Fisheries and Oceans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/068

Pacific Region

Ecological Risk Assessment for the Effects of Human Activities at the Endeavour Hydrothermal Vents Marine Protected Area

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February 2018

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.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Thornborough, K., Rubidge, E., and O, M. 2018. Ecological Risk Assessment for the Effects of Human Activities at the Endeavour Hydrothermal Vents Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/068. ix + 69 p.

TABLE OF CONTENTS

ABSTRACT VIII
RÉSUMÉ IX
1 INTRODUCTION 1
  1.1 REGIONAL SETTING: ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA 1
2 METHODS 5
  2.1 SCOPING 5
    2.1.1 Identification of Significant Ecosystem Components 5
    2.1.2 Identification of Activities, Associated Stressors, and Pathways of Effects Models 6
  2.2 LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT 6
    2.2.1 SEC-Stressor Interaction Matrix 7
    2.2.2 Computation of Risk 7
3 RESULTS 11
  3.1 SCOPING 11
    3.1.1 Identification of Significant Ecosystem Components 11
    3.1.2 Identification of Activities and Associated Stressors 21
  3.2 LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT 23
    3.2.1 SEC-Stressor Interaction Matrix 23
    3.2.2 Computation of Risk 24
4 DISCUSSION 36
  4.1 OUTCOMES OF THE LEVEL 2 RISK ASSESSMENT 36
  4.2 CHALLENGES, LIMITATIONS, AND FUTURE WORK 37
    4.2.1 Challenges of the Semi-Quantitative Method 38
    4.2.2 Interpretation of Uncertainty Incorporation 38
    4.2.3 Cumulative Risk by SEC ($CRisk_c$) 39
    4.2.4 Relative Risk to Ecosystem Structure and Function 39
    4.2.5 Scoring Community $Recovery_c$ 39
    4.2.6 Scoring Indirect and Long-Range Stressors and SEC Life Stages 40
    4.2.7 Selection of Significant Ecosystem Components 40
    4.2.8 PoE Model Development and Stressor Identification 41
    4.2.9 Indicators 42
5 CONCLUSIONS AND RECOMMENDATIONS 42
6 REFERENCES 43
7 GLOSSARY AND ACRONYMS 46
APPENDIX A. CONSIDERATIONS FOR SELECTION OF SPECIES, HABITAT AND COMMUNITY/ECOSYSTEM PROPERTIES SECS 49
APPENDIX B. PATHWAYS OF EFFECTS MODELS 52

APPENDIX C. ATTRIBUTES FOR ASSESSING RECOVERY FACTORS FOR SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS 53

APPENDIX D. R-CODE USED TO CALCULATE RISK AND INCORPORATE UNCERTAINTY 56

D.1. R-CODE USED TO CALCULATE RISK AND INCORPORATE UNCERTAINTY FOR ALL SECS 56

D.2. CALCULATION OF CUMULATIVE RISK AND POTENCY 56

APPENDIX E. EHV MPA SPECIES LIST (BENTHIC INVERTEBRATES AND CHORDATES) .57

APPENDIX F. SEC-STRESSOR INTERACTION MATRIX FOR ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA 59

APPENDIX G. EXPOSURE, RESILIENCE, AND RECOVERY SCORES FOR ALL SECS (SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS) 60

APPENDIX H. RISK RESULTS FOR SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS 61

H.1. *RIDGEIA PISCESAE* (HIGH FLUX)...61

H.2. *RIDGEIA PISCESAE* (LOW FLUX)..62

H.3. *PARALVINELLA SULFINCOLA* 63

H.4. *PARALVINELLA PALMIFORMIS*..64

H.5. *LEPETODRILUS FUCENSIS* 65

H.6. *MACROREGONIA MACROCHIRA*...66

H.7. CLAM BED BENTHIC COMMUNITY 67

H.8. ACTIVE VENTING HYDROTHERMAL MINERAL CHIMNEYS 68

H.9. INACTIVE HYDROTHERMAL CHIMNEYS...68

H.10. DIFFUSE VENTING BASALT FLOWS 69

LIST OF TABLES

Table 2.1: Criteria outlined by O et al. (2015) used for the selection of species, habitat, and community SECs. See Appendix A for full descriptions of considerations by O et al. (2015). 6

Table 2.2: Qualitative scoring bins for sub-terms of **Exposure$_{sc}$** (**Area overlap$_{sc}$**, **Depth overlap$_{sc}$**, **Temporal overlap$_{sc}$)** (adapted from O et al. 2015). 8

Table 2.3: Qualitative scoring bins for sub-terms of **Exposure$_{sc}$** (**Intensity$_{sc}$(amount)**, **Intensity$_{sc}$(frequency))** (adapted from O et al. 2015). 8

Table 2.4: Qualitative scoring bins for sub-terms of **Resilience$_{c}$** (adapted from O et al. (2015) with recommendations from DFO (2015)). 9

Table 2.5: Definitions of uncertainty scoring bins, based on categories outlined in Therriault and Herborg (2007) and Therriault et al. (2011). 10

Table 2.6: Standard deviation levels assigned for each uncertainty score when calculating the distribution of each subcomponent. 11

Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA. 12

Table 3.2: Example of species SEC criteria: habitat-creating species. 13

Table 3.3: Identified biogenic and abiotic habitats at EHV MPA. 15

Table 3.4: Community functional groups identified at EHV MPA from literature and examples.. 17

Table 3.5: Endeavour Hydrothermal Vents Marine Protected Area Significant Ecosystem Components and their selection justification. 18

Table 3.6: EHV MPA activities and associated stressors provided by Oceans Canada. 21

Table 3.7: The number of **Recovery$_{c}$** factors scored for each SEC. 26

Table 3.8: The four stressors with the highest estimated **Risk$_{sc}$** for each SEC showing 10/90% Quantiles, and the associated mean **Exposure$_{c}$** and **Consequence$_{c}$**. 30

Table 3.9: Estimated **CRisk$_{c}$** for all SECs, showing 10/90% quantiles and the number of stressors contributing to the score. 33

Table 3.10: Estimated cumulative risk by stressor (**Potency$_{s}$**) ranked in descending order with 10/90% quantiles (10%Q and 90%Q), along with the number of SECs contributing to the score (#SEC). 35

Table A.1: Considerations for Selecting Species SECs (from O et al. 2015) 49

Table A.2: Considerations for Selecting Habitat SECs (from O et al. 2015) 50

Table A. 3: Considerations for Selecting Community/Ecosystem Properties SECs (from O et al. 2015) 51

Table B.1: List of Pathways of Effects Models and date last modified. 52

Table C.1: Recovery factor attributes for assessing potential risks posed by activities and stressors to Species SECs (O et al. 2015). 53

Table C.2: Recovery factor attributes for assessing potential risks posed by activities and stressors to Habitat SECs (O et al. 2015) 54

Table C.3: Recovery factor attributes for assessing potential risks posed by activities and stressors to Community/Ecosystem Properties SECs (O et al. 2015). 55

Table H.1: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 61

Table H.2: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 62

Table H.3: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 63

Table H.4: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 64

Table H.5: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 65

Table H.6: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 66

Table H.7: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 67

Table H.8: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 68

Table H.9: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 68

Table H.10: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores. 69

LIST OF FIGURES

Figure 1.1: Location figure showing EHV MPA (inside selection). Image source: British Columbia Marine Conservation Analysis Project Team. 2011. Marine Atlas of Pacific Canada: A Product of the British Columbia Marine Conservation Analysis. Available from www.bcmca.ca. ... 3

Figure 1.2: Bathymetric map of the locations of the five main hydrothermal vent fields and smaller sites of diffuse flow (DFO 2009). Depths are in meters. ... 4

Figure 2.1: Normal distribution with a standard deviation of (A) 0.2 and (B) 1.0 (from Murray et al. 2016). ... 11

Figure 3.1: Median risk scores and Exposure/Consequence plots for species SECs: Ridgeia piscesae (high flux), Ridgeia piscesae (low flux), Paralvinella sulfincola, and Paralvinella palmiformis. ... 28

Figure 3.2: Median risk scores and Exposure/Consequence plots for species and community SECs: Lepetodrilus fucensis (species SEC), Macroregonia macrochira (species SEC), and benthic clam bed community (community SEC). **A.** Median risk scores for the above SECs with stressors numbered as: (1) debris [discharge]; (2) oil [oil spill]; (3) Increased contamination [equipment abandonment]; (4) substrate disturbance (crushing) [equipment installation]; (5) substrate disturbance (sediment resuspension) [equipment installation]; (6) removal of organisms [sampling]; (7) substrate disturbance (crushing) [sampling]; (8) substrate disturbance (sediment resuspension) [sampling]; (9) aquatic invasive species [submersible operations]; (10) substrate disturbance/crushing [submersible operations], (11) substrate disturbance (sediment resuspension) [submersible operations],and; (12) sound generation [seismic testing/air guns]. **B.** Exposure/consequence plots showing the four stressors with the highest risk scores labelled (numbering corresponds to that of A.), and the associated uncertainty represented 10/90% error bars. ... 29

Figure 3.3: Median risk scores and Exposure/Consequence plots for habitat SECs: active venting hydrothermal mineral chimneys, inactive hydrothermal chimneys, and diffuse venting flows. **A**. Median risk scores for habitat SECs with stressors numbered as: (1) debris [discharge]; (2) substrate disturbance/crushing [equipment installation]; (3) substrate disturbance/crushing [sampling], and; (4) substrate disturbance/crushing [submersible operations]. **B**. Exposure/consequence plots showing the four stressors with the highest risk scores labeled (numbering corresponds to that of A.), and the associated uncertainty represented 10/90% error bars. ... 30

Figure 3.4: Estimated $\mathbf{CRisk_c}$ for each SEC, ranked in descending order with 10/90% error bars. Numbers above columns denote the number of stressors applicable to that SEC. ... 33

Figure 3.5: Estimated cumulative risk by stressor ($\mathbf{Potency_s}$) ranked in descending order with 10/90% quantiles, and showing the number of SECs contributing to the score. ... 35

ABSTRACT

This project applied the Level 2 Risk Assessment framework proposed by O et al. (2015) to Endeavour Hydrothermal Vents Marine Protected Area (EHV MPA) in order to determine relative risks to the EHV MPA ecosystem from anthropogenic activities. The scoping phase identified 11 ecological significant ecological components (SECs) that appropriately represent the EHV MPA (six species SECs, four habitat SECs, and one community SEC) and anthropogenic activities and associated stressors occurring within EHV MPA. The risk assessment determined the interaction between selected SECs and the stressors, and prioritised SECs and stressors on a relative scale within EHV MPA based on estimated cumulative risk. This identification and prioritisation of SECs and stressors is vital for the selection of indicators, and ultimately the development of monitoring plans. The SECs with the highest estimated cumulative risk scores were *Ridgeia piscesae* (high flux), *Ridgeia piscesae* (low flux), *Paralvinella sulfincola*, and the benthic clam bed community. The stressors with the highest estimated potency (cumulative risk by stressor) scores were *debris [discharge]*, *substrate disturbance (crushing) [sampling]*, *substrate disturbance (crushing) [submersible operations]*, and *aquatic invasive species [submersible operations]*. The uncertainties identified by the risk assessment help to inform Oceans Managers of knowledge gaps and identify priorities for monitoring. The highest uncertainties were associated with potential stressors *debris [discharge], aquatic invasive species [submersible operations],* and *oil [oil spill].* Some criteria outlined by O et al. (2015) for the Level 2 Risk Assessment were not applicable and/or proved challenging to apply without some modification in order to estimate risk. In most cases, this approach was successful, and overall the Level 2 Risk Assessment was effective.

Évaluation du risqué écologique des effets des activités humaines dans les zones de protection marine du champ hydrothermal Endeavour

RÉSUMÉ

Pour ce projet, on a appliqué le cadre d’évaluation du risque de niveau 2 proposé par O *et al*. (2015) à la zone de protection marine du champ hydrothermal Endeavour (ZPM CHE) afin de déterminer le risque relatif que posent les activités anthropiques pour l’écosystème de la ZPM-CHE. La phase d'établissement de la portée a défini 11 composantes importantes de l'écosystème (CIE) qui représentent adéquatement la ZPM-CHE (six CIE relatives aux espèces, quatre CIE relatives à l'habitat, et une CIE relative aux communautés) ainsi que les activités anthropiques et les agents de stress connexes dans la ZPM CHE. L'évaluation des risques a permis de déterminer l'interaction entre les CIE choisies et les agents de stress, et elle a classé par ordre de priorité les CIE et les agents de stress sur une échelle relative dans la ZPM CHE en se basant sur l'estimation du risque cumulatif. Cette détermination et hiérarchisation des CIE et des agents de stress est essentielle pour la sélection des indicateurs et, au bout du compte, pour l'élaboration de plans de surveillance. Les CIE qui présentent les estimations de cotes de risque cumulatives les plus élevées ont été *Ridgeia piscesae* (flux élevé), *Ridgeia piscesae* (flux faible), *(Paralvinella sulfincola)* et la communauté benthique des gisements de myes. Les *débris (décharge)*, la *perturbation du substrat (écrasement) [échantillonnage]*, la *perturbation du substrat (écrasement) [opérations avec submersibles]* et les *espèces aquatiques envahissantes [opérations avec submersibles]* sont les agents de stress qui ont reçu les estimations de cote de puissance (risque cumulatif par agent de stress) les plus élevées. Les incertitudes relevées par l'évaluation des risques aideront à tenir les gestionnaires des océans au courant des lacunes de connaissances et à cerner les priorités en matière de surveillance. Les incertitudes les plus élevées étaient associées aux agents de stress potentiels suivants : les *débris [décharge], les espèces aquatiques envahissantes [opérations avec submersibles],* et *les hydrocarbures [déversements d'hydrocarbures].* Certains critères décrits par O et al. (2015) pour l'évaluation du risque de niveau 2 n'étaient pas applicables ou se sont révélés difficiles à appliquer sans quelques modifications afin de pouvoir estimer le risque. Dans la plupart des cas, cette approche a été une réussite, et, dans l'ensemble, l'évaluation du risque de niveau 2 a donné de bons résultats.

1 INTRODUCTION

The development of systematic, science-based ecological risk-assessment frameworks for Ecosystem-Based Management (EBM) holds significant value for Fisheries and Oceans Canada (DFO) Oceans Management. Such frameworks may be used to determine the linkages between specific anthropogenic activities, their associated stressors, and Significant Ecosystem Components (SECs) deemed vital for the health and survival of an ecosystem. In turn, the application of risk assessment frameworks can prioritise ecological SECs and stressors, and any uncertainties identified help to inform Oceans Managers of knowledge gaps and identify research priorities for monitoring. This information is crucial for the selection of indicators and in turn, the development of research and monitoring plans that will feed into an Integrated Management (IM) approach to ecological monitoring.

An ecological risk-assessment framework (ERAF) was developed by the Pacific Region (O et al. 2015) in order to evaluate and prioritise the single and cumulative threats from multiple anthropogenic activities and their associated stressors on SECs. This framework considers ecological SECs on a species, habitat, and community level. The key elements of this framework consist of an initial scoping phase followed by the risk assessment. The scoping phase includes: the identification of species, habitat, and community SECs; and the identification of anthropogenic activities and stressors that have the potential to affect these SECs.

The risk assessment phase involves 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). The ERAF consists of three levels of risk assessment: Level 1 qualitative; Level 2 semi-quantitative; and, Level 3 fully quantitative. Selection of the risk assessment level is dependent on the availability of information on SECs and activities in the specified area.

This study applied a Level 2 risk assessment framework to the Endeavour Hydrothermal Vent Marine Protected Area (EHV MPA) in DFO Pacific Region. This MPA was selected because it is a geographically defined area where anthropogenic activities are limited and monitored. In applying the ERAF to EHV MPA, this study specifically aims to:

1. identify ecological SECs that appropriately represent the ecosystem at EHV MPA;
2. identify anthropogenic stressors that may have an impact on EHV MPA; and
3. prioritise stressors and SECs on a relative risk scale within EHV MPA.

Ultimately the information gained from this study will increase understanding of human impacts on the EHV MPA, and potential measures to monitor, manage, and mitigate those impacts. The detailed process of the ERAF will reveal knowledge gaps in our understanding of the EHV MPA ecosystem, and the lack of quantitative data on many of the human-induced impacts in the area.

1.1 REGIONAL SETTING: ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA

Hydrothermal vents were first discovered in 1977 (Lonsdale 1977; Corliss et al. 1979), and cold seeps in 1984 (Paull et al. 1984). Hydrothermal vents are complex ecosystems characterised 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 1991; Sibuet and Olu 1998), but have low macro-organism diversity (Banoub 2010). These ecosystems are based on the process of chemosynthesis, wherein bacteria produce the energy and organic matter to the food web (Godet et al. 2011).

The Endeavour Segment is a seismically active area of seafloor formation and hydrothermal venting located on the mid-ocean ridge system of Juan de Fuca Ridge, northeast Pacific Ocean. The Juan de Fuca Ridge is known as a distinct biogeographic region for vent fauna (Tunnicliffe et al. 1996), with ten hydrothermal sites. Some of these sites are volcanically dominated; limiting the development of vent communities by periodic disturbances, while other sites, such as the Endeavour Segment, are tectonically dominated; thus, exposed to few magma disturbances. Endeavour is the largest and possibly oldest hydrothermal site on the Juan de Fuca Ridge, and as a result has the highest diversity (Tunnicliffe et al. 1996). The Endeavour Hydrothermal Venting area is located at a depth of 2,250 m, 250 km southwest of Vancouver Island, and centred at 47°57'N, 129°06'W (Figure 1.1). It exhibits variable morphology and hosts a range of high- and low-temperature vent sites (Bohnenstiehl et al. 2004). Since their discovery in 1982, the Endeavour Hydrothermal Vents have been the focus of significant scientific research (Banoub 2010), which has identified at least twelve endemic species (Butterfield and Massoth 1994; Converse et al. 1984).

The Endeavour Hydrothermal Vents area was officially designated as a 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)…"*

Measures implemented to achieve this objective include the restriction of sampling permits in certain vent fields, allowing long-term observation studies to continue (Banoub 2010). The MPA covers approximately 100 km^2 and encompasses five main vent fields with features such as black smoker chimneys and surrounding lower temperature vents (Banoub 2010). There are four main management areas consisting of venting fields (Figure 1.2): Mothra, Main Endeavour, High Rise, and Salty Dawg (an additional area, Sasquatch, was discovered in 2000). Within fields, there are vent complexes (e.g., the Faulty Towers complex at Mothra). Within these vent complexes, there are individual chimneys that host numerous venting sites (e.g., Giraffe, Roane, and Finn).

The primary use at the EHV MPA is scientific research, which is monitored by a Management Committee (chaired by DFO and involving federal departments, Canadian and foreign scientists, the Canadian private sector, educators, and an NGO) to mitigate use conflicts and environmental disturbance. The main directed surface vessel traffic in the EHV MPA area consists of research vessels. Current scientific sampling methods allow access to unique ecosystems that were previously not accessible, adding increasing pressure on these ecosystems (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 EHV MPA ecosystem (DFO 2009). While commercial fishing for tuna and neon flying squid is known to occasionally occur in the area of 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 (DFO 2009).

