Fisheries and Oceans Canada | Pêches et Océans Canada

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Canadian Science Advisory Secretariat
Science Advisory Report 2015/053

DEVELOPMENT OF RISK-BASED INDICATORS FOR ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA USING THE ECOLOGICAL RISK ASSESSMENT FRAMEWORK

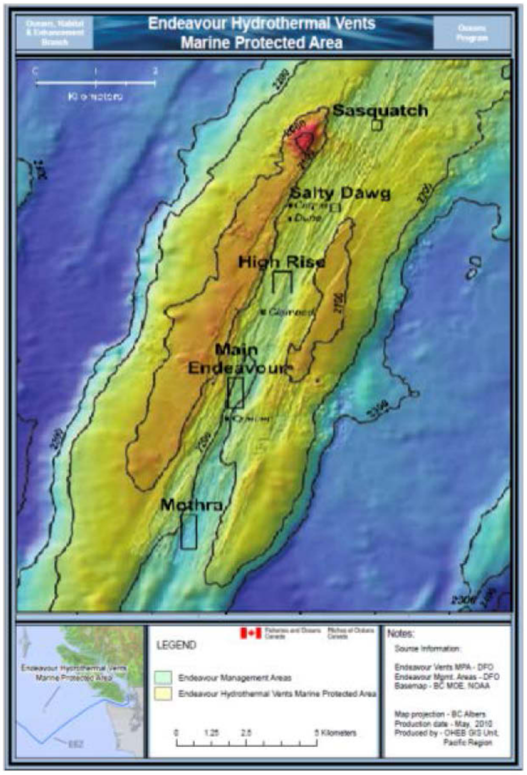

Figure 1. [Bathymetric map of Endeavour Hydrothermal Vents Marine Protected Area](). (Fisheries and Oceans Canada, 2015)

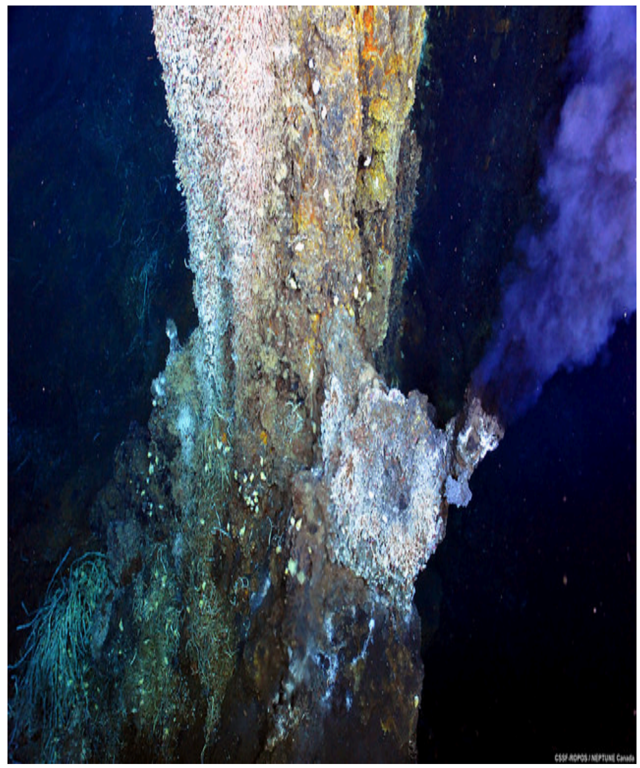

Figure 2. Black smoker on Faulty Towers in the Mothra Vent Field, Endeavour Hydrothermal Vents Marine Protected Area (N47° 55.4273', W129° 6.5253',2270.8m). (Credit: CSSF-ROPOS/Neptune Canada.)

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 Endeavour Hydrothermal Vents 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 Endeavour Hydrothermal Vents 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 Endeavour Hydrothermal Vents MPA while the activities/stressors driving the risk

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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 Endeavour Hydrothermal Vents 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.

