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DEVELOPMENT OF RISK-BASED INDICATORS FOR SGAAN KINGHLAS-BOWIE SEAMOUNT MARINE PROTECTED AREA USING THE ECOLOGICAL RISK ASSESSMENT FRAMEWORK

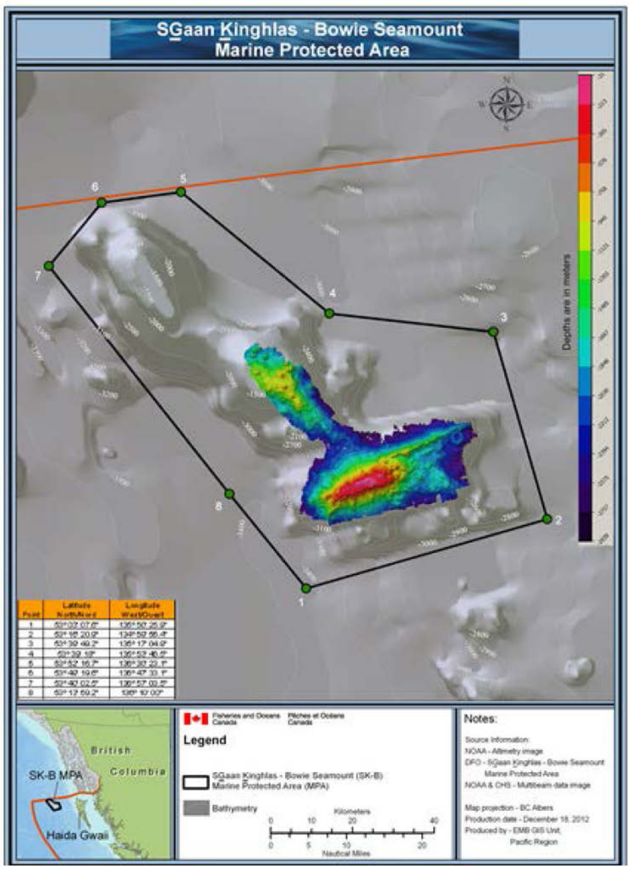

Figure 1. Bathymetric map of SGaan Kinghlas-Bowie Seamount Marine Protected Area. Map provided by G. Oldford, Oceans Management, Fisheries and Oceans Canada, Vancouver, BC.

Context:

Canada's Oceans Act and Oceans Strategy commit Fisheries and Oceans Canada (DFO) to lead the development and implementation of a sustainable, precautionary and integrated ecosystem approach to oceans management. An important step toward meeting these commitments is the application of a risk-based framework to identify and prioritize management issues and inform the development of conservation objectives, management strategies and action plans for Large Ocean Management Areas (LOMAs) and Marine Protected Areas (MPAs).

A five-step framework for the identification of performance indicators in SGaan Kinghlas-Bowie Seamount MPA was developed and reviewed (DFO 2011) and the ecological risk assessment framework was used to develop a list of significant ecosystem components (SECs), ranked by their estimated risk scores resulting from exposure to human activities/stressors in SGaan Kinghlas-Bowie Seamount MPA (DFO 2015).The ranked list of SECs is intended to support the development of risk-based indicators to monitor progress against the achievement of conservation objectives in SGaan Kinghlas-Bowie Seamount MPA while the activities/stressors driving the risk scores will inform the development of monitoring plans.

The identification of indicators, monitoring strategies and plans to assess the achievement of conservation objectives is a key component of MPA planning and implementation in Canadian Pacific marine waters. The indicators proposed through this work for SGaan Kinghlas-Bowie Seamount MPA are intended to be suitable for use once operational conservation objectives have been established.

