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Development of risk-based indicators for the Endeavour Hydrothermal Vents Marine Protected Area

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Fisheries and Oceans Canada (DFO) Science was asked to recommend scientifically defensible indicators to monitor the achievement of the Endeavour Hydrothermal Vents Marine Protected Area (EHV MPA) conservation objective. In response, a framework was developed to select and prioritize ecological risk-based indicators based on the outputs of an ecological risk assessment conducted on the EHV MPA. Risk-based indicators are a novel approach to selecting indicators to monitor the risk of harm to Significant Ecosystem Components (SECs) from anthropogenic activities and associated stressors. Suites of risk-based indicators are 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. Measures of abundance were commonly proposed across all indicator suites, highlighting the need to establish baselines of information as a priority. Both *current snapshot* and *potential* stressor indicator suites should be considered when developing monitoring strategies and plans, using a combination of SEC, stressor, and SEC-stressor interaction indicators. Due to the remote access and associated cost of monitoring indicators at the EHV MPA, many of the suggested indicators may be measured using visual surveys and, due to the overlapping distribution of several SECs, multiple indicators may be measured or sampled during the same operations period. As data are collected through the monitoring of indicators, this information may be fed back into the adaptive management framework for future iterations of risk assessments, evaluation of selected indicators, selection of new indicators, and the refinement of monitoring plans.

Élaboration d’indicateurs fondés sur les risques pour la zone de protection marine du champ hydrothermal Endeavour

RÉSUMÉ

On a demandé au Secteur des sciences de Pêches et Océans Canada (MPO) de recommander des indicateurs justifiables sur le plan scientifique permettant de surveiller l'atteinte de l'objectif de conservation de la zone de protection marine du champ hydrothermal Endeavour (ZPM CHE). En réponse à cette demande, un cadre a été élaboré pour sélectionner des indicateurs fondés sur les risques et les classer par ordre de priorité en fonction des extrants d'une évaluation du risque écologique effectuée dans la ZPM CHE. Il s'agit d'une nouvelle approche de sélection d'indicateurs servant à surveiller le risque de préjudice pour les composantes importantes de l’écosystème (CIE) découlant d'activités anthropiques et des agents de stress connexes. Des ensembles d'indicateurs fondés sur les risques sont proposés pour les agents de stress *actuels* (prévisibles, qui se produisent la plupart des ans) et *potentiels* (imprévisibles, qui se produisent peu fréquemment), et les deux incorporent des indicateurs propres aux CIE, propres aux agents de stress et propres à une interaction CIE-agent de stress. Des mesures de l'abondance ont été fréquemment proposées parmi tous les indicateurs, soulignant la nécessité d'établir des données de référence en priorité. Les ensembles d'indicateurs des agents de stress *actuels* et *potentiels* devraient être pris en considération lors de l'élaboration de stratégies et de plans de surveillance, et l'on devrait utiliser une combinaison d'indicateurs de CIE, d'agents de stress et d'interaction CIE-agent de stress. Étant donné l'accès à distance et le coût associé aux indicateurs de suivi de la ZMP CHE, bon nombre des indicateurs proposés peuvent être mesurés à l'aide de relevés visuels et, comme plusieurs CIE se chevauchent, de nombreux indicateurs peuvent être mesurés ou échantillonnés durant la même période d'opération. Comme les données sont recueillies par la surveillance des indicateurs, elles peuvent être réintégrées dans le cadre de gestion adaptative pour les prochaines évaluations des risques, les prochaines évaluations des indicateurs choisis, le choix de nouveaux indicateurs et le peaufinage des plans de surveillance.

1 INTRODUCTION

1.1 CONTEXT

Fisheries and Oceans Canada (DFO) Science was asked to recommend scientifically defensible indicators to monitor the achievement of the Endeavour Hydrothermal Vents Marine Protected Area (EHV MPA) conservation objective (Section 2.2). This conservation objective is broad, and has yet to be refined into specific operational objectives. In response, Davies et al. (2011) proposed a risk-based approach whereby risk-based indicators would be selected and prioritized based on the outputs of an ecological risk assessment conducted on the EHV MPA. DFO Science developed an ecological risk assessment framework (ERAF; O et al. 2015), creating a structured approach for assessing the potential risk of harm to significant ecosystem components (SECs) from anthropogenic activities and associated stressors.

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

It is essential to establish the context of this work early in the process in order to develop suites of indicators that are meaningful and useful to decision makers. The indicators proposed in this paper are risk-based indicators, and are distinct from ecosystem indicators, as was the design of the indicator selection process for the EHV MPA proposed by Davies et al. (2011). Indicators and their measureable components (how to measure the indicator) identified in this paper focus on ecological SECs (not social or economic), and are not intended to evaluate compliance with regulations, licenses or other management measures, though it is recognized that these factors may influence the final choice of indicators.

The selection of ecological risk-based indicators is a key step in the adaptive management (AM) framework for the EHV MPA (Figure 1.1). Indicators selected during this process will be used to develop monitoring strategies, refine conservation objectives further into operational objectives, and develop monitoring plans. As data are collected through the monitoring of indicators, this information may be fed back into the adaptive management framework for future iterations of risk assessments, evaluation of selected indicators, selection of new indicators, and refinement of monitoring plans (Figure 1.1).

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

[1] Thornborough, K., Rubidge, E, O., M. (2016). Ecological Risk Assessment for the Effects of Human Activities at Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc (in preparation).

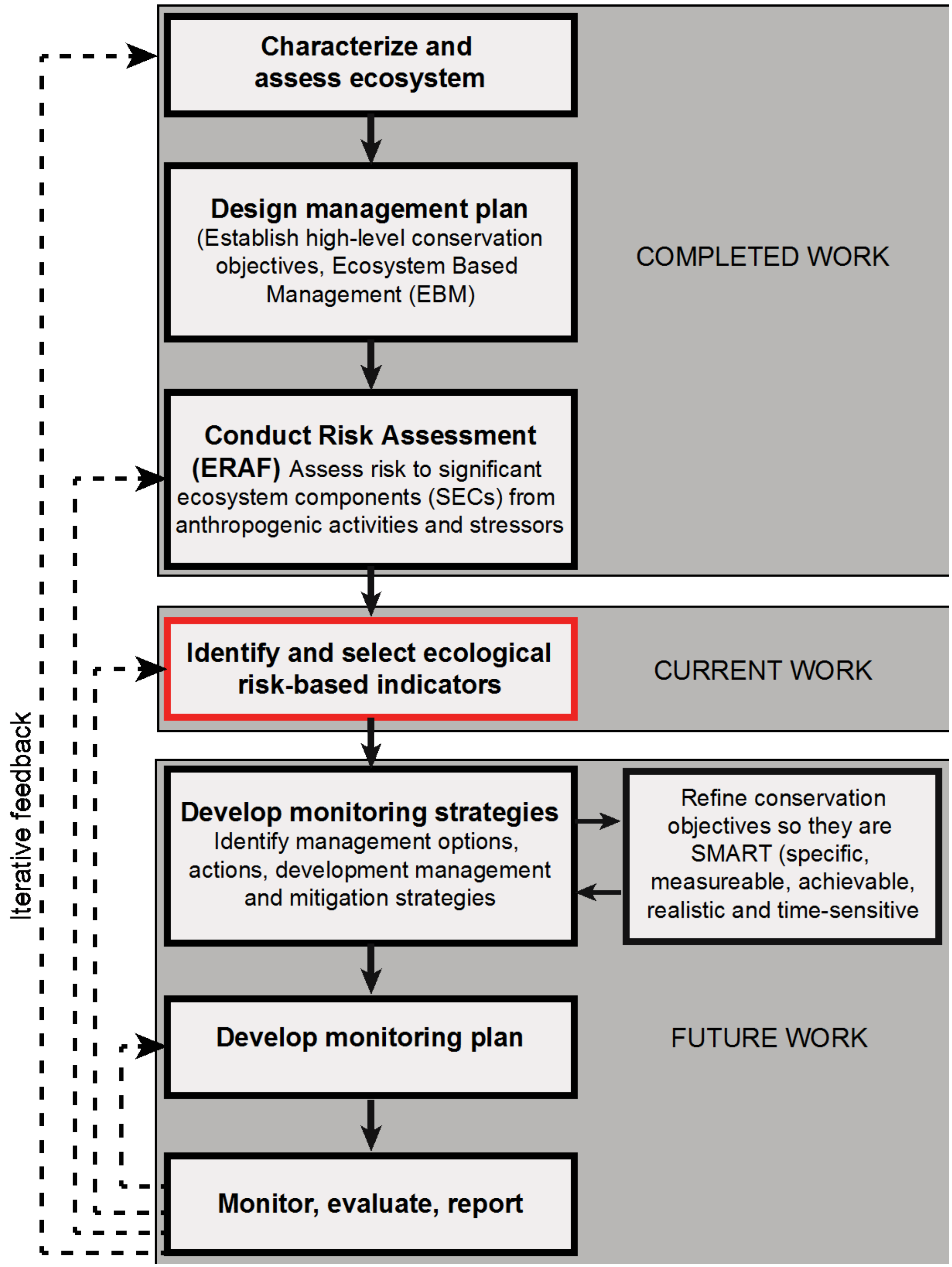

Figure 1.1. Overview of DFO Oceans – Pacific Region adaptive management (AM) framework (adapted from O et al. 2015). This process is iterative, and any information gathered during monitoring can be fed back into the framework.

1.2 INDICATORS

An ecological indicator is a specific measurable component of an ecosystem that is used for monitoring, assessing, and understanding ecosystem status, impacts of anthropogenic activities, and effectiveness of management measures in achieving objectives (adapted from Rice and Rochet 2005). The most effective indicators are sensitive, responsive to change, have specificity to a particular management action, and are relatively simple measurements that can be used to represent a more complex situation (Rice and Rochet 2005). The selection of appropriate indicators is an integral part of DFO Oceans – Pacific Region adaptive management (AM) framework (Figure 1.1), as indicator selection leads to the development of monitoring strategies, that in turn feed into the refinement of broad conservation objectives into operational objectives that are specific, measureable, achievable, realistic, and time-sensitive (SMART). Two types of indicators may be used in this AM framework: risk-based and ecosystem indicators. Risk-based indicators are developed and discussed in this paper.

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

2 REGIONAL SETTING: ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA

2.1 DESCRIPTION OF ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA

The EHV MPA is located on the Juan de Fuca Ridge approximately 250 km southwest of Vancouver Island, in the northeast Pacific Ocean. The MPA is centered at 47°57'N, 129°06'W, encompassing an area of approximately 100 km^2 of the seafloor. 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).

Hydrothermal vents are complex ecosystems characterized by benthic communities that are high in biomass and endemism (Van Dover 2000). Deep-sea hydrothermal vents host one of the highest levels of microbial diversity on the planet (Gage and Tyler 1996; Sibuet and Olu 1998), but have low diversity of macro-organisms (Banoub 2010). The process of chemosynthesis, wherein bacteria produce the energy and organic matter to the food web (Godet et al. 2011) is the foundation of productivity in deep-sea hydrothermal vents. Since their discovery in 1982, the Endeavour Hydrothermal Vents have been the focus of significant scientific research (Banoub 2010). At the time of designation as an MPA, at least 60 species were considered unique to hydrothermal vents and 12 endemic to the Endeavour Hydrothermal Vents (Converse et al. 1984; Butterfield and Massoth 1994; Tunnicliffe and Thomson 1999). The EHV MPA vent fields are found within the axial valley of the Endeavour Segment, where deep faults channel the hydrothermal circulation. The floor of the valley is not sedimented as it is too young geologically to accumulate planktonic sediments (Tunnicliffe and Thomson 1999). Individual chimneys or larger vent complexes have been named and mapped by researchers, however because of the dynamic nature of the vent ecosystem, chimneys can collapse without warning, thus changing the landscape of the vent field (Davies et al. 2011).

The EHV MPA encompasses six main vent fields that include features such as black smoker chimneys with surrounding lower temperature vents (Banoub 2010). Six management areas are centered on these vent fields: Mothra, Main Endeavour, High Rise, Salty Dawg, and Sasquatch, with the minor fields of Clam Bed and Quebec. These areas include the zoning of certain vent fields for sampling and "observation only" areas, allowing long-term observation studies to continue (Banoub 2010).

2.2 CONSERVATION OBJECTIVE

The Endeavour Hydrothermal Vents were officially designated as an MPA in 2003 with the conservation objective to:

> "…ensure that human activities contribute to the conservation, protection and understanding of the natural diversity, productivity and dynamism of the ecosystem such that the impacts remain less significant than natural perturbations (e.g. magmatic, volcanic or seismic)…"

This conservation objective is broad, and more specific operational objectives have not been defined at this time. The lack of clearly defined objectives inhibits the ability to identify and defend specific monitoring requirements without appearing to be an arbitrary selection (Davies et al. 2011). The refinement of SMART conservation objectives is essential to the development of a monitoring program to measure ecosystem parameters that are useful and relevant for the management of anthropogenic stressors in the MPA.

2.3 CURRENT ACTIVITIES AND MANAGEMENT

The EHV MPA is regulated under the *Oceans Act* (SOR/2008-124). The primary use of the EHV MPA is scientific research, which is monitored by a Management Committee to mitigate use conflicts and environmental disturbance. The main directed surface vessel traffic in the EHV MPA area consists of research vessels. With advances in technology allowing for greater access to the vent sites, the biological communities and the inhabitants of hydrothermal vents are starting to be impacted by increasing anthropogenic stressors (Banoub 2010).

Incidental vessel traffic in the area can occur as the result of commercial fishing, naval and commercial shipping activities. This traffic is presumed not to pose a threat to the Endeavour ecosystem (EHV MPA Management Plan 2003). While commercial fishing for Albacore Tuna (*Thunnus alalunga*) and Neon Flying Squid (*Ommastrephes bartramii*) is known to occasionally occur in the area of the EHV MPA, pelagic fishing is not considered to be in conflict with the MPA conservation objectives as it takes place very near the ocean surface.

2.4 CURRENT STATE OF MONITORING AND RESEARCH ACTIVITIES

Scientific research is the only activity that currently takes place on the seafloor within the MPA boundary. Researchers are interested in the site for the purpose of public awareness and education, furthering the understanding of deep ocean community structure and function, and as a natural laboratory to study ore-forming processes. Data collection methods have included measurements of the physical and chemical characteristics along the seabed, deploying time-series observation equipment, collection of sediment and biota samples, seismic and acoustic sampling, and capturing video footage from either submersible vehicles or fixed station cameras (Dando and Juniper 2001; Davies et al. 2011).

Access to the EHV MPA is regulated by DFO to ensure that activities are coordinated. Researchers must submit proposed research plans to the Technical Advisory Committee, which is comprised of members from government agencies, academia, and environmental groups. The committee evaluates the proposed research plans using the Draft Research Activity Review Framework and determines if the potential impacts from proposed studies are acceptable. This framework lays out a decision tree to identify situations where disturbance, damage, destruction and removal may be approved under the regulations, as well as situations where it would not be acceptable (Davies et al. 2011). However, the MPA regulations do not restrict research activities to the management areas, and hence, all research activities can take place throughout the MPA; nor do the regulations restrict the type of activities that can take place within the MPA (Davies et al. 2011). InterRidge and the international research community have developed a code of conduct for sustainable use of deep-sea vent systems (InterRidge 2010). The code of conduct represents guidelines that individual researchers have agreed to adhere to, and is not a binding international commitment made by member nations (Davies et al. 2011).

Most scientific research in the EHV MPA has focused on the geology of the area and geophysical processes of the vent system. Less work has been completed on the biology of the animals found at the vents and the hydrothermal vent ecosystem (Davies et al. 2011). Population baselines have yet to be established at the EHV MPA, as well as information baselines on activities and anthropogenic stressors (particularly for the exposure of the ecosystem to stressors).