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 Endeavour Hydrothermal Vents Marine Protected Area (EHV 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 EHV MPA. It is recommended that indicators for both categories of stressor (*potential* and *current 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 process for decision-making in applying 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 EHV MPA: the need to establish baseline data (e.g., biological, habitat) for all SECs. It is recommended that the appropriate baseline information be collected going forward and that the availability of retrospective information from past research activities dating to 1984 be investigated/catalogued and evaluated for their utility in establishing temporal changes to the present.
- 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 natural variation from human induced variation. Monitoring of SEC and stressor-specific indicators provides baseline data and monitoring of SEC-stressor interaction 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 *Ridgeia piscesae* (high flux tubeworm) (SEC) exposed to removal of organisms (stressor) from sampling (activity), biomass of removed organisms is an indicator of the SEC-stressor interaction, abundance is

proposed as a SEC specific indicator, and areal coverage of removed organisms on a chimney is a proposed stressor-specific indicator.

- Indicators for *potential* SEC-stressor interactions are generally less specific to the SEC-stressor interaction than those for *current snapshot* stressors. *Potential stressors* are unpredictable in their occurrence and there is high uncertainty concerning exposure to and the consequences of such interactions when they occur. 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 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.
- Many of the proposed indicators can be measured and monitored simultaneously during the same operational period because of the overlapping distribution of several SECs within the EHV MPA.
- It is recommended that indicator sampling protocols in the EHV MPA focus on non-destructive sampling methods, including remote tools such as cabled observations, and that vent fields be considered the sample unit for data collection (following current practice). 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 EHV 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 prioritized risk-based indicators in the Endeavour Hydrothermal Vents (EHV) 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; O et al. 2015) was developed to assess the potential risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors and was applied to the EHV MPA (DFO 2015). The key information produced by the ERAF is a list of SECs in the EHV 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 (stressors) are needed to support the development of risk-based indicators. The resulting indicators will be used to monitor progress against the achievement of conservation objectives in the EHV 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 the EHV 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 the EHV MPA are intended to be suitable for use once operational conservation objectives have been established.

Endeavour Hydrothermal Vents Marine Protected Area

The EHV MPA is located on the Juan de Fuca Ridge approximately 250 km southwest of Vancouver Island, at a depth of about 2,250 m in the northeast Pacific Ocean (Figure 1). The MPA is centered at 47°57'N, 129°06'W and encompasses an area of approximately 100 km^2 within its boundaries. The Endeavour Segment is one of ten venting sites along the Juan de Fuca Ridge, and is a seismically active area of seafloor formation and hydrothermal venting. While the majority of the venting sites along the Juan de Fuca Ridge are volcanically active and subjected to periodic disturbances that limit the development of venting communities, the Endeavour Segment is tectonically dominated, and exposed to few magma disturbances. Endeavour is the largest and possibly oldest hydrothermal site on the Juan de Fuca Ridge and consequentially has the highest diversity (Tunnicliffe et al. 1996).

The EHV were discovered in 1982 and were designated as the first MPA under Canada's *Oceans Act* in March 2003. The MPA encompasses five main vent fields - Mothra, Main Endeavour, High Rise, Salty Dawg, and Sasquatch and two minor fields, Clam Bed and Quebec. The vent fields can be subdivided into vent complexes (e.g., The Faulty Towers complex in Mothra) and within these complexes there are individual chimneys that host numerous venting sites (e.g., Figure 2). Each of the main fields is designated as a management area and some vent fields are zoned for sampling (Main and Mothra) and others (Salty Dawg and High Rise) as "observation only" areas, allowing long-term research to continue (Banoub 2010).

ASSESSMENT

Ecological Risk Assessment Framework Results

Eleven SECs (six species SECs, four habitat SECs, and one community SEC) and 20 stressors associated with vessels, research, and seismic surveys were identified during the scoping phase of the ecological risk assessment framework (ERAF) application to the EHV MPA (Thornborough 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., at least annually) 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).

Three species SECs (*Ridgeia piscesae* – high flux, *R. piscesae* – low flux, and *Paralvinella sulfincola*), as well as the benthic clam bed community SEC, had the highest estimated Cumulative Risk scores in the EHV MPA, while the three habitat SECs that were assessed (diffuse basalt flows, inactive chimneys, and active venting chimneys) had the lowest estimated Cumulative Risk scores (DFO 2015). The stressors with the highest Potency (Cumulative Risk scores of a stressor across all SECs) were debris, substrate disturbance (crushing) during sampling, substrate disturbance (crushing) during

[1] Thornborough, K., Rubidge, E., and O, M. 2015. Ecological Risk Assessment for the Effects of Human Activities at Endeavour Hydrothermal Vents Marine Protected Area. Can. Sci. Advis. Sec. Res. Doc. In revision.

submersible operations, and aquatic invasive species from submersible operations (DFO 2015). All *potential* stressors (i.e., oil spills, aquatic invasive species (AIS), and debris) were among the highest Potency scores in the EHV MPA. These scores tend to be driven by high uncertainty, particularly for the Exposure terms in the risk equation, because they are evaluated on a worst-case scenario basis.

