Ecological Risk Assessment for the Effects of Fishing: A Pilot Study for British Columbia Groundfish Fisheries

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ABSTRACT

Holt, K.R., Ackerman, B., Flemming, R., Forrest, R.E., Kronlund, A.R., Lacko, L., Olsen, N., Rutherford, K., Stanley, R.D., Taylor, N.G., and, Workman, G. 2012. Ecological risk assessment for the effects of fishing: A pilot study for British Columbia groundfish fisheries. Can. Tech. Rep. Fish. Aquat. Sci. 2990: viii + 184 p.

The Pacific Region Groundfish Science Section of Fisheries and Oceans Canada applied the Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework to a portion of the groundfish bottom trawl fishery in Hecate Strait, British Columbia. ERAEF was developed as a tool for informing an Ecosystem-based Approach to Fisheries Management in Australia. The method takes a hierarchical approach to risk assessment that allows it to efficiently assess ecological risk from fishery or non-fishery impacts for hundreds of species, habitats, and ecological communities. The goals of the pilot study were to (i) determine how the Australian framework could be adapted to the context of British Columbia groundfish fisheries; and (ii) develop and understanding of how ERAEF risk scores could inform prioritization of research and management activities for a diverse ecosystem. We describe the methods and results of our pilot study, and make conclusions about how ERAEF could be used to inform research and management activities. While further methods development will be necessary before broad-scale implementation in British Columbia, our results demonstrate that ERAEF provides a useful framework for organizing the pursuit of science-based advice about anthropogenic impacts on an ecosystem. Furthermore, some elements of the ERAEF framework could be applied at the present time to provide timely advice on fishery and non-fishery impacts on directed and non-directed species in British Columbia.

RÉSUMÉ

Holt, K.R., Ackerman, B., Flemming, R., Forrest, R.E., Kronlund, A.R., Lacko, L., Olsen, N., Rutherford, K., Stanley, R.D., Taylor, N.G., and, Workman, G. 2012. Ecological risk assessment for the effects of fishing: A pilot study for British Columbia groundfish fisheries. Can. Tech. Rep. Fish. Aquat. Sci. 2990: viii + 184 p.

La section des sciences du poisson de fond, de la région du Pacifique de Pêches et Océans Canada, a procédé à une évaluation des risques écologiques et de leurs effets sur une partie de la pêche au chalut du poisson de fond dans le détroit d'Hecate en Colombie-Britannique. Cette évaluation des risques a été mise au point comme outil visant à appuyer une approche écosystémique de la gestion des pêches en Australie. La méthode adopte une approche hiérarchique à l'évaluation des risques qui permet d'évaluer efficacement le risque écologique des conséquences reliées ou non à la pêche pour des centaines d'espèces, d'habitats et de communautés écologiques. L'étude pilote avait pour objet i) de déterminer de quelle manière on pourrait adapter le cadre australien à la pêche au poisson de fond de la Colombie-Britannique et ii) d'acquérir une compréhension de la manière dont les résultats de l'évaluation des risques pouvait aider à établir les priorités des activités de recherche et de gestion d'un écosystème diversifié. Nous décrivons les méthodes et les résultats de notre étude pilote et tirons des conclusions sur la façon dont l'évaluation des risques peut servir à renseigner les activités de recherche et de gestion. Tandis qu'il faudra élaborer d'autres méthodes avant la mise en oeuvre en Colombie-Britannique, nos résultats démontrent que l'évaluation en question offre un cadre utile pour donner des conseils scientifiques au sujet des répercussions anthropiques sur un écosystème. De plus, certains éléments du cadre de l'évaluation pourraient s'appliquer maintenant pour donner des conseils opportuns au sujet des répercussions sur les pêches et autres sur les espèces réglementées ou non en Colombie-Britannique.

EXECUTIVE SUMMARY

The Pacific Region Groundfish Science Section of Fisheries and Oceans Canada (DFO) is interested in developing a repeatable, transparent framework for prioritizing Groundfish Science activities. In addition to assessing stock status and providing harvest advice for directed species, the section is increasingly asked to provide advice on the impacts of groundfish fisheries on non-directed species and benthic habitats, as well as on the impacts of other human-induced (non-fishery) activities on groundfish species. One potential tool for the prioritization of fisheries research is the Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework developed for Australian fisheries. To investigate how the Australian framework could be adapted to the context of British Columbia groundfish fisheries, we developed a pilot study application of ERAEF to a portion of the bottom-trawl fishery in Hecate Strait, British Columbia.