Research and monitoring activities at the EHV MPA are only feasible from large vessels using submersibles or from Ocean Networks Canada's NEPTUNE cabled observatory infrastructure. Ocean Networks Canada currently has the highest activity level in the EHV MPA, installing and maintaining instruments for *in situ* experimentation and monitoring, and conducting surveys and mapping the seafloor and venting sites. Several federal departments conduct additional monitoring of activities in the vicinity of the EHV MPA. Transport Canada monitors ballast water exchange of ocean-going vessels through the Canadian Ballast Water Program, and the National Aerial Surveillance Program monitors pollution due to oil spills (Davies et al. 2011). Environment Canada also monitors oil spills and other ocean surface anomalies through the Integrated Satellite Tracking of Pollution program.

2.5 ECOLOGICAL RISK ASSESSMENT FRAMEWORK METHODS AND RESULTS

As part of the recommendations for selecting risk-based indicators (Davies et al. 2011), the ERAF (O et al. 2015) was applied to the EHV MPA. The ERAF consists of two main phases: scoping, and risk assessment. The scoping phase identifies significant ecosystem components (SECs) and anthropogenic stressors with the potential to impact the EHV MPA ecosystem. The risk assessment calculates the likelihood that a SEC may be negatively impacted due to exposure to one or more identified stressors. The results of the application of the ERAF to the EHV MPA are presented in Thornborough et al.[1], and are summarized below.

SECs that appropriately represent the EHV MPA ecosystem were identified during the scoping phase of this risk assessment. These SECs consisted of six species, four habitats, and one community (Table 2.1). Selected SECs were confined to components that could be managed at the MPA scale (which excludes highly transient species and microbial organisms) and to ensure that the unique nature of the hydrothermal vent ecosystem was captured. Descriptions of each SEC are presented in Appendix A. Pathways of Effects (PoE) models were developed for activities that may impact the EHV MPA, identifying associated stressors and effects on the ecosystem. The stressors identified as impacting the EHV MPA through this process are presented in Table 2.2.

Table 2.1: Significant ecosystem components for the EHV MPA.

SEC type	SEC
Species SECs	*Ridgeia piscesae (high flux)* (Tubeworm)
	Ridgeia piscesae (low flux) (Tubeworm)
	Lepetodrilus fucensis (Limpet)
	Macroregonia macrochira (Spider crab)
	Paralvinella palmiformis (Palm worm)
	Paralvinella sulfincola (Sulfide worm)
Habitat SECs	Active venting hydrothermal mineral chimneys
	Inactive hydrothermal chimneys
	Hydrothermal plume
	Diffuse venting basalt flows
Community SECs	Benthic clam bed community

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

Activity	Associated stressors
Discharge (vessel)	Debris
Oil spill	Oil
Equipment abandonment	Contamination
Equipment installation	Substrate disturbance / crushing
	Substrate disturbance / re-suspension
Sampling	Removal of organisms
	Substrate disturbance / crushing
	Substrate disturbance / re-suspension
Submersible operations	Substrate disturbance / crushing
	Substrate disturbance / re-suspension
	Aquatic invasive species
Seismic testing / air guns	Sound generation

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

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

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

During the analysis of the risk assessment results, anthropogenic stressors were divided into *current snapshot* and *potential* stressors. *Current snapshot* includes activities and stressors that are somewhat predictable and known to occur at the EHV MPA. *Potential* activities and stressors include those that occur infrequently and/or at unpredictable intervals. *Potential* stressors included (shown as stressor (activity) combinations): *oil (oil spill), debris (discharge),* and *aquatic invasive species (submersible operations)*. *Potential* stressors were more likely to be scored higher than *current snapshot* stressors, as they were scored on a worst-case scenario. For example, *aquatic invasive species* was scored as establishment of an aquatic invasive species (rather than exposure to propagule), and *oil (oil spill)* was scored based on a large-scale tanker spill.

Three species SECs (*Ridgeia piscesae* (high flux), *R. piscesae* (low flux), and *Paralvinella sulfincola)* and the benthic clam bed community SEC had the highest cumulative risk scores in the EHV MPA, while the four habitat SECs that were assessed (diffuse basalt flows, inactive chimneys, active venting chimneys, hydrothermal plume) had the lowest cumulative risk scores. The stressors with the highest *potency* scores (sum of all risk scores for a stressor) were debris (*discharge*), substrate disturbance (crushing) (*sampling*), substrate disturbance (crushing) (*submersible operations*), and aquatic invasive species (*submersible operations*). The highest risk scores were found to be associated with the highest uncertainty.

2.6 INFORMATION GAPS

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

Terms of exposure (area, depth and temporal overlap between SECs and stressors, and the stressor intensity (amount) and frequency) identified knowledge gaps in both the distribution and abundance of SECs. There are currently no established population baselines for SECs at the EHV MPA, and information on stressors is limited. *Potential* stressors were scored on the assumption of a worst-case scenario of high overlap with SECs, and this highlighted the need for established SEC baselines to more accurately calculate overlap. Uncertainty surrounding *current snapshot* stressors varied. Stressors related to research activities (e.g., sampling, equipment installation, etc.) had lower uncertainty for the exposure terms than stressors related to vessel traffic (e.g., discharge).

The resilience terms also highlighted the lack of existing population baselines for species SECs as an information gap, as well as the lack of information on the acute change (defined in the ERAF (O et al. 2015) as a change in population size) and chronic change (a change in population condition) to SECs resulting from impacts from stressors. Uncertainty was highest for *potential* stressors and lowest relating to research activities.

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

3 METHOD: INDICATOR SELECTION AND PRIORITIZATION

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

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

The conservation objective for the EHV MPA is broad, and lacks refined operational objectives. Davies et al. (2011) noted that if the conservation objectives are not measurable, then the identification of the stressors, their effects and the application of the ERAF can inform the development of measureable conservation objectives, otherwise known as operational objectives. In the absence of appropriate consultation and collaboration with MPA managers, the development of operational objectives is difficult and carries the risk that the objectives lack validity. This document focuses on the SECs and stressors with the highest cumulative risk scores on the assumption that operational objectives would be based around those species and habitats most at risk as well as those stressors, both *current snapshot* and *potential*, with the greatest impact on the ecosystem.

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

3.1 GENERAL DESCRIPTION OF THE INDICATOR FRAMEWORK

The selection of risk-based indicators is based on risk scores and the determination of the variable driving that risk score and associated uncertainty, but also on validity and the best available scientific knowledge. Additional selection criteria suggested by Davies et al. (2011) (based on Rice and Rochet (2005)) as well as commonly suggested criteria for indicator selection from the primary literature were also incorporated into this method. The final product includes suites of indicators, rather than one or two, to provide a better understanding of SEC distribution and range and the impacts from anthropogenic stressors (Figure 3.1). The monitoring of these indicators may permit future development of thresholds and appropriate management actions.

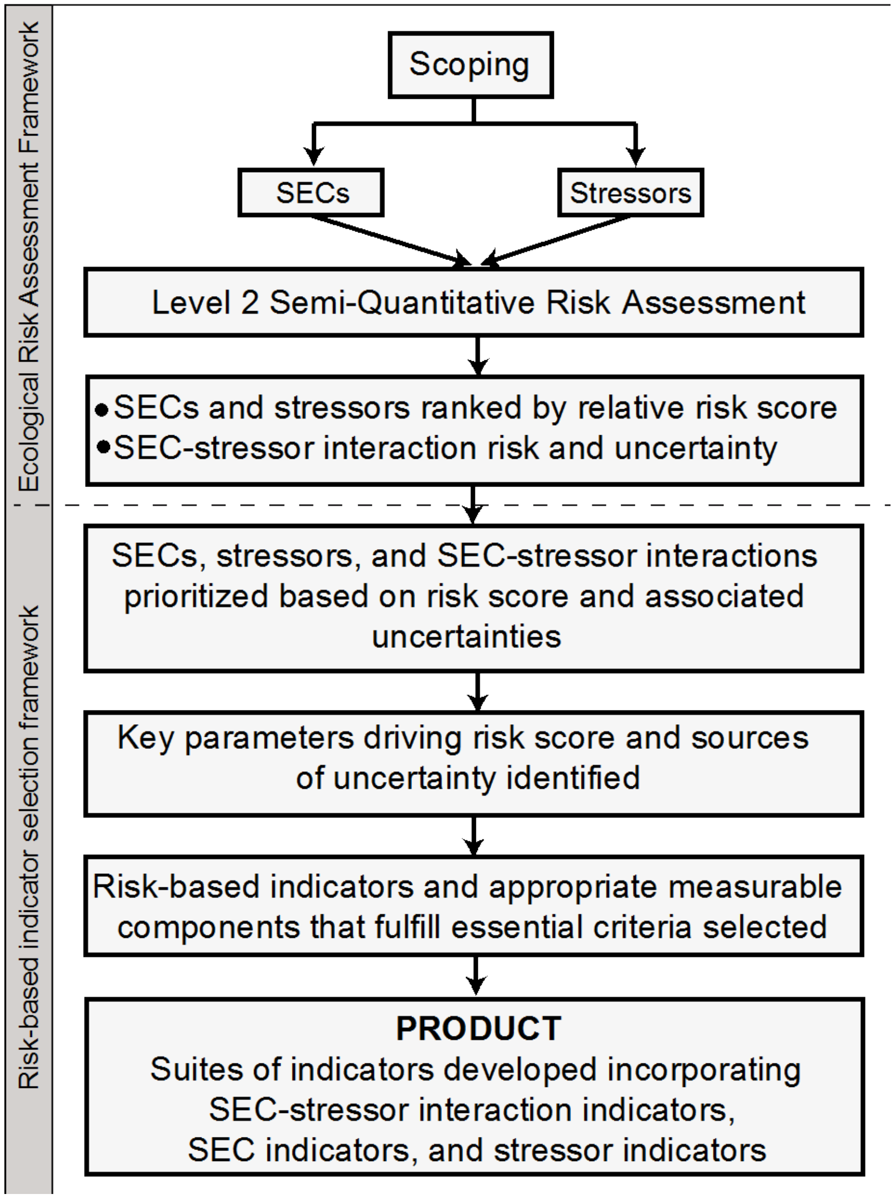

Figure 3.1. Overview of risk-based indicator selection framework, based on the outputs of the ERAF application.

3.2 SELECTION OF RISK-BASED INDICATORS FOR SECS AND STRESSORS

This process involved three steps:

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

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

3.2.1 Prioritization of SECs/Stressors

Prioritization of SECs and stressors for this process was based entirely on the outputs of the risk assessment of the EHV MPA (Thornborough et al.[1]). The application of the ERAF resulted in the ranking of SECs and anthropogenic stressors by cumulative risk score and associated uncertainty (10/90% quantiles) on a relative scale within the MPA. These relative rankings were used to prioritize SECs and stressors prior to indicator selection, where high risk correlated with high priority, and low risk with low priority. All SECs and stressors included in the risk assessment phase of the ERAF were included in this process, and those deemed 'low priority' (based on low relative risk scores) were not removed from this process.

3.2.2 Indicator Criteria

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

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

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

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

Criteria	Sub-criteria	Description
Theoretically sound	Indicator and measureable component established in literature/monitoring programs	Scientific, peer-reviewed findings should demonstrate indicators act as reliable proxies for ecosystem components and stressors.
Measurable/ feasible	- Technically feasible - Quantifiable in real-world units (concreteness of measurement) - Measured using tools and methods that are scientifically sound - Directly measureable (opposed to interpretation through modeling) - Operationally simple - Monitoring method allows for several indicators through a single program - Method should be repeatable over different time scales, and applied to different areas	The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible and repeatable. Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments. Due to the remote location, and therefore limited opportunities for monitoring, several indicators would preferably be monitored within the same program. Methods for monitoring at the EHV MPA are largely restricted to remote methods (e.g. visual surveys by submersibles, grab sampling, existing infrastructure (Ocean Networks Canada), etc.). Therefore, indicators should be able to be measured using feasible remote methods.
Sensitive	Responds predictably and is sufficiently sensitive to changes in specific ecosystem key attribute(s)	Indicators should respond unambiguously to variation in the ecosystem key attribute(s) they are intended to measure, in a theoretically- or empirically-expected direction (not applicable to stressor indicators).
Historical data	- Supported by scientific data and best practices - Historical data is available	Indicators should preferably be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.

3.2.3 Selecting Indicators for SECs and Stressors

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

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

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

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

A total of 93 SEC-stressor interactions were identified at the EHV MPA (Thornborough et al.[1]). In order to provide relevant science advice, these SEC-stressor interactions needed to be prioritized to reduce the number of listed interactions before indicator selection can occur. A method was developed using the outputs of the risk assessment to prioritize SEC-stressor interactions by risk and uncertainty. This process ranked SEC-stressor interactions by both risk score and uncertainty, and divided the interactions into high, moderate, and low priority, and then indicators were selected only for high and moderate priority interactions. The incorporation of both risk score and uncertainty into this prioritization process stems from the findings presented in Thornborough et al.[1] that uncertainty can drive the risk score, and is effective in identifying knowledge gaps. SEC-stressor interactions were divided into *current snapshot* and *potential* interactions prior to prioritization. This categorization was applied so that the final suite of indicators was not dominated by *potential* interactions. Both *current snapshot* and *potential* interactions are required for indicator selection, as each highlight different information gaps and monitoring and management needs.

3.3.1 Prioritization of SEC-stressor Interactions

This process can be summarized in four steps:

1. 10 and 90% quantiles for each SEC-stressor interaction were averaged to give one score representing uncertainty for each interaction.
2. Score range was determined for all risk and uncertainty scores respectively, and then divided by 3, producing high, moderate, and low bins for both scores. This division of scores was confirmed to align with the natural division of the data by plotting raw scores.
3. SEC-stressor interactions were ranked using a combination of both risk and uncertainty, where high risk and low uncertainty was the highest priority, and low risk and low uncertainty was the lowest priority (see Table 3.2).
4. Low priority interactions are removed from this process, and only high and moderate interactions moved onto the next stage of indicator selection.

Table 3.2: Scoring system applied to risk and associated uncertainty scores.

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

3.3.2 Determining the Measure Best Representing the SEC-Stressor Interaction

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

3.3.3 Selection of Indicators for SEC-Stressor Interactions

Indicators and their measureable components were selected from available literature as described in Section 3.2.3. Each selected indicator was required to fulfill all criteria deemed essential in Table 3.1, and preferred criteria (available historical data) where applicable. Indicators were only selected for moderate-high prioritized SEC-stressor interactions, i.e., those interactions with priority rankings of 1-6 in Table 3.2.

Suites of indicators were then presented where SECs were grouped by taxonomy and those with similar indicators for both *current snapshot* and *potential* interactions. Providing a suite rather than just one indicator provides options, and captures a greater range of ecological attributes. SEC and stressor indicators identified through the process outlined in Section 3.2 were incorporated into the indicator suites specific to the SEC-stressor interaction. This approach ensures that a range of attributes is measured, and provides alternative options for monitoring SEC-stressor interactions.

The SEC and stressor specific indicators presented in the final suites of indicators went through an additional refinement process, where only indicators that may help to inform that SEC-stressor interaction were included.

4 RESULTS: SELECTION OF INDICATORS

4.1 INDICATOR IDENTIFICATION FOR SIGNIFICANT ECOSYSTEM COMPONENTS

4.1.1 Prioritization of Significant Ecosystem Components

Prioritization of SECs was derived from the relative rankings of SECs by risk produced as an output from the risk assessment (Thornborough et al.[1]), where the highest cumulative risk score correlates with the highest priority, and the lowest cumulative risk correlates with lowest priority. The outputs were used to prioritize SECs only, and no SECs were removed using this process. SECs prioritized by risk are presented in Table 4.1.

