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Ecological Risk Assessment for the Effects of Human Activities at the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area

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Foreword

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

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ABSTRACT

The Hecate Strait and Queen Charlotte Sound (HS/QCS) Glass Sponge Reefs were designated as a Marine Protected Area (MPA) in February 2017 (SOR/2017-15). In order to adequately protect and manage the HS/QCS Glass Sponge Reefs MPA (HS/QCS MPA), a comprehensive inventory and risk assessment of the human-based activities and stressors likely to interact with the ecosystem is required. In this work, the Level 2 semi-quantitative level of the Ecosystem Risk Assessment Framework (ERAF) developed by O et al. (2015) is applied to the HS/QCS MPA in order to determine relative risks to the ecosystem from anthropogenic activities. The scoping phase identified ten Significant Ecological Components (SECs) to appropriately represent the HS/QCS MPA: 6 species, 2 habitats and 2 community SECs, along with a comprehensive list of relevant anthropogenic activities and associated stressors occurring within the MPA. The application of the risk assessment provides prioritized lists of SECs and stressors on a relative scale, based on their estimated cumulative risk (to SECs) and potency (of individual stressors). The identification and prioritization of SECs and stressors is vital for the selection of risk-based indicators, and ultimately the development of monitoring plans. The SECs with the highest estimated cumulative risk scores were the Sponge Garden Habitat SEC, and the four sponge Species SECs (*A. vastus*, *R. dawsoni*, *H. calyx*, and *F. occa*). The stressors with the highest estimated scores for potency (additive cumulative risk by stressor) were oil from oil spills (Vessel Traffic), sediment re-suspension from bottom trawling (Fishing) and removal of biological material from mid water trawls (Fishing). The uncertainties identified by the risk assessment can inform Oceans Managers of existing knowledge gaps and help to identify priorities for monitoring. The highest uncertainties were associated with contamination from both acute oil spills and chronic low-level discharges, indirect effects from bottom trawling near the MPA and introductions of aquatic invasive species from grounding of vessels. Notable improvements made in this application of the ERAF include: inclusion of supplementary (glass sponge reef-specific) considerations during the species SEC scoping phase, use of truncated normal distributions to estimate uncertainty, and more precautionary treatment of low risk-high uncertainty stressors. As noted in other ERAF applications, assessment of Community/Ecosystem Property SECs continues to be a challenge in this context, given the current state of knowledge of the glass sponge reef ecosystem. Overall, the approach was deemed successful as a first iteration, and the Level 2 semi-quantitative ERAF was considered effective to provide preliminary information to managers and to inform the development of risk-based indicators. Though updates have been incorporated into this assessment, the scoping and scoring for this assessment was originally carried out in 2014-2015, before MPA designation. In light of the amount of new research currently being generated on this ecosystem, it is strongly recommended that a subsequent iteration be completed as soon as feasible. Suggested updates and improvements to be incorporated in the next iteration are summarised in this document.

1. INTRODUCTION

The Hecate Strait and Queen Charlotte Sound (HS/QCS) Glass Sponge Reefs were designated a Marine Protected Area (MPA) under the Oceans Act in February 2017 (SOR/2017-15). These are the largest Hexactinellid (glass) sponge reefs known in the NE Pacific, and are estimated to be up to 9,000 years old and (Conway et al. 2001; Conway et al. 2005; Stone et al. 2014). Glass sponge reefs are complex, three-dimensional structures, composed of a sediment infilled matrix of dead siliceous sponge skeletons with living sponge growing on top. Sponge reefs can form as bioherms (mounds) as well as biostromes (beds or sheets) (Lehnert et al., 2005). Though the living sponges on the reef surface are generally only 1-2m tall, the skeletal reef mounds they grow upon are on average 5–8m tall, but can extend up to 25m (Conway and Barrie, 2007; Lehnert et al., 2005; Shaw et al. 2018). Three species of sponges form the glass sponge reefs in the HS/QCS MPA: *Aphrocallistes vastus*, *Heterchone calyx* and *Farrea occa* (Conway et al., 2001).

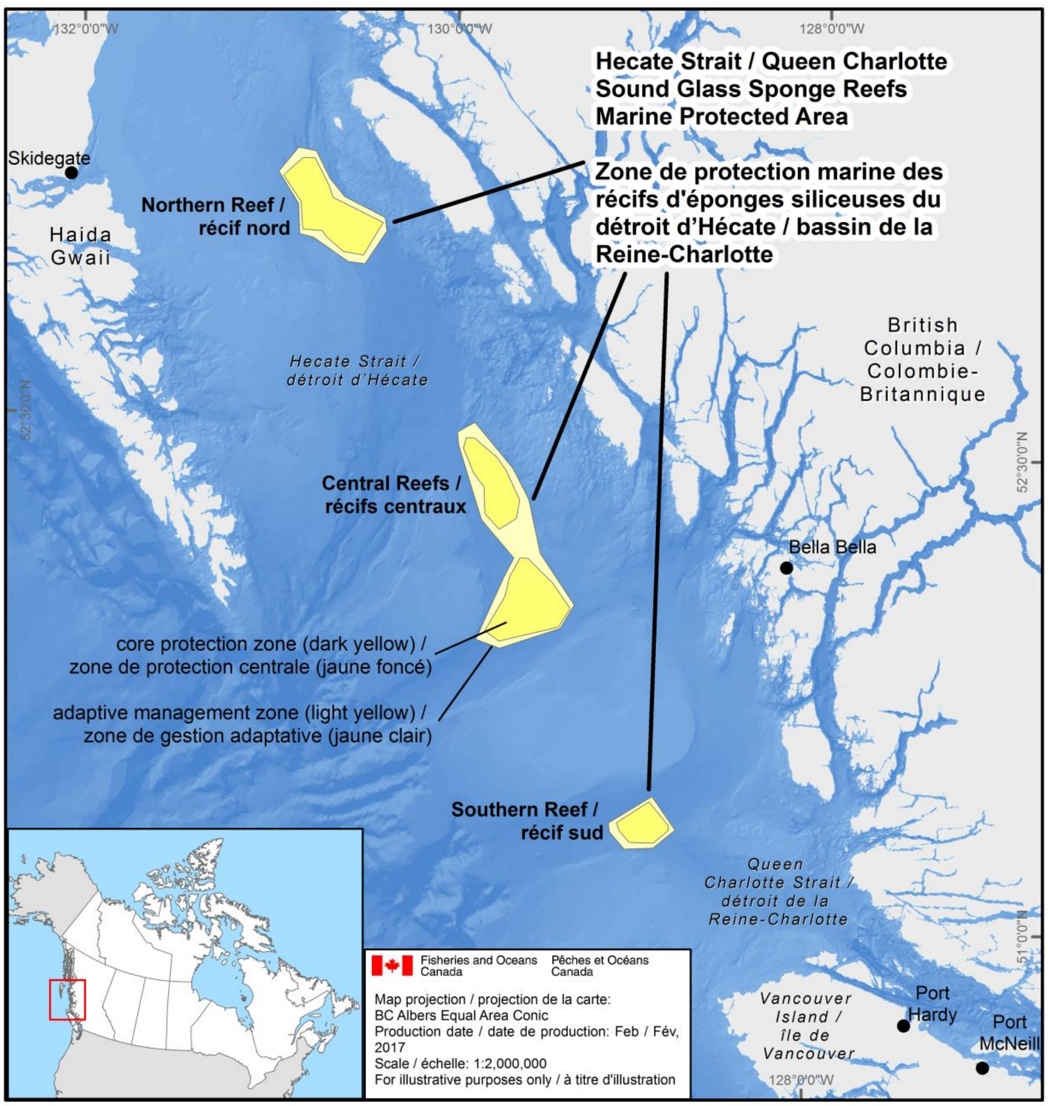

Figure 1. Boundaries of the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area.

The slow growth and fragility of the reef-building sponge species makes them particularly vulnerable to damage and disturbance, since recovery may take tens to several hundreds of years. Human activities in and around the reefs could pose a risk to the structural habitat, biological diversity and ecosystem function of these sensitive and fragile habitats. In order to provide appropriate ecosystem-based management of this diverse and fragile ecosystem, an objective and comprehensive assessment of anthropogenic risks is required.

One way to achieve this is to carry out a risk assessment, such as the approach outlined in the Ecological Risk Assessment Framework (ERAF) developed by Fisheries and Oceans (DFO) Pacific Region, a method that is transparent, systematic and grounded in science (O et al. 2015). The ERAF is a valuable tool for ocean managers as it can be used to evaluate the single and cumulative threats to Significant Ecosystem Components (SECs) from stressors associated with anthropogenic activities. SECs are ecological components identified as significant to the health and functioning of the specific ecosystem at species, habitat and community levels. The first phase of the ERAF is a scoping phase, where SECs, anthropogenic activities and associated stressors are identified. This is followed by a risk assessment phase, where risk is defined as “the likelihood that a SEC will experience unacceptable adverse consequences due to exposure to one or more stressors” (O et al. 2015). In this phase, components of exposure and consequence (broken out by resiliency and recovery considerations) are scored for those stressors and SECs expected to interact. The ERAF estimates three types of risk: relative risk to a SEC, cumulative risk across stressors to a SEC and potency of stressors across all SECs. The ERAF also provides three options for the risk assessment phase: Level 1 (qualitative), Level 2 (semi-quantitative) or Level 3 (quantitative).

To date, the utility of the ERAF process has been evaluated through application of a Level 1 (qualitative) risk assessment to the Pacific North Coast Integrated Management Area (PNCIMA; Murray et al. 2016) and Level 2 (semi-quantitative) risk assessments to two MPAs in the Pacific Region: SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA; Rubidge et al. 2018) and Endeavour Hydrothermal Vents MPA (EHV MPA; Thornborough et al. 2017). In the current work, a Level 2 risk assessment is applied to the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area (HS/QCS MPA; Figure 1). Note that, at present, a lack of data prevents the application of a fully quantitative Level 3 assessment to this MPA.

Analysis of outputs will determine the effectiveness of the ERAF method when applied to a glass sponge reef ecosystem, and ascertain if the scoping outputs and resulting relative risk rankings are appropriate, and relevant to this MPA. The three primary outputs of the risk assessment are a relative ranking of risk to a SEC (by SEC-stressor interaction), cumulative risk across stressors to a SEC, and potency of stressors across all SECs. Of particular importance to managers is the list of SECs ranked by cumulative risk of harm and the identification of the activities/stressors driving those risks (including estimates of associated uncertainty) as this information is important to inform oceans management decisions. The ranked list of SECs and the information on drivers of risk are also needed to support the subsequent step of developing risk-based indicators and monitoring plans for the HS/QCS glass sponge reef.

1.1. LOCATIONS OF GLASS SPONGE REEFS IN THE CANADIAN PACIFIC REGION

Glass sponge reefs are unique to the Northeast Pacific and were first discovered in Hecate Strait and Queen Charlotte Sound in British Columbia (BC) when the Geological Survey of Canada seafloor mapping surveys in 1984 and 1986 found acoustic anomalies in areas that should be flat. In 1987, underwater photography in Hecate Strait found glass sponges present and in 1999, a submersible survey found the glass sponges had formed extensive reefs throughout the area (Krautter et al. 2006). In the last 17 years, surveys have identified additional glass sponge reef locations along the Pacific Coast of Canada: in the Strait of Georgia and Howe Sound (Cook 2005; Dunham et al. 2018), as well as in Portland Canal, Chatham Sound (Shaw et al. 2018) and a number of areas along the Northern and Central BC coasts (Stone et al. 2014). Of the known reefs, the HS/QCS reefs are unique in their size and extent (Krautter et al. 2006).

Sponge reefs are distinct from sponge ‘gardens’ - other dense populations of glass sponges found in British Columbia waters. Sponge gardens differ to reefs as they do not grow on the dead skeletons of previous generations of sponges, and so these areas lack the characteristic reef mounds formation (Chu et al. 2010). The glass sponge reefs found in Hecate Strait and Queen Charlotte Sound are comprised of four discrete reefs (the largest is nearly 120 km^2) which together form a discontinuous band covering almost 390 km^2 at depths of 165-240m (Conway et al. 2004). The reef structures have been estimated to be 6,000 to 9,000 years old (Conway et al. 2001; Conway et al. 2005a).

1.2. GLASS SPONGE REEF FORMATION, STRUCTURE, GROWTH AND PHYSIOLOGY

Hexactinellids (glass sponges) are grouped into two types based on skeletal characteristics: lyssacine sponges have a loose spicule skeleton, and dictyonine sponges have a skeleton of fused spicules (Leys et al., 2004). Glass sponge reefs are composed of dictyonine glass sponges. The spicules of the reef-building glass sponges fuse together creating silica skeletons that remain intact after sponge tissue has died. This skeletal matrix is locked into a rigid structure when it becomes infilled with sediment, and this is what forms the basis for the formation of extensive sponge reefs, with living sponges attaching to, and growing on, the dead sponge skeletons (Conway et al. 2001; Conway et al. 2005b; Krautter et al. 2001; Leys et al. 2007). Sponge reefs form through a balance between sediment input and sponge growth, and though naturally patchy, they can occur in high densities where a balance between high turbidity and sufficient water current prevents the accumulation of excessive sediment, which can lead to smothering (DFO 2013). There is also variation in the growth and shape of the sponge reef mounds among different reef areas in the MPA, which may be due to sponges competing for access to the water field (Cook, 2005). Variations in the shapes of individual sponges among sites can be due to current regimes and sediment loads (Cook, 2005). The sponge reef structure develops through larval attachment, stabilizing accessory outgrowths and skeletal welding (where a living sponge overgrows or incorporates the skeleton of a neighbouring sponge). All these processes require the availability of a bare hexactinosidan skeleton. The development of a sponge reef is also dependent on the preferential recruitment of larvae to the reef surface rather than available adjacent hard substrates. The surface of the sponge reef can only be successfully colonised by sponge larvae where unburied skeletons project from the seabed. Glass sponges other than reef-forming species (e.g., boot sponges such as *Rhabdocalytpus dawsoni*) can also comprise the living portion of the reef (Conway et al. 1991; Cook 2005; Krautter et al. 2002).

Little is known of the growth rates of reef-building sponges in the HS/QCS glass sponge MPA, but growth of reef building glass sponges at sites in the Strait of Georgia has been estimated as ranging between 1-9cm per year (Dunham et al. 2015, Kahn et al. 2016).

In terms of physiology, an important feature of hexactinellid sponges that distinguishes them from other sponges and most other animals, is that their tissues are not divided into separate cells. Instead a major tissue component in hexactinellid sponges is a multinucleated syncytium that thinly covers, and produces, a rigid skeleton of glass spicules (Leys, 2003; Reiswig and Mackie 1983). As a consequence, these sponges are cytoplasmically interconnected and able to transmit electrical signals through a body that lacks nerves (Leys, 2003; Leys et al. 2007) enabling coordinated arrest of the feeding current in response to disturbances such as increases in sediment levels (Leys et al. 1999; Mackie et al. 1983).

1.3. ECOLOGICAL SIGNIFICANCE OF GLASS SPONGE REEFS

Glass sponge reefs are unique to the Northeast Pacific, and are found on the continental shelf of the Pacific Northwest (Cook et al. 2008). They contribute to benthic productivity and maintenance of biodiversity by providing stable, complex and extensive three-dimensional habitat for a diversity of vertebrates and invertebrates, and by providing refuge from stressors such as predation and adverse conditions (e.g. strong bottom currents) (Cook et al. 2008; Chu and Leys, 2010; Stone et al. 2014). Deep water sponges also serve as focal foraging sites for prey species that aggregate in sponge habitat (Krautter et al. 2001; Stone et al. 2011). Fish have been reported to use sponges as spawning substrate, while other species likely use sponge habitat as breeding sites (Stone et al. 2011). In Strait of Georgia reefs, diverse biota is associated with the reefs, including animals from 7 phyla and 14 classes. Though significantly more crustaceans and fish are found in the presence of the sponges there are significantly lower abundances of molluscs and other sponges within some of the Strait of Georgia reefs (Chu and Leys, 2010). In addition to the live sponge, both the bare and sediment-infilled parts of the dead sponge skeleton matrix of the reef are also used by a range of organisms. The bare skeleton is used by tube-building annelid worms (terebellids and serpulids), bryozoans, encrusting sponges (Cook, 2005), and a diverse range of foraminifera (Guilbault et al. 2006). The sediment-infilled skeletons contain endobenthic and semi-infaunal organisms and a diverse assemblage of annelid worms (Cook, 2005). Reef building sponges are consumed by at least two species of nudibranchs (Chu and Leys, 2012) and also potentially by other organisms including sea stars (Leys et al. 2007). Glass sponges have also been observed to be bitten by fish as they capture prey among sponges (Kahn et al., 2016).

Sponge reefs provide an important link between benthic and pelagic environments. They can modify sedimentation processes and bottom currents, influence local water properties, and their high filtration capacity enables them to consume large amounts of bacteria and recycle organic matter, giving them an important role in nitrogen and carbon processing (Kahn et al. 2015; Yahel et al. 2007). In fact, deep-sea glass sponge communities are thought to consume the majority of bacteria and provide the bulk of recycled organic matter exported to these areas (Yahel et al. 2007). Sponge reefs play a role in the local silica cycle by acting as an important sink for biogenic silica. They take up silicic acid from the water column to form their skeletal matrix, sequestering silica long after the death of the living sponge (Chu et al. 2011).

The glass sponge reefs in the HS/QCS MPA are unique in a number of ways, including species composition, species richness and species diversity. Unlike other known glass sponge reef complexes found in the Pacific region, the HS/QCS sponge reefs are built by three reef-building Hexactinellid sponge species: *Farrea occa, Heterochone calyx* and *Aphrocallistes vastus*. (*F. occa* is relatively abundant in the HS/QCS MPA but has not been observed among the known Strait of Georgia/Howe Sound glass sponge reefs). The geological setting of the HS/QCS reefs also differs from other known reef complexes. In the HS/QCS, the sponge reef complexes are located on flat beds of gravelly till located in wide (ca. 20 km) troughs; the edges of the troughs are covered by soft sediment, and there is some sedimentation around the reef edges, but the reefs are generally in sediment-starved areas. In contrast, sponge reefs in the Strait of Georgia and Howe Sound are not able to grow in troughs as these areas are too readily filled with muddy sediment that prevents sponge growth and development. Instead, they survive by living on elevated ridges or promontories of glacial till; basically islands of till surrounded by mud (see

Figure 2). These differences may be important to consider for research on the impacts of sediment re-suspension for example.

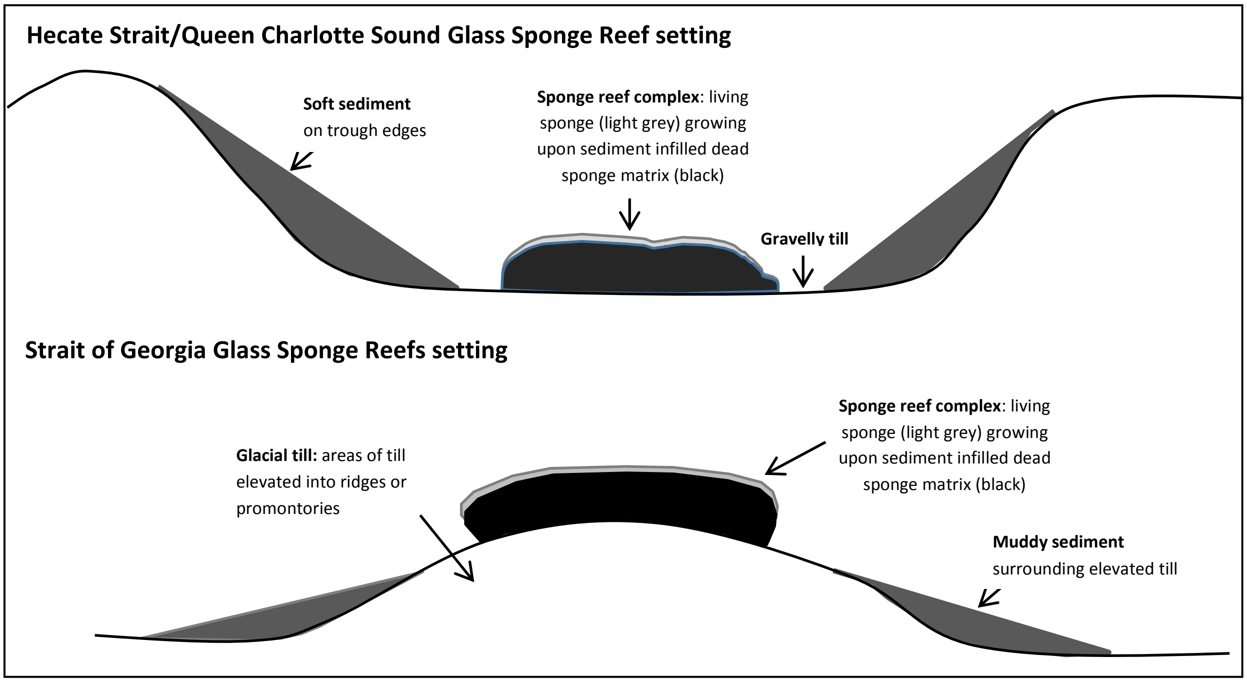

Figure 2. Differences in the geological setting of sponge reefs in Hecate Strait and Queen Charlotte Sound (HS/QCS; A) compared with those in the Strait of Georgia and Howe Sound (B). Figure c*reated based on discussions with K.Conway, Natural Resources Canada (NRC), pers. comm. (2015).*

Unique discoveries at the HS/QCS sponge reefs include a new demosponge species (Lehnert et al. 2005) and two newly-described foraminiferan species that are thought to be specific to these sponge reef complexes (Guilbault et al. 2006). Further, two species of bivalve have been found among the infilled sponge skeletons that are adapted to low oxygen conditions, possibly indicating that the infaunal habitat is oxygen depleted (Cook 2005). Ongoing research is expected to continue to improve habitat characterization and understanding of the functions and services of this unique ecosystem.

1.4. ANTHROPOGENIC THREATS TO GLASS SPONGE REEFS

Glass sponge reefs are ecologically and biologically significant areas (EBSAs) that are particularly vulnerable to damage and disturbance (DFO 2013). Their fragility makes physical disturbance a particular concern and any physical impacts can have severe, long-lasting effects on these slow to recover species. Three categories of human activities occur at the reef and may impact it: vessel traffic, research and fishing. Although all these activities can impact sponge reefs, bottom contact fishing has been identified as a very significant threat. Visual surveys of many reefs in the Pacific region have revealed there to be extensive damage due to bottom contacting fishing gears (e.g., bottom trawling) that occurred prior to implementation of fishing closures (Austin et al. 2007; Conway et al. 2000; Conway et al. 2005b; Jamieson and Chew 2002; Krautter et al. 2001). In addition to the effects from physical impact from fishing activities, the effects of sediment re-suspended during fishing activities is also considered to be a significant threat to sponge reefs. This is because the indirect effects of this stressor have been documented to affect sponge communities including hexactinellid sponges by smothering or adversely affecting feeding (Leys 2013). There are also other impacts that, although not regularly occurring in the area, have a high potential to seriously harm sponge reefs if they were to occur. These include toxic impact (e.g., from a ship-source oil spill) and impacts from aquatic invasive species released from passing vessels. This report considers, describes and evaluates the human-related activities and stressors that have the potential to impact the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs and incorporates them into the assessment. The consideration of the impact of stressors from all activities, even those that may seem insignificant, allows for the cumulative effect of each stressor, combined over all sources to be assessed.

1.5. THE HECATE STRAIT AND QUEEN CHARLOTTE SOUND GLASS SPONGE REEFS MARINE PROTECTED AREA

The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area (MPA) was designated in February 2017 (SOR/2017-15). The MPA encompasses the glass sponge reef complexes previously identified as an Area of Interest in 2010. Before this, the area was voluntarily closed to groundfish trawl fishing in 2000. The groundfish trawl fishery was formally closed in 2002, with expanded closures in 2006.

The total area included in the MPA is approximately 2,410km^2 and is comprised of four reef complexes: the Northern, Central and Southern Reefs. In addition to the glass sponge reefs themselves, the MPA area also encompasses the water column, a buffer area of surrounding waters (i.e., vertical adaptive management and adaptive management zones) and the seabed to a depth of 20m below the subsoil surface (Figure 3) for each complex. These protection zones aim to protect the structural habitat, biodiversity, and ecosystem function of the glass sponge reefs as outlined in the conservation objective of the MPA regulations. The management zones are defined as follows:

- **Core Protection Zone** (CPZ): The core protection zone consists of the seabed, the subsoil to a depth of 20m, and the water column above the seabed to a specified depth below the sea surface (the depth is specific to each reef complex).
- **Vertical Adaptive Management Zone** (VAMZ): The vertical adaptive management zone consists of the water column that extends above the CPZ to the sea surface.
- **Adaptive Management Zone** (AMZ): The adaptive management zone consists of the seabed, subsoil to a depth of 20m and waters above each reef complex within the MPA that do not form part of the CPZ or the VAMZ. The AMZ is designed to mitigate the risk of indirect impacts through adaptive management of allowed activities that are consistent with the MPA's conservation objectives.

Note that the exact extent of each zone differs slightly between reefs (additional details on specification of each of the zones for each of the reef complexes in the MPA can be found in Appendix A).

The designation of the MPA under the *Oceans Act* provides the regulatory mechanism to prohibit those human activities that are not compatible with the conservation objective of the MPA (i.e., the conservation and protection of the biological diversity, structural habitat, and ecosystem function of the glass sponge reefs).

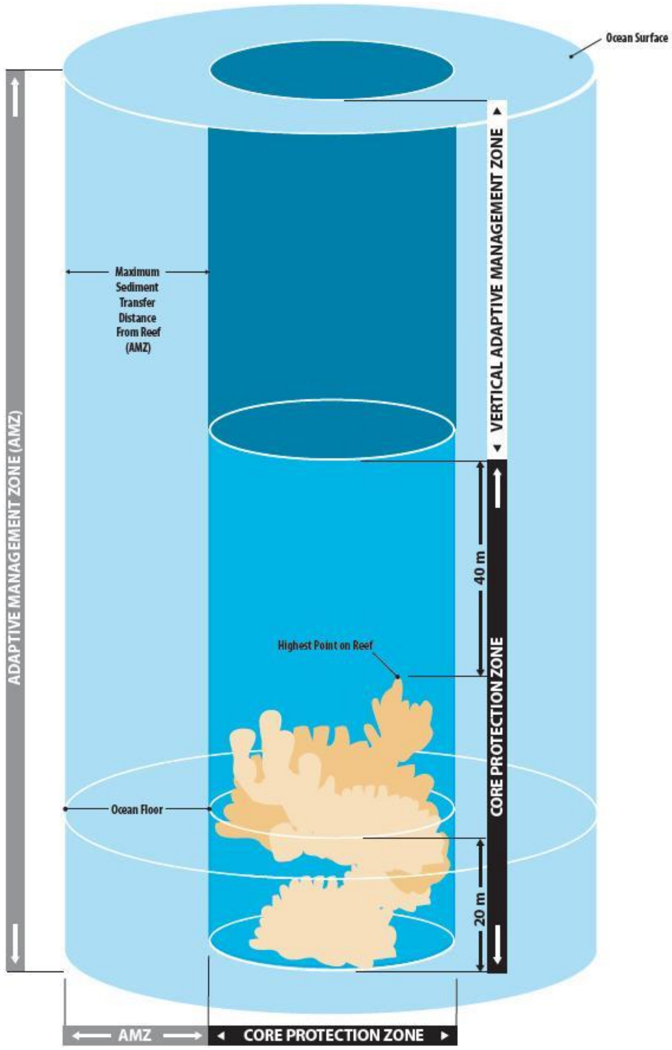

Figure 3. Protective internal management zones for the MPAs (courtesy of DFO Oceans – Pacific Region). Note that the sponge structure found below the ocean floor is dead and buried, so should be differentiated from the live sponge that is found on the reef, above the ocean floor.

This document presents the first application of the Ecological Risk Assessment Framework (ERAF, O et al., 2015) to the glass sponge reef ecosystem. This work is valuable as it examines the utility of the ERAF approach in this system including modifications to tailor the ERAF method to better capture sponge reefs in the assessment. However, it should be noted that this work was originally completed in 2015, when the HS/QCS sponge reefs were designated as an 'Area of Interest' rather than an MPA. At this time there were only recommended guidelines in place to guide the initial scoping and scoring phases of the risk assessment. Though many updates have been incorporated into this document to capture some of the changes since 2015, it is strongly recommended that a subsequent iteration be completed as soon as feasible given new research emerging as well as the regulations associated with MPA designation that are now in effect. It is likely that some of the knowledge gaps identified in this work may have begun to be addressed through new research currently being carried out on this ecosystem, before this work is published.

2. METHODS

This paper will first determine Significant Ecosystem Components (SECs) in the HS/QCS glass sponge reef ecosystem and then identify anthropogenic activities and associated stressors occurring in the MPA (both those occurring at present, and those with foreseeable potential to occur) using scoping guidance from DFO's Ecological Risk Assessment Framework (ERAF; O et al. 2015). The next step examines the expected impact of the activity-linked stressors to the identified SECs using the scoring system described in the ERAF, which considers elements of exposure, resiliency and recovery (O et al. 2015). The final step is to assess the effectiveness of the ERAF when applied to the HS/QCS Glass Sponge Reefs MPA by examining the scoping outputs and resulting relative risk rankings to determine if they are appropriate and relevant to this ecosystem. The outputs of this risk assessment will be used to develop risk-based monitoring protocols and plans for the newly-announced MPA, as well as to inform other oceans management decisions.

2.1. SEC SCOPING PHASE

2.1.1. Identification of Significant Ecosystem Components (SECs)

In the context of this study, a SEC is an environmental element that has ecological importance to an ecosystem. Though all species, habitats, and communities have some degree of ecological significance, the scoping phase aims to identify the ecosystem components with the greatest relative significance.

Existing literature was used to assemble lists of species, habitats, and community/ecosystem properties to be assessed against SEC selection criteria and additional ecosystem-specific considerations. Although it is important to identify all potential SECs, it is impractical to assess them all with the ERAF process and as such only a limited number of key SECs considered to have relatively high ecological significance are ultimately chosen for use in the risk assessment (O et al. 2015).

Table 1. Summary of criteria used for the selection of Species, Habitat and Community/Ecosystem Properties SECs (O et al. 2015) and additional considerations for species (developed for this application and not listed in O et al. 2015). See Appendix B for full descriptions of each criteria and consideration.

SEC Type	SEC Criteria and Supplementary Considerations
Species	**Primary Criteria (O et al. 2015)** 1. Nutrient importer/exporter 2. Specialised or keystone role in the food web 3. Habitat creating species 4. Rare, unique, or endemic species 5. Sensitive species 6. Depleted (listed) species
	Supplementary Considerations (not included in O et al. 2015) 1. Resident on the sponge reefs 2. Dependent on the sponge reef ecosystem 3. Abundant in the area on or around the sponge reefs 4. Has been directly observed to occur in the sponge reef 5. Suited to long-term monitoring 6. Well studied

SEC Type	SEC Criteria and Supplementary Considerations
Habitat	1. Biogenic habitat types 2. Sensitive habitats 3. Habitats critical for sensitive species 4. Threatened or depleted habitat 5. Habitats critical for supporting rare, unique or endemic species 6. Habitats supporting critical life stages 7. Habitats providing critical ecosystem functions or services
Community/ Ecosystem Properties	1. Unique community 2. Ecologically significant community 3. Functional groups that play a critical role in ecosystem functioning 4. Ecological processes critical for ecosystem functioning 5. Sensitive functional groups

2.1.1.1. Selecting Species SECs

A comprehensive species list was assembled using a number of sources: species recorded from research surveys (e.g., ROV) on/in the reef environment (e.g., Cook 2005; Jamieson and Chew 2002); species recorded in catch data from fisheries in the area (e.g., Jamieson and Chew 2002); species inferred to occur on/in the reefs based on data from surrounding areas (e.g., work completed for the Pacific North Coast Integrated Management Area (PNCIMA; Hemmera 2010[1]); and, unpublished work (conference presentations, online resources). For full details of sources, see Appendix C.

The six species SEC selection criteria in O et al. (2015) were used to identify species with greater relative ecological significance due to their role in the ecosystem and to screen the extensive list of species. It was necessary to include additional descriptive detail to the original ERAF criteria descriptions (Table 1, Appendix B) to make it clear how they would be applied to the HS/QCS glass sponge reef ecosystem. Adding more detail provided clear and consistent scoring guidance, minimizing interpretation errors and associated uncertainties. Species were scored a 1 if they met a criterion or a 0 if they did not; those species which fulfilled 3 or more criteria were selected for further examination. However, a large number of species fulfilled three or more of the original criteria, and many species of these were in similar groupings (e.g., several decapod species and a number of fish species).

To guide the species SEC selection process further (and to better differentiate among the remaining larger groups of organisms with similar functions), six supplementary considerations tailored to sponge reef ecosystems and the types of data available were added to the screening process (Table 1, Appendix B). For example, using the supplementary criteria would highlight a species observed directly on the reef by Remotely Operated Vehicle (ROV) but not a species observed in fisheries bycatch from the general area.

2.1.1.2. Selecting Habitat SECs

Though it is recommended that a bioregional classification system is used to identify habitat SECs, this information was unavailable at a suitable resolution for this study. Further, even if available, it may not be appropriate for this type of assessment, which focuses on smaller sub-habitats that are unlikely to be included at the scale of a bioregional classification system. In the

[1] Hemmera. 2010. Overview and Assessment Report for the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs. Prepared for Fisheries and Oceans Canada, Oceans, Habitat and Enhancement Branch, Nanaimo, B.C.

absence of this information, O et al. (2015) suggest considerations for selecting Habitat SECs which were used here (see Table 1 and Appendix B).

2.1.1.3. Selecting Community/Ecosystem Properties SECs

Community/Ecosystem Properties SECs capture important aspects of the ecosystem such as species diversity, trophic diversity, functional redundancy (i.e., community attributes) and ecosystem properties, such as primary production and nutrient cycling (O et al. 2015). At present, there is a general lack of comprehensive, high-resolution community or ecosystem property data available for this MPA, but work in other systems has demonstrated the methods necessary to capture this type of baseline data (e.g., Chu and Leys 2010), and it is expected that similar information will be available for this MPA in the near future. For now, it is possible to identify broad community and/or ecosystem properties that are significant to the ecosystem at an MPA-level spatial scale. The considerations for selecting Community/ Ecosystem Properties SECs suggested by O et al. (2015) used in this assessment are listed in Table 1.

2.1.2. Expert Review

Following the initial scoping exercise, the proposed list of SECs together with a shortened list of other candidates was provided to subject matter experts for their review and comment. The expert reviewers' main tasks were to assess the appropriateness of the selected species and habitat SECs as well as the suitability of the primary criteria and supplementary considerations used for species SEC selection. The output from the scoping phase was a finalized list of Species, Habitat and Community/Ecosystem Properties SECs.

2.2. IDENTIFICATION OF ACTIVITIES, SUB-ACTIVITIES AND ASSOCIATED STRESSORS

2.2.1. Identification of activities and sub-activities

The application of this risk assessment is based on the Marine Protected Area (MPA) regulations that went into effect in February 2017. Further, the list of human activities included in the risk assessment only includes legal activities that are known to occur, or are likely to occur in the foreseeable future, within the MPA boundaries. Conversely, it does not assess the existence of, or potential for, illegal activities or unforeseeable new ventures within the MPA boundaries.

Through consultation with stakeholders, science and policy in September 2011, the DFO Oceans Program compiled a list of activities for the HS/QCS Glass Sponge Reef Area of Interest. The list required additions and updates for this work (see Appendix E). Each activity and sub-activity was then assessed as to whether it was currently occurring or expected to occur in the foreseeable future in the area, resulting in a final list for use in the risk assessment.

2.2.2. Identification of stressors associated with identified activities utilising Pathways of Effects (PoE) models

A Pathway of Effects (PoE) model describes the relationships between human activities, associated stressors and their pathway of effect/impact, where a “stressor” is a factor, environmental or anthropogenic, that causes or drives a behaviour or outcome (Busch et al. 2003). PoEs are developed using peer-reviewed literature to examine how activities affect the environment, specifically helping to identify the stressors associated with each activity and their potential impact on the environment. PoE models were used to guide the identification of stressors that result from the activities/sub-activities relevant to the HS/QCS MPA and to provide detail on the potential impact of stressors using tables of evidence (see Appendix E). A list of the existing PoE models and those developed for the activities relevant to the HS/QCS MPA, along with the date the models were last modified is provided in Appendix E.

PoE models have previously been developed for shipping (which is referred to as vessel traffic here) and research activities, as well as for trap fishing (Appendix E, Table 30). In order to assess stressors related to fishing more generally, a generic fishing PoE model was developed in collaboration with a subject matter expert (Lynne Yamanaka, DFO Science, Nanaimo, BC) and was considered applicable to all fisheries in this risk assessment. Though bottom contacting fisheries are not permitted in the CPZ under MPA regulations, there is the potential for them to be allowed in the AMZ. For these fisheries, direct stressors (e.g. crushing) were not considered relevant for inclusion, but indirect stressors were included. For example, the indirect stressor 'sediment re-suspension' from bottom contact fishing in the AMZ (bottom trawl; long line hooks; long line traps) is considered to have the potential to impact the reef in the CPZ if currents move the sediment into that area and so is included in the assessment. An exception was made for the mid water trawl (Pacific Hake) fishery due to uncertainties around whether it may be allowed to occur in the VAMZ in future (and thus has the potential to impact the MPA directly (e.g., if gear lost in the VAMZ sinks down and directly impacts areas of the CPZ).

Previous ERAF processes had identified the lack of consistency in stressor names in PoE models as an area for improvement in future applications (E. Rubidge, DFO Science, pers. comm.). This challenge was addressed here by standardizing the format of stressor names and consolidating stressors with similar mechanisms of impact (Appendix F). For example, the 'Substrate disturbance [crushing]' stressor was divided into two complementary stressors: 'Substrate disturbance [re-suspension]' and 'Substrate disturbance [crushing]'. Collectively, the goal of these stepwise updates to the PoE models is to improve consistency and facilitate comparisons between activities/sub-activities in the risk assessment. Details of the changes made are provided in the appendices (Appendix E contains the original stressor names and Appendix F has an updated list of activities and associated stressors). Note that PoE models are considered generic and have not been developed relative to specific ecosystems. As such, several of the stressors in the PoE models are not relevant to the glass sponge reef ecosystem and were subsequently screened out of the risk assessment.

2.2.3. Stressor types and implications for scoring

In this risk assessment, as in other ERAF applications, stressors are of two types:

1. 'Potential' stressors – occur at infrequent and unpredictable intervals but with high potential consequences. These stressors are not known to occur in the area at present but have the potential to do so. There are a number of potential stressors in this ERAF; for example, grounding (i.e., ship sinking to the bottom), oil from oil spills, introduction of Aquatic Invasive Species (AIS), and seismic disturbance (from seismic surveys). Unless current data is available, potential stressors are scored as in the worst case scenario with high uncertainty (because exposure terms for these are difficult to predict). Examples include: AIS, where scoring assumes establishment; oil spill, which assumes a large-scale tanker spill; and seismic, where scoring assumes testing has been approved to occur in the MPA.
2. 'Current snapshot' stressors – have occurred in the area recently or are currently occurring at predictable intervals, with some regularity. Scoring is based on a 'snapshot' assessment of what is presently known to occur in the area, using available data or a best estimation. Worst case scenario scoring is not used, but exposure may be referenced to guide resilience scoring. In other words, because factors of exposure are usually known in these cases, they can be scored on a more realistic basis. For this type of stressor, there are two sub-types:

- Point source – stressor impact is localised to one or more well-defined area(s), e.g., 'crushing' from vessel grounding.
- Non-point source – stressor potentially affects a broad area, e.g., 'Introduction of biological material' from vessels (such as black water).

The stressors included in this ERAF, along with their assigned type are provided in Appendix F. Note that this risk assessment does not include 'long range' stressors which originate from a much broader area or operate over much longer temporal scale, and not from within the MPA (e.g., microplastics, which are unlikely to originate from within the MPA, or climatic change which operates on decadal time scales or longer). At present, these are expected be included in a future 'state of the ecosystem' analyses, and as such, are not considered here.

Scoring resilience with reference to exposure

In some cases it is necessary to consult exposure in order to be able to accurately estimate the proportion of the population expected to be affected (under resilience). An example of where this would occur would be point source stressors, for example grounded vessels, where some background knowledge of exposure is important to be able to estimate the proportion of the population that could be affected chronically or acutely.

2.3. LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT

Following the identification of the SECs, activities, and stressors in the scoping phase, the risk assessment moves onto the analytical phase of estimating risk. Risk is defined here as "the likelihood that a SEC will experience unacceptable adverse consequences due to exposure to one or more stressors" (O et al. 2015). We analyse two types of risk here:

1. *Relative risk* ($\boldsymbol{Risk_{sc}}$) to a SEC - describes the chance that a SEC will experience decline due to a stressor (from a particular activity within the HS/QCS Glass Sponge Reefs MPA) based on scores assigned to them for exposure and consequence to that stressor.
2. *Cumulative risk* ($\boldsymbol{CRisk_{c}}$) - incorporates the relative risk to a SEC from more than one stressor that can affect it within HS/QCS Glass Sponge Reefs MPA and can be used to determine overall risk to a given SEC.

2.3.1. SEC-Stressor Interaction Matrix

The first stage in the Level 2 risk assessment is to use a SEC-stressor interaction matrix to screen out stressors-SEC combinations that are not expected to interact. The stressors identified in the scoping phase are tabulated against the SECs identified and each SEC-stressor pair is assessed for a potential interaction, and is scored as either (1) to indicate a potential negative interaction, or (0) no negative interaction based on biological expertise. The potential interactions are explored in greater detail in the scoring stage by consulting primary literature and expert opinion (see Section 2.2.2).

The following should be taken into account when completing the interaction matrix:

- Only ***negative*** SEC-stressor interactions are taken into consideration (i.e., stressor impacts that are detrimental to the health/integrity of the SEC). Positive interactions are not included in the ERAF at present.
- Only ***direct*** impacts of a stressor to ***adult*** life-stages of SECs are considered. Examples of indirect impacts not assessed here include increased predation or competition for food resources following disturbance from light or noise. Note that the ERAF could be used to score indirect impacts in future iterations. Further, juvenile stages are excluded from the

interaction assessment since their inclusion could skew the weightings of stressors that would otherwise have very little impact on the mature organism. This could result in focusing the assessment on stressors that impact sensitive juveniles (e.g., pelagic juvenile stages of benthic invertebrates), rather than on impacts to the more general ecosystem as a whole. Future work should include scoring for juvenile stages that are clearly associated with sponge reef habitat (e.g., juvenile rockfish that have been shown to selectively occupy glass sponge reef habitats over other areas). Generally speaking, larval and unsettled stages of all species should continue to be excluded from scoring for the reasons given above.

The outputs of this phase are a list of screened stressors for each SEC ready to be scored for the risk terms.

2.3.2. Scoring and Calculation of Risk Terms

The scoring procedure for this risk assessment generally follows the method developed by O et al. (2015) and implemented by Thornborough et al. 2017) and Rubidge et al. 2018), with minor variations (see Section 2.3.2.6 and Appendix L). A brief summary is provided here, but readers are encouraged to refer to these sources for further information. Preliminary scoring results were subsequently expert reviewed for accuracy and completeness.

