Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Response 2018/040

ECOLOGICAL RISK ASSESSMENT AND SELECTION OF RISK-BASED INDICATORS FOR THE HECATE STRAIT AND QUEEN CHARLOTTE SOUND GLASS SPONGE REEFS MARINE PROTECTED AREA

Context

The Hecate Strait and Queen Charlotte Sound glass sponge reef complexes were designated as a Marine Protected Area (MPA) in February 2017 (Canada Gazette 2017), representing 2,410 km² of protected aquatic habitat along Canada's Pacific North Coast. Previously thought to be extinct worldwide, these reefs are estimated to be up to 9,000 years old (Conway et al. 2001). The glass sponge reef structures form complex and fragile biogenic habitats and are at risk from both direct contact and indirect effects of human activities. The reefs serve a number of key ecosystem functions, including refuge and rearing habitat for numerous aquatic species at various life stages. In order to adequately monitor and protect the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA (HS/QCS MPA), a comprehensive inventory and assessment of the risk to ecosystem components from the activities and stressors occurring in the ecosystem is required. Collectively, this work contributes to Canada's commitment to a sustainable, precautionary, and integrated ecosystem approach to oceans management as directed in the Oceans Act and Oceans Strategy.

The Ecological Risk Assessment Framework (ERAF) for Ecosystem Based Management (EBM) was developed by Fisheries and Oceans (DFO) Pacific Region (O et al. 2015) to evaluate the single and cumulative threats from human activity-related stressors to Significant Ecological Components (SECs) in the ecosystem of interest. The ERAF is hierarchical and can be applied at different levels. To date, the framework has been evaluated through a Level 1 (qualitative) pilot application to the Pacific North Coast Integrated Management Area (PNCIMA), and through two Level 2 (semi-quantitative) applications to Pacific Region MPAs: SGaan Kinghlas-Bowie Seamount MPA (SK-B MPA; Rubidge et al.[1]) and Endeavour Hydrothermal Vents MPA (EHV MPA; Thornborough et al.[2]). Advice arising from these processes was used to inform the current ecological risk assessment of the HS/QCS MPA (DFO 2015a).

The selection of risk-based ecological indicators is another key step in DFO's adaptive management framework for MPAs. Using the outputs from the HS/QCS MPA ecological risk assessment as a starting point, ecological indicators selected through this process will then be used to develop monitoring strategies, further refine conservation objectives into operational objectives, and develop monitoring plans. A risk-based indicator selection process has previously been applied to the SK-B MPA (DFO 2015b; Thornborough et al. 2016a) and EHV MPA (DFO 2015c; Thornborough et al. 2016b), and advice arising from these processes will inform the current assessment.

[1] Rubidge, E., Thornborough, K., and O, M. Ecological Risk Assessment for the Effects of Human Activities at the SGaan Kinghlas-Bowie Seamount Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc (in press).
[2] Thornborough, K., Rubidge, E, O., M. Ecological Risk Assessment for the Effects of Human Activities at the Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc (in press).

This Science Response summarizes the results and advice arising from the Science Response meeting held on February 2, 2018 to review the ecological risk assessment and selection of risk-based indicators for the HS/QCS MPA.

Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Background

The HS/QCS Glass Sponge Reefs were discovered by the Geological Survey of Canada in the late 1980's (Jamieson and Chew 2002). While glass sponges are found throughout the world's oceans, the HS/QCS reefs are unique in their size and extent. Further, they are considered to be the only living example of the large sponge reefs that were abundant during the Jurassic Period (Krautter et al. 2006), making them globally significant.

The HS/QCS Glass Sponge Reefs are comprised of four discrete reefs forming a discontinuous band covering 425 km^2 at depths of 165-240 m (Conway et al. 2004; Appendix A). The reefs are estimated to be 6,000-9,000 years old (Conway et al. 2001). Glass sponge reefs are complex, three-dimensional structures, composed of a sediment infilled matrix of dead siliceous sponge skeletons with living sponge growing on top. The HS/QCS MPA reefs are formed by three species of sponges: *Aphrocallistes vastus*, *Heterchone calyx* and *Farrea occa* (Conway et al., 2001). The living sponges are 1-2 m tall and sit atop sediment-infilled skeletal mounds which average 5-8 m in height, but can extend up to 21 m (Lehnert et al., 2005; Conway et al, 2007). The HS/QCS sponge reefs provide refuge, habitat, and nursery ground for other aquatic species, including rockfish and other finfish and shellfish species (Chu and Leys 2010). Further, their high filtration capacity gives them an important role in nitrogen and carbon processing (Kahn et al. 2015; Yahel et al. 2007). Sponge reefs also have an important role in the global silica cycle by acting as an important sink for biogenic silica (Chu et al. 2011).