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

SEC	Risk (Cumulative)	10% Q	90% Q
Ridegia piscesae (high flux)	332	292	381
Ridegia piscesae (low flux)	322	271	374
Paralvinella sulfincola	320	275	365
Clam bed benthic community	314	266	373
Lepetodrilus fucensis	273	225	330
Paralvinella palmiformis	210	172	249
Macroregonia macrochira	170	143	202
Inactive mineral chimneys	146	104	188
Active venting mineral chimneys	106	67	150
Diffuse venting flows	83	47	118

4.1.2 Proposed Indicators for Significant Ecosystem Components

Selected indicators and their measureable components for SECs are presented in Table 4.2. Indicators were selected from available literature on ecosystem indicators, with particular focus on those indicators already employed by DFO, and studies on the Pacific Northwest (e.g., Samhouri et al. 2009; Levin et al. 2010; Curtis et al. 2012; Andrews et al. 2013), as well as life history traits of SECs. Where an appropriate indicator could not be found for a specific SEC, a similar species or habitat was used. Each indicator selected fulfilled the essential criteria presented in Table 3.1.

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

Table 4.2: Summary table of proposed SEC indicators, measurable components

SEC			Key parameter	Indicator	Measureable component
Species SEC	Sessile/low mobility invertebrates	*R. piscesae* high flux *R. piscesae* low flux *P. sulfincola* *P. palmiformis* *L. fucensis*	Population size	Abundance	- % coverage of species/species assemblages per chimney/venting location
				Size structure	- Size structure of the population
			Population condition	Organism health	- % 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, but may also increase/decrease the potency of the stressor)
				Genetic diversity	- Population delineations, e.g. allele frequencies, polymorphism, etc.
				Biomass	- Weight/unit area
	Mobile invertebrates	*M. macrochira*	Population size	Abundance	- Count per unit area - Size-frequency distribution
			Population condition	Health/condition	- Visible injury to organism or behavioral indicators (e.g. feeding behavior, reflex actions)
Community SEC	Benthic	Clam bed benthic community	Community size	Abundance (absolute)	- Areal coverage of community (% cover, m^2)
			Community condition/ function	Organism health	- Functional index (e.g. average trophic level, etc.) - % of the population showing visible signs of stress (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)
				Community species richness and diversity	- Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness) applied to the assemblages of species

SEC			Key parameter	Indicator	Measureable component
					- Extent of microbial mats
				Biomass	- Weight/unit area (N.B. Not recommended at this time)
Habitat SEC	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 extent and distribution of habitats is necessary to establish a baseline. NB Approximately 80% of active venting hydrothermal chimneys have been mapped at the EHV MPA
			Habitat condition	Physical damage	- % of chimneys modified - % of the individual chimney modified - Artificial changes in hydrothermal flow - Proportion of active vs. inactive chimneys
	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. However, microbial mats, and live/dead clams and worms may be used to map the extent of this habitat	

4.2 INDICATOR IDENTIFICATION FOR STRESSORS

4.2.1 Prioritization of Anthropogenic Stressors

Prioritization of stressors was derived from the relative rankings of stressors by risk produced as an output from the risk assessment (Thornborough et al.[1]), where the highest cumulative risk score correlates with the highest priority, and the lowest cumulative risk correlates with lowest priority. The outputs were used to prioritize stressors only, and no stressors were removed using this process. Stressors prioritized by risk are presented in Table 4.3.

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

Activity	Stressor	Risk (Cumulative)	10% Q	90% Q
Discharge	Debris*	356	292	438
Sampling	Substrate disturbance / crushing	321	270	368
Submersible operations	Substrate disturbance / crushing	241	198	278
Submersible operations	Aquatic invasive species*	234	207	269
Oil spill	Oil*	216	179	256
Sampling	Removal of organisms	204	169	232
Equipment installation	Substrate disturbance / crushing	155	123	185
Equipment abandonment	Increased contamination	150	109	193
Sampling	Substrate disturbance / re-suspension	125	90	156
Seismic testing / air guns	Sound generation	109	79	142
Submersible operations	Substrate disturbance / re-suspension	107	77	132
Equipment installation	Substrate disturbance / re-suspension	57	42	73

4.2.2 Proposed Indicators for Anthropogenic Stressors

An average of three indicators per stressor were selected from available literature, and are presented in Table 4.4. Where an appropriate indicator could not be found for a specific stressor, a similar stressor was used as a surrogate. Each indicator selected fulfilled the essential criteria presented in Table 3.1, and justifications are provided in Table 4.4. Proposed indicators and their measureable components for stressors and descriptions of the criteria they filled are presented in Appendix E.

Table 4.4: Proposed indicators and measureable components for activities and associated stressors known to impact 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
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
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
Oil spill	Oil	Vessel density in vicinity of the EHV MPA	- Number of vessel movements per traffic reporting zone or per 5 km x 5 km grid cell
		Oil spill volume	- Surface area x minimum thickness
		Oil type	- Determines surface, water column, or benthic coverage. E.g. bitumen – surface coverage of benthic habitats, petroleum – surface spill only
Sampling	Removal of organisms	Biomass	- Weight/unit area of sampled (removed) organisms - Proportion (%) of biogenic habitat removed
		- Maximum potential exposure - Number of allowable samples	- Number of research trips involving sampling per annum x maximum allowable samples
		- Areal coverage of removed organisms (sessile benthic SECs) - Size (area) of the sampling scar	- % cover/area of removed organisms - Size (area) of the sampling scar
	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 %

Activity	Stressor	Indicator	Measureable component
			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
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
Submersible operations	Aquatic invasive species	Frequency of potential exposure	- Number of dive sites per cruise - Existence of cleaning/equipment flushing protocols between dive sites
		Species richness of aquatic invasive species	- 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 - Short-term measurement and would need to be measured in conjunction with other indicators of turbidity to be meaningful
		Frequency of exposure to potential collisions	- Number of collision events
	Substrate disturbance (crushing)	Crushed area	- Proportion (%) of the area crushed - m^2
		Frequency of potential impact	- Number of collision events

4.3 INDICATOR IDENTIFICATION FOR SEC-STRESSOR INTERACTIONS

4.3.1 Prioritization of SEC-Stressor Interactions

The process outlined in Section 3.3 was applied to both *potential* SEC-stressor interactions (included SECs impacted by *oil (oil spill), aquatic invasive species (submersible operations)*, and *debris (discharge)*, and *current snapshot* SEC-stressor interactions (all remaining interactions). The application of the prioritization method reduced the number of SEC-stressor interactions in order to select indicators for only those with moderate to high priority. Of the 24 *potential* SEC-stressor interactions, 12 were categorized as low priority and were removed from this process, leaving 12 *potential* interactions. Of the 69 *current snapshot* interactions, all but 16 interactions fell into the low bin and were removed. Full lists of all interactions and the results of the application of the prioritization method are presented in Appendix F. The resulting SEC-stressor interactions of moderate-high priority are presented in Tables 4.5 and 4.6.

Table 4.5: Current snapshot SEC-stressor interactions remaining after low-priority interactions were removed, presented with the median risk score and 10/90% quantiles for each interaction (Thornborough et al.[1]).

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Ridgeia piscesae (high flux)	Sampling	Removal of organisms	59	12	127
Ridgeia piscesae (high flux)	Sampling	Substrate disturbance (crushing)	58	14	128
Paralvinella sulfincola	Sampling	Substrate disturbance (crushing)	54	18	126
Paralvinella sulfincola	Sampling	Removal of organisms	41	13	99
Inactive mineral chimneys	Sampling	Substrate disturbance (crushing)	40	23	110
Ridgeia piscesae (high flux)	Submersible operations	Substrate disturbance (crushing)	40	9	93
Inactive mineral chimneys	Submersible operations	Substrate disturbance (crushing)	35	17	90
Clam bed benthic community	Sampling	Substrate disturbance (crushing)	29	15	79
Clam bed benthic community	Sampling	Substrate disturbance (sediment re-suspension)	29	14	73
Clam bed benthic community	Sampling	Removal of organisms	28	12	73
Ridgeia piscesae (low flux)	Sampling	Substrate disturbance (crushing)	28	13	69
Ridgeia piscesae (low flux)	Equipment abandonment	Increased contamination	28	18	76
Paralvinella sulfincola	Submersible operations	Substrate disturbance (crushing)	28	12	67
Ridgeia piscesae (low flux)	Sampling	Removal of organisms	27	11	70
Active venting mineral chimneys	Sampling	Substrate disturbance (crushing)	26	15	71
Clam bed benthic community	Equipment abandonment	Increased contamination	25	11	73

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

SEC	Activity	Stressor	Risk Score	10% Q	90% Q
Inactive mineral chimneys	Discharge	Debris	46	24	126
Ridgeia piscesae (low flux)	Submersible operations	Aquatic invasive species	40	11	98
Ridgeia piscesae (low flux)	Discharge	Debris	39	16	106
Ridgeia piscesae (low flux)	Oil spill	Oil	37	15	96
Lepetodrilus fucensis	Discharge	Debris	36	22	96
Lepetodrilus fucensis	Submersible operations	Aquatic invasive species	35	10	82
Active venting mineral chimneys	Discharge	Debris	34	21	106
Lepetodrilus fucensis	Oil spill	Oil	33	15	85
Clam bed benthic community	Discharge	Debris	33	18	95
Clam bed benthic community	Submersible operations	Aquatic invasive species	33	9	83
Paralvinella sulfincola	Discharge	Debris	33	17	85
Clam bed benthic community	Oil spill	Oil	33	13	83

4.3.2 Proposed Indicators for SEC-Stressor Interactions

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

4.3.3 Suites of Indicators

Suites of indicators are provided for both *current snapshot* and *potential* SEC-stressor interactions (Tables 4.7 and 4.8), that incorporate indicators selected for SECs and stressors (Tables 4.2 and 4.4 respectively).

*Table 4.7: Indicator suites for current snapshot SEC-stressor interactions, presented roughly in order of the prioritization results. * denotes SEC is only impacted by matching stressor.*

SEC			Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Species	Sessile/low mobility invertebrates	*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 - Genetic diversity - Size structure	- Biomass of removed organisms - 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	- Abundance - Organism health - Species richness and diversity of assemblage - Size structure	- Crushed area (Proportion (%) of the 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 - Size structure	- Crushed area (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 - Size structure	- Potential contaminant type - Length of exposure
Habitat	Chimneys	Inactive mineral chimneys Active venting mineral	Submersible operations	Substrate disturbance (crushing)	- Size of crushed area on individual chimneys - Number of collisions producing visible particular plume	- Extent and distribution - Physical damage - Active vs. inactive chimneys	- Crushed area (Proportion (%) of the area crushed) - Frequency of potential impact

SEC			Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
		chimneys*	Sampling*	Substrate disturbance (crushing)	- Area sampled/ size (area) of the sampling scar	- Extent and distribution - Physical damage - Active vs. inactive chimneys	- Crushed area (Proportion (%) of the area crushed) - Frequency of potential sampling events
Community	Benthic	Clam bed benthic community	Sampling	Removal of organisms	- Biomass of removed organisms - Size (area) of the sampling scar - Species richness and diversity of assemblage (to be used in time series monitoring – not single event)	- Abundance - Organism health/ functional index 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 (area) of crushed area	- Abundance - Organism health/ functional index Species richness and diversity of assemblage	- Crushed area (Proportion (%) of the area crushed) - Frequency of potential sampling events
				Substrate disturbance (sediment re-suspension)	- Change in abundance/ extent - Abundance (areal extent) of community showing signs of smothering/stress	- Abundance - Organism health/ functional index - 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 4.8: Indicator suites for potential SEC-stressor interactions, presented roughly in order of the prioritization results. * denotes SEC is only impacted by matching stressor.*

SEC			Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
Species	Sessile/ low mobility invertebrates	*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 - Size structure	- 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 - Genetic diversity (allele frequency, polymorphism) - Size structure	- 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 - Size structure	- Relative abundance of debris - Debris characterization
Habitat	Chimneys	Inactive mineral chimneys Active venting mineral chimneys	Discharge	Debris	- Size of crushed area/size of debris	- Extent and distribution - Physical damage - Active vs. inactive chimneys	- Relative abundance of debris - Debris characterization
Community	Benthic	Clam bed benthic community	Discharge	Debris	- Size of crushed area/size of debris	- Abundance - Organism health/ functional index Species richness and diversity of assemblage	- Relative abundance of debris - Debris characterization
			Submersible operations	Aquatic invasive	- Abundance of organisms displaying symptoms of stress	- Abundance - Organism health/ functional index	- Frequency of potential exposure - Occurrence/abundanc

SEC			Activity	Stressor	SEC-stressor interaction indicator	SEC specific indicator	Stressor specific indicator
				species		Species richness and diversity of assemblage - Microbial mat distribution	e of aquatic invasive species
			Oil spill	Oil	- Abundance of organisms displaying symptoms of stress - Species richness/ presence of disease/stress	- Organism health/ functional index - Abundance - Species richness	- Vessel density in vicinity of the EHV MPA - Oil spill volume - Oil type

5 DISCUSSION

The selection of appropriate ecological indicators is a key step in the adaptive management of the EHV MPA (Figure 1.1). By selecting risk-based indicators, monitoring plans may be developed to measure those components identified as crucial to the functioning of the ecosystem and those at risk from anthropogenic stressors. This paper presents risk-based indicators for SECs, stressors, and SEC-stressor interactions. SEC-stressor interactions were divided into *current snapsho*t and *potential* interactions. Tables 4.5 and 4.6 present suites of indicators representing *current snapshot* and *potential* interactions, respectively. These tables display the relevant SEC-stressor interaction indicator(s), as well as the indicator(s) specific to SECs and stressors (independent of one another) that would provide data relevant to that interaction. Suites of indicators are proposed, as no single indicator provides a complete picture of ecosystem state. Suites of indicators focus on different key parameters (population size and condition), using different types and sources of data, to provide information on changes within the ecosystem.

5.1 SUITES OF INDICATORS FOR MONITORING

SEC-stressor interaction indicators are those most specific to measuring the impact of a particular stressor on a SEC or group of SECs. The inclusion of SEC and stressor specific indicators with SEC-stressor interaction indicators in the suites serves two purposes: to provide alternate options if interaction-specific indicators cannot be measured; and information collected by monitoring SEC and stressor specific indicators help establish baselines of information and would complement existing datasets. The order of presentation of the indicator suite tables (Tables 4.5 and 4.6) does not reflect any prioritization of *current snapshot* over *potential* indicators, as each represents a different type of risk, state of knowledge, and management approach. When developing monitoring strategies and plans, both *current snapshot* and *potential* stressor indicator suites should be considered using a combination of SEC, stressor, and SEC-stressor interaction indicators.

The indicators presented in the *current snapshot* suite largely measure the SEC-stressor interaction directly and can be monitored at the same time as collecting general information to establish population baselines. For example, while conducting visual surveys to establish population baselines of *Ridgeia piscesae* (high flux), the proportion of *Ridgeia piscesae* (high flux), and/or other species SECs from the same assemblages (e.g. *Lepetodrilus fucensis*), displaying signs of disturbance can be measured at the same time. The most informative indicators for *current snapshot* interactions are SEC-stressor indicators, followed by SEC and stressor indicators. Managers should note that by using only SEC or stressor indicators, the level of uncertainty surrounding the specificity of a measurement to an interaction increases. The monitoring of *current snapshot* stressor indicators should use a combination of SEC-stressor interaction, SEC, and stressor indicators to establish baselines and measure disturbances concurrently. This approach is particularly relevant at the EHV MPA, where natural ecological succession may confound the results of monitoring, especially when only examining one indicator.