2.3.2.1. Calculation of Relative Risk (*Risk$_{sc}$*) to a SEC from a Single Stressor

The relative risk to SEC, c, from single stressor, s, (termed ***Risk$_{sc}$***) is calculated via the following equations:

$$\boldsymbol{Risk_{sc} = Exposure_{sc} \times Consequence_{sc}} \quad \text{Equation 1}$$

$$\boldsymbol{Exposure_{sc} = \left(\sqrt[3]{Area_{sc} \times Depth_{sc} \times Temp_{sc}}\right) \times \left(\sqrt[2]{i(amt)_{sc} \times i(freq)_{sc}}\right)} \quad \text{Equation 2}$$

$$\boldsymbol{Consequence_{sc} = Resilience_c \cdot Recovery_c} \quad \text{Equation 3}$$

$$\boldsymbol{Resilience_c = AcuteChange_c + ChronicChange_c} \quad \text{Equation 4}$$

$$\boldsymbol{Recovery_c = Mean(RecoveryFactor 1, RecoveryFactor\ 2, \ldots, RecoveryFactor\ n)} \quad \text{Equation 5}$$

where,

Exposure$_{sc}$ quantifies the extent of spatial and temporal interaction (overlap and intensity) between the stressor and SEC;

Area$_{sc}$ is the percentage of area of overlap between a stressor and SEC;

Depth$_{sc}$ is the percentage of depth overlap between a stressor and SEC;

Temp$_{sc}$ is the percentage of temporal overlap between a stressor and SEC;

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

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

Consequence$_{sc}$ quantifies the potential for long-term harm to the SEC as the result of interaction with the stressor (termed ***Resilience$_c$***) and the SEC's capacity to resist/recover from exposure to the stressor (termed ***Recovery$_c$***). ***Resilience$_c$***

Resilience$_c$: AcuteChange$_c$ (ac) is assessed based on the percent change in the population-wide mortality rate of a species SEC when exposed to a given stressor, the loss of area and productive capacity of habitat SECs, and the percentage of species impacted for Community/Ecosystem Properties SECs; and

Resilience$_c$: ChronicChange$_c$ (cc) is assessed based on the percent change in the long-term fitness (including condition and genetic diversity) of a species SEC, the percent change in structural integrity, condition, or loss of productive capacity of habitat SECs, and the percentage of functional groups impacted for Community/Ecosystem Properties SECs.

Recovery$_c$ is assessed based on factors thought to affect the SEC's ability to return to levels similar to those that existed pre-interaction. The recovery factors considered in this assessment (e.g., life history traits and habitat or community characteristics) are listed in Appendix H. Not all recovery factors for species, habitats, and communities listed in O et al. (2015) were applicable to all SECs (e.g., many of the species recovery factors are fish-specific). Factors that were not applicable to a given SEC and those with no available SEC-specific information were not included in the ***Recovery$_c$*** calculation. Review of recovery factors for which information is missing but could be expected should be used to identify areas for priority research (to improve unbiased estimates of recovery).

2.3.2.2. Derivation and Application of the *Risk$_{sc}$* Equation

Exposure$_{sc}$ is calculated using the geometric mean (defined as the n^{th} root of the product of *n* numbers) of the estimated overlap (i.e., area, depth and temporal), multiplied by the geometric mean of the two intensity variables (i.e., amount, frequency). The geometric mean was selected over the arithmetic mean so that the three-term spatial/temporal overlap component does not outweigh the two-term intensity component. The use of the geometric mean ensures that ***Exposure$_{sc}$*** (five terms) and ***Consequence$_{sc}$*** (two terms) are on the same scale (1-16 and 1-18 respectively) for the risk calculations.

Qualitative categorical scoring guidelines for each term in the risk equation are provided in the following section.

2.3.2.3. Qualitative Scoring Bins used to Score Sub-terms of *Risk$_{sc}$*

Unlike many other frameworks that employ only categorical, qualitative metrics of risk (i.e., high, medium, and low), this Level 2 risk assessment captures quantitative information about exposure using a more refined scoring scheme to better reflect the relative extent of impact among stressors on a given SEC (O et al. 2015). Specific ranges used to create scoring bins for each risk term are provided below (Tables 2-4).

*Table 2. Qualitative scoring bins for **Area overlap$_{sc}$**, **Depth overlap$_{sc}$**, and **Temporal overlap$_{sc}$** (the overlap sub-terms of **Exposure$_{sc}$**) measured in percent overlap, adapted from O et al. (2015).*

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

*Table 3. Qualitative scoring bins for **Intensity$_{sc}$(amt)** and **Intensity$_{sc}$(freq)** (the intensity sub-terms of **Exposure$_{sc}$**), adapted from O et al. (2015).*

Intensity (amt)$_{sc}$	Very Low (0.1-1%)	Low (1-20%)	Medium (20-50%)	High (>50%)
Intensity (freq)$_{sc}$	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)
Score	1	2	3	4

*Table 4. Qualitative scoring bins for **AcuteChange**$_c$ and **ChronicChange**$_c$ (the sub-terms of **Resilience**$_c$) measured as percent change in population-wide mortality rates (**AcuteChange**$_c$) or long term fitness (**ChronicChange**$_c$), adapted from O et al. (2015).*

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

2.3.2.4. Calculation of Cumulative Risk (CRisk$_c$) to a SEC from Multiple Stressors

Cumulative risk (termed ***CRisk***$_c$) to SEC, c, across relevant stressors can be calculated by summing the individual risk scores (***Risk***$_{sc}$) from all stressors interacting with that SEC. Although cumulative effects can be of four general types (i.e., additive, synergistic, compensatory, and masking), the most straightforward calculation of cumulative risk was assumed (i.e., all stressor risk scores were assumed to be additive) due to the present lack of understanding of stressor interactions and cumulative effects. Current research of cumulative effects is expected to provide guidance on this assumption in future ERAF iterations.

For a given SEC (c), ***CRisk***$_c$ is then defined by the equation:

$$CRisk_c = \sum_{s=1}^{n} \mathrm{Risk}_{sc} \qquad \text{Equation 6}$$

where n is the number of stressors interacting with the SEC.

Estimation of ***CRisk***$_c$ (across SECs) enables evaluation of the relative risks to all SECs assessed within the HS/QCS Glass Sponge Reefs MPA.

2.3.2.5. Calculation of Cumulative Risk (Potency$_s$) for a Single Stressor across all SECs

To understand which stressors represent the greatest threat to the assessed area, the “potency” (***Potency***$_s$) of each stressor was calculated by summing median risk scores (***Risk***$_{sc}$) for all SECs that the stressor interacted with.

For a given stressor, ***Potency***$_s$ is defined by the equation:

$$Potency_s = \sum_{c=1}^{m} \mathrm{median}(\mathrm{Risk}_{sc}) \qquad \text{Equation 7}$$

where m is the number of SECs interacting with the stressor.

2.3.2.6. Scoring and Incorporation of Uncertainty

Each risk variable score was assigned an associated uncertainty value between 1 and 5 to represent the level of confidence (or amount of evidence) available to support that score, where 1 indicates low uncertainty and 5 represents high uncertainty (Table 5).

Table 5. Definitions of uncertainty scoring bins, based on categories outlined in Therriault and Herborg (2007).

Score	Evidence	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.

Score	Evidence	Definition
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 primary bases are used to assess uncertainty in the risk scoring approach: (1) assessment of the amount and specificity of literature available about the SEC-stressor interaction (i.e., is the available literature species and location-specific, or is it being generalized from findings for other species and/or other places); and, (2) whether there is scientific consensus about the risk inherent in 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 explicitly represented in Table 5. In order to implicitly assess this type of uncertainty, the uncertainty score is increased by one (*n*+1) when there is no scientific consensus.

The uncertainty associated with each scored variable was incorporated into the risk score using one of two methods. The first method applied the approach outlined in Murray et al. (2016), where uncertainty in each risk variable is modelled from a normal distribution with mean equal to the risk score and standard deviation corresponding to the level of uncertainty assigned (Table 6). The score of each $\boldsymbol{Risk_{sc}}$ variable was then randomly sampled from this distribution with 10,000 replicates to produce an array for each variable. The resulting samples were bounded by the minimum and maximum possible scores for each $\boldsymbol{Risk_{sc}}$ variable to ensure scores could not exceed the score range for that variable (i.e., random samples that fell below or above the range were automatically re-assigned to the minimum or maximum score, respectively). This could result in highly skewed results (i.e., in cases where a large number of samples fell outside the scoring range and were re-assigned), the resulting probability distribution would not accurately reflect the range of uncertainty intended (i.e., the mean would be biased toward the score limit and the associated 10/90% percentiles would be artificially narrow, leading to over-confidence in the results; see plots in column “A”, Figure 4 and Figure 5). For this ERAF application, an alternate method employing the truncated normal distribution was developed and applied in an attempt to address this limitation. The truncated normal distribution limits the outcome of random sampling so that the resulting probability distribution is appropriately distributed over the range of the allowable scores limits (column “B” in Figure 4 and Figure 5). The figures illustrate the two methods using the scoring bins for Resilience (bound by 0 and 3, with the score equal to 0 in Figure 4 and equal to 2 in Figure 5). The impact of using a truncated normal distribution is most pronounced for scores equal to the score limits (and with any level of uncertainty). In the example, this effect is evident when mean scores are equal to 0 or 3 (Figure 4). The effect of using the truncated normal distribution is also evident for intermediary mean scores (in the example, scores of 1 or 2) associated with higher levels of uncertainty (uncertainty greater than 2; Figure 5). Results under both uncertainty estimation methods are reported for comparison with previous ERAF assessments and further discussion.

The final $\boldsymbol{Risk_{sc}}$ score for each SEC-stressor relationship was a product of the $\boldsymbol{Exposure_{sc}}$ and $\boldsymbol{Consequence_{sc}}$ variable arrays (Equation 1), where the first score generated from each variable array is calculated using all the $\boldsymbol{Risk_{sc}}$ variables in the first row, then repeated for all 9,999 subsequent replicates, resulting in a final risk array of 10,000 scores. The median, 10% and 90% percentiles from this final array are reported as the final $\boldsymbol{Risk_{sc}}$ score for each SEC-stressor interaction. Percentiles were used instead of reporting the standard deviation or standard error because the resulting distribution of risk scores (under both uncertainty methods) was non-normal. The statistical program R was used to generate and run the code for estimating uncertainty (R Core Team 2016; Appendix J).

Table 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

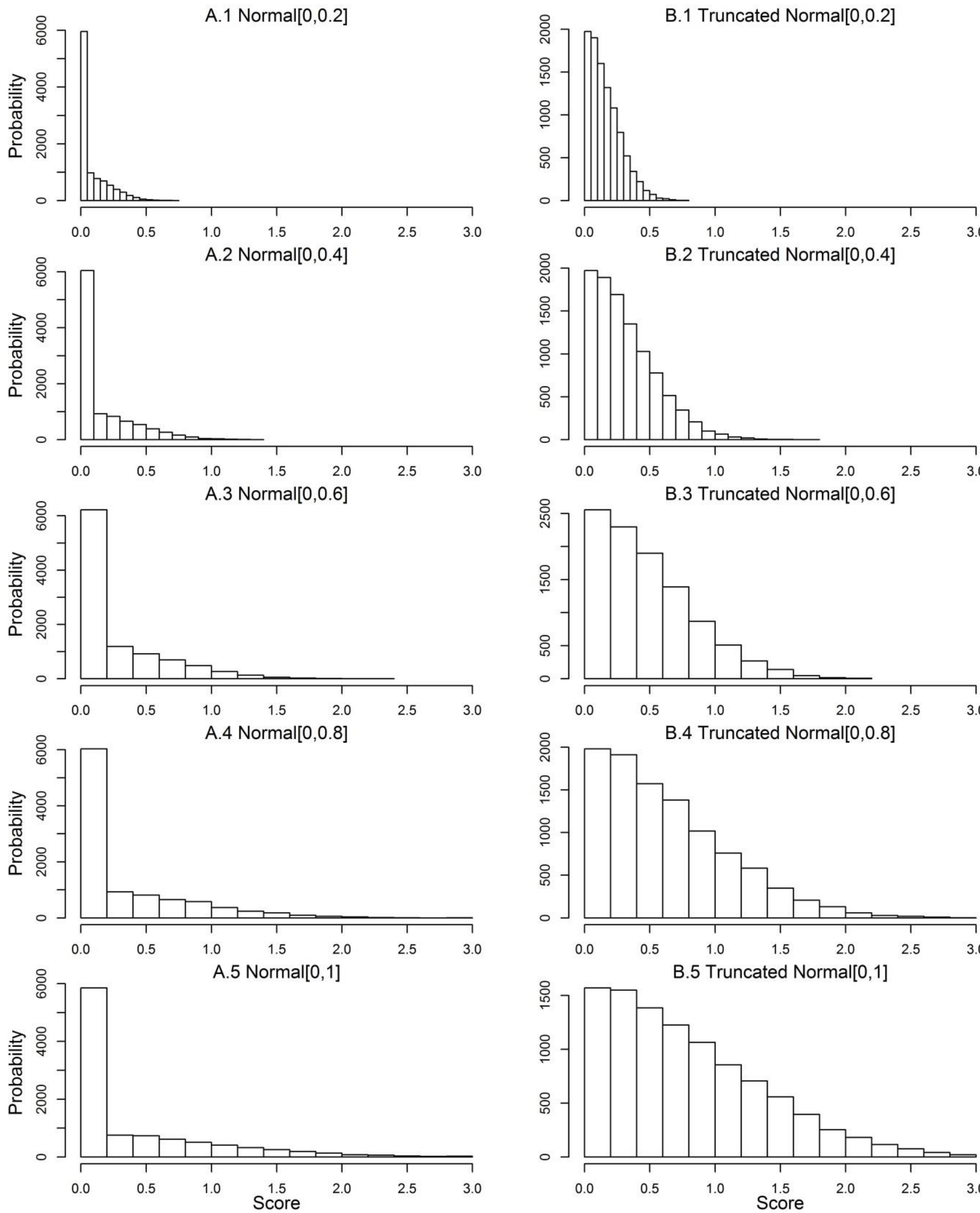

Figure 4. Illustrative example of the differences in distribution between the normal uncertainty method and the truncated normal uncertainty method over a range of uncertainties with a true score equal to 0. In all cases, random scores were bound by 0 and 3, over a range of standard deviations (from 0.2 to 1.0).

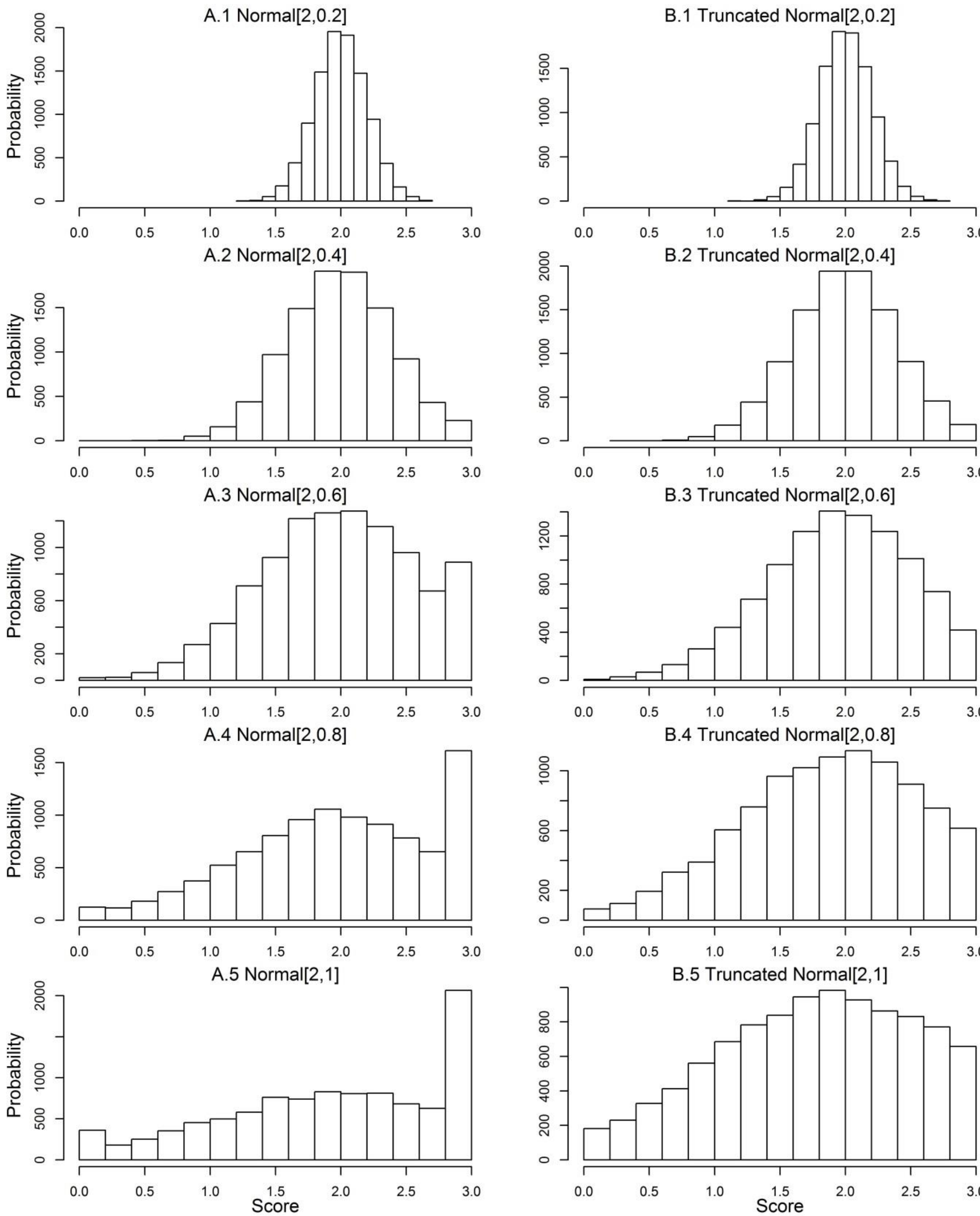

Figure 5. Illustrative example of the differences in distribution between the normal uncertainty method and the truncated normal uncertainty method over a range of uncertainties with a true score equal to 2.In all cases, random scores were bound by 0 and 3, over a range of standard deviations (from 0.2 to 1.0). Note that, in this case, both methods provide essentially equal results if the uncertainty is 0.4 or less.

3. RESULTS

3.1. SCOPING PHASE

3.1.1. Species SEC Identification

A list of almost 400 species present on or adjacent to the HS/QCS glass sponge reefs was compiled for this work, documented from available literature and reports (n=397; see Appendix C for data sources and complete results). The representation of species from some groups in the list is influenced by the types of sampling done at the sites. For example the initial research focus on core sampling is responsible for the large number of polychaete and foraminifera species listed (relative to other groups). As the body of research continues to grow with respect to this MPA, the species list is expected to expand and become more balanced.

Table 7. Results of the initial Species SEC scoping and identification exercise. Cell counts indicate the number of species meeting the specified number of primary ERAF criteria and supplementary considerations. Bold numbers indicate the species shortlisted for consideration as Species SECs.

Number of ERAF Criteria Met	Number of Supplementary Considerations Met						
	0	1	2	3	4	5	6
0	9	16	1	17	5	-	1
1	2	21	15	65	18	4	3
2	3	7	7	53	41	8	2
3	-	-	4	***21***	***36***	***11***	***-***
4	-	1	-	***2***	***11***	***8***	***1***
5	-	-	-	***-***	***1***	***-***	***-***
6	-	-	-	***-***	***-***	***2***	***1***

Following the established ERAF criteria assessment protocol, all species were assessed against the ERAF criteria listed in Table 1. However, a further step was needed to guide SEC selection for this particular assessment and allow for clearer discrimination among species. This was done by also assessing species against a number of supplementary considerations, specific to the sponge reef environment (also listed in Table 1). Efficiency in future iterations of this work can be gained by scoring species for supplementary considerations only if they meet at least 50% (3 of 6) of the ERAF criteria. Species scoring highly on both sets of criteria (appearing in the bold black box in Table 7) were primarily from 3 groups: Polychaetes, Rockfish and Porifera (33, 15, and 34 species, respectively, out of 94).

The shortlist of species produced was used to determine the initial list of proposed Species SECs. The proposed list of Species SECs then underwent a review by subject matter experts (Appendix D) in order to arrive at the final selection of species SECs. It should be noted that though not all species scoring highly were included in the final list of Species SECs, many of these species (as well as others) are captured under other habitat or community/ecosystem properties SECs. Examples include representatives of the foraminifera assemblage, polychaete assemblage and non-reef building sponges.

3.1.2. Habitat SEC Identification

The criteria used for selecting habitat SECs in the ERAF (O et al. 2015) are: biogenic habitat types; sensitive habitats; habitats critical for sensitive species; threatened or depleted species habitat; habitats critical for supporting rare, unique or endemic species; habitats supporting critical life stages; and, habitats providing critical ecosystem functions or services (Table 1).

These habitat criteria worked effectively for capturing Habitat SECs for the HS/QCS Glass Sponge Reefs MPA ecosystem. Two habitats were ultimately selected as SECs: the glass sponge reef skeleton habitat and the non-reef-building sponge garden habitat. Descriptions of how they fulfilled the criteria are provided in Table 10. Though the glass sponge reef itself was initially considered for designation as a Habitat SEC, it was decided that the biogenic habitat created by the three reef-building glass sponges is better captured through the inclusion of all three reef-building glass sponge species as Species SECs.

3.1.3. Community/Ecosystem Properties SEC Identification

Community/Ecosystem Properties SECs aim to capture community composition and ecosystem structure—incorporating SECs at a higher level and complexity than specific species or habitat SECs alone (O et al. 2015). The criteria for selecting Community/Ecosystem Properties SECs are: unique communities, ecologically significant community properties; functional groups critical for ecosystem functioning; sensitive functional groups and critical ecological processes (Table 1).

An earlier review of the HS/QCS Glass Sponge Reefs MPA identified a range of “key ecological communities” chosen as factors that contribute to the health and resilience of the sponge reefs, or important elements of the sponges for overall ecosystem health and diversity (Hemmera 2010[1]). However, these were mostly unsuitable for inclusion in this assessment since they are not manageable at the MPA scale, or are not well-suited to the ERAF scoring method.

Identifying potential communities and ecosystem properties was relatively straightforward and a list of SECs considered with reviewer input is provided below. Though it was possible to identify a number of potential Community/Ecosystem Properties SECs, they were not included in this iteration because of similar difficulties incorporating them as found in ERAF applications for SGaan Kinghlas-Bowie Seamount MPA and the Endeavour Hydrothermal Vent MPA (Rubidge et al. 2018; Thornborough et al. 2017). This was mostly related to a lack of data, but also due to difficulties encountered when scoring the ***Recovery**$_c$* criteria. Alternative methods for community analysis methodology proposed by Hobday et al. (2011) requires detailed knowledge of the food web and important species at all trophic levels, as well as species abundance, diversity and other factors. This is a level of knowledge not presently available for this ecosystem, though it is anticipated to increase with new research initiatives following the MPA designation and may well be appropriate for future iterations of the risk assessment (S. Archer, DFO PDF, pers. comm.). The list of potential Community/Ecosystem Properties SECs outlined in Hemmera (2010[1]) and in Table 8 can provide initial guidance for future integration. The identification of trophic structure and functional groups within the glass sponge reef community would be a first step towards a community-level analysis, followed by research on abundance and diversity of various species and species-habitat associations.

Table 8. Potential Community/ Ecosystem Property SECs and rationale for future selection, where available.

SEC	Notes
Glass sponge reef skeleton community [sediments, foraminifera, polychaetes, etc.]	Criteria: Unique and ecologically significant community. Core samples of this community have identified a range of species living in the sediment infilled skeleton (Cook 2005), and surface sampling has identified diverse species of foraminifera associated with the sponge reef skeleton (Guilbault et al. 2006). However, overall there is only patchy information on diversity and abundance, of only some groups from only a few areas of the reef. There is a lack of information on food web structure and links to other groups and habitats/communities of the reef. This community is well represented by the sponge reef skeleton habitat SEC in this ERAF iteration, as the community is dependent on the habitat, and impacts to the habitat impact the community.
Sponge garden community	Though the habitat function of sponge gardens on reef peripheries is known to be important for rockfish, little is known on the communities associated with the sponge gardens and how they contrast and interact with those of the reef. Until more is known, this is represented under the sponge garden habitat SEC.
Rockfish community	Criteria: Ecologically significant community; functional groups critical for ecosystem functioning; contains sensitive functional groups. This community SEC includes all species of juvenile and adult rockfish associated with the sponge reef and associated sponge gardens. Though initially identified as a Community SEC, not enough is known of the different species, food web relationships, diversity, abundances etc. to enable a community assessment to be completed at this time. Instead, a representative species of rockfish was selected and scored as a Species SEC. Rockfish are abundant in and around the sponge reef and sponge gardens which they use as refugia (Krautter et al. 2001). High densities of small juvenile rockfish are associated with cloud sponges on rock substrates in the Georgia Basin (Richards 1986), and in Alaska (Freese and Wing 2003) and these kinds of sponge gardens are thought to be nursery habitat for early juvenile stages of the Quillback Rockfish (*Sebastes maliger*) (Marliave et al. 2009; Richards 1986). The sponge reef bioherms support an array of commercial fish species, with higher fish catches on the edges of the reefs compared to adjacent non-reef areas (Jamieson and Chew 2002) and are also a nursery habitat for juvenile rockfish (Cook 2005). In the Georgia basin, larval fish and gravid female rockfish have been observed in the sponge reef. Acoustic profiles of “halos” of planktonic organisms over the reef at night indicate a diurnal pattern of habitat usage (Conway et al. 2007). Rockfish-sponge associations have been clearly demonstrated for juvenile rockfish utilizing *Aphrocallistes* sp and *Heterochone calyx* as habitat in Alaskan shelf waters (Freese and Wing 2003). Until more is known about the makeup of the rockfish community on the reef and sponge gardens is known, this SEC is well-represented by the selected Habitat SECs and through the selection of a representative rockfish Species SEC (Bocaccio Rockfish).
Glass sponge reef (living) benthic community	Criteria: Unique and ecologically significant community. The sponge reef community is unique (Cook 2005). There is some data on the sponge reef associated community from ROV observations and sampling and is mostly species presence data. There is a current lack of information on diversity, abundances, food web structure and links to other groups and habitats/ communities. At present, this community is well-represented by three reef-building glass sponge reef Species SECs, which make up the habitat that supports this community.

SEC	Notes
Glacial surfaces and topographic enhancement of reef function	Unlike the Strait of Georgia sponge reefs, where glacial till augments flow and may be susceptible to physical impact, increased flow in the HS/QCS reefs is provided by bathymetric focusing of tidal currents to the reef complexes which sit in the major shelf-crossing troughs (K. Conway, Natural Resources Canada, pers. comm.). Sponge reefs require exposed till and glacial surfaces for attachment, enabling reef development. An expert reviewer suggested a SEC which included the importance of the glacial surfaces and topographic enhancement of reef function to cover all the aspects of this critical habitat element (K. Conway, Natural Resources Canada, pers. comm.). At present, this is not included as a Community SEC as it is not manageable at the MPA level.
Bacteria and picoplankton/ incoming water flows/currents/ suspended sediment	The HS/QCS Glass Sponge Reefs MPA ecosystem is reliant upon the input of bacteria and plankton in the water that flows through the reef to provide the nutrition levels required for the growth and maintenance of the extensive sponge reef ecosystem. The reef is also dependent on the deposition of suspended sediments to form and expand on the reef's structural form. However, this was not currently included as a Community/Ecosystem Property SEC as it is not manageable at the MPA level.
Living function of the reef: Filtration	Although an obvious component of living glass sponge reef and intricately related to the reef-building sponge Species SECs, it is currently unclear how to score this Ecosystem Property SEC, or manage it at the MPA level. Further direction on the scoring and integration of Community/Ecosystem Properties SECs is needed.

3.1.4. Expert Review

Reviewers included S. Leys & A. Kahn (University of Alberta); K. Conway (Natural Resources Canada), and A. Dunham (DFO Science). A summary of their findings is found in Appendix D. The experts considered the process of Species SEC selection appropriate. The process of expert review resulted in the inclusion of two additional Species SECs than originally proposed: the Squat Lobster (*Munida quadrispina*) and the Boot Sponge (*Rhabdocalyptus dawsoni*). One reviewer proposed Squat Lobsters as important for reasons including its abundance on the reef making it potentially a very important link between the sponge reef and fish. Boot Sponges were changed from a Habitat SEC to a Species SEC, in order to allow better characterization of its function during in the scoring process. Subsequent discussion about appropriateness of Species SECs used in this risk assessment is addressed in Section 4.1.1.

In the end, a total of six Species SECs were selected, five of these being invertebrates. In most cases, these species met all or most of the ERAF criteria and supplementary considerations, with the exception of the Squat Lobster. Further, some species scoring highly as candidate Species SECs were ultimately not selected as Species SECs (e.g., polychaetes). Clearly, not all species of ecological significance identified in our species shortlist could be included as Species SECs, but through the selection of the three reef-building sponge species and two additional habitat SECs, risks to any excluded species and their habitats are likely still covered by the risk assessment. In particular, the foraminifera associated with the sponge skeleton scored highly (fulfilling up to 7/12 criteria) but their habitat will also be incorporated with the sponge skeleton Habitat SEC (see Section 3.1.2.)

An important component in the selection of these habitat SECs was through consultation with sponge reef experts (S. Leys and A. Kahn, University of Alberta; and, K. Conway, Natural Resources Canada, pers. comm.) who highlighted and confirmed the importance of the selected habitats in their review of the proposed SEC list.

3.1.5. Summary of Selected SECs

Though many species, habitats and community/ecosystem properties met selection criteria (and considerations) in the scoping phase, the extensive scoring required during the risk assessment phase of the ERAF means that only a handful can ultimately be selected as SECs, ideally fewer than 10 in total (O et al. 2015).

In this iteration, Community/Ecosystem Properties SECs were identified but not included in the risk assessment due to the reasons explained in Section 3.1.3. However, it is important to note that many of the Community SECs under consideration are well-represented by the Species and Habitat SECs that were selected. This also holds true for many of the individual species and habitats that were not selected as SECs.

It is important to stress that the SECs selected for this first risk assessment may be replaced with others in subsequent iterations, particularly once additional field research has been completed (i.e., it may allow for the inclusion of species or groups for which there is currently little reef-specific information, such as sea stars and various rockfish species; and/or the potential inclusion of Community/Ecosystem Properties SECs).

For this risk assessment, the final list of selected SECs for the HS/QCS Glass Sponge Reefs MPA is provided in Table 9 and Table 10, along with a description of how they meet the ERAF criteria (and supplementary criteria, for Species SECs).

Table 9. Species SECs with rationale for selection.

SEC 1. *Heterochone calyx,* SEC 2. *Aphrocallistes vastus* SEC 3. *Farrea occa*
The three species of reef-building glass sponge were selected as individual species SECs which together also comprise the sponge reef habitat. Few distinctions between the species are known at present though *A. vastus* has been more extensively studied.

1. Criteria met: 6 of 6	**Justification**
1. Nutrient Importer/Exporter	The species comprising the glass sponge reefs are highly significant nutrient importers/exporters consuming large amounts of bacteria and picoplankton from the water column.
2. Specialised or keystone role in food web	These reef-building sponge species are the foundation species for the ecosystem and upon which the food web is based.
3. Structural habitat creating species	These three species create a complex three dimensional structural habitat.
4. Rare, unique, or endemic species	Though present in other areas, the presence of these three species together in a reef formation is rare. In addition, this area is one of the few reefs where *F. occa* is observed.
5. Sensitive species	Glass sponge species are known to be sensitive to mechanical impacts and sediment input.
6. Depleted species	The reefs have suffered considerable damage from fishing activities.

2. Considerations met: 5 of 6 (*A. vastus* meets 6 of 6)	**Justification**
1. Resident	These sessile species are resident in the area year-round.

2. Considerations met: 5 of 6 (*A. vastus* meets 6 of 6)	Justification
2. Dependent	Dependent on the reef structure for survival, including the sponge skeleton.
3. Abundant	These species are abundant within the area of study.
4. Observed on reef	ROV surveys found these species to comprise the reef.
5. Simple to monitor	Sessile species comprising the reef should be relatively simple to observe and monitor.
6. Well studied	There has been study on these species, more on *A. vastus* than the other two. New research ongoing. At present, *F. occa* and *H. calyx* do not meet this criterion.

SEC 4. *Rhabdocalyptus dawsoni*
This non-reef-building 'boot' type Rossellid glass sponge is found within and on the periphery of the HS/QCS glass sponge reefs. They have also been found in glass sponge reefs in other areas in BC including the Strait of Georgia and the Boundary Reefs in Northern BC (Stone et al. 2014; Cook 2005; Cook et al. 2008).

Criteria met: 4 of 6	Justification
1. Nutrient Importer/Exporter	Sponges are nutrient importers/exporters consuming bacteria and plankton from the water column.
2. Specialised/keystone role in food web	This species may have a specialised role as its coating of spicules acts as a unique microhabitat (Boyd 1981).
3. Structural habitat creating species	This sponge creates structural habitat and microhabitat in the spicule 'jungle' it is covered with (Boyd 1981) as well as structural habitat or refuge for animals such as fish.
4. Sensitive species	Glass sponge species are sensitive to mechanical impacts and sediment input.

5. Considerations met: 6 of 6	Justification
1. Resident	This sessile species is resident in the area year-round.
2. Dependent	This species lives within and on the periphery of the sponge reefs and is likely to be dependent on the proximity of the reefs for protection, e.g., against water currents.
3. Abundant	This species has been observed by ROV to be abundant.
4. Observed on reef	This species has been observed within and on the periphery of the sponge reefs.
5. Simple to monitor	These sessile, easy to identify species are simple to monitor.
6. Well studied	There has been research done on this species, comparable to *A. vastus.*

SEC 5. *Munida quadrispina*
This species fulfills only two of six ERAF criteria so was not initially selected as a species SEC. However, it was strongly suggested for inclusion by a subject matter expert (S. Leys, U.Alberta) who considered it to have an important role in the ecosystem due to the following factors: i: likely to be an important link between sponges and fish; ii. 'rare' or 'sensitive' species may not exist in their absence; iii. a good representative of mobile decapods, which are abundant on the reef; iv. their abundance likely plays a key role in nutrient cycling (they decrease in abundance from live reef to dead reef in the HS/QCS (Cook 2005), and are also occur in greater abundance in the presence of glass sponge in Strait of Georgia reefs (Chu, 2010)); vi. though present in many places, it is unusual to find them in the type of mud bottom around the sponge reef so they may be an indicator of habitat with potential for monitoring.

6. Criteria met: 2 of 6	**Justification**
1. Nutrient Importer/Exporter	Expected to be an important link between reef and fish (as a prey item), and between the soft sediment community and the reef (as a predator).
2. Specialised or keystone role in food web	The role of this abundant species is expected to be important in the food web, particularly as a link between the reef and fish.

7. Considerations met: 6 of 6	**Justification**
1. Resident	Expected to reside on the reefs year round.
2. Dependent	Dependent on the reef for habitat/refuge/food.
3. Abundant	Observed in abundance on all reefs.
4. Observed on reef	Observed on all reefs in ROV surveys.
5. Simple to monitor	Their defensive nature means that when disturbed, they are likely to stay in place which may simplify monitoring.
6. Well studied	This species has been well studied in other areas.

SEC 6. Bocaccio Rockfish (*Sebastes paucispinis*)
The rockfish assemblage was unable to be included as a community SEC in this iteration, so Bocaccio Rockfish was selected to represent rockfish in the risk assessment as a Species SEC. This species was selected as it was deemed the most sensitive rockfish on our list and so would be scored with the most precaution. This species is one of the few fish species with COSEWIC Endangered designation in the Queen Charlotte Basin (COSEWIC 2013). Bocaccio Rockfish also have commercial value and were caught in fishing trawls on the reefs prior to fishing closures (Jamieson and Chew 2002). At present, we do not know how closely this species is associated with the benthic sponge reef, but it is assumed to be representative of sponge reef-associated rockfish.

Criteria met: 4 of 6	Justification
1. Nutrient Importer/Exporter	It is suspected that rockfish use the sponge reef as a significant source for food: feeding upon decapods in the reef, and organisms such as worms in the soft sediment skeleton community.
2. Specialised/keystone role in food web	Rockfish are expected to be influential top predators in this ecosystem.
3. Sensitive species	Rockfish are long-lived (50 years or more) with low reproductive rates, and are generally territorial (i.e., they do not migrate). This makes them particularly sensitive to local disturbance and fishing pressures.
4. Depleted species	In continuous decline in Canada for 60 years, with 28% decline in the 10-year period since COSEWIC assessment. Recent declines are in areas of highest biomass (west coast of Vancouver Island and in Queen Charlotte Sound). Fishery bycatch is the main threat to the population.

Considerations met: 5 of 6	Justification
1. Resident	It is assumed that this species of rockfish spends a significant part of its life history on the reef.
2. Dependent	It is assumed that the population of this rockfish species is dependent upon the reef for food and shelter.
3. Abundant	The species has been caught on three of the four reefs, and adjacent to the fourth according to DFO catch data (Jamieson and Chew 2002).
4. Simple to monitor	Adult rockfish are relatively simple to identify, though it may be that the rarity of this particular species may make monitoring challenging.
5. Well studied	As a commercial species this species has been well studied and basic life history data is available (Love et al. 1990).

Table 10. Habitat SECs and rationale for selection

SEC 7. Glass Sponge Reef Skeleton Matrix (and material within)
The largest part of the sponge reef is not the living sponges, but the sediment-in filled skeleton forming the basis of the reef (Stone et al. 2014). Sediments that fill the skeleton cavities provides support for the growing reef framework and slow the silica dissolution of the skeletons (Whitney et al. 2005). More recent findings of iron oxide crusts on sponge skeletons (in reefs in Northern BC) may also play a role in preserving the reefs as the siliceous skeletons dissolve more slowly when coated with oxide (Stone et al. 2014).

Criteria met: 5 of 9	**Justification**
Formed by biogenic species	The skeletons are the remains of reef building sponges which form the reef.
Rare or unique habitat	This is a rare and unique habitat; there are few other examples of extensive glass sponge skeleton habitat in the world.
Sensitive or have low tolerance to disturbance and impairment or loss may result in direct impact to species, communities and ecosystem structure and function	Sponge skeletons are fragile with low tolerance to physical disturbance. Older and lower parts of the skeleton may be less fragile once they become infilled with sediment. They support the entire glass sponge reef ecosystem so their damage/loss would severely impact the ecosystem structure and function. The uppermost exposed skeleton habitat is critical for the settlement of new sponge recruits and the continued development of the living component of the reef.
Critical in supporting species of conservation concern (threatened/depleted), sensitive and/or endemic or rare species	The glass sponge skeleton is critical for the survival and support of the living glass sponge reef, a sensitive ecosystem which is of conservation concern. The sediment contained within the skeleton contains species rare for the sponge reef such as worms and bivalves. The large community of polychaete worms living in the sediment provide food for fish living on the reef, such as rockfish, some of which are threatened. The skeleton-associated foraminiferal community also contains some species thought to be unique to this ecosystem or even reef (Guilbault et al. 2006).
Provide critical ecosystem functions or services	Critical for reef preservation and are the basis for the entire sponge reef ecosystem. Similar to live sponges, dead sponge skeletons are also are an important part of the Silica cycle (Chu et al. 2011).

SEC 8. Sponge Gardens (non-reef-building glass sponges and demosponges)
Sponge gardens are defined here as dense assemblages of non-reef-building glass sponges and demosponges occurring within or on the periphery of the reefs). Sponge gardens are distinct from sponge reefs as they grow on rock, not on the dead skeletons of previous generations of sponges (Chu et al. 2010). Sponge gardens are essential fish habitat for later stages of juvenile rockfish, providing cover and prey species aggregations (Collie et al. 1997; Stone et al. 2011). In the Strait of Georgia and Howe Sound, newly recruited juvenile rockfish prefer sponge gardens (defined in the paper as “individual cloud sponges, growing on rock”) to sponge reef bioherms as nursery habitat because sponge gardens provide the necessary food subsidy and are more species-rich (Marliave et al. 2009).

Criteria met: 4 of 9	Justification
Formed by biogenic species	Comprised of non-reef-building glass sponges and demosponges.
Critical in supporting species of conservation concern (threatened/depleted), sensitive and/or endemic or rare species	Sponge gardens are important habitat on reef peripheries (Freese and Wing 2003; Marliave et al. 2009). Sponge reefs and sponge gardens together provide important habitat for different stages of juvenile rockfish (Marliave et al. 2009; Stone et al. 2011, Stone et al, 2014), and several species of conservation concern have been recorded from the area. For example, sponge gardens are an important habitat for newly recruited Quillback Rockfish—a COSEWIC Threatened species-- providing a combination of refuge and feeding opportunity (Marliave et al. 2009; Richards 1986). There are also studies indicating other potential sponge-fish associations may exist (Freese and Wing 2003). Sponge gardens are considered highly important habitat not only for fish but also for crustaceans (S. Leys, University of Alberta, pers. comm.).
Sensitive or have low tolerance to disturbance and impairment or loss may result in direct impact to species, communities and ecosystem structure and function	Sponges are fragile structural species with low tolerance to physical disturbance. Damage or loss would directly impact communities dependent on them.
Supporting critical life stages	Sponge gardens provide important nursery habitat for newly recruited juvenile rockfish, and provide the necessary food subsidy to young-of-year rockfish (Marliave et al. 2009). Several rockfish species found in this area are of conservation concern.

3.2. IDENTIFICATION OF ACTIVITIES, SUB-ACTIVITIES AND ASSOCIATED STRESSORS

Each activity and sub-activity provided by the DFO Oceans Program following consultation with stakeholders, science and policy (September 2011) was assessed as to whether it was expected to actually occur in the HS/QCS MPA, or if it may be permitted under MPA regulations (Appendix E). This resulted in some changes and additions to produce the final list of activities and sub-activities known—or with potential—to occur at present in the HS/QCS Glass Sponge Reefs MPA (Table 11).

Table 11. List of activities and sub-activities identified for inclusion in the HS/QCS Glass Sponge Reefs MPA ecological risk assessment.

Activity	Sub-activity
Vessel Traffic	Discharge
	Grounding
	Movement underway
	Oil Spill
Research	Acoustic mapping
	Equipment abandonment
	Equipment installation/use
	Sampling

Activity	Sub-activity
	Seismic activities
	Submersible operations
Fishing	Bottom trawl
	Long line hooks
	Long line traps
	Mid water trawl
	Rod and reel

The identified list of activities aims to capture the range of human activities thought to pose risk to the HS/QCS Glass Sponge Reefs MPA. A description of each activity is included below.

3.2.1. Vessel Traffic

The Hecate Strait/Queen Charlotte Sound area is an important marine transportation route connecting southern British Columbia domestically and internationally to areas north and west. A range of vessel types travelling the west coast of Canada have the potential to pass near or through the MPA (Table 12).

Table 12. Types of vessel travelling the west coast of Canada and expected to travel in the Hecate Strait and Queen Charlotte Sound, adapted from Hemmera (2010[1]).