The designation of the HS/QCS Glass Sponge Reefs as an *Oceans Act* Marine Protected Area (Canada Gazette 2017) provides comprehensive protection from human activities that could negatively impact the reefs. As a first step toward adequately protecting the HS/QCS MPA, a comprehensive inventory and assessment of the risk to ecosystem components from the activities and stressors occurring in the ecosystem is required. Secondly, suitable indicators must be identified to help inform management decisions with respect to monitoring and assessing status. Collectively, this work contributes to Canada's commitment to a sustainable, precautionary and integrated ecosystem approach to oceans management as directed in the *Oceans Act* and Oceans Strategy.

Ecological Risk Assessment Framework

A previously reviewed and approved ecological risk assessment framework (ERAF) has been applied for assessing and ranking single and cumulative risks to significant ecological components (SECs) (DFO 2015a). In general, the process involves a hierarchical approach to appropriately scope, select, and score relevant SECs that, collectively, provide a comprehensive assessment of the impacts of human-based activities to the ecosystem. The ERAF is hierarchical and has two phases: scoping and risk assessment. Depending on the scale of the application and availability of data, the risk assessment phase can be applied at Level 1 (qualitative), Level 2 (semi-quantitative), or Level 3 (fully quantitative).

In the scoping phase, existing literature was used to assemble lists of species, habitats, and community/ecosystem properties to be assessed against SEC selection criteria and additional ecosystem-specific considerations. Although it is important to identify all potential SECs, only a limited number of key SECs are ultimately chosen for use in the risk assessment. Activities in the area were identified using an informal list previously assembled by DFO Oceans in 2011 through consultation with stakeholders, science and policy. This list was added to and updated for this work and each activity assessed to ensure it was currently occurring or was expected to occur in the foreseeable future in the area. The stressors resulting from the identified activities were identified by the development of Pathways of Effects (PoE) models. PoE models describe the relationships between human activities, associated stressors and their pathway of effect/impact, where a “stressor” is a factor, environmental or anthropogenic, that causes or drives a behaviour or outcome (Busch et al. 2003).

Following the identification of the SECs, activities and stressors in the scoping phase, the risk assessment moves onto the analytical phase of estimating risk. Risk is defined as “the likelihood that a SEC will experience unacceptable adverse consequences due to exposure to one or more stressors” (O et al. 2015). Three types of risk are estimated: relative risk to a SEC, cumulative risk across stressors to a SEC and potency of stressors across all SECs.

The key information produced by the ERAF is a list of SECs in the HS-QCS MPA ranked by cumulative risk of harm and the identification of the activities/stressors driving those risks, along with estimates of uncertainty for each component of the risk equation. This information is valuable for managers as it provides them with information to help guide decision making. The ranked list of SECs and the information on drivers of risk are also needed to support the subsequent step of developing risk-based indicators.

Risk-Based Prioritization and Indicator Selection

The selection of appropriate indicators is an integral part of DFO Oceans – Pacific Region adaptive management framework, as indicator selection leads to the development of monitoring strategies whereby broader conservation objectives are made functional as operational objectives that are specific, measureable, achievable, realistic, and time-sensitive (SMART). 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).

Risk-based indicators are selected based on outputs of an ERAF applied to the specific area, and include indicators of SECs, stressors, and SEC-stressor interactions ranked by relative risk. Uncertainties associated with the calculated relative risk are used in the prioritization process and help to identify knowledge gaps. The division of stressors into two suites, *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 events versus time series). By selecting indicators for the SEC-stressor interactions most at risk, we can provide targeted science advice to managers and increase the effectiveness of the monitoring strategies derived from them.

The selection of risk-based indicators is based on risk scores in concert with an assessment of the uncertainty associated with the factors used to build the indicators. Indicator selection also relies on validation and incorporation of the best available scientific knowledge. The final product includes suites of indicators, rather than one or two, to provide a more comprehensive understanding of SEC distribution and range and the impacts from anthropogenic stressors. The monitoring of these indicators may permit future development of thresholds and appropriate management actions.