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 3) 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 EHV MPA. The indicators are selected based on outputs from the ERAF and will be used to refine policy objectives into operational conservation objectives, and develop monitoring strategies and plans. The AM framework is iterative and there are feedback loops between many steps, which permit the inclusion of data on additional species (e.g., the predatory sea snail, *Buccinum thermophilum*) or stressors (e.g., deep-sea mining) at the EHV MPA, or information on new monitoring technologies to be fed back into the AM framework for future iterations of risk assessments, evaluation of indicators, selection of new indicators, and the refinement of the monitoring plans.

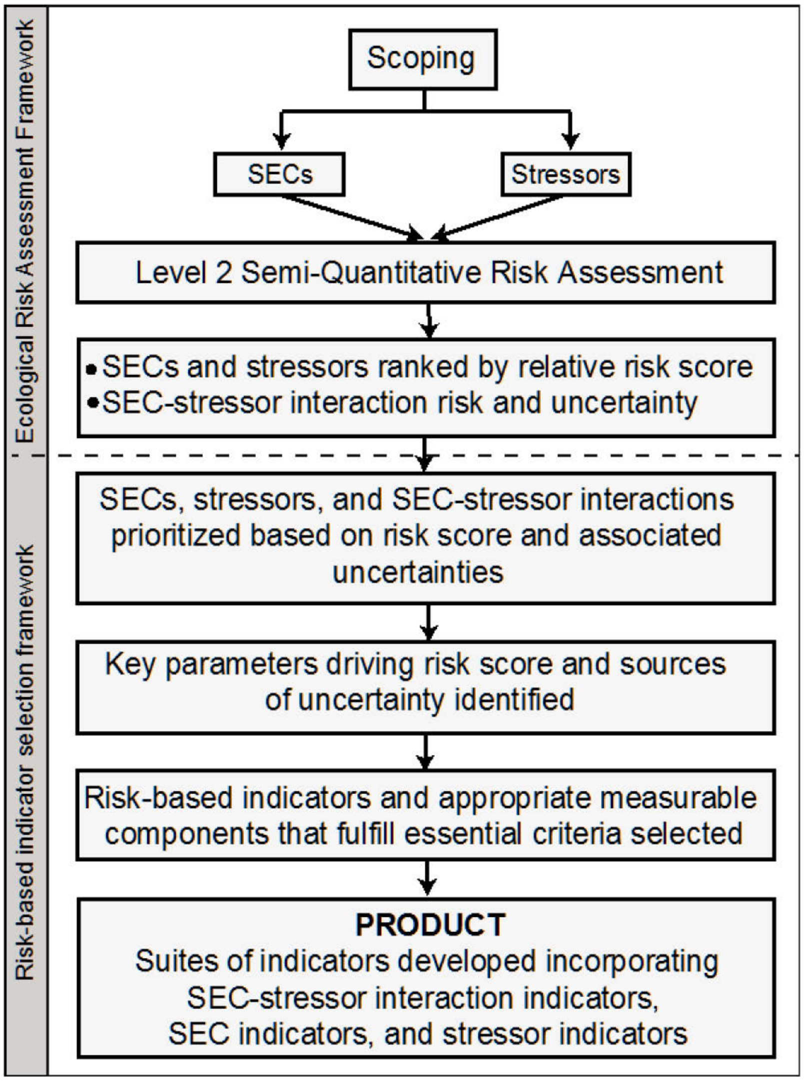

Figure 3. Overview of the framework used to select risk-based indicators for the EHV MPA. The overview shows the linkage with the ERAF and how the outputs of an ERAF application are necessary inputs to the indicator selection framework.

