATOR IDENTIFICATION FOR STRESSORS

4.2.1. 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 (Rubidge et al.[1]), 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 4.3.

4.2.2. Proposed Indicators for Anthropogenic Stressors

An average of three indicators per stressor were selected from available literature, and are presented in Table 4.4. 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 Table 3.1, and justifications are provided in Table 4.4. Proposed indicators and their measureable components for stressors and descriptions of the criteria they filled are presented in Appendix E.

*Table 4.3: The SK-B MPA activities and associated sub-activities and stressors with risk scores (Rubidge et al.[1]). * denotes potential stressors.*

Activity	Stressor	Risk	10% Q	90% Q
Oil spill	Oil*	834	756	915
Seismic testing/ air guns	Sound generation*	703	635	772
Discharge	Aquatic Invasive Species*	540	463	622
Submersible operations	Aquatic Invasive Species*	511	444	582
Discharge	Debris*	459	365	557
Discharge	Oils/contaminants*	452	358	550
Trap/pot fishing	Removal of biological material	360	285	439
Trap/pot fishing	Aquatic Invasive Species*	316	261	375
Discharge	Nutrients*	303	233	377
Trap/pot fishing	Substrate disturbance (crushing)	287	228	350
Movement underway	Noise disturbance	241	177	308
Trap/pot fishing	Substrate disturbance (sediment re-suspension)	227	165	291
Trap/pot fishing	Entrapment/Entanglement	144	99	192
Grounding	Substrate disturbance (sediment re-suspension)	135	109	163
Grounding	Substrate disturbance (crushing)	122	98	147
Equipment abandonment	Contamination	104	79	130
Sampling	Removal of organisms	89	73	105
Submersible operations	Substrate disturbance (sediment re-suspension)	70	48	93
Submersible operations	Substrate disturbance (crushing)	69	47	91
Equipment installation	Substrate disturbance (crushing)	66	44	89
Equipment installation	Substrate disturbance (sediment re-suspension)	60	38	83
Equipment installation	Contamination	38	19	58
Sampling	Substrate disturbance (sediment re-suspension)	32	20	45
Sampling	Substrate disturbance (crushing)	32	19	45
Submersible operations	Light disturbance	6	0	12
Scuba	Substrate disturbance (sediment re-suspension)	5	0	10
Scuba	Substrate disturbance (crushing)	5	0	10

Table 4.4: Proposed indicators and measurable components for activities and associated stressors known to impact the SK-B MPA. Each are presented roughly in order of priority.

Activity	Stressor	Indicator	Measureable component
Discharge	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 SK-B MPA.
		Species richness of aquatic invasive species	- Diversity measures (e.g. Shannon Simpson diversity index, taxonomic redundancy, taxonomic distinctness)
		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
	Debris	Relative abundance of debris	- Frequency of occurrence
		Debris characterization	- Debris type and size
	Oils/ 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 SK-B 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
	Nutrients	Nitrogen	- e.g. total nitrogen, concentration of nitrate, concentration of total ammonia
		Phosphorous	- Total dissolved phosphorous, soluble reactive phosphorous
Equipment abandonment	Contaminants	Proportion of water samples exceeding standards for water quality parameters of interest	- e.g. CCME Water Quality Index
		Potential contaminant	- Linked with equipment type and composition
		Length of exposure	- Length of time since installation
Equipment installation	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2

Activity	Stressor	Indicator	Measureable component
	Substrate disturbance (sediment re-suspension)	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
	Contaminants	Proportion of water samples exceeding standards for water quality parameters of interest	- e.g. CCME Water Quality Index
		Potential contaminant	- Linked with equipment type and installation method
Grounding	Substrate disturbance (sediment re-suspension)	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
	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of area/habitat crushed
		Vessel size/type	- Vessel size (m^2)
Movement underway	Noise disturbance	Vessel density in vicinity of the SK-B MPA	- Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell
		Noise frequency at the SK-B MPA	- Measure sound produced (e.g. hydrophones)
Oil spill	Oil	Vessel density in vicinity of the SK-B 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
Sampling	Removal of organisms	Biomass	- Weight/unit area of sampled (removed) organisms - Proportion (%) of biogenic habitat removed
		Maximum potential exposure	- Number of allowable samples - Number of research trips involving sampling per annum x maximum allowable samples
	Substrate disturbance (sediment re-suspension)	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
	Substrate disturbance	Crushed area	- Proportion (%) of the area crushed - m^2

Activity	Stressor	Indicator	Measureable component
	(crushing)		
Scuba diving	Substrate disturbance (sediment re-suspension)	Potential exposure	- Number of divers/annum
		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
	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2
Seismic testing/air guns	Sound generation	Distance from the SK-B MPA	- Distance-effect relationships for all taxa, particularly for eggs and larvae
		Shots fired (air-guns)	- Level of received sound experienced by sessile invertebrates, and the effects on these organisms (due to changes in bathymetry, could be areas more impacted than others).
		Sound propagation models	- Near-and far-field sound measurements encouraged as part of seismic operations
Submersible operations	Aquatic invasive species	Frequency of potential exposure	- Number of dives sites per cruise - Existence of cleaning/equipment flushing protocols between dive sites
		Species richness of aquatic invasive species	- Diversity measures (e.g. Shannon Simpson diversity index, taxonomic redundancy, taxonomic distinctness)
		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 re-suspension)	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
		Frequency of potential impact	- Number of collision events
	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2
		Frequency of potential impact	- Number of collision events

Activity	Stressor	Indicator	Measureable component
	Light disturbance	Area exposed to artificial light from submersible	- Areal coverage (%)
		Frequency of exposure	- Number of submersible dives within a cruise or given time period
Trap/pot fishing	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
	Aquatic invasive species	Frequency of potential exposure	- Number of traps per unit area
		Species richness of AIS	- Diversity measures (e.g. Shannon Simpson diversity index, taxonomic redundancy, taxonomic distinctness)
		Occurrence/abundance of AIS	- 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 AIS	- Weight/unit area
	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area/habitat crushed
		Maximum potential crushed area	- Size of trap x number deployed. Worst-case scenario dragging scenario = trap width x line length. Best-case scenario = trap footprint x number of traps
		Density of traps/pots	- Number of trap/pots deployed within a given area
	Substrate disturbance (sediment re-suspension)	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
	Entrapment/ Entanglement	Potential exposure to discarded/lost traps	- Number of traps with releasable openings (where ropes dissolve and trap can open) - Number of traps lost

4.3. INDICATOR IDENTIFICATION FOR SEC-STRESSOR INTERACTIONS

4.3.1. Prioritization of SEC-Stressor Interactions

The process outlined in Section 1.12 was applied to both *potential* SEC-stressor interactions (included SECs impacted by *sound generation (seismic surveys), oil (oil spill), aquatic invasive species (submersible operations, discharge,* and *fishing)*, and *debris (discharge)*, and *current snapshot* SEC-stressor interactions (all remaining interactions). Prioritization was implemented to reduce the number of SEC-stressor interactions in order to focus the selection of indicators on interactions with moderate to high priority. Of the 140 *current snapshot* interactions, all but 13 interactions fell into the low bin and were removed. Of the 74 *potential* SEC-stressor interactions, 43 were categorized as low priority and were removed from this process, leaving 31 *potential* interactions. 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 Tables 4.5 and 4.6.

Table 4.5: 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 (Rubidge et al.[1]).

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Isidella tentaculum	Trap/pot fishing	Substrate disturbance (crushing)	102	34	250
Isidella tentaculum	Trap/pot fishing	Substrate disturbance (sediment re-suspension)	89	43	225
Sponges (habitat)	Trap/pot fishing	Substrate disturbance (crushing)	79	27	185
Corals (habitat)	Trap/pot fishing	Substrate disturbance (crushing)	77	21	185
Isidella tentaculum	Trap/pot fishing	Removal of biological material	73	37	188
Sablefish	Trap/pot fishing	Removal of biological material	69	31	163
Rougheye Rockfish	Trap/pot fishing	Removal of biological material	62	37	162
Corals (habitat)	Trap/pot fishing	Removal of biological material	57	25	154
Corals (habitat)	Trap/pot fishing	Substrate disturbance (sediment re-suspension)	56	24	141
Sponges (habitat)	Trap/pot fishing	Substrate disturbance (sediment re-suspension)	54	25	140
Bocaccio	Movement underway	Noise disturbance	49	26	119
Sponges (habitat)	Trap/pot fishing	Removal of biological material	46	18	120
Yelloweye Rockfish	Movement underway	Noise disturbance	40	22	109

Table 4.6: Potential SEC-stressor interactions remaining after low-priority interactions were removed, presented with the median risk score and 10/90% quantiles for each interaction (Rubidge et al.[1]).

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Rougheye Rockfish	Seismic testing / air guns	Sound generation	106	28	235
Yelloweye Rockfish	Seismic testing / air guns	Sound generation	96	23	212
Halibut	Seismic testing / air guns	Sound generation	94	20	217
Bocaccio	Seismic testing / air guns	Sound generation	90	27	211
Prowfish	Seismic testing / air guns	Sound generation	86	21	196
Sablefish	Seismic testing / air guns	Sound generation	85	19	194
Widow Rockfish	Seismic testing / air guns	Sound generation	83	21	186
Macroalgae (habitat)	Oil spill	Oil	70	17	162
Coralline algae (habitat)	Oil spill	Oil	69	18	156
White Primnoa sp.	Oil spill	Oil	63	16	151
Sponges (habitat)	Oil spill	Oil	61	18	146
Corals (habitat)	Oil spill	Oil	60	17	144
Sponges (habitat)	Submersible operations	Aquatic invasive species	59	18	141
Isidella tentaculum	Oil spill	Oil	59	16	144
Corals (habitat)	Submersible operations	Aquatic invasive species	57	18	136
White Primnoa sp.	Discharge	Aquatic Invasive Species	55	23	134
Isidella tentaculum	Trap/pot fishing	Aquatic invasive species	54	19	136
Rougheye Rockfish	Oil spill	Oil	52	20	132
Halibut	Oil spill	Oil	51	20	118
Yelloweye Rockfish	Oil spill	Oil	48	15	117
Sponges (habitat)	Discharge	Aquatic invasive species	47	21	122
Isidella tentaculum	Submersible operations	Aquatic invasive species	46	20	121
Isidella tentaculum	Discharge	Aquatic invasive species	45	13	114
Corals (habitat)	Trap/pot fishing	Aquatic invasive species	45	15	122
Corals (habitat)	Discharge	Aquatic invasive species	45	16	112
Bocaccio	Oil spill	Oil	44	14	113
Prowfish	Oil spill	Oil	44	16	109
White Primnoa sp.	Submersible operations	Aquatic invasive species	44	17	118
Sablefish	Oil spill	Oil	42	17	109
Macroalgae (habitat)	Discharge	Aquatic invasive species	41	19	109
Widow Rockfish	Oil spill	Oil	41	18	104

4.3.2. Proposed Indicators for SEC-Stressor Interactions

Once interactions had been prioritized and low priority SEC-stressor interactions removed, the original scoring in Rubidge et al.[1] for each remaining interaction was analyzed to determine the key parameter driving risk (population size or condition), and to gain detailed information regarding the impact on the SEC-stressor interaction. SECs with similar taxonomic groups and impacting stressors were grouped together, with indicators and measureable components selected for each group (Appendix G). A summary of impacts of stressors on these SECs, as well as analysis on types of indicators that may be appropriate is in Appendix H.

4.3.3. Suites of Indicators

Suites of indicators are provided for both *current snapshot* and *potential* SEC-stressor interactions (Tables 4.7 and 4.8). These suites incorporate indicators selected for SECs and stressors (Tables 4.7 and 4.8 respectively).

Table 4.7: Indicator suites for current snapshot SEC-stressor interactions.

SEC	Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
- *Isidella tentaculum* - Corals (habitat) - Sponges (habitat)	Trap/pot fishing	Substrate disturbance (crushing)	- Abundance of colonies with visible damage/fragmentation - Number of dislodged colonies	- Abundance	- Maximum potential crushed area
		Substrate disturbance (re-suspension)	- Abundance of colonies showing signs of smothering - Number of colonies showing signs of smothering	- Health/ condition - Abundance	- Maximum induced increase in suspended sediments
		Removal of biological material	- No specific indicator that would adequately inform removal of corals and sponges - No specific indicator that would adequately inform removal of corals and sponges	- Abundance - Biomass	- Maximum potential exposure - By-catch
- Sablefish - Rougheye Rockfish	Trap/pot fishing	Removal of biological material	- Abundance/ population density - Biomass of removed organisms	- Abundance - Genetic diversity - Species richness and diversity	- Catch per unit effort - Maximum potential exposure
- Bocaccio - Yelloweye Rockfish	Movement underway	Noise disturbance	- No specific indicator that could be specifically linked to changes in fish population condition resulting from vessel noise.	- Abundance - Genetic diversity - Species richness and diversity	- Frequency of noise at the SK-B MPA - Vessel density in vicinity of the SK-B MPA

Table 4.8: Indicator suites for potential SEC-stressor interactions.