Vessel type	**Description**
Bulk Cargo	Carry bulk cargoes; e.g., grain, iron ore, but also petroleum
General Cargo	Carry general cargoes (not containerized); e.g., farm machinery, market goods.
Container Ships	Primarily carry containerized cargo
Tankers	Carry liquid cargoes and is engaged in oil carriage (not including tugs with oil barges)
Chemical tanker	A tanker engaged in the carriage of liquid chemicals, (excluding petro- chemicals)
LPG/LNG carrier	Designed for and carrying liquid petroleum gas (LPG) or liquid natural gas (LNG)
Passenger vessels	Primarily for the carriage of human passengers (e.g., cruise ships) but not ferries
Ferries	Carry passengers and/or vehicles and transits regularly between two ports
Fishing	Any vessel used, outfitted, or designed for the purpose of catching, processing or transporting of fish (Fisheries Act)
Government vessel	Vessel owned by the Government of any country and not engaged in commercial trade
Tugs and barges	A vessel specifically designed for towing or being towed
Tug with oil barges	A barge used for the transportation of oil and propelled by a towing vessel

The MPA reef complexes are located in an area with a moderately high amount of shipping traffic (relative to the surrounding areas) (Simard et al. 2014), (Appendix I) with traffic expected to increase following new port developments in Vancouver, Prince Rupert, and possibly Kitimat. Of particular concern are vessels transporting oil. In 2013 alone, approximately 1,500 oil tankers moved along Canada's west coast (ITOPF 2013). Another source of potential risk from vessels includes ballast water exchange (which may lead to introduction of aquatic invasive species or discharge of contaminants). Under current regulations (Ballast Water Control and Management Regulations, SOR/2011-237), no ballast water exchange is permitted in Hecate Strait or Queen Charlotte Sound, limiting the potential for direct impacts from this sub-activity. Indirect impacts resulting from natural dispersion of ballast water exchanged outside the MPA boundaries remains a concern though.

In addition to commercial shipping, the BC coast is also a popular location for tourist and leisure vessels, with cruise ships, ferries and small recreational boating occurring along the coast. In Canadian waters, ships must be at least three nautical miles from land to discharge treated wastewater (grey water), and at least 12 nautical miles from land to release untreated sewage (black water) (Transport Canada, 2013). Cruise ships follow similar routes and may discharge wastes in similar locations each time the route is travelled (Hemmera 2010[1]). The MPA allows for navigation of vessels that is carried out (i) in accordance with the *Canada Shipping Act,2001* and its regulations; and (ii) without any anchor entering a core protection zone (SOR/2017-15; see regulations in Appendix A).

Based on these points, the following assumptions are made about vessel traffic activities in the MPA during the scoring phase of this risk assessment:

- No anchors will enter the CPZ (as per MPA guidelines).
- Dumping of material such as wood or mine waste is not allowed in the area.
- Vessels may release black water in areas of the MPA ≥12 nautical miles from land
- Vessels may release grey water in areas of the MPA ≥3 nautical miles from land
- No ballast water exchange permitted in the MPA areas
- Vessels, including those transporting oil, can navigate through the MPA area

3.2.1.1. Vessel traffic sub-activities

The following vessel traffic sub-activities are identified as relevant to vessel traffic transiting the HS/QCS MPA:

1. **Discharge**: The release of anything from a vessel, (liquid/solid) such as black water discharges (sewage); grey water (wastewater); litter; discarded/lost deck debris; and ballast water. Though currents can bring in vessel discharge from surrounding areas, only discharges occurring within the MPA are considered. No information is currently available on the concentration or frequency of vessel discharges.
2. **Grounding**: In the context of this risk assessment, this sub-activity is concerned only with the grounding of vessels on the seabed inside MPA boundaries, so can be linked to data on shipwrecks.
3. **Movement underway**: In the context of this risk assessment, this sub-activity is concerned only with the elements of disturbance (noise and/or light) associated with vessels transiting through the MPA.
4. **Oil spill**: Relates to the impacts associated with an acute, catastrophic oil spill from an oil-transporting vessel (Note: chronic releases of oil and contaminants from any type of vessel are captured under discharge).

3.2.2. Research

Since the discovery of the Hecate Strait/Queen Charlotte Sound sponge reefs in 1986, a number of research cruises have visited the area (see Appendix I, Table 36), resulting in biological and geological data sets including sidescan sonar, high resolution seismic records, core samples, sediment samples, biological samples, still images and video footage (see Table 33 references). Under MPA regulations, it is prohibited to "carry out any scientific research or monitoring, or any educational activity, unless it is part of an activity plan that has been approved by the Minister" (SOR/2017-15).

The following assumptions are made about research activities in the MPA in this risk assessment:

- Seismic activities associated with oil and gas production will not be permitted.
- Scientific research will continue to use methods with a similar impact to those already occurring when the area was an Area of Interest (AOI).

3.2.2.1. Research sub-activities

The following research sub-activities have been identified in association with past and expected future research activities in the HS/QCS MPA:

1. **Acoustic mapping***:* Researchers use sonar for bathymetric mapping, using frequencies ranging from 12 kHz for deep water to 70-100 kHz for shallower water. Multi beam sonars operate at high source levels, but have highly directional beams. High-resolution geophysical surveying has been done over the reefs (EG&G sidescan sonar, a Simrad sidescan sonar, a hull-mounted Kongsberg-Simrad EM 1002 system in 1999 and possibly again since). These instruments are towed by research vessels, apart from the multi-beam system which is hull-mounted.
2. **Equipment abandonment**: This includes research equipment abandoned in the area, such as train wheel weights (used to anchor research moorings).
3. **Equipment installation/utilization**: Installation of equipment such as temperature/salinity loggers, hydrophones, current meters, sediment meters, and their utilisation once installed.
4. **Sampling**: Research sampling on the sponge reef areas involving collection of material, such as from core samples, suction sampling, and specimen removal.
5. **Seismic activities** - Seismic surveys are used to map the seafloor enabling scientists to examine geological features. The offshore oil and gas industry use seismic surveys to test for oil and gas deposits beneath the seafloor. Seismic exploration by the oil and gas industry was carried out in the Hecate Strait and Queen Charlotte Sound in 1968 by Shell Canada, and a study on impacts on fish in the area was also done in the 1960's (Kearns and Boyd 1965). Seismic surveys discovered the reefs in 1986, and since then, there have been intermittent research trips to the area including further mapping up to 2003. Although currently not permitted under the MPA regulations, there remains the potential for future permitting under the adaptive management approach.
6. **Submersible operations**: Submersibles (manned and remotely operated) have been used in the past to examine the sponge reefs in the MPA. Their use is expected to continue for monitoring and research purposes.

3.2.3. Fishing

The fragile and three-dimensionally complex habitat of the sponge reefs is easily damaged by mechanical impacts of fishing gear (Rogers et al. 2008). MPA regulations prohibit any activity in the MPA that disturbs, damages, destroys, or removes any living marine organism or any part of its habitat or is likely to do so. No fishing of any kind (commercial, recreational or First Nations) is permitted in the CPZ, but application of adaptive management principles in the AMZ and

VAMZ permits some types of fishing, and may be subject to review and modification over time. Consistent with other activities in the risk assessment, fishing was assessed using a precautionary approach, and was not necessarily limited in scope by the current MPA regulations.

Specific assumptions made about fishing in the MPA during the scoring phase of the risk assessment include:

- No fishing of any kind permitted in the CPZ (including any type of commercial, recreational, or Aboriginal fishing).
- Non-commercial bottom contact fishing is allowed in the AMZ (by trap, hook or trawl).
- Though some fisheries are closed at present under MPA regulations, these fisheries may be permitted in the future in one or both of the adaptive management zones (AMZ and/or VAMZ). These areas are designated for ‘adaptive’ management, potentially allowing for fisheries that were occurring in this area before MPA designation to resume in the future given certain conditions are met. For example, midwater trawl fishing may be allowed in the VAMZ (above the CPZ) in future (pending methods to ensure gear does not enter the CPZ).
- If gear is lost during fishing, dragging for lost trawl gear in CPZ will not be allowed.

Only indirect stressors (such as sediment re-suspension) are relevant for fisheries occurring in the AMZ rather than direct stressors (such as crushing). In the VAMZ (above the CPZ), direct stressors are relevant since the gear could potentially reach the glass sponge reefs to cause direct harm (e.g., lost gear sinking into the CPZ).

3.2.3.1. Fishing sub-activities

The following fisheries were identified as having the greatest potential impacts within the HS/QCS MPA boundaries at the present time:

1. **Bottom trawl:** targets a variety of demersal slope and shelf rockfish and flatfish species. This fishery has not occurred in the CPZ since 2002 due to fisheries closures under the *Fisheries Act*. Indirect effects (such as sedimentation) from bottom trawl fishing occurring in the AMZ are still considered in the risk assessment as it may occur in the future.
2. **Long line hook**: targets Pacific Halibut, Lingcod and Rockfish. Considered a stationary fixed gear though concerns have been raised over the slicing effect on sponges of demersal long lines when hooked fish are struggling (K. Conway, Natural Resources Canada, pers. comm.) and when they are being pulled up from at depth. This fishery was previously permitted in the core area of the sponge reef, but under MPA regulations is only permitted in the AMZ.
3. **Long line trap**: targets Spot Prawn within the MPA area (Boutillier et al. 2013). This is considered a stationary fixed gear in which a string of traps are attached to a long line anchored at each end of the string. Under MPA regulations, this fishery may only be permitted in the AMZ. Although the individual footprint of traps is small, their cumulative effect across multiple strings must be assessed.
4. **Mid water trawl**: targets Pacific Hake (Boutillier et al. 2013). This fishery is currently not permitted in the CPZ, VAMZ or AMZ under MPA regulations, since bottom contact can occur during fishing operations and there is presently no way to monitor or prevent it from happening. When bottom contact occurs, the effects on the benthic fauna can be similar to that of the bottom trawl fishery (Rogers et al. 2008). In future, this fishery may be allowed in the adaptive management zones (VAMZ/AMZ) once the necessary technology has been

developed to adequately monitor/prevent bottom contact. As such, it has been included in this iteration of the risk assessment.

5. **Rod and Reel (recreational fishing)**: the use of ball weights to sink gear has also been reported to occur in the area (L. Yamanaka, DFO Science, pers. comm.). Although recreational fishing of all types has been prohibited in the CPZ, but there is no data on the extent or frequency of this fishery within the AMZ.

Other fisheries presently excluded from the risk assessment (but that may need to be re-assessed in future ERAF iterations):

1. *Food, Social, Ceremonial (FSC) fisheries* – records from 2016 indicate that the Haisla Nation and the Gitga'at First Nation were issued 27 licenses for FSC fishing in one management area (Sub-Area 106-2), a large sub-area that overlaps with the central portion of the sponge reefs (M. Anthony, DFO Fisheries Management, pers. comm.). However, it is not possible to determine whether the fishing activities undertaken actually overlap with the reef, or occur in other parts of the management area. Of the 27 licenses issued, 10 were for salmon, 3 were for Eulachon and Sablefish, 3 were for clams and cockles, 2 were for Herring, 2 for Pacific Halibut, 2 for marine mammals (Seals and Sea Lions), 2 for Groundfish (other than Halibut and Sablefish), and 2 for 'shellfish'. FSC fisheries are not included in this assessment because the impacts from these activities are expected to be negligible and unlikely to occur this far from shore. Future iterations of the risk assessment will need to distinguish cases of dual fishing (in which FSC is accessed with commercial gear). This type of fishing is not currently excluded from the AMZ.
2. *Recreational fisheries (other than rod and reel)*: there is presently no data or information available on this fishing type in the area of the HS/QCS MPA. This type of fishing is unlikely to occur this far from shore and the scale of the fishery is expected to be negligible.
3. *Research fishing* – test fishing (bottom trawl, mid water trawl, hook and line) is not included because it is assumed that this will no longer occur in the CPZ. Future iterations of this risk assessment may need to revisit this assumption based on a review of activity plan applications and final reports received since the MPA designation was implemented. In particular, there is still potential for research surveys to occur in the AMZ and the indirect impacts of these will need to be assessed.

To clarify, only commercial bottom contact fishing is prohibited in all zones of the MPA. Aboriginal and recreational fishing are still open in the VAMZ and AMZ. Due to limited data availability, it is difficult to assess the extent of Aboriginal bottom contact gear used in the VAMZ and AMZ. As a rough estimate, it was assumed that Aboriginal fishers/harvesters use the gear types that are listed in their fishing licence.

The following list is taken from the variation orders (VO) that close the various fisheries from the CPZ/AMZ/VAMZ. The VO for the CPZ is comprehensive and intended to list all possible fisheries that may occur in the waters of the MPA, so it is considered a comprehensive list of all fisheries.

Table 13. Summary of fisheries and gear types currently allowed in the three zones of the HS/QCS Glass Sponge Reefs MPA.

Fishery	Sector	Gear Types	MPA zone allowed in:		
			CPZ	AMZ	VAMZ[1]
Crab	Recreational	Dip net, ring net, trap, hand picking while diving, hand picking	No	Yes	Yes
Octopus	Recreational	trap, hand picking while diving, hand picking, angling	No	Yes	Yes
Shrimp	Recreational	Trap, spear fishing while diving, ring net	No	Yes	Yes
Fin fish other than Salmon	Recreational	Angling, spear fishing while diving, gill net, dip net, herring jig, herring rake, cast net	No	Yes	Yes
Salmon	Recreational	Angling	No	Yes	Yes
All Species	FSC/ Communal[2]	All Gear Types	No	Yes	Yes
Groundfish	Commercial[3]	Bottom trawl, mid water trawl, hook and line (troll and long-line)	No	No	No
Tuna/bonito	Commercial	Hook and line (troll and long-line)	No	Yes	Yes
Herring	Commercial	Gill net, purse seine, trawl	No	Yes	Yes
Salmon	Commercial	Gill net, purse seine, hook and line (troll)	No	Yes	Yes
Shellfish	Commercial	Diving, gill net, hand picking, hook and line, seine, trap, trawl	No	No	No
Halibut	Commercial	Hook and line (long-line), trap	No	No	No
Sablefish	Commercial	Trawl, hook and line (long-line), trap	No	No	No

[1]Some fisheries that are allowed in the VAMZ use bottom contact gear, but would not be able to use that gear in the VAMZ without it entering the CPZ, thus they are de facto excluded from the VAMZ too.

[2] FSC Fisheries are not listed by species/gear in Aboriginal Communal Fishing Licence Regulations; the regulations state “no person… shall fish for or catch and retain any species of fish…..”.

[3] Groundfish includes: Pacific cod, Pacific Hake, Pacific Tomcod, Walleye Pollock, Greenling, Grenadier, Lingcod, Pomfret, Ratfish, Rockfish, Sculpin, Shark (other than Spiny Dogfish), Skate, Sole and Flounder, Spiny Dogfish, Sturgeon, and any species other than halibut, herring, salmon, shellfish and the species referred to in items 1 to 21 of Schedule III of the Pacific Fishery Regulations, 1993.

3.2.4. Activities and Sub-Activities Presently Excluded

Activities and sub-activities identified during the scoping phase but not included in the risk assessment include:

- laying, maintenance or repair of cables in the AMZ/VAMZ (due to lack of data);
- activities associated with marine safety and defense (no data available due to security constraints);
- offshore oil and gas exploration and production (has not occurred since 1972 due to a federal moratorium); and,
- activities associated with renewable energy projects (not occurring at present and no data available).

These may need to be assessed in future iterations of the risk assessment if there is a change in their status or activity level over time.

3.3. LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT

3.3.1. SEC-Stressor Interaction Matrix

A SEC-stressor interaction matrix was completed to identify all potential negative interactions between SECs and stressors in the risk assessment (Appendix G). Stressors limited to surface waters and lacking the potential to have an impact at the depths occupied by the glass sponge reefs were removed at this stage (e.g., all stressors linked to Vessel Traffic 'movement underway' were removed at this stage, with the exception of the Disturbance [noise] stressor, which may reach the seabed and have negative interactions with fish).

Where a negative interaction was uncertain, the SEC-stressor combination was retained so it was included in the next stage of the risk assessment. Positive interactions (where the SEC benefits from interaction with the stressor), such as the introduction of biological material (sewage/fish processing waste) providing enrichment/food for marine organisms, were not accounted for in the ERAF, or included in the interaction matrix. Subsequently, interactions were marked 0 or 1, depending on whether the stressor was likely to have a negligible (0) or more than negligible (1) negative interaction with the SEC.

Table 14. Summary of possible interactions by SEC and Activity, reported in the interaction matrix. (Appendix G).

		Number of possible interactions		
SEC	**SEC Type**	**Vessel Traffic** (max. 22)	**Research** (max. 25)	**Fishing** (max. 30)
H. calyx	Species	13	15	9
A. vastus	Species	13	15	9
F. occa	Species	13	15	9
R. dawsoni	Species	13	15	9
M. quadrispina	Species	12	15	9
S. paucispinis	Species	6	13	9
Glass sponge skeleton	Habitat	11	11	9
Sponge gardens	Habitat	13	15	9
Glass sponge reef community	Community	Not scored	Not scored	Not scored
Rockfish community	Community	Not scored	Not scored	Not scored

As both Habitat SECs are biogenic in origin, they interacted with a similar number of stressors as Species SECs. In some instances, different SECs had a different suite of stressors selected in the interaction matrix, for example, seismic energy may cause harm to the living species and communities but is not expected to impact the dead glass sponge reef skeleton.

Note that Table 14 is only meant to summarise the output of the interaction matrix. It should not be used for analysis in the risk assessment based on previous ERAF applications. In particular, it was recommended that stressors not be considered as a group under each activity, since all stressors related to any given activity are unlikely to occur at the same time.

3.3.2. Scoring of Risk Components

3.3.2.1. Scoring Resilience$_c$ terms

Scoring ***Resilience$_c$*** factors (acute and chronic change) was relatively simple for Species SECs, but required additional interpretation for Habitat SECs. Guidance from Thornborough et al. (2017) was used to score habitat SECs as follows:

- Acute change (ac): a loss in areal coverage of that habitat; and
- Chronic change (cc): a loss in structural integrity, condition and/or productive capacity.

Challenges were encountered when attempting to score ***Resilience**$_c$* for Community/Ecosystem Properties SECs due to a lack of data on the composition of the communities identified. Scoring ***Resilience**$_c$* in communities with little data has been attempted in another ERAF application (Thornborough et al. 2017) by using habitat factors (aerial extent/productive capacity). However, this was not done for the communities selected in this ERAF (rockfish community and glass sponge reef community). Instead, it was decided that the communities selected were best represented at present within the habitat and species SECs in the risk assessment. Future iterations of the risk assessment will need to address this issue.

For 'potential' stressors (see section 2.2.3 for description of the two stressor types), ***Resilience**$_c$* was scored using a 'worst case' scenario. For example, Introductions [AIS] were scored as if established, rather than just exposed to propagules; Oil (from oil spill), as if a large tanker spill had occurred; and for Disturbance [seismic], a high overlap (as the sound waves can travel large distances underwater) potentially causing fatal impacts to some organisms.

***Resilience**$_c$* scores tended to be low for acute change (Score 1 [<10% loss in area]), as the loss in an area would have to be fairly extensive to exceed 10% relative to the extensive scale of the entire MPA and associated skeleton habitat. Sponge garden habitats were most difficult to score as there is little data on their extent or spatial coverage (though they are known to be present within and on the peripheries of the geologically-defined glass sponge reef). Another aspect that has not been addressed explicitly in this relative scoring exercise is the incorporation of current reef condition and how that affects future resilience (i.e., it is likely inappropriate to assume that all the reefs are currently in some "normal" condition and not heavily compromised to start with. An area that is 50% trawled at the time of discovery would not be expected to be as resilient as other more pristine areas, K. Conway, Natural Resources Canada, pers. comm.).

3.3.2.2. Scoring Recovery$_c$ factors

Though most of the **Recovery$_c$** factors worked well when applied to the Species and Habitat SECs in the HS/QCS Glass Sponge Reefs MPA, not all were applicable to each SEC. The following factors were applicable to invertebrates: age at maturity, life stage, population connectivity, and fecundity. The following factors were only applied to fish: natural mortality rate, breeding strategy, recruitment pattern, maximum age, maximum size, and von Bertalanffy growth coefficient. It is hoped that future research will allow application of some or all of these factors to the other Species SECs. Though the 'listed status' factor is theoretically relevant to invertebrates, they are often under-represented in such lists or remain unassessed (Cardoso et al. 2011, 2012). Thus, this factor is presently only relevant to the Bocaccio Rockfish Species SEC. The number of recovery factors scored for each SEC is provided in Table 15. Score categories and justifications for each level are included in Appendix H.

*Table 15. The number of **Recovery$_c$** factors scored for each SEC.*

SEC Type	SEC	Scored ***Recovery**$_c$* factors
Species	*Heterchone calyx*	4
	Aphrocallistes vastus	4
	Farrea occa	4
	Rhabdocalyptus dawsoni	4
	Munida quadrispina	4
	Sebastes paucispinis	9
Habitat	Sponge reef skeleton	4
	Sponge gardens	6

All of the ***Recovery$_c$*** factors are relative measures, and it is not specified in O et al. (2015) what this relative scale is to be judged by. For example, species richness includes three categories:

1. “relative measure for species richness is high”;
2. “relative measure for species richness is medium”; and
3. “relative measure for species richness is low”.

Previous ERAF processes have suggested that it might be possible to score Communities using Habitat SEC ***Recovery$_c$*** factors (Thornborough et al. 2017). It is anticipated that relative measures are (and hence, Community ***Recovery$_c$*** factors will be) something more readily scored once sufficient baseline level data has been obtained from the glass sponge reef ecosystem.

3.3.2.3. Scoring Exposure$_{sc}$ terms

To score the terms that make up ***Exposure$_{sc}$***, we made the following assumptions for simplification and due to lack of data:

1. The living sponge reef extends relatively consistently throughout the Core Protective Zone (CPZ) (even though they are known to be somewhat discontinuous).
2. The three reef-building glass sponge species have approximately equal biomass and distribution within the reef structure.
3. Species selected as SECs generally spend most of their time closely associated with the sponge reef.
4. Due to the benthic nature of the ecosystem and SECs, the depth component (**Depth overlap$_{sc}$**) was generally scored as high potential overlap with stressors.
5. The ***Temporal overlap$_{sc}$*** term reflects the persistence of the stressor over time, and varied by stressor. For example, oil had high persistence over time compared to a low persistence of seismic energy which occurs in short bursts.

Data and GIS analyses used to inform the scoring of overlap (both spatial and temporal) terms for each SEC-stressor interaction are provided in Appendix I.

Based on recommendations from previous ERAF assessments (Thornborough et al. 2017, Rubidge et al. 2018), the original intensity term from O et al. (2015) was split into amount and frequency components for this risk assessment. ***Intensity(amount)$_{sc}$*** represents the relative amount/density of the stressor (independent of the SEC). For example, the amount of sediment re-suspension from bottom trawling was much higher relative to sediment re-suspension from long line trap fishing. ***Intensity(frequency)$_{sc}$*** is scored based on the frequency that the stressor occurs over the year using the guidance in Table 3, with the highest frequency being once a year. All ***Exposure$_{sc}$*** scores and justifications are presented in Appendix J.

3.3.2.4. Scoring Uncertainty

Uncertainty associated with ***Exposure$_{sc}$*** and ***Consequence$_{sc}$*** were relatively similar (when looking at 10/90% percentiles) for ‘current snap shot’-type stressor interactions. Interactions with little quantitative data support had higher uncertainty scores. Potential stressors, such as Introductions [AIS], generally had higher uncertainty scores than ‘current snap-shot’ stressors such as sampling. (See Section 2.2.3. for definitions of stressor types).

3.3.3. Computation of Relative *Risk*$_{sc}$, *CRisk*$_{c}$ and *Potency*$_{s}$

As a first step, stressors scoring zero for both ***Resilience***$_{c}$ factors (***AcuteChange***$_{c}$ and ***ChronicChange***$_{c}$) with moderate to low uncertainty (associated uncertainty scores of 3 or less) were reasonably certain to have a negligible impact on that SEC and were subsequently screened out. Once removed, these stressors were not included in any of the subsequent risk assessment calculations. This approach is a slight modification of the approach taken in earlier ERAF risk assessments (Thornborough et al. 2017, Rubidge et al. 2018) (where *all* stressors scoring zero for both ***Resilience***$_{c}$ factors were excluded, regardless of their uncertainty). (Note that results based on this more restrictive approach are presented in Appendix L for comparison with previous ERAF processes).

3.3.3.1. Calculating Estimates of *Risk*$_{sc}$

Scores and associated uncertainties for ***Consequence***$_{sc}$, ***Exposure***$_{sc}$ terms were combined and used to estimate ***Risk***$_{sc}$ for each SEC using the R script is provided in Appendix J. Results are plotted by SEC groupings (Figure 6, Figure 7 and Figure 8). For each SEC, there are two plots: **Plot A** shows median ***Risk***$_{sc}$ scores with associated uncertainty for each stressor that interacts with the SEC, while **Plot B** plots the paired ***Exposure***$_{sc}$ (x-axis) and ***Consequence***$_{sc}$ (y-axis) scores for each stressor along with the associated uncertainty for each (these called Exposure-Consequence plots). Note that the axes for ***Exposure***$_{sc}$ and ***Consequence***$_{sc}$ have different maximum values, as the maximum range of scores each variable can take differs. The Exposure-Consequence plots allow insight into what is driving the ***Risk***$_{sc}$ scores in Plot A. For example, a data point far to the right and low on Plot B indicates high ***Exposure***$_{sc}$ and low ***Consequence***$_{sc}$ scores for that interaction, and the reader can discern that the high ***Risk***$_{sc}$ score in Plot A is thus driven by ***Exposure***$_{sc}$. For each SEC, the four stressors scoring highest for ***Risk***$_{sc}$ were labelled in Plot B. Actual scores are provided in Table 17 along with the scores for ***Exposure***$_{sc}$ and ***Consequence***$_{sc}$ (full results for all SEC-stressor interactions are provided in Appendix K). The list of stressor numbers used in the figures is provided in Table 16.

Table 16. Stressor numbers used in Figure 6-7.

Activity	Stressor Number (Fig. 6-8)	Stressor Number (Fig. 9-11)	Stressor
Vessel Traffic	1	-	*Discharge – Entrapment*
Vessel Traffic	2	-	*Discharge – Introductions [AIS]*
Vessel Traffic	3	*1*	*Discharge – Oil/Contaminants*
Vessel Traffic	4	*2*	*Discharge – Substrate disturbance [crushing]*
Vessel Traffic	5	*3*	*Discharge – Substrate disturbance [foreign object]*
Vessel Traffic	6	-	*Grounding – Introductions[AIS]*
Vessel Traffic	7	-	*Grounding – Substrate disturbance [foreign object]*
Vessel Traffic	8	*4*	*Movement underway – Disturbance [noise]*
Vessel Traffic	9	-	*Oil spill – Oil*
Research	10	-	*Seismic activities – Disturbance [seismic]*
Research	11	*5*	*Submersible operations – Disturbance [light]*
Research	12	-	*Submersible operations – Introductions[AIS]*
Research	13	*6*	*Submersible operations – Oil/Contaminants*
Research	14	*7*	*Submersible operations – Substrate disturbance [crushing]*
Research	15	*8*	*Submersible operations– Substrate disturbance [re-suspension]*
Fishing	16	-	*Bottom trawling – Introductions[AIS]*
Fishing	17	*9*	*Bottom trawling – Substrate disturbance [re-suspension]*
Fishing	18	*10*	*Long line hooks – Substrate disturbance [re-suspension]*

Activity	Stressor Number (Fig. 6-8)	Stressor Number (Fig. 9-11)	Stressor
Fishing	19	*11*	*Long line traps – Substrate disturbance [re-suspension]*
Fishing	20	-	*Long line traps – Introductions [AIS]*
Fishing	21	-	*Mid water trawl – Entrapment*
Fishing	22	-	*Mid water trawl – Removal of biological material*
Fishing	23	-	*Mid water trawl – Strikes*
Fishing	24	-	*Mid water trawl – Substrate disturbance [crushing]*
Fishing	25	*12*	*Mid water trawl – Substrate disturbance [re-suspension]*

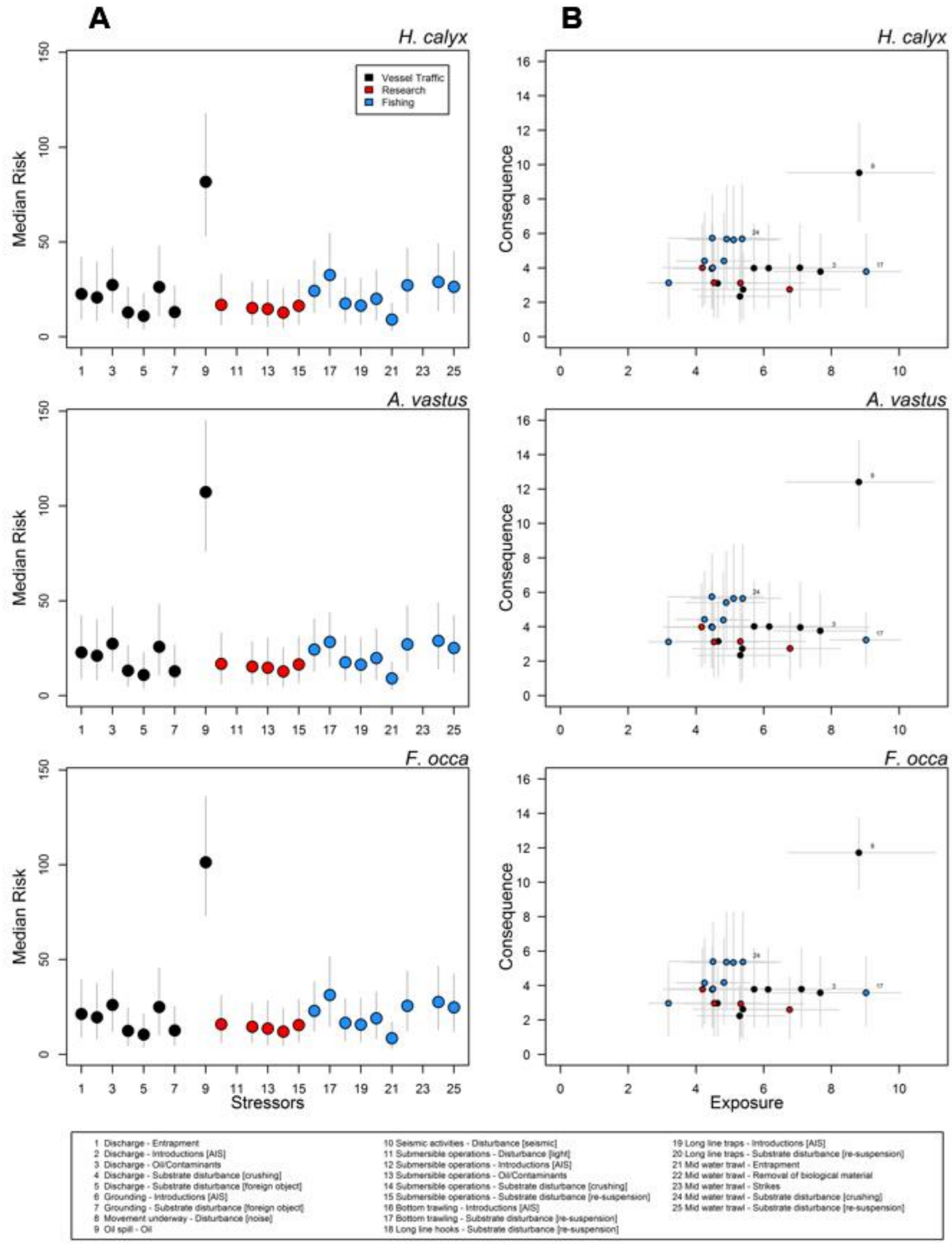

Figure 6. A. Median risk score plots for H.calyx*,* A.vastus *and* F. occa *SECs with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.*

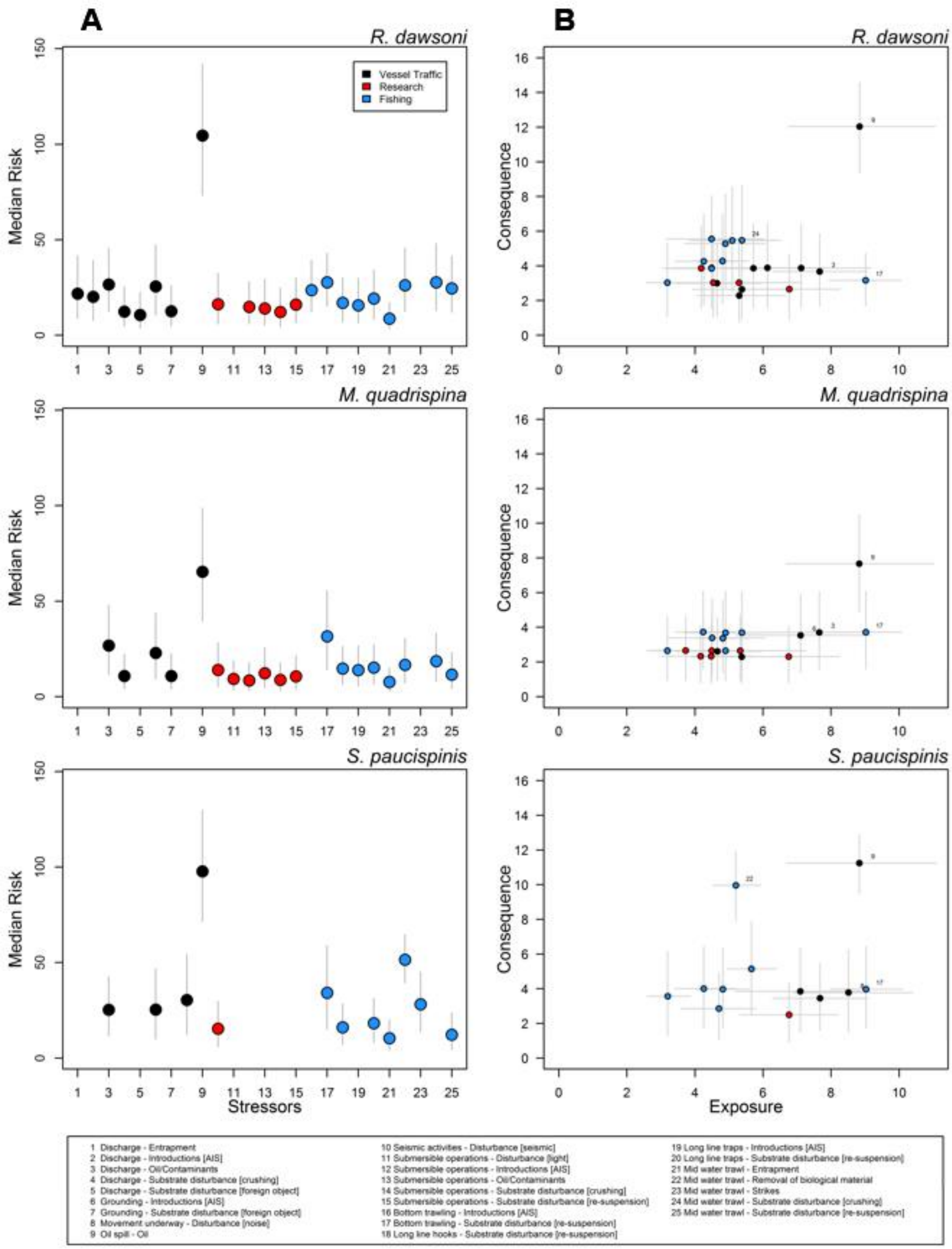

Figure 7. A. Median risk scores for R. dawsoni*,* M.quadrispina *and* S. paucispinis *Species SECs with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.*

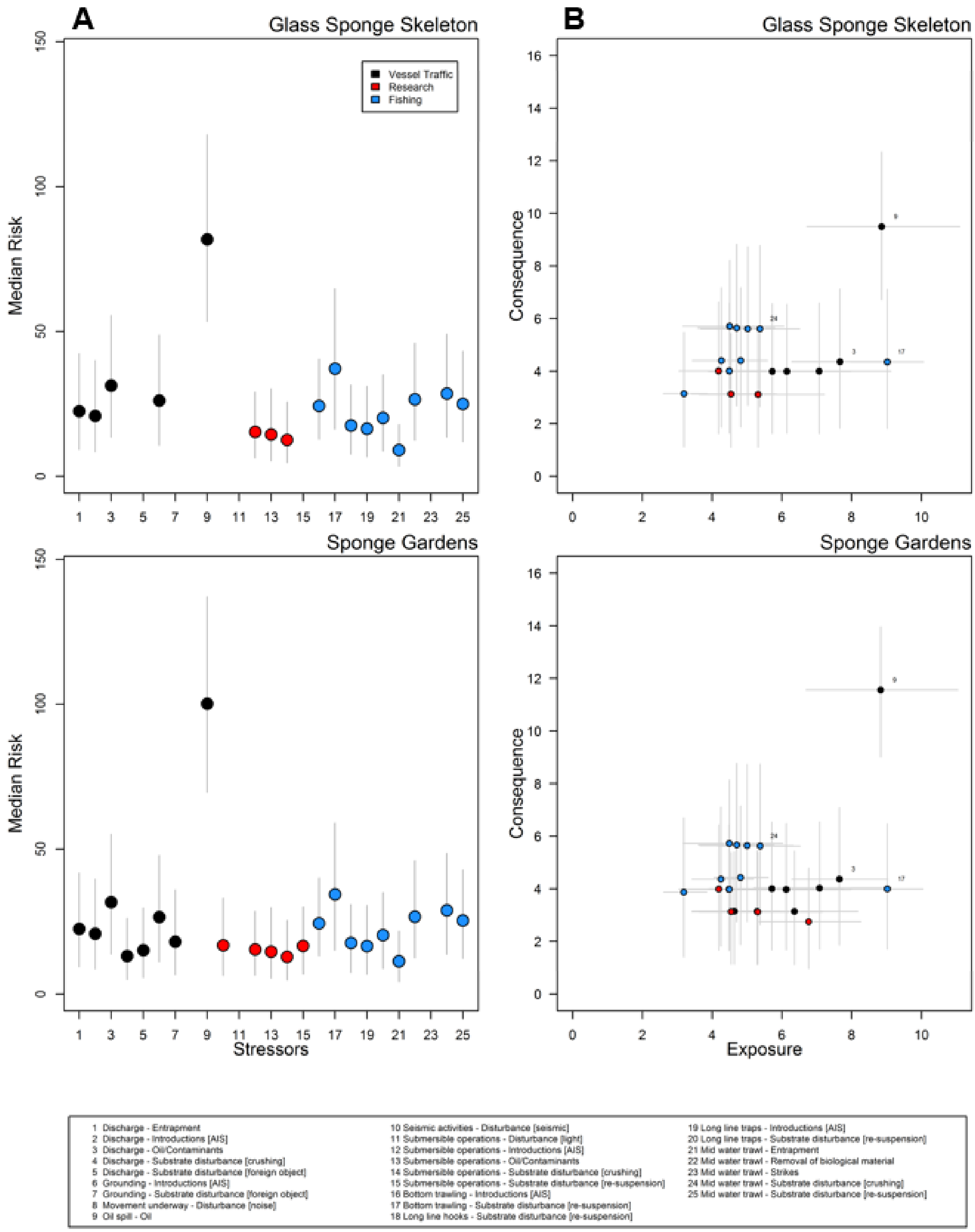

Figure 8. A. Median risk scores for Glass Sponge Garden and Glass Sponge Skeleton Habitat SECs with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/ consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.

*Table 17. For each SEC, the four stressors with the highest **Risk**$_{sc}$ score (sorted in descending order) along with the associated mean **Exposure**$_{sc}$ and **Consequence**$_{sc}$ scores (10/90% percentile uncertainty intervals).*

Heterochone calyx (Glass sponge reef-building glass sponge)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	81.8	53.4	117.7	8.8	6.7	11.0	9.5	6.7	12.4
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	32.6	15.5	54.8	9.0	7.9	10.1	3.8	1.7	6.0
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.9	13.8	49.1	5.4	4.2	6.5	5.7	2.7	8.9
Vessel Traffic	Discharge - Oil/Contaminants	27.4	12.9	47.1	7.7	6.3	9.1	3.8	1.7	6.0

Aphrocallistes vastus (Glass sponge reef-building glass sponge)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	107.4	76.1	145.3	8.8	6.7	11.0	12.4	9.8	14.9
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.9	13.8	48.9	5.4	4.2	6.5	5.6	2.7	8.8
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	28.3	15.5	43.7	9.0	8.0	10.1	3.2	1.7	4.8
Vessel Traffic	Discharge - Oil/Contaminants	27.4	12.8	46.7	7.7	6.3	9.1	3.8	1.7	6.0

Farrea occa (Glass sponge reef-building glass sponge)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	101.3	73.4	136.0	8.8	6.7	11.1	11.7	9.6	13.8
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.4	14.7	51.7	9.0	8.0	10.0	3.6	1.6	5.7
Fishing	Mid water trawl - Substrate disturbance [crushing]	27.6	13.1	46.5	5.4	4.2	6.5	5.4	2.6	8.3
Vessel Traffic	Discharge - Oil/Contaminants	26.1	12.0	44.4	7.7	6.3	9.1	3.6	1.6	5.7

Rhabdocalyptus dawsoni (non reef-building glass sponge)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	104.5	73.2	142.0	8.8	6.7	11.1	12.0	9.4	14.6
Fishing	Mid water trawl - Substrate disturbance [crushing]	27.7	13.0	48.0	5.4	4.2	6.5	5.5	2.6	8.7
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	27.7	15.1	43.0	9.0	7.9	10.1	3.2	1.7	4.7
Vessel Traffic	Discharge - Oil/Contaminants	26.6	12.3	45.7	7.7	6.3	9.1	3.7	1.7	5.9

Munida quadrispina (Squat Lobster)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	65.4	39.5	98.8	8.8	6.7	11.0	7.7	4.9	10.5
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.5	14.2	55.5	9.0	7.9	10.1	3.7	1.6	6.1
Vessel Traffic	Discharge - Oil/Contaminants	26.8	11.5	47.8	7.7	6.3	9.0	3.7	1.5	6.0
Vessel Traffic	Grounding - Introductions [AIS]	22.9	9.3	43.9	7.1	5.2	9.2	3.5	1.4	5.9

Sebastes paucispinis (Bocaccio Rockfish)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	97.8	71.6	129.8	8.8	6.7	11.1	11.2	9.5	12.9
Fishing	Mid water trawl - Removal of biological material	51.5	39.4	64.8	5.2	4.5	5.9	10.0	7.9	11.9
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.2	15.2	58.8	9.0	8.0	10.1	4.0	1.7	6.4
Vessel Traffic	Movement underway - Disturbance [noise]	30.4	12.3	54.4	8.5	6.9	10.4	3.8	1.5	6.2

Glass sponge reef skeleton (Habitat)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	81.8	53.4	118.0	8.9	6.7	11.1	9.5	6.7	12.3
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	37.2	16.3	64.8	9.0	8.0	10.1	4.3	1.8	7.1
Vessel Traffic	Discharge - Oil/Contaminants	31.3	13.4	55.5	7.7	6.3	9.1	4.4	1.8	7.1
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.6	13.5	49.0	5.4	4.1	6.5	5.6	2.6	8.8

Sponge gardens (Habitat)

Activity	Stressor	Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill – Oil	100.2	69.6	137.2	8.8	6.7	11.0	11.6	9.0	14.0
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.4	15.1	59.0	9.0	8.0	10.1	4.0	1.7	6.5
Vessel Traffic	Discharge - Oil/Contaminants	31.7	13.7	55.2	7.6	6.3	9.0	4.4	1.9	7.1
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.9	13.6	48.6	5.4	4.2	6.5	5.6	2.6	8.7

For all SECs, the 'potential' stressor oil from oil spills dominates the ***Risk**$_{sc}$* scores (oil from oil spill ***Risk**$_{sc}$* scores range from 65.4 to 107.4 with the next highest ***Risk**$_{sc}$* score for any SEC equal to 51.5). The universally high scores for the oil from oil spill stressor were driven by a combination of consistently high ***Exposure**$_{sc}$* scores (8.8-8.9 out of a maximum of 18 for all SECs) and high ***Consequence**$_{sc}$* scores (ranging from 7.7 to 12.4 out of 16 across all SECs). In addition, uncertainty values were also high for this stressor (see number '9' on the Exposure-Consequence figures).