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

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

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

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

5.2 DATA COLLECTION AND ADDRESSING KNOWLEDGE GAPS

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

Indicators were selected with consideration given to the limitations of research and monitoring at the EHV MPA. Such limitations include the remote location and extreme depth of the MPA, and the associated high cost of access. As a result, monitoring is heavily reliant on the use of submersibles, the sampling/monitoring techniques available to each submersible, existing datasets (e.g., scientific studies, previous submersible video, vessel density, dive logs, etc.), and existing infrastructure at the EHV MPA (Ocean Networks Canada). With many indicators requiring visual surveys as a measurement technique and the overlapping distribution of several SECs, multiple indicators may be measured or sampled during the same operations period.

Additionally, the use of visual surveys to monitor multiple indicators reduces the incidence of destructive sampling/measurements.

The suites of indicators selected in this process will likely evolve over time as further resources and information become available (Jennings 2005). As more information on monitored SECs and stressors is collected and monitoring methods improve, indicators may be removed or additional indicators may be incorporated into the monitoring plan for the EHV MPA. These changes may include indicators suggested in the SEC and stressor indicators tables (Appendix C and Appendix E) that were not included in the suites of indicators, or new indicators. Any new indicator should fulfill the criteria in Table 3.1 and be scored against the more detailed criteria presented in Appendix B.

While indicators were selected based on the best available knowledge of indicator development and monitoring, the effectiveness of the indicators in measuring changes to SECs resulting from interactions with stressors at the EHV MPA will not be fully realized until after data collection has commenced, smaller scale impact experiments undertaken, and time series data have been analyzed (under ‘monitor, evaluate, and report’ in adaptive management Figure 1.1). The effectiveness of *current snapshot* interaction indicators can be reassessed sooner than *potential* SEC-stressor interaction indicators, which cannot be evaluated until the stressor occurs at the EHV MPA. Any monitoring plan will need to include an indicator reevaluation process once data collection has begun to determine the most effective indicators and which indicators will be monitored long-term. Indicator performance testing will need to employ a formal evaluation method, e.g., retrospective tests based on signal detection theory (proposed by Rice and Rochet 2005), or rule-based management with monitoring and feedback controls (also proposed by Rochet and Rice (2003)). The performance of indicators should be assessed in terms of the indicators’ capacity to track properties of interest (in this case, impacts from stressors, and establish population baselines for SECs) and their ability to detect or predict trends in attributes (Jennings 2005).

The next step in the adaptive management framework (Figure 1.1) is to develop monitoring strategies, which will typically include specifications for data collection, data processing and analysis, the use of analytical outputs in assessment, how the assessment determines any decision rules, and how decisions may be implemented (Jennings 2005). Ultimately, indicators should be linked to reference points for SECs that, if exceeded, trigger management actions. Given the current state of knowledge of communities at the EHV MPA, specific reference points have not been considered. Shin et al. (2010) concluded that the scientific community is still far from able to determine reference points for ecosystem indicators, and the same conclusion is applicable for risk-based indicators. At this stage, linking reference points to risk-based indicators is aspirational, but should not hinder the collection of data through monitoring programs.

5.3 LIMITATIONS AND FUTURE DEVELOPMENT OF THIS WORK

Indicators are subject to the limitations of available or existing data, and sampling design and tools (Kenchington et al. 2010). The need to establish information baselines is crucial in determining the effectiveness of management measures, and of the indicators themselves. For remote, difficult to access areas like the EHV MPA, the sampling design and tools required to collect information on relevant indicators is limited to available technology, funds, and time. There are limitations in each method to measure indicators, however, the suites of indicators are designed so that, as more information is collected, several different methods (measurable components) will be used to validate existing datasets. For example, for *Ridgeia piscesae* (low flux) and substrate disturbance (crushing) from submersible operations, a combination of visual surveys and selective sampling with data on submersible tracks and points of potential collision will provide a more complete picture than only using one of those techniques. The development of new sampling tools in the future will further add to these datasets.

5.3.1 Conservation Objectives

The current conservation objective for the EHV MPA is broad and more specific operational objectives had not been defined. Davies et al. (2011) stated in their risk-based indicator selection recommendations that the refinement of the conservation objective into SMART operational objectives is essential to the development of a monitoring plan that will measure ecosystem parameters that are useful and relevant for the management of anthropogenic stressors at the EHV MPA. While it would have been preferable to have refined conservation objectives to link to selected indicators and use as potential selection criteria throughout this process, the lack of these objectives did not inhibit the selection of proposed indicators that are appropriate for the current state of knowledge in the EHV MPA ecosystem.

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

5.3.2 Ecosystem Indicators

This work proposed risk-based indicators, based on the outputs of the application of the ERAF to the EHV MPA. The scoping phase of the ERAF identified SECs and stressors that appropriately represented the ecosystem (Thornborough et al.[1]). Through this process, an ecosystem SEC, hydrothermal plume, was identified as having high conservation relevance at the EHV MPA, but could not be included in the risk assessment process as it is transient in nature, and stressors were not manageable at the MPA scale. The hydrothermal plume, as well as the zooplankton communities strongly associated with the plume, should be considered in any future development of ecosystem indicators.

There are several species important to the functioning of the ecosystem that were not appropriate for SEC selection in the ERAF process, but were classified as appropriate ‘state of the ecosystem’ indicators instead (Thornborough et al.[1]). These SECs included endemic species such as the large snail *Buccinum thermophilum*, pycnogonid *Sericosura venticola,* and amphipod *Pardalisca endeavouri.* Endemism is one of the EHV MPA’s great ecological and evolutionary contributions and this feature is not represented in the current SEC list. Any future applications of the ERAF and development of additional risk-based or ecosystem indicators should consider these species.

As more data become available through monitoring, the future development of ecosystem indicators should also consider grouping several of the species SECs into distinct assemblages as suggested in the literature (e.g., Dancette and Juniper 2007). Many of the SECs are part of invertebrate assemblages, are interdependent on one another and/or indicate different hydrothermal flow environments. The monitoring of both individual SEC indicators as well as assemblages indicators will provide useful data on ecological succession at the EHV MPA, which may confound the results of monitoring some indicators.

5.3.3 Stressors

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

Long-range stressors were not included in this work, as this work was based directly on the outputs of the ERAF application. For future iterations of this work, the indicator selection criteria (Table 3.1) could be used to select appropriate indicators for impacts associated with long-range transport of atmospheric contamination (persistent organic pollutants), and stressors related to climate change (e.g., ocean acidification, species range changes, and temperature changes). However, indicators for these long-range impacts may not be sensitive to changes in the ecosystem, and would be reliant on stressor specific indicators and established population baselines.

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

6 CONCLUSIONS/RECOMMENDATIONS

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

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

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

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8 GLOSSARY AND ACRONYMS

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

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

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

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

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

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

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

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

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

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

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

Ecological Risk Assessment Framework (ERAF) – Framework developed by the Pacific Region (O et al. 2015) in order to evaluate and prioritize the single and cumulative threats from multiple anthropogenic activities and their associated stressors to SECs. The key elements of this framework consist of an initial scoping phase followed by the risk assessment. Scoping includes:

1. the identification of species, habitat, and community SECs; and
2. the identification of anthropogenic activities and stressors that have the potential to affect these.

The risk assessment consists of evaluating the risk of harm to each SEC from each activity and associated stressor using criteria and scoring methods described in O et al. (2015).

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

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

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

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

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

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

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

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

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

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

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

Indicator - An ecological indicator is a specific measurable component of an ecosystem that is used for monitoring, assessing, and understanding ecosystem status, impacts of anthropogenic activities, and effectiveness of management measures in achieving objectives.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Target species - Primary species captured by a fishery in the area of interest.

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

APPENDIX A: ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA SIGNIFICANT ECOSYSTEM COMPONENTS AND THEIR SELECTION JUSTIFICATIONS (FROM THORNBOROUGH ET AL.[1])

Table A.1. Endeavour Hydrothermal Vents Marine Protected Area Significant Ecosystem Components and their selection justifications (From Thornborough et al.[1])

SEC Type	SEC	Justification for selection
Species	*Ridgeia piscesae (high flux)* (Tubeworm)	Vestimentiferan *Ridgeia piscesae* are extremely abundant at active venting sites within the EHV MPA. This animal has no gut but has a symbiotic relationship with chemosynthetic microbes (internal symbiotic sulphide-oxidizing bacteria). Appearance of tube varies greatly with habitat and the branchial plume can be highly modified by grazers. They form the structural base of the hot vent communities. The extensive 3D structures created by *R. piscesae* can increase the space available for colonization by other sulphide edifice species by up to 28 times (Sarrazin and Juniper 1999). Different phenotypes are present in different flow environments. The term “high flux” has been used by Tunnicliffe et al. (in prep) to describe the *R. piscesae* that occupy higher temperature habitats with greater dissolved sulphide flux. *R. piscesae* (high flux) is fast growing, short-lived, and has a distinctive morphology (often “short-fat”) (Tunnicliffe et al. in prep). Due to the specific nature of this high flux habitat, distribution of this SEC is limited, and restricted mostly to the top of active venting chimneys. A study is currently underway examining the genetic differentiation between *R. piscesae* habitats (Verena Tunnicliffe, University of Victoria *pers. comm.* Dec 2014). Results so far indicate that *R. piscesae* (high flux) may play a significant role in population dynamics of *R. piscesae* species in the EHV MPA (Verena Tunnicliffe, University of Victoria *pers. comm*. Dec 2014). Alvinellidae of the genus Paralvinella are frequently associated with vestimentiferan worms (Desbruyeres et al. 2006; Tunnicliffe and Juniper 1990). Fulfills SEC criteria: - Nutrient importer/exporter (primary consumers) - Specialized role in the food web - Habitat creating species - Sensitive species
	Ridgeia piscesae (low flux) (Tubeworm)	More abundant than *R. piscesae* (high flux) and widespread distribution within the EHV MPA. This phenotype is often found in areas of low diffuse vent flow with very low plume level exposure to sulphide (Desbruyères et al. 2006). Limited breeding, and slow recovery rates. Fulfills SEC criteria: - Nutrient importer/exporter (primary consumers) - Specialized role in the food web

SEC Type	SEC	Justification for selection
		- Habitat creating species - Sensitive species
	Lepetodrilus fucensis (Limpet)	Extremely abundant at the EHV MPA. This species occupies nearly every vent habitat and is capable of grazing, suspension feeding and farming the bacteria that colonize its gills. It can comprise up to 50% of the total faunal biomass at Juan de Fuca Ridge vents. This limpet forms huge masses that coat the sides of chimneys and drape the tubeworms. Perceived as a suspension feeder by Tunnicliffe (1990), its anatomy suggests that it could also graze the tubeworms and rock surfaces that it colonizes (Fretter 1988). Fox et al. (2002) suggested that *L. fucensis* gill bacteria have the potential to serve as a significant source of nutrition for the animal through endocytosis and degradation of bacteria directly by the gill epithelium. This limpet's ability to use multiple methods of acquiring nutrition may account for its ecological success. Fulfills SEC criteria: - Nutrient importer/exporter (primary consumers) - Specialized role in the food web
	Macroregonia macrochira (Spider Crab)	Common, major predators/scavengers at the EHV MPA. The species is found in high concentrations on and around vent sites (Tunnicliffe and Jensen 1987; Tunnicliffe 2000), and benefit from vent productivity. It preys on different vent organisms (Desbruyeres et al. 2006), but will frequent tubeworm colonies on active vents (Tunnicliffe and Jensen 1987; Tunnicliffe et al. 1990; Juniper et al. 1992). It prefers hard substrates. It represents a mechanism for transferring the rich production of chemosynthetic activity to the oligotrophic deep-sea environment (Tunnicliffe and Jensen, 1987). These crabs must account for the greatest biotic attrition on the communities (Tunnicliffe and Jensen 1987). They are an indicator of a healthy system, and are a measurable component of the EHV MPA. Fulfills SEC criteria: - Specialized or keystone role in food web (top-level consumer).
	Paralvinella palmiformis (Palm Worm)	Very abundant at Endeavour, *Paralvinella palmiformis* is found in most intermediate venting conditions. The large palm-like branchiae are used for gas exchange while the oral tentacles ingest bacteria from both the surface of the chimneys and in the water (Tunnicliffe 2000). Deposit feeder (Desbruyères et al. 2006). Fulfills SEC criteria: - Nutrient importer/exporter - Specialized role in food web
	Paralvinella sulfincola	Lives in mucous tubes on the actively growing portions (hottest parts) of sulphide mineral chimneys and is considered to be the

SEC Type	SEC	Justification for selection
	(Sulfide Worm)	pioneering macrofaunal species in this habitat (Grelon et al. 2006). Due to their location at the top of the black smokers, they are more vulnerable to sampling activities. Found on every black smoker at the EHV MPA (Tunnicliffe pers comm. Sept 2013). *Paralvinella sulfincola* is one of the first metazoans to colonize newly formed mineral substrata on hydrothermal vent sulphide edifices of the Juan de Fuca Ridge (Juniper 1994). This polychaete is found on surfaces exposed to intense hydrothermal fluid flow and frequently forms a front between tolerable physicochemical conditions and bare surfaces where conditions are too severe for colonization (Sarrazin et al. 1997). It is a deposit feeder, ingesting particles (bacterial cells, non-living detritus) on mineral surfaces near its tube entrance (Juniper 1994; Grelon 2001). It is often found on walls and summits of structures (Sarrazin et al. 1999) and appears in monospecific populations (Sarrazin et al. 1997). Fulfills SEC criteria: - Nutrient importer/exporter - Specialized role in food web - Habitat creating species
Habitat	Active venting hydrothermal mineral chimneys	These sulphide structures are typical of hydrothermal sites where substantial mineral deposition is occurring. Sulphide structures are built of coalescing chimneys topped by spires often belching black “smoke”. They can be up to tens of meters high and are characterized by multiple orifices, complex overgrowths, and frequent breakouts through chimney walls. They may support most biogenic habitat creating species, including bacterial mats, and tubeworms. Diffuse and actively venting chimneys support most assemblages of organisms in the EHV MPA. The sub-habitats of chimneys may be further broken down into edifice walls, flanges, bases and summits, however; this level of detail is not required for the purposes of this study. Fulfills SEC criteria: - Sensitive habitat - Habitat critical for sensitive species - Habitats critical for supporting rare, unique, or endemic species - Habitats supporting critical life stages - Habitats providing critical ecosystem functions or services
	Inactive hydrothermal chimneys	Distributed throughout the EHV MPA, inactive chimneys can be up to tens of meters high. These structures may persist for decades to millennia and form moderate to massive deposits at and below the sea floor. The mineralogy of sulphide chimneys provides unusual metabolites during controlled oxidation by microbes, implying a potential shift in microbial activity and metabolic guilds on hydrothermal sulphides (Sylvan et al. 2012). These microbes