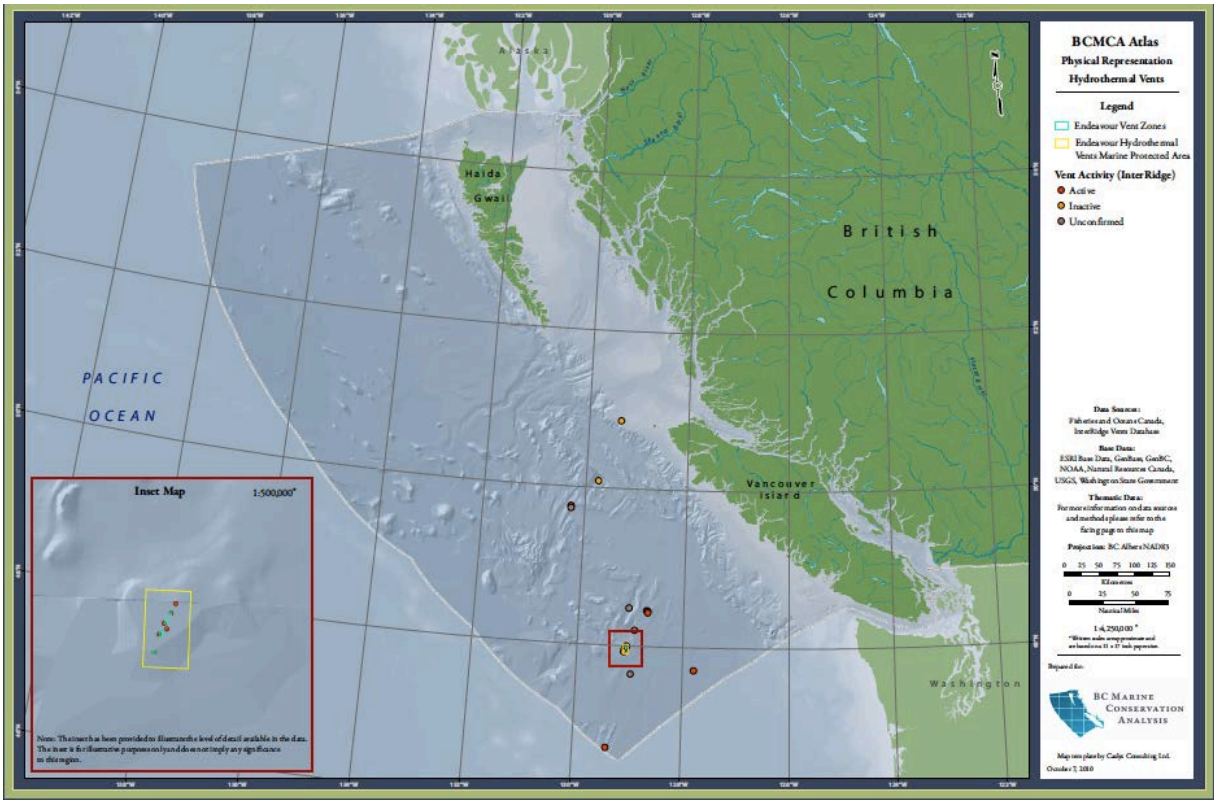

Figure 1.1: Location figure showing EHV MPA (inside selection). Image source: British Columbia Marine Conservation Analysis Project Team. 2011. Marine Atlas of Pacific Canada: A Product of the British Columbia Marine Conservation Analysis. Available from www.bcmca.ca.

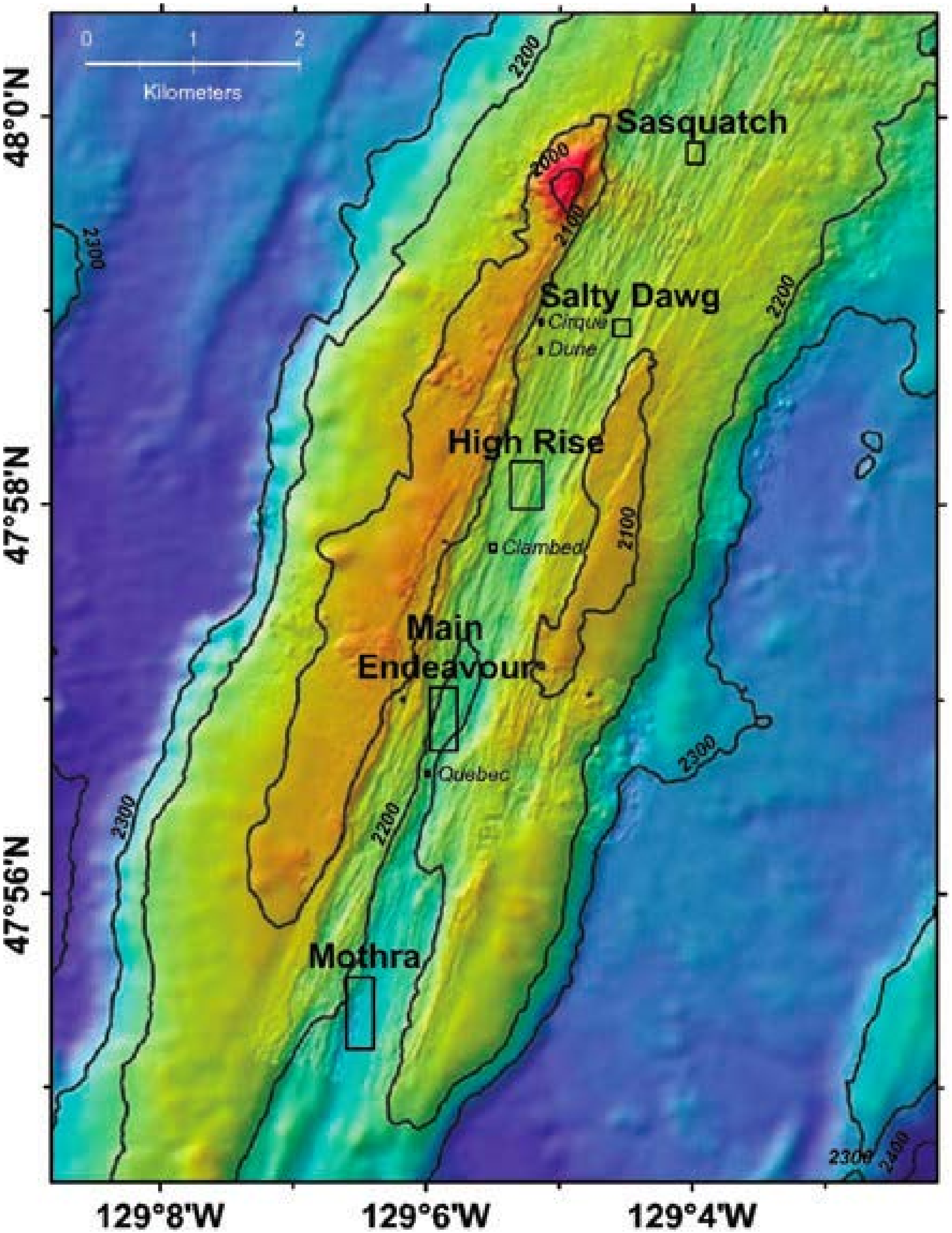

Figure 1.2: Bathymetric map of the locations of the five main hydrothermal vent fields and smaller sites of diffuse flow (DFO 2009). Depths are in meters.

2 METHODS

The ERAF (O et al. 2015) consists of two key phases: scoping and risk assessment. A scoping phase and semi-quantitative risk assessment were applied to the EHV MPA, following the methods outlined by O et al. (2015), but with the inclusion of a revised risk scoring method recommended through the CSAS regional peer review process (DFO 2015). All revisions to the original ERAF method (O et al. 2015) are detailed here including any alterations that were made to accommodate the unique nature of the EHV MPA (i.e. hydrothermal vents).

2.1 SCOPING

Scoping is intended to identify the key features or properties of the system (i.e., SECs) that include species, habitats, and community/ecosystem properties and the activities and associated stressors that have the potential to affect these SECs using Pathways of Effects (PoE) models.

2.1.1 Identification of Significant Ecosystem Components

A Significant Ecosystem Component (SEC) in the context of this study is defined as an environmental element that has ecological importance to the EHV MPA ecosystem. The use of ecologically significant ecosystem components will inform DFO’s implementation of ecosystem-based management (EBM). Although all species, habitats, and communities have some degree of ecological significance, it is important to identify those components with greater relative significance, and those impacted by stressors that are manageable at an MPA scale when conducting a risk assessment.

In order to define the appropriate SECs, the MPA ecosystem was organized into three component groups: species, habitats, and community/ecosystem properties. All known species, habitats, and community properties in the EHV MPA were identified from the literature, using the criteria outlined by O et al. (2015). While information on some criteria was limited, a standard guide of three or more peer-reviewed papers per criteria for each considered component was utilized.

2.1.1.1 Selecting species SECs

O et al. (2015) provided criteria to identify species with greater relative ecological significance due to their role in the ecosystem (see Table 2.1 for full list). In the context of the EHV MPA where the majority of populations are benthic invertebrates, some of the criteria were not applicable. Interpretation of species SEC criteria as they pertain to EHV MPA is discussed in detail in Section 3.1.1.1.

2.1.1.2 Selecting habitat SECs

While a bioregional classification system would ideally be used to identify habitat SECs, this information was unavailable at the time of this study for the Pacific Region. In the absence of this information, O et al. (2015) suggested considerations for selecting habitat SECs (see Table 2.1 for full list). However, we also recognise that many habitats are unique to hydrothermal vents, so some criteria were more useful than others for identifying habitat SECs (see Section 3.1.1.2 for more details).

2.1.1.3 Selecting ecosystem/community SECs

Considerations suggested by O et al. (2015) for selecting ecosystem and community property components include those listed in Table 2.1.

Table 2.1: Criteria outlined by O et al. (2015) used for the selection of species, habitat, and community SECs. See Appendix A for full descriptions of considerations by O et al. (2015).

SEC type	SEC Considerations
Species	• Nutrient importer/exporter • Specialised or keystone role in the food web • Habitat creating species • Rare, unique, or endemic species • Sensitive species • Depleted (listed) species
Habitat	• Biogenic habitat types • Sensitive habitats • Habitats critical for sensitive species • Threatened or depleted habitat • Habitats critical for supporting rare, unique or endemic species • Habitats supporting critical life stages • Habitats providing critical ecosystem functions or services
Ecosystem / community	• Ecologically significant community properties • Functional groups that play a critical role in ecosystem functioning • Ecological processes critical for ecosystem functioning • Sensitive functional groups

2.1.2 Identification of Activities, Associated Stressors, and Pathways of Effects Models

The second step in the scoping phase is the identification of potential activities and the associated stressors that may impact EHV MPA through the development of generic Pathways of Effects (PoE) models. A PoE model is a representation of cause-and-effect relationships between human activities and their associated stressors, and impacts. DFO Oceans Management provided activities that occur within the EHV MPA and our analysis included only known legal activities within the MPA. Based on this list of activities, PoE models were developed using peer-reviewed literature to describe the mechanisms by which these activities affect the environment, identifying the stressors associated with each activity and the potential impact on the environment. The list of activities included: *discharge* (vessels), *oil spill* (vessels), *equipment abandonment, equipment installation, sampling, submersible operations*, and *seismic testing/air guns*. A list of the PoE models developed for these activities and the date the models were last modified is provided in Appendix B. It should be noted that these activities may be divided into ‘current snapshot’ activities and ‘potential’ activities. Current snapshot represents activities that are predictable and known to occur annually at EHV MPA. Potential activities include those that occur infrequently and/or unpredictably and include *oil spill, discharge*, and *seismic testing/air guns*.

2.2 LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT

Risk assessment is an analytical approach for estimating risk, which in this case, is defined as the likelihood that a SEC will experience unacceptable adverse consequences due to exposure to one or more identified stressors (O et al. 2015). Cumulative risk is a calculation of the risk to a SEC from more than one stressor, and is a measure of the overall risk to a given SEC.

The following assessment aims to analyse two types of risk following the methods outlined by O et al. (2015):

1. relative risk (**Risk**$_{sc}$) to a SEC (***c***) from the individual stressors (***s***) that affect it within the EHV MPA, and;
2. cumulative risk (**CRisk**$_{c}$) to a SEC from all of the different stressors that affect it within EHV MPA.

2.2.1 SEC-Stressor Interaction Matrix

The first step in a Level 2 risk assessment is to identify potential interactions between the identified stressors and selected SECs with an interaction matrix. A binary system was used to score interactions as either (1) interaction, or (0) no interaction based on the biological expertise of the authors. These interactions are later explored in detail by consulting primary literature and subject matter expert (SME) reviews of scoring decisions (see Section 2.2.2 for detailed descriptions of scoring methods). It should be noted that the ERAF scoring rubric only takes into account negative SEC-stressor interactions (i.e., where the stressor has a detrimental impact on the health/integrity of the SEC), and does not include any positive interaction (i.e., where interaction would result in an increase in the SEC's overall health/integrity). While the framework may be used to score both direct and indirect impacts of a stressor on a SEC, only direct impacts were scored for this first iteration of a risk assessment on the EHV MPA. Examples of indirect impacts include increased predation due to disturbances, increased competition for food sources as the result of disturbances, etc. This focus on direct impacts creates a baseline unto which future risk assessments may further develop. Additionally, only the impacts of stressors on adult life-stages of the SECs were scored for this application of the Level 2 ERAF for two reasons:

1. there is very limited information available on the juvenile life stages of many of the EHV MPA species SECs, which would result in high uncertainty scores; and,
2. the inclusion of juveniles may skew the weightings of certain stressors that are otherwise benign to the adult organism, focusing on the effect of stressors on the sensitive juveniles (pelagic juvenile forms of benthic invertebrates), rather than on the existing ecosystem.

This could lead to little or no differentiation in scoring between SECs and stressors.

2.2.2 Computation of Risk

2.2.2.1 Calculating relative risk (*Risk*$_{sc}$) to a SEC (*c*) from a stressor (*s*)

The relative risk to SEC from a stressor is defined by the equation:

$$\boldsymbol{Risk_{sc} = Exposure_{sc} \times Consequence_{sc}} \qquad \text{(Equation 1)}$$

Where:

Exposure$_{sc}$ is the estimated magnitude of interaction between the stressor and SEC; and

Consequence$_{sc}$ is the potential for long-term harm to SEC as the result of interaction with the stressor and its estimated metrics that represent the capacity of the SEC to resist/recover from exposure to the stressor.

2.2.2.2 Calculating terms of risk of exposure of SEC (*c*) to stressor (*s*) (*Exposure*$_{sc}$):

Exposure is defined by the equation:

$$\boldsymbol{Exposure_{sc}} = \left(\sqrt[3]{\boldsymbol{Area_{sc}} \times \boldsymbol{Depth_{sc}} \times \boldsymbol{Temporal_{sc}}}\right) \times \left(\sqrt[2]{\boldsymbol{i\,(amount)_{sc}} \times \boldsymbol{i\,(frequency)_{sc}}}\right)$$

(Equation 2)

Where:

$\boldsymbol{Area_{sc}}$ is the percentage of area overlap between a stressor and SEC;

$\boldsymbol{Depth_{sc}}$ is the percentage of depth overlap between a stressor and SEC;

$\boldsymbol{Temporal_{sc}}$ is the percentage of temporal overlap between a stressor and SEC;

$\boldsymbol{i\ (amount)_{sc}}$ is the measure of the intensity (level or effort/density) of the activity/stressor; and

$\boldsymbol{i\ (frequency)_{sc}}$ is the frequency at which the stressor occurs.

$\boldsymbol{Exposure_{sc}}$ was calculated using the geometric mean (defined as the n^{th} root of the product of n numbers) of the spatial overlap (i.e., area, depth) and temporal overlap, multiplied by the geometric mean of the intensity variables (i.e. amount, frequency). The geometric mean was preferred over the arithmetic mean so that the spatial/temporal exposure (three terms) did not outweigh the intensity (with only two terms). The use of the geometric mean ensured that $\boldsymbol{Exposure_{sc}}$ (five terms) and $\boldsymbol{Consequence_{sc}}$ (two terms) would receive the same weightings in the risk calculation. A qualitative scoring procedure that utilises bins (1-4) is shown in Table 2.2 and Table 2.3.

Table 2.2: Qualitative scoring bins for sub-terms of $\boldsymbol{Exposure_{sc}}$ ($\boldsymbol{Area\ overlap_{sc}}$, $\boldsymbol{Depth\ overlap_{sc}}$, $\boldsymbol{Temporal\ overlap_{sc}}$) *(adapted from O et al. 2015).*

Very Low (0.1-1%)	Low (1-20%)	Medium (20-50%)	High (>50%)
1	2	3	4

Table 2.3: Qualitative scoring bins for sub-terms of $\boldsymbol{Exposure_{sc}}$ ($\boldsymbol{Intensity_{sc}(amount)}$, $\boldsymbol{Intensity_{sc}(frequency)}$) *(adapted from O et al. 2015).*

Intensity (amount)$_{sc}$	Very Low (0.1-1%)	Low (1-20%)	Medium (20-50%)	High (>50%)
Intensity (frequency)$_{sc}$	Occurs rarely (1 in 100 year period)	Occurs infrequently (e.g. once every 5-50 year period)	Occurs occasionally but not regularly (e.g. occurs more than 1 years but not every year within a 5 year period)	Occurs frequently (e.g. every year)
	1	2	3	4

2.2.2.3 Calculating Consequence$_{sc}$ of a single stressor (*s*) on SEC (*c*)

$\boldsymbol{Consequence_{sc}}$ is defined by the equation:

$$\boldsymbol{Consequence_{sc}} = \boldsymbol{Resilience_{c}} \times \boldsymbol{Recovery_{c}} \qquad \text{(Equation 3)}$$

Where:

$\boldsymbol{Resilience_{c}}$ is the percent change of the SEC in response to stressors (acute and chronic); and

$\boldsymbol{Recovery_{c}}$ is the time for the SEC to return to pre-stress level once the stressor is removed.

2.2.2.4 Calculating *Resilience*$_{c}$

$\boldsymbol{Resilience_{c}}$ is defined by the equation:

$$\boldsymbol{Resilience_{c}} = \boldsymbol{AcuteChange_{c}} + \boldsymbol{ChronicChange_{c}} \qquad \text{(Equation 4)}$$

Where:

AcuteChange$_c$ is 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 SEC, and the percentage of species impacted for community/ecosystem SEC;

ChronicChange$_c$ is 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 SEC, and the percentage of functional groups impacted for community/ecosystem SEC. Each factor was assigned a score of 0-3 using the qualitative binned system (Table 2.4).

*Table 2.4: Qualitative scoring bins for sub-terms of **Resilience$_c$** (adapted from O et al. (2015) with recommendations from DFO (2015)).*

Negligible/no effect	Low (<10% change)	Medium (10-30% change)	High (>30% change)
0	1	2	3

2.2.2.5 Calculating Recovery$_c$

Recovery$_c$ is defined by the equation:

Recovery$_c$ = Mean of n Recovery factors (Equation 5)

Recovery factors were averaged to determine the ***Recovery$_c$*** variable of the ***Consequence$_{sc}$*** equation (*Equation 3*). The recovery factors for each SEC (species, habitat, and community) are listed in Appendix C. Not all recovery factors for species, habitats, and communities listed by O et al. (2015) were applicable to all SECs (for example, many of the species recovery factors are fish-specific). ***Recovery$_c$*** was calculated using only those factors that could be scored (n) on a scale from 1-3. That is, factors with no available information were not scored, and were not included in the mean. Scoring of recovery factors was based on peer-reviewed information.

2.2.2.6 Computation of cumulative risk (*CRisk$_c$*) to SEC from multiple stressors

Estimation of ***CRisk$_c$*** across SECs enables evaluation of the relative risk (***Risk$_{sc}$***) to SECs within the area assessed. This was calculated by summing the risk scores of all stressors that impact a SEC.

CRisk$_c$ is defined by the equation:

$$\boldsymbol{CRisk_c} = \sum_{s=1}^{n}(\boldsymbol{Risk_{sc}}) \qquad \text{(Equation 6)}$$

Where ***s*** is the stressor interacting with a SEC.

2.2.2.7 Computation of cumulative risk (*Potency$_s$*) by stressor

The ***Potency$_s$*** of each stressor was calculated by summing the ***Risk$_{sc}$*** scores of stressor for each SEC that the stressor interacts with.

Potency$_s$ is defined by the equation:

$$\boldsymbol{Potency_s} = \sum_{c=1}^{n}(\boldsymbol{Risk_{sc}}) \qquad \text{(Equation 7)}$$

Where ***c*** is the SECs that stressor impacts.

2.2.2.8 Uncertainty scoring and incorporation

An uncertainty score between 1-5 was allocated for each risk variable analysed during scoring, where 1 represents low uncertainty and 5 represents high uncertainty (Table 2.5). These variables included up to 16 uncertainty scores per SEC: ***Exposure$_{sc}$*** (***Area overlap$_{sc}$, Depth overlap$_{sc}$, Temporal overlap$_{sc}$, Intensity$_{sc}$(amount), Intensity$_{sc}$(frequency)***), ***Resilience$_{c}$*** (***AcuteChange$_{c}$***, ***ChronicChange$_{c}$***), and **Recovery$_{c}$** (up to nine factors related to the SEC life history).