SEC	Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
- Rougheye Rockfish - Yelloweye Rockfish - Bocaccio - Widow Rockfish - Pacific Halibut - Prowfish - Sablefish	Seismic surveys	Seismic testing/ air guns	- Larval abundance - Change in condition/ sub-lethal effects - Behavioural response	- Abundance - Genetic diversity - Species richness and diversity	- Shots fired (air-guns) - Distance from the SK-B MPA - Sound propagation models - Frequency of sound
	Oil spill	Oil	- Abundance - Population density - Change in condition/ sub-lethal effects - Genetic diversity and structure	- Abundance - Genetic diversity - Species richness and diversity	- Vessel density in vicinity of the SK-B MPA - Oil spill volume - Oil type
- Macroalgae (habitat) - Coralline Algae (habitat)*	Oil spill	Oil	- Abundance - Species richness/ presence of disease	- Health/ condition - Abundance - Species richness	- Vessel density in vicinity of the SK-B MPA - Oil spill volume - Oil type
	Discharge	Aquatic invasive species*	- Abundance - Change in condition	- Health/ condition - Abundance - Species richness	- Frequency of potential exposure - Occurrence/abundance
- Sponges (habitat)* - Corals (habitat) - White Primnoa sp. - *Isidella tentaculum*	Oil spill	Oil	- Abundance of colonies with visible damage/ dead - Change in condition/ sub-lethal effects	- Health/ condition - Abundance - Species richness	- Vessel density in vicinity of the SK-B MPA - Oil spill volume - Oil type
	Submersible operations	Aquatic invasive species	- Abundance of colonies with visible damage/ dead - Change in condition/ sub-lethal effects	- Health/ condition - Abundance - Species richness	- Frequency of potential exposure - Occurrence/abundance
	Discharge	Aquatic invasive species	- Abundance of colonies with visible damage/ dead - Change in condition/ sub-lethal effects	- Health/ condition - Abundance - Species richness	- Frequency of potential exposure - Occurrence/abundance
	Trap/pot fishing	Aquatic invasive species	- Abundance of colonies with visible damage/ dead - Change in condition/ sub-lethal effects	- Health/ condition - Abundance - Species richness	- Frequency of potential exposure - Occurrence/abundance

5. DISCUSSION

The selection of appropriate ecological indicators is a key step in the adaptive management of the SK-B MPA (Figure 1.1). 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 4.7 and Table 4.8 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 size and condition), using different types and sources of data, to provide information on changes within the ecosystem.

5.1. SUITES OF INDICATORS FOR MONITORING

SEC-stressor interaction indicators are 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 to establish baselines of information collected by monitoring SEC and stressor specific indicators, complimenting existing datasets. The order of presentation of the indicator suite tables (Tables 4.7 and 4.8) 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.

Indicators presented in the *current snapshot* suite generally measure the SEC-stressor interaction directly and can be monitored at the same time as collecting general information for establishing population baselines. For example, while conducting visual surveys to establish population baselines of corals, the number of dislodged corals and/or corals showing 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 the measurement to that interaction increases. 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 SEC-stressor interactions, and rely on measures of stressors and/or impacted species. 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, then established baseline information is needed to in order to measure the effect 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). 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 and thus different indicators, and the same indicators measured at different scales and in different ways, will detect true trends on various timescales (Jennings 2005)

Johannes (1998) noted that when resources are very limited, stressor indicators are easier and cheaper to use than SEC indicators. However, information baselines for SECs are still required in the longer term, as it is unlikely that any restrictions on activities in the SK-B MPA would be accepted without evidence that the restrictions helped 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 cheaper 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).

5.2. DATA COLLECTION AND ADDRESSING KNOWLEDGE GAPS

Indicators related to measures of abundance are suggested in most indicator suites, highlighting the need to establish baseline information for all SECs as a priority at the SK-B MPA. Once these baselines are established, changes in population size and condition can be measured and monitored, and perhaps linked to natural and/or anthropogenic stressors. This approach is particularly crucial for *potential* SEC-stressor interactions, as monitoring the impacts from these unpredictable stressor interactions will not be possible until the event occurs.

Indicators were selected with consideration given to the limitations of research and monitoring at the SK-B MPA. Such limitations include the remote offshore location and the associated high cost of access. Large swells, rough seas, and depths at the seamount prohibit scuba diving much of the year, leaving monitoring heavily reliant on the use of remote methods such as submersibles (ROVs/AUVs), drop cameras, box grabs and dredges, etc. Most of the proposed indicators are reliant on visual surveys, selective sampling (reliant on submersibles at this time), or existing datasets (e.g. catch/by catch, vessel density, oceanographic, scientific surveys, etc.). With many indicators requiring visual surveys as a technique to measure the indicator and the overlapping distribution of several SECs, multiple indicators may be measured or sampled during the same operations period. Additionally, the use of visual surveys to monitor multiple indicators reduces the incidences of destructive sampling/measurements.

The suites of indicators selected in this process will likely evolve over time as resources and information become available (Jennings 2005). As more information from 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 SK-B 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 in Table 3.1 and be scored against the more detailed criteria presented in Appendix B.

While indicators were selected based on the best available knowledge of indicator development and monitoring, the effectiveness of indicators at measuring changes to SECs resulting from interactions with stressors at the SK-B 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 Figure 1.1). 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 SK-B 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) and their ability to detect or predict trends in attributes (Jennings 2005).

The next step in the adaptive management framework (Figure 1.1) is to develop monitoring strategies, which will typically include specifications for data collection, 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). 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 SK-B 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.

5.3. 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 for determining the effectiveness of management measures, and of the indicators themselves. For remote, difficult to access areas like the SK-B MPA, the sampling design and tools required to collect information on relevant indicators are limited by technology, funds, and time. The example provided by DFO (2010) may be applied to the SK-B MPA also; trawl surveys may not adequately sample Coral and Sponge communities, as the ability of the gear to capture and retain them is unknown, and ROV surveys only sample small areas at a 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. In the example of Corals and Sponges, a combination of visual surveys and selective sampling, data from scientific trawls, and by-catch data from existing fishery activities will provide a more complete picture than only using only one of those techniques. The development of new sampling tools in the future will further add to these datasets. For example, cameras are being placed on Sablefish trap, providing information on sedimentation, damage to benthic communities, etc.

5.3.1. Conservation Objectives

The current conservation objective at the SK-B MPA is broad and more specific operational objectives had not been defined at the time of this study. 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 useful and relevant for the management of anthropogenic stressors at the SK-B MPA. While it would have been preferable to have refined conservation objectives to link to selected indicators and use as potential selection criteria throughout the risk-based indicator selection process, the lack of SMART objectives did not inhibit the selection of indicators given the current state of knowledge of the SK-B MPA ecosystem.

The refinement of conservation objectives into SMART operational objectives usually occurs earlier in MPA adaptive management than shown in Figure 1.1. J.C Rice (DFO Science, Ottawa, unpublished) has noted that indicators need to be linked to conservation objectives and an effective management process, otherwise the indicators will allow you to see your fate more clearly, but not avoid it (Jennings 2005). Therefore, refined conservation objectives should be developed in conjunction with the next step in the adaptive management cycle, development of monitoring strategies. These operational objectives may be developed in conjunction with the development of monitoring strategies using a combination of the outputs of the risk assessment and the prioritization of SEC-stressor interactions identified during this risk-based indicator selection framework. SECs, those components deemed essential to the diversity and functioning of the ecosystem, were identified during the scoping phase of the ERAF. While refined conservation objectives will consider more than just ecological functioning (e.g., cultural and socio-economic values), the identified SECs should form the basis of ecosystem considerations. Similarly, the anthropogenic stressors identified include those manageable at the MPA scale, and the relative rankings of the stressors by risk to the SK-B MPA will assist in the refinement of conservation objectives. The inclusion of the developed operational objectives in the indicator selection criteria will improve future iterations of risk-based indicator selections.

5.3.2. Ecosystem Indicators

This work produced risk-based indicators, based on the outputs of the application of the ERAF to the SK-B MPA. The scoping phase of the ERAF identified SECs and stressors that appropriately represented the ecosystem (Rubidge et al.[1]). Through this process, some ecosystem components were identified as having high conservation relevance at the SK-B MPA, but could not be included in the risk assessment process as they were transient in nature, and/or stressors were not manageable at the MPA scale. The components that were excluded include Phytoplankton, Zooplankton, several species of seabirds (Murphy's Petrel (*Pterodroma ultima*), Buller's Shearwater (*Puffinus bulleri*), Sooty Shearwater (*Puffinus griseus*), Ancient Murrelet (*Synthliboramphus antiquus*), Black footed Albatross (*Phoebastria nigripes*)), Sharks (Pacific Sleeper Shark (*Somniosus pacificus*), Spiny Dogfish (*Squalus acanthias*), Blue Shark (*Prionace glauca*), Basking Shark (*Cetorhinus maximus*)), and marine mammals (Killer Whale (*Orcinus orca*), Steller Sea Lion (*Eumetopias jubatus*)). See Appendix F6.3 in Rubidge et al.1 for details. Additionally, a newly discovered Glass Sponge species (*Doconesthes dustinchiversi*) has also been identified as having high conservation value at the SK-B MPA. These species should be considered in any future development of ecosystem indicators, as they were identified using criteria similar to those used in other ecosystem indicator identification processes.

Two communities were identified as SECs during the scoping phase of the ERAF but were not included in the risk assessment: benthic invertebrate assemblage and Rockfish species assemblage. These communities should be considered in any future application of the ERAF as well as the development of additional risk-based and ecosystem indicators.

5.3.3. Stressors

The scoping phase of the ERAF identified anthropogenic stressors impacting the SK-B 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 Rubidge et al.[1], future iterations of this work may include the further development of the stressors. For example, debris is a *potential* stressor and is currently scored in the ERAF as the worst-case scenario, that is, crushing of the SEC by debris. In reality, debris type and size may vary significantly, with a greater range of associated stressors, such as: *substrate disturbance (crushing), substrate disturbance (sediment re-suspension); substrate disturbance (foreign object); prey imitation (particularly relevant for plastic debris)*; and *entrapment/entanglement.* Additionally, *sampling* may be divided by sample type (e.g., biological, geological, fluids, etc.).

Long-range stressors were not included in this analysis because it was based directly on the outputs of the ERAF application. For future iterations the indicator selection criteria (Table 3.1) may be used to select appropriate indicators for long-range impacts such as vessel noise, long-range transport of contamination (persistent organic pollutants), and stressors related to climate change (e.g., ocean acidification, AIS 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 SK-B 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, particularly when including community properties and ecosystem services.

6. CONCLUSIONS/RECOMMENDATIONS

The selection of ecological risk-based indicators is a key step in the adaptive management (AM) framework for the SK-B 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 may 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 SK-B MPA are:

- Information baselines need to be established as a priority. This need was highlighted by the proposal of measures of abundance across all indicator suites;
- Both *current snapshot* and *potential* stressor indicator suites using a combination of SEC, stressor, and SEC-stressor interaction indicators should be considered when developing monitoring strategies and plans;
- *Current snapshot* indicator suites should be monitored at the same time as collecting general data to establish baselines and measure disturbances using SEC and stressor indicators;
- *Potential* indicator suites should be monitored in two steps: establish information baselines using SEC and stressor indicators; and if/when a 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; and
- 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 removed from monitoring plans.

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8. 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 variety 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 influences that species have on 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 area of interest.

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: SUMMARY OF SECS FROM RUBIDGE ET AL.[1]

Table A.1. Summary of SECs from Rubidge et al.[1]

SEC	Summary
Prowfish (*Zaprora silenus*)	Prowfish (*Zaprora silenus*) are the only species and genus of Family Zaproridae. This taxonomically distinct and somewhat rare species is distributed in the North Pacific from California north through the Gulf of Alaska, west through the Bering Sea and Aleutian Islands to the Asiatic shelf and then south to Hokkaido (Smith et al. 2004). It inhabits depths between 0 – 800 m but is most often encountered between 10 – 675m (Smith et al. 2004). Prowfish are pelagic as larvae and become demersal as adults (Smith et al. 2004). Juvenile Prowfish use jellyfish aggregations for rearing in order to seek refuge from surface predators; however jellyfish become one of the main prey items as adults (Smith et al. 2004). There are unusually large numbers of Prowfish present at Bowie Seamount, and they are found at much shallower depths (over the seamount pinnacle and near surface) than adults are normally recorded (Canessa et al. 2003).
Sablefish	Sablefish, *Anoplopoma fimbria*, is a demersal fish endemic to the North Pacific Ocean and a key predator associated with the SK-B MPA (Beamish et al. 2005). Although there has been some debate over whether or not sablefish at Bowie are a distinct population from the coast (see Kabata et al. 1988; Kimura et al. 1998; Whitaker and McFarlane 1997), the most recent data suggest the seamount population is not distinct and fish regularly move from the coast to the seamount and vice versa (DFO tagging studies results - DFO seamount database). Although Sablefish may not be a year round resident at Bowie the presence of a sablefish population at Bowie is consistent. Landing data show that sablefish are caught every year at the seamount (DFO database; Canessa et al. 2003). Sablefish were selected as a Significant Ecosystem Component (SEC) of the SK-B MPA because they fill two species SEC selection criteria as outlined in O et al. (2015). First, the movement of Sablefish on and off the seamount could justify this species as an important nutrient importer/exporter, defined by O et al. (2015) as “Species that 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”. Other important groups of species important to the transfer of nutrients and energy on Bowie Seamount include primary producers (Phytoplankton, Macroalgae), detritvores (e.g., Squat Lobsters, Crabs, Sea Stars), sediment reworkers (e.g., Sea Cucumbers) and benthic filter/suspension feeders (bivalves and barnacles). Second, sablefish are a top (mainly piscivorous) predator in the system and fluctuations in the sablefish population will influence the population dynamics of other key predators (Halibut, Rockfish) and prey (rockfish, other demersal fishes, cephalopods, crustaceans etc. Their role as a top predator fulfills the SEC criteria of a species that has “an important food web relationship where an impact to it would cause vertical or horizontal change in food web”.
Pacific Halibut	The Pacific Halibut (*Hippoglossus stenolepis*) has been identified as a keystone predator in coastal ecosystems (Lee et al. 2010) and their diet includes Walleye Pollock (*Gadus chalcogrammus*), Pacific Cod, (*Gadus macrocephalus*), Rockfish, (Sebastes), Pacific Herring (*Clupea pallasi*), Pacific Sandlance (*Ammodytes hexapterus*), Arrowtooth Flounder (*Atheresthes stomias*), Sculpins (Cottidae), salmon (Oncorhynchus spp.), Eelpouts (Lycodes spp.), Crabs, Shrimps, Squids, and Octopi among other species. The fish assemblage at SK-B MPA lacks a small-pelagic fish community and therefore has simplified trophic interactions. Halibut are a key top predator in the seamount ecosystem and prey upon Rockfish, Sablefish and benthic invertebrates (e.g., King Crab). A trophic model of the seamount developed by