This Science Advisory Report is from the May 20-21, 2015 Development of Risk-based Indicators for SGaan Kinghlas-Bowie Seamount and Endeavour Hydrothermal Vents Marine Protected Areas Using the Ecological Risk Assessment Framework. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

December 2015

SUMMARY

- A framework to select and prioritize risk-based ecological indicators, using the outputs of an application of the ecological risk assessment framework (ERAF; O et al. 2015), and a proposed suite of risk-based indicators for the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA), were reviewed.
- Risk-based indicators monitor the risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors and can provide information that is specific to SEC-stressor interactions and to the SECs most at risk. These indicators may be SEC-specific, stressor-specific, or specific to a SEC-stressor interaction.
- The suites of risk-based indicators proposed for *current snapshot* stressors (predictable, and occurring most years) and *potential* stressors (unpredictable, and occurring infrequently) are suitable to support the development of strategies and plans to monitor human impacts in the SK-B MPA. It is recommended that indicators for both categories of stressor (*current and potential snapshot*) be considered as each represents different types of risk, states of knowledge and management needs for effective monitoring.
- The framework for risk-based indicator selection clearly describes the procedures that are followed to prioritize and select indicators, and the decision-making process to apply the framework. These elements of the framework support the achievement of comparable outcomes among users and when applied to other MPAs or management units.
- Indicators related to measures of abundance are proposed in most indicator suites, highlighting a key information gap in the SK-B MPA: the need to establish baseline data (e.g., biological, habitat) for all SECs. Past research activities have focused on SECs located on the pinnacle of Bowie Seamount and, as a result, relatively little information is available from other areas of the MPA. It is recommended that programs to collect the appropriate baseline information be designed and implemented going forward, and that a focused effort to locate and evaluate the utility of retrospective information/data from past research at the site be considered.
- Monitoring a combination of SEC-stressor interactions, SEC, and stressor indicators simultaneously is recommended because there is a need to establish SEC baseline data and measure disturbance impacts concurrently in order to separate naturally induced variation from human induced variation. Monitoring of SEC and stressor-specific indicators provides baseline data and monitoring of SEC-stressor indicators provides information on disturbances.
- *Current snapshot* indicator suites measure the SEC-stressor interaction directly. The most informative indicators for *current snapshot* activities/stressors are SEC-stressor interaction indicators, followed by SEC and stressor indicators. For example, for the SEC Bamboo Coral, *Isidella tentaculum*, exposed to crushing (stressor) from trap fishing (activity), the number of dislodged colonies is proposed as an indicator of SEC-stressor interaction, abundance is proposed as the SEC specific indicator, and area crushed as the stressor specific indicator in SK-B MPA.
- Indicators for *potential* SEC-stressor interactions are generally less specific than those for *current snapshot* stressors because of the unpredictable occurrence of these stressors, the high uncertainty around exposure to and the consequences of such interactions, and the lack of established baseline data against which to measure the impact. It is recommended that a two step process for monitoring of *potential* stressor indicator suites be considered:

(1) establish baseline data on population abundance and the possible exposure to a stressor using SEC and stressor specific indicators prior to the occurrence of a stressor; and,

(2) when the *potential* stressor occurs, use SEC-stressor interaction indicators and compare these values with established baseline data to measure the disturbance.

- 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. It is recommended that the performance of the proposed indicators be assessed in terms of their ability to track properties of interest (in this case, impacts from stressors, and establish population baseline data for SECs) and their ability to detect or predict trends in attributes.
- It is recommended that indicator sampling protocols in the SK-B MPA focus on non-destructive sampling methods such as remotely operated vehicles, drop cameras and moorings with hydrophones and oceanographic instruments, supplemented with current data collected from the ongoing sablefish trap fishery. A tiered approach is recommended to minimize the frequency and extent of destructive monitoring, e.g., to estimate SEC biomass, to those periods/places identified by ongoing visual monitoring.
- It is recommended that an iterative approach be used to develop operational conservation objectives, to further refine the list of proposed risk-based indicators, and to select ecosystem indicators in the SK-B MPA.