Table 2.5: Definitions of uncertainty scoring bins, based on categories outlined in Therriault and Herborg (2007) and Therriault et al. (2011).

Score	Literature	Definition
1	Extensive	Extensive scientific information; peer-reviewed information; data specific to the location; supported by long-term datasets
2	Substantial	Substantial scientific information; non-peer-reviewed information; data specific to the region
3	Moderate	Moderate level of information; data from comparable regions from the area of interest
4	Limited	Limited information; expert opinion based on observational information or circumstantial evidence
5	Little to None	Little or no information; expert opinion based on general knowledge

Two types of uncertainty are inherent in the risk scoring:

1. the amount of literature available about the SEC-stressor interaction; and,
2. scientific consensus about the consequences of the SEC-stressor interaction.

In some cases, there is a wealth of scientific information but no agreement about the consequence. This second type of uncertainty is not represented in Table 2.5; however, it is implicitly considered when scoring uncertainty because the uncertainty score was increased by one (uncertainty score + 1) when there was no scientific consensus.

The uncertainty associated with each scored variable was incorporated into the risk score using the method outlined by Murray et al. (2016). Each risk variable was assigned as the mean of a normal distribution (Figure 2.1) with standard deviation set according to the level of uncertainty assigned, i.e., the width of the sample distribution is based on the perception of uncertainty in the variable score. An uncertainty of 1 was assigned a standard deviation of 0.2, while uncertainty of 5 was assigned a standard deviation of 1 (Table 2.6). The normal distribution was bounded by the minimum and maximum possible scores for each ***Risk$_{sc}$*** variable to ensure scores could not exceed the score range for that variable. The score of each ***Risk$_{sc}$*** variable was then randomly sampled from this distribution with 10,000 replicates to produce an array for each variable. The final ***Risk$_{sc}$*** score for each SEC-stressor relationship was a product of the ***Exposure$_{sc}$*** and ***Consequence$_{sc}$*** variable arrays (*Equations 1,2,* and *3,* respectively), where the first score generated from each variable array is multiplied across all ***Risk$_{sc}$*** variables, followed by the second, and so forth for all 10,000 replicates, resulting in a final risk array of 10,000 scores. The median and 10th and 90th percentiles from this final array are reported as the final ***Risk$_{sc}$*** score for each SEC-stressor interaction. Percentiles were used instead of standard deviation or standard error because the resulting distribution of risk scores was non-normal. The statistical platform R was used to generate and run the code for the uncertainty scoring (R Development Core Team 2008). See Appendix D for full R code.

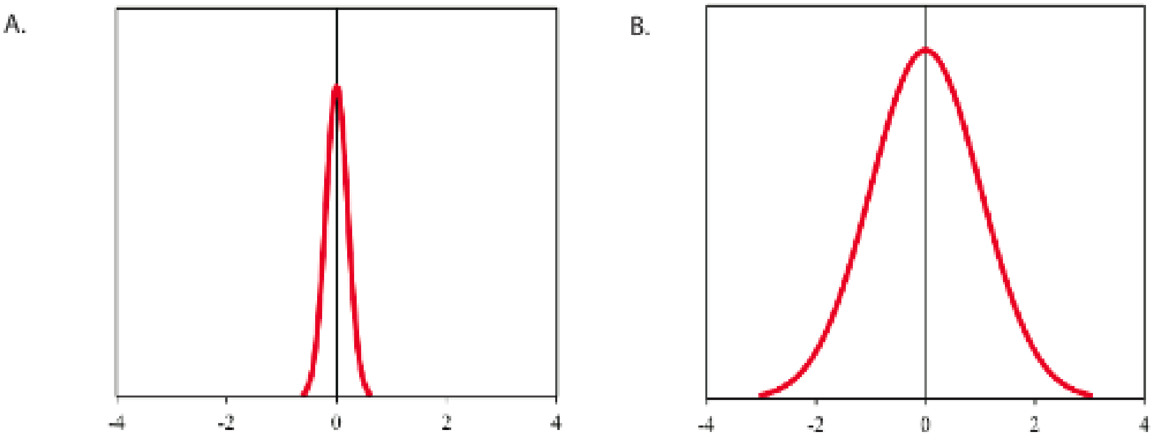

Figure 2.1: Normal distribution with a standard deviation of (A) 0.2 and (B) 1.0 (from Murray et al. 2016).

Table 2.6: Standard deviation levels assigned for each uncertainty score when calculating the distribution of each subcomponent.

Uncertainty Score	Standard Deviation
1	0.2
2	0.4
3	0.6
4	0.8
5	1.0

2.2.2.9 Review process

Subject matter experts (SMEs) were consulted to review each scored SEC/stressor interaction and associated uncertainty score. This process required the SME to review the scores, and then provide feedback in a workshop-style session where suggested changes were discussed. All suggested changes were incorporated into the final scores presented in Appendix G. Subject matter experts for EHV MPA included Dr. Kim Juniper (reviewed Nov. 21 2013) and Dr. Verena Tunnicliffe (reviewed Dec 4 2013; July 11 2014). Since there are potentially several thousand scoring decisions covering a wide variety of SECs and stressors, implementing a review of these scoring decisions by SMEs is an important quality assurance procedure and is recommended for future ERAF applications.

3 RESULTS

3.1 SCOPING

3.1.1 Identification of Significant Ecosystem Components

3.1.1.1 Species SECs

Before the application of the ERAF scoring criteria were applied, a list of all known invertebrate and chordate species at EHV MPA was compiled from the literature. Although microbial communities fulfilled several of the selection criteria, they were not selected as a SEC because their diversity, density, and distribution are independent of anthropogenic activities that occur within the MPA boundaries and, therefore, they are not manageable at the MPA scale. The final list included 98 species (see Appendix E for full list, supporting references, and criteria fulfilled). Through the application of the criteria outlined by O et al. (2015) and described in Section 2.1.1, 75 of the identified species fulfilled at least one criteria, 41 species fulfilled at least two criteria, nine fulfilled at least three criteria, seven fulfilled at least four criteria; and two fulfilled at least five criteria (Appendix E). No species fulfilled all six criteria, which were attributed to the lack of species officially listed as 'depleted'.

Some of the SEC selection criteria outlined by O et al. (2015) were challenging to apply to the EHV MPA. For a full list of the criteria and how they were defined and applied to the EHV MPA, see Table 3.1. An example of one of these criteria (habitat creating species) is presented in Table 3.2. The *rare, unique, or endemic species* criterion as defined in O et al. (2015), while applicable to EHV MPA, was not effective in limiting the number of species SECs. Instead, due to the high level of endemism at hydrothermal vents (Tunnicliffe et al. 1998), and the restriction of most of these organisms to the spatially limited hydrothermal vents, most organisms fulfilled this criterion. Dividing this criterion into *rare* and *endemic* species criteria in order to capture the ecological and evolutionary significance of the EHV MPA may be an appropriate approach in future risk assessments and is discussed in Section 4.2.7. The *depleted species* criterion was not effectively applied at the EHV MPA, as no hydrothermal vent organisms at this site currently hold listed status under relevant domestic legislation/international agreements or treaties, including the Species At Risk Act (SARA), Committee of the Status of Endangered Wildlife in Canada (COSEWIC), International Union for Conservation of Nature (IUCN), or British Columbia Centre for Disease Control (BCCDC). Due to the highly specialised nature of many of the EHV MPA organisms, the criterion of *specialised or keystone role in food web* was interpreted as organisms with symbiotic relationships (usually with chemosynthetic bacteria) and keystone species.

Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.

Species criteria	Description
Nutrient importer/ exporter	Includes species that play a *crucial role* in maintaining ecosystem structure and function through the transfer of energy or nutrients that would *otherwise be limitin*g to an ecosystem (O et al. 2015). EHV MPA is almost entirely dependent on chemosynthetic bacteria to produce carbohydrates from hydrogen sulphide that pours out of the vents. As a result, the food web is based around the chemosynthetic microbes and bacteria (primary producers), and the organisms that derive their food from these primary producers through symbiosis and/or feed directly on the bacteria (primary consumers). Therefore, primary producers and consumers were listed as significant nutrient importers at EHV MPA.
Specialized or keystone role in food web	Includes species that have a highly specialized relationship with another species or guild; an important food web relationship where an impact to it would cause *vertical or horizontal change* in food web; and species that support a temporally or spatially explicit event important for other species. Examples include highly influential predators and forage species (O et al. 2015). While little is known of the functional ecosystem role of many species at EHV MPA, what is known is that hydrothermal vent organisms are highly specialized physiologically. Therefore, the species selected as "specialized or keystone role in the food web" may include (1) primary producers (e.g. microbes, bacteria, and ciliate mats); (2) specialized species with symbiotic relationships (e.g. primary consumers); and (3) keystone species capable of producing a vertical or horizontal shift in the food web (e.g., Octopus *Graneledone pacifica,* Spider Crab *Macroregonia*

Species criteria	Description
	macrochira).
Habitat creating species	Includes species that create habitat for infauna and aerate substrates, or create habitat on the seafloor (O et al. 2015). In the case of EHV MPA, this criterion includes both vent and non-vent specific species which either create habitat by on the seafloor (e.g., bacterial mats and ciliates) or create a physical structure within which other species live (e.g., Tubeworms, Corals, Sponges, etc.).
Rare, Unique, or Endemic Species	Where the existence of a species at relatively low abundance or whose populations are globally or nationally significant within the boundaries of the area of interest (O et al. 2015). Hydrothermal vents are known to have a high percentage of endemic species associated with them (~90%), and there are at least 60 species endemic to the Juan de Fuca Ridge. These unique species are sequestered in very small areas of venting. As a result, the number of species that fulfilled this criterion is high.
Sensitive Species	Species that have a low tolerance and more time needed for recovery from stressors (O et al. 2015). This criterion mostly includes species (or families) known to be sensitive to marine pollution, or those that create a biogenic habitat known to be sensitive to disturbances with slow recovery rates.
Depleted species	Listed under SARA/COSEWIC/IUCN/BCCDC. Target and non-target species impacted beyond their sustainable level (O et al. 2015). Due to the limited data available on EHV MPA species, none of the species are listed under relevant domestic legislation, international agreements or treaties, including Species At Risk Act (SARA), Committee of the Status of Endangered Wildlife in Canada (COSEWIC), International Union for Conservation of Nature (IUCN), or British Columbia Centre for Disease Control (BCCDC).

Table 3.2: Example of species SEC criteria: habitat-creating species.

Habitat creating species	Species	Justification
Microbes and chemosynthetic bacteria	• Mainly chemolithoautotrophs • Proteobacteria • Ciliate (*Folliculina sp.)*	• Primary producers • Mostly dependent on hot vent communities • *Folliculina sp.* is a single celled animal – perhaps with symbionts. It forms extensive mats of a cobalt blue coloration, and is a primary consumer
Glass sponges	• Round Lipped Boot Sponge (*Staurocalyptus dowlingi*) • Sharp Lipped Boot Sponge (*Rhabdocalyptus dawsoni)* • Fluted Funnel Sponge (*Poliopogon mendocino*) • *Saccocalyx pedunculatus* • *Caulophacus sp.*	• Filter feeder • Forms physical habitats • Susceptible to changes in the environment • Slow to recover

Habitat creating species	Species	Justification
Corals	Soft Octocoral (*Paragorgia sp*.) Soft Octocoral (*Parastenella sp*.) Black Coral (*Lillipathes sp.*) Gorgonian (*Swiftia sp.)* Gorgonian (*Swiftia pacifica*) Black Coral (*Parantipathes sp*.) Bamboo Coral (*Keratoisis sp.)*	Filter feeder Forms physical habitats Susceptible to changes in the environment Slow to recover
Tubeworms	Tubeworms (*Ridgeia piscesae)* Pandora's Worm (*Paralvinella pandorae)* Palm Worm (*Paralvinella palmiformis)*	Primary consumers Symbiotic relationship with chemosynthetic microbes (internal symbiotic sulfide-oxidizing bacteria) Form the structural base for the hot vent community Important source of detritus to deposit feeders

In addition to the application of the species SEC criteria outlined by O et al. (2015), expert opinion was also incorporated into SEC selection (V. Tunnicliffe, R. Thomson, and K. Juniper). The final species SEC list included six invertebrates (see Table 3.5 for full list and justifications) with strong emphasis on the *nutrient importer/exporter, keystone role in the food web, habitat creating species,* and *sensitive species* criteria. While zooplankton and microbial communities fulfilled several of the selection criteria, they were not selected as a SEC in this study because the diversity, density, and distribution are independent of anthropogenic activities that occur within the EHV MPA boundary and, therefore, they are not manageable at the MPA scale. While this omission could potentially bias the scoring for ***Resilience$_c$*** factors ***AcuteChange$_c$*** and ***ChronicChange$_c$***, the habitat SECs selected encompasses the habitats of these species with the aim of including the risk of harm to both the habitat and the organisms living within them.

3.1.1.2 Habitat SECs

Some of the habitat SEC selection criteria were not applicable to the EHV MPA, due to the lack of listed status species and habitats, and the high level of endemism and sensitive species/habitats. Criteria that were relevant to EHV MPA habitat SEC selection included those supporting *biogenic habitat types*, *sensitive habitats*, and *habitats providing critical ecosystem functions or services*.

Two main benthic habitat types were initially identified as abiotic and biogenic and these types were then further divided into habitats (Table 3.3). Several of the biogenic habitats are discussed in Section 3.1.1.3 as communities. While abiotic habitat in this instance does not include oceanographic currents, it should be noted that localized flow does affect species distributions. Sarrazin et al. (1999) found that species distributions around the Juan de Fuca Ridge were significantly influenced by local physical and chemical conditions. Their study demonstrated the importance of hydrogen sulphide, visible flow intensity, and substratum type of hydrothermal species distributions. Karl (1995) also observed that temperature can limit species presence and that it had a selective effect on microbial community composition.

Expert opinion was consulted and incorporated into the selection of habitat SECs (V. Tunnicliffe, School of Earth and Ocean Sci., Univ. Victoria, Victoria, B.C.; R. Thomson, DFO Ocean Sciences, Inst. of Ocean Sci., Sydney, B.C.; K. Juniper, School of Earth and Ocean Sci., Univ. Victoria, Victoria, B.C.). Four abiotic habitats were selected because they support the highest number of biogenic habitat creating species, endemic and/or rare invertebrates, and formed the structural basis of the EHV MPA communities. See Table 3.5 for a full list of habitat SECs and justifications.

Table 3.3: Identified biogenic and abiotic habitats at EHV MPA.

Habitat Type	Habitat	Description
Biogenic	Bacterial mats	• This includes mainly chemolithoautotrophs, proteobacteria, and ciliates (*Folliculina sp*.). • Vent specific. • Basis of the food web (primary producers). • Benthic disturbance is measurable. • Support buccinid snails and a wide variety of detritovores. • Compose a major component of vent biomass. • A change in microbial mats would create a change in the food web.
	Tubeworms	• Vent specific. • Tubeworms form the basis of the main hydrothermal vent communities in succession. • The extensive 3-dimensional structure created by tubes of the vestimentiferan *Ridgeia piscesae* can greatly increase (up to 28 times) space available for colonization by other sulfide edifice species, thereby augmenting organism density per m^2 of edifice surface. • Noted to be particularly sensitive to changes and suggested indicators. This community supports a large number of organisms and is key in the food web, making this habitat an appropriate indicator of disturbance.
	Clam Beds	• Vent specific. • Limited area (restricted by sediments). • Created by *Calyptogena cf. pacifica* and bacterial mats.
	Glass sponges	• Both vent and non-vent areas. • Created by species including: *Staurocalyptus dowlingi, Rhabdocalyptus dawsoni, Poliopogon mendocino, Saccocalyx pedunculatus,* and *Caulophacus sp*. • Little data is available of the location that these species are found and how they were identified. There are no studies that examine the abundance and distribution of sponges in and around the EHV MPA. • Known to attach themselves to hard substratum (where minimal sediments occur) in high-flow areas. This may include dormant chimneys or on the basalt floors of the area between the vents. • They are a sensitive habitat susceptible to damage (through either benthic fishing methods or increased sedimentation and bioturbation), with a slow recovery rate (unlikely recovery after disturbance).

Habitat Type	Habitat	Description
	Corals	- Both vent and non-vent areas. - Created by species including: *Paragorgia sp., Parastenella sp., Lillipathes sp., Swiftia sp., Swiftia pacifica, Parantipathes sp., Keratoisis sp*. - Little data is available of the location of these species at EHV MPA and how these species were identified. The distribution of coral communities in and around the vents is yet to be studied. - Known to attach to hard substratum (where minimal sediments occur) in high-flow areas, which may include dormant chimneys or on the basalt floors of the area between the vents. - They are a sensitive habitat susceptible to damage with a slow recovery rate.
Abiotic	Venting hydrothermal mineral chimneys	- These sulfide 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, tubeworms, corals and sponges. - Diffuse and venting chimneys support most assemblages of organisms in 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.
	Diffuse venting basalt flows	- Lower temperature venting (relative to chimneys). - Diffuse venting through the valley floor basalts usually sponsors dense tubeworm bushes or clam beds. Estimates of abundances could range up to half a million animals in a square meter in the diffuse flows and the sulphide structures.
	Inactive hydrothermal chimneys	- Hot spot for discovering new species. - Unique microbial communities present. - Supports biogenic habitat creating species such as corals and sponges.
	Hydrothermal plume	- Extends up to 300 m into the water column to a height of neutral plume buoyancy. - It is strongly influenced by the hydrothermalism and current velocity. - The region 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.

Habitat Type	Habitat	Description
	Basalt in between and outside of venting area	• Basalt covers the roughly 2 km of seafloor between adjacent vent fields. • The floor of the axial valley is not sedimented because it is too young geologically to accumulate planktonic sediments. The bare rock is glassy black basalt that forms a rugged, broken terrain. • Supports the biogenic habitat creating corals and sponges.

3.1.1.3 Community/ecosystem properties SECs

The EHV MPA ecosystem is based on the derivation of energy from chemical compounds in vent plumes, specifically hydrogen sulphide, carbon dioxide, and methane. While studies have identified distinct communities (Dancette and Juniper 2007; Sarrazin et al. 1999), it was difficult to isolate the communities from each other. Due to the interconnectivity of hydrothermal communities, we found that the most effective method of selecting community/ecosystem SECs was by first identifying the functional groups (Table 3.2), then the relevant community groups. The number of community SECs selected was restricted to one, due to issues with the **_Recovery_**$_c$ scoring criteria (discussed in detail in Section 3.2.2.3). In light of these issues, the community SEC selected (benthic clam bed community) was unique, ecologically significant, and sensitive to disturbances, but also located within an extremely limited, relatively small area. This community at the EHV MPA has not been well studied, and was identified through expert opinion (V. Tunnicliffe, School of Earth and Ocean Sci., Univ. Victoria, Victoria, B.C., pers. comm.) as an important community that should be included in this risk assessment.

Table 3.4: Community functional groups identified at EHV MPA from literature and examples.

Community (functional)	Example
Primary producers	• Microbial communities (includes benthic bacterial mats) • Hydrothermal plume zooplankton community
Primary consumers	• Tubeworms • Clams
Secondary consumers	• Gastropods • Scale Worms
Tertiary consumers	• Eel Pouts and Rattails
Top-level consumers	• Spider Crabs, Octopus, etc.

3.1.1.4 EHV MPA SEC list

When analysing the lists of species, habitats, and communities at the EHV MPA, it became apparent that while there are several single species that influence the ecosystem, few species could be singled out as key factors. In order to analyse the ecosystem better as a whole, habitats that could support a large range of significant species were selected. Species, habitats, and communities that were repeated across the categories were given higher weighting, and the final SEC list reflects the emphasis placed on importance to ecosystem function and food web. The selected EHV MPA SECs are presented in Table 3.5.

Table 3.5: Endeavour Hydrothermal Vents Marine Protected Area Significant Ecosystem Components and their selection justification.