Given similarities in their biology and function, the four sponge Species SECs and two sponge Habitat SECs (grouped as "sponge-related SECs") had very similar arrays of ***Risk**$_{sc}$* scores. In addition to the top stressor being oil from oil spills, the remaining top scoring stressors for these SECs were 'current snapshot' stressors: Substrate disturbance [re-suspension] from bottom trawling (number '17'), substrate disturbance [crushing] from mid water trawling (number '24') and oil/contaminants from vessel traffic discharges (number '3'). Note that despite their marginal differences, it is difficult to differentiate any but the top stressor for the sponge-related SECs as almost all the medians are statistically equivalent (differences in medians between the second and fourth highest stressors for each of the sponge-related SECs range from 1.1 to 8.6 points, which is far outweighed by the variability shown in the 10/90th percentile ranges—averaging 36.2 points across all sponge-related SECs).

For the two non-sponge SECs (*M. quadrispina* and *S. paucispinis*), a wider range of stressors were estimated as the top risks (other than oil from oil spill remaining the highest). For Squat Lobster, sediment re-suspension from bottom trawling (number '17'), oil/contaminant impacts from discharges (number '3') and introductions of aquatic invasive species (AIS) (number '6') from grounding round out the top four stressors. Conversely for *S. paucispinis*, removal of biological material from mid water trawl (number '22'), sediment re-suspension from bottom trawling (number '17') and noise disturbance from vessel movement (number '8') round out the top four stressors. In most cases, these ***Risk**$_{sc}$* scores were driven by moderate exposure and low consequence scores, which indicates generally lower ***Risk**$_{sc}$* than for the oil from oil spills stressor. Similar to the sponge-related SECs, many of the non-sponge SEC stressors are statistically indiscernible (differences among the stressor medians are far out-weighed by the variability associated with them). One exception is the removal of biological material from mid water trawl impacts on Bocaccio Rockfish (*S. paucispinis)* which scored relatively low for ***Exposure**$_{sc}$* but high for ***Consequence**$_{sc}$*. Although the resulting ***Risk**$_{sc}$* score is still considerably lower than that for the oil from oil spills stressor (***Risk**$_{sc}$* estimate of 51.5 versus 97.8 for oil from oil spills), it does stand out as a notable exception (Figure 7).

To examine the effects of inclusion of the potential stressors in the risk outputs, the data was re-analysed after the removal of potential stressors. Obviously this resulted in a change in the top six stressors, allowing insight into the top six current snapshot stressors. Perhaps the most helpful outputs from this analysis were the Median Risk plots, where the reduction in the y-axis maximum on the plots from 150 to 60 allowed clarification and clearer visualisation of the current snapshot stressor data points. These figures are shown below (Figure 9, Figure 10 and Figure 11) while the remaining output (data tables and figures) from this analysis are provided in Appendix L (there were few differences in the numbers and patterns observed). These "current snapshot only" outputs may be useful for managers, as it is expected that these stressors are more readily 'managed' than potential stressors (See Section 4.3.6 for more discussion).

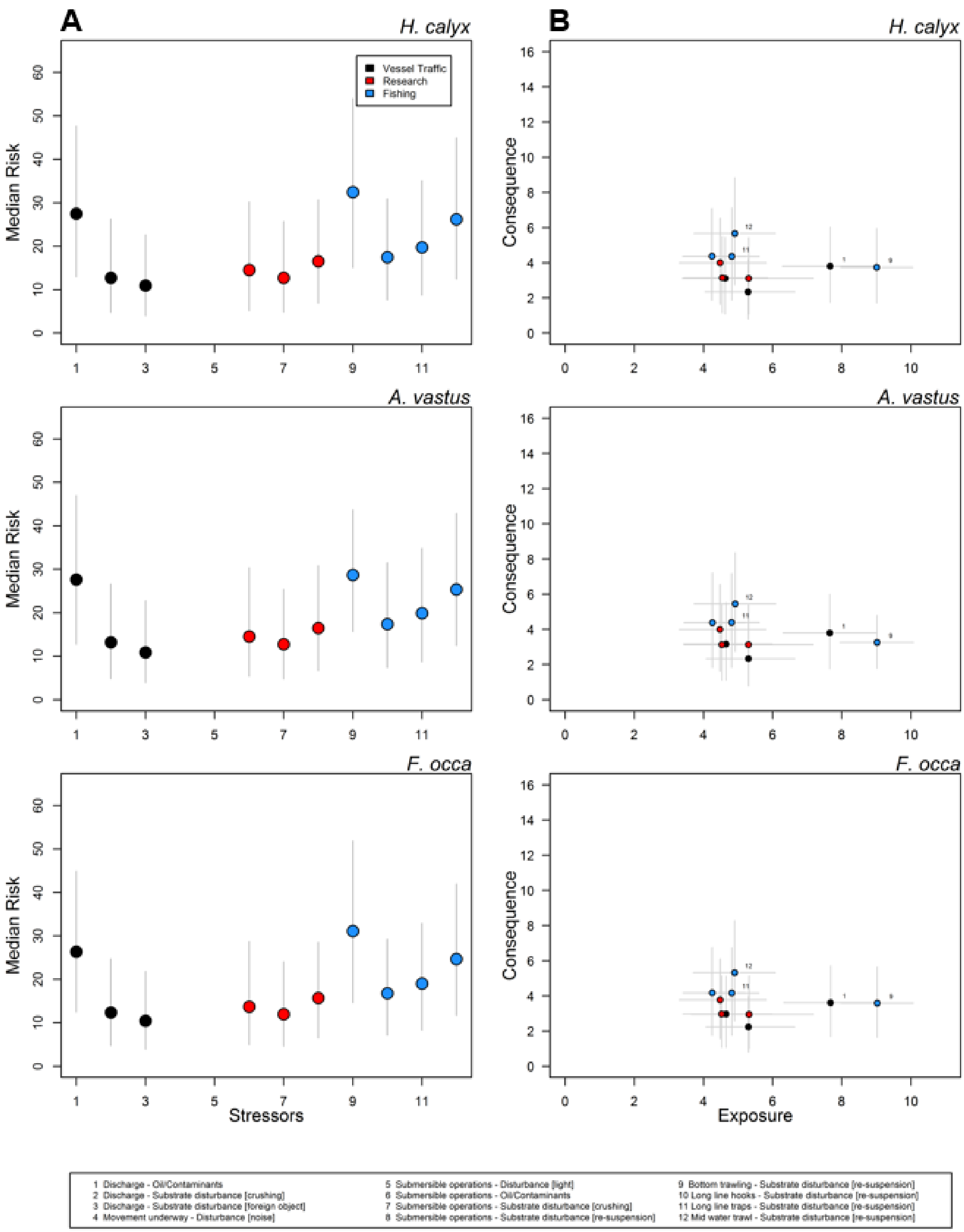

Figure 9. A. Median risk scores for "current snapshot stressors" only (H. calyx, A. vastus, F. occa) with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/ consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.

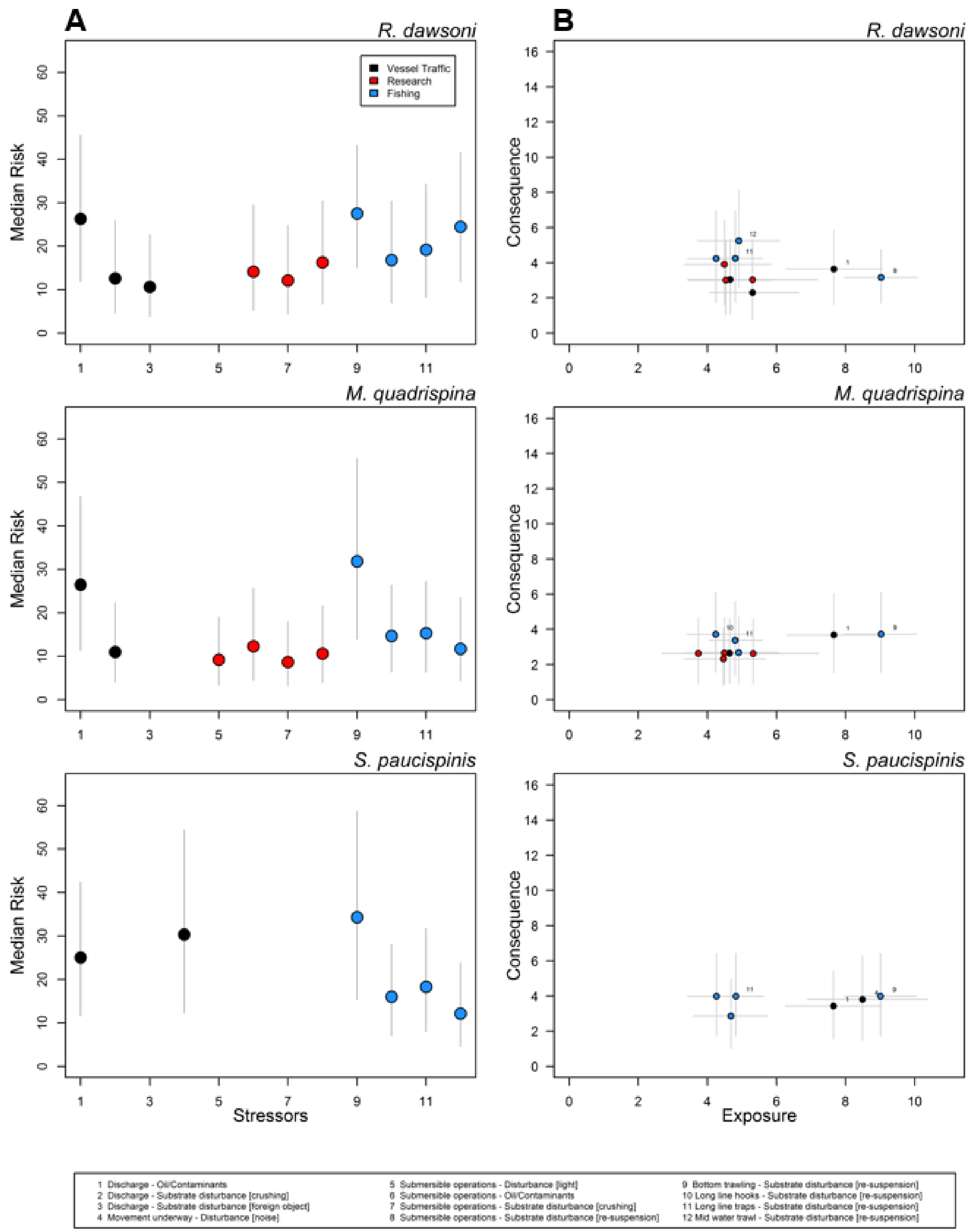

Figure 10. A. Median risk scores for "current snapshot stressors" only (R. dawsoni, M. quadrispina, S. paucispinis) with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/ consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.

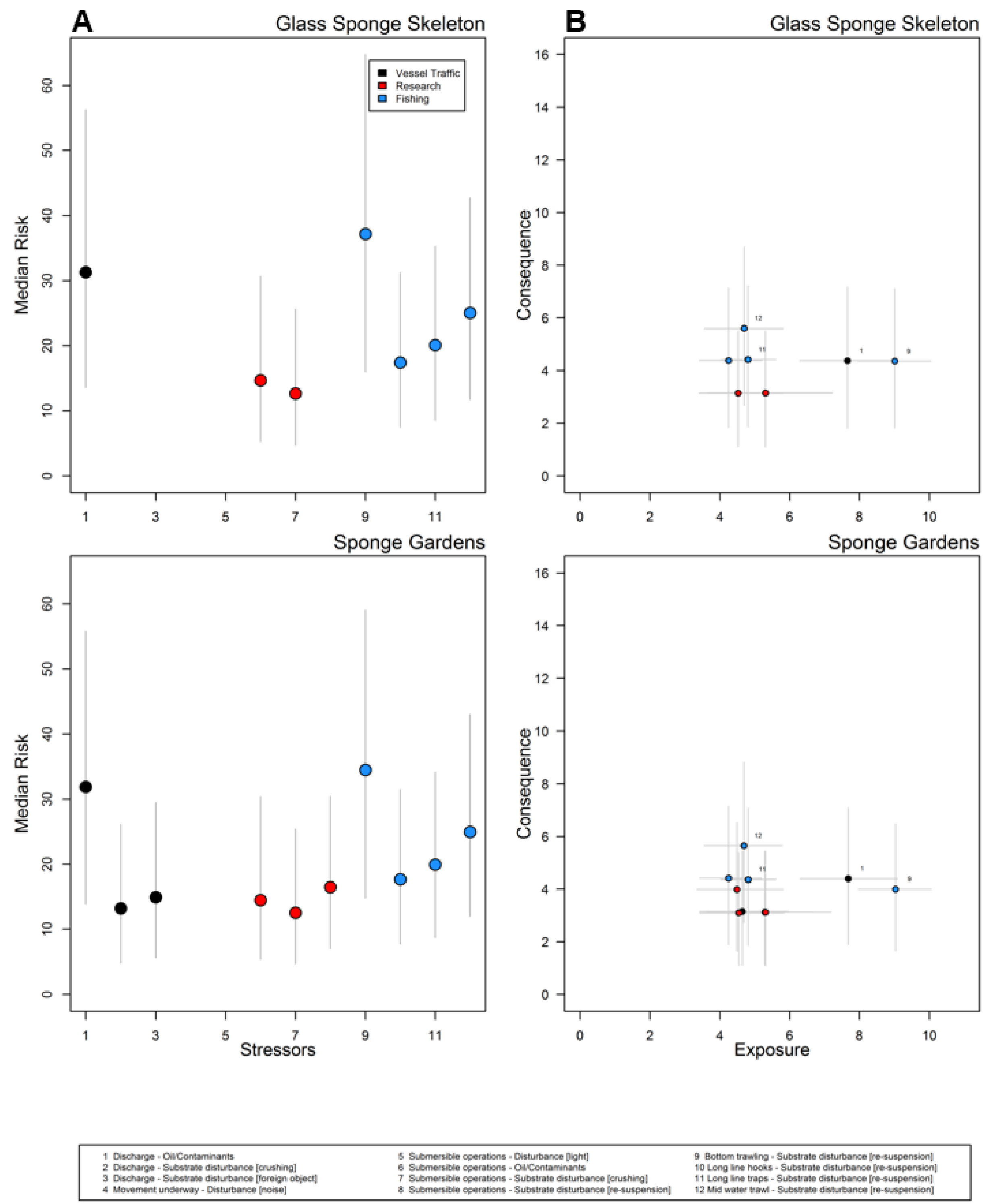

Figure 11. A. Median risk scores for "current snapshot stressors" only (Glass Sponge Skeleton and Sponge Gardens) with numbered stressors (see Table 16 for details of each stressor name), B. Corresponding exposure/ consequence plots with the four highest scoring stressors labelled. Numbering corresponds to the stressor list in Table 16, and the associated uncertainty is represented by 10/90% percentile error bars.

3.3.3.2. Cumulative Risk ($\mathbf{CRisk_c}$) by SEC

Results of the $\mathbf{CRisk_c}$ calculations are displayed in Table 18 and Figure 12. Given the overlap in the confidence intervals, the top five SECs are statistically indistinguishable. The Sponge Garden Habitat SEC had the highest cumulative risk, although only marginally higher that the four sponge Species SECs. (The medians of the top 5 $\mathbf{CRisk_c}$ estimates ranged from 563.0 for Sponge Gardens to 524.6 for *F. occa*). The next highest estimate was the Glass Sponge Skeleton Habitat SEC, followed by the Bocaccio Rockfish (*S. paucispinis*) and Squat Lobster (*M. quadrispina*) Species SECs.

The four sponge Species SECs were impacted with 22 stressor interactions each (with 7 of those interactions scoring zero for resilience with high uncertainty). The other two Species SECs were impacted by 12 (*S. paucispinis*) and 19 (*M. quadrispina*) total stressors, respectively. Of these, 3 stressors were zero-resilience interactions for *S. paucispinis* and 10 were zero-resilience interactions for *M. quadrispina*. The Sponge Garden Habitat SEC was impacted by 22 stressors (7 zero-resilience interactions), similar to the sponge Species SECs, while the Glass Sponge Skeleton Habitat SEC was only impacted by 17 stressor interactions (3 of those being zero-resilience interactions). This illustrates that $\boldsymbol{CRisk_c}$ values are additive for non-zero resilience interactions (i.e., the more non-zero interactions there are, the higher the $\boldsymbol{CRisk_c}$ estimate is likely to be).

Table 18. Cumulative Risk ($\boldsymbol{CRisk_c}$*) scores for all SECs, showing 10/90% percentiles and the number of stressors contributing to the score (total and only those with non-zero Resilience scores).*

		$\mathbf{CRisk_c}$			**Stressor Count**	
SEC	**SEC Type**	**Mean**	**10%Q**	**90%Q**	**All**	**Non-Zero**
Sponge Gardens	Habitat	563.0	487.1	641.1	22	15
Aphrocallistes vastus	Species	547.3	474.7	621.4	22	15
Rhabdocalyptus dawsoni	Species	531.8	459.6	606.7	22	15
Heterochone calyx	Species	529.1	457.5	603.6	22	15
Farrea occa	Species	524.6	456.7	593.1	22	15
Glass Sponge Skeleton	Habitat	458.2	388.1	529.7	17	14
Bocaccio Rockfish	Species	379.9	323.2	438.5	12	9
Munida quadrispina	Species	357.4	299.9	416.3	19	9

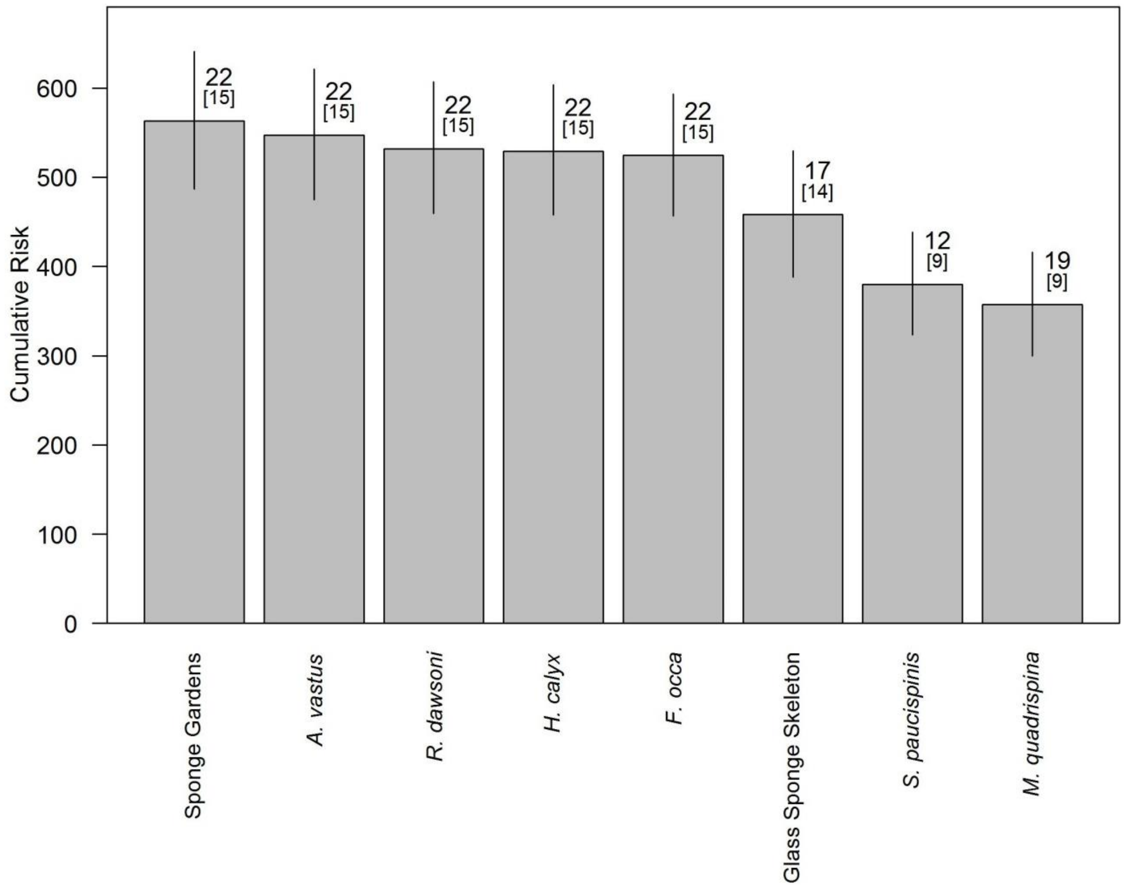

*Figure 12. Cumulative risk (**CRisk$_c$**) for each SEC, ranked in descending order with 10/90% percentile error bars. Numbers above columns denote the number of stressors applicable to that SEC: all stressors and [non-zero stressor interactions only].*

3.3.3.3. Cumulative Risk by Stressor (*Potency$_s$*)

Cumulative risk by stressor (***Potency$_s$***), represents the sum of ***Risk$_{sc}$*** scores for each stressor across all SECs and is presented in Figure 13 and Table 19.

Far surpassing all other stressors, oil from oil spills (associated with Vessel Traffic) has the highest ***Potency$_s$*** estimate (756.2 compared to the next highest 268.5), and it is relevant to all 8 SECs. Stressors related to Fishing (6 stressors) and other Vessel Traffic activities (3 stressors) round out the top 10 highest ***Potency$_s$*** stressors, with mean scores ranging from 145.0 to 268.5 and impacting 6 to 8 SECs each. Disturbance from seismic activities is the highest Research activity-related stressor (with a mean score of 123.7). The remaining stressors are associated with a wide range of Fishing, Research and Vessel Traffic-related sub-activities, with ***Potency$_s$*** scores ranging from 10.4 to 121.3 and impacting anywhere from 1 to 8 SECs each.

*Table 19. Values for cumulative risk by stressor (**Potency$_S$**) ranked in descending order with 10/90% percentiles, and showing the number of SECs contributing to the score.*

Activity	Sub-Activity – Stressor	Potency$_S$			SEC Count
		Mean	10%	90%	
Vessel Traffic	Oil spill – Oil	756.2	667.6	847.8	8
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	268.5	213.4	324.9	8
Fishing	Mid water trawl - Removal of biological material	238.9	194.8	284.9	8
Vessel Traffic	Discharge - Oil/Contaminants	235.0	184.5	287.5	8
Vessel Traffic	Grounding - Introductions [AIS]	220.0	168.8	273.5	8
Fishing	Mid water trawl - Substrate disturbance [crushing]	199.4	155.4	245.0	7
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	185.9	146.4	227.1	8
Fishing	Long line traps - Substrate disturbance [re-suspension]	160.9	125.6	197.3	8
Fishing	Bottom trawling - Introductions [AIS]	152.0	118.9	187.3	6
Vessel Traffic	Discharge – Entrapment	145.0	105.8	186.3	6
Fishing	Long line hooks - Substrate disturbance [re-suspension]	143.5	112.0	176.2	8
Vessel Traffic	Discharge - Introductions [AIS]	135.2	97.4	175.7	6
Research	Seismic activities - Disturbance [seismic]	123.7	89.9	159.7	7
Fishing	Long line traps - Introductions [AIS]	121.3	90.1	154.9	7
Research	Submersible operations - Oil/Contaminants	112.1	79.5	146.6	7
Research	Submersible operations - Introductions [AIS]	108.6	80.8	138.7	7
Research	Submersible operations - Substrate disturbance [re-suspension]	99.6	72.3	128.3	6
Research	Submersible operations - Substrate disturbance [crushing]	93.9	67.6	121.8	7
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	90.1	62.3	120.6	6
Vessel Traffic	Discharge - Substrate disturbance [crushing]	83.6	58.1	110.7	6
Fishing	Mid water trawl – Entrapment	81.2	60.7	102.7	8
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	65.4	43.3	88.9	5
Vessel Traffic	Movement underway - Disturbance [noise]	32.2	12.3	54.4	1
Fishing	Mid water trawl – Strikes	29.1	13.9	45.1	1
Research	Submersible operations - Disturbance [light]	10.4	3.4	18.9	1

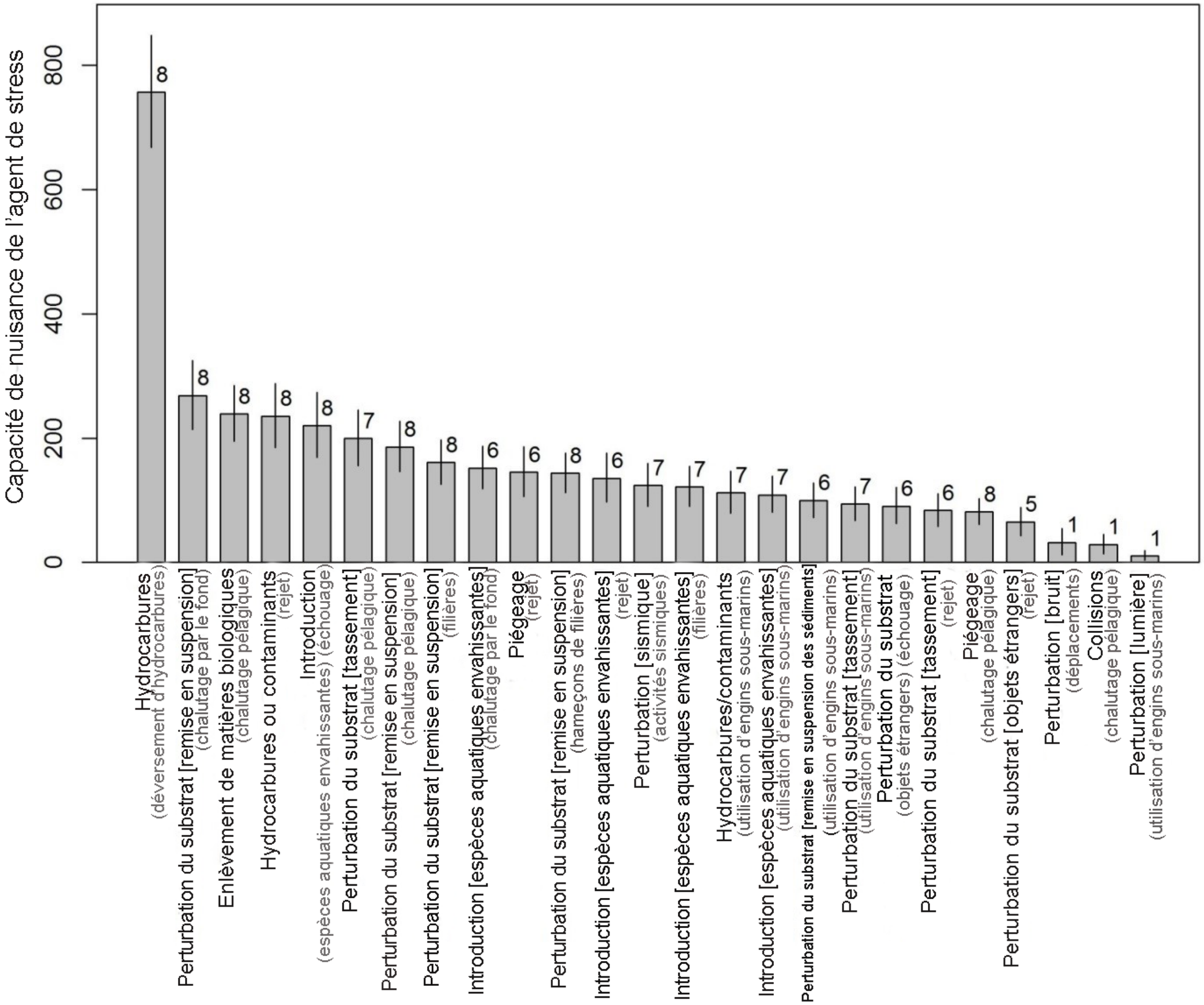

*Figure 13. Cumulative risk by stressor (**Potency$_S$**) plotted in descending order with 10/90% percentiles, and showing the number of SECs (out of 8) contributing to the score (above the corresponding bar).*

3.3.4. Comparison of Results under Different Uncertainty Distribution Models

Results were also computed under the normal distribution model as per Murray et al. (2016) and are provided for comparison in Appendix L. As expected, the 10/90% uncertainty intervals are generally narrower when a normal distribution is used (where estimates falling outside the scoring interval are re-assigned to the nearest score within the limits), while the medians remain relatively unchanged. Although the values are not noticeably different, use of a truncated normal distribution is theoretically more appropriate and is recommended for future use. Alternatively, future efforts could consider employing a multinomial error model which would best match the categorical nature of the score data. Issues with determining appropriate probability definitions for each level of uncertainty precluded its implementation in this application of the ERAF.

4. DISCUSSION

This application of the ecological risk assessment originally developed by O et al. (2015) and refined by Thornborough et al. (2017) and Rubidge et al. (2018), assessed the relative risk to the HS/QCS Glass Sponge Reefs MPA from human-related activities. This was done by first identifying the significant ecosystem components (SECs) best able to represent the MPA at present, then identifying activities and associated stressors in the area that could interact with those SECs. Subsequently, all possible SEC-stressor interactions were scored for exposure, resilience, and recovery, with these scores used as input to the risk assessment calculations. The outputs provide a prioritisation of SECs and stressors on a relative scale within the MPA. These risk assessment outputs, along with full methodological disclosure, are critical for guiding indicator selection to inform subsequent MPA management monitoring plans. Further, the integrated uncertainty estimates provided in the risk assessment can help managers identify knowledge gaps and research priorities for future monitoring efforts.

The following sections discuss the findings of the risk assessment, followed by discussion on the effectiveness of the framework in this application.

4.1. OUTCOMES OF THE LEVEL 2 SEMI-QUANTITATIVE RISK ASSESSMENT

4.1.1. SEC Selection Process

In this application of the ERAF, the Species SEC selection results demonstrate that the six original ERAF criteria are not always sufficient to readily identify the species of greatest importance to specific ecosystems, and that the development and use of supplementary ecosystem-specific criteria/guidance can provide important additional information to tailor the SEC selection appropriately. It also allows researchers to take into account the different data types that may be available to guide the selection process. That said, in many cases, the original criteria worked well, such as in the high scores observed for the reef-building sponges. For other species, the ERAF criteria alone proved insufficient, since in several cases, species that may be important for ecosystem function (such as Squat Lobsters) are not considered to be rare/unique, sensitive or depleted (which comprise 3 of the 6 ERAF criteria); rather, they are abundantly common species with potentially significant roles in the ecosystem food web (Lovrich and Thiel 2011). Essentially, the criteria and additional guidance can help guide the initial selection of Species SECs, but it is by no means a sufficient basis alone and the use of supplementary considerations and expert review is recommended to help refine the list.

Video collected on ROV surveys to the HS/QCS MPA indicates abundant numbers of small/juvenile rockfish present among the reefs, similar to what is seen in other glass sponge reefs in BC (Strait of Georgia: (Cook 2005; Cook et al. 2008), and northern Boundary Reefs

(Stone et al. 2014)). Though scoring high for the initial ERAF criteria, rockfish were not initially considered for inclusion as a Species SEC since the full rockfish assemblage—juvenile and adult—may be better incorporated as a Community SEC. However, due to our current general lack of knowledge on the composition of the rockfish community in and around the sponge reefs, we were unable to analyze them as a Community SEC. Instead, in order to represent rockfish in the risk assessment, we selected the Bocaccio Rockfish (*Sebastes paucispinis*) as a representative Species SEC, as it was one of the four rockfish species that fulfilled the highest number of ERAF criteria and is considered well studied. It is hoped that, over time, systematic identification of rockfish observed on the reef will eventually provide sufficient species composition data to allow full assessment of reef-associated rockfish in the risk assessment, perhaps as both Species SECs and as a species assemblage Community SEC.

Although the food sources of the glass sponge reefs (plankton and bacterial) are important to the sponge reef ecosystem and may fulfill some or all of the ERAF criteria, these were not selected as Species SECs as they are not easily managed at the MPA scale. Further, their diversity, density, and distribution are independent of anthropogenic activities occurring within the MPA boundaries.

Polychaetes and Foraminifera were other groups that scored high for a number of criteria but are not directly represented by a SEC. Polychaetes and Foraminifera are only abundant in the dead skeleton habitat of the sponge reef, either in the sediment infilled parts of the skeleton, or otherwise encrusting the dead skeleton. One reason for not including these groups as standalone SECs included the difficulty to observe/monitor them over wide areas using video surveys, as sampling and species identifications would require invasive or destructive sampling such as sediment cores or removal of skeleton specimens. Also, these groups are considered to be represented within the Sponge Reef Skeleton Habitat SEC.

4.1.2. Potential stressors

When interpreting risk assessment outputs, it is important to keep in mind that, although most stressors associated with anthropogenic activities are generally ‘current snap-shot’ stressors, several are deemed ‘potential’ stressors due to their infrequent and unpredictable occurrence and high potential impact: all stressors relating to grounding, oil (from oil spills), seismic energy from seismic activities and introductions of AIS through any relevant sub-activity (see Section 2.2.3 for further description). Given that the worst case scenario is used to score potential stressors, it is logical that these generally resulted in higher scores (particularly for ***Exposure***$_{sc}$, and consequently higher ***Risk***$_{sc}$) relative to current snap-shot stressors.

The implementation of potential stressors in this risk assessment differed from that of previous ERAF applications (Thornborough et al. 2017 and Rubidge et al. 2018) in three key ways:

1. **‘Seismic surveys’**: In the application to SG̲aan K̲inghlas-Bowie (SKB) Seamount MPA, this was considered a potential stressor, but in the application to Endeavour Hydrothermal Vent (EHV) MPA it was considered a ‘current snapshot’ stressor. The main reason for this difference was due to surveys at EHV MPA being documented and under permit, while those SKB were not (which is similar to the situation at the HS/QCS Glass Sponge Reefs before it became an MPA). At present, there is a lack of knowledge concerning the future MPA regulations on this activity in the MPA under adaptive management. It is possible that—once the MPA regulations are in place—the seismic energy stressor will be removed or changed to a current snapshot stressor, since the occurrence of seismic mapping will become a permitted/documented activity.
2. **‘Debris’** – Previous applications treated ‘debris’ as a potential stressor. However, based on recommendations in these same applications, we separated the ‘debris’ stressor into a

number of other stressors (under vessel discharge), resulting in the removal of 'debris' as a standalone potential stressor.

3. **'Mid water trawl' and 'Bottom trawl'**: Although presently not allowed in the MPA, these sub-activities could be allowed in zones of the MPA through future revisions to the regulations (according to the adaptive management provisions) (i.e., once certain safeguards to protect the CPZ are in place). As such, most stressors relating to these sub-activities are currently included as potential stressors, and will need to be re-assessed when/if the regulations are modified. The main exception is sediment re-suspension, which is considered current

Ultimately, only one potential stressor remained in the risk assessment for all SECs: acute oil (from oil spills), which was assessed as likely to have acute and chronic impacts to all SECs if it were to occur. This stressor has the highest $\boldsymbol{Risk_{sc}}$ score for all individual SECs (Table 18) and the highest $\boldsymbol{Potency_{s}}$ score from cumulative risk analysis (Table 19, Figure 13). This is to be expected given it is an unpredictable potential stressor with potential for high $\boldsymbol{Exposure_{sc}}$ and $\boldsymbol{Consequence_{sc}}$ impacts. The seismic energy stressor (from mapping) was included for all but the Glass Sponge Skeleton SEC, and AIS was included in all 8 SECs through five different sub-activities (discharge, grounding, bottom trawl, long line traps and submersible operations). The removal of some potential stressors helped somewhat to balance the range of top scoring stressors for each SEC and also in the cumulative risk ($\boldsymbol{Potency_{s}}$) output where only one 'potential' stressor was in the top 5.

Potential stressors can be changed to current snap-shot stressors as additional information about the extent of exposure to these stressors becomes available. For example, research on the amount and frequency of vessel discharges in the area, data on all seismic testing carried out at present and expected in the future; or new research on AIS transport. One exception is oil from oil spills as these events are so unpredictable and have variable impacts dependent on the type and amount of oil spilled. Subsequently, it is recommended that this stressor remain a potential stressor in future risk assessments.

4.2. EFFECTIVENESS OF THE FRAMEWORK

The scoping phase of the risk assessment framework was effective in guiding the identification of SECs to provide a general representation of the ecological function of the HS/QCS Glass Sponge Reefs MPA. Further, the use of Pathways of Effects (PoE) models functioned well for identifying stressors associated with anthropogenic activities and summarising how they might impact the ecosystem. The information gathered during these phases was valuable when exploring interactions in more detail during the later scoring phase. Use of an interaction matrix to rapidly assess the potential of each SEC-stressor interaction effectively screened the complete list, helping to focus the risk assessment on the most relevant interactions. Despite the general success of this risk assessment application, there were a number of limitations identified in the methodology which will be discussed in section 4.3.

The Level 2 risk assessment framework aims to prioritise SECs and stressors on a relative scale within the area of interest. To aid in SEC prioritisation, cumulative risk ($\mathbf{CRisk_{c}}$) values to each SEC are examined. In this assessment these values were within a similar range for five of the eight SECs (from 525-563, Table 18) making it challenging to discern between them in order to prioritise SECs. However, this is to be expected to some degree in this relatively extensive area of similar habitat, comprised of similar proportions of three reef-building sponge species (with associated habitats and communities) dominated by benthic marine invertebrates. The expected similar exposure and in some cases, similar response, may be beneficial for management of the area. For example, singular changes to exposure through regulations could simultaneously reduce exposure across many of these benthic SECs. However, future research may increase our knowledge and necessitate a change in the assumptions underlying these responses. The risk assessment did distinguish one SEC with moderate **$CRisk_c$** (Glass Sponge Skeleton, 458.2) and two SECs with relatively lower **$CRisk_c$** values (*S. paucispinis*, 379.9; and Squat Lobster, 357.4).

For the prioritisation of stressors, ***$Potency_s$*** values for each stressor are examined. In contrast to the findings for SECs, there were discernable differences between the ***$Potency_s$*** of stressors within the risk assessment (Table 19, Figure 13), and the risk assessment was effective in prioritising the stressors for the HS/QCS Glass Sponge Reefs MPA. The imbalance in the number of invertebrate SECs compared to vertebrate SECs (only one fish SEC) in this risk assessment may have influenced stressor potency outputs, as stressors that only affected the one rockfish SEC ended up with relatively low ***$Potency_s$*** scores due to a low number of SECs contributing to the score. However, this is appropriate in this invertebrate dominated ecosystem and the outputs are transparent enough to be able to discern these differences.

4.2.1. Drivers behind High *$Risk_{sc}$* Scores and the Incorporation of Uncertainty

The four stressors with the highest ***$Risk_{sc}$*** scores for 6 of the 8 SECs originate from the following activities: acute oil contamination from oil spills, discharges from vessels and impacts from bottom and mid water trawls. For the other two SECs (Squat Lobster and Bocaccio Rockfish), the highest risk stressors come primarily from vessel traffic activities (oil, discharge, grounding and movement underway), along with bottom and mid water trawl fishing activities.

A high ***$Risk_{sc}$*** score can be driven primarily by one factor, though more often it is a combination of factors. For example, a high exposure score with associated high uncertainty inflates a ***$Risk_{sc}$*** score, which is the case for potential stressors that often have high ***$Risk_{sc}$*** and ***$Potency_s$***, scores due to their inherent high consequence paired with high uncertainty.

Including an uncertainty score with each score in the risk assessment provided an additional dimension to the outputs, and additional context to support each term's score, which can appear somewhat arbitrary or subjective at first glance. This additional information can also provide useful outputs to inform managers. Table 20 provides a simplified breakdown of what can drive high ***$Risk_{sc}$*** scores in SEC-stressor interactions and guidance to managers of the most effective options available to reduce high ***$Risk_{sc}$*** scores.

Table 20. Guidance for addressing SEC-stressor interactions with high **Risk**$_{sc}$ *scores identified in the risk assessment by examination of the factors driving scores.*

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

For example, scoring for the stressor “Substrate Disturbance [crushing]” associated with mid water trawl fishing can be generally interpreted as follows:

Consequence$_{sc}$ - Low AcuteChange and ChronicChange scores (both equal to 1) with high uncertainty (5 and 4, respectively); and

Exposure$_{sc}$ – Low scores and uncertainty for both area and temporal overlap, but high intensity (amount and frequency) scores (4 and 3, respectively) with moderate to high uncertainty (3 and 5, respectively)

Indicates that:

- There is confidence in the available knowledge about the area and time overlap of this fishery in the MPA, but that there is a lack of confidence in what is known about the benthic interaction and potential impact (due to a lack of data on bottom interaction rates for mid water trawls). This is reflected in the high uncertainty values for ***Consequence$_{sc}$*** and the scoring for the two intensity ***Exposure$_{sc}$*** terms.

- Overall, this suggests that research on the degree of bottom interaction in the mid water trawl fishery can make the most significant impact on the ***Risk$_{sc}$*** score by reducing uncertainty and better informing the assigned score. Research on ***Consequence$_{sc}$*** would be less effective, as the impacts are expected to be similar to a bottom trawl, and the high uncertainty in these scores relate to the proportion of the population affected, which is linked to the lack of data on bottom interaction.

Many stressors under the mid water trawl activity had high Potency scores likely as a result of high ***Risk$_{sc}$*** scores owing to a combination of high uncertainty and high potential impacts. Though the mid water trawl fishery in the area has recently been halted following MPA designation, it operated for some time before MPA designation in the VAMZ (directly above the core protected sponge reef area (CPZ)), and is expected to be permitted again in the future. This fishery has the potential to impact all SECs. A current lack of data on the extent of bottom interaction in this fishery means that these stressors are scored using a very precautionary approach, with high uncertainty. Research on a comparable Pacific US fishery indicates there is sufficiently high frequency of bottom contact to require reinforcement of the underside of nets to protect against damage. NOAA studies of the mid water US Pacific Coast Hake fishery found 22.3% of hauls (and up to 70.2% of trips) contained one or more benthic taxa (a proxy for bottom contact) Wakefield 2015). For the mid water US Pacific Coast Pollock fishery, the incidence rate is estimated at 44% or higher (C. Rooper, NOAA, pers. comm.). We currently have no data to produce comparable estimates of bottom contact in the Canadian mid water fisheries except general estimations from fishery scientists of approximately 1% (C. Grandin and L. Yamanaka, DFO Science, pers. comm.).