INTRODUCTION

Canada's *Oceans Act* and Oceans Strategy commit Fisheries and Oceans Canada (DFO) to leading the development and implementation of a sustainable, precautionary and integrated ecosystem approach to oceans management. An important step toward meeting these commitments is the application of a risk-based framework to identify and prioritize management issues and inform the development of conservation objectives, management strategies and action plans for Large Ocean Management Areas (LOMAs) and Marine Protected Areas (MPAs).

A framework to identify, select and prioritize risk-based indicators in SGaan Kinghlas-Bowie Seamount (SK-B) MPA using the outputs of an ecological risk assessment as inputs was proposed by Davies et al. (2011) and reviewed (DFO 2011). An ecological risk assessment framework (ERAF) was developed to assess the potential risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors (O et al. 2015) and was applied to SK-B MPA (DFO 2015). The key information produced by the ERAF is a list of SECs in the SK-B MPA ranked by cumulative risk of harm and the identification of activities/stressors driving those risks. The ranked list of SECs and the information on risk drivers are needed to support the development of risk-based indicators. These indicators will be used to monitor progress in achieving conservation objectives in SK-B MPA while the activities/stressors driving the risk scores will inform the development of monitoring plans.

DFO's Oceans Program requested advice from DFO Science on the selection and prioritization of risk-based indicators in SK-B MPA. The identification of indicators, monitoring strategies and plans to assess the achievement of the conservation objectives is a key component of MPA planning and implementation in Canadian Pacific marine waters. The indicators proposed through this work for SK-B MPA are intended to be suitable for use once operational conservation objectives have been established.

SGaan Kinghlas-Bowie Seamount Marine Protected Area

The SGaan Kinghlas-Bowie Seamount Marine Protected Area is located in the North Pacific Ocean, approximately 180 km west of Haida Gwaii, British Columbia, Canada (Figure 1). Three seamounts - Bowie, Hodgkins and Davidson - 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 3,000 m into the photic zone, within 25 m of the surface, 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).

The SGaan Kinghlas-Bowie Seamount is culturally significant to the Haida First Nation, with SGaan Kinghlas meaning “supernatural being looking outward”. DFO identified Bowie seamount as a pilot MPA in 1998 and, with official designation as an MPA in 2008, the area of interest expanded to include the neighbouring Hodgkins and Davidson Seamounts. DFO and the Council of Haida Nation (CHN) signed a Memorandum of Understanding (MOU) for collaborative management in 2007 (Davies et al. 2011) and established a DFO-CHN management board in 2009.

ASSESSMENT

Ecological Risk Assessment Framework Results

Sixteen significant ecosystem components (SECs) were identified at SK-B MPA during the scoping phase of the ERAF application, but only fourteen SECs (ten species and four habitat SECs) and 32 stressors associated with vessels, research, seismic surveys and fishing were subjected to the Level 2 ERAF application in the SK-B MPA (Rubidge et al.[1]). Stressors were categorized into *current snapshot* and *potential* stressors based on their predictability and frequency of occurrence. *Current snapshot* stressors occur predictably and at relatively high frequencies (e.g., most years) whereas the occurrence of *potential* stressors is unpredictable in time and space and their frequency is less than annual, e.g., once every 5-10 years (DFO 2015).

The Bamboo Coral, *Isidella tentaculum*, and two biogenic habitat SECs, Alcyonacea coral habitat, and sponge habitat, had the highest estimated Cumulative Risk scores in the SK-B MPA. Rougheye Rockfish had the highest Cumulative Risk score of all fish SECs. Rougheye Rockfish had the fourth highest estimated Cumulative Risk and the highest among fish SECs, but there was considerable overlap in the uncertainty around the risk estimates for fish SECs, which is interpreted to mean that fish SECs experience comparable Cumulative Risk levels in the SK-B MPA. Squat lobsters had the lowest cumulative risk score in SK-B and was impacted by the lowest number of stressors (9) of all SECs, possibly because its mobility and population characteristics allow it to avoid benthic impacts and recover faster than more sessile invertebrates. All *potential* stressors (oil spills, aquatic invasive species (AIS), seismic testing) had the highest Potency scores (cumulative risk scores of a stressor summed across all SECs) in the SK-B MPA. Potency scores tend to be driven by high uncertainty, particularly for the Exposure term in the risk equation, because they are evaluated on a worst-case scenario basis for both Exposure and Consequences.