SEC Type	SEC	Justification for selection
Species	*Ridgeia piscesae (high flux)* (Tubeworm)	Vestimentiferan *Ridgeia piscesae* are extremely abundant at active venting sites within 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. (2014) 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. 2014). 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 (V. Tunnicliffe, School of Earth Ocean Sci., Univ. Victoria, Victoria, B.C., *pers. comm.*, Dec 2013). Results so far indicate that *R. piscesae* (high flux) may play a significant role in population of *R. piscesae* species in EHV MPA (V. Tunnicliffe School of Earth Ocean Sci., Univ. Victoria, Victoria, B.C., *pers. comm*., Dec 2013). Alvinellidae of the genus *Paralvinella* are frequently associated with vestimentiferan worms (Desbruyeres et al. 1985; 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 • 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 (1991), its anatomy suggests that it could also graze the Tubeworms and rock surfaces that it colonises (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

SEC Type	SEC	Justification for selection
		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), 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 the EHV MPA, *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 surface 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 (Sulfide Worm)	Lives in mucous tubes on the actively growing portions (hottest parts) of sulphide mineral chimneys and is considered to be the 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. *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 worm 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

SEC Type	SEC	Justification for selection
		tubeworms. Diffuse and venting chimneys support most assemblages of organisms in 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 support endemic species specific to this habitat. In addition, these structures are 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 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 can change considerably over a tidal period due to the changes in strength and direction of the net current (mean plus time varying) (R Thomson, DFO, Inst. Ocean Sci., Sydney, B.C., *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. 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	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

SEC Type	SEC	Justification for selection
	flows	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
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

3.1.2 Identification of Activities and Associated Stressors

Anthropogenic activities at the EHV MPA have been restricted primarily to scientific research, occasional vessel traffic, and limited fishing since its official designation as a MPA in 2003. DFO Oceans Management provided a list of anthropogenic activities with the potential to negatively affect the EHV MPA, which focus on vessels, research, and seismic surveys. PoE models of each activity were used to identify associated stressors with the potential to interact with the SECs. A full list of activities and associated stressors identified from the PoE models is presented in Table 3.6 and described below. The interaction between the identified stressors and EHV MPA SECs is discussed in detail in Section 3.2.1.

Table 3.6: EHV MPA activities and associated stressors provided by Oceans Canada.

Activity	Associated stressors
Discharge	Aquatic invasive species
	Debris
	Oils / contaminants
	Nutrients
Oil spill	Oil
Equipment abandonment	Introduction of foreign material
	Contamination
Equipment installation	Substrate disturbance (crushing)
	Substrate disturbance (resuspension)
	Light disturbance
	Noise disturbance
Sampling	Removal of organisms

Activity	Associated stressors
	Substrate disturbance (crushing)
	Substrate disturbance (resuspension)
Submersible operations	Substrate disturbance (crushing)
	Substrate disturbance (resuspension)
	Light disturbance
	Noise disturbance
	Aquatic invasive species
Seismic testing / air guns	Sound generation

3.1.2.1 Discharge

Discharge from vessels may include: *aquatic invasive species* from hull fowling, chest fowling, and ballast water; *debris* from waste disposal and lost cargo; *oils/contaminants* from ballast and bilge water, lost cargo, and waste disposal; and *nutrients* from waste disposal, lost cargo, sewerage and grey water. There are no data quantifying the concentration or frequency of vessel discharge released at the EHV MPA. Few vessels transit through the EHV MPA; however, research and fishing vessels are stationed at the EHV MPA for up to a month at a time, exposing the EHV MPA ecosystem to potential stressors associated with discharges.

3.1.2.2 Oil spill

Oils spilled into marine environments are comprised of a complex suite of several thousand hydrocarbon and synthetic substances. The environmental impacts of an oil spill can be catastrophic and result in direct mortality of marine organisms in addition to sub-lethal effects that can persist for years after the spill. There have been no reports of an oil spill of any size in the vicinity of the EHV MPA. However, with vessel traffic in the region, it cannot be ruled out as a potential stressor to the EHV MPA ecosystem.

3.1.2.3 Equipment abandonment

Stressors associated with equipment abandonment include: *contaminants* (oil/contaminant seepage); and, the *introduction of foreign material*. Scientific research is the primary source of abandoned equipment at the EHV MPA, which is particularly prevalent in deep-sea installations where equipment may be easily lost during deployment and retrieval using remotely operated vehicles (ROVs). In this context abandoned equipment includes only lost/discarded equipment, and not equipment installed on the sea floor (such as Oceans Network Canada equipment). Equipment abandonment at the EHV MPA occurs annually and may include cable ties, lost sampling traps, malfunctioning cables, submersible weights, etc.

3.1.2.4 Equipment installation

Stressors associated with equipment installation include: *substrate disturbance (crushing); substrate disturbance (sediment resuspension); light disturbance*; and *noise disturbance*. The EHV MPA is part of the Oceans Network Canada underwater observatory, and is subjected to annual equipment installation/maintenance activities. Installed equipment includes oil-filled cables, instrument platforms, nodes, instruments, etc. Equipment installation at the EHV MPA requires the use of submersibles, which have associated stressors similar to that of equipment installation. However, the stressors associated with equipment installation are limited to the act of installation only and do not take into consideration the presence/impact of submersibles.

3.1.2.5 Sampling

Stressors associated with sampling include: *removal of biological material; substrate disturbance (crushing);* and, *substrate disturbance (sediment resuspension)*. At hydrothermal vents, there is a shift in research priorities from exploration and discovery to those emphasising temporal processes through observation, often involving geological, biological, or geochemistry sampling. The removal of organisms during sampling of hydrothermal vents may occur during geological sampling (e.g., chimney removal), through environmental manipulation experiments (such as clearance experiments where organisms are removed in order to sample the hydrothermal fluids for geochemistry analysis), or through direct sampling of organisms. Direct impacts include chimney (habitat) removal, environmental manipulation, clearing fauna, faunal transplantation between sites, and instrument placement and boring. Substrate disturbance may occur through direct geological or biological sampling, or by accidental disturbance by associated sampling equipment (e.g., box grab samplers).

3.1.2.6 Submersible operations

Research conducted at the EHV MPA is limited to the use of either manned submersibles or remotely operated vehicles used to install and maintain equipment, make observations, and take samples. Submersibles are machines with high momentum with which navigation may be difficult, especially around hydrothermal vent sites. The stressors from submersible use include: *introduction of invasive species*; *light disturbance; noise disturbance; substrate disturbance (crushing);* and, *substrate disturbance (sediment resuspension)*. Submersible operations occur annually at the EHV MPA, with single dives often exceeding 24 hours.

3.1.2.7 Seismic testing/air guns

Scientists use seismic surveys to map the seafloor and look for geological features. The offshore oil and gas industry also uses seismic surveys to help determine the location of oil and gas deposits beneath the seafloor. In general, there was little information available on exposure to air gun blasts at the EHV MPA ecosystem. Seismic surveys have occurred at the EHV MPA approximately every four years in the past 20 years.

3.2 LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT

3.2.1 SEC-Stressor Interaction Matrix

The SEC-stressor interaction matrix is presented in Appendix F, showing potential negative interactions between identified stressors and selected SECs. Most notably, the hydrothermal plume (habitat SEC) did not have any direct negative interaction with the stressors. While indirect impacts were considered, including the impact of *substrate disturbance (crushing)* on the volume and density of the plume, the focus of this application of the ERAF was direct impacts only. As a result, scoring of this SEC could not proceed and it fell out of the risk assessment at this stage.

Not all activities and stressors identified from the PoE models (listed in Table 3.6) had the potential to impact the SECs due to the remote nature of the EHV MPA (~2,200 m below sea surface). Several *discharge [vessels]* stressors had the potential to only impact the surface or non-pelagic zone of the MPA. These stressors included *aquatic invasive species* (as species living in the ballast waters of a vessel are unlikely to survive the change in pressure and temperatures between the surface and seafloor), *oils/contaminants* (as this is a point source from ballast water the volumes are likely relatively low and will mostly remain in the surface layer), and *nutrients* (any resulting algal bloom resulting from nutrient discharge will primarily impact the surface layer).

Many stressors had the potential to affect biotic (species and community) SECs, but not abiotic (habitat) SECs. For example, *sound generation [seismic testing/air guns]* may cause harm to the Tubeworm *Ridgeia piscesae*, but not to inactive hydrothermal chimneys. The only stressors capable of negative interaction with habitat SECs were *substrate disturbance (crushing)*. As a result, habitat SECs had the lowest number of potential interactions with stressors.

Some potential positive interactions (where the SEC benefits from interaction with the stressor) were identified. For example, the *introduction of foreign material [equipment abandonment]* may provide a new settling location for larvae or a new habitat that would improve the survival of a SEC. However, these positive interactions were not included in the matrix, as this interaction is not accounted for in the ERAF scoring rubric.

Fishing was not on the initial list of activities with the potential to impact the EHV MPA provided by DFO Oceans Management and it was not included in our analysis. The EHV MPA is subjected to occasional commercial fishing for Albacore Tuna and Neon Flying Squid. However, any commercial fishing within the MPA takes place very near the ocean surface, and is not thought to significantly affect the EHV MPA benthic ecosystem (DFO 2009).

3.2.2 Computation of Risk

Note that all scoring data is provided through Canada's Open Data initiative. Supporting files with rationale for scores and species lists are available from the authors upon request. Links to the appropriate data repository are included in the Appendices, where appropriate.

3.2.2.1 Risk of exposure to a SEC from a single stressor

Quantitative data were not available on the overlap between EHV MPA SECs and anthropogenic activities (and associated stressors). While work is currently being undertaken by DFO Oceans Management to compile information on the location and density of activities occurring at EHV MPA, at the time of this study very little information was available. This lack of information resulted in higher uncertainty associated with scored ***Exposure***$_{sc}$ variables, in particular, ***Area overlap***$_{sc}$, ***Depth overlap***$_{sc}$, and ***Intensity(amount)***$_{sc}$.

3.2.2.2 Exposure$_{sc}$ factors

Very little information was publically available at the time of this study as to the aerial extent (***Area overlap***$_{sc}$) of both the SECs and the stressors at the EHV MPA. Due to the benthic nature of EHV MPA SECs, the depth component (***Depth overlap***$_{sc}$) was scored as high potential overlap. The ***Temporal overlap***$_{sc}$ between the SECs and the associated research stressors was calculated from data provided by InterRidge (2000) on the historical number of research trips to the EHV MPA per annum. This calculation is the average of two one-month long cruises per annum during which these cruises visited other sites (i.e., the full two months is rarely spent solely at the EHV MPA). This approach resulted in scoring all stressors requiring the use of *submersible operations* as low (2:1-20% temporal overlap) with very low uncertainty. ***Temporal overlap***$_{sc}$ between the EHV MPA SECs and stressors resulting from vessels (surface), were analysed separately due to the unknown amount of traffic (separate of research vessels) in the area and lack of temporal vessel restrictions. ***Intensity(amount)***$_{sc}$ was interpreted from O et al. (2015) as the density of the stressor independent of the SEC. For example, the intensity of *oil [oil spill]* was scored as high (4) for species SECs, due to the potential for a spill to include high volumes of oil concentrated around the spill area. Information on the frequency of stressors (***Intensity(amount)***$_{sc}$) occurring at the EHV MPA (independent of the SEC) was available through primary literature and expert opinion, and were scored with the lowest uncertainty. All ***Exposure***$_{sc}$ scores and justifications are presented in Appendix G.

Throughout this study, we encountered the issue of how to score specific areas within the MPA that are zoned as “off-limits” for sampling. While venting sites ‘Salty Dawg’ and ‘High Rise’ are zoned as off-limits, except for minimally intrusive study, permission to sample within these sites is still granted for biological sampling of organisms. Therefore, while perhaps less vulnerable, these areas and the SECs within them may still be exposed to the same stressors. We felt that it was important to capture the impact of current scientific research activities occurring throughout the entire EHV MPA, rather than focusing on particular areas, so exposure was scored the same throughout the entire EHV MPA.

3.2.2.3 Resilience$_c$ factors

Resilience$_c$ factors ***AcuteChange***$_c$ and ***ChronicChange***$_c$ for each SEC are presented in Appendix G. While the scoring for species SECs was straight forward, the scoring of habitat and community SECs required some interpretation of the ERAF scoring rubric. Habitat SECs could only be scored on the basis of a loss of aerial coverage of the habitat, as they included only abiotic habitats. Scoring was further complicated by the lack of information on the aerial extent of these habitats. The interpretation of ***Resilience***$_c$ factors for community/ecosystem SECs proved to be a difficult task, due to the unknown number of species and functional groups in the benthic clam bed community. As a result, the aerial extent and productive capacity (habitat ***Resilience***$_c$ factors) were used as a guide for scoring instead.

At this stage in the scoring, several stressors fell out of the risk assessment and were not included in the final count of stressors, or final estimated risk scores. This reduction occurred when a stressor was scored as zero for both ***AcuteChange***$_c$ and ***ChronicChange***$_c$, and therefore had no impact on the SEC. Both *light disturbance* and *noise disturbance* for *equipment installation* and *submersible operations* were removed from the risk assessment for all SECs for this reason (see Appendix G for justifications).

We distinguish between scoring ***Resilience***$_c$ factors based on a ‘current snapshot’ and ‘potential’ stressors. A current snapshot represents activities that are known to currently occur at the EHV MPA. Potential stressors include those that occur infrequently and/or unpredictably, and include *aquatic invasive species [submersible operations]*, *debris [discharge],* and *oil [oil spill]*. While scoring of current snapshot stressors was straightforward, scoring of potential stressors required allocating scores based on the worst-case scenario. This difference means that *aquatic invasive species [submersible operations]* was scored as establishment of an aquatic invasive species (rather than exposure to propagule), *debris [discharge]* was scored based on the debris type being capable of crushing, and *oil [oil spill]* was scored based on a large-scale tanker spill.

3.2.2.4 Recovery$_c$ factors

Several **Recovery**$_c$ factors were found to be more applicable to the EHV MPA species SECs than others. *Fecundity, population connectivity*, and *age at maturity* were applicable to marine invertebrates, while several **Recovery**$_c$ factors were applicable only to fish populations (including *breeding strategy, recruitment pattern, natural mortality rate, maximum age, maximum size,* and *von Bertalanffy growth coefficient*). The **Recovery**$_c$ factor *listed status* was not applicable to any SEC, as there are no currently listed organisms at the EHV MPA. Two to three **Recovery**$_c$ factors were scored for each SEC (Table 3.7). See Appendix G for all **Recovery**$_c$ scores and justifications.

Table 3.7: The number of ***$\textit{Recovery}_c$*** *factors scored for each SEC.*

SEC Type	SEC	Scored ***$\textit{Recovery}_c$*** factors
Species	*Ridgeia piscesae* (high flux)	3
	Ridgeia piscesae (low flux)	3
	Paralvinella sulfincola	2
	Paralvinella palmiformis	3
	Lepetodrilus fucensis	3
	Macroregonia macrochira	2
Habitat	Active venting hydrothermal mineral chimneys	2
	Inactive hydrothermal chimneys	2
	Diffuse venting basalt flows	2
Community	Benthic clam bed community	3

Most ***$\textit{Recovery}_c$*** factors for habitat catered to biogenic habitats rather than abiotic habitat SECs with the exception of *frequency of natural disturbance, distribution range/fragmentation,* and the *connectivity rating*. Some factors specific to biogenic habitats were adapted to abiotic habitat types as they applied to the EHV MPA habitat SECs. For example, the *age at maturity/recovery time* could be estimated for substratum features such as active vents due to their ability to regenerate/continue to develop.

Attempts to apply the ***$\textit{Recovery}_c$*** factors for community/ecosystem SECs proposed by O et al. (2015) benthic clam bed community SEC were unsuccessful. These factors required detailed information on the number of species and functional groups relative to a known population baseline. As this information was not available for the EHV MPA benthic clam bed community, it was initially scored as a precautionary high for all categories. However, scoring a precautionary high proved to be inconsistent with the scoring approach for other SECs for which data were available (i.e., lower uncertainties). In addition to the lack of information on the populations of the benthic clam bed community, the criteria suggested by O et al. (2015) are relative measures, and the criteria used to judge this relative scale were not specified. For example, species richness included three categories of high, medium, and low. As a result, the benthic clam bed community was scored using habitat SEC ***$\textit{Recovery}_c$*** factors (similar to those in Hobday et al. 2007).

3.2.2.5 Uncertainty

Uncertainty was scored higher for ***$\textit{Exposure}_{sc}$*** than for ***$\textit{Consequence}_{sc}$*** because we lacked quantitative data on the overlap between stressors and SECs and because there was more information available on the consequences of interactions between a stressor and either the SEC specifically or with a related species/habitat. Potential stressors, such as *aquatic invasive species [submersible operations], oil [oil spill],* and *debris [discharge]* had higher uncertainty scores than ‘current snap-shot’ stressors (stressors known to currently occur at EHV MPA), such as those associated with *submersible operations* and *sampling*.

3.2.2.6 Relative risk ($\textbf{Risk}_{sc}$)

Median **$\textbf{Risk}_{sc}$** scores and associated uncertainties were calculated for each SEC, as were the **$\textbf{Consequence}_{sc}$** and **$\textbf{Exposure}_{sc}$** scores (Figure 3.1; Figure 3.2; Figure 3.3). The resultant plots highlight the uncertainty of each variable and the degree to which **$\textbf{Exposure}_{sc}$/$\textbf{Consequence}_{sc}$** drives the estimated **$\textbf{Risk}_{sc}$** scores. Species and community SECs achieved similar **$\textbf{Risk}_{sc}$** scores. The four stressors that had the highest estimated **$\textbf{Risk}_{sc}$** scores for each SEC are presented in Table 3.8 along with the mean **$\textbf{Exposure}_{sc}$** and **$\textbf{Consequence}_{sc}$** scores used to create the **Risk$_{\text{sc}}$** score (full results are presented in Appendix H). Potential stressors *debris [discharge]*, *aquatic invasive species [submersible operations]*, and *oil [oil spill]* were in the top four stressors for all species and community SECs (Figure 3.1; Figure 3.2), with the exception of *Paralvinella sulfincola* (sulfur worm) where *oil [oil spill]* was the fifth highest stressor. *Debris [discharge]* had high uncertainty associated with **Exposure$_{\text{sc}}$** (Figure 3.1B; Figure 3.2B), and consistently had the highest mean **Exposure$_{\text{sc}}$** score paired with a low mean **Consequence$_{\text{sc}}$** score (Table 3.8). While *aquatic invasive species [submersible operations]* did not have notably high uncertainty, it consistently achieved the highest **Consequence$_{\text{sc}}$** scores (Figure 3.1B; Figure 3.2B), paired with low mean **Exposure$_{\text{sc}}$** (Table 3.8). Equipment installation stressors *substrate disturbance (crushing)* and *substrate disturbance (sediment resuspension)* achieved the lowest **Risk$_{\text{sc}}$** scores for species and community SECs with low associated uncertainties (Figure 3.1; Figure 3.2). Two species SECs that stood out were *Ridgeia piscesae* (high flux) (tubeworm) and *Paralvinella sulfincola* (sulfur worm). They achieved higher estimated **Risk$_{\text{sc}}$** scores than other species and community SECs for sampling stressors *removal of organisms* and *substrate disturbance (crushing)* with low to moderate associated uncertainties (Figure 3.1), and relatively high estimated mean **Exposure$_{\text{sc}}$** and **Consequence$_{\text{sc}}$** (Table 3.8). *Ridgeia pisescae* (high flux) (Tubeworm) achieved the highest estimated **Risk$_{\text{sc}}$** scores overall with 56.8 and 56.3 for *removal of organisms [sampling]* and *substrate disturbance (crushing) [sampling]* respectively (Figure 3.1). The associated mean **Exposure$_{\text{sc}}$** and **Consequence$_{\text{sc}}$** scores driving this score were also nearly identical (Table 3.8).