ERAEF takes a hierarchical approach to risk assessment that allows it to assess ecological risk from fishery or non-fishery impacts for hundreds of species, habitats, and ecological communities. After an initial Scoping stage, assessments move from a comprehensive but qualitative analysis of risks at Level 1, through a more focused and semi-quantitative approach at Level 2, and finally to a highly focused quantitative "model-based" approach at Level 3. Assessments only extend to the next level if risk is judged to be above a pre-defined threshold, which results in the three levels acting as a series of filters to efficiently screen out low risk issues. The ecosystem is characterized using five ecosystem, components: (i) *Directed Species*, (ii) *Non-directed Species*, (iii) *Threatened, Endangered and Protected Species*, (iv) *Habitats,* and (v) *Communities*. At each level of the ERAEF hierarchy, a series of fishery stressors (e.g., fishery capture, gear loss, anchoring) are assessed based on the risk they pose to each of the five ecosystem components. The pilot study was limited to the first three stages of ERAEF: Scoping, Level 1, and Level 2, and was only applied to a subset of species and habitats present in the study area.

Methods and Results

Scoping - The scoping stage set the bounds for the Level 1 and 2 analyses in our pilot study by compiling lists of species and habitats affected by the fishery, identifying stressors arising from the fishery and other external activities in Hecate Strait, and selecting fishery objectives against which risk scores could be evaluated. Only three of the five ecosystem components usually considered in ERAEF were included in the pilot study: *Directed species*, *Non-directed species*, and *Habitats*. A combined total of 25 Directed and Non-directed species were selected. The *Habitat* component was considered in a very limited context: only five habitat-types consisting of sponge reef biota were included. Twenty-two stressors were identified for the bottom trawl fishery.

Level 1 Assessment - At Level 1, a Scale Intensity Consequence Analysis (SICA) was conducted using expert opinions from within the Groundfish Science section to qualitatively assign potential risk scores to each combination of stressor and ecosystem

component. A total of 66 combinations of ecosystem component and stressor were evaluated using SICA. All three ecosystem components had at least one stressor that was scored ≥ moderate risk, so no ecosystem components were screened out at Level 1. However, the advantage of SICA was its ability to efficiently screen-out low-risk stressors rather than to screen out ecosystem components. Of the 22 stressors identified during scoping, 18 were assessed as negligible or minor risk for all ecosystem components, and were thus excluded from further analysis. The following combinations of stressor and ecosystem component were identified as being a moderate risk or higher, and were recommended for a Level 2 assessment:

Ecosystem Component	**Stressors**
Directed species	• Capture by fishery (removal of species) • Translocation of species (i.e., introduction of invasive species) • Capture by other fisheries
Non-directed species	• Capture by fishery (removal of species) • Translocation of species (i.e., introduction of invasive species) • Capture by other fisheries
Habitats	• Disturbances of physical processes due to fishing (i.e., sedimentation) • Capture by other fisheries (removal of habitats)

Level 2 Assessment - At Level 2 of the pilot study, a Productivity Susceptibility Analysis (PSA) was used to estimate the potential risk of fishery capture for individual species using low levels of empirical data. Data sources included DFO Pacific Region Groundfish databases and published literature. Ecological risk was measured as a function the productivity of the species (i.e., the ability to recover from an impacted state) and the susceptibility of the species to harm from fishery capture. PSA methods in Australia have only been developed for a single stressor so far: fishery capture. Thus, while our Level 1 analysis identified eight component-stressor combinations to be moved forward to Level 2, only two of these were actually carried forward for the pilot study: (i) capture by fishery of directed species and (ii) capture of by fishery of non-directed species. The focus of PSA on individual species allowed 21 of the 25 groundfish species to be screened out from proceeding to a quantitative, model-based Level 3 assessment for fishery capture. Two Directed species (Big Skate and Longnose Skate) and two Non-directed species (Brown Catshark and Spiny Dogfish) were identified as needing a Level 3 assessment.