SEC Type	SEC	Justification for selection
		support endemic species specific to this habitat. In addition, these structures host biogenic habitat-creating species, such as corals and sponges that are capable of creating their own genetically unique communities. Fulfills SEC criteria: - Sensitive habitat - Habitat critical for sensitive species - Habitats critical for supporting rare, unique, or endemic species - Habitats supporting critical life stages - Habitats providing critical ecosystem functions or services
	Hydrothermal plume	The hydrothermal plume, formed by the coalescing of smaller individual plumes within 10 m of the seafloor, extends up to 300 m into the water column above the EHV MPA to a height of neutral plume buoyancy. This height of rise can change considerably over a tidal period due to the changes in strength and direction of the net current (mean plus time varying) (Richard Thomson, Fisheries and Oceans Canada, Institute of Ocean Sciences pers. comm. Nov 2013). It is strongly influenced by the hydrothermalism and current velocity. The stronger the current, the lower the plume rise height. Semidiurnal tidal currents and mean background flows dominate the near-bottom circulation in the MPA. The regions immediately above the neutrally buoyant plumes are regions of enhanced macrozooplankton aggregation and abundance; the toxic inner plume layers are regions of reduced zooplankton abundance. Plume macrozooplankton aggregations comprise both deep species as well as species normally found in the upper ocean. The increased zooplankton aggregations attract other types of animals including fish and jellyfish, and lead to enhanced productivity throughout the entire water column overlying the broad venting region. Fulfills SEC criteria: - Sensitive habitat - Habitat critical for sensitive species - Habitats critical for supporting rare, unique, or endemic species - Habitats supporting critical life stages - Habitats providing critical ecosystem functions or services
	Diffuse venting basalt flows	Often located near chimneys, but with lower temperature fluids (~0.2-100°C) (Bemis et al. 2012). Fluids seep out of cracks in ocean floor, and can support abundances of up to half a million organisms per square meter. Fulfills SEC criteria: - Habitat critical for sensitive species - Habitats critical for supporting rare, unique, or endemic species - Habitats supporting critical life stages - Habitats providing critical ecosystem functions or services

SEC Type	SEC	Justification for selection
Community	Benthic clam bed community	Occupies an extremely limited area within the EHV MPA. It is a unique habitat within the EHV MPA, and is comprised of chemosynthetic organisms. The group of foundation species includes at least two vesicomyid clams (of which the systematics are only just being sorted out with molecular approaches (Audzijonyte et al. 2012)). This community includes mainly chemolithoautotrophs, proteobacteria, ciliates (Folliculina sp.), buccinid snails, and clams (including *Calyptogena cf. pacifica*) Fulfills SEC criteria: - Ecologically significant community properties - Sensitive functional groups

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

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

Criteria	Sub-criteria	Description
Theoretically sound	Indicator and measureable component established in literature/monitoring programs	Scientific, peer-reviewed findings should demonstrate that indicators act as reliable surrogates for ecosystem components and stressors.
Measurable/ feasible	- Quantifiable in real-world units (concreteness of measurement) (e.g. number of individuals per m^2, etc.) - Measured using tools and methods that are scientifically sound - Directly measureable (opposed to interpretation through modeling) - Operationally simple - Monitoring method allows for several indicators through a single program - Method should be repeatable over different time scales, and applied to different areas	The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible and repeatable. Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments. Due to the remote location, and therefore limited opportunities for monitoring, several indicators would preferably be monitored within the same program. Methods for monitoring at the EHV MPA are largely restricted to remote methods (e.g. visual surveys by submersibles, box-grab sampling, etc.). Therefore, indicators should be able to be measured using feasible remote methods.
Sensitive	Responds predictably and is sufficiently sensitive to changes in specific ecosystem key attribute(s)	Indicators should respond unambiguously to variation in the ecosystem key attribute(s) they are intended to measure, in a theoretically- or empirically-expected direction (not applicable to stressor indicators).
Historical data	- Supported by scientific data and best practices - Historical data or information is available	Indicators should preferably be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.
Related to MPA management	- Linked to conservation objectives/operational objectives - Relevant to management concerns	Indicators should be linked to operational objectives, and provide information related to specific management goals and strategies.
Other considerations (Kershner et al.	Understood by the public and policy makers	Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with

Criteria	Sub-criteria	Description
2011; Rice and Rochet 2005)		technical definitions.
	History of public reporting	Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators
	Cost-effective	Ensures that measurement tools are widely available and inexpensive to use. Sampling, measuring, processing, and analyzing the indicator data should make effective use of limited financial resources.
	Anticipatory or leading indicator	A subset of indicators should signal changes in ecosystem attributes before they occur, and ideally with sufficient lead-time to allow for a management response
	Regionally/nationally/internationally compatible	Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status
	Complements existing indicators	This criterion is applicable in the selection of a suite of indicators, performed after the evaluation of individual indicators in a post-hoc analysis. Sets of indicators should be selected to avoid redundancy, increase the complementary of the information provided, and to ensure coverage of key attributes
	Linkable to scientifically-defined reference points and progress targets	It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.

APPENDIX C: SEC INDICATOR JUSTIFICATIONS

Table C.1. Proposed indicators for sessile/low mobility invertebrate SECs (Ridgeia piscesae (high flux), Ridgeia piscesae (low flux), Paralvinella sulfincola, Paralvinella palmiformis, Lepetodrilus fucensis).

Proposed indicator	Measureable component	Justification
Population size		
Abundance	- % coverage of species/species assemblages per chimney/venting location	- Commonly used metric - Comparable across venting sites - Feasible, quantitative and repeatable. Visual approaches verified by spot collection
Population condition		
Biomass	- Size structure - Weight/unit area (only to be used when sampling is already taking place)	- May be determined using existing sampling data (biomass) and visual surveys (size structure) - Quantitative and repeatable - Changes in biomass are detectable depending on the frequency of data collection - Biomass is subject to sampling gear selectivity
Species richness and diversity	- Size structure	- Size structure of the populations, and if it is both supplying progeny and recruiting new members.
Organism health	- Measure of reproductive condition (critical for the maintenance of populations) - Organism weight - % of the population showing visible signs of stress/parasitism (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)	- Existing data (visual surveys) may help to inform this indicator - Highly sensitive to sampling effort as well as the selectivity of the sampling device
Genetic diversity	Allele frequency, polymorphic loci	- Quantifiable and repeatable - Well-used index, comparable across ecosystems - Highly sensitive to sampling effort as well as the selectivity of the sampling device

Table C.2. Proposed indicators for mobile invertebrate SECs (Macroregonia macrochira).

Proposed indicator	Measureable component	Justification
Population size		
Abundance	- Abundance at distance from venting site (density vs. distance measure) - Size-frequency distribution	- Commonly used metric - Comparable across venting sites within the MPA - Quantitative and repeatable - Achievable by visual survey
Population condition		
Organism health	- Visible injury to organism or behavioural indicators (e.g. feeding behaviour, reflex actions) - Assessment of male versus female/juvenile (indicating recruitment)	- Commonly used metric for other crustaceans - Comparable across ecosystems - Quantitative and repeatable using visual surveys - Previously applied to squat lobsters

Table C.3. Proposed indicators for community SEC clam bed benthic community

Proposed indicator	Measureable component	Justification
Community size		
Abundance	Areal coverage of community (% cover, m^2)	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
Community condition/function		
Biomass	Weight/unit area (NB Not recommended at this time)	- May be informed using existing data - Quantitative and repeatable - Changes in biomass are detectable depending on the frequency of data collection - Biomass is subject to sampling gear selectivity
Community species richness and diversity	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	- Commonly used metric - Comparable across ecosystems - Quantitative and repeatable
Organism health	- Functional index (e.g. average trophic level) - % of the population showing visible signs of stress/damage (NB should be used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator, and is to be used only if Functional Index cannot be measured)	- Commonly used indicator biotic habitats - For the clam bed benthic community, the general heath and boundaries can often be assessed by the number of dead organisms

Table C.4. Proposed indicators for habitat chimney SECs (active venting hydrothermal mineral chimneys and inactive mineral chimneys)

Proposed indicator	**Measureable component**	**Justification**
Habitat size		
Extent and distribution	- Volume of venting flow from chimneys (expanded versus reduced venting)	- 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 extent and distribution of habitats is necessary to establish a baseline. - Commonly used metric for other habitats - Quantitative and repeatable - May not be sensitive to small-scale anthropogenic disturbances
Habitat condition		
Physical damage	- % of chimneys modified - % of the individual chimney modified - Artificial changes in hydrothermal flow - Count of equipment/experiments	- Commonly used metric for other habitat types. - Repeatable - Quantifiable - Should include an overall view of infrastructure (ONC specifically) near venting sites

Table C.5. Proposed indicators for benthic habitat SEC (diffuse venting flows)

Proposed indicator	Measureable component	Justification
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.	- Commonly used metric for other abiotic habitat types - Quantitative and repeatable
Habitat condition		
Extent of benthic mircrobial mats	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.	

APPENDIX D: SEC INDICATOR CRITERIA SUMMARY

Table D.1. Species and community SEC Indicators scored against criteria

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
Population/community size						
Abundance / species density	- Number of individuals (number per m^2, density) - Density - % cover	- Commonly used metric and is comparable across venting sites	- Quantifiable - Repeatable - Several different measureable components - Areal coverage suitable for colonial, gregarious, large species - Number/counts suitable for conspicuous and distinguishable taxa - Frequency of occurrence measurements are simple, provided the taxon can be distinguished - Species density estimates use numerical abundances of individual per unit area - Habitat suitability models may be used to predict presence	- There may be issues related to sampling sensitivity between gear types (DFO 2010A)	- Some data exist from scientific sampling. No baselines have been established.	- Good way to establish population baselines - Also related to habitat quality and community structure - There may be issues related to sampling sensitivity between gear types (DFO 2010A) - Measurements repeatable, quantifiable, and comparable across venting sites - Data can be collected using visual surveys

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
			and/or abundance in unsurveyed areas, but may be highly uncertain.			
Population/community condition						
Biomass	Weight/unit area	- Commonly used indicator for individual focal species - Blanchard et al. 2010; Large et al. 2014); Shin et al. 2010)	- Quantifiable - Measurement can be achieved using existing data and extractive scientific sampling - Repeatable - Comparable within and among gear types - Changes in biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance	- Changes in biomass are detectable depending on the frequency of data collection (DFO 2010A) - For assemblages: changes in a single group may or may not be indicative of the entire community (Andrews et al. 2013) - Benthic inverts: Correlates well with ecosystem health; gradual change should show major community	Some data available based on scientific sampling	- Should be used in conjunction with other population size indicators, such as abundance - Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling - Subject to sampling gear selectivity (DFO 2010A)

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
				reorganization (Andrews et al. 2013)		
Species richness/ diversity	- Diversity measures - e.g. Shannon-Weiner, Simpson Indexes	- Commonly used metric and is comparable across ecosystems and venting fields - (Large et al. 2014)	- Quantifiable - Repeatable - Can't be calculated without biomass estimates, and it is limited by taxonomic resolution - Species richness measures are a dimension of biodiversity, but does not require estimates of abundance - Diversity measures the number and evenness among species	- Sensitive to the different sampling methods (DFO 2010A) - Highly sensitive to sampling effort as well as selectivity of sampling device (DFO 2010A) - Species diversity may not be sensitive to disturbance - Species richness is sensitive to sampling effort	Part of this measurement can be informed using existing scientific sampling	- Indicator of community structure - Metrics used are well established - Repeatable, quantifiable, and comparable across ecosystems
Organism health	% of the population showing visible signs of stress/disease (NB should be used in combination	May be related to condition, but changes in the attribute are not likely to vary with this indicator at any scale but the	- Measurement mostly reliant on extractive sampling - Quantifiable as a percentage of sampled organisms - Repeatable	Highly sensitive to sampling effort as well as the selectivity of the sampling device	Data on scientific samples exist	Highly sensitive to sampling effort as well as the selectivity of the sampling device

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
	with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	very smallest				
Genetic diversity of populations	Population delineation, allele frequency	Commonly used metric. Strongly supported by literature	Measurement mostly reliant on extractive sampling	- Scientific sampling - Sensitive to sampling techniques	- Data on scientific samples exist	- Genetic diversity is an important component in order to determine the health and success of a population

Table D.2. Habitat SEC Indicators scored against criteria

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
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 extent and distribution of habitats is necessary to establish a baseline. The abundance of benthic microbial communities is strongly associated with this habitat, as are some low flow	Commonly used metric	- Quantifiable - Repeatable - Several different measureable components - Frequency of occurrence measurements are simple	This is not a very sensitive indicator and is more at the mercy of natural perturbations than anthropogenic stressors	Data exist for chimney distribution	- Related to hydrothermal flow conditions - Measurements repeatable, quantifiable - Data can be collected using visual surveys

Indicator	Measureable component	Criteria				Notes
		Theoretically sound	Measurable/ feasible	Sensitive	Historical data	
	communities. These may be used as an indicator for locating and mapping this habitat.					
Habitat condition						
Physical damage	- % of chimneys modified - % of the individual chimney modified - Artificial changes in hydrothermal flow	Commonly used for other habitat types	- Quantifiable as a percentage of surveyed chimneys - Repeatable	Highly sensitive to sampling effort (visual surveys)	Data exist for occurrences of anthropogenic stressors causing damage (e.g. ROV video showing submersible collisions, sampling, installation, etc.)	Sensitive to sampling effort as well as the selectivity of the sampling device

APPENDIX E: STRESSOR INDICATOR CRITERIA SUMMARY

Table E.1. Stressor Indicators scored against criteria

Discharge

Stressor	Indicator	Measureable component	Criteria: Theoretically sound	Criteria: Measurable/ feasible	Criteria: Historical data*	Notes
Debris	Relative abundance of debris	- Frequency of occurrence (over distance surveyed) - Mass of recovered debris (from clean up programs)	Established indicator with known limitations	- Quantifiable - Repeatable - Measurement obtained by visual surveys or debris clean-up programs	There have been previous debris clean up events at the EHV MPA. Instances of debris were recently identified from Oceans Network Canada video logs to be fed into a GIS database.	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)
	Debris characterization	- Debris type and size	Established as part of ocean-based surveys, with known limitations	- Quantifiable - Repeatable - Measurement obtained by visual surveys or debris clean-up programs	There have been previous debris clean up events at the EHV MPA. Instances of debris were recently identified from Oceans Network Canada video logs to be fed into a GIS database.	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)

Equipment abandonment

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

Equipment installation

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Substrate disturbance (crushing)	- Crushed area - Proportion (%) of the area crushed	- m^2 - Equipment footprint	Established method	- Quantifiable in real-world units - Specific to both SEC and stressor - Several different methods to measure	No habitat mapping or sediment characteristics known.	- May be difficult to measure at time of disturbance - Visual surveys may not give the most accurate measurement, but are realistically the best option for

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				proportion crushed		measuring impacts
	Frequency of potential impact	Number of installation events	Commonly used metric	- Quantifiable - Simple to obtain data and calculate	Data exist for previous samples, as well as video from submersibles	
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.	Video data exist over many years/cruises	- May be difficult to measure at time of disturbance - Visual surveys may not give the most accurate measurement, but is realistically the best option for measuring impacts

Oil spill

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Oil	Vessel density in vicinity of the EHV MPA	Number of vessel movements per traffic reporting zone or per designated grid cell	Established indicator (Andrews et al. 2013)	Correlated with shipping activity. (Andrews et al. 2013) suggested that this indicator could be improved if the size of the vessel and transit mileage was added to quantify	- No records of oil spills at the EHV MPA - Vessel movement data available	Ocean-based pollution, including oil spills, was assumed to be primarily driven by vessel activities and port volume. This indicator evaluated well in most criteria and is a combination of indicators for commercial shipping

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				the vessel's footprint and pathway. Otherwise, the number of trips doesn't tell us anything about the extent of areas affected by these trips.		activity and invasive species *(Andrews* et al. 2013).
	Oil spill volume	Surface area *x* minimum thickness	Currently used indicator in BC waters (DFO)	Measurement can be obtained by remote sensing/imagery	Data exist on remote sensing of discharged oils in BC. These data would be available during a spill (DFO)	Oil volume determines the spatial overlap with SECs
	Oil type	Determines surface, water column, or benthic coverage. e.g. bitumen – surface coverage of benthic habitats, petroleum – surface spill only	Oil type is an effective indicator of the species/ habitats impacted	Composition of transported material will provide an accurate indication of those components of the ecosystem impacted	Data should be available from vessel spilling oil	Oil type determines the components of the ecosystem impacted. The addition of dispersants may confound oil type as an indicator of potentially impacted components