The three habitat SECs achieved similar estimated **Risk$_{\text{sc}}$** scores. Inactive hydrothermal chimneys had the highest estimated **Risk$_{\text{sc}}$** scores, and diffuse venting basalt flows the lowest estimated score. *Debris [discharge]* had the highest estimated median **Risk$_{\text{sc}}$** score for habitat SECs (Figure 3.3), corresponding with the highest associated uncertainty (Figure 3.3A), which was driven by **Exposure$_{\text{sc}}$** uncertainty (Figure 3.3B). S*ubstrate disturbance (crushing) [sampling]/[submersible operations]* had lower estimated **Risk$_{\text{sc}}$** scores, with lower associated uncertainty. *Substrate disturbance (crushing) [equipment installation]* had the lowest estimated median **Risk$_{\text{sc}}$** score for habitats, with the lowest associated uncertainty, driven by low **Exposure$_{\text{sc}}$** uncertainty.

Overall, the highest estimated **Risk$_{\text{sc}}$** scores were associated with the highest uncertainties, and similarly, the lowest estimated **Risk$_{\text{sc}}$** scores were associated with the lowest uncertainties. In most cases the uncertainty associated with **Exposure$_{\text{sc}}$** was higher than the uncertainty associated with **Consequence$_{\text{sc}}$** (Figure 3.1; Figure 3.2; Figure 3.3).

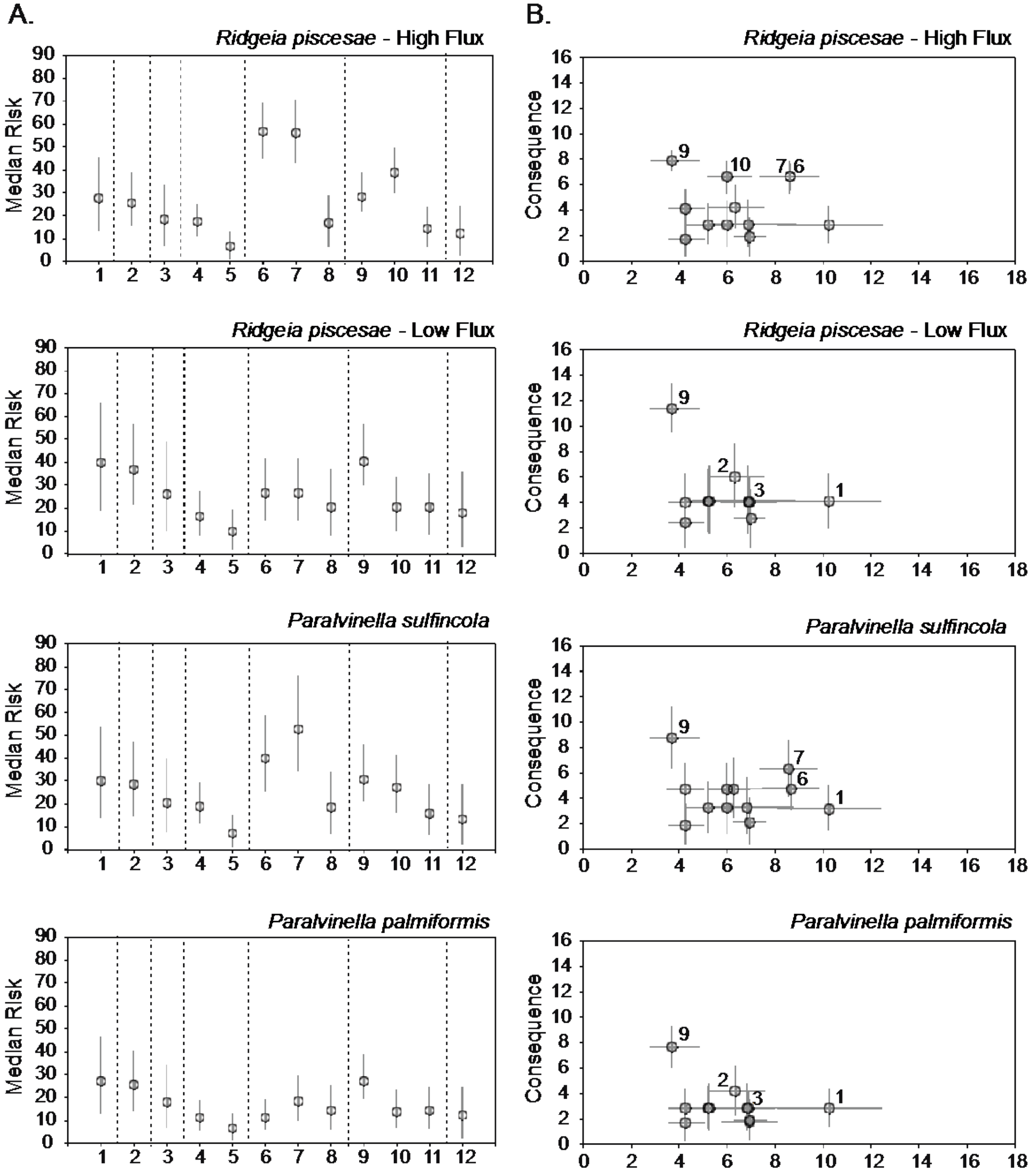

Figure 3.1: Median risk scores and Exposure/Consequence plots for species SECs: Ridgeia piscesae (high flux), Ridgeia piscesae (low flux), Paralvinella sulfincola, and Paralvinella palmiformis. ***A.*** *Median risk scores for the above SECs with stressors numbered as: (1) debris [discharge]; (2) oil [oil spill]; (3) increased contamination [equipment abandonment]; (4) substrate disturbance (crushing) [equipment installation]; (5) substrate disturbance (sediment resuspension) [equipment installation]; (6) removal of organisms [sampling]; (7) substrate disturbance (crushing) [sampling]; (8) substrate disturbance (sediment resuspension) [sampling]; (9) aquatic invasive species [submersible operations]; (10) substrate disturbance/crushing [submersible operations], (11) substrate disturbance (sediment resuspension) [submersible operations],and; (12) sound generation [seismic testing/air guns].* ***B.*** *Exposure/consequence plots showing the four stressors with the highest risk scores labelled (numbering corresponds to that of A.), and the associated uncertainty represented 10/90% error bars.*

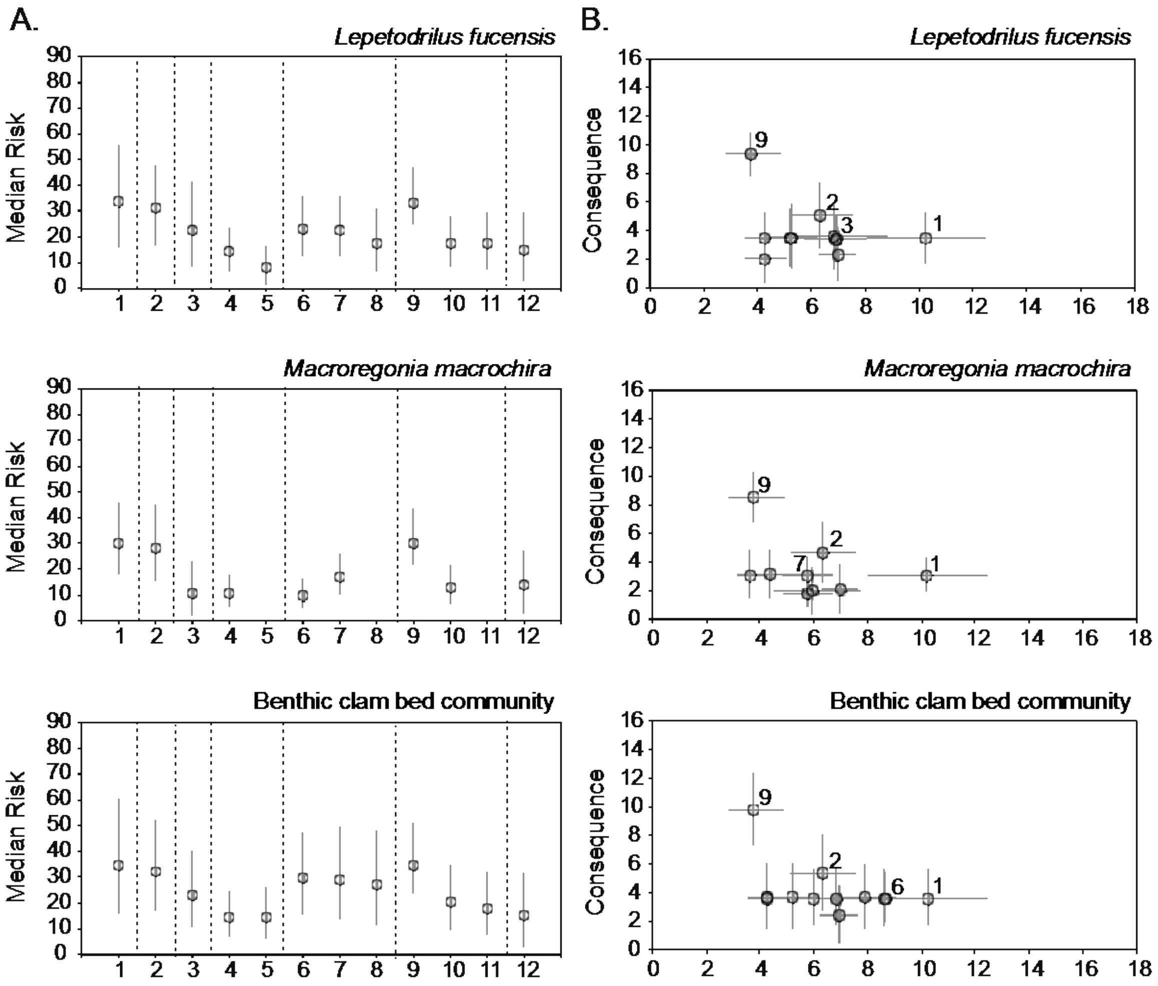

Figure 3.2: Median risk scores and Exposure/Consequence plots for species and community SECs: Lepetodrilus fucensis (species SEC), Macroregonia macrochira (species SEC), and benthic clam bed community (community SEC). **A.** Median risk scores for the above SECs with stressors numbered as: (1) debris [discharge]; (2) oil [oil spill]; (3) Increased contamination [equipment abandonment]; (4) substrate disturbance (crushing) [equipment installation]; (5) substrate disturbance (sediment resuspension) [equipment installation]; (6) removal of organisms [sampling]; (7) substrate disturbance (crushing) [sampling]; (8) substrate disturbance (sediment resuspension) [sampling]; (9) aquatic invasive species [submersible operations]; (10) substrate disturbance/crushing [submersible operations], (11) substrate disturbance (sediment resuspension) [submersible operations],and; (12) sound generation [seismic testing/air guns]. **B.** Exposure/consequence plots showing the four stressors with the highest risk scores labelled (numbering corresponds to that of A.), and the associated uncertainty represented 10/90% error bars.

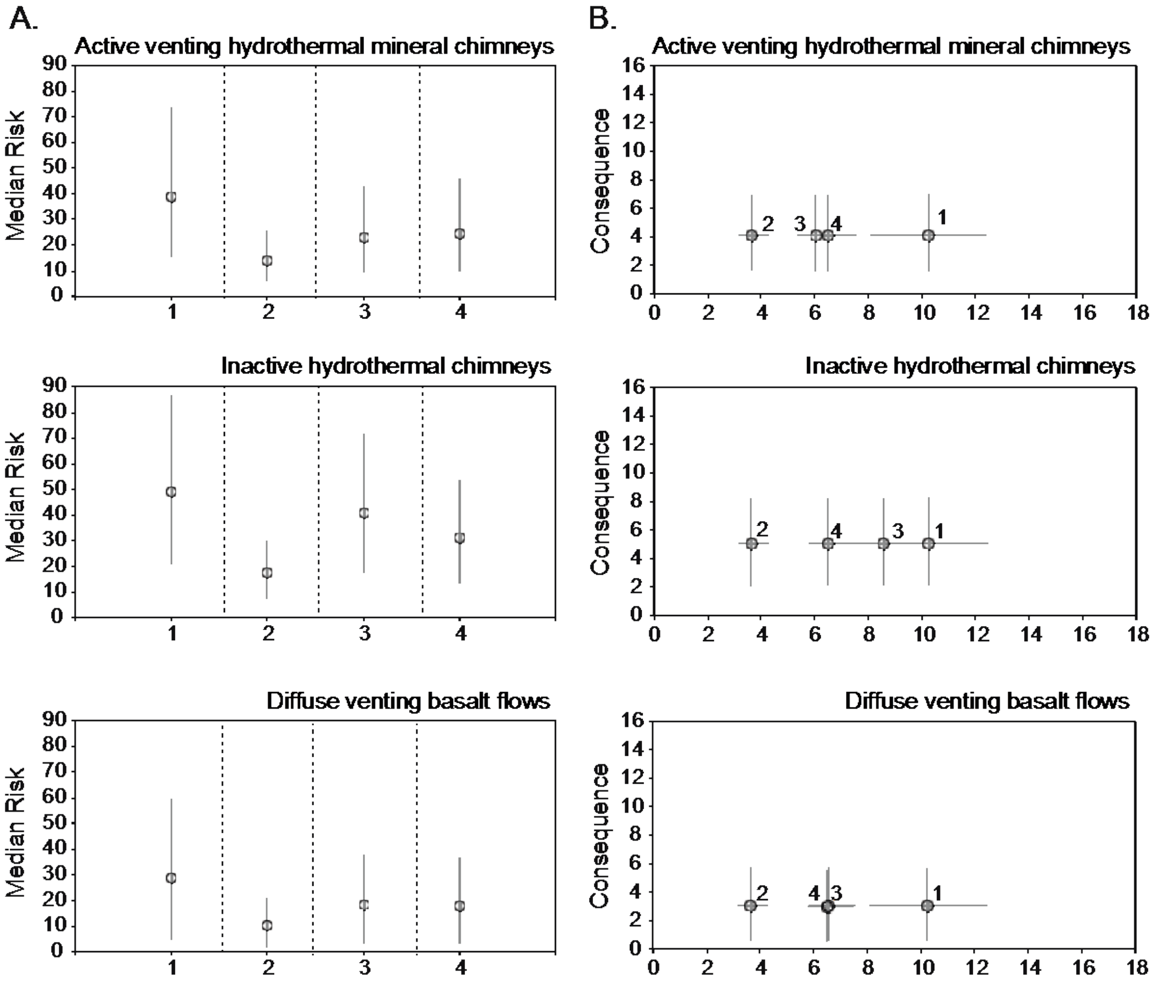

Figure 3.3: Median risk scores and Exposure/Consequence plots for habitat SECs: active venting hydrothermal mineral chimneys, inactive hydrothermal chimneys, and diffuse venting flows. **A**. Median risk scores for habitat SECs with stressors numbered as: (1) debris [discharge]; (2) substrate disturbance/crushing [equipment installation]; (3) substrate disturbance/crushing [sampling], and; (4) substrate disturbance/crushing [submersible operations]. **B**. Exposure/consequence plots showing the four stressors with the highest risk scores labeled (numbering corresponds to that of A.), and the associated uncertainty represented 10/90% error bars.

Table 3.8: The four stressors with the highest estimated ***Risk***$_{sc}$ *for each SEC showing 10/90% Quantiles, and the associated mean* ***Exposure***$_{c}$ *and* ***Consequence***$_{c}$*.*

Ridgeia piscesae (high flux) (tubeworm)

Activity	**Stressor**	**Median Risk**	**10% Quantile**	**90% Quantile**	**Mean Exposure**	**Mean Consequence**
Sampling	Removal of organisms	56.81	44.66	69.55	8.68	6.71
	Substrate disturbance (crushing)	56.28	42.92	70.66	8.47	6.75
Submersible operations	Substrate disturbance (crushing)	38.90	29.87	49.71	6.09	6.70
	Aquatic invasive species	28.16	21.32	38.93	3.78	7.87

Ridgeia piscesae (low flux) (tubeworm)

Activity	**Stressor**	**Median Risk**	**10% Quantile**	**90% Quantile**	**Mean Exposure**	**Mean Consequence**
Submersible	Aquatic invasive species	40.44	29.63	56.85	3.75	11.13

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
operations						
Discharge	Debris	39.90	18.58	66.2	10.41	4.25
Oil spill	Oil	36.93	21.55	56.58	6.44	6.01
Sampling	Substrate disturbance (crushing)	26.82	14.45	41.99	6.82	4.18

Paralvinella sulfincola (sulfur worm)

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Sampling	Substrate disturbance (crushing)	52.57	34.27	76.04	8.68	6.23
	Removal of organisms	39.77	25.16	59.06	8.67	4.91
Submersible operations	Aquatic invasive species	30.92	21.03	45.96	3.62	8.71
Discharge	Debris	30.40	13.89	53.5	10.07	3.29

Paralvinella palmiformis (palm worm)

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	27.22	12.64	46.57	10.19	2.71
Submersible operations	Aquatic invasive species	27.18	19.35	39.03	3.62	7.78
Oil spill	Oil	25.52	13.78	40.35	6.22	3.97
Sampling	Substrate disturbance (crushing)	18.65	9.76	29.48	6.98	2.86

*Lepetodrilus fucensis (*limpet)

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	33.56	15.94	56.02	10.31	3.54
Submersible operations	Aquatic invasive species	33.46	24.58	47.08	3.88	9.22
Oil spill	Oil	31.25	16.6	48.35	6.29	5.36
Sampling	Removal of organisms	23.14	12.16	35.73	6.96	3.37

Macroregonia macrochira (spider crab)

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Submersible operations	Aquatic invasive species	30.48	21.62	43.5	3.68	8.64
Discharge	Debris	30.18	18.03	46.25	10.32	3.12
Oil spill	Oil	28.34	15.4	45.07	6.34	4.67
Sampling	Substrate disturbance (crushing)	17.18	9.93	26.36	5.62	3.03

Clam bed benthic community

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	34.95	15.89	60.4	10.10	3.51
Submersible operations	Aquatic invasive species	34.71	23.71	51.42	3.68	9.86
Oil spill	Oil	32.18	16.75	52.12	6.42	5.29
Sampling	Removal of organisms	29.70	15.55	47.5	8.70	3.38

Active venting hydrothermal mineral chimneys

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	38.85	15.21	73.41	10.05	3.84
Submersible operations	Substrate disturbance (crushing)	24.69	9.83	45.83	6.43	3.86
Sampling	Substrate disturbance (crushing)	23.21	9.16	43.02	6.13	4.28
Equipment installation	Substrate disturbance (crushing)	13.77	5.68	25.56	3.57	4.34

Inactive hydrothermal chimneys

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	49.16	20.73	86.92	10.30	4.75
Sampling	Substrate disturbance (crushing)	41.04	17.28	71.69	8.60	4.89
Submersible operations	Substrate disturbance (crushing)	31.10	13.21	53.96	6.49	5.46
Equipment installation	Substrate disturbance (crushing)	17.46	7.14	30.39	3.60	5.12

Diffuse venting basalt flows

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	28.64	23.88	31.19	10.16	2.76
Sampling	Substrate disturbance (crushing)	18.40	15.26	19.36	6.59	3.16
Submersible operations	Substrate disturbance (crushing)	18.07	15.12	18.70	6.47	3.51
Equipment installation	Substrate disturbance (crushing)	10.17	8.41	11.08	3.67	3.02

3.2.2.7 Cumulative risk (CRisk$_c$)

Cumulative risk (***CRisk$_c$***) was estimated by adding the ***Risk$_{sc}$*** scores of stressors for each SEC. The results are displayed in Figure 3.4 and Table 3.9. Twelve stressors impacted species and community SECs, with the exception of *Macroregonia macochira* (Spider Crab), which was impacted by nine stressors; four stressors impacted habitat SECs. Overall, species and community SECs received higher ***CRisk$_c$*** scores than habitat SECs. Both morphologies of Tubeworm *Ridgeia pisescae* had the highest estimated ***CRisk$_c$*** scores with 332.2 (high flux) and 322.2 (low flux) (Figure 3.4; Table 3.9). Sulfur Worm *Paralvinella sulfincola* and benthic clam bed community had similar estimated ***CRisk$_c$*** scores of 320.0 and 313.8, respectively (Figure 3.4; Table 3.9). Spider Crab *Macroregonia macrochira* had the lowest estimated ***CRisk$_c$*** of the species SECs (170.0), coinciding with the lowest number of impacting stressors (9) (Figure 3.4; Table 3.9). Habitat SECs received the lowest estimated ***CRisk$_c$*** scores, coinciding with low consequence scores and number of stressors impacting them (four stressors compared with 9-12 stressors). Inactive hydrothermal chimneys had the highest estimated ***CRisk$_c$*** score of the habitat SECs, and diffuse venting basalt flows had the lowest estimated ***CRisk$_c$*** score (Figure 3.4; Table 3.9).