Conclusions

Our results demonstrate that ERAEF provides a means to organize the pursuit of science-based advice of fishery impacts on a diverse ecosystem. Examples for Directed Species, Non-Directed Species, and sponge reef Habitats indicate that the Level 1 SICA analysis could be useful for directing management actions and research towards potentially high-risk stressors. However, further development of methods for classifying Community and Habitat components in BC will be needed before ERAEF can be fully applied at this level. While the Level 2 PSA analysis is narrower in the scope of fishery impacts it can currently assess (only fishery capture), it demonstrates one type of tool that could be used for a more intensive analysis of potential risk at Level 2. We believe that ERAEF could also be a useful tool for the assessment of impacts from non-fishery activities (e.g., aquaculture, offshore wind farms) on marine ecosystems in British Columbia. Additional work will be needed to better develop pathways for describing non-fishery impacts, but this exercise in itself would be useful for defining issues for which fisheries scientists, managers, and stakeholders have little experience.

The outputs of ERAEF communicate a broader view of anthropogenic impacts on ecosystem features than that given by traditional assessment approaches that view individual issues in isolation. As such, it has the potential to inform an ecosystem-based approach to management (EAM) by providing a comprehensive summary of existing knowledge, information, and data on the ecological impacts of anthropogenic activities on marine ecosystems, as well as by identifying areas in which information is lacking. Outstanding issues that are necessary for EAM but that are not addressed by ERAEF at Levels 1 and 2 include the assessment of cumulative impacts over multiple activities and the consideration of socioeconomic benefits and risks when making management decisions.

1. INTRODUCTION

The Pacific Region Groundfish Science Section of Fisheries and Oceans Canada (DFO) has a mandate that covers over 250 different fish species. In addition to assessing stock status and providing harvest advice for target species, the section is increasingly asked to provide advice on a range of human-induced impacts on groundfish resources (e.g., overlap of fishery footprint with sensitive benthic habitats and impacts of proposed offshore wind farms on groundfish species). At the same time, the number and complexity of single-species stock assessments has increased due to requirements of the Species at Risk Act, eco-certification, the objectives of the multi-species, multi-gear groundfish fishery, and DFO's emerging Sustainable Fisheries Framework which includes policies on "A Fishery Decision-Making framework Incorporating the Precautionary Approach" (DFO 2009a) and "Managing Impacts of Fishing on Benthic Habitat, Communities and Species" (DFO 2009b).

These new complexities have intensified the need for a repeatable, transparent framework for prioritizing Groundfish Science activities. The relative risk incurred by groundfish stocks and their ecosystems due to human-induced impacts (e.g., fisheries) should be an important consideration within this framework. One potential tool for risk-based prioritization of fisheries research is the Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework developed for Australian fisheries (Smith et al. 2007, Hobday et al. 2011, Williams et al. 2011). ERAEF takes a hierarchical approach to risk assessment that allows it to assess ecological risk from fishery or non-fishery impacts for hundreds of species, habitats, and ecological communities. Assessments move from a comprehensive but qualitative analysis of risks at Level 1, through a more focused and semi-quantitative approach at Level 2, and finally to a highly focused quantitative "model-based" approach at Level 3. Assessments only extend to the next level if risk is judged to be above a pre-defined threshold, which results in the three effectively acting as a series of filters to efficiently screen out low risk issues.

In addition to helping prioritize groundfish science activities, ERAEF has the potential to summarize available science inputs for ecosystem-based management if assessment results are linked to management responses. An "Ecosystem Approach" to fisheries management has been identified as a priority for Canadian fisheries, which DFO policy defines as a set of management approached that "consider the impact of the fishery not only on the directed species, but also on non-directed species, seafloor habitats, and the ecosystems of which these species are a part" (DFO 2009c). As a result, ERAEF outputs for BC groundfish fisheries may provide useful science input to an Ecosystem Approach to Fisheries Management (EAM).

To investigate how the Australian ERAEF framework could be used to help inform the prioritization of Groundfish Science activities and provide science input for EAM, a pilot application of ERAEF was developed for a portion of the multi-species groundfish bottom-trawl fishery in Hecate Strait, in northern British Columbia (BC). This report summarizes the methods, results, and conclusions from this exercise. Section 1 provides background on the Australian ERAEF framework, an overview of the objectives for our BC pilot study, and a glossary of ERAEF terms. Sections 2 to 4 describe pilot study methods and results for the first three stages in ERAEF: Scoping, Level 1 Assessment, and Level 2 Assessment, respectively. In Section 5 we discuss the outcomes of the pilot study with regard to the objectives defined in Section 1, and make recommendations for future applications of ERAEF to BC fisheries.