[1] Rubidge, E., Thornborough, K., and O. M. 2015. Ecological risk assessment for the SGaan Kinghlas Bowie Seamount Marine Protected Area. Can. Sci. Advis. Sec. Res. Doc. In revision.

Indicator Selection Framework

Risk-based indicators are used to monitor the risk of harm to SECs from anthropogenic activities and associated stressors and are identified using the outputs of an ERAF applied to a specific area. Risk-based indicators may be selected for SECs, stressors, and SEC-stressor interactions, depending on their relative risk rankings. 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) allows for differentiation in the approach to monitoring indicators at different time scales (i.e., single event or time series monitoring).

The framework for selecting risk-based indicators (Figure 2) uses outputs from an ERAF application and follows three steps:

(1) prioritizing SECs and stressors based on the outputs of the ERAF application (estimated Cumulative Risk and uncertainty);

(2) identifying key drivers of risk and uncertainty that indicators are expected to monitor; and

(3) identifying indicators that meet several selection criteria.

SEC indicators were selected based on the key attributes of population (or habitat) size and population (or habitat) condition, which are linked directly to the resilience term in the ERAF risk equation, where Acute Change and Chronic Change correspond to population size and condition, respectively. Stressor indicators are based on the components of the Exposure term in the risk equation, including distribution (Area/Depth), seasonality (Temporal overlap), and scale and frequency of disturbance (Intensity). Indicators were selected for all SECs and stressors and were incorporated into suites of indicators for *current snapshot* and *potential* SEC-stressor interactions where appropriate.

The selection of risk-based indicators is one component in the adaptive management (AM) framework implemented by DFO for the SK-B MPA. The indicators are selected based on outputs from an application of the ERAF and will be used to develop monitoring strategies, refine policy objectives into operational conservation objectives, and develop monitoring plans. The AM framework is iterative and there are feedback loops between many steps, which permit the inclusion of data on additional species or stressors (e.g., sound frequency of vessel noise) at the SK-B MPA, or information on new monitoring technologies to be in future iterations of risk assessments, evaluation of indicators, selection of new indicators, and the refinement of monitoring plans.