The risk-based indicator selection framework has previously been applied to both SK-B MPA and EHV MPA (Thornborough et al. 2016a, 2016b) and involves three steps:

1. Individually prioritize SECs, stressors, and SEC-stressor interactions based on the outputs of the ERAF application (using cumulative risk, potency, and uncertainty scores);
2. Determine the criteria that each 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 selected 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.

SEC-stressor interactions were divided into *current snapshot* and *potential* interactions, and then ranked by their ERAF relative risk scores and uncertainties. Only interactions ranking moderate to high priority were retained for indicator selection.

Finally, suites of indicators were selected for both *current snapshot* and *potential* SEC-stressor interactions. The indicator suites incorporate indicators selected for the individual SEC and stressor, as well as the interaction between the two. Providing suites of indicators rather than single indicators provides options to management, and captures a greater range of ecological attributes. This approach ensures that a range of attributes are measured, and provides alternative options for monitoring relevant SEC-stressor interactions. Further, the inclusion of SEC- and stressor-specific indicators in the indicator suites serves two purposes: to provide alternate options if interaction-specific indicators cannot be measured; and information collected by monitoring SEC- and stressor-specific indicators can help establish baselines of information to complement existing datasets.

Analysis and Response

Ecological Risk Assessment Results

In the preliminary scoping phase, 397 species, three habitats, and seven community/ecosystem properties were considered as possible SECs. Species SECs were initially assessed via the original ERAF criteria (O et al. 2015). In order to provide further refinement to the list of candidate species, it was necessary to assess them against six supplementary considerations that are specific to glass sponge reef ecosystems. Habitat and community/ecosystem property SECs were readily identified from the original criteria provided by O et al. (2015). From the list of candidate SECs, eight were ultimately selected for inclusion in the Level 2 semi-quantitative risk assessment phase (six species SECs, two habitat SECs and two community SECs). Note that, in addition to four species SECs and two habitat SECs generally selected via objective application of the ERAF criteria and supplementary considerations, expert reviewers recommended that two additional species SECs of particular interest to the glass sponge reef ecosystem be included. Additionally, it was determined that there was insufficient data at this time to inform the semi-qualitative risk assessment of the two community SECs but that these communities were sufficiently represented by the species and habitat SECs that were to be assessed.

The scoping phase also identified a wide range of stressors through the use and adaption of existing PoE models, along with development of a new PoE model to assess the generic effects of fishing. The complete list of possible interactions were further refined through the use of a

SEC-stressor interaction matrix, ultimately resulting in a total of 278 SEC-stressor interactions across the eight SECs that were fully scored for the three main components of the risk equation: ***Exposure**$_{sc}$*, ***Resilience**$_{c}$*, and ***Recovery**$_{c}$* along with estimates of uncertainty for each term. Overall uncertainty was approximated for each relative risk estimate using a heuristic approach, modified from Murray et al. (2016). Use of a newly updated and automated analytical R software tool (R Core Team 2016) enabled a range of underlying assumptions to be tested for robustness and impact on the final results.

For all SECs, the *potential* stressor of acute oil contamination from oil spills dominates the ***Risk**$_{sc}$* scores, driven by a combination of consistently high ***Exposure**$_{sc}$* and ***Consequence**$_{sc}$* scores. In addition, uncertainty values were also high for this stressor. Given similarities in their biology and function, the four sponge species SECs and two sponge habitat SECs (grouped as "sponge-related SECs") had very similar ***Risk**$_{sc}$* scores. In addition to sharing the top-ranking stressor (acute oil contamination from oil spills), the SECs also shared the same remaining top-scoring stressors (although their relative order changed among SECs): substrate re-suspension from bottom trawling, substrate crushing from midwater trawling, and chronic oil/contaminant effects from vessel discharges. For the two non-sponge SECs (*M. quadrispina* and *S. paucispinis*), a wider range of stressors were estimated as the top risks (other than oil contamination from oil spill remaining the highest). For Squat Lobster, sediment re-suspension from bottom trawling, chronic oil/contaminant effects from vessel discharges, and introductions of aquatic invasive species (AIS) from vessel grounding round out the four top-ranking stressors. Conversely for *S. paucispinis*, removal of biological material from midwater trawl, sediment re-suspension from bottom trawling and noise disturbance from vessel movement round out the top four stressors. As with the sponge-related SECs, most of the stressors for the non-sponge SECs are statistically indiscernible (i.e., differences between stressor medians are far out-weighed by the variability associated within them).