1.1. WHAT IS ERAEF?

ERAEF is a risk assessment framework that was developed to inform ecosystem-based fisheries management in Australia (Smith et al. 2007, Hobday et al. 2011). The framework has been applied to over 30 federally-managed fisheries in Australia in the past five years. The framework has also recently been adopted by the Marine Stewardship Council eco-certification organization as a method for assessing the impact of a fishery footprint on marine ecosystems (MSC 2009).

The ERAEF framework takes a hierarchical approach to risk assessment that moves from a comprehensive but qualitative analysis of risks at Level 1, through to a more focused and semi-quantitative approach at Level 2, and finally to a highly focused quantitative "model-based" approach at Level 3 (see Figure 1-1 for schematic framework). Each level becomes increasingly time- and data-intensive. Assessments only extend to the next level if risk is judged to be above a threshold, which allows the three levels to act as a series of filters to efficiently screen out low risks. At any point in the hierarchy, high risk issues can be dealt with by implementing mitigating management actions to reduce risk instead of proceeding to the next level of analysis (Figure 1-1).

Under ERAEF, the ecosystem is characterized using five components: (i) *Directed Species*, (ii) *Non-directed Species*, (iii) *Threatened, Endangered and Protected (TEP) Species*, (iv) *Habitats* and (v) *Communities*. Individual species, habitat-types, or ecological communities within each of these components are called units of analysis.

At each level of the ERAEF hierarchy in Figure 1-1, fishery stressors are assessed based on the risk they pose to each of the five ecosystem components. Fishery stressors are defined as a combination of a "Fishing Activity" (e.g., Bait collection, Fishing, Anchoring / Mooring) and a "Direct Impact of Fishing" (e.g., Capture, Addition / Movement of Biological Material) (Figure 1-2). External (non-fishing) stressors that affect the ecosystem are also considered. However, methods for assessing these stressors past Level 1 have not yet been developed.

Prior to initiating the Level 1 assessment in ERAEF, an initial Scoping stage is undertaken in which the fishing activity of interest and fishery objectives are described. Lists of all units of analysis that could be affected by the fishing activity are constructed during scoping. Following the Scoping stage, Level 1 assessment methods are qualitative, with expert opinion used to assign potential risk scores to each of the five ecosystem components. The analysis used at this level is called Scale Intensity Consequence Analysis (SICA). Only components that are assessed with a risk score greater than or equal to moderate at Level 1 are moved forward to the Level 2 assessment. At Level 2, the analysis combines empirical data in a quantitative Productivity Susceptibility Analysis (PSA). Species, habitats, or communities that still have high potential risk scores after Level 2 progress to a Level 3 Assessment, which uses a variety of model-based methods to assess risk, including traditional stock assessment models.