SEC	Summary
	Beamish and Neville (2003) showed that a reduction in the Halibut population increased the production of Sablefish, Rockfish and Crab in the ecosystem because these species are key items in the halibut diet. Halibut fishing has occurred at the seamount (either longline or bottom trawls) since the 1950s but there have been no records of commercial halibut landings from the seamount since 1991 (reviewed in Canessa et al. 2003). Currently, no legal halibut fishery occurs within the MPA boundary. Due to its importance as a top predator at the SK-B, Pacific Halibut was selected as a species level Significant Ecosystem Component (SEC) for the ecological risk assessment.
Rockfish	The fish community at the SK-B is dominated by rockfish (25 species), including 7 listed species. The most abundant rockfish species in the MPA are Rougheye, Yelloweye, and Widow Rockfish (Canessa et al. 2003). Rockfish are a key component of the Bowie ecosystem but rather than complete the risk assessment on all 25 species that are present in the MPA, we have selected representative rockfish species from 1. each rockfish community assemblage (inshore, shelf and slope), 2. species that are of high conservation concern (threatened or endangered) and 3. species that are known to be highly abundant at the MPA.
Bocaccio Rockfish	Bocaccio Rockfish have been documented to occur at the SK-B MPA (Yamanaka and Brown 1999) and are a designated as “Threatened” by COSEWIC, listed as “Endangered” under US ESA and IUCN has designated this species as “Critically Endangered”. Given their slow recovery time and internationally threatened status, it is important to better understand the impacts of human activities on this species within SK-B MPA. Bocaccio Rockfish are a shelf species that are most common between 50-250 m in depth, but may be found between 12-478 m.
Yelloweye Rockfish (*Sebastes ruberrimus*)	Yelloweye Rockfish (*S. ruberrimus*) are an abundant species of inshore rockfish found at the SK-B MPA (Canessa et al*.* 2003; McDaniel et al*.* 2003; Yamanaka et al*.* 2005). This SEC is a representative species SEC for the inshore rockfish group. Yelloweye Rockfish have a COSEWIC status of “Special Concern” and the Puget Sound/Georgia Basin Distinct Population Segment is listed under USA Endangered Species Act as “Threatened”. In general they are found at depths between 15-549 m. Due to their depth and habitat preferences, Yelloweye Rockfish do not overlap much with the sablefish trap fishery and this species has not been reported as non-target catch between 2006-2012 (DFO seamount database).
Rougheye/ Blackspotted Rockfish (*Sebastes aleutianus/ S. melanostictus*)	The Rougheye/Blackspotted Rockfish complex is made up of two species, *S. aleutianus* and *S. melanostictus*, which are nearly impossible to distinguish from external morphology. The most effective method for distinguishing between the two species in the complex is through DNA analyses (Fisheries and Oceans Canada 2012). For the purposes of this risk assessment, we assessed the two species in the complex together and refer to them as Rougheye Rockfish. Rougheye Rockfish are highly abundant at Bowie and make up the dominant rockfish species at the seamount (Canessa et al. 2003; McDaniel et al. 2003; Yamanaka 2005). Rougheye Rockfish are in the slope rockfish group and generally inhabit depths between 25 – 2000 m. COSEWIC status is “Special Concern” and they are listed under SARA in “Schedule 1, Special Concern”. Because of the simplified fish community at Bowie, Rougheye Rockfish are considered both a key predator and prey in the ecosystem, and modeling results indicate that fluctuations in the Rougheye Rockfish population will impact the Sablefish and Halibut populations at the SK-B MPA. Although a prey switch from rockfish to crab may occur, Beamish and Neville (2003) speculate that sablefish and halibut would likely leave the ecosystem if the rockfish population significantly declined. Rougheye Rockfish are the most common non-target catch species at the SK-B MPA

SEC	Summary
	(Canessa et al. 2003; IFMP 2012) and legally, fisherman can keep up to 2.2 metric tonnes (5,000 lbs) of Rougheye Rockfish each month of the fishing season. In general, however, landed catch is much lower than allowable catch. For example, between 2006 -2012, the average monthly catch of Rougheye Rockfish at the SK-B was 0.5 metric tonnes (1,100 lbs; DFO seamount database).
Widow Rockfish	The Widow Rockfish, *S. entomelas*, like both the Rougheye and Yelloweye rockfish are highly abundant at the SK-B MPA (Canessa et al. 2003; McDaniel et al. 2003). The complete age range of Widow Rockfish has been observed at Bowie indicating that it is a self-sustaining population. Perhaps most interesting are the high numbers of juveniles present at the seamount, suggesting that this species is likely a key prey fish for other rockfish species, Halibut and Sablefish (Yamanaka *pers. comm.* 2014). Due to its abundance, its potentially self-sustaining resident population, and its likely importance in the trophic dynamics at the seamount, Widow Rockfish was selected as a SEC. In general, Widow Rockfish are found at depths between 24-549 m and at the SK-B, large schools of many thousands have been observed at 25 m depth (McDaniel et al. 2003).
Squat Lobster (*Munida quadrispina*)	The Squat Lobster, *Munida quadrispina*, is a highly abundant species at SGaan Kinghlas Bowie MPA (SK-B MPA; Canessa et al. 2003; McDaniel et al. 2003). Because of this abundance, likely plays a key role in nutrient cycling as a detritivore and also a key prey species (Boutillier *pers. comm*.). In addition, because Squat Lobsters are known to be quite resilient to certain stressors (such as oxygen deficiency, Mataboas et al. 2012) a change in the abundance in squat lobster may indicate an extreme change in the environment.
Isidella tentaculum	*Isidella tentaculum* is a newly described species (Etnoyer 2008), with little available data from BC waters (J. Boutillier *pers. comm.*). The taxonomy of the Isidella group is not yet well understood and aging in this family of corals has indicated that they can live hundreds if not thousands of years. This species is a large (up to 132 cm high), abundant, and conspicuous habitat former. This species is not endemic to the SK-B MPA, and is known to occur at the peaks of Northeast Pacific seamounts, continental slopes, and shelf canyons. The depth range is greater than for Primnoa sp., ranging from 720-1050 m. This species was chosen as a SEC as it fulfills the criteria of rare, unique, sensitive, and habitat creating species.
White Primnoa sp.	White Primnoa sp. is highly prevalent at the seamount and is found predominantly in the protected zone (above 457m) at the SGaan Kinghlas Bowie Seamount Marine Protected Area (SK-B MPA) (Boutillier *pers. comm.*). White Primnoa is known from Alaska but has not been identified within BC waters and there are no reports anywhere else of the large concentrations as seen at the SK-B MPA, making the high prevalence unique to the SK-B MPA (J. Boutillier *pers. comm.).*
Demosponges	Encrusting demosponges were chosen as a habitat SEC at the SK-B MPA because they are sensitive to disturbances, slow to recover, and provides three dimensional structure and food source for many associated species.
Deep-water Alcyonacea Corals (Habitat)	Deep-water Alcyonacea corals were chosen as a habitat SEC because they are sensitive to disturbance and slow to recover; they provide a three dimensional and complex structure and are associated with numerous species that utilize corals for food, settlement, and protection. However, the catchability of corals and sponges in commercial and research trawl sets are unlikely to be the same. Consequently, thresholds based on research vessel data

SEC	Summary
	are not likely to reflect those that would be appropriate for commercial fisheries, but unfortunately there are minimal data available from commercial vessels. There is considerable additional uncertainty introduced by estimating catches based on survey tows to derive encounter thresholds that will be applied to commercial-length tows; therefore this is not a recommended approach if alternative sources of thresholds for commercial catches are available.
Macroalgae	Macroalgae provides habitat for numerous invertebrates and fish species (particularly for juvenile rockfish, including sensitive and listed species). They serve as spawning habitat and nursery areas for fishes as well as providing a food source for various taxa. Macroalgae are present only in the restricted shallowest areas at the seamount pinnacle, but their depth range is still greater at the seamount than the coast.
Coralline Algae	Coralline Algae play a critical role in binding and consolidating materials and providing larval settlement substrate. Coralline algae are associated with numerous algal and invertebrate species at the SK-B MPA.

APPENDIX B: RISK-BASED INDICATOR SELECTION CRITERIA FOR FUTURE APPLICATIONS OF THE RISK-BASED INDICATOR SELECTION FRAMEWORK

Table B.1. Risk-based indicator selection criteria for future applications of the risk-based indicator selection framework.

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) - 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 SK-B 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.
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

Criteria	Sub-criteria	Description
	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
	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 JUSTIFICATIONS

Table C.1. Proposed indicators for sessile benthic invertebrate SECs (Isidella tentaculum, corals (habitat), white Primnoa sp, sponges (habitat), Coralline algae (habitat), macroalgae (habitat)).

Proposed indicator	Measureable component	Justification
Population size		
Abundance	Areal coverage (%) – (Macroalgae, coralline algae) Patch area (m^2) Number per m^2 (corals, sponges)	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
Population condition		
Biomass	Weight/unit area	- 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
Condition (disease/ aquatic invasive species)	Abundance (proportion of the population %) of organisms displaying visible signs of disease, aquatic invasive species	- The percentage of scientific articles reporting the presence of disease/pathogens in marine taxa is a worldwide measure. This indicator does not account for the severity of the disease outbreak; a very large outbreak counts the same as a relatively small outbreak. Overall deemed not very useful (Andrews et al. 2013). - Highly sensitive to sampling effort as well as the selectivity of the sampling device
Health/ condition	Abundance (proportion of colony/habitat (%)) displaying visible signs of damage.	- Quantifiable and repeatable - Well-used index, comparable across ecosystems - Highly sensitive to sampling effort as well as the selectivity of the sampling device

Table C.2. Proposed indicators for mobile benthic invertebrate SEC squat lobster.

Proposed indicator	Measureable component	Justification
Population size		
Abundance/ species density	Average density/count of organisms within a given range	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
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.3. Proposed indicators for fish SECs.

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
Size structure	- Size-frequency distribution	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
Species richness and diversity	- Population or stock delineation	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
Population condition		
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
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 (Hooff and Peterson 2006; Andrews et al. 2013)
Spatial distribution	Spatial distribution of the species within the MPA	- The species home range can be an indicator of fish condition
Genetic diversity of populations	Population or stock delineation	- Strongly supported in the literature (Andrews et al. 2013). - Genetic diversity is an important component in order to determine the health and success of a population

APPENDIX D: SEC INDICATOR CRITERIA SUMMARY

Table D.1. SEC indicators scored against criteria.