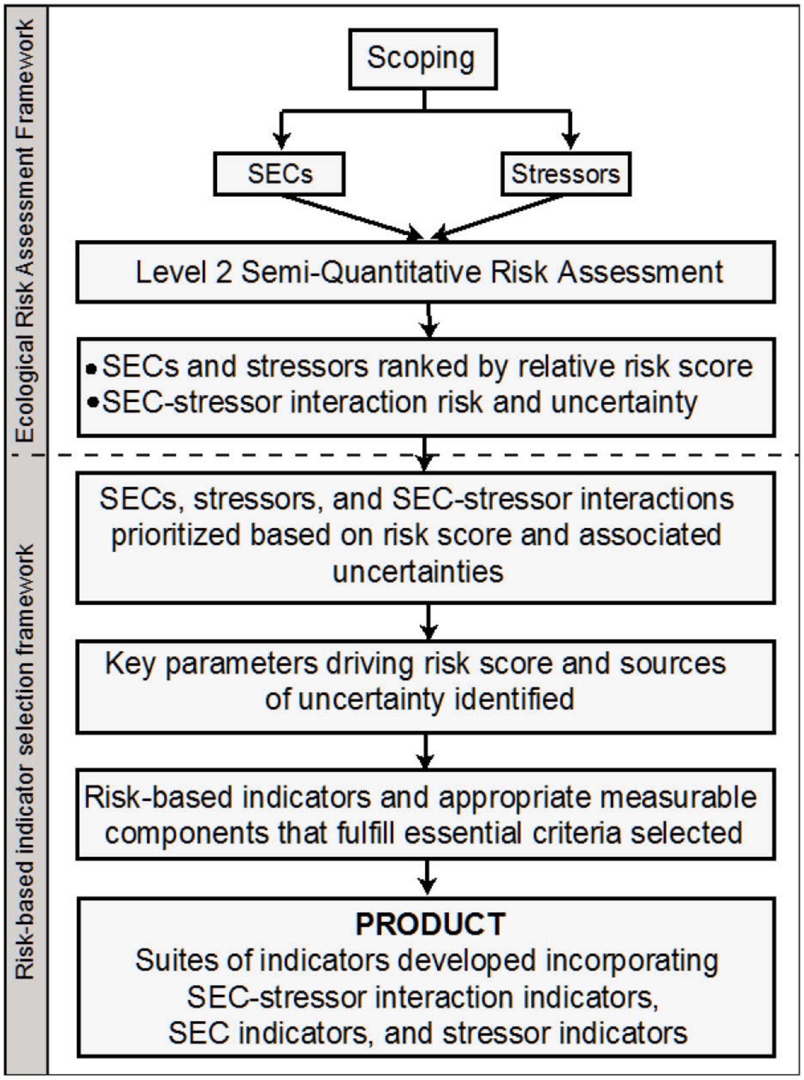

Figure 2. Overview of the framework used to select risk-based indicators for the SK-B MPA. The overview shows the linkage with the ERAF and how the outputs of an ERAF application are necessary inputs to the indicator selection framework.

Risk-based indicators were selected to meet the goal of providing useful measurements of the SECs, stressors, and SEC-stressor interactions identified by the ERAF. The selection process was guided by indicator criteria found in the scientific literature, including

(1) theoretical soundness (evidence of use),

(2) measureable/feasible,

(3) sensitive to changes in a specific ecosystem attribute, and

(4) availability of historical data.

Three additional selection criteria - cost-effectiveness, public awareness, and linkages to management concerns/measures/targets – were also identified in the scientific literature but not used in this process because these criteria relate to program implementation and are better suited to refining or narrowing the list of risk-based indicators identified here when concrete monitoring strategies and plans have been developed.

Indicators for SECs and stressors were chosen from the scientific literature and discussion with MPA area experts, and were required to fulfill the first four criteria listed above. The fourth criterion, availability of historical data, was not considered essential for indicator selection in the SK-B MPA because historical data related to biology, habitat, bathymetry, and oceanographic processes are either sparse or access to those data is limited at present. The historical data criterion could be an essential selection criterion in other applications of this framework. If an appropriate indicator was not available in the literature or could not be found for a specific SEC or stressor, a similar species/habitat or stressor was used, respectively. The sensitivity criterion was not applied to stressor indicators, as stressors do not respond to changes in specific ecosystem attributes. Instead, greater importance was placed on the historical data criterion for stressor indicators.

The 196 SEC-stressor interactions identified in SK-B MPA (Rubidge et al.[1]) were prioritized to reduce the number of interactions before indicator selection began. The prioritization process ranked SEC-stressor interactions by both risk score and uncertainty, and divided the interactions into high, moderate, and low priority. Indicators were selected only for high and moderate priority interactions. Both the risk score and uncertainty were used in this process because the risk assessment results clearly showed 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 before prioritization to avoid the final suite of indicators being dominated by *potential* interactions. Both *potential* and *current snapshot* interactions are required for indicator selection, as each highlights different information gaps and monitoring and management needs.

Risk-based Indicators

SECs with similar life history traits were grouped, and suites of indicators were developed, for both *current snapshot* (Table 1) and *potential* stressors (Table 2). An indicator suite rather than just one indicator provides options, and captures a greater range of attributes. 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. The proposed suite of indicators for *current snapshot* and *potential* SEC-stressor interactions are shown in Tables 1 and 2, respectively. The measurable components for these indicators, which describe how the indicator is measured, are shown in the Appendix. The inclusion of SEC, stressor specific, and SEC-stressor interaction indicators in the suites serves two purposes:

(1) to provide alternate options if interaction-specific indicators cannot be measured; and

(2) since baselines have not been established, information collected by monitoring SEC and stressor-specific indicators will create baselines of information against which trends from subsequent surveys will inform management on conservation objectives.