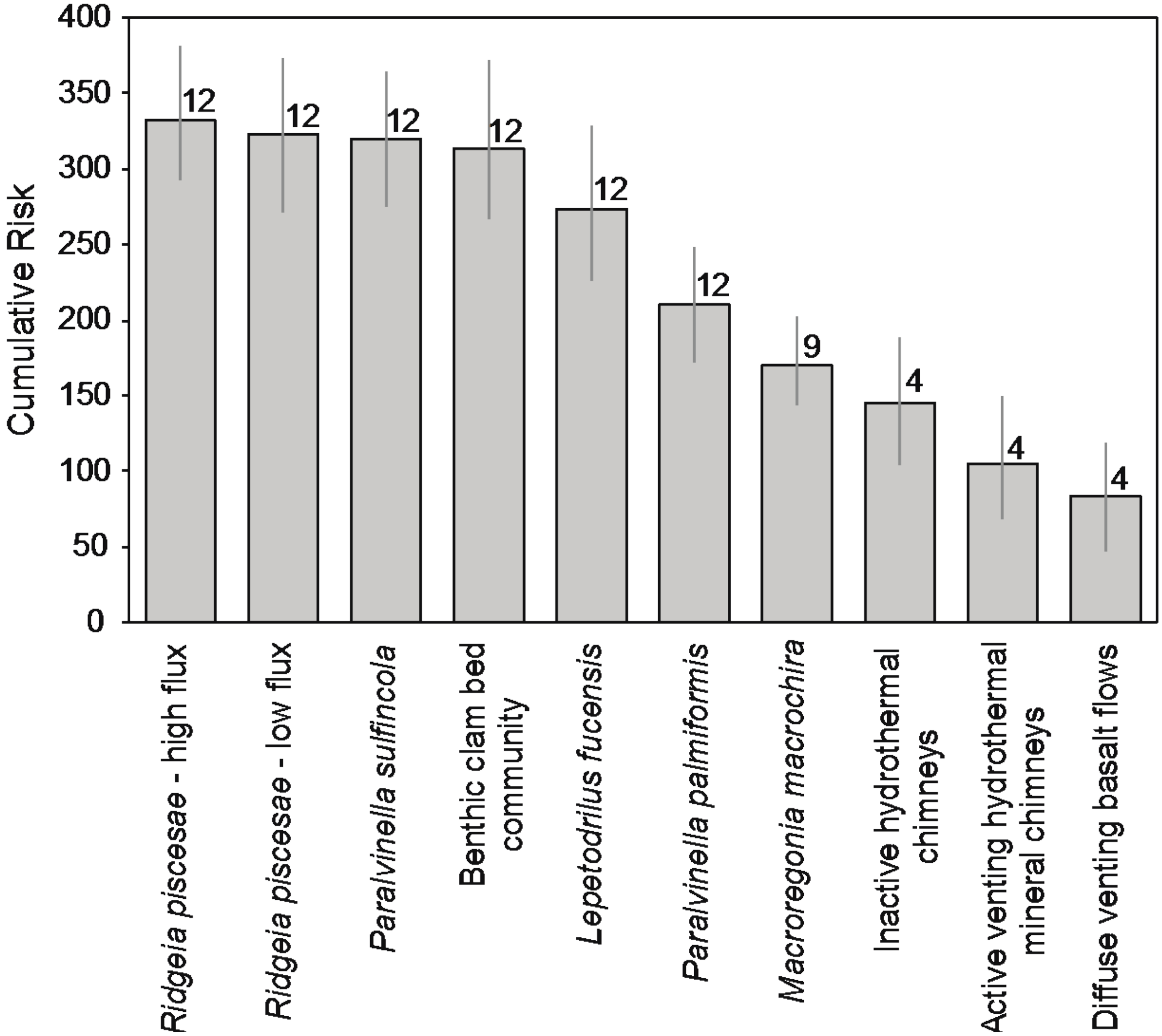

Figure 3.4: Estimated ***CRisk$_c$*** *for each SEC, ranked in descending order with 10/90% error bars. Numbers above columns denote the number of stressors applicable to that SEC.*

Table 3.9: Estimated ***CRisk$_c$*** *for all SECs, showing 10/90% quantiles and the number of stressors contributing to the score.*

Stressor	**SEC type**	**Cumulative Risk**	**10%Q**	**90%Q**	**Stressor Count**
Ridgeia piscesae - high flux	Species	332.26	292.41	381.36	12
Ridgeia piscesae - low flux	Species	322.24	270.93	373.67	12
Paralvinella sulfincola	Species	320.02	274.78	365.02	12
Clam bed benthic community	Community	313.77	266.22	372.9	12
Lepetodrilus fucensis	Species	272.66	224.74	329.7	12
Paralvinella palmiformis	Species	209.72	171.66	248.64	12
Macroregonia macrochira	Species	170.48	143.05	202.47	9
Inactive hydrothermal chimneys	Habitat	145.66	103.93	188.46	4

Stressor	SEC type	Cumulative Risk	10%Q	90%Q	Stressor Count
Active venting hydrothermal mineral chimneys	Habitat	105.58	67.42	149.69	4
Diffuse venting basalt flows	Habitat	82.65	46.9	118.26	4

3.2.2.8 Cumulative risk by stressor (Potency$_s$)

Cumulative risk by stressor (**Potency$_s$**) was calculated by adding the **Risk$_{sc}$** for each stressor across SECs together. The results are displayed in Figure 3.5 and Table 3.10. The number of SECs contributing to the estimated **Potency$_s$** scores ranged between six and ten. *Debris [discharge]* had the highest estimated **Potency$_s$** score, with a score of 356.4 (10 stressors) (Figure 3.5; Table 3.10). *Substrate disturbance (crushing)* from *sampling* and *submersible operations* had the second and third highest estimated **Potency$_s$** scores with 320.7 and 240.8, respectively (Figure 3.5; Table 3.10). While the top three stressors have 10 SECs contributing to their estimated **Potency$_s$** score, the number of SECs does not necessarily translate to the highest estimated **Potency$_s$** score. For example, *substrate disturbance (crushing) [equipment installation]* also has 10 SECs contributing to the estimated **Potency$_s$** score, but is ranked seventh with a score of 154.7 (Figure 3.5; Table 3.10). *Substrate disturbance (sediment resuspension)* from *sampling, submersible operations*, and *equipment installation* have the lowest estimated **Potency$_s$** scores (six SECs each), along with *sound generation [seismic testing/air guns]* (Figure 3.5; Table 3.10).

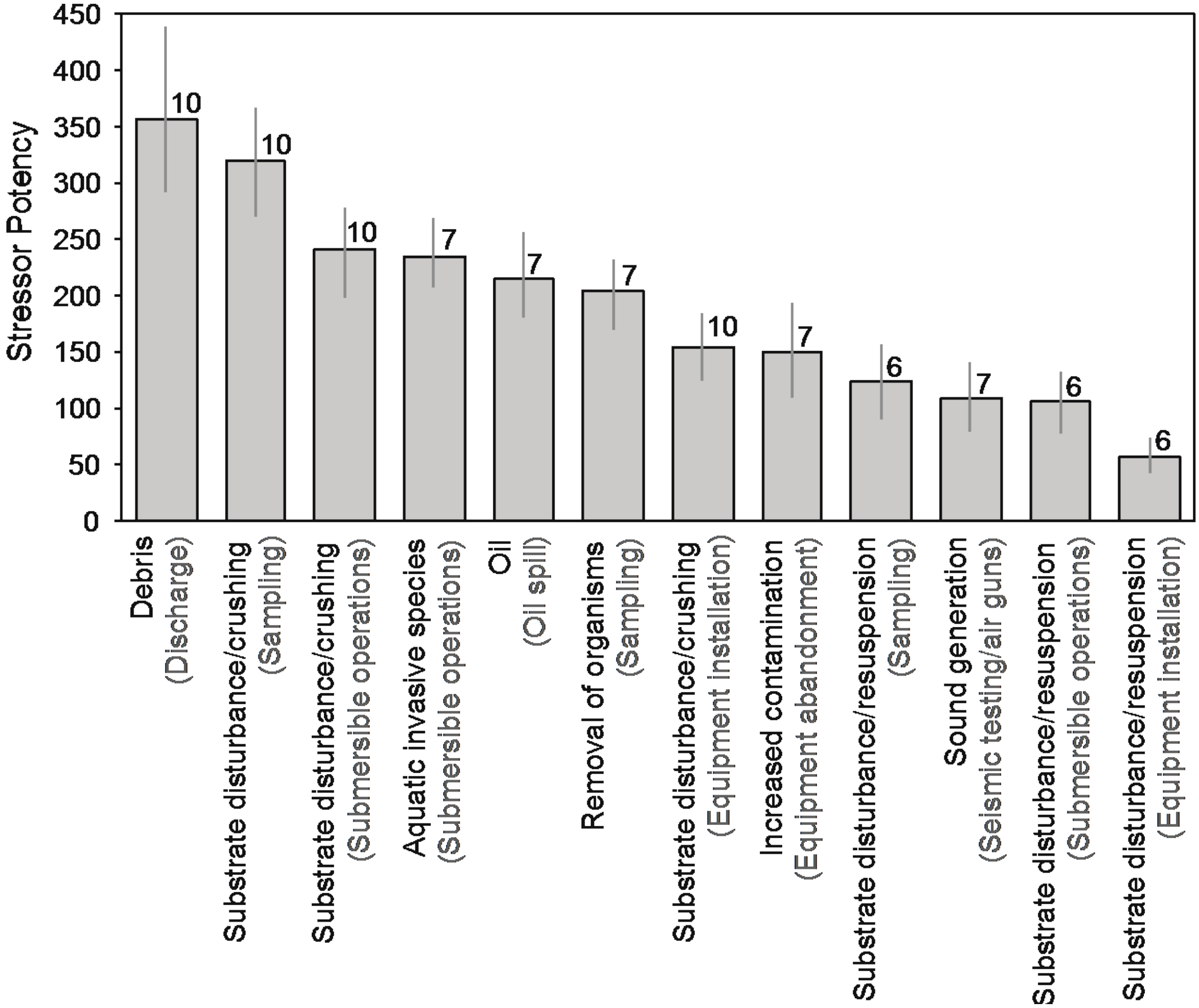

*Figure 3.5: Estimated cumulative risk by stressor (**Potency**$_s$) ranked in descending order with 10/90% quantiles, and showing the number of SECs contributing to the score.*

*Table 3.10: Estimated cumulative risk by stressor (**Potency**$_s$) ranked in descending order with 10/90% quantiles (10%Q and 90%Q), along with the number of SECs contributing to the score (#SEC).*

Activity	Stressor	Potency Score	10%Q	90%Q	#SEC
Discharge	Debris	356.36	291.68	438.42	10
Sampling	Substrate disturbance / crushing	320.65	269.79	367.58	10
Submersible operations	Substrate disturbance / crushing	240.78	197.82	278.39	10
Submersible operations	Aquatic invasive species	234.41	206.91	269.05	7
Oil spill	Oil	216.10	179.38	256.33	7
Sampling	Removal of organisms	204.11	169.37	231.99	7
Equipment installation	Substrate disturbance / crushing	154.70	122.98	185.26	10
Equipment abandonment	Increased contamination	149.83	109.2	193.31	7
Sampling	Substrate disturbance / resuspension	124.80	90.03	155.95	6
Seismic testing/ air guns	Sound generation	109.21	79.12	142.21	7
Submersible operations	Substrate disturbance / resuspension	106.85	77.11	132.45	6
Equipment installation	Substrate disturbance / resuspension	57.25	41.89	73.34	6

4 DISCUSSION

This project applied the Level 2 Risk Assessment framework proposed by O et al. (2015) to the EHV MPA in order to estimate the relative risk to the EHV MPA ecosystem from anthropogenic activities. The scoping phase identified ecological SECs that appropriately represent the EHV MPA and anthropogenic activities and associated stressors impacting the EHV MPA. The risk assessment determined the interaction between selected SECs and the stressors, and prioritised SECs and stressors on a relative scale within EHV MPA. This identification and prioritisation of SECs and stressors is vital for the selection of indicators, and ultimately the development of monitoring plans. All SECs, ranked by **CRisk**$_c$, are presented in Figure 3.4; Table 3.9. The SECs with the highest estimated **CRisk**$_c$ were *Ridgeia piscesae* (high flux), *Ridgeia piscesae* (low flux), *Paralvinella sulfincola*, and benthic clam bed community. All stressors ranked by their estimated ***Potency***$_s$ are presented in Figure 3.5; Table 3.10). The stressors with the highest estimated ***Potency***$_s$ were *debris [discharge]*, *substrate disturbance (crushing) [sampling], substrate disturbance (crushing) [submersible operations],* and *aquatic invasive species [submersible operations]*. The uncertainties identified by the risk assessment help to inform DFO Oceans Managers of knowledge gaps and identify priorities for monitoring. The highest uncertainties were associated with potential stressors *debris [discharge]*, *aquatic invasive species [submersible operations]*, and *oil [oil spill]*.

4.1 OUTCOMES OF THE LEVEL 2 RISK ASSESSMENT

Risk$_{sc}$ represents the relative estimated risk to the EHV MPA SECs by anthropogenic activities and their associated stressors. When interpreting the results, a distinction should be made between ‘current snap-shot’ and ‘potential’ stressors (‘potential’ activities are introduced in Section 2.1.2 and associated ‘potential’ stressors are described in Section 3.2.2.2). Current snapshot represents activities that we know currently occur at EHV MPA. Potential stressors include those that occur infrequently and/or unpredictably: *debris [discharge], aquatic invasive species [submersible operations],* and *oil [oil spill]*. While scoring of current snapshot stressors was straightforward, scoring of potential stressors required allocating scores based on the worst-case scenario, resulting in relatively high estimated ***Risk***$_{sc}$ and associated uncertainties, particularly for terms of ***Exposure***$_{sc}$ (Table 3.8). All three potential stressors were in the top five ***Potency***$_s$ scores (Figure 3.5). Given the unpredictable nature of these stressors and the lack of information, particularly for terms of ***Exposure***$_{sc}$, the resultant ***Risk***$_{sc}$ rankings are appropriate. However, it should be noted that the availability of more data would most likely reduce the ***Risk***$_{sc}$ for these stressors, particularly for *debris [discharge],* as discussed below.

Debris [discharge] was in the top four stressors for species and community SECs (except for Tubeworm *Ridgeia piscesae* (high flux), where *debris [discharge]* had the fifth highest ***Risk***$_{sc}$), and was the top stressor for habitat SECs (Table 3.9). Overall, *debris [discharge]* had the highest estimated ***Potency***$_s$, and had the potential to affect all ten SECs (Figure 3.5). When examining the scores driving this result, we notice that the mean ***Exposure***$_{sc}$ is high, as is the uncertainty surrounding the estimated median ***Risk***$_{sc}$, and the mean ***Consequence***$_{sc}$ is relatively low (Table 3.8). The high mean ***Exposure***$_{sc}$ is due to the unpredictable nature of *debris [discharge]*. While it is unlikely that *debris [discharge]* will overlap with >20% of any SEC at any given time, it could occur anywhere within the MPA, at any time of the year, and the type of debris is unpredictable, including size and buoyancy (see Appendix G for scoring justifications). While *debris [discharge]* may have a range of impacts, scoring of this stressor was based on the worst-case scenario: crushing of the SEC. Scoring in this way resulted in low mean ***Consequence***$_{sc}$, but scoring as if debris will always result in crushing most likely raised the overall estimated ***Risk***$_{sc}$ for this stressor. With more data available on the ***Exposure***$_{sc}$

factors of *debris [discharge],* we would expect a reduction in the estimated $\boldsymbol{Risk_{sc}}$ and $\boldsymbol{Potency_{s}}$.

Stressors related to *submersible operations* and *sampling* appeared in the top four stressors for all SECs (Table 3.8). *Aquatic invasive species [submersible operations]* was in the top four stressors affecting species SECs, and *substrate disturbance (crushing) [submersible operations]* was in the top three stressors for habitat SECs. The top stressors for *sampling* included *removal of organisms* and *substrate disturbance (crushing).* Stressors associated with *sampling* had relatively high mean $\boldsymbol{Exposure_{sc}}$ and $\boldsymbol{Consequence_{sc}}$ for species SECs, particularly for two species SECs; Tubeworm *Ridgeia piscesae* (high flux) and Sulfur Worm *Paralvinella sulfincola* (Figure 3.1; Table 3.8). The increased susceptibility of these SECs to these stressors may be explained by their limited distribution in a restricted and sensitive environment on the tops of actively venting hydrothermal chimneys in high flow conditions.

Habitat SECs had on average, lower $\boldsymbol{CRisk_{c}}$ than species and community SECs. The number of stressors affecting habitat and species/community SECs may explain this difference in $\boldsymbol{CRisk_{c}}$. Species/community SECs had between five and eight more stressors than habitat SECs (nine or twelve compared with four) (Table 3.9). This trend shows that the number of stressors affecting SECs influences the $\boldsymbol{CRisk_{c}}$, but also how abiotic habitats are less susceptible to stressors, as reflected in the lower $\boldsymbol{CRisk_{c}}$. The relatively low $\boldsymbol{CRisk_{c}}$ show that current activities occurring at the EHV MPA are having little impact on the abiotic habitats. However, it is likely that the organisms inhabiting these abiotic habitats would be affected by the same stressors that impact species and community SECs.

The two different phenotypes of Tubeworm *Ridgeia piscesae* had the highest estimates of $\boldsymbol{CRisk_{c}}$, with the high flux phenotype achieving a higher score than low flux. The inclusion of different species phenotypes in this risk assessment allowed us to examine the drivers behind $\boldsymbol{Risk_{sc}}$. Both phenotypes are impacted by the same number of stressors (12), but the main difference is the higher $\boldsymbol{Consequence_{sc}}$ for the high flux phenotype (Table 3.8), and the lower $\boldsymbol{Recovery_{c}}$ of the low flux phenotype (see Appendix H and Appendix G respectively). In this case, the higher $\boldsymbol{Consequence_{sc}}$ had greater influence over the total cumulative risk score than the $\boldsymbol{Recovery_{c}}$ rates. Stressors also affected them differently, with high flux Tubeworms more susceptible to *removal of organisms [sampling]* and *substrate disturbance (crushing),* and low flux Tubeworms more susceptible to *oil [oil spill]* and *debris [discharge].*

The stressors affecting the most SECs (all 10 SECs) had the highest $\boldsymbol{Potency_{s}}$. While there is a correlation between number of SECs and $\boldsymbol{Potency_{s}}$, the number of affected SECs does not necessarily drive the $\boldsymbol{Potency_{s}}$. For example, *substrate disturbance (crushing) [equipment installation]* affected all SECs, but was ranked seventh (of 11 stressors) in $\boldsymbol{Potency_{s}}$.

4.2 CHALLENGES, LIMITATIONS, AND FUTURE WORK

Several limitations were identified in this application of the ERAF to the EHV MPA. The Level 2 Risk Assessment framework proposed by O et al. (2015) was effective in identifying ecological SECs that appropriately represent EHV MPA, but not all selection criteria were applicable and/or required minor modification in order to apply the framework to the EHV MPA. The community/ecosystem selection criteria were particularly broad, and may require additional, more specific criteria for ecosystems not based on schooling fish as discussed in detail in Section 4.2.7.

Pathways of Effects models were an effective tool in the identification of anthropogenic activities and associated stressors impacting the EHV MPA. The combination of the PoE models with the SEC-stressor interaction matrix ensured that any potential interaction was explored in depth during scoring. The justifications in the PoE models were able to explore potential indirect stressors and any positive impacts of the stressors on the SECs, and then the SEC-stressor interaction matrix narrowed the focus to direct impacts and stressors with harmful impacts only, aligning the scoring of interactions with ERAF requirements (only score negative impacts).