Research or data gathering to investigate the rate of bottom contact in this fishery would go a long way to address these high ***Risk$_{sc}$*** scores and reduce uncertainty. This could be done through observers monitoring bottom contact with cameras or depth sounders, or more in-depth investigations of bycatch. Additionally, there are other potential impacts from this fishery associated with loss of gear (which would likely sink down to the CPZ) because nets are usually recovered by dragging.

Please note that Table 20 is simplified, only looking at what may be driving high ***Risk$_{sc}$*** scores with an emphasis on uncertainty, it does not take into account the full range of possible scoring combinations that can drive the full range of ***Risk$_{sc}$*** scores.

Any actions taken to address high uncertainty can lead to changes in the outputs for the SEC-stressor interaction in the risk assessment, and may not always reduce ***Risk$_{sc}$***. For example, reducing uncertainty through research can result in a ***Risk$_{sc}$*** score remaining unchanged, but it can also cause a risk score to be lowered or increased. For ***Consequence$_{sc}$***, low uncertainty values provide more confidence in the assigned score and certainty in the effects the stressor has on that SEC. To further reduce risk, ***Exposure$_{sc}$*** could be addressed next, meaning a higher priority for reducing or researching ***Exposure$_{sc}$*** terms (spatial/temporal overlap and/or intensity).

Similarly, reducing uncertainty for ***Exposure$_{sc}$*** terms may ultimately increase, reduce or not change the ***Risk$_{sc}$*** score.. If both terms have low uncertainty, the only remaining action would be to reduce ***Exposure$_{sc}$*** through management, as little can be done to change ***Consequence$_{sc}$*** .

4.2.2. Relevance of Findings for Future Research

Several research surveys have been conducted in the HS/QCS Glass Sponge Reefs MPA since this risk assessment was first initiated (Table 36, Appendix I). Specific objectives for these surveys have included: mapping the abundance of sponges and associated fauna; quantifying the number of filtration units (oscula), rates of sponge filtration and oxygen consumption among the reef-building sponge species; determining flux (difference in bacteria and nutrients ingested and egested) in reef-building sponge species; quantifying sediments suspended over the reefs; studying the effects of suspended sediment on filtration; and initiation of food web dynamics and sponge feeding energetics studies. The data gathered aims to determine the role of glass sponge reefs as habitat for fish and crustaceans, the effect of filtration on water column properties, potential vulnerability of the sponges to clogging by sediment, and the effect of reduced filtration due to sediment might have on water column properties. Outcomes of this research are expected to include maps of the abundance of sponge species, counts of diversity and abundance of species associated with sponge reefs, concentrations of sediment suspended over sponges over tidal cycles, the energetic cost of filtration and the effect sediment has on the cost of sponge filtration. The data obtained from these surveys will be valuable to feed into the scoring of future iterations of this risk assessment; particularly those scores relating to the impacts of sediment re-suspension, which will help clarify the high uncertainties associated with the ***Consequence**$_{sc}$* terms for this stressor. Estimates of ***Exposure**$_{sc}$* will benefit from the maps of sponge abundance produced.

4.2.3. Additional Outputs of Value

In addition to the final risk outputs, the application of the ecological risk assessment framework to the HS/QCS Glass Sponge Reefs MPA has produced a suite of other valuable outputs that could be utilised in a number of different ways, for example:

- Collation of species list from multiple sources provides a knowledge base for the ecosystem and a reference source for future work and can be updated as new research is carried out.
- Identification of activities and associated stressors in the area and the collection of data on their overlap with the HS/QCS Glass Sponge Reefs MPA will similarly provide a knowledge base for researchers and managers to reference when changes in activity regulations are considered, while also highlighting areas where more information is needed.
- Reference database, all articles referenced while researching the sponge reefs and associated activities is essentially a reference library for future work with most of the papers saved as electronic files and archived in citation software.

4.3. CHALLENGES, LIMITATIONS, AND FUTURE WORK

The limitations of applying the Level 2 framework in many cases stemmed from a lack of baseline knowledge on the ecosystem and in some cases lack of data on the stressors affecting it. The initial scoping and scoring phases of this work were originally completed in 2013 and although considerable field research has been conducted since that time, it was not incorporated in this initial assessment. It is strongly recommended that a second full iteration of the assessment is completed as soon as possible.

In particular, the community level analyses proposed by O et al. (2015) could not be applied to the Community SECs identified during the scoping phase (i.e., the rockfish assemblage and benthic sponge reef associated assemblage). This iteration of the risk assessment is not sensitive enough to detect changes on an ecosystem level based on the relative risk to the ecosystem structure and function method proposed by O et al. (2015), and there was not enough citable research on the HS/QCS glass sponge reef ecosystem to complete this type of analysis at the time (see Section 4.1.1). As the first iteration of the risk assessment, this work provides a solid base for incorporating current and future research. It is expected that field research prior to and following the recent MPA designation, in addition to more explicit guidance provided by the MPA regulations, will lead to an substantial increase to the knowledge base, and confidence in that knowledge base of this ecosystem. It is expected that the availability of this baseline data combined with further development of the methods will allow for a community level analysis in future iterations. For this initial assessment, it is felt that the potential Community SECs identified were sufficiently well- represented in the Species and Habitat SECs that were fully assessed.

Challenges encountered when applying SEC selection criteria outlined by O et al. (2015) were dealt with effectively by adding clarifying text to the original criteria and by developing a set of additional considerations specific to the ecosystem and data. Many species scored high for the original ERAF criteria, and the additional considerations were important to guide SEC selection. For example, there was an important distinction to make between species that had been observed by ROV on the sponge reef over those that were observed only from fishing catches near the sponge reef. Also very important was feedback from experts, which is emphasised as a critical part not only in the SEC selection process but at all stages of the risk assessment. The Squat Lobster is one example of a species identified by experts which scored relatively low on original ERAF criteria, but high on additional considerations and was selected by experts.

The activities included in the ERAF are generally limited to only those permitted to occur (with the present exception of mid water and bottom trawl, which may conceivably be permitted in future), and this may exclude some important potential risks to the ecosystem, particularly in the remote and rarely monitored area of the sponge reefs. Once the MPA has been in place for 1-2 years, re-assessment of actual activities and associated stressors occurring in the area (identified through approved Activity Plans as well as suspected illegal activities) will be important for assessing the ongoing effectiveness of the MPA.

Another limitation is the ***Depth overlap$_{sc}$*** sub-term of Exposure which, for benthic ecosystems, is scored as high overlap for all SECs that are associated with the benthos. Previous ERAF applications have identified that this can result in the double weighting of ***Exposure$_{sc}$*** (Thornborough et al. 2017). However, given that all SECs in this assessment are benthic—or benthic- associated—in this iteration, this should not affect the overall relative ***Risk$_{sc}$*** rankings of the SECs presented here. However, if pelagic SECs are included in future iterations, it may be necessary to address implications from this when comparing benthic SECs with pelagic SECs (Thornborough et al. 2017).

4.3.1. The semi-quantitative method

Due to the mix of quantitative and qualitative data, the risk assessment required all scores to be binned for consistency, even when there was specific fully quantitative data available, such as for fishing. To differentiate between the different data sources, low uncertainty was generally associated with scores where sufficient quantitative data were available, and higher uncertainty assigned to scores associated with qualitative data. Consequently, relative ***Risk$_{sc}$*** scores based on qualitative data were driven by uncertainty more than those scores based on quantitative data and can be identified as areas of focus for future research or data gathering.

4.3.2. Discerning between ‘Temporal overlap’ and ‘Intensity (frequency)’ sub-terms of ***Exposure*$_{SC}$**

In this assessment, an updated ERAF methodology previously used in two applications to other MPAs in BC was used (Rubidge et al. 2018; Thornborough et al. 2017). One of the principal changes involved splitting the intensity term of ***Exposure*$_{SC}$,** into amount and frequency. This required clear distinctions to be made between the terms of ‘temporal overlap’ and ‘Intensity(frequency)’. In other applications, the scoring of ‘temporal overlap’ represents the fraction of the year the activity occurs annually (e.g., Boutillier et al. 2013). Conversely, temporal overlap is scored in this application as the persistence of the stressor, in keeping with previous ERAF findings (Rubidge et al. 2018 and Thornborough et al. 2017). For example, oil has a high temporal persistence in the ecosystem, and takes a long time to break down (i.e., high temporal overlap), whereas organic matter such as sewage has a low temporal persistence, being absorbed or broken down relatively fast (i.e., low temporal overlap).

To account for the other type of temporal component, the Intensity(frequency) sub-term was used to represent how often the activity/stressor occurs in the ecosystem. One issue encountered with this approach was the lack of sensitivity in the scoring bins for events with very high frequency (i.e., that occur many times per year). The most frequent occurrence possible was “occurs frequently (e.g., every year)”, and the next category was “more than 1 year but not every year within a 5 year period”. In some cases, there was often data available (particularly for fishing-related stressors) detailing the exact number of days fished per year which could not really be adequately captured except by using the lowest scoring bin (occurs most frequently) and with low uncertainty score.

4.3.3. Interpretation of Uncertainty Incorporation

When risk and uncertainty are examined separately, the uncertainty component can be overlooked leaving the ***Risk*$_{sc}$** score to be interpreted on its own without reference to uncertainty. In this study, this problem was addressed by incorporating the uncertainty of each score into the ***Risk*$_{sc}$** score using the method developed by Murray et al. (2016), with the minor variation of distribution used to select the random samples (i.e., a truncated normal distribution was used instead of a normal distribution). This removed any problems with analyzing risk and uncertainty separately. The uncertainty is incorporated into each scored variable using random sampling and matrices of variable scores for all interactions. This has the added benefit of improving the consistency and relativity of scoring between SECs and interactions that are similar. However, there is the possibility that this method may result in median ***Risk*$_{sc}$** scores becoming more similar due to the incorporation of uncertainty at each stage. However, comparisons of calculations with and without uncertainty incorporation in another study resulted in no change in the ***Risk*$_{sc}$** ranking of SECs (Thornborough et al. 2017).

4.3.4. Cumulative Risk by SEC (*CRisk*)

Though cumulative effects can be of four general types (i.e., additive, synergistic, compensatory, and masking), the methods of estimating cumulative impacts in this risk assessment assume that ***Risk*$_{sc}$** is solely additive and does not take the interaction between stressors and the resulting impacts on SECs into account, for example the combination of substrate disturbance [re-suspension] and [crushing] from fishing activities, discharged material from vessels or research sampling. To be incorporated in a Level 3 risk assessment, further research would be required such as empirical research and modelling of these types of cumulative effects.

4.3.5. Scoring Community SEC ***Recovery$_c$*** Factors

It was not possible to score ***Recovery$_c$*** factors for the Community SECs identified in this application of the ERAF to the HS/QCS Glass Sponge Reefs MPA. This is consistent with applications to MPAs in other areas (Rubidge et al. 2018; Thornborough et al. 2017). Scoring Community SECs in ecosystems with a lack of quantitative data is problematic (as described in Section 3.3.2). One possible approach to deal with this issue is a community methodology outlined by Hobday et al. (2011). In this approach, a basic food web is developed, and species are assigned to a functional group or trophic level using information from the literature or through solicitation of expert opinion. The trophic interactions are then estimated to give an overview of how the system may function as a whole.

As a unique ecosystem, the HS/QCS Glass Sponge Reef ecosystem is difficult to assess without similar ecosystems for comparison, and it is expected that the food web may include important linkages to a number of other communities and habitats, such as the sponge gardens on the periphery of the reef, the sediment-infilled glass sponge skeleton community, as well as the associated rockfish community. It may be more logical to consider the ecosystem as one community and assess as a whole interlinking the food web, with recovery assessed as changes in trophic balance or diversity due to changes in abundance. The downside of this approach is the extensive amount of data required and lack of an established method, which do not exist at present. Although it was beyond the scope of this project, preliminary data collection and study of this issue has begun and new information is expected in the next several years (S. Archer, DFO PDF, pers. comm.)

Though Community SECs were not included in the semi-quantitative risk assessment, the combination of Species and Habitat SECs selected implicitly cover a broad range of communities by association in the sponge reef ecosystem. For now, many of the communities identified are supported by the Habitat SECs selected, meaning that they are implicitly part of the assessment as inhabitants of the habitat being assessed. Although not ideal, this is considered to be sufficient for the first iteration of this risk assessment.

4.3.6. Scoring indirect and long-range stressors, and SEC life stages

As described earlier, the application of the Level 2 ERAF does not consider indirect impacts from stressors and only considers the impact of stressors to adult life stages. Previous ERAF applications have recommended that indirect effects and effects to non-adults may be incorporated into the Level 3 framework when this is developed in the future (Rubidge et al. 2018; Thornborough et al. 2017).

Long-range stressors are also not part of the risk assessment as they are not manageable at an MPA scale, owing to the fact that they occur outside of the area being assessed. Examples of long range stressors that may be relevant to the HS/QCS MPA include microplastics (which are most likely to originate from outside the MPA), contamination and debris originating from sources outside the MPA, ocean acidification and climate change. In particular, glass sponges are one of the most temperature-sensitive groups in the oceans and it is suspected that they will face substantial thermal-stress/hypoxia-induced mortality within the next decade (J. Chu, DFO PDF, pers. comm.). These are factors that could be considered in future iterations of the risk assessment as baselines are established through monitoring.

4.3.7. Future work

Through subject matter expert feedback and the literature review associated with the risk assessment, we have identified a number of potential future research activities which would also help to inform and strengthen the scoring in the risk assessment.

- The determination of a baseline condition/status for each sponge reef to ascertain the proportion of the reef living and healthy compared to the proportion that is damaged or dead. Submersible methods recently developed and applied to the Strait of Georgia and Howe Sound glass sponge reefs could be used as guidelines (e.g., oscula counts and sponge cover estimates; Dunham et al. 2018). Establishing a baseline will allow comparisons to past and future surveys; this reef characterisation is considered of highest priority (K. Conway, Natural Resources Canada, pers. comm.). In addition surveys should revisit and monitor areas previously surveyed, including those where mechanical damage by fishing had been observed (e.g., trawl scarred areas) to assess patterns and rates of recovery. Survey data are available going back to 1999. In particular, research and assessment of the southern reef complex would be important, as this reef was historically subject to extensive trawling (K. Conway, Natural Resources Canada, pers. comm.).
- Along with the determination of baseline condition, continue to characterise the fauna associated with the sponge reefs during submersible surveys, linking the associated fauna observations to the specific characteristics of the reef in the area. This work can inform and support SEC selection and indicator selection components of this work and may discern differences in the associated fauna of healthy reef versus more degraded reef areas. Characterising the associated fauna of each reef will also allow for comparisons among reef areas, as done in the Strait of Georgia, where composition of the community of sponge reef associated biota differed significantly between the three reefs examined (Chu and Leys, 2010).
- Gain further understanding of the varying abundance and distribution of the three reef-building glass sponge species; in particular, how species composition varies with respect to prior physical disturbance. It is thought that *H. calyx* is the most robust of the reef building sponge species, and *F. occa* the least robust due to its thin walled, brittle living tissue (Krautter et al. 2001). As such it may be that the balance between the distribution and abundance of the three reef-building species can give an indication of the degree to which the area has been exposed to physical stressors. It is uncommon in other areas for reefs to be composed of all these three species and sponge reefs in the Strait of Georgia/ Howe Sound do not include *F. occa*, they are composed of *H.calyx* and *A. vastus* and in some cases only *A. vastus*. Similarly the boundary sponge reefs are composed of *H.calyx* and *A. vastus,* though one site has been found to include *F.occa* (Stone et al. 2014). Depth may also play a role in distribution of the three sponge species, as among reefs in Portland Canal, *A. vastus* was the dominant reef builder at depths less than 104 m, whereas, *H. calyx* was dominant in deeper water (Stone et al. 2014). In addition, the distribution of lyssacine Rossellid sponges such as boot sponges could also give an indication of impacted areas, as they are less able to bend and more likely to shear (Chu, 2010).
- Research on the distribution, composition and role of sponge gardens within the sponge reef environment in the MPA is needed. An expert reviewer (A. Dunham, DFO) has suggested that dense, healthy reefs may be less likely to contain sponge gardens. Increasing our knowledge of sponge gardens within the MPA will be important for future iterations of the assessment and will also help to improve how sponge gardens within the sponge reef environment are defined.
- Examination for indications of changed environmental conditions. For example, the exposed skeletons of some sponge reefs on the BC-Alaska border are encrusted with oxides and heavy colonised by zoanthids and encrusting sponges (e.g., *Desmacella*). In this case, a localised environmental change such as a change in sedimentation may be causing a transition from sponge reef accumulation to encrusted skeleton and zooanthid growth

(Stone et al. 2014). The coating of sponge reef skeletons in oxides (iron, magnesium, phosphate, manganese) has also been recorded in the Strait of Georgia/Howe Sound. In another boundary reef site, sponge reef skeleton are densely covered with bryozoans in an area of low sedimentation (Stone et al. 2014). Monitoring of such areas may determine if there has been a change in environmental conditions, and how the sponge reef may be affected by this.

- Review and update of Species SEC selections. Squat lobsters are strongly suggested to be reconsidered as a species SEC in the next iteration of this assessment. Though this SEC did not fulfill enough criteria for selection, it was included based on a subject matter expert recommendation. Reasons for this SEC to be removed and replaced include that although squat lobsters are common on the reef, they are also common in many other habitats including bare substrate and (perhaps most notably) low oxygen zones (Chu 2016). In addition, recent work has also found that squat lobsters are simply associated with glass sponge reef structure, not necessarily live sponge (DFO 2017). In other words, it is likely that just as many squat lobsters would be observed on a completely dead reef as on a live reef. Future iterations of the ERAF for the HS/QCS MPA are advised to reconsider this SEC and select an alternative. Options include other species of decapods living in the sponge reef environment, such as king, decorator and spider crabs, which are present likely due to the fact their protective exoskeletons are favored in the spicule-rich environment of the sponge reef (Chu and Leys 2010). A future iteration may consider including a different crab species, or even a broader grouping of crustaceans as a separate SEC (e.g., Decapoda) to represent the numerous species of crab found on the reef. Other logical choices for species SEC for consideration in future iterations are seastars (e.g., *Mediaster spp*, *Ceramaster spp*, and *Henricia spp*.) or nudibranchs. Nudibranchs have been shown to consume glass sponges in the Strait of Georgia reefs (Chu and Leys 2012), and seastars are known to eat sponge in other systems, and can structure whole communities through their feeding (Dayton 1972; Paine 1969; S. Archer, DFO PDF, pers. comm.).
- Gain a better understanding of fishing activities in the area through a detailed examination of fishing records and other sources to obtain more in depth information on historical and current fishing effort in sponge reef areas (including research fishing and First Nation fishing). In particular it will be important to distinguish cases of dual fishing (in which FSC is accessed with commercial gear), as this type of fishing is not currently excluded from the AMZ. This information could inform a baseline estimate of fishing impact for each reef area. Though some of this data has been obtained for this study and others (e.g., Boutillier et al. 2013), a more in-depth spatial analysis would be beneficial.
- Research into the potential transport of AIS to the sponge reefs via fishing gear, including investigation of locations previously fished and whether they harbour AIS that could be transported.
- Quantification of the degree of bottom contact in the mid water trawl fishery.
- Quantification of the amount and transport of sediment re-suspended from different activities (not only fishing) taking into account sediment characteristics in the area.
- Quantification of anthropogenic materials such as litter and lost fishing gear present within the sponge reef. Plastic bags have been observed on a number of submersible transects (K. Conway, Natural Resources Canada, pers. comm.), surveys in the Strait of Georgia sponge reefs have included counts of anthropogenic items encountered (Dunham et al. 2018). This could inform scoring of vessel discharge stressors.

- Quantification of background noise levels at the level of the sponge reef, and the noise generated by different anthropogenic activities (in particular from vessels underway). Ongoing DFO work is looking into some of these components. In addition examination of responses by sponges and their biota to noise is another area of knowledge that is lacking.
- Experimental examination of responses and recovery of the three reef-building species to stressors identified as producing high $\boldsymbol{Risk_{sc}}$ scores (e.g., oil/contaminants).
- Determine whether seismic activity is to be permitted at all under MPA management, and if so the expected allowable frequency and extent.

4.3.7.1. Activities/Stressors which may increase in the future

This work only tries to capture a snapshot of current activities and does not project into the future; here we discuss some activities/stressors that may increase in the future.

- **Liquid Natural Gas (LNG) transportation –** Although there are no approved projects currently underway to expand LNG capacity along the North Coast, it is still possible that this activity may still occur in the future. As such, the inclusion of an LNG spill as a stressor could be included in a future iteration of the ERAF, as well as updates relating to anticipated increases in vessel traffic transporting natural resources.
- **Diluted bitumen** – The transport of diluted bitumen in an important and potentially damaging future risk to the ecosystem. The risk may be high to sponge reefs due to the fact that it can sink and may be transported to the reefs on the currents that funnel through the sponge reefs. Future iterations of the risk assessment may need to separate out the different types of oil, with diluted bitumen analysed separately, or as part of a dense oil category. Oil spill is already a potential stressor that is identified as having the highest risk in the risk assessment and the transport of this type of oil was considered in the scoring.
- **Changes in fishing activity** – if there were significant changes in an activity such as fishing, the intensity/exposure score would be increased and risk recalculated.

4.3.8. Indicator development and monitoring plan

The outputs and of this risk assessment, will be used to inform the development of indicators and a risk-based monitoring plan for the newly announced HS/QCS Glass Sponge Reefs MPA (SOR/2017-15). Indicators development will follow the framework provided in Thornborough et al. (2016a, 2016b) where risk assessment outputs directly contribute to indicator selection as applied to SKB MPA and EHV MPA. Indicators are expected to include both SECs, stressors, and the interaction between them. Each indicator is linked to a measurable component, for example, size of a sampling scar, etc.

5. CONCLUSIONS AND RECOMMENDATIONS

This application of the Level 2 ERAF to the HS/QCS Glass Sponge Reefs MPA was effective in selecting and prioritizing SECs with some modifications to tailor the method to this ecosystem and the data available for it. Other findings from this work include:

- The risk assessment outputs highlighted the SECs with the highest cumulative risk ($\boldsymbol{CRisk_c}$): including the Sponge Gardens Habitat SEC, the three reef-building sponges and the boot sponge (*R. dawsoni*), all with similar $\boldsymbol{CRisk_c}$ values. Stressors with the highest $\boldsymbol{Potency_s}$ were: oil (acute sources from oil spills) and oil/contaminants from chronic discharges; substrate disturbance [re-suspension] and substrate disturbance [crushing] from bottom and mid water trawling activities.

- Guidelines are provided to highlight the most effective way for managers to address interactions with high ***Risk****$_{sc}$* scores (as identified in the risk assessment) based on the underlying drivers of the ***Risk****$_{sc}$* scores (i.e., high ***Exposure****$_{sc}$* scores, high ***Consequence****$_{sc}$* scores, or both).
- The risk assessment identified a range of research priorities that will be very helpful in future iterations of the risk assessment. For example, in order to facilitate the future inclusion of Community/Ecosystem Properties SECs in the risk assessment, baseline data and food web analysis is required. The identification of trophic structure and functional groups within the glass sponge reef community are a first step for community analysis followed by research on abundance and diversity. Further, there is a continued need for species-specific research of the reef-building glass sponge species to better differentiate their relative risks from human-based activities.
- A number of methodological improvements were made in this application of the ERAF. Specifically, use of a truncated normal distribution for modelling uncertainty, alternate treatment of interactions that score zero for the ***Resilience****$_{c}$* sub-terms but with high uncertainty, data management tools to improve relativity and consistency of scoring across SEC-stressor interactions). It is recommended that all of these be adopted in future applications and iterations of the ERAF. Further, it is strongly recommended to continue incorporating expert review at every stage of the risk assessment (streamlined to the greatest extent possible).
- This analysis was completed using a “current snapshot” interpretation of the MPA regulations that have recently been put in place. It will be important to assess how the regulations are interpreted (i.e. based on information from approved activity plans and updated vessel traffic data) in a subsequent iteration of the risk assessment, once the MPA regulations have been in effect for several years.
- Given the adaptive nature of the MPA regulations and recent field survey activities that have been undertaken to address knowledge gaps, it is recommended that a subsequent iteration of the risk assessment be conducted as soon as feasible. Recommendations have been provided to guide improvements in the next iterations of this assessment.
- Work to finalize, review and document existing Pathways of Effects Models is recommended to continue. Future analyses will depend on the ability to easily find, update and incorporate these models for future ERAF applications.
- The ERAF assessment results in the aggregation and synthesis of large volumes of data and information. It is strongly recommended that efforts be undertaken to preserve these intermediary outputs through tools such as Canada’s Open Data Portal to enable outputs to be reproduced and also for use in future iterations of the process.

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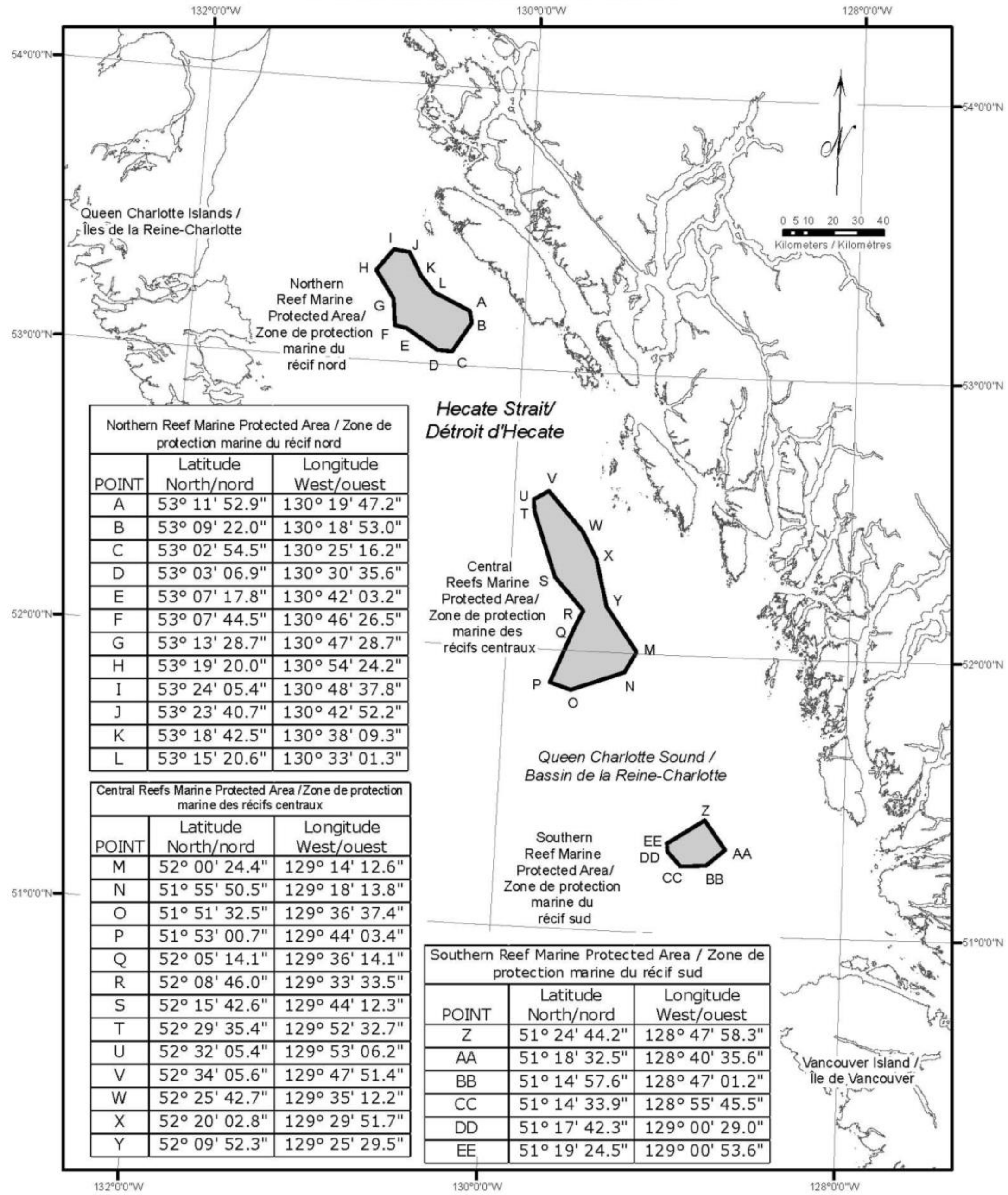
7. APPENDICES

APPENDIX A. THE HECATE STRAIT AND QUEEN CHARLOTTE SOUND GLASS SPONGE REEFS MARINE PROTECTED AREA

A.1. Location and Boundaries

Established under the Oceans Act, the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Areas Regulations define the boundaries of the Northern Reef, the Central Reefs and the Southern Reef Marine Protected Areas, including the boundaries of the management zones within each protected area.



Northern Reef Marine Protected Area / Zone de protection marine du récif nord

POINT	Latitude North/nord	Longitude West/ouest
A	53° 11' 52.9"	130° 19' 47.2"
B	53° 09' 22.0"	130° 18' 53.0"
C	53° 02' 54.5"	130° 25' 16.2"
D	53° 03' 06.9"	130° 30' 35.6"
E	53° 07' 17.8"	130° 42' 03.2"
F	53° 07' 44.5"	130° 46' 26.5"
G	53° 13' 28.7"	130° 47' 28.7"
H	53° 19' 20.0"	130° 54' 24.2"
I	53° 24' 05.4"	130° 48' 37.8"
J	53° 23' 40.7"	130° 42' 52.2"
K	53° 18' 42.5"	130° 38' 09.3"
L	53° 15' 20.6"	130° 33' 01.3"

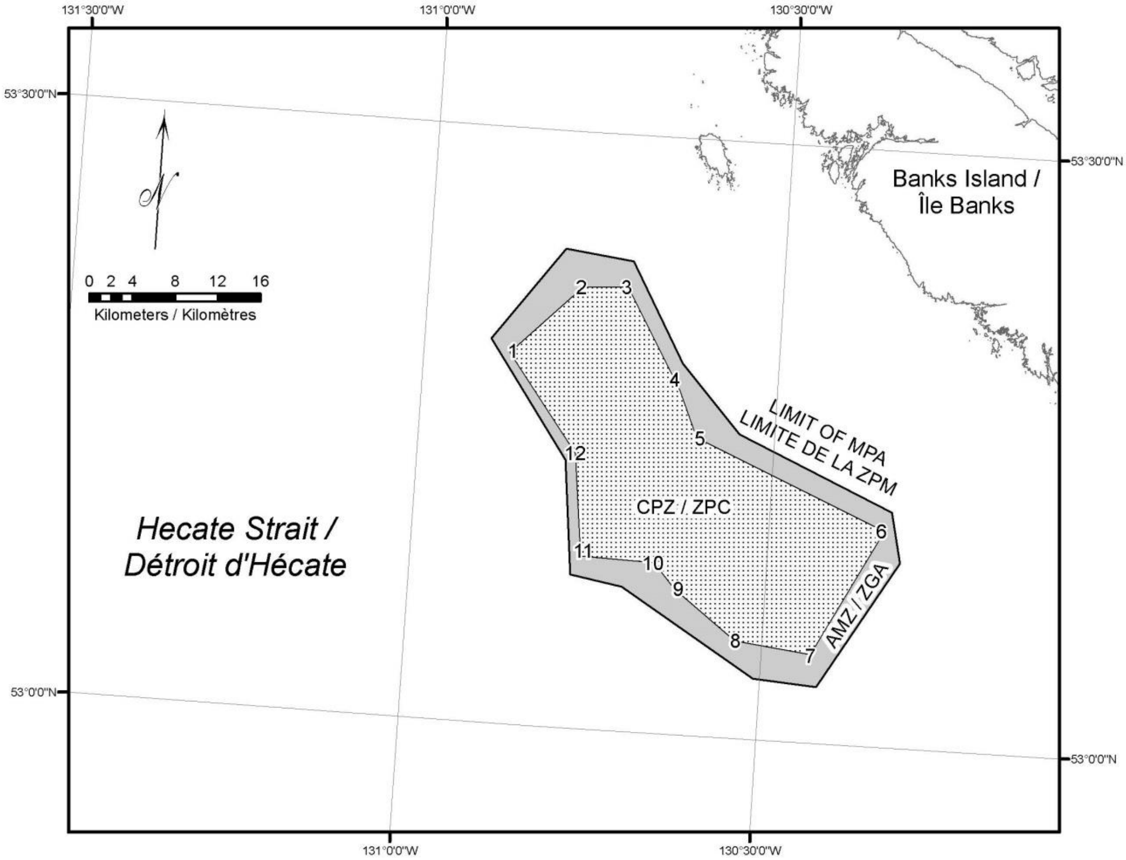
Central Reefs Marine Protected Area /Zone de protection marine des récifs centraux

POINT	Latitude North/nord	Longitude West/ouest
M	52° 00' 24.4"	129° 14' 12.6"
N	51° 55' 50.5"	129° 18' 13.8"
O	51° 51' 32.5"	129° 36' 37.4"
P	51° 53' 00.7"	129° 44' 03.4"
Q	52° 05' 14.1"	129° 36' 14.1"
R	52° 08' 46.0"	129° 33' 33.5"
S	52° 15' 42.6"	129° 44' 12.3"
T	52° 29' 35.4"	129° 52' 32.7"
U	52° 32' 05.4"	129° 53' 06.2"
V	52° 34' 05.6"	129° 47' 51.4"
W	52° 25' 42.7"	129° 35' 12.2"
X	52° 20' 02.8"	129° 29' 51.7"
Y	52° 09' 52.3"	129° 25' 29.5"

Southern Reef Marine Protected Area / Zone de protection marine du récif sud

POINT	Latitude North/nord	Longitude West/ouest
Z	51° 24' 44.2"	128° 47' 58.3"
AA	51° 18' 32.5"	128° 40' 35.6"
BB	51° 14' 57.6"	128° 47' 01.2"
CC	51° 14' 33.9"	128° 55' 45.5"
DD	51° 17' 42.3"	129° 00' 29.0"
EE	51° 19' 24.5"	129° 00' 53.6"

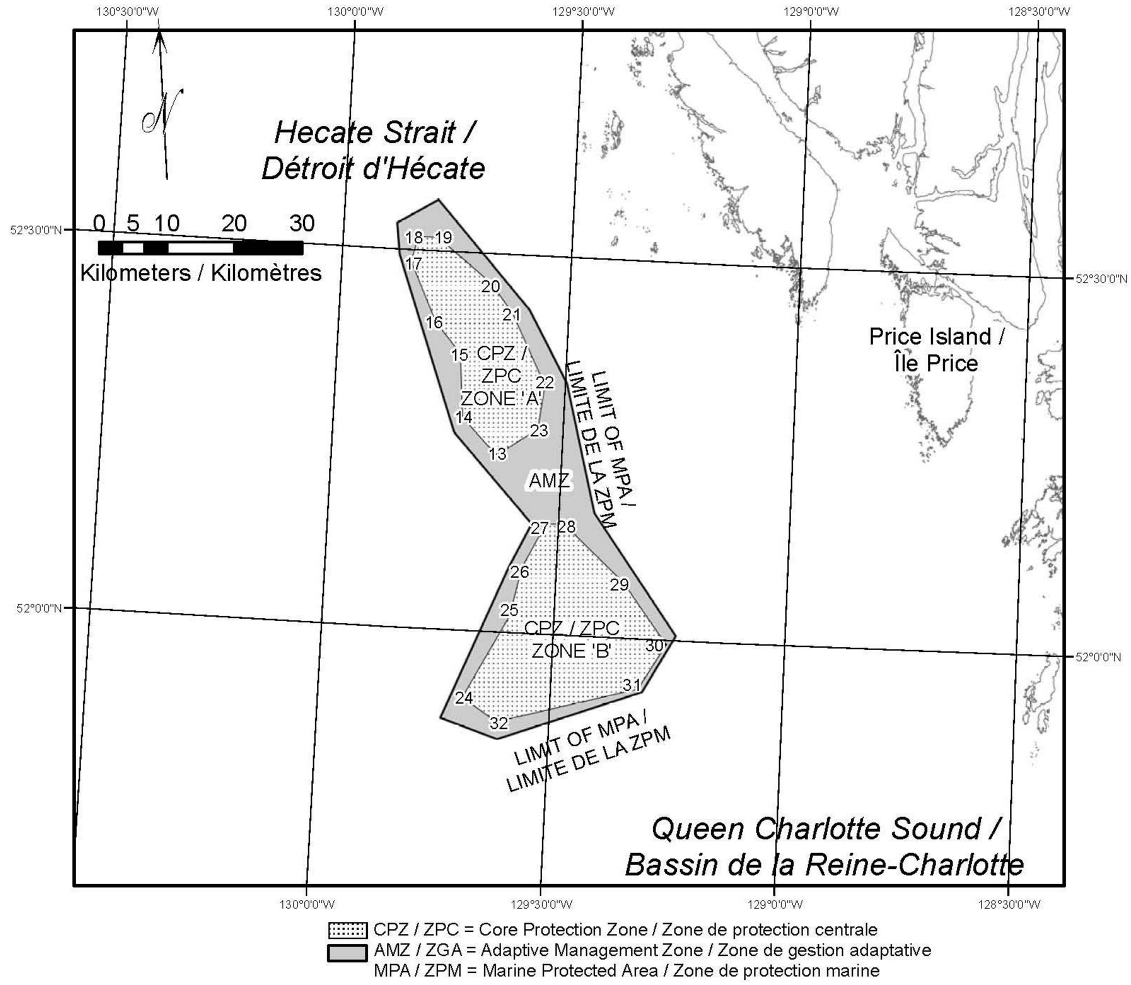
Figure 14. The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area, comprising Northern, Central and Southern Reefs Marine Protected Areas.



CPZ / ZPC = Core Protection Zone / Zone de protection centrale
AMZ / ZGA = Adaptive Management Zone / Zone de gestion adaptative
MPA / ZPM = Marine Protected Area / Zone de protection marine

Northern CPZ / ZPC nord		
POINT	Latitude North/nord	Longitude West/ouest
1	53° 18' 40.4"	130° 52' 46.5"
2	53° 22' 12.1"	130° 47' 01.7"
3	53° 22' 20.2"	130° 43' 12.5"
4	53° 17' 22.8"	130° 38' 18.2"
5	53° 15' 01.7"	130° 36' 35.5"
6	53° 10' 55.2"	130° 20' 19.3"
7	53° 04' 30.2"	130° 25' 53.6"
8	53° 04' 58.0"	130° 32' 16.9"
9	53° 07' 22.2"	130° 37' 37.6"
10	53° 08' 36.6"	130° 39' 29.5"
11	53° 08' 41.8"	130° 45' 40.0"
12	53° 13' 51.2"	130° 46' 41.2"

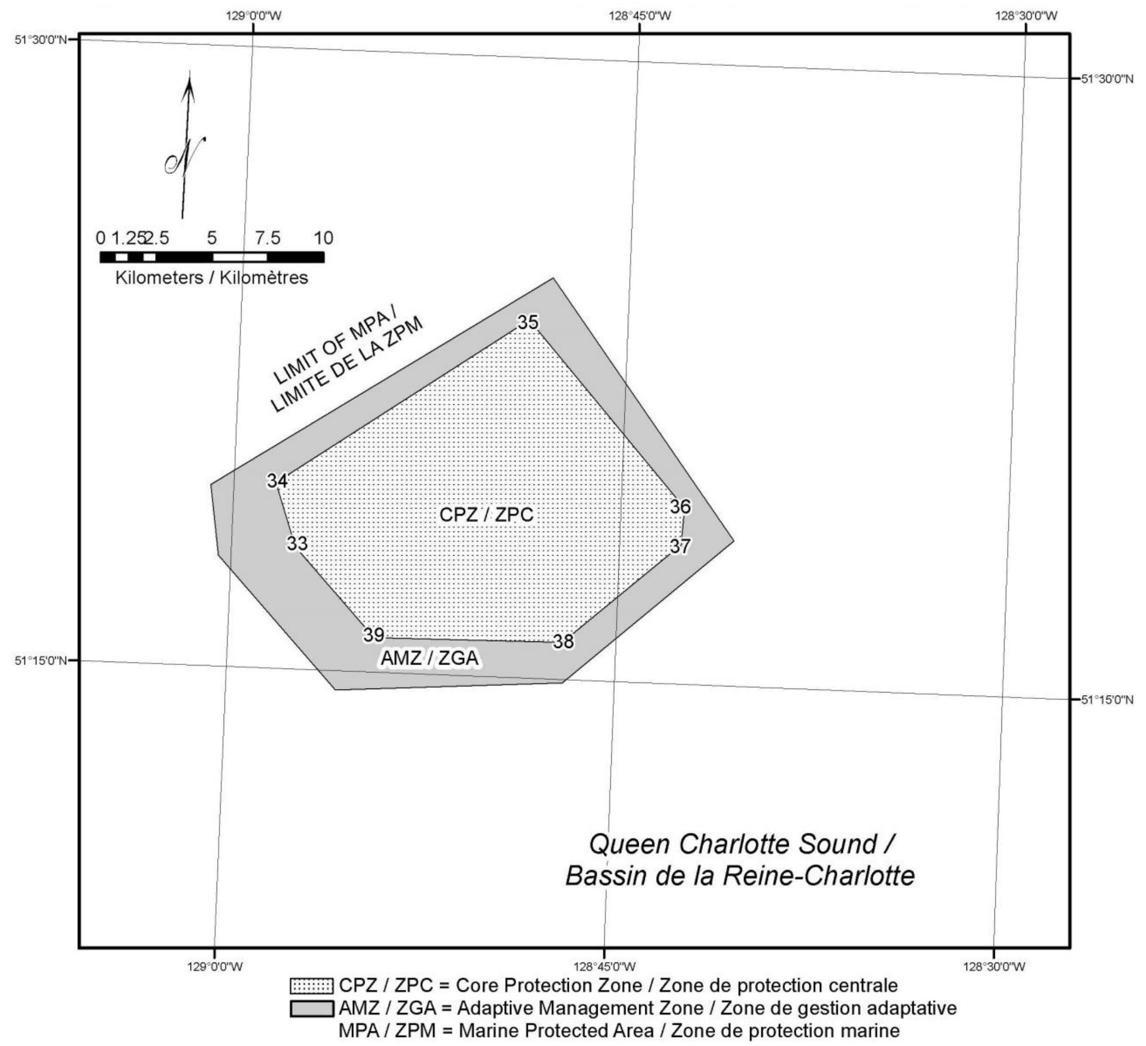
Figure 15. Waypoints delineating the management zones of the Northern Reef Marine Protected Area.



Central CPZ / ZPC centrale - Zone 'A'		
POINT	Latitude North/nord	Longitude West/ouest
13	52° 14' 03.4"	129° 38' 33.2"
14	52° 16' 54.8"	129° 43' 13.4"
15	52° 21' 57.1"	129° 43' 56.5"
16	52° 24' 24.5"	129° 47' 22.8"
17	52° 29' 05.9"	129° 50' 59.4"
18	52° 31' 05.2"	129° 50' 13.9"
19	52° 31' 06.7"	129° 47' 40.9"
20	52° 27' 42.0"	129° 40' 25.1"
21	52° 25' 22.9"	129° 37' 24.0"
22	52° 19' 47.0"	129° 32' 43.2"
23	52° 16' 18.2"	129° 33' 22.8"

Central CPZ / ZPC centrale - Zone 'B'		
POINT	Latitude North/nord	Longitude West/ouest
24	51° 54' 43.1"	129° 41' 22.2"
25	52° 01' 22.5"	129° 35' 48.4"
26	52° 05' 13.5"	129° 34' 32.5"
27	52° 08' 48.5"	129° 31' 44.1"
28	52° 08' 51.3"	129° 29' 18.0"
29	52° 04' 27.1"	129° 21' 17.3"
30	51° 59' 40.8"	129° 15' 23.9"
31	51° 56' 04.5"	129° 18' 46.2"
32	51° 52' 55.7"	129° 36' 49.8"

Figure 16. Waypoints delineating the management zones of the Central Reefs Marine Protected Area.