Risk-based indicators for *current snapshot* and *potential* SEC-stressor interactions represent a different type of risk and state of knowledge, and may require different management approaches.

Table 1. Proposed Indicator suites for current snapshot SEC-stressor interactions in the SK-B MPA, presented roughly in order of the prioritization results. Only moderate and high priority interactions are shown.

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)	• Number of colonies with visible damage/fragmentation • Number of dislodged colonies	• Abundance	• Maximum potential crushed area
		Substrate disturbance (re-suspension)	• Number of colonies showing signs on 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	• 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 • Genetics • Species richness and diversity	• Catch • 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 • Genetics • Species richness and diversity	• Level of noise at SK-B MPA • Vessel density in vicinity of SK-B MPA

*Table 2. Proposed Indicator suites for potential SEC-stressor interactions in the SK-B MPA, presented roughly in order of the prioritization results. Only moderate and high priority interactions are shown. A bolded **SEC** is only impacted by the matching bolded **stressor**.*

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 • Genetics • Species richness and diversity	• Shots fired (air-guns) • Distance from SK-B MPA • Sound propagation models
	Oil spill	Oil	• Abundance • Population density • Change in condition/ sub-lethal effects • Genetic diversity and structure	• Abundance • Genetics • Species richness and diversity	• Vessel density in vicinity of 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 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

SEC	Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
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 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

Current snapshot indicators (Table 1) largely measure SEC-stressor interactions directly and can be monitored at the same time as collecting general information to establish population baselines. The most informative indicators for *current snapshot* interactions are SEC-stressor indicators, followed by SEC and stressor indicators. Monitoring only SEC or stressor indicators will reduce uncertainty concerning the specificity of these measurements to a SEC-stressor interaction. Although vessel traffic and noise analysis is underway to investigate sound frequency effects on SECs, data on *current snapshot* stressor exposures are lacking for SK-B MPA.

Indicators for *potential* SEC-stressor interactions (Table 2) are generally less specific to the SEC-stressor interaction than those for *current snapshot* interactions. This suite of indicators relies on monitoring the stressor or impacted SEC separately because of the unpredictable occurrence of these stressors, the high uncertainty around the Exposure and Consequence of such interactions, and the lack of established baseline data against which to measure the impact. SEC indicators are more closely linked to measures of abundance (to establish population baselines), and stressor indicators measure the possible exposure to the stressor once the event has occurred (e.g., an oil spill).

Performance testing of these indicators should be conducted using either a formal evaluation method such as retrospective tests based on signal detection theory, or rule-based management with monitoring and feedback controls (Rochet and Rice 2005). Indicator performance can be assessed in terms of the 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).

Indicators related to measures of abundance are proposed in most indicator suites, highlighting a key information gap in the SK-B MPA: baseline data related to habitat, bathymetry, oceanographic processes, and SECs are sparse. Although sporadic research activity has occurred at the site historically, the data from these activities has not been catalogued nor evaluated for its usefulness in establishing historical changes over time to the present. Furthermore, data related to SEC exposure to stressors is limited in the SK-B MPA. Establishing baselines is needed to monitor SEC population size and condition going forward, and link to anthropogenic stressors. This process is particularly crucial for potential SEC-stressor interactions, as monitoring the impacts from these unpredictable stressor interactions is not possible until the event occurs.