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 criteria - cost-effectiveness, public awareness, and linkages to management concerns/measures/targets – were also identified but not used 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 EHV MPA because historical data are either limited 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 93 SEC-stressor interactions identified in the EHV MPA (Thornborough 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 and uncertainty scores, and divided the interactions into high, moderate, and low priority ranges based on the risk and uncertainty scores. 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 showed that uncertainty can drive the risk score, and that understanding the drivers of uncertainty 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). This provides managers with different indicator options from which to choose, as monitoring strategies and plans are developed and refined. 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 suites 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 EHV MPA, presented roughly in order of the prioritization results. Only interactions with moderate and high priority 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
Ridgeia piscesae (high flux) *Paralvinella sulfincola* *Ridgeia piscesae* (low flux)	Sampling	Removal of organisms	• Biomass of removed organisms • Size of the sampling scar • Species richness and diversity of assemblage (to be used in time series monitoring – not single event)	• Abundance • Organism health • Species richness and diversity of assemblage • Genetics	• Biomass • Maximum potential exposure (number of allowable samples) • Areal coverage of removed organisms
		Substrate disturbance (crushing)	• Abundance/population density of sampled assemblage • Size of the sampling scar • Death of surrounding organisms (altered fluid flow)	• Abundance • Organism health • Species richness and diversity of assemblage	• Proportion (%) of sampled area crushed • Frequency of potential sampling events
Ridgeia piscesae (high flux) *Paralvinella sulfincola*	Submersible operations	Substrate disturbance (crushing)	• Abundance of organisms displaying symptoms of crushing • Total size of crushed area	• Abundance • Organism health • Species richness and diversity of assemblage	• Proportion (%) of the area crushed • Frequency of potential impact
Ridgeia piscesae (low flux)	Equipment abandonment	Increased contamination	• Abundance (areal extent) of assemblages showing signs of stress • Species richness/ presence of disease/stress • Change in genetic diversity	• Abundance • Organism health • Species richness and diversity of assemblage	• Potential contaminant type • Length of exposure
Inactive mineral chimneys **Active venting mineral chimneys**	Submersible operations	**Substrate disturbance (crushing)**	• Size of crushed area on individual chimneys • Number of collisions producing visible particular plume	• Extent and distribution • Physical damage	• Proportion (%) of the area crushed • Frequency of potential impact
	Sampling	Substrate disturbance (crushing)	• Area sampled/ size of the sampling scar	• Extent and distribution • Physical damage	• Proportion (%) of the area crushed • Frequency of potential sampling events
Clam bed benthic community	Sampling	Removal of organisms	• Biomass of removed organisms • Size of the sampling scar • Species richness and diversity of assemblage (to be used in time series monitoring – not single event)	• Abundance • Organism health • Species richness and diversity of assemblage • Biomass	• Biomass • Maximum potential exposure (number of allowable samples) • Areal coverage of removed organisms
		Substrate disturbance (crushing)	• Abundance of organisms displaying symptoms of crushing • Total size of crushed area	• Abundance • Organism health • Species richness and diversity of assemblage	• Proportion (%) of the area crushed • Frequency of potential sampling events

SEC	Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
		Substrate disturbance (sediment re-suspension)	• Change in abundance/ extent • Abundance (areal extent) of community showing signs of smothering/stress	• Abundance • Organism health • Species richness and diversity of assemblage	• Maximum induced increase in suspended sediments • Frequency of potential sampling events
	Equipment abandonment	Increased contamination	• Abundance (areal extent) of assemblages showing signs of stress • Species richness/ presence of disease/stress • Change in genetic diversity	• Abundance • Organism health • Species richness and diversity of assemblage	• Potential contaminant type • Length of exposure

Table 2. Proposed indicator suites for potential SEC-stressor interactions in the EHV MPA, presented roughly in order of the prioritization results. Only interactions with moderate and high priority 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
Ridgeia piscesae (low flux) *Lepetodrilus fucensis* ***Paralvinella sulfincola***	Submersible operations	Aquatic invasive species	• Presence of aquatic invasive species in SEC assemblages	• Abundance • Organism health • Species richness and diversity of assemblage	• Frequency of potential exposure • Occurrence/abundance of aquatic invasive species
	Oil spill	Oil	• Abundance of organisms displaying symptoms of stress • Species richness/ presence of disease/stress • Change in genetic diversity	• Abundance • Organism health • Species richness and diversity of assemblage • Genetics	• Vessel density in vicinity of the EHV MPA • Oil spill volume • Oil type
	Discharge	**Debris**	• Size of crushed area/size of debris	• Abundance • Species richness and diversity of assemblage	• Relative abundance of debris • Debris characterization
Inactive mineral chimneys Active venting mineral chimneys	Discharge	Debris	• Size of crushed area/size of debris	• Extent and distribution • Physical damage	• Relative abundance of debris • Debris characterization
Clam bed benthic community	Discharge	Debris	• Size of crushed area/size of debris	• Abundance • Organism health • Species richness and diversity of assemblage	• Relative abundance of debris • Debris characterization
	Submersible operations	Aquatic invasive species	• Abundance of organisms displaying symptoms of stress	• Abundance • Organism health • Species richness and diversity of	• Frequency of potential exposure • Occurrence /