The Level 2 Risk Assessment framework was effective in prioritizing stressors and SECs on a relative scale within the EHV MPA. However, as the EHV MPA SECs are benthic, there is a possibility of double weighting the ***Exposure*** $_{sc}$, as ***Depth overlap*** $_{sc}$ was scored as high overlap for all SECs. This scoring approach did not affect the overall relative estimated ***Risk*** $_{sc}$ rankings of the SECs at the EHV MPA. However, this should be noted in the results when comparing benthic SECs with pelagic SECs. No changes to the ***Exposure*** $_{sc}$ criteria are recommended, as most other systems would undoubtedly have a pelagic component/pelagic SECs, e.g. SGaan Kinghlas-Bowie Seamount MPA has many fish SECs with different depth ranges.

The incorporation of uncertainty into the estimated ***Risk*** $_{sc}$ showed that while uncertainty is not the sole driver, it could be influential in the final ***Risk*** $_{sc}$ estimate. In addition, the inclusion of uncertainty allows us to address whether the source of uncertainty is known (for example, from a lack of quantitative data), which is a crucial step in the development of research and monitoring plans for MPAs.

At this stage, the ERAF proposed by O et al. (2015) (see Section 4.2.4) is not sensitive enough to detect changes on an ecosystem level. In addition to the further development of the ERAF methods for estimating relative risk to ecosystem structure and function, further information is needed on life history traits, SEC populations and spatial extent, and stressor locations and duration in order to lower uncertainty scores. Additionally, information should be collected on the state of the ecosystem to form a baseline before change may be monitored and attributed to any particular activity or stressor.

4.2.1 Challenges of the Semi-Quantitative Method

Few quantitative data on the activities and spatial distributions of SECs at the EHV MPA were available, resulting in relatively high uncertainty scores. Despite using a binning scoring method in this ERAF application, access to quantitative data would reduce uncertainty values. Results showed that estimates of ***Risk*** $_{sc}$ based on qualitative data were driven by uncertainty more than estimates of ***Risk*** $_{sc}$ based on quantitative data. Therefore, the results need to be interpreted as a gap analysis, where scores with high estimated ***Risk*** $_{sc}$ and high uncertainty may be indicative of a lack of quantitative information for these stressor–SEC combinations. Such a gap analysis may be used as input for developing research and monitoring priorities.

4.2.2 Interpretation of Uncertainty Incorporation

The uncertainty incorporation method was developed during the PNCIMA pilot study using the Level 1 ERAF (Murray et al. 2016) in order to better address the uncertainty associated with qualitative scoring. By incorporating the uncertainty of each score into ***Risk*** $_{sc}$, the issue of analysing risk and uncertainty separately is removed (Murray et al. 2016). Often when risk and uncertainty are separated, the uncertainty component can be easily dropped from the discourse and ***Risk*** $_{sc}$ will be interpreted at face value. The incorporation of the uncertainty into every scored variable using random sampling and variable arrays avoids this problem, but it also has a “dampening” effect on the results, where ***Risk*** $_{sc}$ become similar across SECs because of the uncertainty incorporated at each stage. However, a comparison of straight calculations (no uncertainty incorporation) with calculations incorporating uncertainty did not change the ***Risk*** $_{sc}$ ranking of the SECs.

4.2.3 Cumulative Risk by SEC ($CRisk_c$)

The methods of estimating cumulative impacts presented here assume that $\boldsymbol{Risk_{sc}}$ is additive across stressors, rather than another relationship (multiplicative, synergistic, etc.). The current ERAF does not take into consideration the interaction between stressors and the resulting impacts on SECs, for example, the combination of *removal of organisms [sampling]* and *substrate disturbance (crushing) [submersible operations]* that occurs during *sampling*). Additional study is required to investigate the nature of these relationships using both ecological experimentation and modelling and should be considered in the fully quantitative Level 3 risk assessment framework.

4.2.4 Relative Risk to Ecosystem Structure and Function

Ecosystem risk is a reinterpretation of a SEC's cumulative risk based on the component's perceived contribution to ecosystem structure and function (O et al. 2015). A framework was proposed in the original ERAF (O et al. 2015) that would estimate the risk to ecosystem structure and function that results from risk to different SECs. Two approaches were proposed: ecosystem risk associated with risks to individual SECs; and ecosystem risk associated with defined ecosystem structure and functions. The first approach involved estimating ecosystem sensitivity to the loss of each SEC across a set of criteria (ecosystem roles) to be calculated using equations proposed by Park et al. (2010). The second approach involved calculating the risk to ecosystem structure and function to estimate the potential risk of loss in ecosystem structure and function, using a set of defined ecological roles or functions. Neither approach was successfully applied to the EHV MPA. This lack of success is attributed primarily to the lack of available information on the weighting of the ecosystem structure and function. Both approaches required allocating a weight for role R (role in the ecosystem structure and function), and while no specific method for defining this term was proposed, alternate methods were suggested including using ecosystem function or food web criteria. Without extensive information on the structure, function, food web, and specific role of SECs, the relative weighting for role R was not possible in the present application of the Level 2 ERAF method. The reliance on food web analysis limits the inclusion of the habitat SECs at the EHV MPA because they are abiotic features and would not be included in food web analysis. At this stage in its development, the ERAF is better suited to fish, rather than invertebrates and abiotic habitats. We suggest that future work include further investigation into relative measures of the role in the ecosystem structure and function.

4.2.5 Scoring Community $Recovery_c$

Hydrothermal vent ecosystems are dynamic systems periodically exposed to changing conditions. The succession and subsequent recovery of hydrothermal vent communities from disturbance, both natural and anthropogenic, has been documented for a range of flow conditions at the EHV MPA (Marcus et al. 2009; Sylvan et al. 2012). Using known succession rates and impacts to the composition of the original communities, it may be possible to develop a scoring framework (for communities) that puts recovery on a relative scale with habitats and species within the EHV MPA. However, additional criteria would need to be incorporated into this approach in order to include communities that have not been well studied, such as the benthic clam bed community.

Where little or no quantitative data are available on recovery, an approach that focuses on taxonomic groups within the community, and then assesses them together may be appropriate, and several of the existing recovery criteria for species may be applicable. Creating food webs for the communities at the EHV MPA would provide an overview of community structure and function, giving a baseline for future changes. Clearly, the main drawback of a food web approach is the amount of data required on the organisms present and their likely role in the ecosystem. Due to the unusual nature of the food webs in the EHV MPA, it would be appropriate to create food webs tailored to each community within the ecosystem. Where information is lacking, species can be assigned to a functional group to which congeners or close allies are assigned using information from the literature or expert review as done in Hobday et al. (2011). The basic food web provided in Hobday et al. (2011) could be adapted, while referencing food webs from similar systems found in the literature. For example, though unusual, ecosystems based on chemosynthesis are tied together by food webs similar to those of better-known communities and have four layers: primary producers; primary consumers; first order carnivores and top order carnivores. Further development of these criteria was beyond the scope and time budget of this project. However, any future work on this topic should ensure that the recovery scoring for communities is still on a relative scale to that of habitats and species recovery.

4.2.6 Scoring Indirect and Long-Range Stressors and SEC Life Stages

The present application of the Level 2 ERAF does not currently consider indirect impacts from stressors (for example, increased predation of Tubeworm *Ridgeia piscesae* by Spider Crab *Macroregonia macrochira* due to the attraction of this species to the area by the *introduction of foreign material [equipment abandonment].* As this was the first risk assessment to be conducted at the EHV MPA, it was important to first assess the direct effects of individual stressors on SECs before the impact of any indirect stressors is assessed. The Level 2 framework attempts to examine the compounding impacts of stressors on a SEC with $\boldsymbol{CRisk_c}$, which was concluded to be an effective tool in ranking SECs based on estimated relative risk. It is recommended that indirect effects be incorporated into the fully quantitative Level 3 ERAF.

Long-range stressors capable of impacting the Pacific Region MPAs include long-range contamination and debris resulting from the 2011 Japan earthquake and tsunami, and vessel noise. Such long-range impacts are currently not taken into account for the EHV MPA, as these stressors are not manageable at the MPA level. However, the addition of long-range impacts as stressors may add value to future risk assessments. Any inclusion of long-range stressors should be noted in the results analysis and discussed separately.

This application of the framework does not consider impact of stressors on all life-stages of the SECs. For example, the impact of *sound generation [seismic testing/air guns]* on juvenile (pelagic/transient) stages of invertebrate SECs was not scored. Juvenile life-stages of SECs were not included for two reasons:

1. there is very limited information available on the juvenile life stages of many of the EHV MPA species SECs, which would result in high uncertainty scores; and,
2. the inclusion of juveniles may skew the weightings of certain stressors that are otherwise benign to the adult organism, focusing the effect of stressors on the sensitive juveniles (and producing uniform results across all invertebrate SECs), rather than on the existing ecosystem.

Assessing the impacts of stressors on SEC juvenile life stages may be more appropriate for additional scoring criteria, and/or for a Level 3 Risk Assessment.

4.2.7 Selection of Significant Ecosystem Components

Not all species of high ecological significance identified using the criteria from O et al. (2015) were included in the final SEC list. Species that fulfilled more of the SEC selection criteria were given priority over others deemed significant, but with fewer criteria fulfilled. Future applications of this risk assessment should expand the SEC list to include endemic species such as the large Snail *Buccinum thermophilum*, Pycnogonid *Sericosura venticola,* and Amphipod *Pardalisca endeavouri.* Endemism is one of the EHV MPA's ecological and evolutionary contributions and this feature is not represented in the current SEC list. Future applications of ERAF to the EHV MPA should divide the *rare, unique, or endemic* species SEC selection criteria into two categories: *rare* and *endemic to the EHV MPA*. This separation would ensure that abundant species endemic to the EHV MPA, such as the large snail *Buccinum thermophilum,* are not overlooked in the selection process.

Habitat SECs were selected to include as many species and communities as possible with the aim of assessing the risk of harm to both the habitat and the organisms living within them. Several identified communities were encompassed within habitat SECs due to the problems with the community SEC ***Recovery***$_c$ factors. As abiotic habitats were selected, all scoring was based on stressor impacts to the structural integrity of the habitat, rather than to the living organisms inhabiting them. While the resulting ***Risk***$_{sc}$ scores are accurate on a relative scale, they do not depict the estimated ***Risk***$_{sc}$ to those living organisms inhabiting abiotic habitats. Future iterations of this assessment (once the community ***Recovery***$_c$ factors are developed) should consider dividing the current habitat SECs into appropriate community SECs. The assemblages selected should cover the majority of biogenic habitat species (including vestimentiferan Tubeworms), and primary consumer species that lay the foundation for other organisms to colonise.

It was an interesting exercise to include the hydrothermal plume as a habitat SEC, because while it fulfilled several selection criteria, the lack of physical structure meant that it was very difficult to conceive of stressors impacting the 'structural integrity' of the plume, and this SEC fell out of the risk assessment while scoring ***Resilience***$_c$. It should be noted that indirect stressors would have impacted this SEC, such as a change in the size and density of the plume following *substrate disturbance (crushing)* of active venting hydrothermal mineral chimneys. The hydrothermal plume was selected as a SEC because in the region immediately above the plumes is a zone of enhanced macrozooplankton aggregation and abundance, comprising both deep species (i.e., from the EHV MPA) as well as species normally found in the upper ocean. We suggest that future applications of this framework to the EHV MPA include the hydrothermal plume as a community SEC, thereby assessing the impacts of stressors on the actual organisms that may be important.

4.2.8 PoE Model Development and Stressor Identification

We suggest that the *debris [discharge]* stressor be changed to an activity (*discharge of debris*), and a separate PoE model developed for the activity. The PoE model would divide debris into: *substrate disturbance (crushing), substrate disturbance (sediment resuspension); substrate disturbance (foreign object); prey imitation* (particularly relevant for plastic debris); and *entrapment/entanglement*. The addition of the extra stressors will stop the scoring of *debris* on a worst-case scenario basis, i.e., *substrate disturbance (crushing)*, and will reduce the associated uncertainty and overall ***Risk***$_{sc}$.

An activity that occurs frequently at the EHV MPA (between one to two months per annum annually) but was not identified in the list provided by DFO Oceans Management is mapping activities. While multibeam sonar from submersibles was included under *noise disturbance [submersible operations]*, stressors associated with mapping from surface ships and towed bodies were not considered in this assessment. The development of a mapping PoE model is suggested for future iterations of this work.

4.2.9 Indicators

The next stage in development of a risk-based monitoring plan for the EHV MPA is to develop appropriate indicators from the knowledge gained from the present study. Indicators should include both SECs and stressors, taking into consideration measureable components such as population abundance, size of habitat scarring from sampling, etc.

The development of indicators for the EHV MPA should not be restricted to those species and habitats presented as SECs in this risk assessment. Several endemic species were identified at the EHV MPA, but were not classified as a SEC due to the limited criteria they fulfilled. However, these endemic species should be considered in any future application of the ERAF to the EHV MPA and as indicators. Species or groups of species that are important to the functioning of the ecosystem, but were not appropriate for SEC selection (e.g., microbial communities, zooplankton in the outer plume, etc.) are classified as 'state of the ecosystem' indicators, and should be considered when selecting indicators.

Similarly, the development of indicators should not be restricted to the stressors identified in this risk assessment. Natural stressors, such as structural collapses and rapid shifts in the intensity and location of hydrothermal fluid discharge, were not considered in this application of the ERAF. However, natural stressors cannot be ignored as separating variability related to natural and anthropogenic stressors is of fundamental importance to the development of monitoring plans designed to detect the effects of anthropogenic stressors.

5 CONCLUSIONS AND RECOMMENDATIONS

- Application of the Level 2 risk assessment framework to the EHV MPA was effective in selecting and prioritizing SECs (six species SECs, four habitat SECs, and one community SEC). Some modifications were necessary to accommodate the EHV MPA's unique nature, but overall the criteria were appropriate.
- The SECs with the highest cumulative risk were *Ridgeia piscesae* (high flux), *Ridgeia piscesae* (low flux), *Paralvinella sulfincola*, and benthic clam bed community.
- PoE models were effective in determining the activities and associated stressors capable of affecting the SECs at the EHV MPA. The development of the SEC-stressor matrix corroborated the PoE models.
- The stressors with the highest estimated potency were *debris [discharge]*, *substrate disturbance (crushing) [sampling]*, *substrate disturbance (crushing) [submersible operations]*, and *aquatic invasive species [submersible operations]*.
- Uncertainty associated with estimated risk scores identified knowledge gaps, particularly for 'potential' stressors. These uncertainties strongly influence the overall risk scores.
- While results from a Level 2 risk assessment would not be comparable between MPAs, this method was deemed effective in prioritising SECs and stressors across a relative scale within the EHV MPA and in identifying knowledge gaps.
- Overall, the use of an MPA to evaluate the effectiveness of this Level 2 Risk Assessment framework was appropriate. This framework is applicable to MPAs, and has some limitations that may be further developed and/or incorporated into future applications of this ERAF. These include the SEC selection criteria, recovery factor criteria for communities, scoring of indirect and long-range stressors, and all life-stages of the SEC.

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7 GLOSSARY AND ACRONYMS

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

Biodiversity - The full range of variety and variability within and among living organisms and the ecological complexes in which they occur. Encompasses diversity at the ecosystem, community, species, and genetic levels and the interaction of these components" (DFO). 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.

Bycatch → (redirect to 'Non-target species')

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.

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 should also take into account the cumulative impact of all human activities on the ecosystem within that area.

Ecosystem components – Components selected through a defined process to represent the ecosystem of interest.

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.

Endangered – Species facing imminent extirpation or extinction.

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

Fitness - the ability to survive and reproduce.

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

Habitat - Habitats can be defined in many ways, but one of the simplest is the “place where an organism lives”. Habitats not only represent the fundamental ecological unit in which species interact, but it is the matrix that supports an essential range of ecological processes. The loss or impairment of habitat integrity can result in direct impacts to species, communities and ecosystem structure and function (Bax et al.1999; Bax and Williams 2001).

Infauna - Benthic animals that live in the substrate of a body of water, especially in a soft sea bottom. Infauna usually construct tubes or burrows and are commonly found in deeper and subtidal waters. Examples include clams, tubeworms, and burrowing crabs.

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 (Pitcher et al. 2007).

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

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

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.

Resilience – the capacity of an ecosystem to respond to a stressor by resisting damage and/or recovering quickly.

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 – (specific for this process) -*** the likelihood that a Valued Ecosystem Component will experience unacceptable adverse consequences due to exposure to one or more identified stressors.

SARA, Species at Risk Act - The purposes of the SARA are 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 significance 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 - often given simply as the number of species, more commonly used is an index which incorporates the total number of individuals.

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

Species of special concern – Species particularly sensitive to human activities or natural events but not necessarily endangered or threatened [as used by COSEWIC - 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 (BCCDC).

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

Susceptibility - Susceptibility is composed of three aspects: availability, encounterability and selectivity.

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 richness of species 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 utilises only simple species lists (presence/absence data) (Clarke and Warwick 1999).

Target species - Species targeted by a fishery in the area of interest, information from the literature and DFO sources.

Vulnerable species - Particularly sensitive to human activities or natural events. [As used by NatureServe - Vulnerable due to a restricted range, relatively few populations, recent and widespread declines, or other factors making it vulnerable to extirpation.] (BCCDC).

APPENDIX A. CONSIDERATIONS FOR SELECTION OF SPECIES, HABITAT AND COMMUNITY/ECOSYSTEM PROPERTIES SECS

Table A.1: Considerations for Selecting Species SECs (from O et al. 2015)

Species Criteria	Description
Nutrient Importer/Exporter	Crucial role in maintaining ecosystem structure and function through the transfer of energy or nutrients that would otherwise be limiting to an ecosystem
Specialized or keystone role in food web	Species has a highly specialized relationship with another species or guild; has an important food web relationship where an impact to it would cause vertical or horizontal change in food web; species supports a temporally or spatially explicit event important for other species. Examples include highly influential predators and forage species (see glossary for definitions).
Habitat creating species	Species which create habitat for infauna and aerate substrates Species which create habitat on the seafloor
Rare, Unique, or Endemic Species	Existence of a species at relatively low abundance or whose populations are globally or nationally significant within the boundaries of the area of interest.
Sensitive Species	Low tolerance and more time needed for recovery from stressors
Depleted Species	Listed under SARA/COSEWIC/IUCN/BCCDC Target and non-target species impacted beyond their sustainable level.

Table A.2: Considerations for Selecting Habitat SECs (from O et al. 2015)

Habitat Considerations	Description
Biogenic habitat types	Habitats formed by biogenic species.
Rare or unique habitats	Habitat types with very restricted distribution in the area of interest, or habitats that are globally or nationally significant within the boundaries of the area of interest.
Sensitive habitats	Habitats with low tolerance to disturbance requiring more time to recover, or no tolerance to disturbance. May be fragile habitat, such as biogenic coral. The loss or impairment of habitat integrity can result in direct impacts to species, communities and ecosystem structure and function.
Habitats critical for sensitive species	Habitats supporting species with low tolerance which need more time for recovery from stressors.
Threatened or depleted habitats	Habitats in danger of disappearance in their natural range. Determined from literature reviews, expert review, or relevant conservation lists.
Habitats critical for depleted species	Habitats critical for supporting species listed under SARA/COSEWIC/IUCN/BCCDC and target and non-target species impacted beyond their sustainable level.
Habitats critical for supporting rare, unique or endemic species	Habitats supporting species at relatively low abundance or whose populations are globally or nationally significant within the boundaries of the area of interest.
Habitats supporting critical life cycle stages	For example, habitat important for the shelter, feeding, spawning and rearing of seamount associated fish.
Habitats providing critical ecosystem function(s) or service(s)	Habitats that provide critical physical, chemical, and biological processes or functions contributing to the self-maintenance of an ecosystem. Ecosystem services are the beneficial outcomes, for the natural environment or people, which result from ecosystem functions.