Estimates of cumulative risk to SECs across all stressors (***CRisk**$_{c}$*) are displayed in Figure 1. The Sponge Garden habitat SEC had the highest cumulative risk, though only marginally higher that the four sponge species SECs (which collectively are used in this iteration to represent a Sponge Reef habitat SEC). It is suspected that this is most likely due to the less predictable nature of Sponge Garden occurrence generating higher uncertainty in the stressor scores. Given the overlap in their 10/90% uncertainty intervals, the top five sponge-related SECs are statistically indistinguishable (and the sixth is only marginally differentiable).

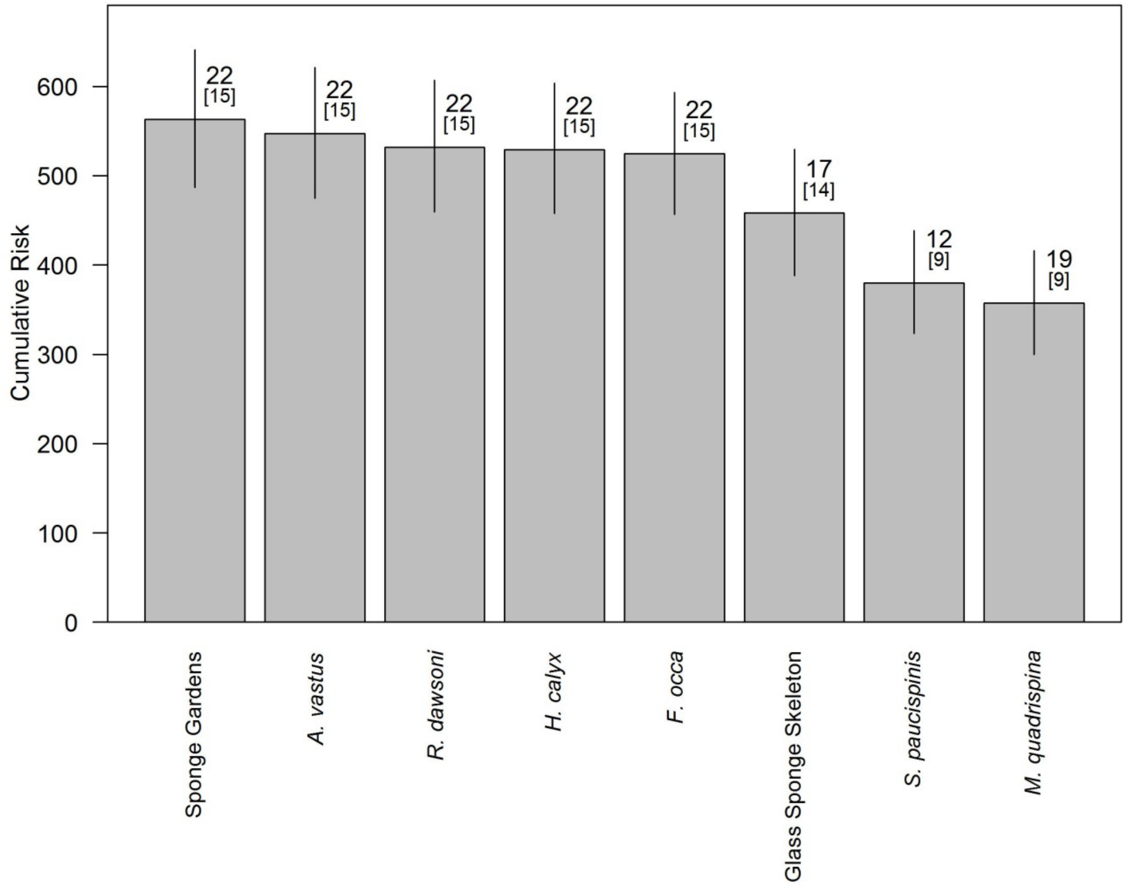

*Figure 1. Cumulative risk (**CRisk$_c$**) for each SEC, ranked in descending order with 10/90% percentile error bars. Numbers above columns denote the number of stressors applicable to that SEC: all stressors and [non-zero stressors only].*

Potency$_s$ represents the sum of ***Risk$_{sc}$*** scores for each stressor across all SECs and is presented in Figure 2. Far surpassing all other stressors, acute oil contamination from oil spills (associated with vessel traffic) has the highest ***Potency$_s$*** estimate, and is relevant to all eight SECs. Stressors related to fishing (six stressors) and other vessel traffic activities (three stressors) round out the top 10 highest ***Potency$_s$*** stressors, impacting six to eight SECs each. Disturbance from seismic activities is the highest research activity-related stressor. The remaining stressors are associated with a wide range of fishing, research, and vessel traffic-related sub-activities.