Southern CPZ / ZPC sud		
POINT	Latitude North/nord	Longitude West/ouest
33	51° 17' 59.2"	128° 57' 31.9"
34	51° 19' 30.8"	128° 58' 22.7"
35	51° 23' 41.9"	128° 48' 50.9"
36	51° 19' 17.5"	128° 42' 33.6"
37	51° 18' 24.5"	128° 42' 37.7"
38	51° 15' 56.0"	128° 47' 04.2"
39	51° 15' 52.2"	128° 54' 20.4"

Figure 17. Waypoints delineating the management zones of the Southern Reef Marine Protected Area.

A.2. Prohibited Activities

The core protection zones contain the sponge reefs and are designed to provide the highest level of protection to the reefs. The vertical adaptive management zones consist of the water column that extends above the core protection zones to the sea surface. The adaptive management zones consist of the seabed, subsoil and waters of the Marine Protected Areas that are not part of the core protection zones or the vertical adaptive management zones.

The regulations prohibit:

carrying out any activity that disturbs, damages, destroys or removes any living marine organism or any part of its habitat or is likely to do so; or

carrying out any scientific research or monitoring, or an educational activity, unless it is part of an activity plan that has been approved by the Minister.

There are exceptions to these prohibitions that identify activities that may be allowed to occur in the MPA in certain zones. The following activities are allowed in the MPA:

Certain fishing activities in the adaptive management and vertical adaptive management zones. (Fishing activities will be managed in accordance with integrated fisheries management plans, annual variation orders, regulations, and license conditions in a manner consistent with the conservation objective of the MPA. In order to protect the sponge reefs, additional fisheries management measures for bottom-contact and mid water trawl fisheries are currently required throughout the MPA.);

Navigation activities throughout the MPA; however, anchoring is not allowed in the core protection zones;

The laying, maintenance or repair of cables in the adaptive management zones;

Activities carried out for public safety, public health, national defense, national security, law enforcement or in response to an emergency; and

Scientific research, monitoring and educational activities that have been approved by the Minister.

All fishing, anchoring and cable installation, maintenance and repair are prohibited in the core protection zones.

The complete MPA regulations can be found at the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Areas Regulations.

A.3. Area and Depth of the Protection Zones

Table 21. Area and vertical depth of the Core Protection Zone (CPZ), Adaptive Management Zone (AMZ) and Vertical Adaptive Management Zone (VAMZ) for each of the four reef complexes included the MPA (adapted from Boutillier et al. 2012).

<table>
<tr><th>Protection Zone</th><th>Northern Reef</th><th>Central Reef (Zone A)</th><th>Central Reef (Zone B)</th><th>Southern Reef</th></tr>
<tr><td>Core Protection Zone (CPZ) size (km2)</td><td>524</td><td>313</td><td>498</td><td>168</td></tr>
<tr><td>Adaptive management zone (AMZ) size (km2)</td><td>235</td><td colspan="2">573</td><td>100</td></tr>
<tr><td>Depth range of Vertical Adaptive Management Zone (VAMZ) (metres depth) over the CPZ
i.e. the distance from sea surface to the start of the CPZ
Depth range (m)</td><td>0-100</td><td colspan="2">0-120</td><td>0-146</td></tr>
<tr><td>Depth range of Core Protection Zone (CPZ)
i.e. the distance from where the CPZ and VAMZ meet to the subsoil to a depth of 20m
Depth range (m)</td><td>100 to -20</td><td colspan="2">120 to -20</td><td>146 to -20</td></tr>
</table>

APPENDIX B. DEFINITIONS OF SPECIES, HABITAT AND COMMUNITY SEC SELECTION CRITERIA

B.1. Considerations for Selecting Species SECs

B.1.1. Original Guidance for Selecting Species SECs

Table 22. Species SEC selection criteria outlined in O et al. (2015) with additional information specific to glass sponge reefs.

Species SEC Criteria	Description from O et al. (2015)	Additional guidance and examples specific to glass sponge reefs
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.	Incorporates organisms abundant/large enough to significantly: (i) extract and consume materials suspended in the water column; and/or, (ii) recycle, or significantly bioturbate or disturb sediments (such as burrowers). Can include mobile species that move on and off the reef but that spend enough time on the reef to contribute to nutrient import and export.
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.	Specialized: species with a highly specialized relationship with the reef building sponges such as those that use Hexactinellid spicules to construct their tubes or tests. Rockfish are abundant in the sponge reef ecosystem and are considered to be highly influential predators in the sponge reef environment.

Species SEC Criteria	Description from O et al. (2015)	Additional guidance and examples specific to glass sponge reefs
Habitat Forming Species	Species which create habitat for infauna and aerate substrates. Species which create habitat on the seafloor.	Species which create structure due to their physical presence or activities. Species which create structural habitat above the seabed include the species of sponge that form the sponge reef. Species that create significant new habitat utilised by other species in the sediment through burrowing or significant sediment disturbance. Small scale habitat creation such as bivalve shells and worm tubes are excluded.
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.	Rare species: species considered rare due to their low abundance in the sponge reef ecosystem such as bivalves and gastropods. Unique species: may be found elsewhere but their presence in the sponge reef habitat is unusual or unexpected, species may have an unusual life history, or is the sole representative of the genera. The reef building sponge species are considered unique species. Endemic species: those unique to the area; some of the Foraminifera species present are only found in the glass sponge reef environment.
Sensitive Species	Low tolerance and more time needed for recovery from stressors.	Includes fragile, sessile species, but also mobile species with life histories that include slow growth and recovery (such as rockfish).
Depleted Species	Listed under SARA/COSEWIC/IUCN/ BCCDC and target and non-target species impacted beyond their sustainable level.	In addition, species that are determined to require protection or be depleted from other sources (e.g., peer reviewed papers, stock assessments), or identified through DFO Oceans Management processes.

B1.1.2. Supplementary considerations to guide the selection of Species SECs for the HS/QCS Glass Sponge Reefs MPA

Table 23. Supplementary considerations used to guide the selection of Species SECs in the glass sponge reef ecosystem. These are in addition to those found in O et al. (2015).

Species Criteria	Description
Resident	Species that are expected to reside in the glass sponge reef ecosystem for the majority of the year as opposed to species that are transient to the area (such as squid, sharks).
Dependent	Species intricately associated with the reef and expected to be dependent on it. Includes species reliant on the reef for habitat, substrate, critical life stage or food.
Abundant	Abundant species can have an important influence on ecosystem processes (Neam et al. 1999) and in the remote deep glass sponge reef ecosystem, abundance can be an important factor in selecting species for monitoring by submersible. Abundance can be determined using observations from surveys, literature and data. Note: a species can still be 'rare' in the region but locally abundant.
Directly observed in the reef area	Indicates species directly observed on or sampled from the reef area (and adjacent to), as opposed to species observation data originating from historical trawl data from a broader area surrounding the reefs (Jamieson and Chew 2002), or inferred to occur from data from surrounding areas (Hemmera 2010[1]).
Suited to long-term monitoring	Species that can be reasonably expected to be simple to monitor to obtain reliable long term trend data over time to track reef health and function. Species that are simple to monitor using minimally destructive methods, such as ROV. These should be visible species with a relatively uniform distribution (non-patchy) to reduce variability related to sampling large reef areas. May exclude species that can only be observed by using grab samples. May exclude species that have patchy distributions. Examples of easy to monitor species include: large sessile species, visible mobile species.
Well studied	Assessed by consulting if the species has been studied (consult peer reviewed literature and reports) and/or has data available. This consideration may allow to help discern between several representatives of a similar functional group (e.g., several crabs) when selecting suitable species SECs.

Results of the HS/QCS MPA Species SEC scoping assessment can be found through the Government of Canada's Open Data Portal.

B.1.2. Considerations for Selecting Habitat SECs

Table 24. Considerations for selecting Habitat SECs, O et al. (2015).

Habitat Consideration	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 which 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 that contribute to the self-maintenance of an ecosystem. Ecosystem services are the beneficial outcomes, for the natural environment or people, which result from ecosystem functions.

B.1.3. Considerations for Selecting Communities/Ecosystem Properties SECs

Table 25. Considerations for selecting Communities/Ecosystem Properties SECs, O et al. (2015).

Community/Ecosystem Properties Consideration	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 C. SOURCES USED TO IDENTIFY SPECIES RECORDED AT THE HS/QCS GLASS SPONGE REEFS MPA

Table 26. Sources used to assemble the species recorded on or close to the Hecate Strait / Queen Charlotte Sound glass sponge reefs. Codes in the first column are used to identify the source of species listed in the Species SEC Scoping table (Open Data; last updated in 2014). It is important to note that many fish species found on the list originated from indirect sources such as fishery catch data from the area.

Code	Document	Type of data	Description
A	Guilbault et al. 2006	Research surveys	Species identified from samples obtained from on reef surveys using three types of bottom samplers: slurp gun, Shipek and IKU grab sampler. All species are Foraminifera.
B	Krautter, M. 1999 cruise report (unpublished)	Research surveys	Some additional Foraminifera species that were not reported in Guilbault et al. 2006 (A).
C	Krautter et al. 2001	Research surveys	Summary paper reviewing species found on the reef from various studies.
D	Jamieson and Chew 2002	Research surveys	Species listed in Appendix 1 of this document - those observed by Bill Austin from video observations on sponge reef A (modified from Sloan et al. 2001)
E	Jamieson and Chew 2002	Fisheries catch data	Targeted and bycatch species list from groundfish trawl activity in the vicinity of sponge reefs A, B, C and D
F	Lehnert et al. 2005	Research surveys	Detail on one species - *Desmacella austini* sp. nov.
G	Conway 2005	Primary research	Book chapter – general summary of the sponge reef ecosystem.
H	Cook 2005 and unpublished species list	Research surveys	Thesis, focusing on sediment grabs from within the reef. Consequently, mainly composed of infaunal species (primarily Annelids). Includes an additional updated species list (Sarah Cook, Coastal and Ocean Resources, Victoria, BC, pers. comm.).
I	Leys et al. 2007	Primary research	Book chapter – general summary of glass sponge reef biology.
J	Sloan et al. 2001	Research surveys	Report to Parks Canada on invertebrate resources in Gwaii Haanas.

Results of this HS/QCS MPA Species SEC scoping assessment can be found through the Government of Canada's Open Data Portal.

APPENDIX D. SUBJECT MATTER EXPERT QUESTIONNAIRE AND REVIEWER COMMENTS

Table 27. Summary of reviewers who provided feedback and guidance at various stages of the risk assessment.

Reviewer	Affiliation at time of review	Topic of review	Date reviewed
Sally Leys and Amanda Kahn	University of Alberta	Significant Ecosystem Component (SEC) selection	Jan 2014
Kim Conway	Natural Resources Canada (NRCAN)	Interaction matrix	Sept 2014
		SEC selection	Sept 2014
		Scores from one sample SEC (*Heterchone calyx)*	Sept 2014
		First draft of RESDOC	June 2015
Anya Dunham	DFO	Scores from one sample SEC (*Munida quadrispina*)	Nov, 2014
Matthias Herborg	BC Province	Scores relating to Aquatic Invasive Species (AIS)	Sept 2014

D.1. REVIEW OF SEC SELECTION PROCESS AND SECS IDENTIFIED

An initial review was provided by S. Leys and A. Kahn (UAlberta). After the incorporation of suggestion changes, it was then sent for review by K. Conway (NRCAN).

Reviewers were requested to assess the suitability of the SEC selection process to select SECs, as well as the SECs that were selected (species, habitat and community/ecosystem properties). A number of specific questions were also posed:

- Does the final list of SECs (Table 4 in document) capture the biological and ecological components for the Hecate Strait Glass Sponge Reefs?
- If you have any concerns with the criteria and their descriptions which were used to select SECs, or if you consider there to be important criteria missing
- If you see any crucial gaps in our SEC list, given the selection criteria.
- We came across several groups of organisms during our selection process and primary literature searches that had unclear roles in the sponge reef ecosystem. We would appreciate any feedback or knowledge you may have on the roles / functions / importance of the following groups in the sponge reef ecosystem:
    a. Foraminifera within the dead reef
    b. Polychaete assemblage in sediment filled dead reef areas
    c. Echinoderms

d. Decapod crustaceans (crabs, squat lobsters) and shrimps

e. Juvenile rockfish

f. Adult rockfish

Considerations include their potential roles as important nutrient importers/exporters, maintaining the ecosystem, nutrient cycling, maintaining sponge reef biodiversity etc.

An accompanying document provided reviewers with a basic background to the method used (the same method outlined the main document here) and detailed how the SEC selection process was done, including the additional considerations developed for this specific application to the sponge reefs. Provided below are tables reviewers were asked to examine.

Table of Selected SECs sent to Reviewer #1

A list of proposed Significant Ecosystem Components with description of why they were chosen based on criteria.

SEC Type	Significant Ecosystem Component (SEC)	Justification (criteria met)
Species	***Heterochone calyx*** (Reef building glass sponge)	**ERAF criteria**: nutrient importer/exporter; specialized or keystone role in the food web; structural habitat creating species; rare, unique, or endemic species; sensitive species, and; depleted species **Additional criteria**: non-transient species; able to be monitored; abundant; observed with ROV; Present on live/dead reef complex (rather than adjacent); depend on reef (dead or live) for critical life stage or other critical requirement)
	Aphrocallistes vastus (Reef building glass sponge)	**ERAF criteria**: nutrient importer/exporter; specialized or keystone role in the food web; structural habitat creating species; rare, unique, or endemic species; sensitive species, and; depleted species. **Additional criteria**: non-transient species; able to be monitored; abundant; observed with ROV; Present on live/dead reef complex (rather than adjacent); depend on reef (dead or live) for critical life stage or other critical requirement)
	Farrea occa (Reef building glass sponge)	**ERAF criteria**: nutrient importer/exporter; specialized or keystone role in the food web; structural habitat creating species; rare, unique, or endemic species; sensitive species, and; depleted species. **Additional criteria**: non-transient species; able to be monitored; abundant; observed with ROV; Present on live/dead reef complex (rather than adjacent); depend on reef (dead or live) for critical life stage or other critical requirement).
	Rhabdocalyptus dawsoni (Rossellid/boot sponge)	**ERAF criteria**: nutrient importer/exporter; specialized or keystone role in the food web; structural habitat creating species; sensitive species, and; depleted species. **Additional criteria**: non-transient species; able to be monitored; abundant; observed with ROV; Present on live/dead reef complex (rather than adjacent); depend on reef (dead or live) for critical life stage or other critical requirement).
Habitat	**Dead glass sponge matrix** (includes material contained within, such as sediments and foraminifera)	**ERAF criteria**: sensitive habitat (easily destroyed); habitat critical for sensitive species; habitat critical for threatened or depleted species; habitat critical for supporting rare, unique, or endemic species; habitat critical for supporting critical life stages; habitat providing critical ecosystem functions or services.

SEC Type	Significant Ecosystem Component (SEC)	Justification (criteria met)
	Reef-building sponge habitat (includes primarily glass sponges, but also boot sponges)	**ERAF criteria**: biogenic habitat; sensitive habitat; habitat critical for sensitive species; habitat critical for threatened or depleted species; habitat critical for supporting rare, unique, or endemic species; habitat critical for supporting critical life stages; habitat providing critical ecosystem functions or services.
	Boot sponges (as a biogenic, structural habitat)	**ERAF criteria**: biogenic habitat; sensitive habitat; habitat critical for sensitive species; habitat critical for threatened or depleted species; habitat critical for supporting rare, unique, or endemic species; habitat critical for supporting critical life stages; habitat providing critical ecosystem functions or services.
Community	**Demosponges**	Sensitive functional group; functional groups that play a critical role in ecosystem functioning; sensitive functional groups.
	Juvenile rockfish community	Functional groups that play a critical role in ecosystem functioning; sensitive functional groups.
	Benthic, dead sponge community (of sediments, foraminifera, and polychaetes)	Unique community; ecologically significant community properties; functional groups which play a critical role in ecosystem functioning.

Table 28: Excerpt of Appendix sent to Reviewers. Species ranked highly based on selection criteria, as possible species to include as SECS, at present these are not chosen as SECs. The highest scoring groups (and species) identified from primary literature at the Hecate Strait sponge reefs. As Porifera were already captured as species (Heterochone calyx, Aphrocallistes vastus, Farrea occa, and Rhabdocalyptus dawsoni), habitat (dead glass sponge matrix, reef-building sponges, and Rossellid/boot sponges), and community (demosponges) SECs, these were excluded from this analysis. Due to the difficulty identifying the juvenile rockfish to species, individual rockfish species were also excluded. Groups/species were ranked in order of their overall total score, and all groups/species with a score of <2 for ERAF criteria were removed.

			ERAF criteria							**Other considerations**							
Taxonomic group	**Family**	**Group**	Nutrient Importer/Exporter	Specialised or keystone role in food web	Structural habitat creating species	Rare, unique, or endemic species	Sensitive species	Depleted species	ERAF criteria total	Non-transient species	Able to be monitored	Abundant	Observed with ROV or from samples on/in reef?	Present on reef complex (rather than adjacent)	Depend on reef for critical life stage or other critical requirement?	Other considerations total	OVERALL TOTAL
Actinopterygii (Class)	Scorpaenidae	Rockfish<20 cm	1	1	0	0	1	1	4	1	1	1	1	1	1	6	10
Polychaeta (Class), Terebellida (Suborder)	Terebellidae	Terebellida (order)	1	1	0	1	1	0	4	1	1	1	1	1	1	6	10
Actinopterygii (Class)	Scorpaenidae	Rockfish >20 cm	1	1	0	0	1	1	4	1	1	1	1	1	?	5	9
Foraminifera		Arenaceous	0	1	0	1	1	0	3	1	1	1	1	1	1	6	9
Foraminifera		Calcareous type	0	1	0	1	1	0	3	1	1	1	1	1	1	6	9
Polychaeta (Class), Sabellida (Suborder)	Sabellidae	Sabellidae (order)	1	0	0	1	1	0	3	1	1	1	1	1	1	6	9
Gastropoda	Cymatiidae	*Fusitriton oregonensis* (Oregon triton)	0	1	0	1	0	1	3	1	1	1	1	1	1	6	9
Bivalvia		Including *Astarte alaskensis, Axinopsida serricata, Hiatella arctica, Thyasira flexuosa*	0	1	0	1	1	0	3	1	1	0	1	1	1	5	8
Anthozoa (Class), Octocorallia (SubClass)		Soft corals (general)	0	0	1	0	1	1	3	1	1	0	1	0	0	3	6
Anthozoa (Class), Octocorallia (SubClass)		Gorgonian corals (general)	0	0	1	0	1	1	3	1	1	0	0	0	0	2	5
Anthozoa (Class), Madreporia (Order)		Stony corals (general)	0	0	1	0	1	1	3	1	1	0	0	0	0	2	5

SEC selection review #1: Sally Leys and Amanda Kahn, University of Alberta

Excerpts from e-mail, January 26, 2014

“We both felt the criteria for selecting SECs were fine, and that the definitions of the SECs as laid out in your table, also fine.

There seems to be something rather important to sponge reefs which is not captured in any of these 'SEC Types' though, and that is the type of terrain. A sponge reef will not form on flat ground. It must have a raised topography -- in the northern reefs this is provided by the glacial iceberg scours and the ridges of rubble that the sponges originally settle on. Elsewhere it can be similar glacial till, which forms sills, ridges, etc. The essential feature of raised topography is to generate increased flow (usually unidirectional) which brings sustained food to the sponges. Trawling is well documented to flatten the seafloor. It will be essential to maintain seafloor topography to sustain the sponge reefs, so capturing something about the terrain topography in the SECs will be essential for the future of reefs.

Both Amanda and I had the same reaction to the Community SEC component 'Demosponges'. Where sponge gardens exist, both glass sponges and demosponges cohabit, and these are highly important habitat for crustaceans and fish. Somehow capturing the diversity of the 'sponge garden' and possibly distinguishing that from reef but retaining its significance will be important in establishing these SEC components. It seems otherwise there may be a risk of saying that area was not included and that it's difficult to retrace steps so as to include it.

Another point was the Community "Dead Sponge". I consider 'dead sponge' to be the same as 'live rock' that aquarists import for their aquaria. It carries all the animals and nutrients for sustaining a community. Possibly it would be better branded as sponge skeletons rather than 'dead sponge'.

A community that I feel seems glaringly missing is the squat lobsters (*Munida quadrispina*) and small decorator crabs - both of which are highly abundant and form a lively and probably hugely important link between the sponges and fish. Perhaps I missed that in your descriptions? If not, though, I would definitely include them as a Community that requires independent attention.

Another community that is marked but not identified in your tables is sea whips (which can occur in large numbers at the edges of reefs).

Finally, neither Amanda nor I found we had much more to offer in terms of function or role for the other animals listed in your appendix. More research needs to be done! Possibly some information is already there for foraminifera, but I'm not well-versed in the literature, so it would be worth checking it.”

Changes made as a result of this review (including further discussion):

1. Propose to ask second reviewer (K. Conway) about inclusion of Seafloor topography as a 'community and ecosystem properties' SEC.
2. The boot sponge R. dawsoni changed from a Habitat SEC to a Species SEC to allow it to be better captured in the scoring process
3. Restructured habitat and community/ecosystem properties SECs to:
4. Habitat SECs: (1) Glass sponge reef skeletons; (2) Live reef-building sponge; and (3) Sponge gardens.
5. Community/Ecosystem Properties SECs: (1) Glass sponge reef skeleton community; (2) Glass sponge living reef community; (3)Sponge garden community [demosponge/glass sponge mix]; and (4) Glacial till topography critical for maintaining flow to reefs (an Ecosystem Property SEC).
6. Sponge gardens – defined more clearly as 'non-reef building occurrences of a mixture of sponge types which occur outside of the glass reef building structure'.
7. Include squat lobsters as a species SEC (as a representative of small crustaceans) given the confidence of the subject matter experts, despite the fact that they did not score (8, rather than the usual 10-12 range for SEC selection). A similar situation occurred in the Bowie Seamount ERAF application, where squat lobsters were selected despite low scores due to reviewer suggestion due to: potential for monitoring, potential role as an indicator species due to their ability to tolerate low oxygen environments, and as a representative of a mobile species in the species SEC category plus their high abundance in that environment.

Review of updated SEC selection (including the above changes), and interaction matrix review: Kim Conway, Natural Resources Canada, Excerpts from in-person interview - September 16, 2014

The scoring is an interesting way to get at the SEC importance and looks for the most part to be effective. I would support your emphasis on the habitat SECs as opposed to the species level SECs. For example - I am a little confused as to why Red tree corals Paragorgia score at all since they are not part of the reefs. This is a little odd as they score higher than squat lobsters which are possibly the most common macro fauna on the reefs by far. I would therefore support the use of Table 4 as shown in your results.

I would also suggest that perhaps a [broader] grouping of crustaceans that occur would be supported by the data. I am pretty sure that there are many species of crab including Puget Sound King crabs and smaller "decorator" and "spider"crabs as well as the ubiquitous Munida occur. **So should the Decapoda be the taxa level recognized as the SEC in this case**? This would cover off 2 other taxa in your species listing of possible SEC species. Or should "Other Decapoda" be a category to distinguish these from Munida spp? (Discussions with ecologists suggest that exoskeleton equipped invert groups are favored in the spicule rich environment of the sponge reef, compared to other groups like soft bodied cnidarians like anemones which are very rare - except on Fraser Ridge sponge reef for some reason where they are common.)

There is no mention of euphausids or chaetognaths, which are very common benthic "swimmers" at some reef sites. I am not suggesting you include these at my behest – just wondering why these don't show up in any lists.

Back to the till discussion - I would agree with the perspective that the exposed till and glacial surfaces are required for reefs to develop. Without gravel as substrate the reef builders cannot attach. This is a substrate function not a topographic elevation function however. So – perhaps a merged SEC statement around the importance of the glacial surfaces and topographic enhancement of reef function should be included to cover all the aspects of this critical habitat element could be included?"

Note: K. Conway also reviewed the interaction matrix, which is used to determine which stressors and SECs are expected to interact, response:

"The matrices are very complete and I can't really see errors or omissions with one possible exception. I was wondering if you don't include cable laying because this will be excluded specifically from the sponge reef AOI or if I missed something".

The final list of SECs in the main document illustrates the final changes made as a result of all reviews and discussions (Table 9 and Table 10).

D.2. REVEW OF RISK ASSESSMENT SCORES

Risk scores were reviewed by two subject matter experts. Due to the large number of scores to review within each SEC, each reviewer undertook a full review of a single SEC only. These reviews were done in person in a 3 hour meeting, present were the reviewer, L. Hannah and Miriam O. Any notes taken from those meetings are provided below the questionnaire that was provided ahead of the meeting.

QUESTIONNAIRE PROVIDED:

Ecological Risk Assessment Framework for Ecosystem-Based Management

Applied to the Hecate Strait/Queen Charlotte Sound Glass Sponge Reef Ecosystem

Background

The Ecological Risk Assessment Framework (ERAF) for Ecosystem Based Management (EBM) developed by DFO Pacific Region (O et al. 2015) evaluates the single and cumulative threats from human activities (and associated stressors) to components identified as significant to the ecosystem of interest (Significant Ecosystem Components, or 'SECs').

To date, the ERAF has been evaluated by applying it to two Marine Protected Areas in the Pacific Region: Bowie Seamount MPA and Endeavour Hydrothermal Vents MPA. The current project involves application to the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Area of Interest. The framework consists of several phases, the scoping phase is complete and the outputs are listed in Tables 1 and 2. In Table 1 are the activities determined to be occurring in the area with their associated stressors, and in Table 2 are the selected and reviewed Significant Ecosystem Components (SECs).

Here, we are seeking review of the semi-quantitative scores assigned to interactions between the ecosystem components (SECs) and activity-associated stressors. Each SEC-stressor pair is scored for exposure, consequence and recovery, with linked uncertainty scores and justifications, explained in detail in the 'Reviewer Reference Sheet' which follows. These scores are the basis for calculating cumulative risk of SECs from human activities.

The outputs of the risk assessment provide managers with science advice on the ecological risk consequences of anthropogenic stressors on the ecosystem which can be used to develop conservation objectives, management strategies and action plans including monitoring, research, and management. Throughout the application of the risk assessment, review and feedback from experts such as yourself are critical for its success and accuracy and we greatly appreciate any input you are able to provide. Feedback from other risk assessments indicates the most efficient approach for reviewers is to provide feedback in person in a 2-3 hour long meeting to go over scores and deal with questions or queries.

Provided for review are the following attachments:

1. Scoring tables for review for one species SEC - (scores exported from excel worksheets containing the raw scores assigned to one Significant Ecosystem Component).
2. Reviewers reference sheet (to refer to during review, contains information on the bins used, and explanations of the column headings etc.).

During this review we would be grateful to receive any feedback, in particular:

(a) Are allocated scores appropriate?

If you do not agree with the scores, please change the score accordingly and provide some justification (e.g., explanatory text, or key references).

Additional justifications deemed appropriate can be added.

(b) Are there are any interactions between SECs and activities that we may have missed?

Important points to remember when scoring /reviewing exposure:

- Overlap is with the stressor and SEC, not the stressor and the AOI [MPA].
- Scores based on average annual exposure (e.g., average over latest 5+ years).
- Assumes MPA regulations are in place (i.e., no bottom contact fishing etc.).

For species SECs, overlap is the % overlap with the population of that species.

Temporal overlap represents the persistence of the interaction between the stressor and SEC over the duration of a year, e.g., oil can have a longer persistence time than a plume of sediment.

Intensity (amount) - is a relative measure, e.g., relative to the worst case example of that stressor in the risk assessment/in the same activity, for example - crushing from vessel debris is low relative to that of bottom trawling.

AIS and Oil Spills differ for scoring from other stressors. As they are scored for potential exposure in unpredictable circumstances, they are both stressors with severe consequences that can result from activities in the area, but to date there is no evidence that they have occurred. The other stressors are likely to, or have already occurred in the past.

Depth overlap example: Seamount - In a seamount environment, the seabed varies a great deal in depth. In this environment, activities and stressors that affect the whole water depth are considered. For example, sablefish trap fishing only goes to a certain depth, so depth overlap with SECs below this would have low depth overlap (e.g., sponges at the base), whereas corals higher up (circles) would have a higher depth overlap.

[Diagrams to illustrate examples removed]

Depth overlap example: Sponge Reef - In the sponge reef environment, only activities and stressors that would interact with the benthic sponge reef environment were included in the analysis. This means that depth overlap will almost always be high for stressors in the risk assessment.

D.2. REVIEWER COMMENTS

D.2.1. K. Conway, Natural Resources Canada, Sep 16, 2014

K. Conway reviewed SEC 1 – *Heterochone calyx*. Review was done in person and comments here are noted from this meeting

- Went over every score and uncertainty for SEC#1 – H. calyx
- Agreed that the scores reviewed for this one species of reef-building sponge could be used to apply to the other sponge species with only minor changes
- Some changes but mostly agreed with the scores
- Some discussion about including things that are highly unlikely to ever be an issue, in particular shipwrecks when compared to something like entangling debris. Concluded that the final calculated outputs will shed more light on this.
- Many could also be applied to the boot sponge but this will be a little different
- Some confusion regarding depth overlap and intensity (amount)
- Concerned about increases in fishing/other activities around the peripheries of the sponge reef as a response to fishermen being told they cannot fish in the sponge reef area any more. [For example,] may be an increase in mid water trawling as this is the only type allowed in the reef, and operators may touch bottom often. We really don't know.
- Suggested contacting Bob Stone to see if he has any information on mid water trawling bottom interaction for clarity on scoring this activity
- Brought up the dumping of woody debris or mine tailings as a stressor (dumping), however due to the location and lack of precedent for this he can understand why it is not included. Mentioned that there used to be a log sort at Malcolm island and that Haida Gwaii may have some. Also MPA regulations would not allow dumping.
- Difficult to score based on the assumption that MPA regulations are in place when we do not know what they will be. In the document list what the assumed regulations are.
- Something missing is litter thrown overboard from vessels, this will be included under some of the shipping discharge stressors, this is apparently a common problem. Said that when he saw the ROV videos he saw quite a few plastic bags and debris entangling sponges
- Some of the justifications need expanding
- Since the work he did 10 years ago, since then there has been only 2 ROV only research trips to the reefs Hecate/QCS
- Scoring effects of ROV / sampling etc use – bear in mind that what is generally done is a research area is selected to be monitored, a relatively small area within the sponge reef. Once small research area selected, research effects may be scored higher as it is relative to a smaller area – depends how it is done.

D.2.2. A. Dunham, DFO Science, November 21, 2014.

A. Dunham reviewed scores for SEC5 – *Munida quadrispina*, notes from meeting:

- General agreement with the scores assigned with a few minor changes
- Helpful to include table showing relative scores for intensity for the same stressor over different activities in the review tables.
- Oil spill - frequency of spills - could determine what this could be by looking into comparable areas for frequency of oil spills, e.g., Alaska?
- Light from non-ROV research. What types of research equipment other than ROV use light?
- Relative intensity needs to be fixed for those which refer to worst case being bottom trawling direct effects. Can only compare to stressor-activity pairs that are in the risk assessment.
- Discussed the consideration of exposure when scoring resilience and need to clearly define how this is done without referencing, i.e., point source versus nonpoint types. Almost just need a yes or no for acute and chronic. Seems like exposure will have to be taken into account for all stressors where exposure is needed to be referenced (this would not be the case if it would be a yes or no whether this interaction may produce an effect, we are looking at degrees of the population, requiring exposure to be referenced).
- Indirect and long range impacts – to discuss at end and how it affects outcomes, e.g., pathogens from AIS. These should be excluded and put under state of the ecosystem.

REVIEW OF DRAFT RESEARCH DOCUMENT

K. Conway, Natural Resources Canada, June 2015

I attach my comments on the risk assessment study. I think the assessment is fairly clear - though I need to say that I am maybe not the best person to critically read these kinds of assessments because this is a bit outside my comfort zone in terms of expertise. I think that the assessment captures the main risks quite well, and I would agree with your approach and general assessment of the risks and how they are rated and where they end up in ranking. The description of the approach is very complete, and the criteria that were used are examined in a thorough fashion.

I am bit concerned that “Sponge Garden” has become one of two habitat SEC’s and, in some sections, dominates the discussion of habitat for this reason. (the other one is the dead skeleton habitat). The sponge reefs are normally considered to be very different from sponge gardens so it is concerning that an assessment of sponge reefs would become, to some extent, a discussion of the importance of sponge garden habitat. For some ecologists sponge gardens are clearly more important than sponge reefs in terms of habitat provision, despite the fact that we know very little about sponge reefs. So it is important to be clear about what we know or don’t know about sponge reefs taken in total as a habitat system. We break this system down into these components and are left with no sponge reef as a habitat which is very odd and perhaps an unintended consequence of this breakdown. No one would talk about coral reef as a habitat without actually talking about coral reefs as a habitat - but that seems to be what we are doing here. We talk about the dead skeleton habitat as the other type which is sort of like talking about coral reef rubble or fore reef rubble as a habitat – again without talking about the coral reef habitat itself. I am not sure if there is an easy solution to this in the document beyond discussing this clearly in where the habitat “value” or function is assigned and captured between the community and habitat criteria.

In addition no one has studied sponge gardens adjacent to the sponge reefs in the AOI, so for this element to end up with such prominence in the final risk analysis for the AOI is problematic. We know very little about the reefs as a habitat system and need to be careful about this aspect. I suspect inshore reefs in SCUBA depths, Strait of Georgia reefs, Queen Charlotte sound reefs and Hecate Strait reefs are all quite different in species composition, accompanying fauna, sediment input and other sediment parameters and oceanography which ultimately drives these systems.

One other issue I would raise in general is the degree to which we assume a general functioning state for the reefs when we know many of them have been very heavily damaged. To my mind the absolute requirement for future work in the [MPA] is an assessment of the trawled versus un-trawled areas, and living versus non-living reef areas. The largest question to be answered is whether or not the large areas that have been extensively trawled or that are dead can recover. If they cannot recover - having a large sponge reef MPA will not be very useful, and in fact may be detrimental, as an assumed function will be assigned when no valuable biological function is actually happening. So in discussion of resilience and other related aspects in the document this should be mentioned, and in terms of possible future research this requirement should be emphasized.

APPENDIX E. SCOPING OF ACTIVITIES AND ASSOCIATED STRESSORS BASED ON PREVIOUS ERAF ASSESSMENTS

Table 29. Initial list of activities provided by DFO Oceans (2011) and additional activities identified for inclusion from other sources.

The initial list of activities and potential stressors can be found through the Government of Canada's Open Data Portal.

Table 30. List of pathways of effects models (PoE), the date they were last modified and whether they had undergone a formal review.

PoE model	Date last modified	Formal review?
Grounding	29/11/12	Yes (DFO 2015)
Discharge	29/11/12	Yes (DFO 2015)
Movement underway	29/11/12	Yes (DFO 2015)
Oil spill	29/11/12	Yes (DFO 2015)
Equipment abandonment	11/01/13	No
Equipment installation	20/12/12	No
Scuba	18/01/13	No
Sampling	11/01/12	No
Submersible operations	21/12/12	No
Seismic testing / air guns	23/12/12	No
Trap/Pot fishing	15/07/13	No
Fishing (generic)	13/06/2014	No

APPENDIX F. ACTIVITIES, SUB-ACTIVITIES AND ASSOCIATED STRESSORS CONSIDERED FOR USE IN THE HS/QCS MPA RISK ASSESSMENT

Table 31. List of activities, sub-activities and associated stressors considered in the HS/QCS Glass Sponge Reefs MPA risk assessment (with standardized stressor names).Stressor Types include: Current/PS – current snap-shot stressor (point source); Current/NPS – current snap-shot (non-point source); Potential – potential stressor; or, "-" screened out of assessment (not relevant to any SEC).

Activity	Sub-activity	Stressor	Stressor Type
Vessel Traffic	Anchoring	Substrate disturbance [re-suspension]	-
		Substrate disturbance [crushing]	-
		Substrate disturbance [foreign object]	-
		Disturbance [noise]	-
		Disturbance [light]	-
		Introductions [AIS]	-
	Discharge (including on-board fish processing)	Oil/Contaminants	Current/NPS
		Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Substrate disturbance [foreign object]	Current/PS
		Entrapment	Current/PS
		Introductions [biological material]	-
		Prey imitation	-
		Introductions [AIS]	Potential
	Grounding	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Substrate disturbance [foreign object]	Current/PS
		Disturbance [noise]	Current/PS
		Disturbance [light]	Current/PS
		Introductions [AIS]	Potential
	Movement underway	Substrate disturbance [re-suspension]	-
		Disturbance [noise]	Current/NPS
		Disturbance [light]	-
		Disturbance [turbulence]	-
		Disturbance [water displacement]	-
		Strikes	-
	Oil spill	Oil	Potential
Research	Acoustic mapping	Disturbance [acoustic]	Current/NPS
	Equipment abandonment	Oil/Contaminants	-
		Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Substrate disturbance [foreign object]	-
	Equipment installation/use	Oil/Contaminants	-
		Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Substrate disturbance [foreign object]	-
		Disturbance [noise]	-

Activity	Sub-activity	Stressor	Stressor Type
		Disturbance [light]	-
	Sampling	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Strikes	Current/PS
		Removal of biological material	Current/PS
	Seismic surveys	Disturbance [seismic]	Potential
	Submersible operations	Oil/Contaminants	Current/PS
		Strikes	Current/PS
		Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Disturbance [noise]	Current/PS
		Disturbance [light]	Current/PS
		Introductions [AIS]	Potential
Fishing	Bottom trawl	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	-
		Removal of biological material	-
		Entrapment	-
		Strikes	-
		Introductions [AIS]	Potential
	Mid water trawl	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	Current/PS
		Removal of biological material	Current/PS
		Entrapment	Current/PS
		Strikes	Current/PS
		Introductions [AIS]	-
	Long line hooks	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	-
		Removal of biological material	-
		Entrapment	-
		Strikes	-
		Introductions [AIS]	-
	Long line traps	Substrate disturbance [re-suspension]	Current/NPS
		Substrate disturbance [crushing]	-
		Removal of biological material	-
		Entrapment	-
		Strikes	-
		Introductions [AIS]	Potential
	Rod and reel	Substrate disturbance [re-suspension]	-
		Substrate disturbance [crushing]	-
		Removal of biological material	-
		Entrapment	-
		Strikes	-
		Introductions [AIS]	-
	Processing	See Vessel →Discharge	-

Table 32. Descriptions of all stressors considered for use in the risk assessment.

Stressor	Activity(ies) linked to stressor	Description and/or Examples
Disturbance [acoustic]	Research	This is the only stressor associated with acoustic mapping. Researchers use frequencies ranging from 12kHz for deep water to 70-100kHz for shallower water mapping, multi beam sonars operate at high source levels with highly directional beams. There is little data on impacts of acoustic disturbance on sponges and other species in this assessment (i.e., impact of multi beam surveys).
Disturbance [light]	Vessel Traffic	Light associated with Anchoring, Grounding, Movement underway
	Research	Light from research submersibles
Disturbance [noise]	Vessel Traffic	Shipping noise is pervasive throughout the marine environment especially at low (<300Hz) frequencies (Erbe et al. 2012; Merchant et al. 2012). Anthropogenic ocean noise is a chronic stressor for marine organisms and can have deleterious effects on a variety of marine organisms such as mammals, fish and cephalopods. In fish effects include disturbance and deterrence, fitness consequences, predator-prey interactions and communication and masking effects (reviewed in Slabbekoorn et al. 2010).
	Research	Noise from research activities (submersible, equipment installation and abandonment).
Disturbance [seismic]	Research	Impacts from sound generated by seismic surveying. Physiological and behavioural impacts on marine organisms have been observed, and sometimes death (Kearns and Boyd 1965; McCauley et al. 2000). Though most studies have examined impacts on marine mammals and fish, lower taxonomic groups can also be impacted (e.g., Hirst and Rodhouse 2000).
Disturbance [turbulence]	Vessel Traffic	Disturbance from the turbulence created by the propellers of moving vessels (‘propeller wash’) can impact community composition, shoreline structure and benthic environments.
Disturbance [water displacement]	Vessel Traffic	Disturbance resulting from the displacement of water due to the movement of vessels (wake) can have similar impacts as described above under Disturbance(turbulence)

Stressor	Activity(ies) linked to stressor	Description and/or Examples
Entrapment	Vessel Traffic	The entrapment or entanglement of organisms in discharged material/debris such as plastics, containers etc. Entanglement can include smothering such as from plastic bags.
	Fishing	The entrapment or entanglement of organisms in fishing gear actively fishing and lost (includes ghost fishing and bycatch).
Introduction of Aquatic Invasive Species (AIS)	Vessel Traffic	Impacts of AIS introduced through ballast water exchange or hull fouling.
	Research	Impacts of AIS introduced via transport on submersibles / ROV.
	Fishing	Impacts of AIS introduced via fishing gear carrying AIS.
Introduction of biological material	Vessel Traffic	Release of nutrient rich sewage from vessels and/or fish processing waste material from vessels (can increase nutrient levels). or other biological material in the area.
Oil/Contaminants	Vessel Traffic	Discharge of chronic amounts of oil from vessels.
	Oil spill	A catastrophic (non-chronic) spill of oil/contaminants from a vessel. The environmental impacts of an oil spill can be severe and cause extensive direct mortality in addition to sub-lethal effects that can persist for years after the spill.
	Research	Discharge of contaminants and small amounts of oil during equipment installation, abandonment and submersible use.
Prey imitation	Vessel Traffic	Plastic or other debris which could be mistaken for prey by marine organisms leading to ingestion (a range of types of plastic debris)
Removal of biological material	Research	Removal of biota due to research sampling
	Fishing	Removal of biota due to fishing activities
Strikes	Vessel Traffic	Strikes to mobile organisms (e.g., marine mammals) by vessels (including propellers) while underway
	Fishing	Strikes to mobile organisms by fishing gear
Substrate disturbance [crushing]	Vessel Traffic	Crushing from vessel discharge (e.g., falling rocks, shipping containers) and Grounding (sunken vessels)
	Research	Crushing of the substrate from equipment installation; abandonment; sampling and submersibles.

Stressor	Activity(ies) linked to stressor	Description and/or Examples
	Fishing	Crushing of substrate and sessile or slow moving benthic organisms from the operation of fishing gear
Substrate disturbance [foreign object]	Vessel Traffic	An obstacle affecting or altering habitat that results from discharged material, e.g., cargo, ship equipment.
	Research	An obstacle affecting or altering habitat that results from research equipment installation.
Substrate disturbance [re-suspension]	Vessel Traffic	Sediment re-suspension from propeller use in shallow waters and/or from effects of discharged materials.
	Research	Disturbance and suspension of sediment during equipment installation, abandonment, sampling and submersible operations that can smother benthic organisms.
	Fishing	Fishing activities cause disturbance and suspension of sediment which can smother benthic organisms.