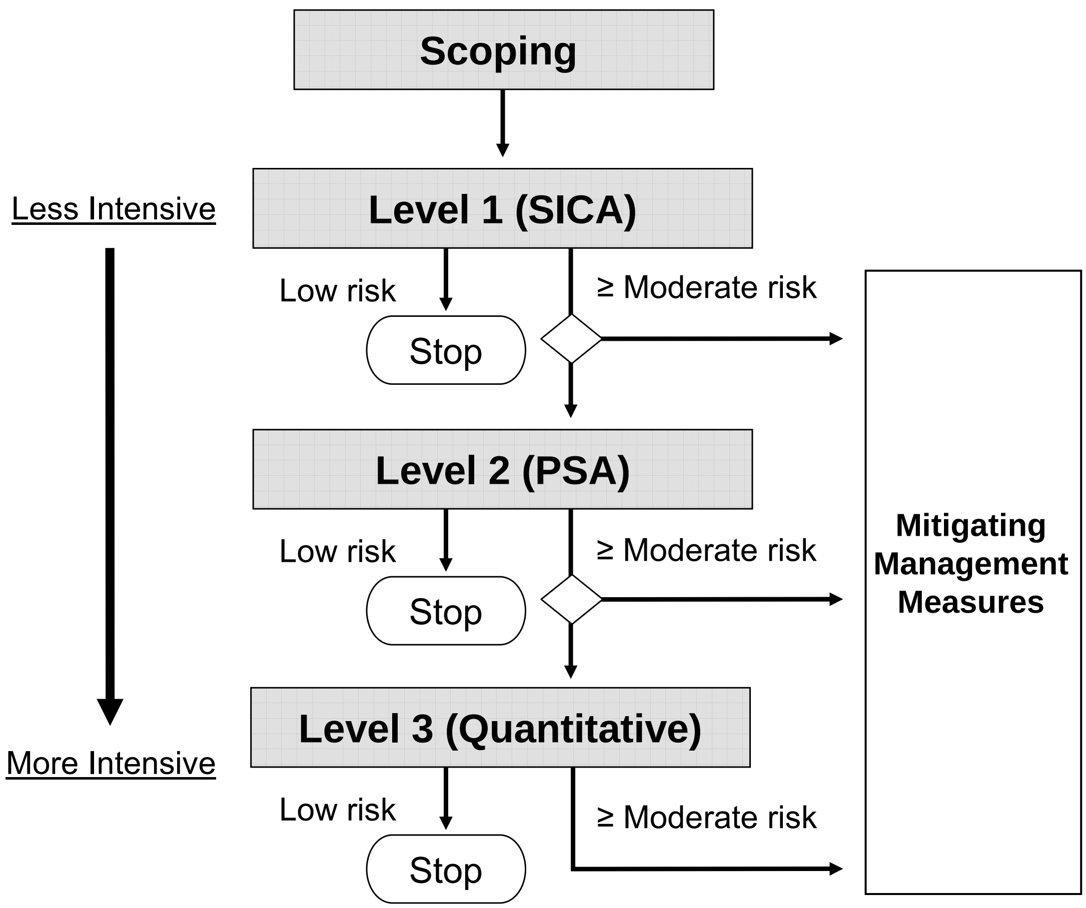


Figure 1-1. Schematic overview of the ERAEF hierarchical assessment framework with three levels of analysis. At each level, managers have the option to implement mitigating management measures for issues assessed as ≥ medium risk instead of proceeding to the next level of analysis. (Adapted from Hobday et al. 2011).