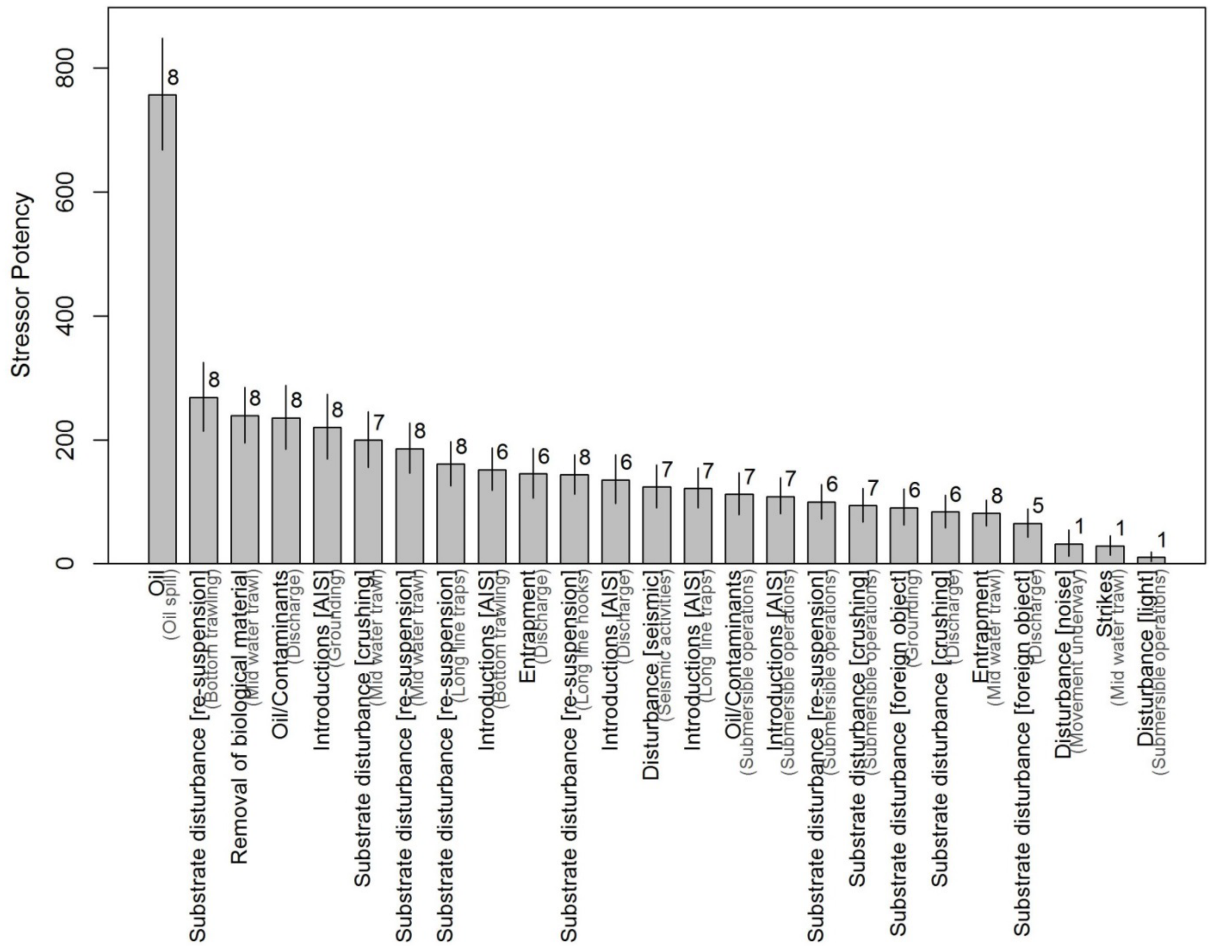

*Figure 2. Cumulative risk by stressor (**Potency**$_s$) plotted in descending order with 10/90% percentiles, and showing the number of SECs (out of 8) contributing to the score (above the corresponding bar).*

It is important to investigate the drivers of high ***Risk***$_{sc}$ scores in order to better understand the impacts of human-based activities and how to mitigate their risk. A high ***Risk***$_{sc}$ score can be driven primarily by one factor, though more often it is the result of a combination of factors. For example, high exposure scores associated high uncertainties inflate ***Risk***$_{sc}$ scores; this is often the case for potential stressors due to their inherent high consequence and higher uncertainty (e.g. given their low incidence, less is known about their acute and chronic impacts).