Sampling

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Removal of organisms	Biomass	- Weight/unit area of sampled (removed) organisms - Proportion (%) of biogenic habitat removed	Commonly used indicator	- Quantifiable - Repeatable - Comparable within and among gear types - Changes in biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance	Data exists for previous samples	Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling Subject to sampling gear selectivity (DFO 2010A)
	Maximum potential exposure	Number of research trips involving sampling per annum x maximum allowable samples	Commonly used metric	- Quantifiable - Simple to obtain data and calculate	Data exist for previous samples, as well as video from submersibles	
	Areal coverage of removed organisms (sessile benthic	% cover of removed organisms	Commonly used metric	- Quantifiable - Simple to obtain data and calculate - Visual surveys	Data exist for previous samples, as well as video from submersibles	

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	SECs)					
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.	Video data is available for all Oceans Network Canada dives. Other international institutions working at the EHV MPA also keep records of their video logs (MBARI, WHOII)	
	Maximum increase in turbidity	e.g. Nephelometric Turbidity Units, NTUs or % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension. Difficult to measure magnitude of disturbance without characteristic of sediment known and habitat classifications	No habitat mapping or sediment characteristics known.	Requires baselines of sediment and habitat types
Substrate disturbance (crushing)	- Crushed area - Proportion	- m^2 - Size (area) of the sampling	Established method	Quantifiable in real-world units - Specific to both	Video data is available for all Oceans Network	- May be difficult to measure at time of disturbance

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
	(%) of the area crushed	scar		SEC and stressor - Several different methods to measure proportion crushed	Canada dives. Other international institutions working at the EHV MPA also keep records of their video logs (MBARI, WHOII)	- Visual surveys may not give the most accurate measurement, but are realistically the best option for measuring impacts
	Frequency of potential impact	Number of sampling events	Commonly used metric when other information is not available	- Quantifiable - Simple to obtain data and calculate	Data exist for previous samples, as well as video from submersibles	

Seismic surveys

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

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		encouraged as part of seismic operations				can then focus on measuring disturbances

Submersible operations

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
Aquatic invasive species	Frequency of potential exposure	- Number of dives sites per cruise - Existence of cleaning/ equipment flushing protocols between dive sites	Commonly used metric when other information is not available	- Quantifiable - Simple to obtain data and calculate	Data exist for previous samples, as well as video from submersibles	
	Species richness of aquatic invasive species	Diversity measures (e.g. Shannon Simpson diversity index, taxonomic redundancy, taxonomic distinctness)	Commonly used metric	- Quantifiable - Repeatable - Can't be calculated without biomass estimates, and it is limited by taxonomic resolution	No existing data on AIS at the EHV	- Metrics used are well established - Repeatable, quantifiable
	Occurrence/ abundance of aquatic invasive species	- Number per m^2 - Total count of non-native species with established	Commonly used metric	- Quantifiable - Repeatable - Several different measureable components - Areal coverage	No existing data on AIS at the EHV	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
		breeding populations (and potential change in distribution) - Areal coverage/patch area		suitable for colonial, gregarious, large species - Number/counts suitable to conspicuous and distinguishable taxa - Frequency of occurrence measurements are simple, provided the taxon can be distinguished - Species density estimates use numerical abundances of individuals per unit area		viability and integrity of native species and natural biodiversity (Conservation Gateway). This database is polled by region, serves as a baseline for invasion, but has been updated since its creation (Andrews 2013). This approach may be applied to the EHV.
	Biomass of aquatic invasive species	Weight/unit area	Commonly used indicator	- Quantifiable - Measurement can be achieved using extractive scientific sampling - Repeatable - Comparable within and among gear types - Changes in	No existing data on AIS at the EHV	- Cannot be achieved using visual surveys, and needs to rely on existing data and extractive scientific sampling - Subject to sampling gear selectivity (DFO 2010A)

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
				biomass over time may lead to misinterpretation (Andrews et al. 2013) and should be used in conjunction with other population size indicators, such as abundance		
Substrate disturbance (sediment re-suspension)	Maximum induced increase in suspended sediments	e.g. mg/L, ppm, % of background	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.	Little to no data exist	- May be difficult to measure at time of disturbance - Visual surveys may not give the most accurate measurement, but are realistically the best option for measuring impacts
	Frequency of exposure to potential collisions	Number of collision events	Commonly used metric	May be difficult to measure at time of disturbance. Visual surveys (% of background) are the most realistic method for measuring sediment re-suspension.	No habitat mapping or sediment characteristics known. Video data will help inform this	- May be difficult to measure at time of disturbance - Visual surveys may not give the most accurate measurement, but are realistically the best option for measuring impacts
Substrate	Crushed area	- Proportion	Established	- Quantifiable in	No habitat	- May be difficult to

Stressor	Indicator	Measureable component	Criteria			Notes
			Theoretically sound	Measurable/ feasible	Historical data*	
disturbance (crushing)		(%) of the area crushed - m^2	method	real-world units - Specific to both SEC and stressor - Several different methods to measure proportion crushed	mapping or sediment characteristics known.	measure at time of disturbance - Visual surveys may not give the most accurate measurement, but are realistically the best option for measuring impacts
	Frequency of potential impact	Number of collision events	Theoretically sound	Quantifiable	Submersible video may be reviewed	

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

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

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Ridgeia piscesae (high flux)	Sampling	Removal of organisms	58.56	High	46.80	68.87	57.83	High
Ridgeia piscesae (high flux)	Sampling	Substrate disturbance (crushing)	57.82	High	43.70	70.22	56.96	High
Paralvinella sulfincola	Sampling	Substrate disturbance (crushing)	53.74	High	35.52	72.59	54.06	High
Paralvinella sulfincola	Sampling	Removal of organisms	41.03	Moderate	27.68	57.81	42.75	High
Inactive mineral chimneys	Sampling	Substrate disturbance (crushing)	40.21	Moderate	17.44	69.38	43.41	High
Ridgeia piscesae (high flux)	Submersible operations	Substrate disturbance (crushing)	39.74	Moderate	30.73	52.89	41.81	High
Inactive mineral chimneys	Submersible operations	Substrate disturbance (crushing)	34.76	Moderate	17.52	54.91	36.21	Moderate
Clam bed benthic community	Sampling	Substrate disturbance (crushing)	28.89	Moderate	13.97	49.89	31.93	Moderate
Clam bed benthic community	Sampling	Substrate disturbance (sediment re-suspension)	28.64	Moderate	14.51	44.66	29.58	Moderate

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Clam bed benthic community	Sampling	Removal of organisms	28.37	Moderate	16.46	44.94	30.70	Moderate
Ridgeia piscesae (low flux)	Sampling	Substrate disturbance (crushing)	28.20	Moderate	15.33	40.93	28.13	Moderate
Ridgeia piscesae (low flux)	Equipment abandonment	Increased contamination	27.96	Moderate	10.23	48.33	29.28	Moderate
Paralvinella sulfincola	Submersible operations	Substrate disturbance (crushing)	27.88	Moderate	15.98	38.80	27.39	Moderate
Ridgeia piscesae (low flux)	Sampling	Removal of organisms	26.90	Moderate	15.89	42.87	29.38	Moderate
Active venting mineral chimneys	Sampling	Substrate disturbance (crushing)	25.62	Moderate	10.26	44.94	27.60	Moderate
Clam bed benthic community	Equipment abandonment	Increased contamination	24.51	Moderate	13.23	48.40	30.82	Moderate
Active venting mineral chimneys	Submersible operations	Substrate disturbance (crushing)	23.95	Low	8.24	41.47	24.86	Moderate
Lepetodrilus fucensis	Sampling	Substrate disturbance (crushing)	23.79	Low	12.46	35.48	23.97	Low
Lepetodrilus fucensis	Sampling	Removal of organisms	23.09	Low	13.86	35.04	24.45	Moderate
Clam bed benthic community	Submersible operations	Substrate disturbance (crushing)	21.96	Low	8.96	34.57	21.77	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Ridgeia piscesae (low flux)	Sampling	Substrate disturbance (sediment re-suspension)	21.95	Low	9.91	36.10	23.01	Low
Ridgeia piscesae (low flux)	Submersible operations	Substrate disturbance (crushing)	21.17	Low	9.61	32.10	20.86	Low
Diffuse venting flows	Submersible operations	Substrate disturbance (crushing)	20.83	Low	6.78	41.80	24.29	Moderate
Paralvinella sulfincola	Equipment abandonment	Increased contamination	20.50	Low	9.03	37.25	23.14	Low
Ridgeia piscesae (low flux)	Submersible operations	Substrate disturbance (sediment re-suspension)	20.30	Low	10.24	36.05	23.14	Low
Lepetodrilus fucensis	Equipment abandonment	Increased contamination	20.10	Low	7.83	39.33	23.58	Low
Clam bed benthic community	Seismic surveys/air guns	Sound generation	19.46	Low	6.20	35.10	20.65	Low
Lepetodrilus fucensis	Sampling	Substrate disturbance (sediment re-suspension)	19.40	Low	5.38	32.01	18.70	Low
Paralvinella palmiformis	Sampling	Substrate disturbance (crushing)	19.39	Low	10.19	28.97	19.58	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Paralvinella sulfincola	Sampling	Substrate disturbance (sediment re-suspension)	19.32	Low	8.00	35.08	21.54	Low
Paralvinella sulfincola	Equipment installation	Substrate disturbance (crushing)	19.19	Low	12.84	28.09	20.47	Low
Diffuse venting flows	Sampling	Substrate disturbance (crushing)	19.01	Low	5.32	38.98	22.15	Low
Ridgeia piscesae (low flux)	Equipment installation	Substrate disturbance (crushing)	17.74	Low	6.69	29.47	18.08	Low
Lepetodrilus fucensis	Submersible operations	Substrate disturbance (crushing)	17.58	Low	7.66	27.00	17.33	Low
Ridgeia piscesae (high flux)	Equipment abandonment	Increased contamination	17.38	Low	5.53	33.44	19.49	Low
Lepetodrilus fucensis	Submersible operations	Substrate disturbance (sediment re-suspension)	17.23	Low	8.33	32.80	20.56	Low
Macroregonia macrochira	Sampling	Substrate disturbance (crushing)	17.21	Low	10.72	23.68	17.20	Low
Clam bed benthic community	Submersible operations	Substrate disturbance (sediment re-suspension)	17.18	Low	6.98	32.81	19.89	Low
Ridgeia piscesae (high flux)	Equipment installation	Substrate disturbance (crushing)	17.16	Low	11.13	24.88	18.00	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Paralvinella palmiformis	Equipment abandonment	Increased contamination	17.12	Low	5.40	35.74	20.57	Low
Paralvinella sulfincola	Submersible operations	Substrate disturbance (sediment re-suspension)	16.90	Low	8.51	27.52	18.01	Low
Ridgeia piscesae (high flux)	Sampling	Substrate disturbance (sediment re-suspension)	16.90	Low	7.86	27.47	17.66	Low
Inactive mineral chimneys	Equipment installation	Substrate disturbance (crushing)	16.88	Low	8.76	30.90	19.83	Low
Ridgeia piscesae (low flux)	Seismic surveys/air guns	Sound generation	16.86	Low	2.16	35.97	19.07	Low
Clam bed benthic community	Equipment installation	Substrate disturbance (sediment re-suspension)	16.36	Low	6.03	26.52	16.28	Low
Lepetodrilus fucensis	Seismic surveys/air guns	Sound generation	15.74	Low	5.85	26.98	16.41	Low
Paralvinella palmiformis	Submersible operations	Substrate disturbance (crushing)	15.30	Low	7.59	25.64	16.62	Low
Lepetodrilus fucensis	Equipment installation	Substrate disturbance (crushing)	14.98	Low	7.22	22.93	15.08	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Ridgeia piscesae (high flux)	Submersible operations	Substrate disturbance (sediment re-suspension)	14.93	Low	6.12	24.48	15.30	Low
Paralvinella palmiformis	Submersible operations	Substrate disturbance (sediment re-suspension)	14.72	Low	6.16	23.12	14.64	Low
Paralvinella palmiformis	Sampling	Substrate disturbance (sediment re-suspension)	14.51	Low	5.77	25.58	15.68	Low
Active venting mineral chimneys	Equipment installation	Substrate disturbance (crushing)	14.47	Low	5.95	24.89	15.42	Low
Clam bed benthic community	Equipment installation	Substrate disturbance (crushing)	14.40	Low	4.79	25.68	15.24	Low
Paralvinella sulfincola	Seismic surveys/air guns	Sound generation	13.50	Low	4.62	28.69	16.65	Low
Macroregonia macrochira	Equipment abandonment	Increased contamination	12.51	Low	1.12	22.42	11.77	Low
Macroregonia macrochira	Submersible operations	Substrate disturbance (crushing)	12.45	Low	4.91	22.00	13.45	Low
Paralvinella palmiformis	Seismic surveys/air guns	Sound generation	12.44	Low	3.23	21.09	12.16	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Macroregonia macrochira	Seismic surveys/air guns	Sound generation	12.15	Low	2.03	24.44	13.24	Low
Ridgeia piscesae (high flux)	Seismic surveys/air guns	Sound generation	11.98	Low	3.02	23.91	13.46	Low
Paralvinella palmiformis	Equipment installation	Substrate disturbance (crushing)	11.90	Low	5.26	20.03	12.65	Low
Paralvinella palmiformis	Sampling	Removal of organisms	10.69	Low	5.75	19.03	12.39	Low
Diffuse venting flows	Equipment installation	Substrate disturbance (crushing)	10.65	Low	1.97	21.01	11.49	Low
Ridgeia piscesae (low flux)	Equipment installation	Substrate disturbance (sediment re-suspension)	10.08	Low	1.51	18.34	9.93	Low
Macroregonia macrochira	Equipment installation	Substrate disturbance (crushing)	9.97	Low	4.56	18.82	11.69	Low
Macroregonia macrochira	Sampling	Removal of organisms	9.91	Low	5.65	16.36	11.01	Low
Lepetodrilus fucensis	Equipment installation	Substrate disturbance (sediment re-suspension)	8.12	Low	1.38	15.86	8.62	Low

Current snap-shot interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
Paralvinella palmiformis	Equipment installation	Substrate disturbance (sediment re-suspension)	7.58	Low	0.62	13.55	7.08	Low
Paralvinella sulfincola	Equipment installation	Substrate disturbance (sediment re-suspension)	7.22	Low	1.32	14.76	8.04	Low
Ridgeia piscesae (high flux)	Equipment installation	Substrate disturbance (sediment re-suspension)	7.16	Low	1.26	13.20	7.23	Low
		Max	*58.56*				*57.83*	
		Min	*7.16*				*7.08*	
		Mean	*20.52*				*21.76*	
		Median	*17.38*				*19.58*	
		Range	*51.40*				*50.75*	
		Range/3	*17.13*				*16.92*	
		Low	*24.30*				*24.00*	
		Medium	*41.43*				*40.92*	
		High	*58.56*				*57.83*	