SEC	Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
				assemblage	abundance of aquatic invasive species
	Oil spill	Oil	• Abundance of organisms displaying symptoms of stress • Species richness/ presence of disease/stress	• Health/ condition • Abundance • Species richness	• Vessel density in vicinity of the EHV MPA • Oil spill volume • Oil type

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.

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, 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 EHV MPA: the need to establish baseline data for all SECs. Research activity has occurred at the site since 1984, but the data from these cruises have not been catalogued nor evaluated for their usefulness in establishing historical changes over time to the present. Once baselines are established, changes in population size and condition can be measured and monitored going forward, and linked 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 management 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 EHV 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 the EHV MPA will not be fully realized until after data collection commences 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 application of the risk-based indicator selection framework.

Sources of Uncertainty

The indicators identified for the EHV 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 EHV 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 high species endemism at the EHV MPA, which is a key feature, is not captured/represented in the ERAF application or the proposed indicator suites. Future iterations may consider incorporating this feature.

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 EHV 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 requirements for effective monitoring.

The framework for risk-based indicator selection clearly describes the procedures that are followed to prioritize and select indicators, and the process for decision-making in applying 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 EHV MPA: the need to establish baseline data (e.g., biological, habitat) for all SECs. It is recommended that the appropriate baseline information be collected going forward and that the availability of retrospective information from past research activities dating to 1984 be investigated/catalogued and evaluated for their utility in establishing temporal baseline changes over time.

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 and human-induced variation. Monitoring SEC-stressor indicators provides baseline data and monitoring of SEC and stressor indicators provides information on disturbances.

Indicators for *potential* SEC-stressor interactions are generally less specific to the SEC-stressor interaction than those for *current snapshot* stressors. *Potential* stressors are unpredictable in their occurrence and there is high uncertainty concerning exposure to and the consequences of such interactions when they occur. 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 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 EHV MPA focus on non-destructive sampling methods, including remote tools such as cabled observations, and that vent fields be considered the sample unit for data collection (following current practice). 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 indicators, and to select ecosystem indicators in the EHV 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 baselines 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.

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APPENDIX

Table A1. Proposed SEC indicators in the EHV MPA and their measureable components.

<table>
<tr><th colspan="3">SEC</th><th>Key parameter</th><th>Indicator</th><th>Measureable component</th></tr>
<tr><td rowspan="9">Species SEC</td><td rowspan="6">Sessile/low mobility invertebrates</td><td rowspan="6">R. piscesae high flux
R. piscesae low flux
P. sulfincola
P. palmiformis
L. fucensis</td><td rowspan="2">Population size</td><td>Abundance</td><td>• % coverage of species/species assemblages per chimney/venting location</td></tr>
<tr><td>Biomass</td><td>• Weight/unit area</td></tr>
<tr><td rowspan="3">Population condition</td><td>Community species richness and diversity</td><td>• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness) applied to the assemblages of species</td></tr>
<tr><td>Organism health</td><td>• % of the population showing visible signs of stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)</td></tr>
<tr><td>Genetics</td><td>• Population delineations</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="2">Mobile invertebrates</td><td rowspan="2">M. macrochira</td><td>Population size</td><td>Abundance</td><td>• Average count
• Size-frequency distribution</td></tr>
<tr><td>Population condition</td><td>Health/condition</td><td>• Visible injury to organism or behavioural indicators (e.g. feeding behaviour, reflex actions)</td></tr>
<tr><td rowspan="4">Community SECs</td><td rowspan="4">Benthic</td><td rowspan="4">Clam bed benthic community</td><td rowspan="2">Community size</td><td>Abundance</td><td>• Areal coverage of community (% cover, m^2)</td></tr>
<tr><td>Biomass</td><td>• Weight/unit area (NB Not recommended at this time)</td></tr>
<tr><td rowspan="2">Community condition</td><td>Species richness and diversity</td><td>• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)</td></tr>
<tr><td>Organism health</td><td>• % of the population showing visible signs of stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)</td></tr>
</table>