The identification of indicators, monitoring strategies and plans to assess the achievement of conservation objectives is a key component of MPA planning and implementation in Canadian Pacific marine waters. The refinement of conservation objectives into SMART (specific, measureable, achievable, realistic, and time-sensitive) operational objectives usually occurs before indicators are identified in the adaptive management process. The indicators proposed for the SK-B MPA are based on the best available knowledge of indicator development and monitoring and are intended to be suitable for use once operational conservation objectives have been established. While the match between proposed indicators and operational conservation objectives is unknown at present, the broad range of indicators is expected to result in appropriate matches. The effectiveness of these indicators in measuring changes to SECs resulting from interactions with stressors at SK-B MPA will not be fully realized until after data collection has commenced and the data are analyzed. This process can be implemented sooner for *current snapshot* interaction indicators than *potential* SEC-stressor interaction indicators, which cannot be evaluated until the stressor occurs. Operational conservation objectives can be developed in conjunction with monitoring strategies and plans 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.

Sources of Uncertainty

The indicators identified for the SK-B MPA can be used to monitor direct impacts or changes to SECs. Identifying indicators to monitor indirect impacts or changes associated with ecological interactions is challenging and was not attempted.

The proposed risk-based indicators were selected prior to the development of operational conservation objectives for the SK-B MPA. The match between indicators and objectives is unknown at present, although the proposed indicators suites are sufficiently broad that matches are expected.

SECs and stressors that were screened out during the scoping phase of the ERAF, or were excluded from the ERAF because they are not manageable at the MPA scale (e.g., transient species such as marine mammals or birds, natural stressors), were not considered in the selection of risk-based indicators.

The pinnacle of Bowie Seamount has been the focus of management attention and research in the SK-B MPA. Much less is known about the depths below the pinnacle and, importantly, the other seamounts (Hodgkins, Davidson).

CONCLUSIONS AND ADVICE

The suites of risk-based indicators proposed for *current snapshot* stressors (predictable, and occurring most years) and *potential* stressors (unpredictable, and occurring infrequently) are suitable to support the development of strategies and plans to monitor human impacts in the SK-B MPA. It is recommended that indicators for both categories of stressor (*current snapshot* and *potential*) be considered as each represents different types of risk, states of knowledge and management needs for effective monitoring.

The framework for risk-based indicator selection clearly describes the procedures that are followed to prioritize and select indicators, and the decision-making process to apply the framework. These elements of the framework support the achievement of comparable outcomes among users and when applied to other MPAs or management units.

Indicators related to measures of abundance are proposed in most indicator suites, highlighting a key information gap in the SK-B MPA: the need to establish baseline data (e.g., biological, habitat) for all SECs. Past research activities have tended to focus on SECs located on the pinnacle of Bowie

Seamount and as a result relatively little information is available from other areas of the MPA. It is recommended that programs to collect the appropriate baseline information be designed and implemented going forward and that a focused effort to locate and evaluate the utility of retrospective information from past research at the site be considered.

It is recommended that a two step process for monitoring of *potential* stressor indicator suites be considered:

(1) establish baseline data on population abundance and the expected exposure to a stressor using SEC and stressor specific indicators prior to an occurrence of the stressor ; and,

(2) when the *potential* stressor occurs, use SEC-stressor interaction indicators and compare these values with established baseline data to measure the disturbance.

It is recommended that indicator sampling protocols in the SK-B MPA focus on non-destructive sampling methods such as remotely operated vehicles, drop cameras and moorings with hydrophones and oceanographic instruments, supplemented with current data collected from the ongoing sablefish trap fishery. A tiered approach is recommended to minimize the frequency and extent of destructive monitoring, e.g., to estimate SEC biomass, to those periods/places identified by ongoing visual monitoring.

It is recommended that an iterative approach be used to develop operational conservation objectives, to refine the list of proposed risk-based indicators, and to select ecosystem indicators in the SK-B MPA.

It is recommended that the performance of the proposed indicators be assessed in terms of their ability to track properties of interest (in this case, impacts from stressors, and establish population baseline data for SECs) and their ability to detect or predict trends in attributes.