Population size

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
Abundance/ species density	- Number of individuals (count/ number per m^2, density) - Number of colonies (corals/ sponges) - Density - Areal coverage (%/m^2) - Frequency of occurrence - Habitat suitability model - Size-frequency distribution	Commonly used metric and is comparable across ecosystems	- 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 individual per unit area - Catch and by-catch data are fishery-dependent and are biased toward fisher behaviour, fleet dynamics, and	There may be issues related to sampling sensitivity among different coral and sponge species and between gear types (DFO 2010A)	- Catch data only exists for economically valuable species - Bycatch data are heavily influenced by fisher behaviour and management restrictions	- Good way to establish population baselines - Also related to habitat quality and community structure - There may be issues related to sampling sensitivity among different coral and sponge species and between gear types (DFO 2010A) - Measurements repeatable, quantifiable, and comparable across ecosystems - Data can be collected using visual surveys

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
			management restrictions (Andrews et al. 2013) - Habitat suitability models may be used to predict presence and/or abundance in unsurveyed areas, but may be highly uncertain.			
Species richness/ diversity	- Diversity measures - e.g. Shannon-Weiner, Simpson Indexes	- Commonly used metric and is comparable across ecosystems - (Large et al. 2014)	- Quantifiable - Repeatable - Can't be calculated without biomass estimates, and it is limited by taxonomic resolution (DFO - Adult sablefish biomass – Shannon Diversity: Theoretically correlated with community diversity in British Columbia ecosystem during modeling exercises (Andrews et al. 2013) - Species richness measures ne dimension of biodiversity, but does not require estimates of abundance - Diversity measures the	- Sensitive to the different catchabilities of different components of marine systems (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 catch/by-catch data	- Indicator of community structure - Metrics used are well established - Repeatable, quantifiable, and comparable across ecosystems

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
			number and evenness among species			
Biomass	Weight/unit area	- Commonly used indicator for individual focal species - Blanchard et al. 2010; Shin et al. 2010; Large et al. 2014)	- 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	- Changes in biomass are detectable depending on the frequency of data collection (DFO 2010A) - Changes in a single rockfish group may or may not be indicative of the entire community (Andrews et al. 2013) - For demersal fish: 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 and responds to fishing pressure; gradual change	- Some data is available for fish from catch records - Some data available for corals and sponges from by-catch records	- Should be used in conjunction with other population size indicators, such as abundance - Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling - Subject to sampling gear selectivity (DFO 2010A) - Relevant to fishing

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
				should show major community reorganization (Andrews et al. 2013)		

Population condition

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
Size/ age structure of populations		- Theoretically sound - Commonly used metric	- Size structure is generally biased by sampling gear and catchability of sampling/survey method	- Useful and simple indicator to evaluate effects of fishery removals, but may not be observable over short-term monitoring data sets.	- Catch: Good indicator of fishing effects but poor indicator of marine ecosystem performance, primarily a function of fishing effort and a poor approximation of production, landings can be misleading in assessments ecosystems (Andrews et al. 2013)	- Cannot be used for cold water corals and sponges
Parasitic load	Presence/ absence of parasites (external/internal)	- Theoretically sound - Known metric	- Measurement mostly reliant on catch/ bycatch data. - Quantifiable as a percentage of sampled catch - Repeatable	- Could be achieved in short-term monitoring. Time series monitoring preferable, but not necessary.	- Catch data only exists for economically valuable species - Bycatch data are heavily influenced by fisher behaviour and management restrictions	- Not relevant to management actions or reference points - May be difficult to sample depending on AIS /parasite type. Organism stress may be expressed in other ways (e.g. increase

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
						mucous production for corals, etc.). - Sampling method invasive
Disease	Presence/ absence of disease	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 mostly reliant on catch/ bycatch data. - Quantifiable as a percentage of sampled catch - Repeatable - Sampling most likely opportunistic	Could be achieved in short-term monitoring. Time series monitoring preferable, but not necessary.	- Catch data only exists for economically valuable species - Bycatch data are heavily influenced by fisher behaviour and management restrictions	- Not relevant to management actions or reference points - May be difficult to sample depending on disease/how organisms responds to stress
Health/ condition	Abundance of organisms/habitat displaying visible injury to organism or behavioral indicators (e.g. righting and feeding behavior, reflex actions)	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 mostly reliant on catch/ bycatch data for fish and visual surveys for benthic habitat SECs (e.g., corals) - Quantifiable as a percentage of sampled catch - Repeatable	Highly sensitive to sampling effort as well as the selectivity of the sampling device	- Catch data only exists for economically valuable species - Bycatch data are heavily influenced by fisher behaviour and management restrictions	Highly sensitive to sampling effort as well as the selectivity of the sampling device
Species range	Spatial extent/range of species	Well-used index, comparable across ecosystems	- This could be informed through monitoring other indicators - Repeatable - Quantitative	- Results directly related to the coverage of the sampling method - Fairly	Reliant on visual surveys and catch data	May occur outside the limits of the MPA

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
				insensitive as an indicator and is slow to respond after perturbation. - Often by the time significant changes are documented, usually any other ecological consequences have occurred (DFO 2010A) occurrence,		
Condition factor, k	e.g. weight/length, age, stomach contents, presence of disease or invasive species, parasitic load	Commonly used metric for fish. FISH: Theoretically sound as condition of fish is directly related to growth and fecundity	Measurement mostly reliant on catch/ bycatch data for fish and visual surveys for benthic habitat SECs (e.g. corals)	- Visual survey - Stock assessment techniques - Catch data	- Catch data only exists for economically valuable species - Bycatch data are heavily influenced by fisher behaviour and management restrictions	Theoretically sound as condition of fish is directly related to growth and fecundity (Hooff and Peterson 2006; Andrews et al. 2013)
Genetic diversity of populations	Population or stock delineation	Commonly used metric for fish. Strongly supported by literature	Measurement mostly reliant on catch/ bycatch data for fish and visual surveys for benthic habitat SECs (e.g., corals)	- Stock assessment techniques - Catch data	Catch data only exists for economically valuable species Bycatch data are heavily influenced by fisher behaviour and management restrictions	Genetic diversity is an important component in order to determine the health and success of a population

APPENDIX E: STRESSOR INDICATOR CRITERIA SUMMARY

Table E.1. Stressor indicators scored against criteria.

Discharge

Stressor	Indicator	Measureable component	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 designated grid cell	- 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 areas affected by these trips. - The number of ports the vessels visit correlates with potential harmful species introductions in most regions globally.	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	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Species richness	- Diversity measures - e.g., Shannon-Weiner and Simpson Indexes, taxonomic redundancy, taxonomic distinctness	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
	Abundance	- Total count of non-native species with established breeding populations (and potential changes in distribution) - Areal coverage (%/m^2) - Count 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 taxon can be distinguished - Species density estimates use numerical abundances of individual per unit area	- 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 it's creation. (Andrews et al. 2013).

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Biomass	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)
Debris	Relative abundance	- Frequency of occurrence - Weight – clean up attempts	Established indicator with known limitations	- Quantifiable - Repeatable - Measurement obtained by visual surveys or debris clean-up programs	No debris data is available for the SK-B MPA	Ocean-based surveys have not used consistent methods and have been performed sporadically at small spatial scales. Estimates are likely lagging indicators of debris currently going into the ecosystem (Andrews et al. 2013)

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Debris characterization	Debris type and size	Established as part of ocean-based surveys, with known limitations	- Quantifiable - Repeatable - Measurement obtained by visual surveys or debris clean-up programs	No debris data is available for the SK-B MPA	Ocean-based surveys have not used consistent methods and have been performed sporadically at small spatial scales. Estimates are likely lagging indicators of debris currently going into the ecosystem (Andrews et al. 2013)
Oils/ contaminants	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)

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	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 appropriate time series	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, 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)
Nutrients	Nitrogen	e.g. total nitrogen, concentration of nitrate, concentration of total ammonia	Commonly used metric	- Requires time series data to be effective - Repeatable - - Measurements are possible, but may be difficult to establish appropriate time series	Many impacting factors, and may not be able to trace back to particular event.	Long range indicator and lacks specificity
	Phosphorous	Total dissolved phosphorous, soluble reactive phosphorous	Commonly used metric	- Requires time series data to be effective - Repeatable - Measurements are possible, but may be difficult to establish appropriate time series	Many impacting factors, and may not be able to trace back to particular event.	Long range indicator and lacks specificity

Equipment abandonment

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Contaminants	Proportion of water samples exceeding standards for water quality parameters of interest	e.g. CCME Water Quality Index	Commonly used metric	- Quantifiable - Repeatable - Not very specific to stressor	No/little data	
	Potential contaminant	Linked with equipment type and composition	Commonly used metric	- Quantifiable - Repeatable - Not very specific to stressor		
	Length of exposure	Length of time since installation	Commonly used metric	- Quantifiable - Repeatable - Not very specific to stressor	Some data available from remote sensing studies	

Equipment installation

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	No habitat mapping or sediment characteristics known.	- 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	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended sediments/ turbidity	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 re-suspension.	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 re-suspension. - 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
Contaminants	Proportion of water samples exceeding standards for water quality parameters of interest	e.g. CCME Water Quality Index	Commonly used metric	- Quantifiable - Repeatable - Not very specific to stressor	No/little data	

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	Potential contaminant	Linked with equipment type and installation method	Commonly used metric	- Quantifiable - Repeatable - Not very specific to stressor	No/little data	

Grounding

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (sediment re-suspension)	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 re-suspension.	Little to no data exist	
	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 re-suspension. - 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	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (crushing)	Crushed area	Proportion (%) of area/habitat crushed	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	No habitat mapping or sediment characteristics known.	- 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
	Vessel size/type	Vessel size (m^2)	Not an established metric for vessel groundings, but established for debris/crushing impacts			

Movement underway

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Noise disturbance	Vessel density in vicinity of the SK-B 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
	Level of noise at the SK-B MPA	Measure sound produced (e.g., hydrophones)	Established metric	- Quantifiable - Repeatable - Ongoing monitoring possible	Hydrophones have recently been installed at the SK-B the MPA	Long-range stressor.

Oil spill

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Oil	Vessel density in vicinity of the SK-B 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 areas affected by these trips.	No records of oil spills at the SK-B MPA	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).
	Oil spill volume	Surface area *x* minimum thickness	Currently used indicator in BC waters (DFO)	Measurement can be obtained by remote sensing/imagery	Data exists on remote sensing of discharged oils in BC. This 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

Sampling

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Removal of organisms	Biomass	- Weight/unit area of sampled (removed) organisms - Proportion (%) of biogenic habitat removed	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)
	Maximum potential exposure	- Number of allowable samples - Number of research trips involving sampling per annum x maximum allowable samples				
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended	e.g. mg/L, ppm, % of background	Commonly used metric	- May be difficult to measure at time of disturbance. - Visual surveys (% of	Little to no data exist	

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	sediments			background) are the most realistic method for measuring sediment re-suspension.		
	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 re-suspension. - 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
Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	No habitat mapping or sediment characteristics known.	- 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

Scuba diving

<table>
<tr><th rowspan="2">Stressor</th><th rowspan="2">Indicator</th><th rowspan="2">Measureable component</th><th colspan="3">Criteria</th><th rowspan="2">Notes</th></tr>
<tr><th>Theoretically sound</th><th>Measurable/ feasible</th><th>Historical data*</th></tr>
<tr><td rowspan="2">Substrate disturbance (sediment re-suspension)</td><td>Maximum induced increase in suspended sediments/ turbidity</td><td>e.g. mg/L, ppm, % of background</td><td>Commonly used metric</td><td>- May be difficult to measure at time of disturbance.
- Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.</td><td>Little to no data exist</td><td>- 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</td></tr>
<tr><td>Substrate composition</td><td>- e.g. % of substrate particles <6.35 mm</td><td>Commonly used metric</td><td>- May be difficult to measure at time of disturbance.
- Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.
- Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications</td><td>No habitat mapping or sediment characteristics known.</td><td>Requires baselines of sediment and habitat types</td></tr>
</table>

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	No habitat mapping or sediment characteristics known.	- 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

Seismic surveys

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Seismic testing/air guns	Distance from the SK-B MPA	Distance-effect relationships for all taxa, particularly for eggs and larvae	Suggested in other studies	Simple to measure/collect data	There are huge information gaps on the effects of seismic surveys on the marine environment	Informs of the likelihood of exposure to seismic activity, but not the effect on the ecosystem
	Shots fired (air-guns)	Number of shots fired during sampling operations	Suggested in other studies	Simple to measure/collect data	Information gaps on the effects of number of shots fired on the marine environment	Informs of the exposure of the seismic activity, but not the effect on the ecosystem
	Sound propagation models	Near-and far-field sound measurements encouraged as part of seismic operations	Known method.	Modelled from bathymetric data	Some bathymetric data available for the SK-B MPA	Once baselines of sound are established, studies can then focus on measuring disturbances

Submersible operations

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species	Frequency of potential exposure	Number of dives sites per cruise				
	Species richness	- Diversity measures - e.g. Shannon-Weiner and Simpson Indexes, taxonomic redundancy, taxonomic distinctness	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
	Abundance	- Total count of non-native species with established breeding populations (and potential changes in distribution) - Areal coverage (%/m^2) - Count 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 taxon can be distinguished - Species density estimates use numerical abundances	- 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	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				of individual per unit area		
	Biomass	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).
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended sediments/ turbidity	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 re-suspension.	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	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				background) are the most realistic method for measuring sediment re-suspension. - Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications		
	Frequency of potential impact	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 re-suspension.	No habitat mapping or sediment characteristics known.	- 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 (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	No habitat mapping or sediment characteristics known.	- 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
	Frequency of potential impact	Number of collision events	Theoretically sound	Quantifiable	Submersible video may be reviewed	

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Light disturbance	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	

Trap/pot fishing

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Removal of biological material	Catch (commercial landings)	- 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)
	Maximum potential exposure	- Number of days per annum fishing is allowed - Number of vessels x maximum allowable	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

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		catch				economically valuable species Andrews et al. 2013)
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	- Diversity measures - e.g. Shannon-Weiner and Simpson Indexes, taxonomic redundancy, taxonomic distinctness	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
	Abundance	- Total count of non-native species with established breeding populations (and potential changes in distribution) - Areal coverage (%/m^2) - Count 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.