Including an uncertainty score with each risk term in the assessment provides additional context to the scoring and subsequent outputs and this additional information linked to the score can inform managers of the level of certainty surrounding an assigned score and potential knowledge gaps. Table 1 provides a simplified breakdown of what can drive high ***Risk***$_{sc}$ scores in SEC-stressor interactions and guidance to managers of the most effective options available to reduce high ***Risk***$_{sc}$ scores.

Table 1. Simplified guidance for addressing SEC-stressor interactions with high ***Risk***$_{sc}$ *scores identified in the risk assessment by examination of the scores and what may be driving them.*

<table>
<tr><th rowspan="3">High Risk$_{sc}$ score driven mainly by relatively high:</th><th rowspan="2"></th><th colspan="2">High Risk$_{sc}$ score paired with:</th></tr>
<tr><th>Low uncertainty</th><th>High uncertainty</th></tr>
<tr><td>Exposure$_{sc}$</td><td>A high Exposure$_{sc}$ score paired with low uncertainty indicates confidence in the high exposure of the SEC to this stressor.
The Risk$_{sc}$ score from these types of interactions has potential to be reduced through management actions.
Reducing Exposure$_{sc}$ through reductions in area overlap, depth overlap, frequency and/or amount of the activity that produces the stressor may reduce the Risk$_{sc}$ score. For example, reducing the frequency of a fishery, or the allowable area for a vessel traffic activity that produces the stressor could lower Risk$_{sc}$.</td><td>A high Exposure$_{sc}$ score paired with high uncertainty can indicate a data gap, where the associated Risk$_{sc}$ score is inflated due to a lack of knowledge/ data on the terms of Exposure$_{sc}$ (spatial/temporal overlap, frequency and/or intensity of the stressor).
Managers can try to reduce Risk$_{sc}$ by identifying which terms of Exposure can be addressed through research priorities or data gathering on the stressor and activity.</td></tr>
<tr><td></td><td>Consequence$_{sc}$</td><td>A high Consequence$_{sc}$ score paired with low uncertainty value indicates that it has been well established that the stressor has a detrimental effect on the SEC.
In this case, managers could try to address Exposure$_{sc}$ terms (spatial/temporal overlap, frequency and/or intensity of the activity/stressor) as much as possible to reduce the Risk$_{sc}$ score.</td><td>A high Consequence$_{sc}$ score paired with high uncertainty indicates the detrimental impact to the SEC from the stressor could be inflated due to a lack of data/knowledge of the effect of the stressor on the SEC.
Indicates a data gap in the knowledge of the biology of this SEC and/or mechanism for stressor impact in this SEC-stressor interaction.
Managers could direct research into the nature of the impact of the stressor on the SEC to reduce the Risk$_{sc}$ score.</td></tr>
</table>

Risk-Based Prioritization and Indicator Selection

Preliminary prioritization of SECs and stressors were derived from the ERAF outputs, where the highest and lowest ***CRisk***$_{c}$ and ***Potency***$_{s}$ scores correlate to the highest and lowest priorities for SECs and stressors, respectively. For each of the eight SECs and 18 stressors identified in the ERAF, several indicators (average of three) were selected from available literature that met the indicator selection criteria.

A total of 106 SEC-stressor interactions were identified as impacting the HS/QCS MPA. To provide relevant science advice, these SEC-stressor interactions were prioritized to reduce the number of listed interactions prior to the selection of indicators using the method outlined in the risk-based indicator selection framework (Thornborough et al. 2016a, 2016b). Once interactions were prioritized, and low priority SEC-stressor interactions removed, each remaining interaction was examined to both determine the key parameter driving risk (population size or condition), and gain detailed information regarding the impact on the SEC-stressor interaction based on the original scoring in the ERAF application. Ultimately, eight *potential* interactions and 21 *current snapshot* interactions were retained for indicator selection. Table 2 and Table 3 summarize the finalized indicator suites for both *current snapshot* and *potential* SEC-stressor interactions that are considered to be of moderate to high priority for the HS-QCS MPA.