SEC			Key parameter	Indicator	Measureable component
Habitat SECs	Chimneys	Inactive mineral chimneys Active venting mineral chimneys	Habitat size	Extent and distribution	• The extent and distribution of chimneys (both active and inactive) change over extended time periods, and changes are usually the result of a tectonic disturbance. However, establishing the current extend and distribution of habitats is necessary to establish a baseline
			Habitat condition	Physical damage	• % of chimneys modified • % of the individual chimney modified • Artificial changes in hydrothermal flow
	Benthic habitat	Diffuse venting flows	Habitat size	Extent and distribution	• The abundance of benthic microbial communities is strongly associated with this habitat, as are some low flow communities. These may be used as an indicator for locating and mapping this habitat.
			Habitat condition	No known indicator for structural integrity/ condition of diffuse venting flows	

Table A2. Proposed indicators and measurable components for human activities and associated stressors known to occur in the EHV MPA

Activity	Stressor	Indicator	Measureable component
Discharge	Debris	Relative abundance of debris	• Frequency of occurrence (count/distance surveyed) • Mass of recovered debris (from clean up programs)
		Debris characterization	• Debris type and size
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
		Areal coverage of removed organisms (sessile benthic SECs)	• - % cover of removed organisms
	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 disturbance (crushing)	Crushed area - Proportion (%) of the area crushed	• m^2 • Size (area) of the sampling scar
		Frequency of potential impact	• Number of sampling events
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
		Frequency of exposure to potential collisions	• Number of collision events
	Substrate disturbance (crushing)	Crushed area	• Proportion (%) of the area crushed • m^2
		Frequency of potential impact	• Number of collision events

Activity	Stressor	Indicator	Measureable component
Oil spill	Oil	Vessel density in vicinity of the EHV 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
Equipment installation	Substrate disturbance (crushing)	Crushed area Proportion (%) of the area crushed	• m^2 • Equipment footprint
		Frequency of potential impact	• Number of installation events
	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
Equipment abandonment	Contaminants	Proportion of water samples exceeding standards for water quality parameters of interest	• e.g. CCME Water Quality Index
		Potential contaminant type	• Linked with equipment type and composition
		Length of exposure	• Length of time since installation
Seismic testing/ air guns	Sound generation	Distance from the EHV 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

*Table A3. Proposed indicators and their measurable components for current snapshot SEC-stressor interactions occurring in the EHV MPA. A bolded **SEC** is only impacted by the matching bolded **stressor**.*

<table>
<tr><th colspan="3">SEC</th><th>Activity</th><th>Stressor</th><th>Key parameter</th><th>Indicator</th><th>Measureable component</th><th>Data collection</th></tr>
<tr><td rowspan="6">Species</td><td rowspan="6">Sessile/low mobility invertebrates</td><td rowspan="6">Ridgeia piscesae (high flux)
Paralvinella sulfincola
Ridgeia piscesae (low flux)</td><td rowspan="6">Sampling</td><td rowspan="3">Removal of organisms</td><td rowspan="2">Population size</td><td>Abundance/ population density</td><td>• % coverage of species/species assemblages at sampled vents</td><td>• A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.</td></tr>
<tr><td>Size of the sampling scar</td><td>• Areal extent of sample scar</td><td>• Measurements taken from video logs of submersible sampling (size of scar at sampling event)
• Visual surveys of sampled site as part of a time series (re-visit sampled locations)</td></tr>
<tr><td>Population condition</td><td>Biomass of removed organisms</td><td>• Weight/unit area of sampled (removed) organism
• Proportion (%) of biogenic habitat removed</td><td>• Data is available on collected samples
• Should be used in conjunction with the size of the sampling scar and abundance
• Population baselines should be established prior to sampling</td></tr>
<tr><td rowspan="3">Substrate disturbance (crushing)</td><td rowspan="2">Population size</td><td>Abundance/ population density of sampled assemblage</td><td>• Size (area) of the sampling scar</td><td>• A combination of visual surveys/video data and sample size will inform this indicator</td></tr>
<tr><td>Community species richness and diversity</td><td>• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness) applied to the assemblages of species</td><td>• Visual surveys and sampling events</td></tr>
<tr><td>Population condition</td><td>Organism health</td><td>• % of the population showing visible signs of</td><td>• Visual surveys and sampling events</td></tr>
</table>