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				taxon can be distinguished - Species density estimates use numerical abundances of individual per unit area		(Andrews et al. 2013).
	Biomass	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)
Substrate disturbance (crushing)	Crushed area	Proportion (%) of the area/habitat crushed	Commonly used metric	Number of traps/pots relates to the amount of habitat disturbed and crushed areas will show different community characteristics. However, the magnitude of modification is dependent on the size of the trap/pot, length of	Cameras are being placed on trap/pots to monitor impact and may be a way of quantifying this. In addition, visual surveys in fished areas will 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

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				drag, and habitat type.		impacts
	Maximum potential crushed area	Size of trap x number deployed	Commonly suggested metric. Effectiveness unknown.	Number of traps/pots relates to the amount of habitat disturbed and crushed areas will show different community characteristics. However, the magnitude of modification is dependent on the size of the trap/pot, length of drag, and habitat type.	Data available on exposure side of trap/pots	
	Density of traps/pots	Number of trap/pots deployed within a given area	Number of traps/pots relates to the amount of habitat disturbed and crushed areas will show different community characteristics. However, the magnitude of modification is dependent on the size of the trap/pot and habitat type.	Similar to above. Number of traps/pots relates to the amount of habitat disturbed and crushed areas will show different community characteristics. However, the magnitude of modification is dependent on the size of the trap/pot, length of drag, and habitat type.	Data available on exposure side of trap/pots	
Substrate disturbance (sediment re-suspension)	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 re-	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				suspension. - Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications		
	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 re-suspension. - 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
Entrapment/ Entanglement	Potential exposure to discarded /lost traps	- Number of traps with releasable openings (where ropes dissolve and trap can open) - Number of traps lost	Theoretically feasible	Unknown and unpredictable stressor to be measured	Data exists for trap/pots at the SK-B MPA	

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

Table F.1. Full prioritized list of current snapshot SEC-stressor interactions

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Isidella, Fishing, Trap/Pot Fishing, Substrate disturbance (crushing)	101.61	High	68.26	148.34	108.30	High
Isidella, Fishing, Trap/Pot Fishing, Substrate disturbance (sediment resuspension)	89.47	High	46.34	136.16	91.25	High
Sponges (habitat), Fishing, Trap/Pot Fishing, Substrate disturbance (crushing)	78.71	High	51.87	105.65	78.76	High
Corals (habitat) , Fishing , Trap/Pot Fishing, Substrate disturbance (crushing)	77.33	High	56.05	108.03	82.04	High
Isidella, Fishing , Trap/Pot Fishing, Removal of biological material	72.94	High	36.25	114.95	75.60	High
Sablefish , Fishing , Trap/Pot Fishing , Removal of biological material	69.11	High	38.24	93.65	65.94	Moderate
Rougheye , Fishing , Trap/Pot Fishing , Removal of biological material	61.83	Moderate	24.50	100.16	62.33	Moderate
Corals (habitat) , Fishing , Trap/Pot Fishing , Removal of biological material	57.38	Moderate	32.18	96.97	64.57	Moderate
Corals (habitat) , Fishing , Trap/Pot Fishing , Substrate disturbance (sediment resuspension)	56.09	Moderate	31.83	84.62	58.22	Moderate
Sponges (habitat) , Fishing , Trap/Pot Fishing , Substrate disturbance (sediment resuspension)	53.95	Moderate	28.50	85.64	57.07	Moderate
Bocaccio , Vessel , Movement underway , Noise disturbance	48.63	Moderate	23.47	69.54	46.51	Moderate
Sponges (habitat), Fishing , Trap/Pot Fishing , Removal of biological material	45.61	Moderate	28.49	73.66	51.08	Moderate
Yelloweye , Vessel , Movement underway , Noise disturbance	39.79	Moderate	18.22	69.21	43.72	Moderate
Corals (habitat) , Vessel , Discharge , Oils/contaminants	31.16	Low	9.20	68.94	39.07	Moderate
Isidella , Vessel , Discharge , Oils/contaminants	31.15	Low	11.79	62.40	37.09	Low
Rougheye , Vessel , Discharge , Nutrients	30.25	Low	6.93	58.39	32.66	Low
Halibut , Vessel , Discharge , Oils/contaminants	29.54	Low	10.57	55.20	32.88	Low
Sponges (habitat) , Vessel , Discharge , Oils/contaminants	29.47	Low	9.41	51.57	30.49	Low
Macro algae (habitat) , Vessel , Grounding , Substrate disturbance (sediment resuspension)	28.94	Low	20.63	45.40	33.01	Low

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Coralline algae (habitat) , Vessel , Grounding , Substrate disturbance (sediment resuspension)	28.75	Low	19.63	42.30	30.96	Low
Yelloweye , Vessel , Discharge , Oils/contaminants	28.68	Low	12.43	49.94	31.18	Low
Coralline algae (habitat) , Vessel , Grounding , Substrate disturbance (crushing)	28.10	Low	19.23	37.51	28.37	Low
Prowfish , Vessel , Discharge , Oils/contaminants	28.00	Low	9.36	51.48	30.42	Low
Rougheye , Vessel , Discharge , Oils/contaminants	27.84	Low	12.32	53.46	32.89	Low
Halibut , Vessel , Movement underway , Noise disturbance	27.17	Low	4.83	49.67	27.25	Low
Primnoa , Vessel , Discharge , Oils/contaminants	27.05	Low	8.64	53.83	31.24	Low
Halibut , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	27.03	Low	7.32	53.82	30.57	Low
Macro algae (habitat) , Vessel , Discharge , Nutrients	26.64	Low	14.18	47.72	30.95	Low
Coralline algae (habitat) , Vessel , Discharge , Nutrients	25.43	Low	12.96	43.12	28.04	Low
Rougheye , Vessel , Movement underway , Noise disturbance	24.77	Low	5.89	60.95	33.42	Low
Widow , Vessel , Discharge , Nutrients	24.40	Low	5.25	44.68	24.96	Low
Yelloweye , Vessel , Discharge , Nutrients	23.21	Low	5.57	52.44	29.00	Low
Prowfish , Vessel , Movement underway , Noise disturbance	22.81	Low	5.85	41.95	23.90	Low
Widow , Vessel , Movement underway , Noise disturbance	22.80	Low	5.26	44.88	25.07	Low
Bocaccio , Vessel , Discharge , Oils/contaminants	22.76	Low	8.37	44.20	26.28	Low
Sablefish , Vessel , Discharge , Oils/contaminants	22.67	Low	8.83	50.35	29.59	Low
Widow , Vessel , Discharge , Oils/contaminants	22.28	Low	11.35	41.74	26.55	Low
Macro algae (habitat) , Vessel , Discharge , Oils/contaminants	22.20	Low	5.71	42.60	24.16	Low
Prowfish , Vessel , Discharge , Nutrients	21.55	Low	5.25	42.23	23.74	Low
Squat lobster , Vessel , Discharge , Oils/contaminants	21.27	Low	5.86	37.12	21.49	Low
Primnoa , Vessel , Grounding , Substrate disturbance (sediment resuspension)	21.05	Low	15.57	30.03	22.80	Low
Primnoa , Vessel , Grounding , Substrate disturbance (crushing)	20.96	Low	14.51	30.89	22.70	Low
Coralline algae (habitat) , Vessel , Discharge , Oils/contaminants	20.84	Low	5.73	43.70	24.71	Low
Rougheye , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	20.44	Low	7.36	42.59	24.98	Low
Halibut , Fishing , Trap/Pot Fishing , Removal of biological material	20.42	Low	7.25	33.86	20.55	Low

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Sablefish , Vessel , Movement underway , Noise disturbance	20.20	Low	1.44	42.43	21.94	Low
Squat lobster , Vessel , Movement underway , Noise disturbance	20.14	Low	5.67	36.89	21.28	Low
Sablefish , Vessel , Discharge , Nutrients	19.41	Low	1.88	38.96	20.42	Low
Bocaccio , Vessel , Discharge , Nutrients	18.59	Low	2.71	50.58	26.64	Low
Bocaccio , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	18.33	Low	8.11	37.70	22.91	Low
Sablefish , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	18.24	Low	3.80	34.30	19.05	Low
Sponges (habitat) , Vessel , Grounding , Substrate disturbance (crushing)	17.50	Low	7.72	27.38	17.55	Low
Corals (habitat) , Vessel , Grounding , Substrate disturbance (crushing)	16.70	Low	9.41	25.28	17.35	Low
Macro algae (habitat) , Vessel , Grounding , Substrate disturbance (crushing)	16.69	Low	11.69	22.79	17.24	Low
Yelloweye , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	15.65	Low	3.43	34.73	19.08	Low
Sponges (habitat) , Vessel , Grounding , Substrate disturbance (sediment resuspension)	15.41	Low	6.12	23.81	14.97	Low
Widow , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	14.90	Low	2.93	29.69	16.31	Low
Corals (habitat) , Vessel , Grounding , Substrate disturbance (sediment resuspension)	14.48	Low	6.86	24.51	15.68	Low
Sponges (habitat) , Research , Equipment installation , Substrate disturbance (crushing)	14.42	Low	4.47	22.78	13.63	Low
Sponges (habitat) , Research , Sampling , Removal of organisms	14.32	Low	7.35	24.48	15.91	Low
Sponges (habitat) , Research , Equipment installation , Substrate disturbance (sediment resuspension)	14.01	Low	5.44	25.36	15.40	Low
Corals (habitat) , Research , Sampling , Removal of organisms	13.74	Low	7.74	23.27	15.50	Low
Halibut , Vessel , Discharge , Nutrients	13.36	Low	0.00	34.50	17.25	Low
Sponges (habitat) , Research , Equipment installation , Contamination	13.33	Low	1.75	30.31	16.03	Low
Primnoa , Vessel , Discharge , Nutrients	12.71	Low	4.36	24.44	14.40	Low
Corals (habitat) , Research , Equipment abandonment , Contamination	12.63	Low	0.59	30.06	15.32	Low
Prowfish , Fishing , Trap/Pot Fishing , Entrapment/Entanglement	12.29	Low	2.00	25.61	13.80	Low

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Primnoa , Research , Submersible operations , Substrate disturbance (sediment resuspension)	12.02	Low	1.88	24.02	12.95	Low
Isidella , Research , Submersible operations , Substrate disturbance (crushing)	11.91	Low	2.77	23.32	13.04	Low
Sponges (habitat) , Vessel , Discharge , Nutrients	11.77	Low	2.50	23.02	12.76	Low
Primnoa , Research , Submersible operations , Substrate disturbance (crushing)	11.77	Low	1.65	22.55	12.10	Low
Corals (habitat) , Vessel , Discharge , Nutrients	11.61	Low	2.32	23.22	12.77	Low
Isidella , Research , Equipment installation , Substrate disturbance (sediment resuspension)	11.37	Low	2.66	19.94	11.30	Low
Isidella , Vessel , Discharge , Nutrients	10.74	Low	1.64	27.03	14.33	Low
Sponges (habitat) , Research , Submersible operations , Substrate disturbance (crushing)	10.67	Low	4.50	20.62	12.56	Low
Isidella , Research , Submersible operations , Substrate disturbance (sediment resuspension)	10.57	Low	1.71	24.52	13.12	Low
Corals (habitat) , Research , Submersible operations , Substrate disturbance (sediment resuspension)	10.52	Low	2.03	20.41	11.22	Low
Corals (habitat) , Research , Submersible operations , Substrate disturbance (crushing)	10.31	Low	2.74	19.76	11.25	Low
Primnoa , Research , Equipment installation , Substrate disturbance (sediment resuspension)	10.24	Low	0.00	21.28	10.64	Low
Isidella , Research , Equipment installation , Contamination	10.20	Low	2.07	20.88	11.48	Low
Primnoa , Research , Equipment installation , Substrate disturbance (crushing)	10.19	Low	2.01	20.34	11.18	Low
Rougheye , Research , Equipment abandonment , Contamination	10.12	Low	3.48	18.58	11.03	Low
Halibut , Research , Equipment abandonment , Contamination	10.08	Low	4.23	17.37	10.80	Low
Prowfish , Research , Equipment abandonment , Contamination	9.59	Low	2.82	18.92	10.87	Low
Corals (habitat) , Research , Equipment installation , Substrate disturbance (sediment resuspension)	9.49	Low	2.06	19.48	10.77	Low
Sponges (habitat) , Research , Sampling , Substrate disturbance (crushing)	9.46	Low	2.74	15.32	9.03	Low
Coralline algae (habitat) , Research , Sampling , Substrate disturbance (sediment resuspension)	9.42	Low	4.23	14.68	9.46	Low
Bocaccio , Research , Equipment abandonment , Contamination	9.37	Low	3.29	16.84	10.06	Low