APPENDIX G. SEC-STRESSOR INTERACTION MATRIX

Interactions were assessed as: “1” = a possible interaction; “0” = no interaction possible or no negative interaction likely; “NS” = not scored (for Community/Ecosystem Properties SECs).

The HS/QCS MPA SEC-Stressor interaction matrix can be found through the Government of Canada’s Open Data Portal.

APPENDIX H. RECOVERY FACTOR TABLES FOR SPECIES, HABITAT AND COMMUNITIES/ECOSYSTEM PROPERTIES SECS

H.1. Species SECs

Table 33. Factors for assessing risk to Species SECs posed by activities and stressors (O et al. 2015).

Recovery Factor Description	Risk Category		
	Low (1)	Moderate (2)	High (3)
Fecundity The population-wide average number of offspring produced by a female each year	>100,000	100-100,000	<100
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 at first sexual reproduction	<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 is likely to be inhibited.	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):

	Risk Category		
Recovery Factor Description	Low (1)	Moderate (2)	High (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

H.2. Habitat SECs

Table 34. Risk factors for assessing potential risks to Habitat SECs posed by activities and stressors (O et al. 2015).

Recovery Factor Description	Category		
	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
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 km2; low fragmentation	Extent of occurrence 5000-20000 km2; somewhat fragmented, known to exist at <50 locations	Extent of occurrence <5000 km2; 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)

H.3. Community/Ecosystem Properties SECs

Table 35. 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 I. GIS ANALYSES TO ESTIMATE SPATIAL AND TEMPORAL OVERLAP (COMPONENTS OF EXPOSURE)

I.1. VESSEL TRAFFIC

I.1.1. Cargo vessel traffic

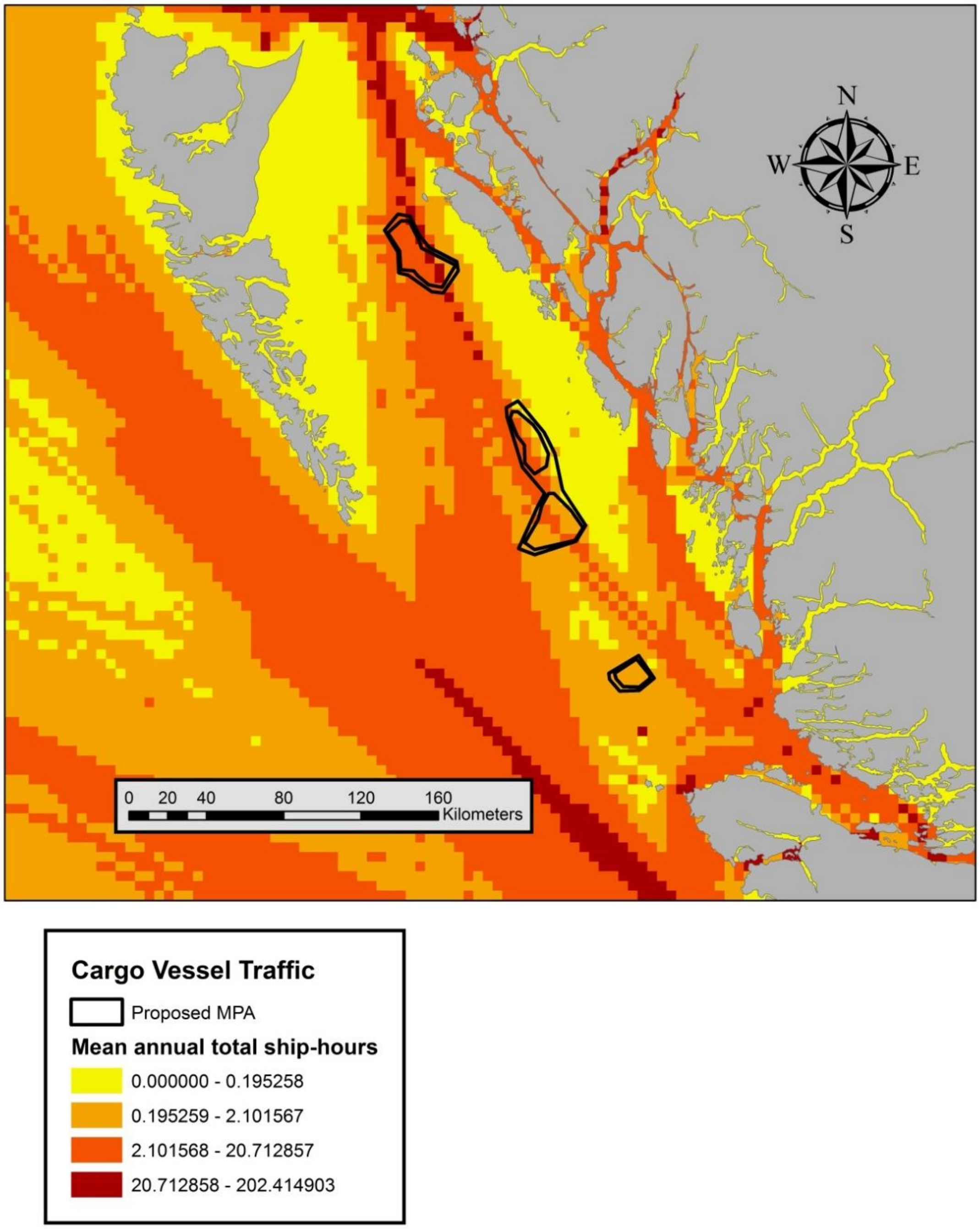


Figure 18. Cargo vessel traffic data shows mean annual ship hours per day gridded to 5x5km2, 2008-2010. Data was log normalised to counteract the effects of intense inshore vessel traffic. Data source: Hillard and Pelot 2012. Figure courtesy of P. O'Hara, Environment Canada.

I.1.2. Other vessel traffic

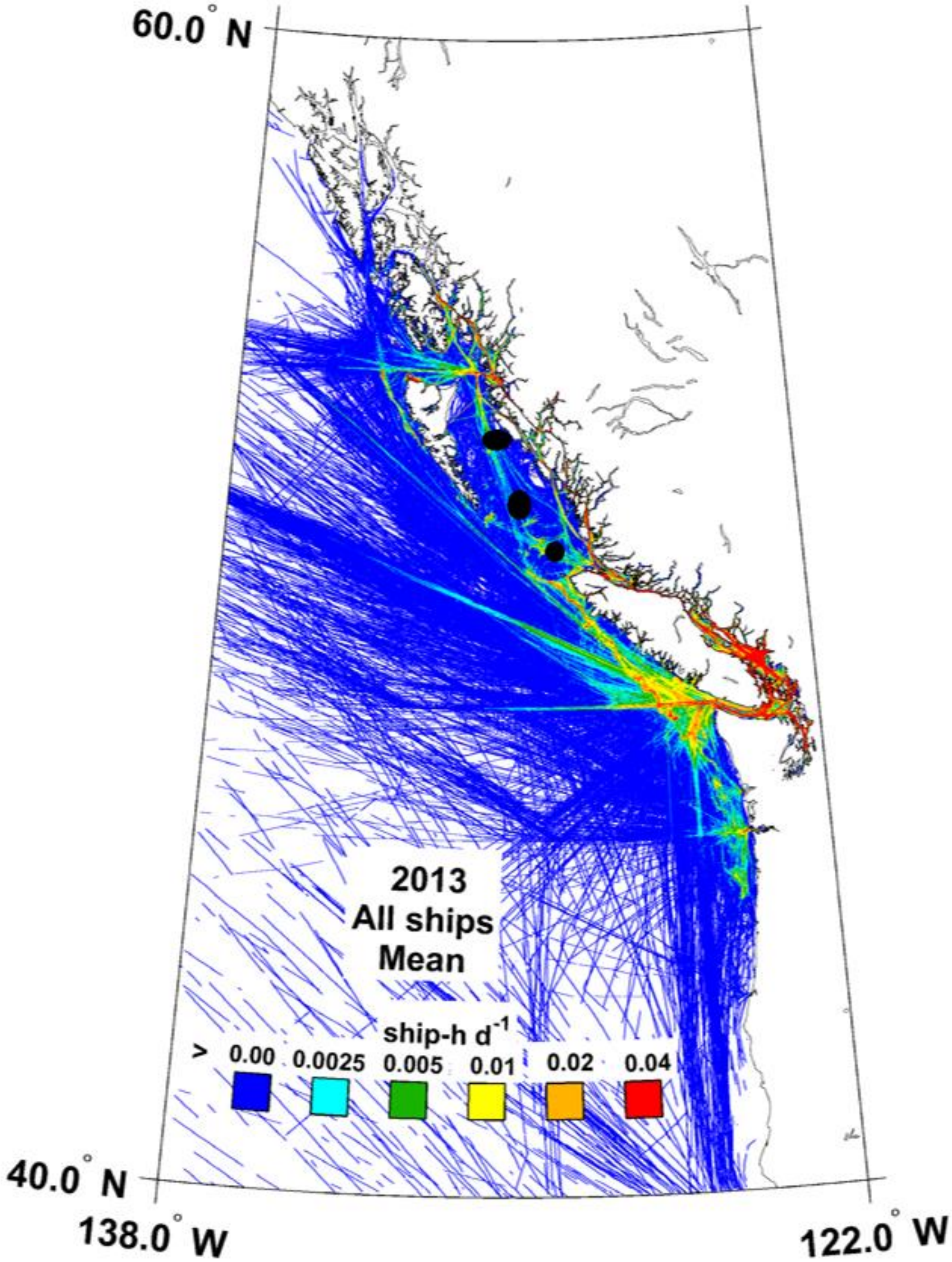


Figure 19. Map of mean density (all vessel traffic) in 2013 (based on Automatic Identification System (AIS) vessel reporting; unit of measurement is daily ship hours per day). Black shapes show approximate locations of the three HS/QCS MPA glass sponge reef complexes. Base figure is taken from Simard et al. (2014).

I.2. RESEARCH

I.2.1. Submersible surveys completed near the MPA footprint provided by L. Barton, DFO Science, DFO Shellfish Database.

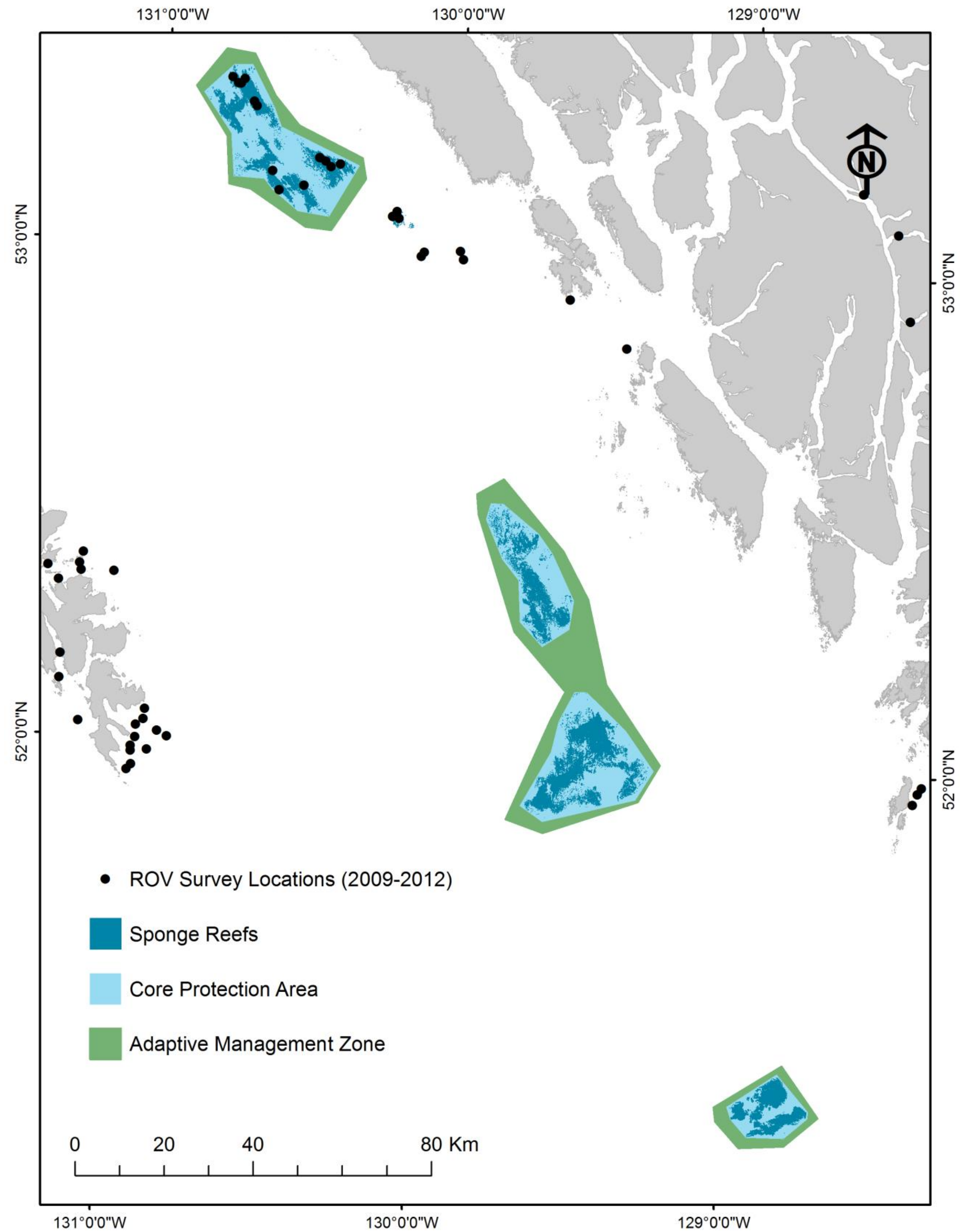


Figure 20. Submersible surveys completed near the MPA footprint provided by L. Barton, DFO Science, DFO Shellfish Database (J. Nephin, DFO Science, 2017).

I.2.2. Research surveys to the HS/QCS Glass Sponge Reefs MPA, 1986-2017.

Table 36. Descriptions of research cruises to the HS/QCS Glass Sponge Reefs MPA.

Year	ID	Vessel	Description
1986	PAR 86A		A geophysical survey found acoustic anomalies in Queen Charlotte Sound, later identified as sponge reefs.
1987 1988	END 87A END 88B	CFAV Endeavour	High resolution geophysical surveys of bioherms using 100 kHz sidescan sonar and deep-tow "boomer" seismic profiler; seabed photographs (Umel underwater camera); cores collected using a piston corer (inside diameter 66 mm) (Conway et al. 1991).
1994	VEC 94A	CCGS Vector	Geo-mapping survey on Dogfish Banks, Hecate Strait to evaluate sea level rise. Opportunistic sediment and sponge samples were collected. Dr. V. Barrie chief scientist.
1999	PGC 99001	CCGS John P. Tully	Video and still images from extensive diving operations on the manned two-person submersible Delta, additional images with drift cameras. Three types of bottom samplers used: Slurp guns (vacuums up the top 1mm surface sediment); Shipek samplers (a spring loaded “clam shell” sampler which obtains samples of surficial seafloor sediments in an area 20 cm x 20 cm to 10 cm deep); and IKU grab samplers (widespread spring-loaded jaws penetrating to 50 cm depth and collecting a large sediment volume [0.5m^3] with stratigraphy retained) (Conway et al. 2005b; Guilbault et al. 2006). Hundreds of sponge skeleton samples were collected with the IKU sampler (Krautter et al. 2001).
2000	DFO 2000-01	CCGS John P. Tully	Detailed oceanographic surveys in the vicinity of the Northern and Southern Reef complexes collecting oxygen, chlorophyll, and nutrients data (via rosette of Niskin bottles); transmissivity, conductivity, temperature and depth (CTD) data; and zooplankton (bongo net) samples (Conway et al. 2005b).
2001	PGC 01001	CCGS Vector	Detailed geophysical surveys around Porcher Island, Prince Rupert (including Tuck Inlet, Metlakatla Bay), Big Bay, Port Simpson, Skeena Delta, and northern Banks Island, as well as a geophysical survey of the extent of the recently discovered sponge reefs along the eastern side of northern Hecate Strait and southern Queen Charlotte Sound. Shipek sediment grabs of mud and sponge samples were collected.
2002	PGC 02004	CCGS John P. Tully	Extensive video and still imagery of the Hecate Strait reefs using a Phantom HD2+2 ROV. Grab samples using Van Veen and Shipek samplers in 30 on-reef and 20 off-reef locations 172 – 237 m deep (Conway et al. 2005b; Cook 2005).
2003	PGC 03003	CCGS Vector	Multi-beam swath bathymetric data in two of the four reef complexes.

Year	ID	Vessel	Description
2012	DFO	CCGS Vector	Glass sponge reef MPA cruise. ROV video and still imagery. Miriam O (chief scientist); with Dr. S. Leys (University of Alberta).
2015	DFO	CCGS John P. Tully	Cruise to the Northern Reef complex where acoustic Doppler current profilers were deployed over two sponges (*F. occa*) for 24-h continuous recording of flow, oxygen, and turbidity data. Water sampling and video mapping of the reef was completed using the ROPOS submersible. Dr. S. Leys (University of Alberta) chief scientist with J. Dunham (DFO Science).
2017	DFO	CCGS John P. Tully	Survey of the Northern Reef complex. Drs. A. Dunham (DFO Science) and S. Leys (University of Alberta) co-chief scientists. Deployed and retrieved hydrophones, conducted sediment experiments, video mapping and image transects completed via ROPOS submersible, deployed current profilers, collection of organisms for food web ecology study.

I.3. FISHING

I.3.1. Fishing events near the MPA footprint by gear type, 2006-2013.

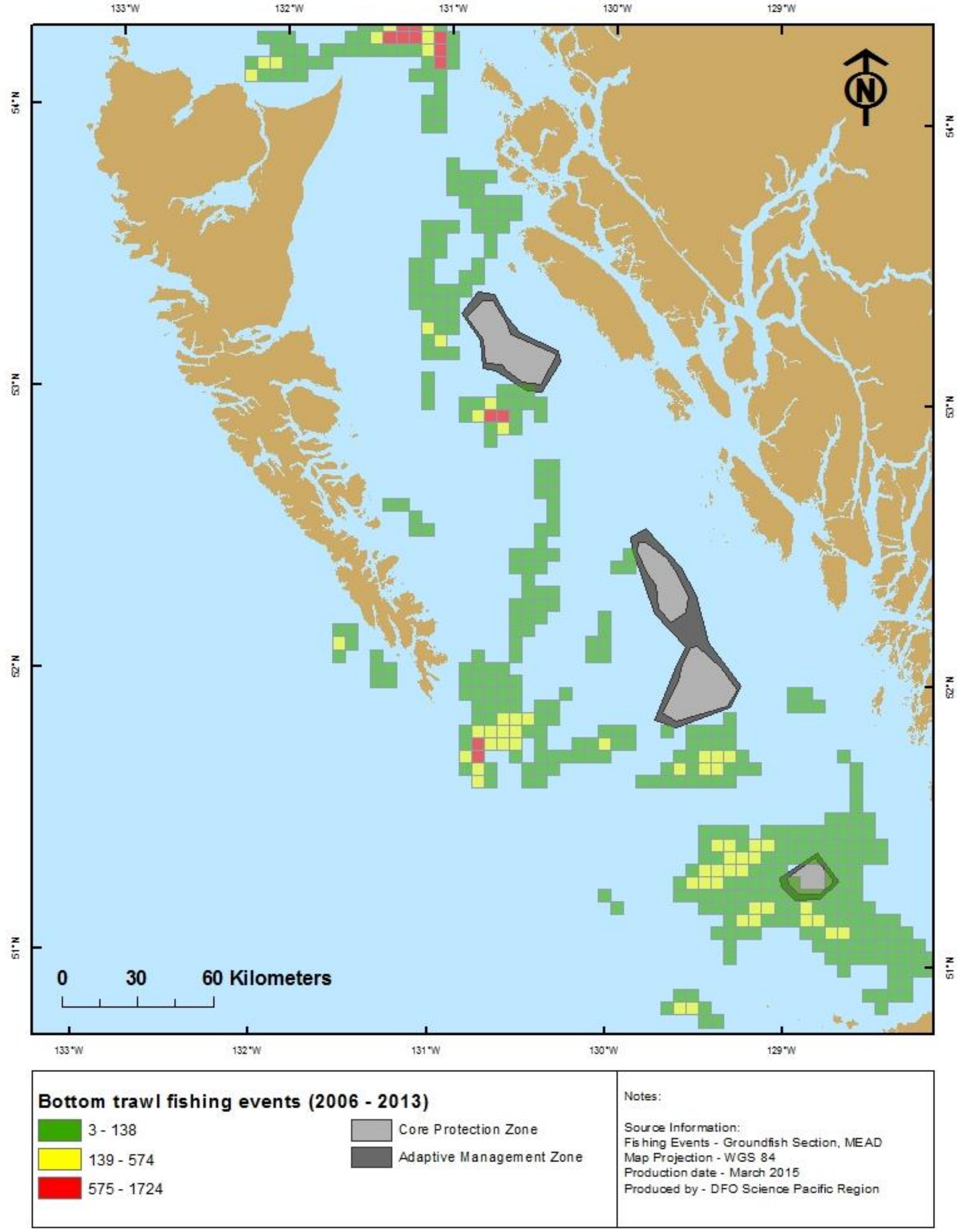


Figure 21. Bottom trawl fishing events (2006-2013) near the MPA footprint (S.Davies, DFO Science, 2015)

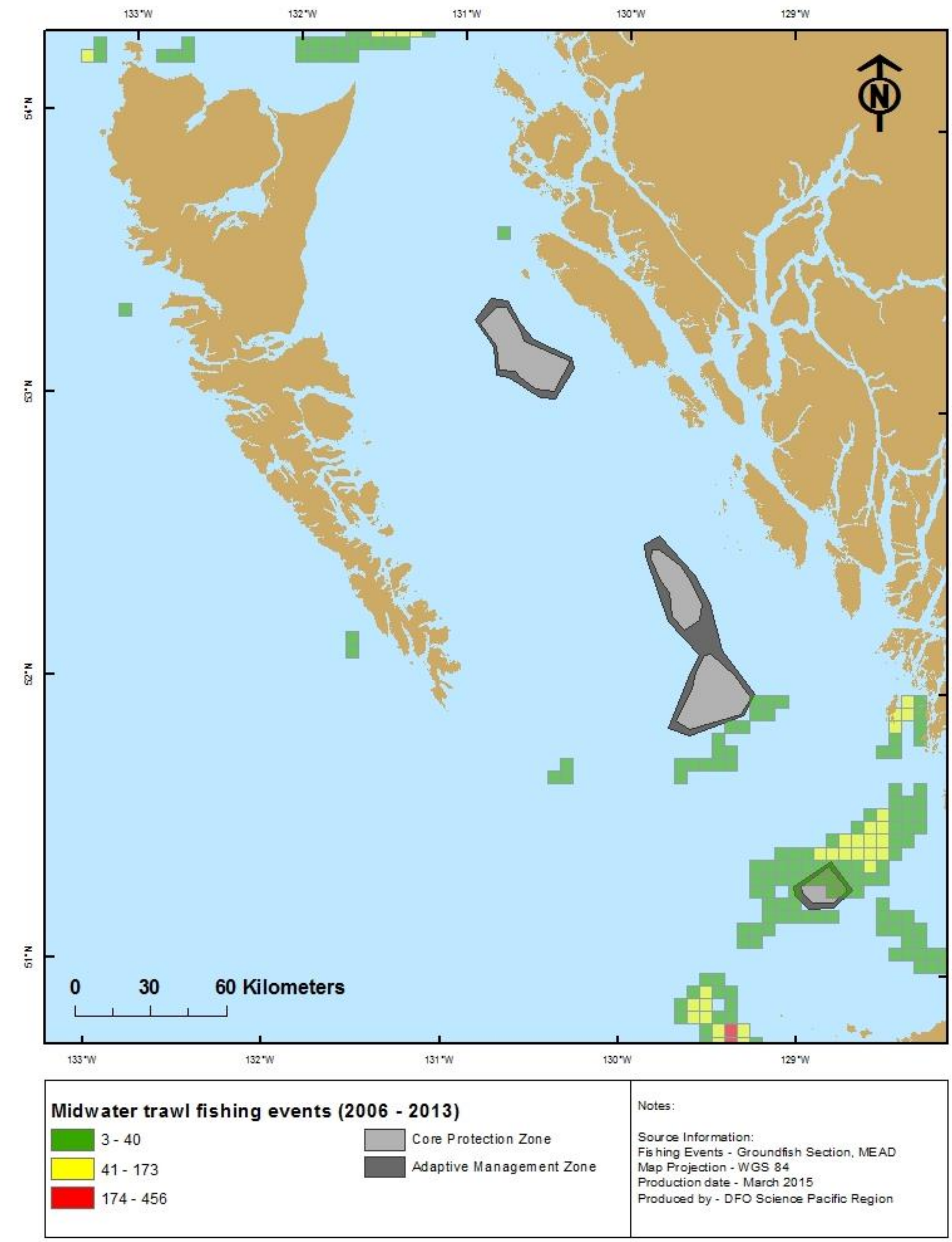


Figure 22. Mid water trawl fishing events near the MPA footprint, 2006-2013 (S. Davies, DFO Science, 2015).

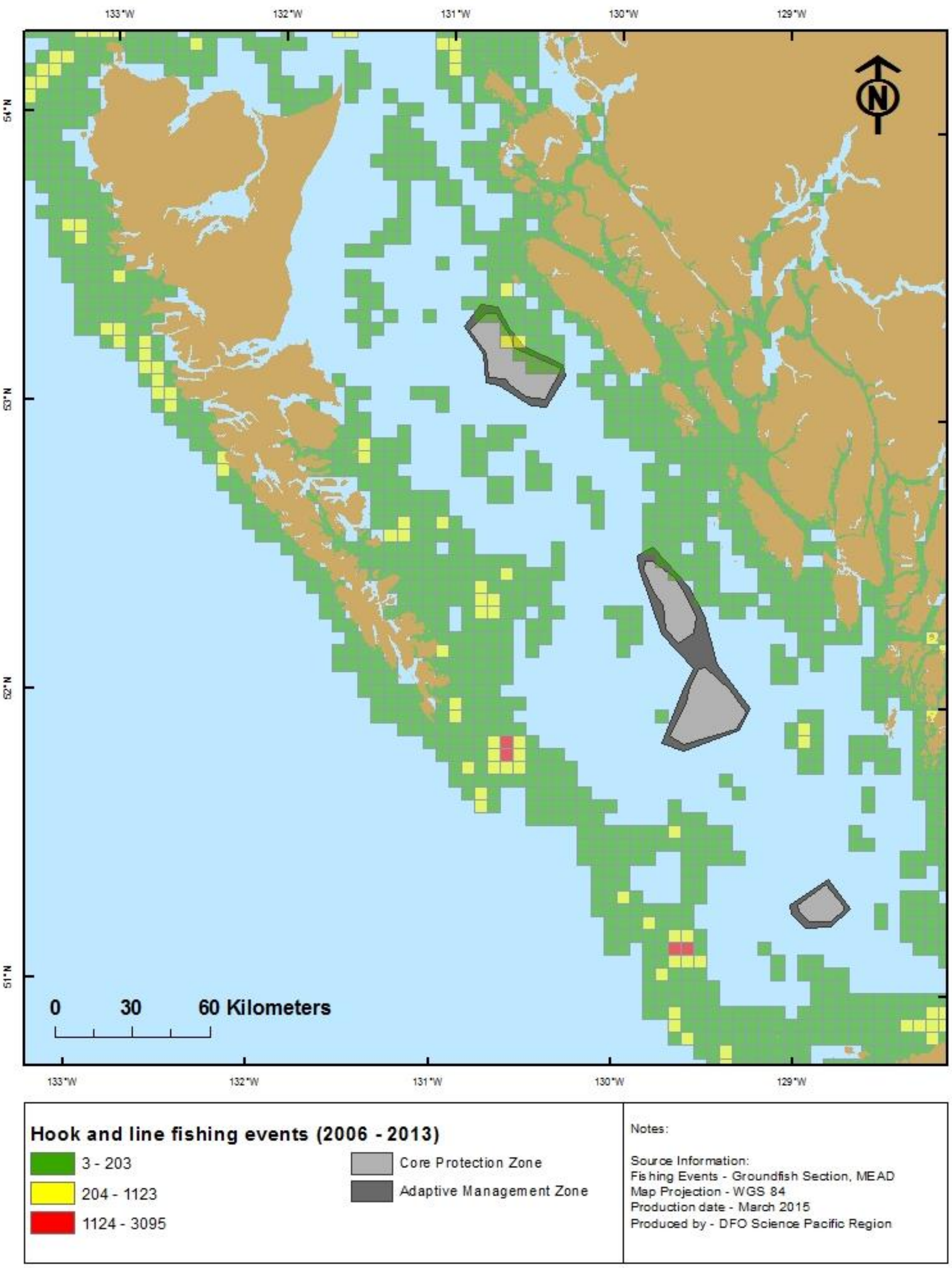


Figure 23. Hook and line fishing events near the MPA footprint, 2006-2013 (S. Davies, DFO Science, 2015).

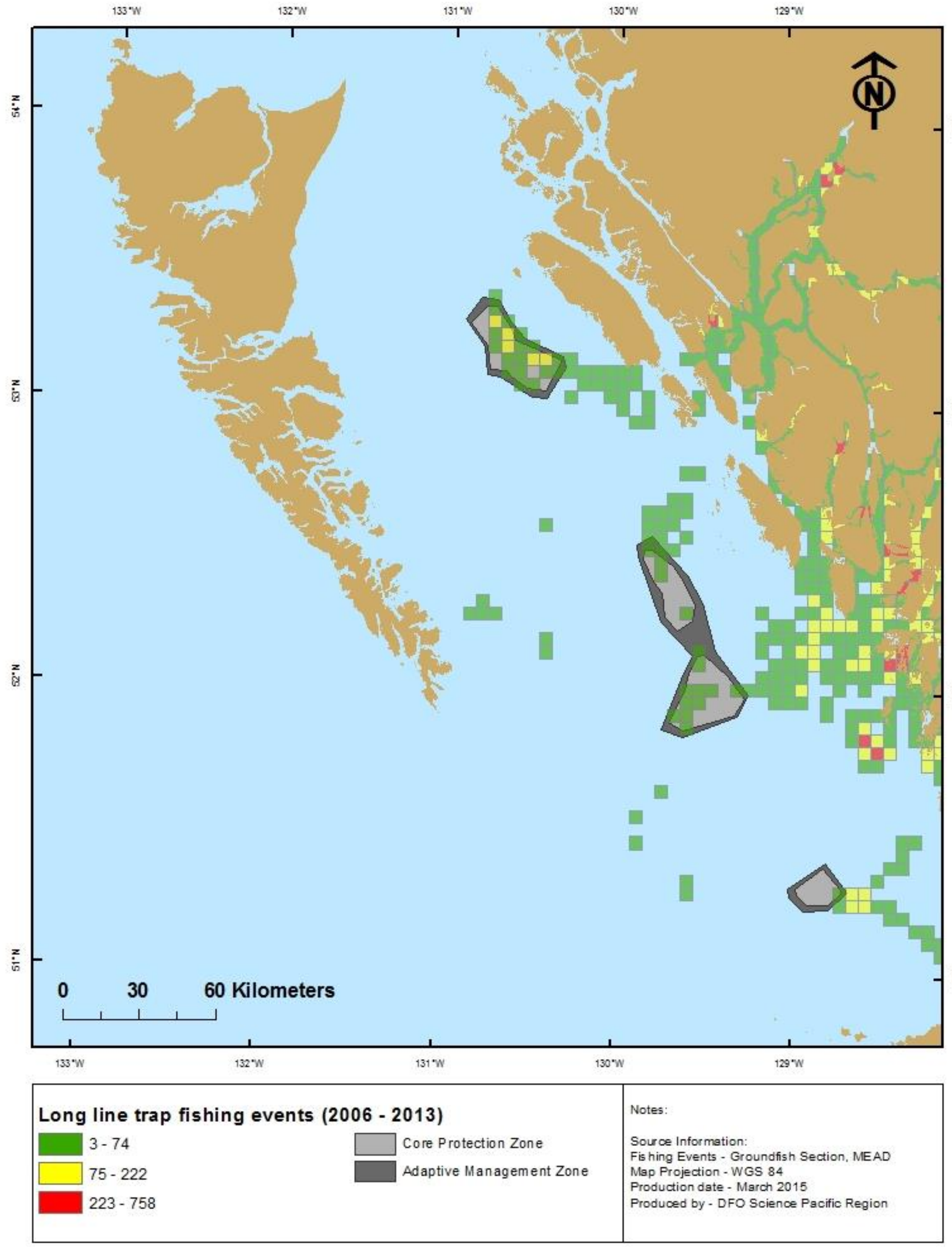


Figure 24. Long line trap fishing events near the MPA footprint, 2006-2013 (S.Davies, DFO Science, 2015).

I.3.2. Rockfish Catch

Table 37. Cumulative catch of all Rockfish species (Sebastes spp.) from mid water trawl fisheries within the MPA footprint, 2007-2013. Provided by L. Yamanaka, DFO Science, DFO Groundfish Database.

Species name	AMZ (total kg)	VAMZ (total kg)	AMZ Average (kg/year)	VAMZ Average (kg/year)
Bocaccio	98.18	136.30	14.0	19.5
Greenstriped Rockfish	4.45	0.00	0.6	0.0
Pacific Ocean Perch	11898.91	2371.53	1699.8	338.8
Redbanded Rockfish	60.50	3.63	8.6	0.5
Redstripe Rockfish	181.44	3017.76	25.9	431.1
Silvergray Rockfish	355.08	678.22	50.7	96.9
Widow Rockfish	521.63	25.39	74.5	3.6
Yelloweye Rockfish	0.00	5.44	0.0	0.8
Yellowmouth Rockfish	6734.43	11275.51	962.1	1610.8
Yellowtail Rockfish	2034.84	1059.56	290.7	151.4
Total (kg) or (kg/year)	21889.46	18573.34	3127.07	2653.33

I.3.3. Overlap calculations

Temporal overlap calculation method for Groundfish fisheries occurring in the footprint of the HS/QCS Glass Sponge Reefs MPA, 2006 to 2013. Source: AOI area estimates from Norm Olsen, March 27, 2014. Strait of Georgia sponge reef area estimates Mike Kattilakoski, March 28, 2014. Groundfish fishing data from Norm Olsen via Danielle Perron March 28, 2014. (Provided by L. Yamanaka, DFO Science)

The overlap of groundfish fishing gear on the sponge reefs is estimated by:

1. Estimating the average swept area (SA) of the seafloor by the gear during a deployment or event.
2. Multiplying the SA by the average number of fishing events.
3. Assumes:
    a. Gear maintains a straight line between start and end of gear deployment (resulting estimates maybe biased low if the gear meanders).
    b. No overlap of individual gear deployments (resulting estimated maybe biased high if there is overlap).

Table 38. Hecate Strait AOI: total number of fishing events (2007-2013) and annual average by MPA zone (CPZ, AMZ, VAMZ), gear type and estimate of maximum fishing days in a year as a percentage, based on observer data.

	Bottom Trawl		**Mid water Trawl**		**Longline**	
MPA Zone	**Fishing Days**	**%year**	**Fishing Days**	**%year**	**Fishing Days**	**%year***
AMZ	96	26.3	38	10.4	749	205.5
CPZ	0	0	0	0	80	21.9
VAMZ	0	0	54	14.8	0	0
All zones	96	26.3	92	25.2	829	227.1

*more likely averages 4 sets per fishing day for 51.3% in AMZ, 5.5% in CPZ.

Annual Mean MPA Zone	**Bottom Trawl**		**Mid water Trawl**		**Longline**	
	Fishing Days	**%year**	**Fishing Days**	**%year**	**Fishing Days**	**%year***
AMZ	13.7	3.8	5.4	1.5	107	29.3
CPZ	0	0	0	0	11.4	3.1
VAMZ	0	0	7.7	2.1	0	0
All Zones	13.7	3.8	15.3	4.2	118.4	32.4

%year = maximum number of fishing days/365 days x 100 (assumes 1 fishing event per day, as a worst case scenario).

APPENDIX J. R SCRIPT TO CALCULATE RISK AND INCORPORATE UNCERTAINTY

Results of the HS/QCS MPA risk assessment scoring and risk calculations (input file and R script) can be found through the Government of Canada's Open Data Portal.

Example of the .csv input file format for use with the associated R script.

Table 39. Header for the .csv data input file to be used with the R script to complete the risk assessment. Each row corresponds to a single SEC-stressor interaction. The number of lines in the input file should equal the number of interactions scored "1" in the SEC-stressor interaction matrix.

SEC	Activity	Sub-Activity	Stressor	Area	U_area	Depth	U_depth	Temporal	U_temp	Intensity	U_int	Intensity2	U_int2	AcuteChange	U_ac	ChronicChange	U_cc	MaxAge	U_ma	MaxSize	U_ms	vonBert	U_vb	AgeMat	U_am	LifeStage	U_ls	PopConn	U_pc	NatMort	U_nm	Listed	U_list	Fecundity	U_fec

APPENDIX K. RESULTS FOR ALL SEC-STRESSOR INTERACTIONS

These results include all stressors (both potential and "current snap-shot") and use a truncated normal distribution to model uncertainty in the scores. Table 17 is a subset of the results reported here.