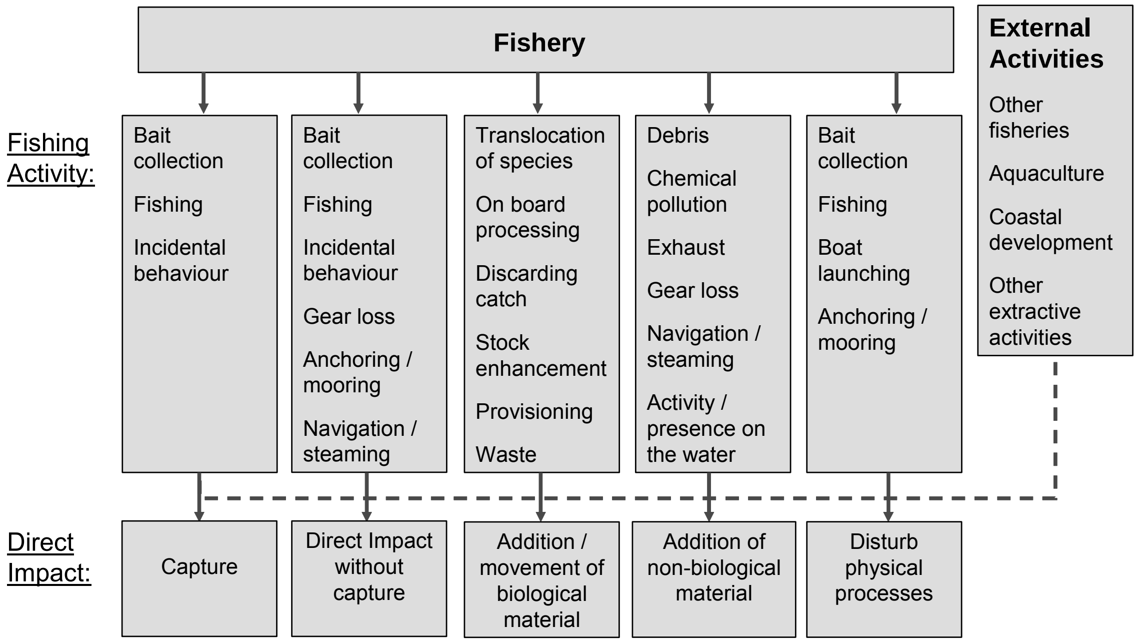


Figure 1-2. Conceptual diagram showing how Stressors are characterized as a unique combination of a fishing activity and a direct impact arising from that activity. For example, the *Capture* of an ecosystem component during *Bait Collection* is one Stressor, while the *Capture* of an ecosystem component during regular *Fishing* (setting and retrieving gear for the purpose of catching the targeted species) is another. External activities can also give rise to Stressors. Definitions of each of Stressors identified in this diagram are provided in Table 2-3. (Adapted from Hobday et al. 2007).

1.2. OBJECTIVES OF PILOT STUDY

Four objectives were identified for the pilot study, each of which helps address the increasing complexities of providing groundfish science advice to managers. These objectives were as follows:

1) To evaluate the ability of ERAEF to provide timely advice on the impacts of BC fisheries on marine ecosystems using a risk-based triage approach

2) To evaluate the ability of ERAEF to provide timely advice on the impacts of non-fishing activities in BC on marine ecosystems using a risk-based triage approach

3) To determine whether risk-based outputs from ERAEF could help prioritize scheduling of science advice related to groundfish species and fisheries

4) To demonstrate a potential format for science input to an Ecosystem Approach to Management.

Note that objectives 1-3 are linked to the Groundfish Advisory Activities Strategic Plan, which is an internal discussion document for the Pacific Region Groundfish Science Section at the Pacific Biological Station (contact person: Greg Workman, Groundfish Section Head, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC). The first two objectives relate directly to Strategy 2 of the plan (Timely advice on resource impacts via risk-based triage), while objective 3 relates to Strategy 3 of the plan (Develop a system for risk-based prioritization and scheduling).

1.3. SCOPE OF THE PILOT STUDY

The scope of the pilot study was restricted to a subset of species and habitats within Hecate Strait and Dixon Entrance (see Section 2 for maps). As a result, risk scores assigned during the pilot study do not reflect realistic risk scores for the fishery and will not be used to inform management decisions. The narrowly defined scope of the pilot study served to simplify methods during the initial learning stage, as well as to prevent the pilot study from becoming too focused on controversial issues rather than on learning and capacity building.

Only three of the five ecological components usually considered in ERAEF were included in the pilot study. *Directed species*, *Non-directed species*, and *Habitats* were included. *TEP species* and *Communities* were excluded. The number of fish species in the pilot study was restricted to 25, with approximately half of these being *Directed Species* and half being *Non-directed Species*. As a result, several species encountered by bottom-trawl gear in the pilot study area were excluded. The *Habitat* component was considered in a very limited context; only habitat-types consisting of sponge reef biota were included in the risk assessment. Further details about the scope of units of analysis included in the pilot study are provided in Section 2.2.

1.4. GLOSSARY OF TERMS

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

- **External Activity** – An activity that is not associated with fishery operations of the assessed sub-fishery. Examples include other fisheries (commercial and recreational), logging, and land-based pollution.
- **Fishing Activity –** An activity that occurs during the course of fishery operations for the assessed fishery. Examples include fishing (i.e., setting and retrieving gear), bait collection, anchoring, and discarding of catch.

Component - See “Ecosystem Component” definition

Consequence Score – (Used for Level 1 risk assessment) A qualitatively-derived measure of risk incurred by an ecosystem component as a result of a fishery or external activity. Consequence scores are based on the expected magnitude of impact that may occur as a result of a stressor. Since the magnitude of an impact will affect the likelihood of achieving operational objectives (e.g., maintain biomass above a given level), consequence scores are alternatively defined as the likelihood of not achieving the operational objective.

Core Objectives –Broad-scale goals that represent a desired endpoint but that may not be stated in terms that are measurable. Core objectives in ERAEF are applied at the level of ecological component. For example, "to prevent stock collapse" may be a core objective for the Directed Species component.

Cumulative Impacts - The combined total of incremental effects that multiple human activities through space and time can have on an environment. The concern is that while several activities may have insignificant impacts by themselves, the combined effects of all activities may lead to a degradation of the ecosystem as a whole. While ERAEF is comprehensive in the range of fishery and non-fishery impacts assessed, analyses at Levels 1 and 2 only considers risk on an impact-by-impact basis. Cumulative impacts are not addressed at these levels.