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Isidella , Research , Equipment installation , Substrate disturbance (crushing)	9.28	Low	1.18	20.13	10.66	Low
Sponges (habitat) , Research , Submersible operations , Substrate disturbance (sediment resuspension)	9.25	Low	3.59	18.17	10.88	Low
Coralline algae (habitat) , Research , Sampling , Substrate disturbance (crushing)	9.17	Low	4.38	15.59	9.99	Low
Primnoa , Research , Equipment installation , Contamination	8.99	Low	1.96	18.92	10.44	Low
Corals (habitat) , Research , Sampling , Substrate disturbance (crushing)	8.48	Low	2.81	14.51	8.66	Low
Corals (habitat) , Research , Equipment installation , Substrate disturbance (crushing)	8.40	Low	2.41	19.03	10.72	Low
Sablefish , Research , Equipment abandonment , Contamination	8.36	Low	1.98	14.95	8.46	Low
Macro algae (habitat) , Research , Submersible operations , Substrate disturbance (crushing)	8.21	Low	2.91	15.05	8.98	Low
Yelloweye , Research , Equipment abandonment , Contamination	7.82	Low	2.37	16.22	9.29	Low
Coralline algae (habitat) , Research , Submersible operations , Substrate disturbance (crushing)	7.76	Low	2.23	14.69	8.46	Low
Widow , Research , Equipment abandonment , Contamination	7.75	Low	2.15	14.54	8.34	Low
Sponges (habitat) , Research , Sampling , Substrate disturbance (sediment resuspension)	7.69	Low	1.35	16.08	8.72	Low
Corals (habitat) , Research , Sampling , Substrate disturbance (sediment resuspension)	7.68	Low	2.68	13.89	8.28	Low
Coralline algae (habitat) , Research , Submersible operations , Substrate disturbance (sediment resuspension)	7.61	Low	3.15	14.73	8.94	Low
Macro algae (habitat) , Research , Submersible operations , Substrate disturbance (sediment resuspension)	7.25	Low	2.46	13.80	8.13	Low
Coralline algae (habitat) , Research , Sampling , Removal of organisms	7.19	Low	3.51	10.95	7.23	Low
Coralline algae (habitat) , Research , Equipment abandonment , Contamination	6.85	Low	0.98	13.26	7.12	Low
Macro algae (habitat) , Research , Equipment abandonment , Contamination	6.84	Low	0.22	13.79	7.01	Low
Macro algae (habitat) , Research , Equipment installation , Substrate disturbance (crushing)	6.51	Low	1.64	12.74	7.19	Low
Coralline algae (habitat) , Research , Equipment installation ,	6.37	Low	0.15	13.06	6.61	Low

Current snap-shot	Risk Score	Risk grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty grouping
Substrate disturbance (sediment resuspension)						
Rougheye , Research , Sampling , Removal of organisms	6.06	Low	4.12	9.72	6.92	Low
Bocaccio , Research , Sampling , Removal of organisms	5.87	Low	3.99	8.92	6.45	Low
Yelloweye , Research , Sampling , Removal of organisms	5.59	Low	3.64	8.98	6.31	Low
Squat lobster , Research , Submersible operations , Light disturbance	5.54	Low	0.64	11.11	5.88	Low
Coralline algae (habitat) , Research , Equipment installation , Substrate disturbance (crushing)	5.52	Low	1.77	13.66	7.72	Low
Prowfish , Research , Sampling , Removal of organisms	5.51	Low	3.53	8.00	5.76	Low
Halibut , Research , Sampling , Removal of organisms	5.18	Low	3.75	7.59	5.67	Low
Widow , Research , Sampling , Removal of organisms	5.14	Low	3.73	7.29	5.51	Low
Sablefish , Research , Sampling , Removal of organisms	4.93	Low	3.20	8.82	6.01	Low
Macro algae (habitat) , Research , Sampling , Removal of organisms	4.41	Low	1.33	7.53	4.43	Low
Coralline algae (habitat) , Research , Scuba , Substrate disturbance (crushing)	3.33	Low	0.79	7.62	4.21	Low
Coralline algae (habitat) , Research , Scuba , Substrate disturbance (sediment resuspension)	2.71	Low	0.00	7.30	3.65	Low
Max	101.61			Max	108.30	
Min	2.71			Min	3.65	
Range	98.90			Range	104.65	
Range/3	32.97			Range/3	34.88	
Low	*35.68*			*Low*	*38.53*	
Medium	*68.64*			*Medium*	*73.42*	
High	*101.61*			*High*	*108.30*	

Table F.2. Full prioritized list of potential SEC-stressor interactions

Potential	Risk Score	Priority	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Priority
Rougheye , Seismic Surveys , Seismic testing / air guns , Sound generation	106.23	High	77.70	129.22	103.46	High
Yelloweye , Seismic Surveys , Seismic testing / air guns , Sound generation	96.29	High	73.27	116.42	94.85	High
Halibut , Seismic Surveys , Seismic testing / air guns , Sound generation	94.26	High	73.78	123.22	98.50	High
Bocaccio , Seismic Surveys , Seismic testing / air guns , Sound generation	89.54	High	62.83	121.20	92.01	High
Prowfish , Seismic Surveys , Seismic testing / air guns , Sound generation	85.86	High	65.32	109.89	87.61	High
Sablefish , Seismic Surveys , Seismic testing / air guns , Sound generation	84.94	High	65.70	109.48	87.59	High
Widow , Seismic Surveys , Seismic testing / air guns , Sound generation	83.35	High	62.15	102.79	82.47	High
Macro algae (habitat) , Vessel , Oil Spill , Oil	69.52	Moderate	53.03	92.31	72.67	High
Coralline algae (habitat) , Vessel , Oil Spill , Oil	68.68	Moderate	51.29	86.64	68.97	Moderate
Primnoa , Vessel , Oil Spill , Oil	62.50	Moderate	46.72	87.94	67.33	Moderate
Sponges (habitat) Vessel , Oil Spill , Oil	61.07	Moderate	43.25	85.37	64.31	Moderate
Corals (habitat) , Vessel , Oil Spill , Oil	60.37	Moderate	42.62	84.27	63.45	Moderate
Sponges (habitat) , Research , Submersible operations , Aquatic Invasive Species	59.02	Moderate	40.93	81.82	61.37	Moderate
Isidella , Vessel , Oil Spill , Oil	58.60	Moderate	42.60	85.49	64.04	Moderate
Corals (habitat) , Research , Submersible operations , Aquatic Invasive Species	56.74	Moderate	39.02	79.11	59.07	Moderate
Primnoa , Vessel , Discharge , Aquatic Invasive Species	54.51	Moderate	32.08	78.52	55.30	Moderate
Isidella , Fishing , Trap/Pot Fishing , Aquatic Invasive Species	53.69	Moderate	35.44	82.05	58.75	Moderate
Rougheye , Vessel , Oil Spill , Oil	52.03	Moderate	32.27	79.79	56.03	Moderate
Halibut , Vessel , Oil Spill , Oil	51.28	Moderate	31.15	67.44	49.30	Moderate
Yelloweye , Vessel , Oil Spill , Oil	48.30	Moderate	33.09	68.83	50.96	Moderate
Sponges (habitat) , Vessel , Discharge , Aquatic Invasive Species	46.58	Moderate	26.28	74.79	50.53	Moderate
Isidella , Research , Submersible operations , Aquatic Invasive	46.07	Moderate	26.47	75.13	50.80	Moderate

Potential	Risk Score	Priority	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Priority
Species						
Isidella , Vessel , Discharge , Aquatic Invasive Species	45.40	Moderate	31.60	68.79	50.20	Moderate
Corals (habitat) , Fishing , Trap/Pot Fishing , Aquatic Invasive Species	45.12	Moderate	30.16	76.73	53.44	Moderate
Corals (habitat) , Vessel , Discharge , Aquatic Invasive Species	45.00	Moderate	28.55	66.99	47.77	Moderate
Bocaccio , Vessel , Oil Spill , Oil	44.39	Moderate	30.47	68.75	49.61	Moderate
Prowfish , Vessel , Oil Spill , Oil	43.80	Moderate	28.30	65.24	46.77	Moderate
Primnoa , Research , Submersible operations , Aquatic Invasive Species	43.50	Moderate	27.12	74.05	50.59	Moderate
Sablefish , Vessel , Oil Spill , Oil	42.21	Moderate	25.41	66.57	45.99	Moderate
Macro algae (habitat) , Vessel , Discharge , Aquatic Invasive Species	40.92	Moderate	22.33	68.07	45.20	Moderate
Widow , Vessel , Oil Spill , Oil	40.54	Moderate	23.31	63.33	43.32	Moderate
Sponges (habitat) , Fishing , Trap/Pot Fishing , Aquatic Invasive Species	36.45	Low	20.81	56.47	38.64	Low
Isidella , Vessel , Discharge , Debris	36.36	Low	10.16	68.70	39.43	Low
Corals (habitat) , Vessel , Discharge , Debris	34.00	Low	14.04	60.15	37.10	Low
Squat lobster , Seismic Surveys , Seismic testing / air guns , Sound generation	33.93	Low	14.85	51.68	33.27	Low
Coralline algae (habitat) , Vessel , Discharge , Aquatic Invasive Species	32.50	Low	16.23	52.08	34.15	Low
Halibut , Vessel , Discharge , Debris	32.21	Low	12.10	65.61	38.85	Low
Rougheye , Vessel , Discharge , Debris	31.72	Low	13.85	63.28	38.56	Low
Yelloweye , Vessel , Discharge , Debris	31.56	Low	13.83	64.01	38.92	Low
Bocaccio , Vessel , Discharge , Debris	31.25	Low	14.13	56.13	35.13	Low
Widow , Vessel , Discharge , Aquatic Invasive Species	30.86	Low	14.54	48.12	31.33	Low
Halibut , Vessel , Discharge , Aquatic Invasive Species	29.89	Low	12.50	51.35	31.93	Low
Rougheye , Research , Submersible operations , Aquatic Invasive Species	29.35	Low	16.49	46.26	31.38	Low
Squat lobster , Vessel , Oil Spill , Oil	29.09	Low	19.62	43.83	31.73	Low
Rougheye , Fishing , Trap/Pot Fishing , Aquatic Invasive Species	28.90	Low	15.95	44.01	29.98	Low
Macro algae (habitat) , Research , Submersible operations ,	28.80	Low	16.67	49.65	33.16	Low

Potential	Risk Score	Priority	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Priority
Aquatic Invasive Species						
Rougheye , Vessel , Discharge , Aquatic Invasive Species	28.27	Low	15.64	46.72	31.18	Low
Primnoa , Vessel , Discharge , Debris	27.98	Low	8.11	57.08	32.60	Low
Widow , Vessel , Discharge , Debris	27.16	Low	11.83	49.13	30.48	Low
Prowfish , Vessel , Discharge , Debris	26.96	Low	11.30	49.65	30.48	Low
Coralline algae (habitat) , Research , Submersible operations , Aquatic Invasive Species	26.93	Low	16.57	45.07	30.82	Low
Sablefish , Vessel , Discharge , Debris	26.75	Low	12.10	51.16	31.63	Low
Bocaccio , Research , Submersible operations , Aquatic Invasive Species	26.25	Low	15.22	41.25	28.24	Low
Yelloweye , Research , Submersible operations , Aquatic Invasive Species	25.52	Low	14.60	37.53	26.06	Low
Bocaccio , Vessel , Discharge , Aquatic Invasive Species	24.98	Low	13.87	48.93	31.40	Low
Sponges (habitat) , Vessel , Discharge , Debris	24.95	Low	6.27	59.63	32.95	Low
Yelloweye , Vessel , Discharge , Aquatic Invasive Species	24.60	Low	15.75	41.47	28.61	Low
Squat lobster, Vessel, Discharge, Debris	24.04	Low	8.65	45.59	27.12	Low
Bocaccio, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	23.04	Low	11.55	34.03	22.79	Low
Prowfish, Research, Submersible operations, Aquatic Invasive Species	22.96	Low	13.62	32.03	22.82	Low
Sablefish, Vessel, Discharge, Aquatic Invasive Species	22.43	Low	9.77	48.98	29.38	Low
Widow, Research, Submersible operations, Aquatic Invasive Species	22.22	Low	13.49	36.43	24.96	Low
Prowfish, Vessel, Discharge, Aquatic Invasive Species	22.13	Low	12.76	39.87	26.31	Low
Yelloweye, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	21.60	Low	11.51	32.89	22.20	Low
Macro algae (habitat), Vessel, Discharge, Debris	21.08	Low	6.33	42.00	24.17	Low
Sablefish, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	20.97	Low	7.88	37.01	22.44	Low
Halibut, Research, Submersible operations, Aquatic Invasive Species	20.67	Low	8.03	38.20	23.11	Low
Sablefish, Research, Submersible operations, Aquatic Invasive Species	19.35	Low	7.87	35.19	21.53	Low
Coralline algae (habitat), Vessel, Discharge, Debris	19.08	Low	5.79	46.28	26.03	Low
Halibut, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	18.87	Low	7.16	35.65	21.41	Low

Potential	Risk Score	Priority	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Priority
Widow, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	15.90	Low	6.54	26.96	16.75	Low
Prowfish, Fishing, Trap/Pot Fishing, Aquatic Invasive Species	11.78	Low	3.04	21.17	12.10	Low
Squat lobster, Research, Submersible operations, Aquatic Invasive Species	7.89	Low	1.08	17.09	9.09	Low
Squat lobster, Vessel, Discharge, Aquatic Invasive Species	6.57	Low	0.00	17.80	8.90	Low
Max	*106.23*			*Max*	*103.46*	
Min	*6.57*			*Min*	*8.90*	
Range	*99.66*			*Range*	*94.56*	
Range/3	*33.22*			*Range/3*	*31.52*	
Low	*39.79*			*Low*	*40.42*	
Medium	*73.01*			*Medium*	*71.94*	
High	*106.23*			*High*	*103.46*	

APPENDIX G: SEC-STRESSOR INTERACTION INDICATORS AND MEASURABLE COMPONENTS

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

SEC		Activity	Stressor	Key parameter	Proposed indicator	Measureable component of indicator	Data collection
Invertebrates (sessile benthic)	Corals: - *Isidella tentaculum* - Corals (habitat) Sponges: - Sponges (habitat)	Trap/pot fishing	Substrate disturbance (crushing)	Population size	Abundance of colonies with visible damage/ fragmentation	Proportion of sampled population (%) with visible damage/fragmentation	- Visual survey - Catch data will help inform this, but would only include corals crushed/damaged, but not removed. - Scientific dredge data will help to inform, but will not be as accurate
				Population condition	Abundance of dislodged colonies	Proportion of sampled population (%) dislodged	- Visual survey
			Substrate disturbance (sediment re-suspension)	Population size	Abundance of colonies showing signs on smothering	Proportion of sampled population (%) impacted	- Visual survey
				Population condition	Abundance of colonies showing signs of smothering	Proportion of sampled population (%) impacted	- Visual survey
			Removal of biological material	Population size	By-catch	Fisheries by-catch data. NB: This measures removed corals and sponges only	- Catch data will help inform this, but would only include corals crushed/damaged, but not removed. - Scientific dredge data will help to inform, but will not be as accurate
				Population condition	No specific indicator that would adequately inform removal of corals and sponges.	Further research is needed. However, some measurable that may help this process include: recorded by-catch, baselines of spatial	- Catch data will help inform this, but would only include corals crushed/damaged, but not removed. - Scientific dredge data

SEC		Activity	Stressor	Key parameter	Proposed indicator	Measureable component of indicator	Data collection
						distribution of populations/density	will help to inform, but will not be as accurate
Fish	Demersal: - Sablefish Pelagic (rockfish): - Rougheye	Trap/pot fishing	Removal of biological material	Population size	Abundance/ population density	Count/size-frequency distribution	- Visual survey - Stock assessment techniques - Catch data
					Biomass of removed organisms	Landed catch	- Catch data can be used for this
	Pelagic (rockfish): - Bocaccio - Yelloweye	Movement underway	Noise disturbance	Population condition	No specific indicator that could be specifically linked to changes in fish population condition resulting from vessel noise.	Further research is needed. However, some measurable that may help this process include: spatial distribution of population/ density, and behavioural response studies.	