H.calyx

		Relative Risk			Exposure			Consequence		
Activity	Sub-Activity – Stressor	Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill – Oil	81.78	53.38	117.72	8.82	6.69	11.04	9.53	6.70	12.42
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	32.65	15.45	54.76	9.03	7.95	10.07	3.78	1.72	6.00
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.94	13.79	49.15	5.36	4.15	6.52	5.68	2.70	8.87
Vessel Traffic	Discharge - Oil/Contaminants	27.44	12.88	47.11	7.68	6.29	9.07	3.79	1.74	6.01
Fishing	Mid water trawl - Removal of biological material	27.23	12.68	46.76	5.11	3.82	6.39	5.62	2.66	8.77
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	26.37	12.65	45.01	4.90	3.70	6.07	5.68	2.74	8.80
Vessel Traffic	Grounding - Introductions [AIS]	26.29	11.09	47.93	7.07	5.17	9.11	4.01	1.67	6.55
Fishing	Bottom trawling - Introductions [AIS]	24.22	12.76	40.49	4.48	3.16	5.97	5.73	3.17	8.27
Vessel Traffic	Discharge – Entrapment	22.55	9.35	41.97	6.15	4.43	8.00	3.99	1.66	6.55
Vessel Traffic	Discharge - Introductions [AIS]	20.73	8.32	39.59	5.71	3.90	7.74	3.98	1.60	6.55
Fishing	Long line traps - Substrate disturbance [re-suspension]	20.07	8.70	35.25	4.82	4.06	5.62	4.40	1.87	7.19
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.57	7.52	31.28	4.25	3.42	5.21	4.40	1.86	7.18
Research	Seismic activities - Disturbance [seismic]	16.85	6.30	33.20	6.77	5.32	8.27	2.74	0.97	4.82
Fishing	Long line traps - Introductions [AIS]	16.44	6.77	30.88	4.49	3.18	6.02	4.01	1.66	6.56
Research	Submersible operations - Substrate disturbance [re-suspension]	16.38	6.77	30.41	4.47	3.32	5.80	3.97	1.62	6.55
Research	Submersible operations - Introductions [AIS]	15.28	6.47	28.90	4.19	3.00	5.53	4.01	1.68	6.57
Research	Submersible operations - Oil/Contaminants	14.67	5.27	30.12	5.31	3.66	7.20	3.12	1.11	5.47
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	13.13	4.90	26.95	5.39	3.90	7.04	2.75	0.98	4.82
Vessel Traffic	Discharge - Substrate disturbance [crushing]	12.89	4.77	26.22	4.65	3.42	5.95	3.11	1.11	5.47
Research	Submersible operations - Substrate disturbance [crushing]	12.83	4.86	25.60	4.53	3.41	5.81	3.15	1.12	5.44
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	10.99	4.01	22.88	5.30	4.06	6.66	2.34	0.81	4.19
Fishing	Mid water trawl - Entrapment	9.13	3.40	17.79	3.19	2.59	3.87	3.13	1.11	5.48

A. vastus

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	107.44	76.09	145.26	8.81	6.66	11.03	12.40	9.80	14.86
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.86	13.84	48.89	5.38	4.16	6.51	5.64	2.70	8.77
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	28.28	15.48	43.68	9.02	7.96	10.05	3.23	1.75	4.80
Vessel Traffic	Discharge - Oil/Contaminants	27.40	12.81	46.66	7.67	6.29	9.06	3.76	1.73	5.96
Fishing	Mid water trawl - Removal of biological material	27.11	12.90	47.27	5.11	3.83	6.39	5.64	2.73	8.78
Vessel Traffic	Grounding - Introductions [AIS]	25.73	10.67	48.34	7.08	5.18	9.13	3.96	1.62	6.58
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.08	12.33	42.31	4.89	3.70	6.05	5.40	2.67	8.36
Fishing	Bottom trawling - Introductions [AIS]	24.28	12.64	40.41	4.47	3.16	5.97	5.73	3.20	8.24
Vessel Traffic	Discharge - Entrapment	22.76	9.26	42.16	6.17	4.44	8.02	4.01	1.65	6.55
Vessel Traffic	Discharge - Introductions [AIS]	21.01	8.44	40.17	5.72	3.91	7.77	4.02	1.65	6.63
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.80	8.46	35.37	4.81	4.04	5.60	4.38	1.79	7.21
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.60	7.61	31.58	4.26	3.41	5.21	4.42	1.87	7.22
Research	Seismic activities - Disturbance [seismic]	16.74	6.13	33.17	6.78	5.31	8.25	2.73	0.94	4.81
Research	Submersible operations - Substrate disturbance [re-suspension]	16.44	6.87	30.70	4.47	3.29	5.81	3.99	1.64	6.60
Fishing	Long line traps - Introductions [AIS]	16.31	6.61	30.65	4.48	3.15	6.01	3.96	1.61	6.53
Research	Submersible operations - Introductions [AIS]	15.32	6.26	28.50	4.17	3.03	5.47	3.98	1.66	6.52
Research	Submersible operations - Oil/Contaminants	14.71	5.36	30.64	5.31	3.65	7.23	3.14	1.12	5.49
Vessel Traffic	Discharge - Substrate disturbance [crushing]	13.14	4.85	26.48	4.66	3.40	6.00	3.15	1.10	5.47
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	12.83	4.70	26.76	5.37	3.89	6.97	2.73	0.94	4.80
Research	Submersible operations - Substrate disturbance [crushing]	12.79	4.70	25.25	4.53	3.42	5.84	3.12	1.11	5.41
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	10.94	3.93	22.88	5.31	4.06	6.66	2.33	0.78	4.20
Fishing	Mid water trawl - Entrapment	9.04	3.39	17.74	3.19	2.60	3.86	3.12	1.10	5.46

F. occa

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	101.35	73.39	135.97	8.81	6.73	11.07	11.72	9.61	13.77
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.36	14.69	51.67	9.02	7.99	10.04	3.58	1.63	5.67
Fishing	Mid water trawl - Substrate disturbance [crushing]	27.64	13.09	46.54	5.39	4.18	6.51	5.37	2.55	8.28

Activity	Sub-Activity – Stressor	Relative Risk Median	Relative Risk 10%	Relative Risk 90%	Exposure Mean	Exposure 10%	Exposure 90%	Consequence Mean	Consequence MC.10	Consequence MC.90
Vessel Traffic	Discharge - Oil/Contaminants	26.11	12.04	44.37	7.67	6.28	9.05	3.57	1.62	5.66
Fishing	Mid water trawl - Removal of biological material	25.62	12.29	43.97	5.11	3.86	6.36	5.33	2.58	8.28
Vessel Traffic	Grounding - Introductions [AIS]	24.96	10.30	45.64	7.12	5.21	9.18	3.79	1.57	6.19
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.78	11.96	42.28	4.90	3.71	6.08	5.35	2.61	8.26
Fishing	Bottom trawling - Introductions [AIS]	23.00	12.26	38.13	4.51	3.18	6.05	5.39	3.10	7.69
Vessel Traffic	Discharge - Entrapment	21.35	9.07	39.52	6.13	4.41	7.96	3.77	1.60	6.14
Vessel Traffic	Discharge - Introductions [AIS]	19.54	8.10	37.60	5.72	3.86	7.80	3.78	1.57	6.17
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.10	8.21	33.00	4.83	4.06	5.60	4.17	1.77	6.75
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.61	7.15	29.25	4.25	3.41	5.20	4.15	1.77	6.75
Research	Seismic activities - Disturbance [seismic]	15.89	5.98	31.10	6.77	5.29	8.23	2.59	0.92	4.50
Fishing	Long line traps - Introductions [AIS]	15.65	6.54	29.61	4.50	3.19	6.02	3.80	1.60	6.18
Research	Submersible operations - Substrate disturbance [re-suspension]	15.47	6.48	28.84	4.48	3.31	5.84	3.76	1.55	6.21
Research	Submersible operations - Introductions [AIS]	14.54	6.06	27.09	4.19	3.03	5.54	3.78	1.55	6.19
Research	Submersible operations - Oil/Contaminants	13.66	5.11	28.40	5.33	3.67	7.19	2.93	1.04	5.10
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	12.62	4.63	25.41	5.39	3.91	7.02	2.61	0.92	4.57
Vessel Traffic	Discharge - Substrate disturbance [crushing]	12.43	4.56	24.41	4.64	3.40	5.94	2.96	1.07	5.12
Research	Submersible operations - Substrate disturbance [crushing]	12.01	4.63	24.29	4.54	3.43	5.81	2.96	1.08	5.16
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	10.44	3.87	21.45	5.29	4.04	6.64	2.23	0.77	3.98
Fishing	Mid water trawl - Entrapment	8.58	3.24	16.90	3.19	2.59	3.85	2.97	1.05	5.21

R. dawsoni

Activity	Sub-Activity – Stressor	Relative Risk Median	Relative Risk 10%	Relative Risk 90%	Exposure Mean	Exposure 10%	Exposure 90%	Consequence Mean	Consequence MC.10	Consequence MC.90
Vessel Traffic	Oil spill - Oil	104.52	73.20	141.97	8.84	6.74	11.06	12.03	9.37	14.58
Fishing	Mid water trawl - Substrate disturbance [crushing]	27.73	13.01	48.01	5.38	4.17	6.53	5.47	2.58	8.65
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	27.67	15.14	43.01	9.01	7.94	10.06	3.16	1.69	4.72
Vessel Traffic	Discharge - Oil/Contaminants	26.62	12.32	45.70	7.67	6.29	9.06	3.67	1.65	5.87
Fishing	Mid water trawl - Removal of biological material	26.20	12.22	45.54	5.10	3.83	6.36	5.46	2.53	8.56
Vessel Traffic	Grounding - Introductions [AIS]	25.52	10.61	47.42	7.12	5.22	9.17	3.88	1.59	6.39
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.53	12.06	41.39	4.89	3.69	6.07	5.28	2.64	8.14

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Fishing	Bottom trawling - Introductions [AIS]	23.58	12.20	39.40	4.49	3.15	6.03	5.55	3.03	8.05
Vessel Traffic	Discharge - Entrapment	21.79	8.88	41.66	6.13	4.42	7.97	3.88	1.58	6.46
Vessel Traffic	Discharge - Introductions [AIS]	20.09	7.90	39.22	5.72	3.89	7.75	3.86	1.54	6.41
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.25	8.37	34.13	4.81	4.04	5.58	4.28	1.80	6.98
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.93	7.14	30.35	4.26	3.41	5.23	4.25	1.76	6.97
Research	Seismic activities - Disturbance [seismic]	16.25	6.03	32.55	6.78	5.31	8.27	2.66	0.91	4.69
Research	Submersible operations - Substrate disturbance [re-suspension]	16.07	6.69	30.04	4.49	3.33	5.82	3.88	1.59	6.40
Fishing	Long line traps - Introductions [AIS]	15.65	6.46	29.90	4.49	3.18	6.02	3.85	1.54	6.41
Research	Submersible operations - Introductions [AIS]	14.83	6.02	28.11	4.18	3.03	5.50	3.86	1.56	6.36
Research	Submersible operations - Oil/Contaminants	14.00	5.07	29.32	5.29	3.67	7.13	3.03	1.06	5.31
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	12.60	4.76	26.01	5.38	3.91	7.00	2.65	0.93	4.64
Vessel Traffic	Discharge - Substrate disturbance [crushing]	12.37	4.66	25.37	4.65	3.43	5.95	3.00	1.09	5.29
Research	Submersible operations - Substrate disturbance [crushing]	12.18	4.56	24.79	4.54	3.43	5.83	3.02	1.06	5.29
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	10.58	3.81	22.47	5.30	4.05	6.66	2.28	0.76	4.11
Fishing	Mid water trawl - Entrapment	8.69	3.35	17.13	3.19	2.58	3.87	3.02	1.08	5.32

Squat Lobster

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	65.40	39.45	98.81	8.83	6.69	11.02	7.66	4.90	10.49
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.55	14.23	55.46	9.02	7.94	10.08	3.71	1.60	6.08
Vessel Traffic	Discharge - Oil/Contaminants	26.75	11.50	47.83	7.65	6.26	9.05	3.70	1.54	6.04
Vessel Traffic	Grounding - Introductions [AIS]	22.85	9.26	43.86	7.11	5.21	9.16	3.53	1.39	5.92
Fishing	Mid water trawl - Substrate disturbance [crushing]	18.63	7.89	33.30	5.38	4.14	6.51	3.69	1.54	6.04
Fishing	Mid water trawl - Removal of biological material	16.60	7.24	30.53	4.90	3.69	6.06	3.68	1.56	6.08
Fishing	Long line traps - Substrate disturbance [re-suspension]	15.25	6.48	27.22	4.82	4.05	5.61	3.37	1.38	5.57
Fishing	Long line hooks - Substrate disturbance [re-suspension]	14.74	6.37	26.39	4.24	3.41	5.20	3.72	1.59	6.08
Research	Seismic activities - Disturbance [seismic]	14.03	5.20	28.30	6.76	5.31	8.25	2.31	0.81	4.05
Fishing	Long line traps - Introductions [AIS]	13.86	5.55	26.76	4.51	3.18	6.06	3.39	1.35	5.62
Research	Submersible operations - Oil/Contaminants	12.28	4.56	25.88	5.33	3.69	7.26	2.64	0.94	4.66

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	11.55	4.23	23.18	4.90	3.70	6.08	2.64	0.92	4.61
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	10.84	3.97	22.44	5.38	3.89	7.00	2.29	0.80	4.07
Vessel Traffic	Discharge - Substrate disturbance [crushing]	10.77	4.07	22.13	4.66	3.42	5.98	2.61	0.94	4.55
Research	Submersible operations - Substrate disturbance [re-suspension]	10.60	3.94	21.41	4.49	3.30	5.83	2.65	0.93	4.64
Research	Submersible operations - Disturbance [light]	9.27	3.42	18.91	4.48	3.34	5.69	2.33	0.81	4.11
Research	Submersible operations - Substrate disturbance [crushing]	8.77	3.27	17.87	3.73	2.68	4.93	2.66	0.94	4.64
Research	Submersible operations - Introductions [AIS]	8.50	3.17	17.84	4.17	3.03	5.49	2.33	0.80	4.09
Fishing	Mid water trawl - Entrapment	7.63	2.85	15.06	3.19	2.58	3.86	2.64	0.93	4.62

Bocaccio Rockfish

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	97.77	71.61	129.78	8.83	6.69	11.10	11.25	9.49	12.89
Fishing	Mid water trawl - Removal of biological material	51.49	39.42	64.78	5.21	4.52	5.93	9.96	7.90	11.93
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.15	15.22	58.83	9.03	7.97	10.08	3.97	1.70	6.44
Vessel Traffic	Movement underway - Disturbance [noise]	30.39	12.31	54.36	8.51	6.89	10.40	3.78	1.49	6.24
Fishing	Mid water trawl - Strikes	28.19	13.87	45.13	5.66	4.96	6.39	5.14	2.50	7.89
Vessel Traffic	Grounding - Introductions [AIS]	25.39	10.00	46.90	7.10	5.19	9.15	3.84	1.51	6.32
Vessel Traffic	Discharge - Oil/Contaminants	25.32	11.86	42.56	7.68	6.28	9.09	3.45	1.60	5.45
Fishing	Long line traps - Substrate disturbance [re-suspension]	18.24	8.17	31.21	4.82	4.04	5.60	3.97	1.75	6.36
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.06	7.10	28.40	4.26	3.41	5.23	4.01	1.75	6.45
Research	Seismic activities - Disturbance [seismic]	15.39	5.93	29.69	6.76	5.30	8.21	2.49	0.91	4.33
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	12.20	4.58	23.79	4.71	3.57	5.79	2.86	1.02	4.94
Fishing	Mid water trawl - Entrapment	10.41	4.00	20.02	3.20	2.59	3.87	3.56	1.31	6.17

Glass Sponge Skeleton

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	81.78	53.40	117.99	8.86	6.71	11.10	9.49	6.71	12.34
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	37.17	16.28	64.82	9.02	7.97	10.06	4.35	1.82	7.11
Vessel Traffic	Discharge - Oil/Contaminants	31.30	13.45	55.53	7.67	6.28	9.06	4.35	1.82	7.13

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.57	13.47	49.05	5.37	4.14	6.51	5.61	2.64	8.77
Fishing	Mid water trawl - Removal of biological material	26.58	12.43	45.92	5.02	3.67	6.35	5.61	2.70	8.73
Vessel Traffic	Grounding - Introductions [AIS]	26.16	10.67	48.75	7.07	5.14	9.12	3.99	1.62	6.59
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.98	11.95	43.14	4.71	3.58	5.80	5.64	2.67	8.82
Fishing	Bottom trawling - Introductions [AIS]	24.28	12.77	40.47	4.50	3.15	6.06	5.70	3.21	8.22
Vessel Traffic	Discharge - Entrapment	22.51	9.28	42.42	6.14	4.45	7.98	3.99	1.65	6.55
Vessel Traffic	Discharge - Introductions [AIS]	20.83	8.44	39.98	5.73	3.89	7.74	3.99	1.63	6.57
Fishing	Long line traps - Substrate disturbance [re-suspension]	20.14	8.73	35.08	4.82	4.07	5.59	4.40	1.87	7.17
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.52	7.60	31.60	4.26	3.43	5.22	4.40	1.87	7.17
Fishing	Long line traps - Introductions [AIS]	16.41	6.69	31.12	4.50	3.18	6.03	4.00	1.64	6.59
Research	Submersible operations - Introductions [AIS]	15.30	6.37	29.12	4.18	3.04	5.52	4.01	1.62	6.64
Research	Submersible operations - Oil/Contaminants	14.43	5.31	30.20	5.32	3.64	7.22	3.11	1.10	5.47
Research	Submersible operations - Substrate disturbance [crushing]	12.55	4.72	25.69	4.54	3.41	5.84	3.12	1.10	5.43
Fishing	Mid water trawl - Entrapment	9.07	3.41	17.86	3.19	2.59	3.86	3.14	1.11	5.48

Sponge Garden

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Vessel Traffic	Oil spill - Oil	100.22	69.62	137.20	8.83	6.69	11.05	11.55	9.01	13.96
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.38	15.10	59.00	9.02	7.97	10.05	3.99	1.70	6.48
Vessel Traffic	Discharge - Oil/Contaminants	31.67	13.71	55.17	7.65	6.28	9.04	4.36	1.86	7.09
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.86	13.61	48.58	5.38	4.17	6.52	5.62	2.64	8.74
Fishing	Mid water trawl - Removal of biological material	26.67	12.47	46.01	5.01	3.65	6.33	5.64	2.74	8.74
Vessel Traffic	Grounding - Introductions [AIS]	26.54	11.06	47.84	7.08	5.18	9.14	4.03	1.71	6.53
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.36	12.26	42.95	4.71	3.60	5.77	5.66	2.74	8.77
Fishing	Bottom trawling - Introductions [AIS]	24.40	13.11	40.13	4.49	3.16	6.03	5.72	3.27	8.14
Vessel Traffic	Discharge - Entrapment	22.47	9.42	41.83	6.13	4.44	7.98	3.97	1.67	6.48
Vessel Traffic	Discharge - Introductions [AIS]	20.80	8.63	39.80	5.71	3.90	7.77	4.00	1.67	6.53
Fishing	Long line traps - Substrate disturbance [re-suspension]	20.33	8.75	34.97	4.82	4.05	5.61	4.42	1.87	7.15
Vessel Traffic	Grounding - Substrate disturbance [foreign object]	18.03	6.58	36.00	6.36	4.65	8.17	3.14	1.12	5.44

Activity	Sub-Activity – Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	MC.10	MC.90
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.60	7.38	30.85	4.25	3.42	5.19	4.37	1.82	7.11
Research	Seismic activities - Disturbance [seismic]	16.83	6.31	33.14	6.77	5.34	8.26	2.75	0.96	4.78
Research	Submersible operations - Substrate disturbance [re-suspension]	16.58	6.87	30.13	4.48	3.32	5.80	3.97	1.65	6.45
Fishing	Long line traps - Introductions [AIS]	16.53	6.80	30.62	4.50	3.17	6.06	3.98	1.67	6.51
Research	Submersible operations - Introductions [AIS]	15.35	6.42	28.51	4.19	3.04	5.53	3.98	1.66	6.44
Vessel Traffic	Discharge - Substrate disturbance [foreign object]	15.05	5.63	29.70	5.29	4.04	6.62	3.14	1.13	5.46
Research	Submersible operations - Oil/Contaminants	14.62	5.43	29.84	5.31	3.63	7.17	3.12	1.13	5.38
Vessel Traffic	Discharge - Substrate disturbance [crushing]	13.06	4.93	26.17	4.64	3.42	5.95	3.14	1.13	5.42
Research	Submersible operations - Substrate disturbance [crushing]	12.80	4.83	25.45	4.55	3.41	5.86	3.13	1.13	5.38
Fishing	Mid water trawl - Entrapment	11.31	4.26	21.72	3.19	2.60	3.85	3.87	1.40	6.70

APPENDIX L. RESULTS USING ALTERNATIVE ANALYTIC ASSUMPTIONS

L.1. Subset of Results for "Current Snap-Shot" SEC-Stressor Interactions Only

Table 40. Top six SEC-stressor interactions for "current snap-shot" stressors only.

H. calyx

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	32.5	15.1	54.0	9.0	8.0	10.1	3.7	1.7	6.0
Vessel Traffic	Discharge - Oil/Contaminants	27.5	12.9	47.7	7.7	6.3	9.0	3.8	1.7	6.0
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	26.2	12.4	44.9	4.9	3.7	6.1	5.7	2.7	8.8
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.7	8.7	35.1	4.8	4.0	5.6	4.4	1.9	7.1
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.5	7.6	30.9	4.2	3.4	5.2	4.4	1.9	7.1
Research	Submersible operations - Substrate disturbance [re-suspension]	16.5	6.8	30.6	4.5	3.3	5.8	4.0	1.6	6.5

A. vastus

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	28.7	15.6	43.7	9.0	7.9	10.1	3.3	1.8	4.8
Vessel Traffic	Discharge - Oil/Contaminants	27.6	12.8	47.0	7.7	6.3	9.0	3.8	1.7	6.0
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.4	12.5	42.9	4.9	3.7	6.1	5.4	2.7	8.4
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.9	8.6	34.8	4.8	4.1	5.6	4.4	1.8	7.2
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.4	7.4	31.6	4.3	3.4	5.2	4.4	1.8	7.2
Research	Submersible operations - Substrate disturbance [re-suspension]	16.5	6.7	30.8	4.5	3.3	5.8	4.0	1.6	6.6

F. occa

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.1	14.6	51.9	9.0	8.0	10.1	3.6	1.6	5.7
Vessel Traffic	Discharge - Oil/Contaminants	26.4	12.5	44.9	7.7	6.3	9.1	3.6	1.7	5.7
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.7	11.7	41.9	4.9	3.7	6.1	5.3	2.6	8.3
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.0	8.3	32.9	4.8	4.0	5.6	4.2	1.8	6.7
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.8	7.2	29.3	4.3	3.4	5.2	4.2	1.7	6.8

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Research	Submersible operations - Substrate disturbance [re-suspension]	15.7	6.5	28.6	4.5	3.3	5.8	3.8	1.6	6.1

R. dawsoni

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	27.5	15.1	43.2	9.0	8.0	10.1	3.2	1.7	4.7
Vessel Traffic	Discharge - Oil/Contaminants	26.3	11.9	45.6	7.7	6.3	9.1	3.6	1.6	5.8
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.5	11.9	41.6	4.9	3.7	6.1	5.3	2.6	8.1
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.2	8.2	34.2	4.8	4.0	5.6	4.2	1.8	7.0
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.8	6.9	30.4	4.3	3.4	5.2	4.2	1.7	7.0
Research	Submersible operations - Substrate disturbance [re-suspension]	16.3	6.7	30.4	4.5	3.3	5.8	3.9	1.6	6.4

Squat Lobster

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	31.8	13.9	55.5	9.0	8.0	10.1	3.7	1.6	6.1
Vessel Traffic	Discharge - Oil/Contaminants	26.5	11.3	46.8	7.7	6.3	9.0	3.7	1.5	6.0
Fishing	Long line traps - Substrate disturbance [re-suspension]	15.3	6.4	27.2	4.8	4.0	5.6	3.4	1.4	5.6
Fishing	Long line hooks - Substrate disturbance [re-suspension]	14.7	6.4	26.4	4.2	3.4	5.2	3.7	1.6	6.1
Research	Submersible operations - Oil/Contaminants	12.3	4.4	25.7	5.3	3.7	7.2	2.6	0.9	4.6
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	11.7	4.4	23.6	4.9	3.7	6.1	2.7	0.9	4.7

Glass Sponge Skeleton

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	37.2	16.0	64.8	9.0	8.0	10.0	4.3	1.8	7.1
Vessel Traffic	Discharge - Oil/Contaminants	31.3	13.5	56.3	7.7	6.3	9.0	4.4	1.8	7.2
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.0	11.7	42.7	4.7	3.6	5.8	5.6	2.7	8.7
Fishing	Long line traps - Substrate disturbance [re-suspension]	20.1	8.6	35.3	4.8	4.0	5.6	4.4	1.8	7.2
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.4	7.5	31.2	4.3	3.4	5.2	4.4	1.8	7.1
Research	Submersible operations - Oil/Contaminants	14.7	5.2	30.7	5.3	3.6	7.2	3.1	1.1	5.5

Sponge Garden

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.5	14.8	59.1	9.0	8.0	10.1	4.0	1.7	6.5
Vessel Traffic	Discharge - Oil/Contaminants	31.9	13.9	55.8	7.7	6.3	9.1	4.4	1.9	7.1
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.0	12.0	43.0	4.7	3.5	5.8	5.6	2.7	8.8
Fishing	Long line traps - Substrate disturbance [re-suspension]	19.9	8.7	34.1	4.8	4.0	5.6	4.4	1.9	7.1
Fishing	Long line hooks - Substrate disturbance [re-suspension]	17.7	7.7	31.5	4.3	3.4	5.2	4.4	1.9	7.1
Research	Submersible operations - Substrate disturbance [re-suspension]	16.5	7.0	30.5	4.5	3.3	5.8	4.0	1.6	6.5

Bocaccio Rockfish

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Fishing	Bottom trawling - Substrate disturbance [re-suspension]	34.3	15.3	58.7	9.0	8.0	10.0	4.0	1.7	6.4
Vessel Traffic	Movement underway - Disturbance [noise]	30.3	12.3	54.4	8.5	6.9	10.4	3.8	1.5	6.3
Vessel Traffic	Discharge - Oil/Contaminants	25.1	11.7	42.4	7.7	6.3	9.0	3.4	1.6	5.4
Fishing	Long line traps - Substrate disturbance [re-suspension]	18.3	8.0	31.7	4.8	4.0	5.6	4.0	1.7	6.4
Fishing	Long line hooks - Substrate disturbance [re-suspension]	16.0	7.0	28.1	4.3	3.4	5.2	4.0	1.7	6.4
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	12.1	4.6	23.8	4.7	3.6	5.7	2.9	1.0	5.0

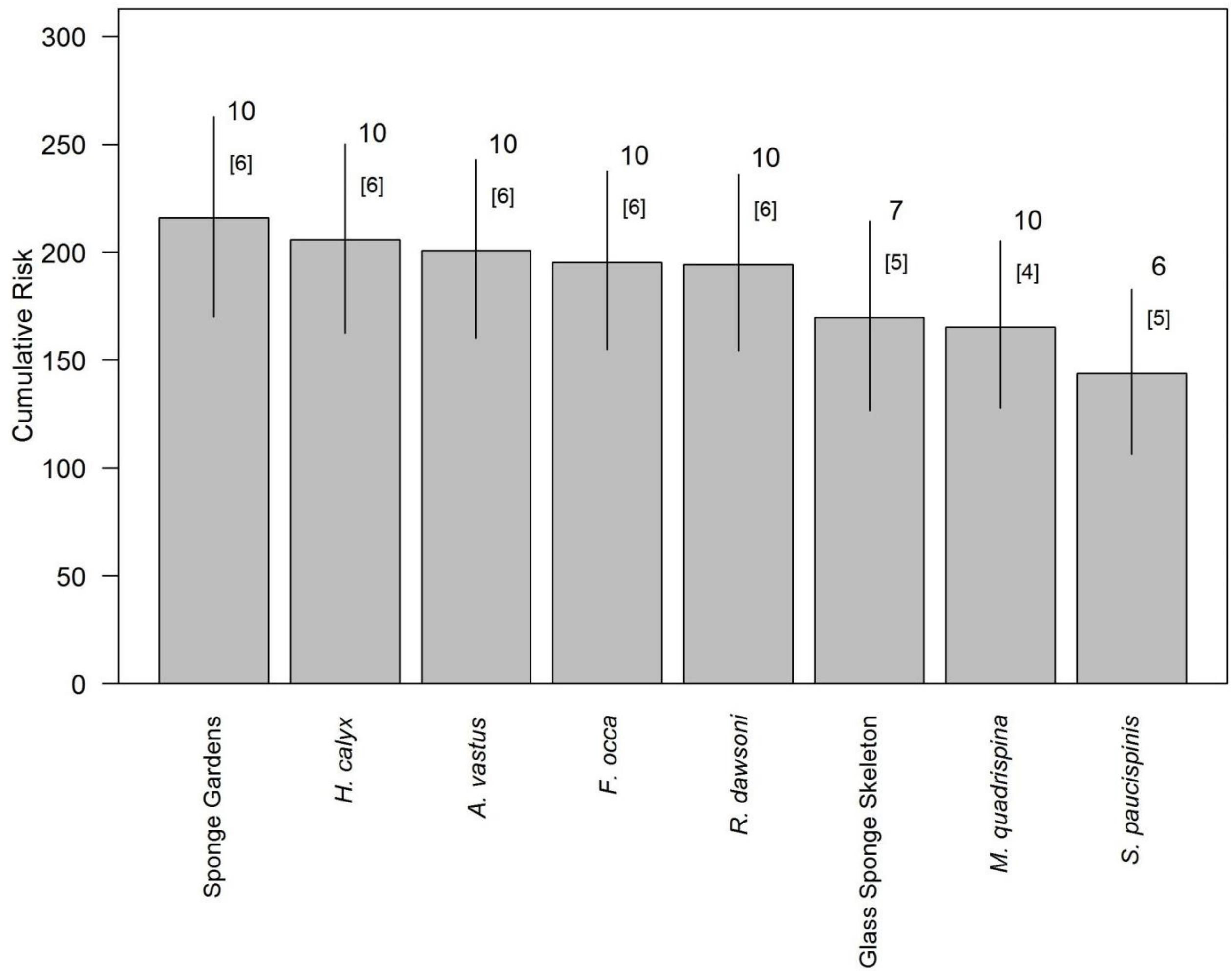


Figure 25. Cumulative risk to each SEC from "current snap-shot" stressors only. Numbers in square brackets indicate the number of non-zero resilience "current snap-shot" stressors contributing to the cumulative score.

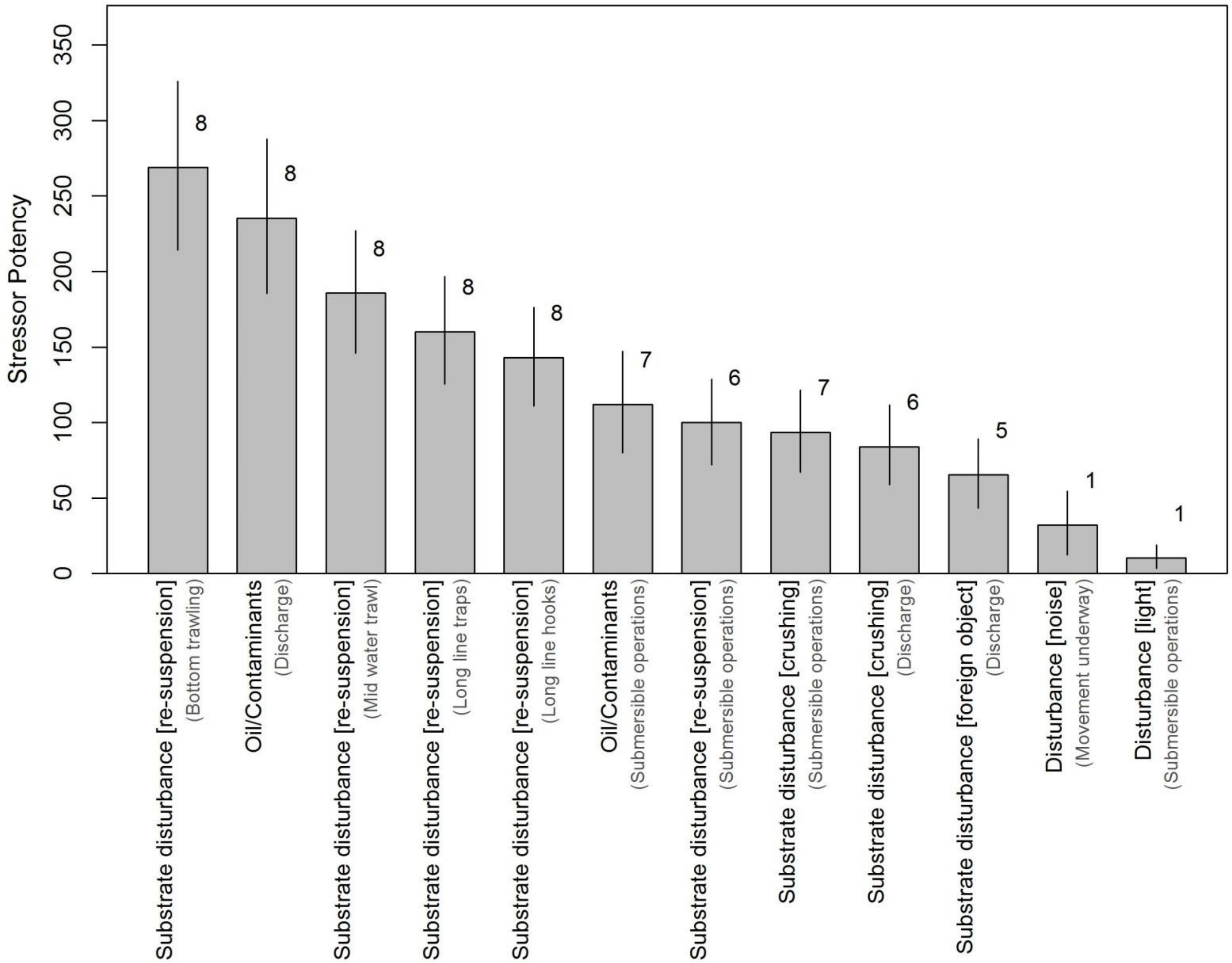


Figure 26. Potency of "current snap-shot" stressors only across all SECs.

L.2. Subset of Results Based on Excluding Interactions with Both Resilience Terms Equal to Zero and using the Normal Distribution

The original approach for screening interactions prior to calculating risk used in previous ERAF processes (Thornborough et al. 2017, Rubidge et al. 2018) excluded any stressor interactions scoring zero for both Acute Change and Chronic Change (the two Resilience terms). Using the R script provided with the current work, comparable results for Hecate are provided here so that they can be directly compared to existing ERAF processes (i.e., Endeavour Hydrothermal Vents and SGaan Kinghlas – Bowie Seamount), including use of the Normal Distribution for uncertainty estimation.

Table 41. For each SEC, the top six non-zero resilience interactions.

H. calyx

		Relative Risk			Exposure			Consequence		
Activity	Sub-Activity - Stressor	Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	98.5	62.4	145.2	9.4	6.8	12.1	10.8	7.6	14.1
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	30.8	9.4	56.4	9.5	8.4	10.6	3.4	1.0	5.9
Fishing	Mid water trawl - Substrate disturbance [crushing]	29.3	10.0	53.4	5.4	4.1	6.6	5.7	2.0	9.5
Vessel Traffic	Discharge - Oil/Contaminants	26.3	8.3	49.8	8.3	6.8	9.8	3.4	1.0	5.9
Fishing	Mid water trawl - Removal of biological material	26.2	9.2	49.0	4.9	3.6	6.3	5.7	2.0	9.6
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.8	9.8	47.8	4.8	3.5	6.1	5.7	2.1	9.5

A. vastus

		Relative Risk			Exposure			Consequence		
Activity	Sub-Activity - Stressor	Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	137.7	94.8	188.8	9.3	6.8	12.0	15.0	12.1	17.7
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	28.9	14.3	46.9	9.5	8.4	10.6	3.2	1.5	4.9
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.6	10.1	53.2	5.5	4.1	6.7	5.6	2.0	9.5
Vessel Traffic	Discharge - Oil/Contaminants	26.9	8.5	49.8	8.2	6.7	9.7	3.4	1.0	5.9
Fishing	Mid water trawl - Removal of biological material	26.0	9.4	48.5	4.9	3.6	6.3	5.6	2.1	9.4
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.2	10.4	45.6	4.8	3.6	6.1	5.6	2.3	9.0

F. occa

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	128.5	88.8	174.7	9.3	6.7	12.0	14.0	11.5	16.2
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	29.1	9.0	52.8	9.5	8.4	10.6	3.2	0.9	5.5
Fishing	Mid water trawl - Substrate disturbance [crushing]	26.8	9.6	49.0	5.4	4.1	6.6	5.2	1.9	8.7
Vessel Traffic	Discharge - Oil/Contaminants	24.5	7.9	46.4	8.2	6.7	9.7	3.2	1.0	5.5
Fishing	Mid water trawl - Removal of biological material	24.3	9.0	45.3	4.9	3.6	6.2	5.3	2.0	8.8
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	24.0	8.7	44.3	4.9	3.6	6.1	5.3	1.9	8.8

R. dawsoni

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	135.9	93.8	187.6	9.4	6.8	12.1	14.8	11.7	17.6
Fishing	Mid water trawl - Substrate disturbance [crushing]	28.6	10.3	52.6	5.5	4.1	6.7	5.6	2.0	9.3
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	28.5	14.2	46.1	9.5	8.4	10.6	3.1	1.5	4.8
Vessel Traffic	Discharge - Oil/Contaminants	26.3	8.2	49.7	8.2	6.8	9.7	3.4	1.0	5.9
Fishing	Mid water trawl - Removal of biological material	25.3	9.1	48.1	4.9	3.6	6.3	5.5	1.9	9.3
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.2	10.1	45.7	4.9	3.5	6.1	5.5	2.3	8.9

Squat Lobster

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	72.1	41.5	112.0	9.4	6.8	12.0	8.0	5.0	11.1
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	24.3	4.3	49.7	9.5	8.4	10.6	2.8	0.5	5.2
Vessel Traffic	Discharge - Oil/Contaminants	21.2	4.0	44.0	8.2	6.7	9.7	2.8	0.5	5.3
Vessel Traffic	Grounding - Introductions [AIS]	16.5	1.2	38.9	7.0	4.9	9.3	2.7	0.2	5.3
Fishing	Mid water trawl - Substrate disturbance [crushing]	13.5	2.2	28.9	5.5	4.1	6.6	2.7	0.4	5.2
Fishing	Mid water trawl - Removal of biological material	12.2	2.2	25.8	4.9	3.5	6.1	2.8	0.5	5.2

Glass Sponge Skeleton

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	98.0	62.2	143.2	9.3	6.8	12.0	10.8	7.5	14.0
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	33.0	5.8	66.0	9.5	8.4	10.6	3.7	0.6	7.0
Fishing	Mid water trawl - Substrate disturbance [crushing]	29.2	10.5	53.3	5.5	4.1	6.7	5.7	2.1	9.5
Vessel Traffic	Discharge - Oil/Contaminants	28.9	5.2	58.5	8.3	6.8	9.7	3.7	0.7	7.0
Fishing	Mid water trawl - Removal of biological material	25.9	9.3	48.5	4.9	3.5	6.3	5.7	2.1	9.5
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.1	9.2	46.8	4.7	3.5	5.9	5.7	2.1	9.6

Sponge Garden

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	133.9	93.4	183.7	9.3	6.8	12.0	14.6	11.8	17.1
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	31.0	5.5	61.7	9.5	8.4	10.6	3.5	0.6	6.4
Fishing	Mid water trawl - Substrate disturbance [crushing]	29.3	10.7	53.2	5.4	4.1	6.6	5.7	2.1	9.4
Vessel Traffic	Discharge - Oil/Contaminants	28.6	5.3	58.0	8.3	6.8	9.7	3.7	0.7	6.9
Fishing	Mid water trawl - Removal of biological material	26.0	9.6	48.6	4.9	3.5	6.3	5.7	2.1	9.5
Fishing	Mid water trawl - Substrate disturbance [re-suspension]	25.1	9.3	45.8	4.7	3.5	5.9	5.6	2.1	9.3

Bocaccio Rockfish

Activity	Sub-Activity - Stressor	Relative Risk			Exposure			Consequence		
		Median	10%	90%	Mean	10%	90%	Mean	10%	90%
Vessel Traffic	Oil spill - Oil	117.7	83.7	158.7	9.3	6.8	12.0	12.8	10.9	14.5
Fishing	Mid water trawl - Removal of biological material	54.7	42.1	68.8	5.0	4.3	5.7	11.1	8.9	13.2
Fishing	Bottom trawl - Substrate disturbance [re-suspension]	28.5	5.4	56.8	9.5	8.4	10.6	3.2	0.6	5.9
Fishing	Mid water trawl - Strikes	25.7	9.5	45.1	5.6	4.9	6.3	4.8	1.7	8.0
Vessel Traffic	Movement underway - Disturbance [noise]	23.5	1.9	51.0	8.3	6.9	10.6	3.1	0.2	6.1
Vessel Traffic	Discharge - Oil/Contaminants	23.0	7.4	41.8	8.2	6.8	9.7	2.9	0.9	5.0

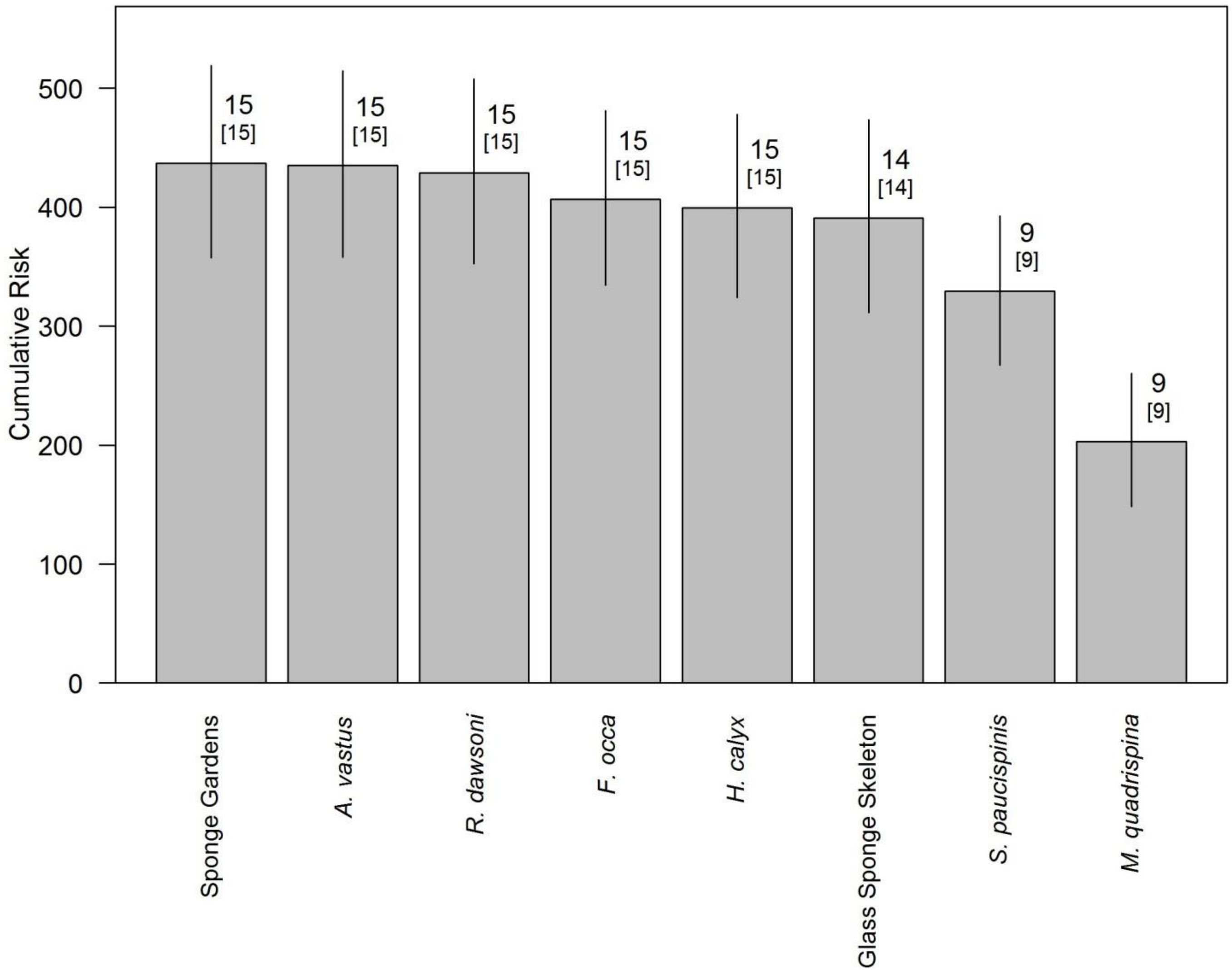


Figure 27. Cumulative risk to each SEC limited to non-zero resilience score interactions and using the Normal distribution method for uncertainty estimation.

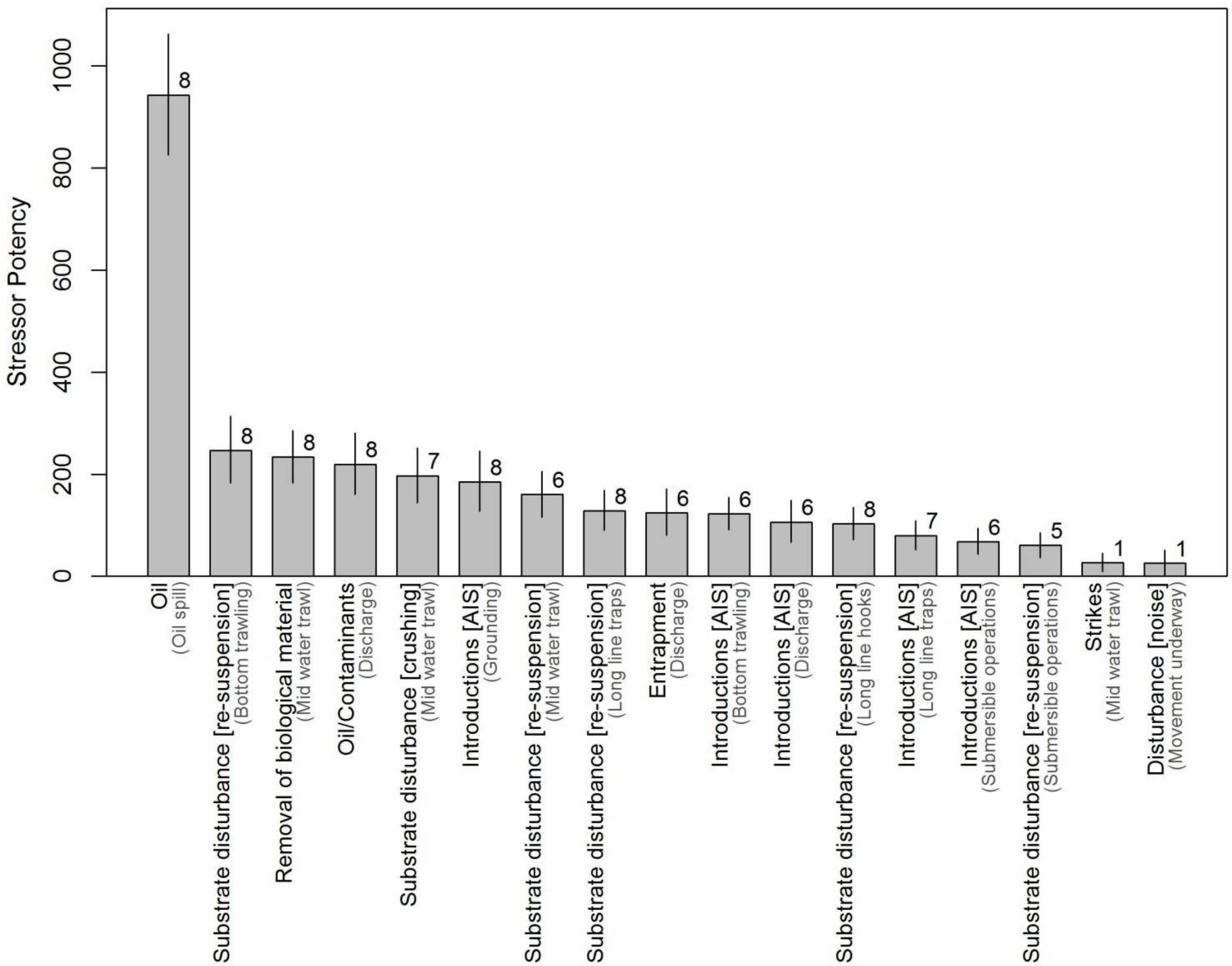


Figure 28. Potency of stressors (limited to non-zero resilience interactions only) across all SECs. Uncertainty estimates were obtained using the Normal distribution method.