Table 2. Indicator suites for current snapshot *SEC-stressor interactions, presented roughly in order of the prioritization results.*

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

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

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

Table 3. Indicator suites for potential SEC-stressor interactions, presented roughly in order of the prioritization results.

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

Conclusions and Advice

The ecological risk assessment and risk-based indicator selection process very closely follows similar processes recently completed, with several minor exceptions to the analytic approach. The selection of ecological risk-based indicators is a key step in the adaptive management framework for the HS/QCS MPA. Suites of indicators were proposed for *current snapshot* stressors (predictable, and occurring most years) and *potential* stressors (unpredictable, and occurring infrequently), and both incorporated SEC specific, stressor specific, and SEC-stressor interaction indicators. Once an updated iteration of the risk assessment is completed, the indicators selected during the process can 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.

- The risk assessment outputs highlighted the SECs with the highest cumulative risk (***CRisk$_c$***): including the Sponge Gardens habitat SEC, the three reef-building sponges and the boot sponge (*R. dawsoni*), all with similar ***CRisk$_c$*** values. Stressors with the highest ***Potency$_s$*** (the sum of ***Risk$_{sc}$*** scores for each stressor across all SECs) were: oil (acute sources from oil spills) and oil/contaminants from chronic discharges; substrate disturbance [re-suspension] and substrate disturbance [crushing] from bottom and mid water trawling activities.
- Guidelines are provided to highlight the most effective way for managers to address interactions with high **Risk$_{sc}$** scores (as identified in the risk assessment) based on the underlying drivers of the **Risk$_{sc}$** scores (i.e. high ***Exposure$_{sc}$*** scores, high ***Consequence$_{sc}$*** scores, or both). (Table 1)
- The risk assessment identified a range of research priorities that will be helpful in future iterations of the risk assessment. For example, in order to facilitate the future inclusion of community/ecosystem properties SECs in the risk assessment, baseline ecosystem data and food web analyses are required. The identification of trophic structure and functional groups within the glass sponge reef community are a first step for community analysis followed by research on abundance and diversity. Further, there is a continued need for species-specific research of the reef-building glass sponge species to better differentiate their relative risks from human-based activities.
- A number of methodological improvements were made in this application of the ERAF. Specifically, use of a truncated normal distribution for modelling uncertainty, alternate treatment of interactions that score zero for the ***Resilience$_c$*** sub-terms but with high uncertainty, data management tools to improve relativity and consistency of scoring across SEC-stressor interactions). It is recommended that these methodological improvements be adopted in future applications and iterations of the ERAF, and that future ERAP applications continue to incorporate expert review at every stage of the risk assessment (streamlined to the greatest extent possible).
- This analysis was completed using a “current snapshot” interpretation of the MPA regulations that have recently been put in place. To ensure that the analysis remains applicable to the MPA, it will be important to assess how the regulations are interpreted (i.e. based on information from approved activity plans and updated vessel traffic data) in a subsequent iteration of the risk assessment, once the MPA regulations have been in effect for several years.

- The ERAF and indicator selection processes result in the aggregation and synthesis of large volumes of data and information. It is recommended that efforts be undertaken to preserve these intermediary outputs through tools such as Canada's Open Data Portal to enable outputs to be reproduced and also for use in future iterations of the process.
- When developing monitoring strategies and plans, both *current snapshot* and *potential* stressor indicator suites should be considered using a combination of SEC, stressor, and SEC-stressor interaction indicators.
- *Current snapshot* indicator suites should be monitored at the same time as collecting general information to establish baselines and measure disturbances using SEC and stressor indicators.
- *Potential* indicator suites should be monitored in two steps: establish baselines of information using SEC and stressor indicators; and if/when the potential stressor occurs, use SEC-stressor interaction indicators to measure the disturbance and compare with population baselines.
- Indicators should be measured using non-destructive methods where possible, such as visual surveys and existing datasets/samples. Multiple indicators may be measured or sampled during the same operations period using visual surveys.
- The effectiveness of the proposed indicators in measuring changes to SECs resulting from interactions with stressors will not be fully realized until after monitoring has commenced. The performance of indicators should be assessed in terms of the indicators' capacity to track properties of interest (in this case, impacts from stressors, and establish population baselines for SECs) and their ability to detect or predict trends in attributes. This assessment process may result the indicators being added or discarded from monitoring plans.

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May 9, 2018

Sources of information

This Science Response Report results from the Science Response Process on February 2, 2018 to review the ecological risk assessment and selection of risk-based indicators for the Hecate Strait-Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area.

Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Appendix A

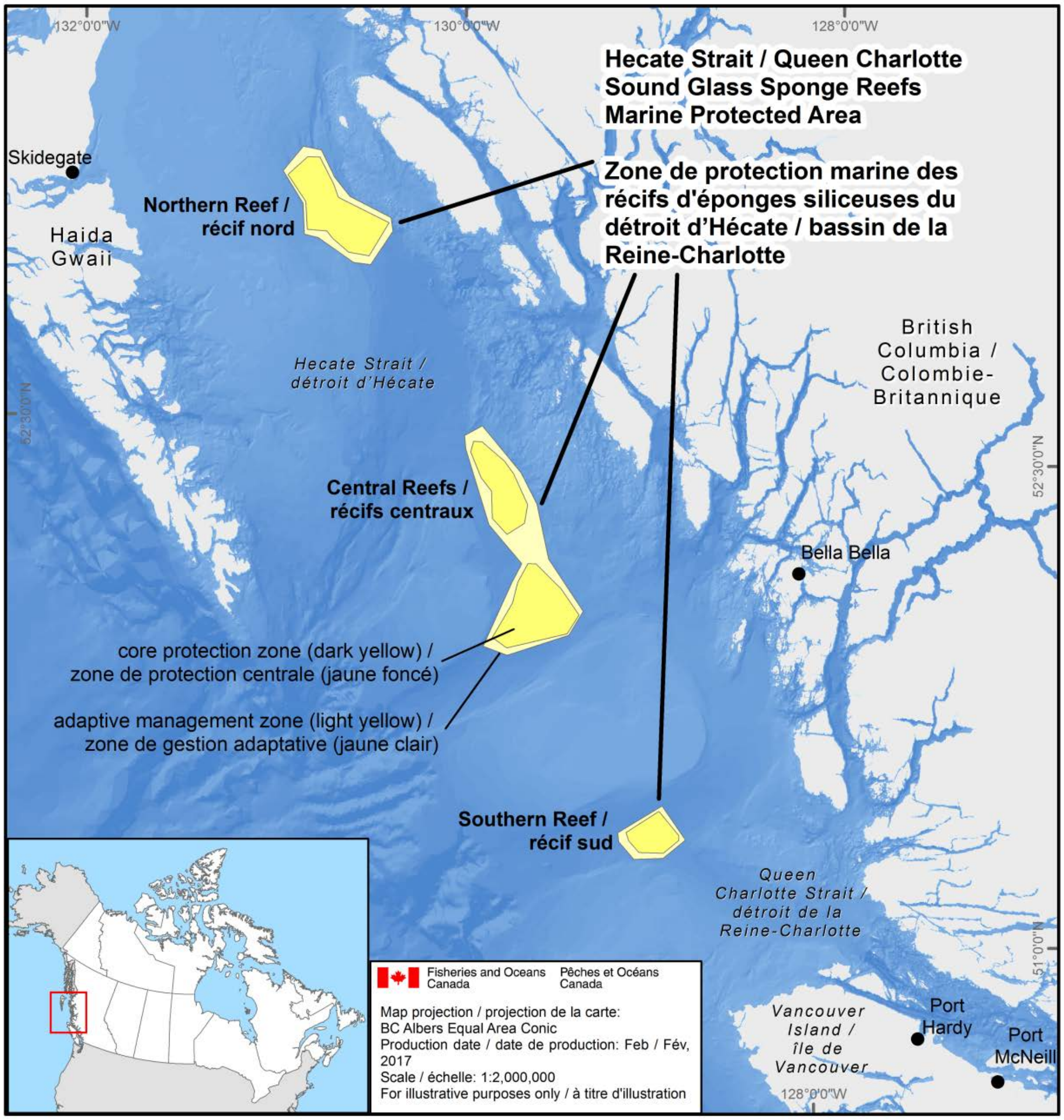

Figure A.1- Map illustrating the boundaries of the Hecate Strait-Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area.

This Report is Available from the

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ISSN 1919-3769
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Correct Citation for this Publication:

DFO. 2018 Ecological risk assessment and selection of risk-based indicators for the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/040.

Aussi disponible en français :

MPO. 2018. Évaluation du risque écologique et choix d'indicateurs fondés sur le risque pour la zone de protection marine des récifs d'éponges siliceuses du Détroit d'Hécate et du bassin de la Reine-Charlotte. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2018/040.