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	• Requires some baseline information
		Ridgeia piscesae (high flux) *Paralvinella sulfincola*	Submersible operations	Substrate disturbance (crushing)	Population size	Crushed area	• Proportion (%) of the area crushed • m^2	• Video data of sampling event
					Population condition	Abundance of organisms displaying symptoms of crushing	• Proportion (%) of the assemblage • m^2	• Visual surveys of sampled organisms, post sampling
		Ridgeia piscesae (low flux)	Equipment abandonment	Increased contamin-ation	Population size	Abundance (% cover) of species and assemblages showing signs of stress	• % of the population showing visible signs of stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	• Visual surveys • Aided by sampling. Sampling would likely be opportunistic
					Population condition	Change in genetic diversity	• Genetic delineation	• Requires baselines of populations and extractive sampling
						Species richness/ presence of disease/stress	• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	• Requires baselines of populations • Needs to be combined with independent SEC and stressor indicators to link oil with SEC • Visual surveys

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
Habitat	Chimneys	Inactive mineral chimneys **Active venting mineral chimneys**	Submersible operations	Substrate disturbance (crushing)	Habitat size	Size of crushed area on individual chimneys	• % of the assemblage crushed (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	• A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
					Habitat condition	Collisions producing visible particular plume	• Number of collisions producing particulate plume	• From submersible dive videos (involves post-processing, or dive log tagging protocol)
			Sampling	**Substrate disturbance (crushing)**	Habitat size	Size of sampled area/ size of sample scar	• Areal extent of crushed area as a proportion of overall abundance (extent)	• A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
					Habitat condition	Sample type – NB this determines extent chimney is impacted	• Physical sample types at EHV: geological, biological, water/fluids	• Visual surveys • Aided by sampling. Sampling would likely be opportunistic
Community	Benthic	Clam bed benthic community	Sampling	Removal of organisms	Community size	Abundance/ population density	• % coverage of species/species assemblages at sampled vents	• A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
						Area sampled/ size of the sampling scar	• Areal extent of sample scar	• Measurements taken from video logs of submersible sampling (size of scar at sampling event) • Visual surveys of sampled site as part of a time series (re-visit sampled locations)

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
					Community condition	Biomass of removed organisms	• Weight/unit area of sampled (removed) organism • Proportion (%) of biogenic habitat removed	• Data is available on collected samples • Should be used in conjunction with the size of the sampling scar and abundance • Population baselines should be established prior to sampling
				Substrate disturbance (crushing)	Community size	Crushed area	• Proportion (%) of the area crushed • m^2	• Combination of size of the sample, the measured (visually) sample scar size, and sampling method employed
					Community condition	Abundance of organisms displaying symptoms of crushing	• Proportion (%) of the assemblage • m^2	• Visual surveys • Aided by sampling. Sampling would likely be opportunistic
				Substrate disturbance (sediment re-suspension)	Community size	Change in abundance/ areal extent	• Proportion (%) of the assemblage • m^2	• Visual surveys and sampling events • Requires some baseline information
					Community condition	Abundance (areal extent) of community showing signs of smothering/stress	• % of the population showing visible signs of stress/disease (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	• Visual surveys and sampling events • Requires some baseline information
			Equipment abandonment	Increased contaminatio n	Community size	Abundance/ extent of community	• Areal extent (% cover), m^2	• Visual surveys (submersible video), GIS mapping

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
					Community condition	Species richness/ presence of disease/stress	• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	• Requires baselines of populations • Needs to be combined with independent SEC and stressor indicators to link oil with SEC • Visual surveys
						Change in genetic diversity	• Genetic delineation	• Requires baselines of populations and extractive sampling

*Table A4. Proposed indicators and their measureable components for potential SEC-stressor interactions in the EHV MPA. A bolded **SEC** is only impacted by the matching bolded **stressor**.*