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

***Potential* interactions**			**Risk Score**	**Risk Grouping**	**10% Q**	**90% Q**	**Mean Q (Uncertainty)**	**Uncertainty Grouping**
Inactive mineral chimneys	Discharge	Debris	46.25	High	21.97	79.94	50.95	High
Ridgeia piscesae (low flux)	Submersible operations	Aquatic invasive species	40.15	High	29.34	57.93	43.63	High
Ridgeia piscesae (low flux)	Discharge	Debris	39.20	High	23.23	66.68	44.95	High
Ridgeia piscesae (low flux)	Oil spill	Oil	36.69	Moderate	22.05	59.67	40.86	High
Lepetodrilus fucensis	Discharge	Debris	35.97	Moderate	14.32	60.33	37.33	High
Lepetodrilus fucensis	Submersible operations	Aquatic invasive species	34.63	Moderate	24.88	46.93	35.90	High
Active venting mineral chimneys	Discharge	Debris	34.06	Moderate	13.25	71.78	42.51	High
Lepetodrilus fucensis	Oil spill	Oil	33.44	Moderate	18.17	51.86	35.02	Moderate
Clam bed benthic community	Discharge	Debris	33.26	Moderate	14.77	61.87	38.32	Moderate
Clam bed benthic community	Submersible operations	Aquatic invasive species	33.01	Moderate	23.97	50.17	37.07	Moderate
Paralvinella sulfincola	Discharge	Debris	32.92	Moderate	15.94	52.00	33.97	Moderate
Clam bed benthic	Oil spill	Oil	32.68	Moderate	19.84	50.16	35.00	Moderate

Potential interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
community								
Macroregonia macrochira	Submersible operations	Aquatic invasive species	30.64	Low	22.49	42.46	32.48	Moderate
Paralvinella sulfincola	Submersible operations	Aquatic invasive species	30.41	Low	22.12	42.41	32.27	Moderate
Macroregonia macrochira	Discharge	Debris	30.03	Low	19.19	48.53	33.86	Moderate
Ridgeia piscesae (high flux)	Discharge	Debris	29.77	Low	16.48	46.45	31.47	Low
Macroregonia macrochira	Oil spill	Oil	28.66	Low	14.00	46.92	30.46	Low
Paralvinella sulfincola	Oil spill	Oil	28.31	Low	14.96	41.33	28.14	Low
Ridgeia piscesae (high flux)	Submersible operations	Aquatic invasive species	27.80	Low	20.69	40.50	30.60	Low
Paralvinella palmiformis	Submersible operations	Aquatic invasive species	27.49	Low	20.29	37.81	29.05	Low
Paralvinella palmiformis	Discharge	Debris	26.66	Low	11.04	47.31	29.17	Low
Ridgeia piscesae (high flux)	Oil spill	Oil	26.06	Low	16.22	41.25	28.73	Low
Diffuse venting flows	Discharge	Debris	24.58	Low	3.17	53.07	28.12	Low
Paralvinella palmiformis	Oil spill	Oil	23.67	Low	12.79	37.56	25.17	Low

Potential interactions			Risk Score	Risk Grouping	10% Q	90% Q	Mean Q (Uncertainty)	Uncertainty Grouping
		Max	*46.25*			*Max*	*50.95*	
		Min	*23.67*			*Min*	*25.17*	
		Mean	*31.93*			*Mean*	*34.79*	
		Median	*31.66*			*Median*	*33.92*	
		Range	*22.58*			*Range*	*25.78*	
		Range/3	*7.53*			*Range/3*	*8.59*	
		Low	*31.20*			*Low*	*33.77*	
		Medium	*38.72*			*Medium*	*42.36*	
		High	*46.25*			*High*	*50.95*	

APPENDIX G: SEC-STRESSOR INTERACTION INDICATORS AND MEASURABLE COMPONENTS

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

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
Species	Sessile/low mobility invertebrates	*Ridgeia piscesae* (high flux) *Paralvinella sulfincola* *Ridgeia piscesae* (low flux)	Sampling	Removal of organisms	Population 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.
						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)
					Population condition	Biomass of removed organisms	- Weight/unit area of sampled (removed) organism - Proportion (%) of	- Data is available on collected samples - Should be used

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							biogenic habitat removed	in conjunction with the size of the sampling scar and abundance - Population baselines should be established prior to sampling
				Substrate disturbance (crushing)	Population size	Abundance/ population density of sampled assemblage	Size (area) of the sampling scar	A combination of visual surveys/video data and sample size will inform this indicator
						Community species richness and diversity	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness) applied to the assemblages of species	Visual surveys and sampling events
					Population condition	Organism health	% of the population showing visible signs of stress/disease (NB should be	- Visual surveys and sampling events - Requires some baseline information

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							used in combination with other indicators and monitoring. Succession of assemblages in changing hydrothermal flows may confound the results of this indicator)	
		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 contamination	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	Visual surveys Aided by sampling. Sampling would likely be opportunistic

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							hydrothermal flows may confound the results of this indicator)	
					Population condition	Change in genetic diversity	Genetic delineation (allele frequency, polymorphism, etc.)	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
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	A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							confound the results of this indicator)	
					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 the 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.

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
								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)
					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

SEC				Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
									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	- Visual surveys and sampling events - Requires some baseline information

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							hydrothermal flows may confound the results of this indicator)	
			Equipment abandonment	Increased contamination	Community size	Abundance/ extent of community	Areal extent (% cover), m^2	Visual surveys (submersible video), GIS mapping
					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 (allele frequency, polymorphism, etc)	Requires baselines of populations and extractive sampling

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

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

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
								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 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 (allele frequency, polymorphism, etc)	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

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
								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.

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
								The monitoring of stressor-specific indicators 'debris characterization and relative abundance' will help 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 and 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	Ocean-based surveys have not used consistent methods and have been performed

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							(extent)	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 resulting from crushing by debris		
			Submersible operations	Aquatic invasive species	Community size	Abundance/ density of AIS	% change of areal extent of benthic clam bed community	Requires a combination of visual surveys and sampling. Species are still being discovered at the 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.

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
					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	- Requires baselines of populations - Needs to be combined with independent SEC

SEC			Activity	Stressor	Key parameter	Indicator	Measureable component	Data collection
							redundancy, taxonomic distinctness)	and stressor indicators to link oil with SEC - Visual surveys
						Change in genetic diversity	Genetic delineation (allele frequency, polymorphism, etc)	- Requires baselines of populations and extractive sampling

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

Table H.1. SEC-stressor interaction indicators for sessile/low mobility invertebrate SECs: Ridgeia piscesae (high flux), Ridgeia piscesae (low flux), Paralvinella sulfincola. Interaction justifications summarised from Thornborough et al.[1].

Sampling → Removal of organisms

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Areal coverage (%, m^2)	- Tunnicliffe (1990) studied the effects of sampling on the hydrothermal vent habitat and associated fauna, including *R. piscesae*. This study found that unsampled vents appeared unchanged in terms of animal abundance, but vents that had been sampled were depleted/gone. - Observed recovery by some fauna, and specifically *R. piscesae* was negligible, however, *P. sulfincola* was noted to be one of the first to recruit the disturbed area. Sampling of these organisms may also encourage increased predation by	- Studies have been conducted on the effects of sampling on tubeworm communities (Tunnicliffe 1990). - Video data is available of all sampling activities - Records exist of samples taken - Previously used metric to examine vent community abundance and distribution	- Review video data, cruise logs, sample records - A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
	Size of the sampling scar	Areal extent of sample scar			

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	Biomass of sampled (removed) organisms	Weight/unit area	*Macroregonia macrochira* (Tunnicliffe and Jensen 1987).		- Data from sample records
				- Studies have been conducted on the effects of sampling on tubeworm communities (Tunnicliffe 1990). - Video data is available of all sampling activities - Records exist of samples taken	

Sampling → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance/ population density of sampled assemblage	Size (area) of the sampling scar	- Directly crushing the habitat and organisms - geological sampling may destroy the *R. piscesae* high flux habitat - It is possible that extensive sampling of the habitat (active venting chimneys) would produce a particulate plume	- Studies have been conducted on the effects of sampling on tubeworm communities (Tunnicliffe 1990). - Video data is available of all sampling activities - Records exist of samples taken	- Review video data, cruise logs, sample records - A combination of visual surveys/video data and sample size will inform this

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
	Community species richness and diversity	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness) applied to the assemblages of species	(Dando and Juniper 2001). This plume may smother organisms, or replace once colonized hard substrata with soft particles, and removal of sections of the sulphide deposits may change or even stop the hydrothermal fluid flow, impacting the populations reliant of this flow (Dando and Juniper 2001).		indicator. Population baselines will greatly increase the accuracy of this measurement.
Population condition	Organism health	% 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)	- Any impact will be localised, and the primary impact from crushing will be mortality (Tunnicliffe 1990).	- Video data is available of all sampling activities - Records exist of samples taken	- Visual surveys and sampling events - Requires some baseline information

Submersible operations → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Crushed area	- Proportion (%) of the area crushed - m^2	- Impacts may include destruction of habitat (chimneys), increased sedimentation associated with thruster use (addressed in substrate re-suspension),	- Video data is available of all sampling activities. Submersible collision events are easily determined from video data - Records exist of samples taken	Video data of sampling event

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			associated changes in hydrothermal fluid flow, and direct crushing of organisms. - While *R. piscesae* is known to not recover from direct crushing/sampling (Tunnicliffe,1990), the strong localization of the impact and any crushing of this species would occur during an accidental collision with the submersible		
Population condition	Abundance of organisms displaying symptoms of crushing	- Proportion (%) of the assemblage - m^2	- Any impact will be localised, and the primary impact from crushing will be mortality (Tunnicliffe1990). - This indicator may not be particularly informative, and measurements on crushing from submersible operations should be linked back to the crushed area.	- Video data is available of all sampling activities - Records exist of samples taken	- Visual surveys of sampled organisms, post sampling - Measurement may be taken at time of collision or later from processing video

Submersible operations → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance of organisms with visible damage/ dead	Area (proportion) showing evidence of disease die-off or smothering by organisms	- Very few cases of introduced aquatic invasive species as the result of submersible operations have been documented. However, a study by Voight et al. 2012 found through gene sequencing that 38 *Lepetodrilus gordensis* were able to survive pressure changes and transport from one site to another 635 km away. This indicates that submersibles (both manned and remotely operated) are capable of introducing aquatic invasive species between venting sites. Bates et al. (2005) found that at least three genera of hydrothermal vent gastropods (including SEC *Lepetodrilus fucensis*) tolerate transport to the surface, being maintained in an aquarium at the surface, and then have high survival rates when they are returned to depth. A	- The potential impact of invasive species at the EHV MPA is currently unknown. - Some peer-reviewed information available on the transmission of aquatic invasive species by submersibles, but no information directly related to the EHV MPA. - No information available on the genetic or fitness consequences	Visual surveys, genetic testing, extractive sampling methods.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			later study by Bates et al. (2010) found 14 species across three phyla capable of this. Similarly, Van Dover et al. 2007 suggested that submersibles may be capable of transmitting pathogens, specifically fungal infections found in bathymodiolin mussel populations in the Fiji Basin (Van Dover et al. 2007).		
Population condition	Change in condition/ sub-lethal effects	Area (proportion) showing evidence of stress/increased predation/change in reproductive success	- Specific effects of AIS on these organisms unknown. There have been no documented cases of AIS establishment at hydrothermal vents, just the potential. - Impacted organisms are expected to show signs of stress or disease, and changes in reproductive success		- 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

Equipment abandonment → Increased contamination

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance (areal extent) of 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)	- The majority of equipment installed on the seafloor at the EHV MPA is rust-resistant (NEPTUNE Canada), and many of the instruments are oil-filled, such as the cables and sensors. It is possible for these oil-filled instruments/cables to leak, discharging into the environment. The impact of this oil on the benthic communities is unknown, however, in this case is assumed to have a similar effect, yet less dramatic impact, as an oil spill	The impact of contamination associated with equipment abandonment on the benthic communities at the EHV MPA is unknown.	Visual surveys Aided by sampling. Sampling would likely be opportunistic
Population condition	Change in genetic diversity	Genetic delineation (allele frequency, polymorphism, etc)	- The potential volume of this discharged material is low and would be highly localized, and would not be expected to impact >10% of the communities	- There have been an increasing amount of population genetics studies conducted on populations at the EHV MPA in recent years (and published).	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys
	Species richness/ presence of disease/ stress	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	- May impact one species within assemblage, and not others, having an indirect impact on SEC.	- Some data available from literature	

Oil spill → Oil

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Areal coverage of habitats	- Oil has been known to alter the metabolic rate, feeding rate, and shell formation of some benthic organisms (Elmgren et al. 1983; Gómez Gesteira and Dauvin 2000; US Fish & Wildlife Service 2004). Contact of oil hydrocarbons with respiratory organs (e.g. filtration organs, gills) and/or ingested can damage related tissues, leading to increased mortality (Patin 1999). Certain types of oil hydrocarbons are capable of inducing mutagenic (genetic damage) and carcinogenic effects in marine organisms, leading to increased mortality (Patin 1999). Research by Thornhill (2011) focusing on the impact of the 2010 Gulf of Mexico BP oil spill on benthic, deepwater siboglinid worms (tubeworms) found that although siboglinids live off of the by-products of fossil fuels, they do not directly interact with oil under normal conditions. As a result, Thornhill (2011) found dead, dying, or injured animals covered as the result of an oil plume and its dispersants. However, due to the remote nature of this site, the use of	- No known instances of oil spill in vicinity of the EHV MPA. Requires baselines to measure against.	- The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended - Visual surveys - Needs to be combined with independent SEC and stressor indicators to link oil with SEC

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			dispersants is unlikely, and the source will be from the surface (not the seafloor as in the above mentioned 2010 spill). The likelihood of oil impacting the organisms 2300 m from the surface is low, however, ERAF scoring reflects a precautionary approach.		
Population condition	Abundance of organisms displaying symptoms of stress	% cover of stressed area as a proportion of overall abundance (extent). Extractive sampling and analysis.	- Studies have shown a link between reduced fitness and death (Patin 1999; Thornhill 2011) and siboglinid worms (Thornhill 2011), including mutagenic (genetic damage) effects (Patin 1999). However, these impacts were not examined for surface spill, and it is unlikely that there will be any lasting impacts on >10% of the population (S. Kim Juniper, University of Victoria *pers. comm*., 21 Nov. 2013).		- 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)	- May impact one species within assemblage, and not others, having an indirect impact on SEC.	- Some data available from literature	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
	Change in genetic diversity	Genetic delineation (allele frequency, polymorphism, etc)	- Studies have shown a link between reduced fitness and death (Patin 1999; Thornhill 2011) and siboglinid worms (Thornhill 2011), including mutagenic (genetic damage) effects (Patin 1999). However, these impacts were not examined for surface spill, and it is unlikely that there will be any lasting impacts on >10% of the population (S. Kim Juniper, University of Victoria, *pers. comm.*, 21 Nov. 2013).	- There have been an increasing amount of population genetics studies conducted on populations at the EHV MPA in recent years (and published).	- Requires baselines of populations and extractive sampling

Discharge → Debris

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Size of crushed area/size of debris	% of crushed area as a proportion of overall abundance (extent)	- Debris may directly crush *R. piscesae* as it sinks to the seafloor. - recovery of organisms directly crushed is unlikely. - the strong localization of the impact and high abundance of this species - There have been no documented cases of debris impacts on *L. fucensis*, however, recovery of organisms directly crushed is unlikely. Uncertainty	There have been no documented cases of debris impacts on *R. piscesae*, however, the impact from debris is similar to that of crushing during submersible operations, whereby impacted organisms are known to not recover (Tunnicliffe 1990).	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)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			scored as moderate, with no information directly linking impacts from debris on this species.		
Population condition	No known indicators to directly measure change in population condition resulting from crushing by debris.		- There are currently no known impacts on the long-tem fitness (condition or genetic diversity) of *L. fucensis* with the direct crushing of the organisms or their habitat.	- There are currently no known impacts on the long-tem fitness (condition or genetic diversity) of *R. piscesae* with the direct crushing of the organisms or their habitat.	

Table H.2. SEC-stressor interaction indicators for chimney habitat SECs: Active venting hydrothermal mineral chimneys and inactive hydrothermal mineral chimneys. Interaction justifications summarised from Thornborough et al.[1].