SOURCES OF INFORMATION

This Science Advisory Report is from the May 20-21, 2015 Development of Risk-based Indicators for SGaan Kinghlas-Bowie Seamount and Endeavour Hydrothermal Vents Marine Protected Areas Using the Ecological Risk Assessment Framework. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Davies, S., O, M., and Boutillier, J., 2011. Recommendations for indicator selection for SGaan Kinghlas Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/069. vi + 30p. (Accessed July 3, 2015)

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APPENDIX

*Table A1. Proposed SEC indicators and their measurable components in the SK-B MPA. A bolded **SEC** is only impacted by the matching bolded **stressor**.*

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)
				Biomass	Weight/unit area
			Population condition	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 behavioural indicators (e.g. righting and feeding behaviour, reflex actions)
				Species range	Range of species
Vertebrates (fish)	Pelagic	Rockfish: - Rougheye - Widow - Bocaccio - Yelloweye	Population size	Abundance	Size-frequency distribution
				Biomass	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
				Genetics	Population or stock delineation

Table A2. Proposed indicators and measurable components for stressors known to impact the SK-B MPA. Activities/stressors are presented in rough order of priority.

Activity	Stressor	Indicator	Measureable component
Oil spill	Oil	Vessel density in vicinity of SK-B MPA	• Number of vessel movements per traffic reporting zone or per 5km x 5km 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
Seismic testing/air guns	Sound generation	Distance from 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
Discharge	Aquatic invasive species	Frequency of potential exposure	• Number of vessel movements per traffic reporting zone or per 5km x 5km grid cell • Number of ballast water exchanges in vicinity of 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 5km x 5km grid cell • Number of ballast water exchanges in vicinity of 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

Activity	Stressor	Indicator	Measureable component
Trap/pot fishing	Removal of biological material	Catch	• 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 <6.35mm
	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
Movement underway	Noise disturbance	Vessel density in vicinity of SK-B MPA	• Number of vessel movements per traffic reporting zone or per 5km x 5km grid cell
		Level of noise at SK-B MPA	• Measure sound produced (e.g. hydrophones)
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 <6.35mm
	Substrate disturbance (crushing)	Crushed area	• Proportion (%) of area/habitat crushed
		Vessel size/type	• Vessel size (m^2)
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

Activity	Stressor	Indicator	Measureable component
		Length of exposure	• Length of time since installation
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 <6.35mm
	Substrate disturbance (crushing)	Crushed area	• Proportion (%) of the area crushed • m^2
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 <6.35mm
		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
	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
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 <6.35mm
	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
Scuba diving		Potential exposure	• Number of divers/annum
	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 <6.35mm
	Substrate disturbance (crushing)	Crushed area	• Proportion (%) of the area crushed • m^2

Table A3. Proposed indicators for current snapshot SEC-stressor interactions in the SK-B MPA and their measureable components.

SEC		Activity	Stressor	Key parameter	Proposed indicator	Measureable component of indicator	Data collection
Invertebrates (sessile benthic)	Corals: - *Isidella tenta-culum* - Corals (habitat) Sponges: - Sponges (habitat)	Trap/pot fishing	Substrate disturbance (crushing)	Population size	Number 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	Number of dislodged colonies	Proportion of sampled population (%) dislodged	• Visual survey
			Substrate disturbance (sediment re-suspension)	Population size	Number of colonies showing signs on smothering	Proportion of sampled population (%) impacted	• Visual survey
				Population condition	Number 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 distribution of populations/density	• 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

SEC		Activity	Stressor	Key parameter	Proposed indicator	Measureable component of indicator	Data collection
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 A4. Proposed indicators for potential SEC-stressor interactions and their measurable components. An asterisk (*) denotes a SEC and stressor interaction that is not categorized as moderate or 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
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	Species richness/	Diversity measures (e.g.	• Requires baselines of

SEC	Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
			condition	presence of disease	Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	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	Number 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
	Submersible operations	Aquatic invasive species	Population size	Number 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

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	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)	• 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	Number 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
		Trap/pot fishing	Aquatic invasive species*	Population size	Number 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,

SEC		Activity	Stressor	Key parameter	Potential indicator	Measureable component of indicator	Data collection
							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

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Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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