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
Species	Sessile/low mobility invertebrates	*Ridgeia piscesae* (low flux) *Lepetodrilus fucensis*	Submersible operations	Aquatic invasive species	Population size	Abundance of organisms with visible damage/dead	• Area (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 will help inform this
					Population condition	Change in condition/sub-lethal effects	• Area (proportion) showing evidence of stress/increased predation/change in reproductive events	• Requires baselines of populations • Needs to be combined with independent SEC and stressor indicators to link source of AIS with SEC • Visual surveys, will help inform this
			Oil spill	Oil	Population size	Abundance	• Areal coverage of habitats	• The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended • Visual surveys • Needs to be combined with independent SEC and stressor indicators to link oil with SEC
						Abundance of organisms displaying symptoms of stress	• % cover of stressed area as a proportion of overall abundance (extent). Extractive sampling and analysis.	• Visual surveys • Aided by sampling. Sampling would likely be opportunistic
						Species richness/ presence of	• Diversity measures (e.g. Shannon Simpson,	• Requires baselines of populations • Needs to be combined with

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
						disease/stress	taxonomic redundancy, taxonomic distinctness)	independent SEC and stressor indicators to link oil with SEC • Visual surveys
						Change in genetic diversity	• Genetic delineation	• Requires baselines of populations and extractive sampling
		Paralvinella sulfincola	Discharge	**Debris**	Population size	Size of crushed area/size of debris	• % of crushed area as a proportion of overall abundance (extent)	• Ocean-based surveys have not used consistent methods and have been performed sporadically at small spatial scales. Estimates are likely lagging indicators of debris currently going into the ecosystem (Andrews et al. 2013)
					Population condition	No known indicators to directly measure change in population condition resulting from crushing by debris		
Habitat	Chimneys	Inactive mineral chimneys	Discharge	Debris	Habitat size	Chimney toppling/ destruction and presence of debris	• Proportion (%) of surveyed chimneys displaying evidence of crushing that can be linked to debris	• No known indicator that would specifically link debris with the loss of hydrothermal chimneys. However, crushing of the chimney did occur, it would be from large, heavy debris, and would remain on top of chimneys until surveyed at a later date. Visual surveys would be an appropriate data collection method. The monitoring of stressor-specific indicators ‘debris characterization and relative abundance’ will help

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
								inform the exposure of chimneys to debris
						Debris characterization and relative abundance	• Frequency of occurrence (count/distance surveyed) • Mass of recovered debris (from clean up programs) • Debris type & size	• The monitoring of stressor-specific indicators, 'debris characterization and relative abundance' while not specific to the SEC-stressor interaction, will help inform the exposure of chimneys to debris
		Active venting mineral chimneys			Habitat condition	Physical damage to structure	• % of chimneys modified • % of the individual chimney modified • Artificial changes in hydrothermal flow	• Visual surveys, mapping of venting structures. Data exists on debris distribution (ONC). No debris was observed to have made contact with vents.
Community	Benthic	Clam bed benthic community	Discharge	Debris	Community size	Size of crushed area/size of debris	• Areal extent of crushed area as a proportion of overall abundance (extent)	• Ocean-based surveys have not used consistent methods and have been performed sporadically at small spatial scales. Estimates are likely lagging indicators of debris currently going into the ecosystem (Andrews *et al.* 2013)
					Community condition	No known indicators to directly measure change in population condition due to crushing by debris		
			Submersible operations	Aquatic invasive species	Community size	Abundance/ density of AIS	• % change of areal extend of benthic clam bed	• Requires a combination of visual surveys and sampling. Species are still being discovered at

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							community	EHV, and care needs to be taken to differentiate AIS from new species. Results should be compared with other sites visited using the same submersible on the same cruise.
					Community condition	Abundance of AIS	• Areal coverage of habitats • Number of individuals, etc.	• Visual surveys • Needs to be combined with independent SEC and stressor indicators to link oil with SEC
			Oil spill	Oil	Community size	Abundance	• Areal coverage of habitats	• The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended • Visual surveys • Needs to be combined with independent SEC and stressor indicators to link oil with SEC
						Abundance of organisms displaying symptoms of stress	• % cover of community displaying symptoms of stress	• Visual surveys • Aided by sampling. Sampling would likely be opportunistic
						Species richness/ presence of disease/stress	• Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	• Requires baselines of populations • Needs to be combined with independent SEC and stressor indicators to link oil with SEC • Visual surveys
						Change in genetic diversity	• Genetic delineation	• Requires baselines of populations and extractive sampling

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