Table A. 3: Considerations for Selecting Community/Ecosystem Properties SECs (from O et al. 2015)

Community/Ecosystem Property Considerations	Description
Unique communities	Communities (species assemblage) that are unique within the region, or within the area of interest
Ecologically significant community properties	Communities that are ecologically “significant” because of the functions that they serve in the ecosystem and/or because of features that they provide for other parts of the ecosystem to use (EBSA national document definition)
Functional groups which play a critical role in ecosystem functioning	Biodiversity and productivity of functional groups which are central to the functioning and resilience of the ecosystem
Ecological processes critical for ecosystem functioning	Ecological processes which are central to the functioning of the ecosystem. Include oceanographic factors critical to ecosystem functioning. Material flows, or the cycling of organic matter and inorganic nutrients (e.g., nitrogen, phosphorus), can mediate how energy travels through the food web.
Sensitive functional groups	Functional groups which are sensitive to disturbance, and if impacted would result in significant effects on community composition and ecosystem function. Includes functional groups with low functional redundancy, and low response diversity. For example, a food web containing several species of herbivores would be considered to have high functional redundancy with respect to the ecosystem function of grazing, if species of herbivores show a differential response to hypoxia, there is also high response diversity.

APPENDIX B. PATHWAYS OF EFFECTS MODELS

Table B.1: List of Pathways of Effects Models and date last modified.

Developed PoE model	Date last modified	Formal review?
Discharge	22/11/12	No
Oil spill	29/11/12	No
Equipment abandonment	11/01/13	No
Equipment installation	20/12/12	No
Sampling	11/01/12	No
Submersible operations	21/12/12	No
Seismic testing / air guns	23/12/12	No

APPENDIX C. ATTRIBUTES FOR ASSESSING RECOVERY FACTORS FOR SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS

Table C.1: Recovery factor attributes for assessing potential risks posed by activities and stressors to Species SECs (O et al. 2015).

Description	Category		
Recovery factors	**High (1)**	**Moderate (2)**	**Low (3)**
Fecundity The population-wide average number of offspring produced by a female each year	>100,000	100-100,000	<100
Breeding strategy (Indexed using Winemiller's (1989) method) provides an indication of the level of mortality that may be expected for offspring in the first stages of life	<1	1-3	>3
Recruitment rating Populations with sporadic and infrequent recruitment success are often long-lived and thus may be expected to have lower levels of productivity. Recruitment success is defined as frequency of recruitment greater than long-term average level.	>75%	10-75%	<10%
Natural mortality rate Instantaneous mortality rate. Populations with naturally higher instantaneous mortality rates likely have higher recovery rates	>0.4	0.2-0.4	<0.2
Age at maturity Age of sexual maturity	<2 years	2-4 years	>4 years
Life stage The life stage(s) affected by a stressor. If stressor affects individuals before they have the opportunity to reproduce, recovery	Not affected or only mature stages	Only immature stages	All stages
Population connectivity Realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability	Regular (not a distinct DPs or ESU)	Occasional	Negligible (DPS or ESU)
Listed species Describes the status of protected, species of concern, threatened or endangered species for COSEWIC/SARA/IUCN species. If not listed or not under consideration do not include this term in the calculation.	Data deficient	Species of concern	Endangered or threatened
Additional recovery factors for fish (Hobday et al. 2007)			

Description	Category		
Recovery factors	**High (1)**	**Moderate (2)**	**Low (3)**
Maximum age	<10 years	10-30 years	>30 years
Maximum size	<60 cm	60-150 cm	>150 cm
von Bertalanffy growth coefficient (k)	>0.25	0.15-0.25	<0.15

Table C.2: Recovery factor attributes for assessing potential risks posed by activities and stressors to Habitat SECs (O et al. 2015).

Description	Category		
Recovery factors	**High (1)**	**Moderate (2)**	**Low (3)**
Life Stage Affected (biotic habitats) Life stages affected by a stressor.	Not affected or only mature stages	Only immature stages	All stages
Frequency of Natural Disturbance Frequency of natural disturbances of a similar type to the stressor.	Daily to weekly	Several times per year	Annual or less often
Natural Mortality Rate (biotic habitats) Describes instantaneous morality rate.	>0.4	0.2-0.4	<0.2
Natural Recruitment Rate (biotic habitats)	Annual or more frequent	1-2 years	>2 years
Age at Maturity/recovery time	<1 year	1-10 years	>10 years
Distribution Range/Fragmentation Estimated extent of occurrence and fragmentation or number of locations. Values are based on 2010 COSEWIC assessment process.	Extent of occurrence > 20000 km^2; low fragmentation	Extent of occurrence 5000-20000 km^2; somewhat fragmented, known to exist at <50 locations	Extent of occurrence <5000 km^2; severely fragmented or known to exist at <10 locations
Connectivity Rating Based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability.	Regular (not a distinct DPs or ESU); High dispersal (>100 km)	Occasional; Medium dispersal (10-100 km)	Negligible (DPS or ESU); Low dispersal (<10 km)

Table C.3: Recovery factor attributes for assessing potential risks posed by activities and stressors to Community/Ecosystem Properties SECs (O et al. 2015).

Description	**Category**		
Recovery factors	**Low (1)**	**Moderate (2)**	**High (3)**
Species richness (s) Higher richness, more resistant and faster recovery	Relative measure for species richness is high	Relative measure for species richness is medium	Relative measure for species richness is low
Taxonomic distinctness (Presence/absence data). Higher taxonomic distinctness suggests higher resistance	Relative measure for taxonomic distinctness is high	Relative measure for taxonomic distinctness is medium	Relative measure for taxonomic distinctness is low
% of functional groups with total number of members per group >5 or 10 More groups, less susceptible	>50%	30-50%	<30%
Abundance per functional group (higher abundance per functional group, more resilient)	Relative abundance is high	Relative abundance is medium	Relative abundance is low

APPENDIX D. R-CODE USED TO CALCULATE RISK AND INCORPORATE UNCERTAINTY

D.1. R-CODE USED TO CALCULATE RISK AND INCORPORATE UNCERTAINTY FOR ALL SECS

The R code (R Core Team 2014) and input file used to calculate risk and incorporate uncertainty can be found on Canada’s Open Data Portal.

D.2. CALCULATION OF CUMULATIVE RISK AND POTENCY

The R code (R Core Team 2014) and input file used to calculate cumulative risk and potency can be found on Canada’s Open Data Portal.

APPENDIX E. EHV MPA SPECIES LIST (BENTHIC INVERTEBRATES AND CHORDATES)

NB: To maintain focus on those species crucial to the functioning of the EHV MPA ecosystem, the final species list only includes benthic invertebrates and chordates (other species included but greyed out were not included in the final species count). Species in **BOLD** are endemic to EHV MPA. *This species list was last updated February 2014.*

The species list generated through this review can be obtained by contacting the authors. Fields contained in this file are described below.

Column Heading	Description
MPA Zone	Area within the MPA where species is found. One of: Near vents, Vents only, Vent visitor.
Category	Main species classification (e.g. Genus): Birds, Fish, Invertebrates, Macrophytes, Marine Mammals, Phytoplankton, Sharks and Rays.
Sub-Category	Species sub-classification (e.g. Family): specific to each classification.
Species	Latin species name, where possible. Some species were not identified to this taxonomic level (marked as [unid] or unidentified species).
Common name	Common names are provided where available.
Feeding/Ecological Guild	Provided where possible. One or more of: Filter feeder, Primary producer, Primary consumer, Secondary consumer, Tertiary consumer, Top-level consumer.
ERAF1: Nutrient Importer/exporter	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
ERAF2: Specialized/ Keystone role	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
ERAF3: Habitat creating species	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
ERAF4: Rare, unique or endemic species	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
ERAF5: Sensitive species	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
ERAF6: Depleted species	Research document Table 3.1: Species criteria from O et al. (2015), and how they were applied to EHV MPA.
Ecological justification/Notes	Justification, observations and references to inform the scoping assessment.
Symbiotic relationship with chemosynthetic bacteria?	Does this species have a symbiotic relationship with chemosynthetic bacteria? Yes = “1”; No = “0” or blank. (3.1.1.1.)
Dependent on vent?	Does this species depend on vent conditions for any of its life functions?
Distribution	Published range observed for species.

Column Heading	Description
Include in species counts?	To maintain focus on those species crucial to the functioning of the EHV MPA ecosystem, the final species list only includes benthic invertebrates and chordates. (Species included in the species count summaries are indicated by a 1.)
Candidate SEC?	Candidate Species SECs are indicated by a 1.

APPENDIX F. SEC-STRESSOR INTERACTION MATRIX FOR ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA

SEC-stressor interactions to be considered for risk scoring are indicated by a “1”. Non-negative or non-existent interactions are indicated by a “0” (Section 2.2.1).

Activity	Stressor	Significant Ecosystem Component										
		Ridgeia piscesae – high flux	*Ridgeia piscesae – low flux*	*Lepetodrilus fucensis*	*Macroregonia macrochira*	*Paralvinella palmiformis*	*Paralvinella sulfincola*	Inactive chimneys	Hydrothermal plume	Active venting hydrothermal mineral chimneys	Diffuse venting flows	Benthic clam bed community
Discharge	Aquatic invasive species	0	0	0	0	0	0	0	0	0	0	0
	Debris	1	1	1	1	1	1	1	0	1	1	1
	Oils/contaminants	0	0	0	0	0	0	0	0	0	0	0
	Nutrients	0	0	0	0	0	0	0	0	0	0	0
Oil spill	Oil	1	1	1	1	1	1	0	0	0	0	1
Equipment abandonment	Increased contamination	1	1	1	1	1	1	0	0	0	0	1
	Introduction of foreign material	0	0	0	1	0	0	0	0	0	0	0
Equipment installation	Substrate disturbance/ crushing	1	1	1	1	1	1	1	0	1	1	1
	Substrate disturbance/ sediment resuspension	1	1	1	1	1	1	0	0	0	0	1
	Light disturbance	1	1	1	1	1	1	0	0	0	0	1
	Noise disturbance	1	1	1	1	1	1	0	0	0	0	1
Sampling	Removal of organisms	1	1	1	1	1	1	0	0	0	0	1
	Substrate disturbance/ crushing	1	1	1	1	1	1	1	0	1	1	1
	Substrate disturbance/ sediment resuspension	1	1	1	1	1	1	0	0	0	0	1
Submersible operations	Aquatic invasive species	1	1	1	1	1	1	0	0	0	0	1
	Light disturbance	1	1	1	1	1	1	0	0	0	0	1
	Noise disturbance	1	1	1	1	1	1	0	0	0	0	1
	Substrate disturbance/ crushing	1	1	1	1	1	1	1	0	1	1	1
	Substrate disturbance/ sediment resuspension	1	1	1	1	1	1	0	0	0	0	1
Seismic testing/ Air guns	Sound generation	1	1	1	1	1	1	0	0	0	0	1

APPENDIX G. EXPOSURE, RESILIENCE, AND RECOVERY SCORES FOR ALL SECS (SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS)

The Exposure, Resilience and Recover scores for all SEC-stressor interactions along with scoring justification can be found on Canada’s Open Data Portal. This file is also the input file to be used with the R code (R Core Team 2014) in Appendix D.

APPENDIX H. RISK RESULTS FOR SPECIES, HABITAT, AND COMMUNITY/ECOSYSTEM PROPERTIES SECS

H.1. *RIDGEIA PISCESAE* (HIGH FLUX)

Table H.1: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Sampling	Removal of organisms	56.81	44.66	69.55	8.68	6.71
Sampling	Substrate disturbance / crushing	56.28	42.92	70.66	8.47	6.75
Submersible operations	Substrate disturbance / crushing	38.90	29.87	49.71	6.09	6.70
Submersible operations	Aquatic invasive species	28.16	21.32	38.93	3.78	7.87
Discharge	Debris	27.57	13.24	45.49	10.77	2.82
Oil spill	Oil	25.73	15.28	39.14	6.36	4.26
Equipment abandonment	Increased contamination	18.68	6.73	33.56	6.70	2.69
Equipment installation	Substrate disturbance / crushing	17.26	11.01	24.91	4.26	4.15
Sampling	Substrate disturbance / resuspension	16.71	6.45	28.97	6.01	2.92
Submersible operations	Substrate disturbance / resuspension	14.39	6.24	24.25	5.26	2.83
Seismic testing / air guns	Sound generation	12.49	2.29	24.57	7.00	1.84
Equipment installation	Substrate disturbance / resuspension	6.66	1.09	13.48	4.26	1.72

H.2. *RIDGEIA PISCESAE* (LOW FLUX)

Table H.2: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Submersible operations	Aquatic invasive species	40.44	29.63	56.85	3.75	11.13
Discharge	Debris	39.90	18.58	66.2	10.41	4.25
Oil spill	Oil	36.93	21.55	56.58	6.44	6.01
Sampling	Substrate disturbance / crushing	26.82	14.45	41.99	6.82	4.18
Sampling	Removal of organisms	26.76	14.54	42.22	6.97	4.04
Equipment abandonment	Increased contamination	26.15	9.6	49.1	6.63	4.28
Sampling	Substrate disturbance / resuspension	20.64	7.71	37.18	5.24	4.36
Submersible operations	Substrate disturbance / crushing	20.40	9.59	33.76	5.19	4.05
Submersible operations	Substrate disturbance / resuspension	20.28	8.41	35.36	5.32	4.20
Seismic testing / air guns	Sound generation	17.91	2.87	35.79	6.98	2.65
Equipment installation	Substrate disturbance / crushing	16.50	7.68	27.42	4.22	4.19
Equipment installation	Substrate disturbance / resuspension	9.59	1.56	19.47	4.25	2.34

H.3. *PARALVINELLA SULFINCOLA*

Table H.3: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Sampling	Substrate disturbance / crushing	52.57	34.27	76.04	8.68	6.23
Sampling	Removal of organisms	39.77	25.16	59.06	8.67	4.91
Submersible operations	Aquatic invasive species	30.92	21.03	45.96	3.62	8.71
Discharge	Debris	30.40	13.89	53.5	10.07	3.29
Oil spill	Oil	28.51	14.58	47.13	6.29	4.56
Submersible operations	Substrate disturbance / crushing	27.10	16.01	41.59	6.01	4.63
Equipment abandonment	Increased contamination	20.67	7.56	39.77	6.74	3.22
Equipment installation	Substrate disturbance / crushing	19.14	11.23	29.76	4.24	4.80
Sampling	Substrate disturbance / resuspension	18.47	6.87	34.44	6.10	3.33
Submersible operations	Substrate disturbance / resuspension	15.84	6.42	28.53	5.31	3.37
Seismic testing / air guns	Sound generation	13.56	2.36	28.65	6.95	2.18
Equipment installation	Substrate disturbance / resuspension	7.40	1.13	15.48	4.26	1.85

H.4. *PARALVINELLA PALMIFORMIS*

Table H.4: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	27.22	12.64	46.57	10.19	2.71
Submersible operations	Aquatic invasive species	27.18	19.35	39.03	3.62	7.78
Oil spill	Oil	25.52	13.78	40.35	6.22	3.97
Sampling	Substrate disturbance / crushing	18.65	9.76	29.48	6.98	2.86
Equipment abandonment	Increased contamination	18.18	6.79	34.08	6.89	2.76
Sampling	Substrate disturbance / resuspension	14.26	5.47	25.67	5.16	2.98
Submersible operations	Substrate disturbance / resuspension	14.20	6.06	24.82	5.20	2.79
Submersible operations	Substrate disturbance / crushing	14.09	6.54	23.53	5.24	2.98
Seismic testing / air guns	Sound generation	12.21	2.13	24.72	6.94	1.86
Equipment installation	Substrate disturbance / crushing	11.40	5.42	19.17	4.30	2.83
Sampling	Removal of organisms	11.33	5.54	19.51	7.02	1.72
Equipment installation	Substrate disturbance / resuspension	6.52	1.03	13.38	4.27	1.79

H.5. *LEPETODRILUS FUCENSIS*

Table H.5: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	33.56	15.94	56.02	10.31	3.54
Submersible operations	Aquatic invasive species	33.46	24.58	47.08	3.88	9.22
Oil spill	Oil	31.25	16.6	48.35	6.29	5.36
Sampling	Removal of organisms	23.14	12.16	35.73	6.96	3.37
Sampling	Substrate disturbance / crushing	22.77	12.3	35.61	6.92	3.52
Equipment abandonment	Increased contamination	22.58	8.21	41.66	6.72	3.38
Sampling	Substrate disturbance / resuspension	17.63	6.68	31.21	5.30	3.71
Submersible operations	Substrate disturbance / crushing	17.43	8.21	28.28	5.06	3.50
Submersible operations	Substrate disturbance / resuspension	17.28	7.35	29.9	5.23	3.58
Seismic testing / air guns	Sound generation	14.90	2.72	29.95	6.90	2.40
Equipment installation	Substrate disturbance / crushing	14.23	6.73	23.38	4.26	3.56
Equipment installation	Substrate disturbance / resuspension	8.09	1.22	16.55	4.24	1.96

H.6. *MACROREGONIA MACROCHIRA*

Table H.6: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Submersible operations	Aquatic invasive species	30.48	21.62	43.5	3.68	8.64
Discharge	Debris	30.18	18.03	46.25	10.32	3.12
Oil spill	Oil	28.34	15.4	45.07	6.34	4.67
Sampling	Substrate disturbance / crushing	17.18	9.93	26.36	5.62	3.03
Seismic testing / air guns	Sound generation	13.71	2.53	27.29	6.97	1.81
Submersible operations	Substrate disturbance / crushing	13.09	6.23	21.49	4.37	2.99
Equipment installation	Substrate disturbance / crushing	10.74	5.07	17.86	3.58	3.00
Equipment abandonment	Increased contamination	10.72	1.74	22.86	6.07	2.10
Sampling	Removal of organisms	9.86	4.88	16.28	5.80	1.83

H.7. CLAM BED BENTHIC COMMUNITY

Table H.7: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	34.95	15.89	60.4	10.10	3.51
Submersible operations	Aquatic invasive species	34.71	23.71	51.42	3.68	9.86
Oil spill	Oil	32.18	16.75	52.12	6.42	5.29
Sampling	Removal of organisms	29.70	15.55	47.5	8.70	3.38
Sampling	Substrate disturbance / crushing	29.08	13.48	49.65	8.63	3.52
Sampling	Substrate disturbance / resuspension	26.96	11.45	48.11	7.82	3.75
Equipment abandonment	Increased contamination	22.88	10.53	40.31	7.03	3.94
Submersible operations	Substrate disturbance / crushing	20.27	9.35	34.63	5.98	3.68
Submersible operations	Substrate disturbance / resuspension	17.83	7.49	32.29	5.24	3.50
Seismic testing / air guns	Sound generation	15.36	2.71	31.9	6.90	2.89
Equipment installation	Substrate disturbance / crushing	14.48	6.8	24.55	4.45	3.50
Equipment installation	Substrate disturbance / resuspension	14.45	6.04	26.25	4.36	3.74

H.8. ACTIVE VENTING HYDROTHERMAL MINERAL CHIMNEYS

Table H.8: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	38.85	15.21	73.41	10.05	3.84
Submersible operations	Substrate disturbance / crushing	24.69	9.83	45.83	6.43	3.86
Sampling	Substrate disturbance / crushing	23.21	9.16	43.02	6.13	4.28
Equipment installation	Substrate disturbance / crushing	13.77	5.68	25.56	3.57	4.34

H.9. INACTIVE HYDROTHERMAL CHIMNEYS

Table H.9: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	49.16	20.73	86.92	10.30	4.75
Sampling	Substrate disturbance / crushing	41.04	17.28	71.69	8.60	4.89
Submersible operations	Substrate disturbance / crushing	31.10	13.21	53.96	6.49	5.46
Equipment installation	Substrate disturbance / crushing	17.46	7.14	30.39	3.60	5.12

H.10. DIFFUSE VENTING BASALT FLOWS

Table H.10: Median risk score results and associated 10% and 90% quantiles ranked by risk score, along with mean exposure and consequence scores.

Activity	Stressor	Median Risk	10% Quantile	90% Quantile	Mean Exposure	Mean Consequence
Discharge	Debris	28.64	4.76	59.83	10.16	2.76
Sampling	Substrate disturbance / crushing	18.40	3.14	37.76	6.59	3.16
Submersible operations	Substrate disturbance / crushing	18.07	2.95	36.77	6.47	3.51
Equipment installation	Substrate disturbance / crushing	10.17	1.76	21.25	3.67	3.02