*Table G.2. Potential SEC-stressor interaction indicators. * denotes that SECs and stressors that do not interact as moderate/high priority.*

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
Fish	Pelagic (Rockfish): - Rougheye - Yelloweye - Bocaccio - Widow Demersal: - Pacific Halibut - Prowfish - Sablefish	Seismic surveys	Seismic testing/ air guns	Population size	Larval abundance	Average density and species richness of larvae	- Requires baselines of populations, including seasonal variations - Doppler current profiler - Net hauls
				Population condition	Change in condition/ sub-lethal effects	Presence of tissue/organ damage. For example, swim bladder.	- Population or stock delineation methods
					Behavioural response	Further research is needed. However, some measurable that may help this process include: spatial distribution of population/ density, and behavioural response studies.	- Requires baselines of populations - Visual surveys, stock assessment techniques, and catch data will help inform this
		Oil spill	Oil	Population size	Abundance	Size-frequency distribution	- Requires baselines of populations
					Population density	Age/size structure, count per area	- Requires baselines of populations - Visual surveys (ROV), Stock assessment techniques, and catch data will help inform this
				Population condition	Change in condition/ sub-lethal effects	Presence of disease, change in age/size structure	- Requires baselines of populations
					Genetic diversity and structure		- Requires baselines of populations

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
Invertebrates	Algae: - Macroalgae (habitat) - Coralline Algae (habitat)*	Oil spill	Oil	Population size	Abundance	Areal coverage of habitats	- Visual surveys - Needs to be combined with independent SEC and stressor indicators to link oil with SEC
				Population condition	Species richness/ presence of disease	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys
		Discharge	Aquatic invasive species*	Population size	Abundance	Change in areal extent of habitats	- Requires baselines of populations -
				Population condition	Change in condition	Proportion of habitat (%) displaying disease die-off, smothering, etc.	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC
	Sponges: - Sponges (habitat)* Corals: - Corals (habitat) - White Primnoa sp.* - *Isidella tentaculum*	Oil spill	Oil	Population size	Abundance of colonies with visible damage/ dead	Proportion of sampled population (%) impacted	- Requires baselines of populations
				Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
		Submersible operations	Aquatic invasive species	Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
				Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
		Discharge	Aquatic invasive species	Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
				Population	Change in	Tissue loss, sclerite	- Requires baselines of

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
				condition	condition/ sub-lethal effects	enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
		Trap/pot fishing	Aquatic invasive species*	Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
				Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this

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

Table H.1. SEC-stressor interaction indicators for sessile benthic SECs: Isidella tentaculum, corals (habitat), and sponges (habitat). Interaction justifications summarised from rubidge et al.[1].

Trap/pot fishing → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/ fragmentation	Proportion of sampled population (%) impacted	- Change in population size (average mortality rate) from substrate disturbance (crushing) from traps is difficult to estimate due to the patchy and unmapped distribution of corals and sponges at the SK-B MPA. - Proportion of habitat damaged depends on many factors: size, weight, and material of traps; hauling speed and ocean conditions; depth of haul; number of traps set; and the substrate where the trap is placed. - Traps cause benthic disturbance, especially during hauling or dragging - Corals and sponges can be scraped, fragmented, and dislodged. - Troffe et al. (2005) found that prawn trap fishing caused more damage to sea whips (*Halipteris willemoesi*) than beam trawling does, including acute mortality through uprooting of the colonies. - Dungeness crab traps are larger and heavier than prawn traps, and may therefore cause more damage to sea whips. In contrast, Eno et al. (2001) observed that flexible sea pens and sea pens in Great Britain were relatively unaffected by fishing with lobster and crab pots, however they did find that some individual ross corals (*Pentapora foliacea*) were damaged.	- There have been no studies specific to corals and sponges at the SK-B MPA, but other studies show impacts to be highly localised - Lack of established population baselines at the SK-B MPA.	- Visual survey - Catch data will help inform this, but would only include corals crushed/damaged, but not removed. - Scientific dredge data will help to inform, but will not be as accurate

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Abundance of dislodged colonies	Proportion of sampled population (%) impacted	- The structural integrity of corals and sponges may be impacted by substrate disturbance (crushing) from trap/pots. - Potential change in polyp density given the size of the trap path and coral distribution. - Signs of impact include: scraped, fragmented, and dislodged coral and sponge colonies.	- No studies conducted at the SK-B MPA collecting data on health/condition of corals and sponges.	- Visual survey

Trap/pot fishing → Substrate disturbance (sediment re-suspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies showing signs on smothering	Proportion of sampled population (%) impacted	- Change in population size due sediment re-suspension difficult to estimate because distribution of corals patchy and unmapped at Bowie - Sedimentation occurs mostly during retrieval of trap	- There have been no study specific to corals and sponges at the SK-B MPA, but other studies show impacts from traps to be highly localised - Lack of established population baselines at the SK-B MPA.	- Visual survey

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Abundance of colonies showing signs of smothering	Proportion of sampled population (%) impacted	- Change in population condition such as a change in polyp density for corals - Settling of suspended sediments can result in reduced fitness of biogenic habitat species. This magnitude and area effect will depend on the amount and coarseness of the sediment and the velocity of currents in the area. - Trawl activities cause temporary re-suspension of bottom sediment during increased ambient current flows. Reef sponges take 6 hours or longer to recover normal filtration levels, which would reduce the daily time to feed. 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). - Some sponges have acquired the ability to arrest feeding when their surrounding environment has high levels of silt or sediment (Leys et al. 2004). However, excessive amounts of sediment may lead to the smothering of the animal and result in death.	- No studies conducted at the SK-B MPA collecting data on health/condition of corals and sponges.	- Visual survey

Trap/pot fishing → Removal of biological material

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	No specific indicator that would adequately inform removal of corals and sponges.	Further research is needed. However, some measurables that may help this process include: recorded by-catch, baselines of spatial distribution of populations/density	**CORALS:** - Population change due to by-catch difficult to estimate as coral distribution and corals patchy and unmapped at the SK-B MPA. - Traps dragging and snagging corals upon retrieval have potential to have high impact given the recurrent nature of fishing. - Corals (black corals, thorny corals and gorgonian corals) are pulled up on traps (~6.5 kg from 2006-2012; DFO database); known records of corals being destroyed in fishery but actual intensity of fishery compared to other areas is low. - Corals are pulled up on traps but not at a high rate (<1% DFO database). **SPONGES:** - Population change due to by-catch difficult to estimate as coral distribution and sponges patchy and unmapped at the SK-B MPA. - Sponges are pulled up on traps (~2.3 kg from 2006-2012; DFO database); known records of sponges being destroyed in fishery but actual intensity of fishery compared to other areas is low. - Sponges are pulled up on traps but not at a high rate (<1% DFO database).	- There have been no studies specific to corals and sponges at the SK-B MPA, but some by-catch data is available - Lack of established population baselines at the SK-B MPA. - Corals by-catch data: Corals: ~6.5 kg from 2006-2012 (DFO database); corals are pulled up on traps at a rate of <1% (DFO database). - Sponge by-catch data: ~2.3 kg from 2006-2012 (DFO database); sponges are pulled up on traps at a rate of <1% (DFO database).	- Catch data will help inform this, but would only include corals crushed/ damaged, but not removed. - Scientific dredge data will help to inform, but will not be as accurate

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	No specific indicator that would adequately inform removal of corals and sponges.	Further research is needed. However, some measurable that may help this process include: recorded by-catch, baselines of spatial distribution of populations/density	- Change in productivity or structural integrity from by-catch potentially high.	- There have been no studies specific to corals and sponges at the SK-B MPA, but some by-catch data is available	- Catch data will help inform this, but would only include corals crushed/damaged, but not removed. - Scientific dredge data will help to inform, but will not be as accurate

Oil spill → Oil

	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	- Changes in population size could be high. - Oil regularly reaches sediments after a spill; oil in anoxic sediments is persistent; oil regularly contaminates zooplankton and benthic invertebrates; fish are also contaminated, but to a lesser extent; oil contamination decreases the abundance and diversity of benthic communities (Teal and Howarth 1984). - Deep-water Horizon spill: Healthy coral communities were observed at all sites >20 km from the Macondo well, including seven sites previously visited in September 2009, where the corals and communities appeared unchanged. However, at one site 11 km southwest of the Macondo well, coral colonies presented widespread signs of stress, including varying degrees of tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc). Life in deep-water	- There have been no studies specific to corals and sponges at the SK-B MPA, but some by-catch data is available - Lack of established population baselines at the SK-B MPA. - Corals by-catch data: Corals: ~6.5 kg from 2006-2012 (DFO database); corals are pulled up on traps at a rate of <1% (DFO database). - Sponge by-catch data: ~2.3 kg from 2006-2012 (DFO	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys and catch data will help inform this

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			coral ecosystems is known to operate at a slow pace, consequently it is too early to fully evaluate the footprint and long-term effects of acute and sub acute exposure to potential waterborne contaminants resulting from the Deepwater Horizon oil spill (White et al. 2012). Oil dispersants, used to clean up oil spills also have detrimental impact to corals and sponges (Negri and Heyward 2000; Epstein et al. 2000; Shafir et al. 2007; Goodbody-Gringley 2013). Dispersants have been found to inhibit fertilization of mature eggs and the metamorphosis of coral larvae for stony and soft coral species. Exposure of coral larvae to oil spill related contaminants, particularly the dispersants have the potential to negatively impact coral settlement and survival, thereby affecting the resilience and recovery of corals.	database); sponges are pulled up on traps at a rate of <1% (DFO database).	
Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production (corals), bleached commensal ophiuroids (corals), and covering by brown flocculent material (floc)	- Change in productivity of habitat could be high. - Corals: tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc). Inhibition of fertilization of mature eggs and the metamorphosis of larvae - Sponges: tissue loss, smothering.		- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys and catch data will help inform this

Submersible operations → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	**CORALS**: - Impacts of invasive species unknown on cold water corals unknown - However, based on studies on gorgonians in other regions, impacts can be devastating, primarily from disease die-off. - Example: *Carijoa riisei*, an Octocoral native to the Western Atlantic, was discovered in 2001 overgrowing black corals in Hawaii. In areas where *C. riiesei* had become established, up to 90% of the native black coral populations were killed or completely overgrown by the invader (Kahng and Grigg 2005). - There are no reports of similar situations in Canadian waters; however the issue has not been the subject of significant scientific attention. **SPONGES**: - Impacts of invasive species on demosponges at Bowie unknown. Based on studies from other regions impacts can be devastating - disease die offs could occur - For example, the invasive alga (*Womersleyella setacea*) in Mediterranean benthic communities negatively impacts reproductive capacity of several species of sponge (de Caralt and Cebrian 2013).	No existing data on AIS at the SK-B MPA or similar system for modelling.	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys and catch data will help inform this

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Impacts of invasive species could be high and significantly change polyp density (corals) Chronic Impacts of invasive species can be persistent, as native species cannot successfully recolonize.		- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys and catch data will help inform this

Discharge → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	- Impacts of invasive species unknown on cold water corals and demosponges unknown - There are no reports of AIS situations in Canadian waters; however the issue has not been the subject of significant scientific attention. - Shipping is a major vector for introduction of alien invasive species (AIS), which may be transported through ballast water or hull fouling, especially in niche areas of the hull such as rudders, stern tubes and sea chests that provide habitats for marine species. - It is estimated that at least 7,000 – 10,000 different marine species are transported in ballast water. - Ballast water introductions range from pathogenic microorganisms, to vertebrates, e.g. biofilm, phytoplankton, zooplankton,	Requires baselines of information, and no data exists for AIS at the SK-B MPA	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys and catch data will help inform this