Direct Impact– The end result of an Activity on an ecosystem (i.e., the ecological effect). Examples include capture of species or habitats, addition or movement of biological materials, and the disturbance of physical processes.

Ecosystem Component – Categories used in ERAEF to represent the ecosystem. Five ecological components are considered: (i) Directed species; (ii) Non-directed species; (iii) Threatened, endangered, and protected (TEP) species; (iv) Habitats; and (v) Communities. Each of these components serves as an area of focus when evaluating the impacts of fishing on the ecosystem.

Ecosystem Approach to Fisheries Management – Extends the principles of sustainable fisheries management to broader ecosystem considerations. Broadly defined as fisheries management that "strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (FAO 2003). DFO policy defines it as management decisions that "consider the impact of the fishery not only on the directed species, but also on non-directed species, seafloor habitats, and the ecosystems of which these species are a part" (DFO 2009c).

Ecosystem-Based Management – "An integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive, and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity, or concern; it considers the cumulative impacts of different sectors." Note that this is one of many definitions of ecosystem-based management, this one from McLeod et al. (2005), as cited in Rosenberg and McLeod (2005).

Intensity Score - (Used for Level 1 risk assessment) The intensity of the activity is scored based on a combination of three factors: (i) the spatial scale of the stressor, (ii) the temporal scale of the stressor, and (iii) the severity of impact that a unit of analysis will experience as a result of a single interaction with the stressor.

Operational Objectives – Clear and measurable objectives for managing a fishery that represent specific components of fisheries management policy. In ERAEF, operational objectives are applied at the level of sub-component. Operational objectives are required to (*i*) be associated with at least one measurable indicator, and (*ii*) identify limits to acceptable change. For example, an operational objective related to the population size sub-component of directed species could be "biomass remains above 40% of unfished biomass".

Productivity - (Used for Level 2 risk assessment) Refers to the capacity of a unit of analysis (i.e., a species, habitat, or ecological community) to recover rapidly from a depleted state. In other words, the resilience of a unit of analysis to disturbance.

Productivity Susceptibility Analysis (PSA) – A semi-quantitative method of assessing the vulnerability of a unit of analysis to a stressor (i.e., risk) based on two characteristics: 1) the productivity of the impacted unit of analysis and 2) the susceptibility of the unit to harmful impacts from the stressor. PSA forms the basis of the Level 2 risk assessment method in ERAEF.

Risk (ecological risk) – A measure of the probability that adverse ecological effects may occur, or are occurring, as a result of the exposure to one or more stressors. Within ERAEF, risk is defined as the probability that a specified fishery management objective is not achieved (Hobday et al. 2010). Note that risk is also alternatively defined as the product of (i) the probability of a stressor resulting in an adverse event and (ii) the severity of the event.

Scale – Two types of scale are considered in the Level 1 risk assessment:

Spatial Scale - Describes the relative area that a fishery stressor or external stressor occurs over. Spatial scale is defined as the largest possible areal extent of the stressor within the geographic extent of the assessed fishery.

Temporal Scale - Describes the relative frequency of a fishery stressor or external stressor. Temporal scale is measured as the frequency of an event within the geographic extent of the assessed fishery, using a scale that ranges from decadal to daily.

Scale, Intensity, Consequence Analysis (SICA) - A rapid screening tool that relies on expert opinion to assess potential risk on a qualitative scale. SICA forms the basis of the Level 1 risk assessment method in ERAEF.

Severity - (Used for Level 1 risk assessment) A measure of the degree of negative impact that a stressor is expected to have on a unit of analysis during a single interaction. Within BC-ERAEF, a qualitative four-point scale is used (low, moderate, severe, and very severe). Severity should be scored independent of spatial and temporal scale.

Stressor – Any physical, chemical, or biological means that, at some given level of intensity, has the potential to negatively affect an ecosystem. Within the current pilot study, it is characterized as the Direct Impact (e.g., capture, addition /movement of biological material) that arises from a given Activity (e.g., bait collection, fishing, anchoring / mooring).

External Stressor – A stressor arising from external activities that are not associated with the assessed fishery.

Fishery Stressor – A stressor arising from an activity associated with the assessed fishery.