Submersible operations → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population 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)	The loss of the dormant chimney habitat as the result of submersible operations will be <10%, due to the strong localization of the impact. Submersible pilots aim to avoids damaging chimneys, and while accidental collisions may occur (Tunnicliffe 1990), it is highly unlikely that >10% of dormant chimneys within the EHV MPA would be damaged/destroyed. Substrate may be disturbed and/or crushed through direct geological or biological samples, or by accidental disturbance by associated sampling equipment, such as submersibles, etc. Uncertainty scored as high.	Submersible videos may be reviewed to collect information on collision events and attempt measurements of size of impact. This may be an indicator that can only be measured at the time, suggesting it be included in the dive logging protocols recommended to the EHV MPA users.	A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
Population condition	Collisions producing visible particular plume	Number of collisions producing particulate plume	There is potential for a change in structural integrity/condition or a loss of productive capacity as the result of localized substrate disturbances resulting from debris to those structures directly impacted, however it is unlikely that >10% of this SEC will be impacted in this way. Uncertainty scored as high.		From submersible dive videos (involves post-processing, or dive log tagging protocol)

Sampling → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Size of sampled area/ size of sample scar	Areal extent of crushed area as a proportion of overall abundance (extent)	- The loss of the active venting chimney habitat as the result of debris will be <30%, due to the strong localization of the impact. Equipment installation for scientific research aims to avoids damaging chimneys, and while accidental collisions may occur (Tunnicliffe 1990), it is highly unlikely that >10% of active chimneys within the EHV MPA would be damaged/destroyed. Substrate may be disturbed and/or crushed through direct geological or biological samples, or by accidental disturbance by associated sampling equipment, such as submersibles, etc (Dando and Juniper 2001). Uncertainty scored as moderate - The loss of the dormant chimney habitat as the result of debris will be <10%, due to the strong localization of the impact. Equipment installation for scientific research aims to avoids damaging chimneys, and while accidental collisions may occur (Tunnicliffe 1990), it is highly unlikely that >10% of dormant chimneys within the EHV MPA would be damaged/destroyed. Substrate may be disturbed and/or crushed through direct geological or biological samples,	Information available on sampling events. Data from institutions sampling data, e.g. MBARI and ONC, as well as reports submitted to DFO.	A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			or by accidental disturbance by associated sampling equipment, such as submersibles, etc. Uncertainty scored as high.		
Population condition	Sample type – NB this determines extent chimney is impacted	Physical sample types at the EHV: geological, biological, water/fluids	- Disturbances to the flow volume of active venting chimneys as the result of substrate disturbance/crushing, while unlikely, have the potential to change the flow and/or the structural integrity of the habitat. However, it is unlikely to impact >10% of the SEC. Uncertainty scored as high. - There is potential for a change in structural integrity/condition or a loss of productive capacity as the result of localized substrate disturbances resulting from debris to those structures directly impacted, however it is unlikely that >10% of this SEC will be impacted in this way. Uncertainty scored as high.		- Visual surveys - Aided by sampling. Sampling would likely be opportunistic

Discharge → Debris

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Size of crushed area/size of debris	Areal extent of crushed area as a proportion of overall abundance (extent)	- The loss of the active venting chimney habitat as the result of debris will be <10%, due to the strong localization of the impact. Marine debris has the potential to impact the active venting chimneys through direct crushing of the features, either damaging or toppling these features. However, due to the low density of debris from vessel traffic over the EHV MPA, it is unlikely that >10% of the dormant chimney habitats will be destroyed. Uncertainty scored as moderate - The loss of the inactive mineral chimney habitat as the result of debris will be <10%, due to the strong localization of the impact. Marine debris has the potential to impact the dormant vent chimney features through direct crushing of the features (increased sedimentation will not impact these features). Depending on the size and weight of the debris, it may be possible for the debris to topple dormant chimneys. However, due to the low density of debris from vessel traffic over the EHV MPA, it is unlikely that >10% of the dormant chimney habitats will be destroyed. Uncertainty scored as moderate.	Data has recently compiled by Ocean Networks Canada on the distribution of debris at the EHV MPA (processing of video logs). It covers the distribution and debris type. This data has been compiled for an interactive GIS map delivered to DFO Oceans March 2015.	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 inform the exposure of chimneys to debris

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	No known indicators to directly measure change in population condition resulting from crushing		- There is potential for a change in structural integrity/condition or a loss of productive capacity as the result of localized substrate disturbances resulting from debris to those structures directly impacted, however it is unlikely that >10% of this SEC will be impacted in this way. Uncertainty scored as high. - There is potential for a change in structural integrity/condition or a loss of productive capacity as the result of localized substrate disturbances resulting from debris to those structures directly impacted, however it is unlikely that >10% of this SEC will be impacted in this way. Uncertainty scored as high.	- Data has recently compiled by Ocean Networks Canada on the distribution of debris at the EHV MPA (processing of video logs). It covers the distribution and debris type. This data has been compiled for an interactive GIS map delivered to DFO Oceans March 2015.	- 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

Table H.3. SEC-stressor interaction indicators for Benthic clam bed community SEC. Interaction justifications summarised from Thornborough et al.[1].

Sampling → Removal of organisms

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance/ population density	% coverage of species/species assemblages at sampled vents	The removal of organisms will result directly in the mortality of these sampled organisms. Due to permitting (and the abundance aerial coverage of this assemblage), it is extremely unlikely that >10% of the population would be sampled. Tunnicliffe (1990) found an increase in abundance of clams and vent fish post vent sampling. This may lead to direct competition and increased predation of clams. Uncertainty scored as low.	No existing population baselines of clam bed benthic community	A combination of visual surveys/video data and sample size will inform this indicator. Population baselines will greatly increase the accuracy of this measurement.
Population condition	Area sampled/ size of the sampling scar	Areal extent of sample scar	It is unlikely that a decrease in the aerial extent of this assemblage by <10% will producing lasting fitness impacts on the population. Impacts will be localized. Uncertainty scored as moderate.	No existing population baselines of clam bed benthic community	- 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)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
	Biomass of removed organisms	- Weight/unit area of sampled (removed) organism - Proportion (%) of biogenic habitat removed		- No existing population baselines of clam bed benthic community	- Extractive sampling combined with existing sample data

Sampling → Substrate disturbance (crushing)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Crushed area	- Proportion (%) of the area crushed - m^2	It is possible that extensive sampling of the habitat (active venting chimneys) would produce a particulate plume (Dando and Juniper 2001). This plume may smother organisms, or replace once colonized hard substrata with soft particles, and removal of sections of the sulphide deposits may change or even stop the hydrothermal fluid flow, impacting the populations reliant of this flow (Dando and Juniper 2001). Substrate disturbance during scientific sampling may potentially impact the benthic assemblage by increasing sedimentation/turbidity, or by direct crushing during sampling.	No existing population baselines of clam bed benthic community	Combination of size of the sample, the measured (visually) sample scar size, and sampling method employed

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			Both will be localized and restricted to the sampled area. Clam mortality may increase as the result of smothering. Bacterial mats and other invertebrate species are highly abundant, and >10% of the aerial extent of these species is unlikely. Uncertainty scored as low.		
Population condition	Abundance of organisms displaying symptoms of crushing	- Proportion (%) of the assemblage - m^2	There have been no documented cases of long-term fitness implications for this SEC as the result of re-suspended sediments during scientific operations at the EHV MPA. Due to the limited distribution of this SEC, sampling around these areas are undertaken carefully to reduce damage to the community. Uncertainty scored as moderate sediment disturbance and re-suspension are unpredictable and dependent on the type of equipment being installed.	No existing population baselines of clam bed benthic community	- Visual surveys - Aided by sampling. Sampling would likely be opportunistic

Sampling → Substrate disturbance (re-suspension)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Change in abundance/ areal extent	- Proportion (%) of the assemblage - m^2	It is possible that extensive sampling of the habitat (active venting chimneys) would produce a particulate plume (Dando and Juniper 2001). This plume may smother organisms, or replace once colonized hard substrata with soft particles, and removal of sections of the sulphide deposits may change or even stop the hydrothermal fluid flow, impacting the populations reliant of this flow (Dando and Juniper 2001). Substrate disturbance during scientific sampling may potentially impact the benthic assemblage by increasing sedimentation/turbidity, or by direct crushing during sampling. Both will be localized and restricted to the sampled area. Clam mortality may increase as the result of smothering. Bacterial mats and other invertebrate species are highly abundant, and >10% of the aerial extent of these species is unlikely. Uncertainty scored as low.	No existing population baselines of clam bed benthic community	- Visual surveys and sampling events - Requires some baseline information

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population 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)	There are currently no known impacts on the long-tem fitness of benthic habitat with sedimentation associated with sampling. However, the smothering or crushing of this habitat would be localized and any mortality would be limited. This would not impact the long-term distribution/density of this habitat. Uncertainty scored as high	No existing population baselines of clam bed benthic community	- Visual surveys and sampling events - Requires some baseline information

Equipment abandonment → Increased contamination

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance/ extent of community	Areal extent (% cover), m^2	The impact of contamination associated with equipment abandonment on the benthic communities at the EHV MPA is unknown. This would be dependent on the type of equipment, and any potential discharges that would occur as the result of this material breaking down. The majority of equipment installed on the seafloor at the EHV MPA is rust-resistant (NEPTUNE Canada),	No existing population baselines of clam bed benthic community	Visual surveys (submersible video), GIS mapping

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			and many of the instruments are oil-filled, such as the cables and sensors. It is possible for these oil-filled instruments/cables to leak, discharging into the environment. The impact of this oil on the benthic communities is unknown, however, in this case is assumed to have a similar effect, yet less dramatic impact, as an oil spill (see above for details). This would result in a reduction of fitness and/or mortality. However, the potential volume of this discharged material is low and would be highly localized, and would not be expected to impact >10% of the communities. Uncertainty scored as moderate.		
Population condition	Species richness/ presence of disease/stress	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	The long-term fitness consequences of this type of contamination are unknown. However, the impacts are assumed to be similar to that of oil spill, but at a much smaller scale, not impacting >30% of the population. Uncertainty scored as moderate.	No existing population baselines of clam bed benthic community	- Requires baselines of populations - Needs to be combined with independent SEC and stressor indicators to link oil with SEC - Visual surveys

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
	Change in genetic diversity	Genetic delineation (allele frequency, polymorphism, etc)		There has been an increasing amount of population genetics studies conducted on populations at the EHV MPA in recent years (and published).	Requires baselines of populations and extractive sampling

Discharge → Debris

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Size of crushed area/size of debris	Areal extent of crushed area as a proportion of overall abundance (extent)	The percent change in the population-wide mortality rate, as the result of debris will be <10%, due to the strong localization of the impact. Debris may directly crush the assemblage as it sinks to the seafloor. There have been no documented cases of debris impacts on this assemblage; however, clams are not expected to recover from direct crushing. Uncertainty scored as moderate, with no information directly linking impacts from debris on this species.	No existing population baselines of clam bed benthic community	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)

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population condition	No known indicators to directly measure change in population condition resulting from crushing by debris		This localized decrease in the aerial coverage of this assemblage will not significantly decrease the density or functional properties of this SEC by >10%. Uncertainty scored as moderate.	No existing population baselines of clam bed benthic community	

Submersible operations → Aquatic invasive species

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance/ density of AIS	% change of areal extent of benthic clam bed community	The potential impact of invasive species at the EHV MPA is currently unknown. Very few cases of the introduction of aquatic invasive species as the result of submersible operations have been documented. However, a study by Voight et al. (2012) found through gene sequencing that 38 *Lepetodrilus gordensis* were able to survive pressure changes and transport from one site to another 635 km away. This indicates that submersibles (both manned and remotely operated) are capable of introducing aquatic invasive species between venting sites. Similarly, Van Dover et al. 2007	No existing population baselines of clam bed benthic community	Requires a combination of visual surveys and sampling. Species are still being discovered at the 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.

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			suggested that submersibles may be capable of transmitting pathogens, specifically fungal infections found in bathymodiolin mussel populations in the Fiji Basin (Van Dover et al. 2007). As the impacts of succession or predation have not been explored at EHV MPA as the result of invasive species, this is scored as a precautionary high, as >30% of the population may be impacted. Uncertainty scored as moderate. Some peer-reviewed information available on the transmission of aquatic invasive species by submersibles, but no information directly related to the clam bed bacterial mat benthic assemblage.		
Population condition	Abundance of AIS	- Areal coverage of habitats - Number of individuals, etc.	No information available on the genetic or fitness consequences, or of any instances of aquatic invasive species capable of impacting the clam bed bacterial mat benthic assemblage. However, if this were to occur, there is potential for >30% of the SEC to be impacted. Uncertainty scored as moderate.	No existing population baselines of clam bed benthic community	- Visual surveys - Needs to be combined with independent SEC and stressor indicators to link oil with SEC

Oil spill → Oil

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
Population size	Abundance	Areal coverage of habitats	There are no documented studies on the impact of oil spill on benthic bacterial mats and clam bed benthic assemblages. Oil has been known to alter the metabolic rate, feeding rate, and shell formation of some benthic organisms (Elmgren et al. 1983; Gómez Gesteira and Dauvin 2000; US Fish & Wildlife Service 2004; Gov of Aus, undated). Contact of oil hydrocarbons with respiratory organs (e.g., filtration organs, gills) and/or ingested can damage related tissues, leading to increased mortality (Patin 1999). Certain types of oil hydrocarbons are capable of inducing mutagenic (genetic damage) and carcinogenic effects in marine organisms, leading to increased mortality (Patin 1999). Some benthic organisms are particularly resilient to oil chemicals and survive, passing oil on to predators further up the food chain and contributing to reduced fitness and possibly mortality of their predators. Benthic organisms such as bivalves usually have an increased ability to accumulate oil constituents due to their high filtration activity, enzyme poor metabolic systems, and contact with bottom sediments, inhibiting subsequent shell formation	No existing population baselines of clam bed benthic community	- The impacts of oil on these organisms is disputed in the literature, and the use of several different indicators is recommended - Visual surveys - Needs to be combined with independent SEC and stressor indicators to link oil with SEC

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
			(Elmgren et al. 1983; Gómez Gesteira and Dauvin 2000; Patin 1999). However, due to the remote nature of this site, the use of dispersants is unlikely, and the source will be from the surface (not the seafloor as in the above mentioned 2010 spill). The likelihood of oil impacting the organisms 2300 m from the surface is low, however, scoring reflects a precautionary approach.		
Population condition	Abundance of organisms displaying symptoms of stress	% cover of community displaying symptoms of stress	The long-term impact on the fitness of the assemblage is unknown. Studies have shown a link between reduced fitness and death (Patin 1999; Thornhill) and bivalves (Gómez Gesteira and Dauvin 2000), including mutagenic (genetic damage) effects (Patin 1999). However, these impacts were not examined for surface spill, and it is unlikely that there will be any lasting impacts on >10% of the population (S. Kim Juniper, University of Victoria, *pers. comm*., 21 Nov. 2014).	No existing population baselines of clam bed benthic community	- Visual surveys - Aided by sampling. Sampling would likely be opportunistic

	Proposed indicator	Measureable component of indicator	Interaction	Existing data	Data collection
	Species richness/ presence of disease/ stress	Diversity measures (e.g. Shannon Simpson, taxonomic redundancy, taxonomic distinctness)	May impact one species within assemblage, and not others, having an indirect impact on SEC.	Some data available from literature	- 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 (allele frequency, polymorphism, etc.)	Studies have shown a link between reduced fitness and death (Patin 1999; Thornhill) and bivalves (Gómez Gesteira and Dauvin 2000), including mutagenic (genetic damage) effects (Patin 1999).	There has been an increasing amount of population genetics studies conducted on populations at the EHV MPA in recent years (and published).	Requires baselines of populations and extractive sampling

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