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			protozoa, algae and macro-algae, invertebrates, fish, fish parasites and others. - Examples include tunicates, algae and macro-algae, hydroids, bryozoans, bi-valves, bacteria, protists, dinoflagellates, diatoms, zooplankton, benthic invertebrates, and fish and other exotic "hitch-hikers" arrive as organisms that have encrusted on hulls (Bax et al. 2003; Sylvester et al. 2011; Coutts and Dodgshun 2007).		
Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Impacts of invasive species could be high and significantly change polyp density (corals) - Chronic Impacts of invasive species can be persistent, as native species cannot successfully recolonize.	Requires population baselines Little data available on SEC distribution	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this

Trap/pot fishing → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of colonies with visible damage/ dead	Number of colonies (proportion) showing evidence of disease die-off or smothering by organisms	CORALS: - Impacts of invasive species unknown on cold water corals unknown - However, based on studies on gorgonians in other regions, impacts can be devastating,	Requires population baselines Little data available on SEC distribution	- Requires baselines of populations - Needs to be combined with independent SEC and stressor

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			primarily from disease die-off. - Example: *Carijoa riisei*, an octocoral native to the Western Atlantic, was discovered in 2001 overgrowing black corals in Hawaii. In areas where *C. riiesei* had become established, up to 90% of the native black coral populations were killed or completely overgrown by the invader (Kahng and Grigg 2005). - There are no reports of similar situations in Canadian waters; however the issue has not been the subject of significant scientific attention. SPONGES: - Impacts of invasive species on demosponges at Bowie unknown. Based on studies from other regions impacts can be devastating - disease die offs could occur - For example, the invasive alga (*Womersleyella setacea*) in Mediterranean benthic communities negatively impacts reproductive capacity of several species of sponge (de Caralt and Cebrian 2013).		ndicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this
Population condition	Change in condition/ sub-lethal effects	Tissue loss, sclerite enlargement (corals), excess mucous production, bleached commensal ophiuroids, and covering by brown flocculent material (floc)	- Impacts of invasive species could be high and significantly change polyp density (corals) - Chronic Impacts of invasive species can be persistent as native species cannot successfully recolonize.	Requires population baselines Little data available on SEC distribution	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC - Visual surveys, stock assessment techniques, and catch data will help inform this

Table H.2. SEC-stressor interaction indicators for algae habitat SECs: coralline algae and macroalgae. interaction justifications summarised from rubidge et al.[1].

Oil spill → Oil

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Areal coverage of habitats	- Change in areal extent of habitat could be high - Impacts of oil spills on benthic biogenic habitats documented from other sites. - Oil regularly reaches sediments after a spill; oil in anoxic sediments is persistent; oil regularly contaminates zooplankton and benthic invertebrates; fish are also contaminated, but to a lesser extent; oil contamination decreases the abundance and diversity of benthic communities (Teal and Howarth 1984). - Massive die off of crustose coralline algae on Rose Atoll due to oil spilled from wreck (US Fish & Wildlife Service 2004).	- There have been no studies specific to algae at the SK-B MPA, but other studies show impacts to be highly localised - Lack of established population baselines at the SK-B MPA.	- Visual surveys - Needs to be combined with independent SEC and stressor indicators to link oil with SEC
Population condition	Species richness/ presence of disease	Proportion (%/areal coverage) of algae displaying signs of stress	- Change in productivity of habitat could be high - Oil spills on algal habitats well documented in other areas.	- There have been no studies specific to algae at the SK-B MPA, but other studies show impacts to be highly localised - Lack of established population baselines at the SK-B MPA.	- Requires populations baselines - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys

Discharge → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Change in areal extent of habitats	- Impacts of invasive species on coralline algae not well understood in Pacific, however based on related species impacts likely moderate - Shipping is a major vector for introduction of alien invasive species (AIS) that may be transported through ballast water or hull fouling, especially in niche areas of the hull such as rudders, stern tubes and sea-chests that provide habitats for marine species. - It is estimated that at least 7,000 – 10,000 different marine species are transported in ballast water. Ballast water introductions range from pathogenic microorganisms, to vertebrates, e.g. biofilm, phytoplankton, zooplankton, protozoa, algae and macro-algae, invertebrates, fish, fish parasites, tunicates, algae and macro-algae, hydroids, bryozoans, bi-valves and others. - Examination of ballast water upon arrival of vessels has revealed bacteria, protists, dinoflagellates, diatoms, zooplankton, benthic invertebrates, and fish and other exotic “hitch-hikers” arrive as organisms that have encrusted on hulls (Bax et al. 2003; Sylvester et al. 2011; Coutts and Dodgshun 2007)	- There have been no studies specific to algae at the SK-B MPA, but other studies show impacts to be highly localised - Lack of established population baselines at the SK-B MPA.	- Requires baselines of populations

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Change in condition (abundance)	Proportion of habitat (%) displaying disease die-off, smothering, etc.	- Impacts of invasive species could be high - Once established, invasive species such as *D. vexillum* can smother benthic organisms. - Chronic impacts of invasive species can be persistent, as native species cannot successfully recolonize.	- There have been no studies specific to algae at the SK-B MPA, but other studies show impacts to be highly localised - Lack of established population baselines at the SK-B MPA.	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC

Table H.3. SEC-stressor interaction indicators for fish species SECs. Interaction justifications summarised from Rubidge et al.[1].

Trap/pot fishing → Removal of biological material

Sablefish, Rougheye					
	Proposed indicator	**Measureable component of indicator**	**Interaction**	**Existing data**	**Data collection**
Population size	Abundance/ population density	Count/size-frequency distribution	**Sablefish**: - The change in population-wide average mortality rate due to the sablefish fishery at Bowie is not easily determined without an estimation of population size. - Given that the sablefish population at the SK-B MPA is not strictly considered a distinct population (individuals regularly move on and off the seamount), the Bowie seamount fishery likely does not change the average mortality rate for the entire BC coastal sablefish population. However if we consider the impact the fishery has on the number of individuals within the MPA at any given time, the impact of the fishery could be substantial. - Scoring of the ERAF was applied at the scale of the MPA, for the purposes of scoring the impact of the removal of sablefish from the MPA, we will consider the acute change in the "MPA population-wide" average mortality rate (i.e., does the removal of sablefish from the Bowie seamount area have a low, med, or high impact to the sablefish numbers within the MPA boundary at that given time). If every fisher met their individual monthly quota for sablefish at Bowie, the maximum amount of fish removed in a year could be 204 tonnes. - The actual landed catch from 2006-2012 inclusive was 377.4 metric tonnes – however if they met their quotas, in a six-year period as much as 1,224 tonnes of sablefish could be removed. - The potential impact to the population if the individual quota was met for every month for 6 months has the potential to high. (Source: DFO database)	- Lack of established population baselines at the SK-B MPA. - Catch data available	- Visual survey - Stock assessment techniques - Catch data

Sablefish, Rougheye					
	Proposed indicator	**Measureable component of indicator**	**Interaction**	**Existing data**	**Data collection**
			Rougheye: - Catch is unknown - No population size data is available for rougheye at Bowie. - If every fisherman met their individual monthly limit for rougheye at Bowie, the maximum amount of fish removed would be 13.2 tonnes/year which is nearly half of the total landed catch of Rougheye reported between 2006 - 2012 (21.1 tonnes – see main report for calculation). Fishermen do not generally meet their limits but if they did, the population impact would increase substantially; Unc = 4, no population size estimate. Also, this is a conservative estimate based on the maximum amount of fish legally allowed to be removed from the system, not the actual amount that is removed. See Section 2.1 for more details). Finally, this does not include individuals that are released (100% mortality). Some evidence to suggest from past fisheries that the population is very large (check landed catch data from 90s).		
	Biomass of removed organisms	Landed catch			Catch data can be used for this

Movement underway → Noise disturbance

<table>
<tr><th colspan="6">Bocaccio, Yelloweye</th></tr>
<tr><th></th><th>Proposed indicator</th><th>Measureable component of indicator</th><th>Interaction</th><th>Existing data</th><th>Data collection</th></tr>
<tr><td>Population condition</td><td>No specific indicator that could be specifically linked to changes in fish population condition resulting from vessel noise.</td><td>Further research is needed. However, some measurables that may help this process include: spatial distribution of population/ density, and behavioural response studies.</td><td>- Anthropogenic ocean noise is considered a chronic stressor for marine organisms.
- It has deleterious effects on a variety of marine organisms including mammals, fish, and cephalopods. Noise from shipping is pervasive throughout the marine environment especially at low (<300 Hz) frequencies and is therefore a key concern regarding chronic noise exposure on the marine environment (Erbe et al. 2012; Merhant et al. 2012).
- Large numbers of fish are exposed to moderate but widespread low-frequency noise; produced by vessels, offshore wind farms and other coastal activities. Detrimental effects of sound on fish populations include disturbance and deterrence, fitness consequences (reduced growth & reproduction), predator-prey interactions (interference and community effects), and communication and masking effects (reviewed in Slabbekorn et al. 2010).
- Some studies report an effect of vessel noise on fish flight behavior in the context of population assessments and catch rates for commercially important fish stocks. For example, horizontal and vertical movements away from vessels have been reported for Atlantic herring (Clupea harengus) and Atlantic cod (Gadus morhua) (Vabo et al. 2002, Handegard et al. 2003), presumably in response to ship noise. Another example concerns effects of nearby boating noise on blue-fin tuna (Thunnus thynnus) in large oceanic pens. In the presence of boat noise, tuna schools were less coheren than when the noise was not present and individual fish often swam independently towards the surface or the bottom (Sara et al., 2007].
- No specific study on the effect of noise for rockfish but vessel noise is more likely to result in a chronic change(sublethal and/or behavioral changes) than acute change</td><td></td><td></td></tr>
</table>

Seismic surveys → Seismic testing/air guns

Rougheye, Yelloweye, Bocaccio, Widow, Pacific Halibut, Prowfish, Sablefish					
	Proposed indicator	**Measureable component of indicator**	**Interaction**	**Existing data**	**Data collection**
Population size	Larval abundance	Average density and species richness	- Fish have been reported to flee from seismic shooting areas as inferred from decreased catch rates for both long lines and trawler fisheries (Hirst and Rodhouse 2000; Slotte et al. 2004). - Seismic can result in mortality of fish embryos and larvae but population level effects of fish mortality unknown	Limited data available	- Requires baselines of populations, including seasonal variations - Doppler current profiler - Net hauls
Population condition	Change in condition/ sub-lethal effects	Presence of tissue/organ damage. For example, swim bladder.	- Studies have shown that air gun blasts can cause a variety of sub-lethal impacts on fish such as damaging orientation systems and reducing their ability to find food. - Seismic surveys can cause physical damage to fish ears and other tissues and organs such as swim bladders (Hirst and Rodhouse 2000). Although such effects may not kill fish immediately, they may lead to reduced fitness, which increases their susceptibility to predation and decreases their ability to carry out important life processes. - Important prey species (i.e., squid and zooplankton), are also harmed by seismic testing, so the fish dependent on these creatures likely negatively impacted (McCauly et al. 2000).	Requires baselines of information. Catch data may help inform this	- Population or stock delineation methods
	Behavioural response	Further research is needed. However, some measurable that may help this process include: spatial distribution of population/ density, and behavioural response studies.		Requires baselines of information. Catch data may help inform this	- Requires baselines of populations - Visual surveys, stock assessment techniques, and catch data will help inform this

Oil spill → Oil

Rougheye, Yelloweye, Bocaccio, Widow, Pacific Halibut, Prowfish, Sablefish					
	Proposed indicator	**Measureable component of indicator**	**Interaction**	**Existing data**	**Data collection**
Population size	Abundance	Size-frequency distribution	- Oils spilled into marine environments are comprised of a complex suite of several thousand hydrocarbon and synthetic substances, including radionuclides, mineral salts, trace elements and heavy metals (Davenport and Davenport 2006). - The toxicity depends on its type with more refined products generally having higher toxicity (e.g. the heavy fuel oil used for powering ships is more toxic than crude oil). - A substantial hydrophobic amount of oil can be adsorbed into biotic and abiotic suspended solids, which directly affect filter-feeding species leading to food chain bioaccumulation. - In general, toxicity of oil hydrocarbons is less in open water and much higher if released in near- shore environments or shoreline contact occurs. - Oil can persist in habitats long after a spill has occurred, especially in areas sheltered from weathering (e.g. subsurface sediments, under gravel shorelines and some soft substrates) (Elmgren et al. 1983). - 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), and the addition of dispersants is likely to increase this effect (Couillard et al. 2005). 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	- Some data is available for target and non-target species	- Requires baselines of populations

Rougheye, Yelloweye, Bocaccio, Widow, Pacific Halibut, Prowfish, Sablefish					
	Proposed indicator	**Measureable component of indicator**	**Interaction**	**Existing data**	**Data collection**
	Population density	Age/size structure, count per area	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 condition	Change in condition/ sub-lethal effects	Presence of disease, change in age/size structure	- Low levels of dissolved oil hydrocarbons may also slow larval growth rates, and affect swimming and feeding behaviors (Tilseth et al. 1984). - Increased susceptibility to disease, reduced reproductive success, genetic mutations	Requires baselines of information. Catch data may help inform this	- Requires baselines of populations
	Genetic diversity and structure	Population or stock delineation		Requires baselines of information. Catch data may help inform this	- Requires baselines of populations

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