Sub-component – A characteristic of a population, habitat, or community that is linked to operational objectives for the fishery. Examples of sub-components for the Directed species component include population size, geographic range, and age /size/ sex structure. Examples sub-components for the Habitat component include substrate quality, water quality, and habitat structure and function. For a full list of sub-components associated with each of the five ecological components, see Table 2-2.

Units of Analysis – Individual species, habitat-types, or community-types within each of the five ecological components that form the basis of Level 1 – 3 analyses. For example, within the Directed species component, units of analysis are the list of species targeted by the fishery (e.g., Arrowtooth Flounder, Big Skate, etc.). For the Habitat component, units of analysis are unique habitat types. For the Community component, units of analysis are unique species assemblages.

2. SCOPING

The scoping stage of ERAEF requires existing information about the fishery to be summarized so that all scientists, managers, and stakeholders participating in the risk assessment have the same background information available to them at the start of the process. In addition, the scoping stage sets the bounds for Level 1 to 3 analyses by compiling lists of species, habitats, and communities (i.e., units of analysis) that are affected by the fishery, identifying stressors arising from the fishery and other external activities, and selecting fishery objectives against which risk scores can be evaluated.

The scoping stage consists of four steps, each of which requires a form to be filled out by the assessment team. The scoping stage for the current pilot study closely follows the steps developed for Australia's ERAEF, with several of the forms identical to those provided in Hobday et al. (2007). Some slight modifications have been made to these forms to better suit the context of BC fisheries. These four steps and their associated forms are as follows:

<u>Step 1:</u> Describe general fishery characteristics (Form S1)
<u>Step 2:</u> List units of analysis (Forms S2.1, S2.2, and S2.3)
<u>Step 3:</u> Select fishery objectives (Form S3)
<u>Step 4:</u> Identify fishery and external stressors (Form S4)

The four steps listed above are described in Sections 2.1 to 2.4. The methods used and results obtained for our BC pilot study are described in Sections 2.1 to 2.4. Completed scoping forms for each step are included under the Results heading within each section.

2.1. STEP 1: GENERAL FISHERY CHARACTERISTICS

2.1.1. <u>Methods</u>

Scoping Form S1 summarizes background fishery information under five major headings: (i) General Fishery Characteristics, (ii) Gear, (iii) Current Issues, (iv) Management, and (v) Data. Specific information requirements and corresponding instructions are provided on the form.

Whenever possible, summary statistics entered into the Form S1 for the pilot study, such as annual value of fishery or annual levels of species-specific discards, were calculated for the pilot study area alone. In cases where this was not possible, such as Total Allowable Catches (TACs) that apply to the entire BC coast, footnotes are used to note the discrepancy.

2.1.2. Results

The completed version of Form S1 is shown below.

Form S1: General Fishery Characteristics

Fishery Name: Groundfish Trawl Fishery – Hecate Strait Pilot Study
Date of Assessment: Winter-Spring 2010
Assessor: Groundfish Section, ERAEF Pilot Study Working Group

I. General Fishery Characteristics

Fishery Name

BC Groundfish Trawl Fishery – Hecate Strait Pilot Study

Sub-fisheries
Identify all sub-fisheries on the basis of fishing method and area.

Two gear types can be used within the Groundfish Trawl Sector, bottom trawl and mid-water trawl, each of which is considered a sub-fishery for the purposes of this ERAEF assessment.

Sub-fisheries assessed
Specify the sub-fishery to be assessed in this report.

The bottom trawl portion of the Groundfish Trawl Fishery within Hecate Strait is the focus of this risk assessment.

Start date / history
Provide an indication of the length of time the fishery has been operating.

The first reports of bottom trawling in the pilot study area range from 1903 to 1909 (Wallace 1945; Alverson et al. 1964). However, initial attempts to establish markets for the fishery were unsuccessful. Some small boat trawling was conducted close to shore throughout the 1920s and 1930s, but it is not known to what extent the vessels operated in Hecate Strait.

Offshore bottom trawling by US vessels began in 1933 in Washington State, and spread south to Oregon and California (Alverson et al. 1964). In the early 1940's the US fishery expanded into waters off BC, including Hecate Strait. The Canadian groundfish bottom trawl fishery also expanded around this time. By the early 1940's, most areas of the BC coast were being explored by Canadian vessels. With the advent of World War II and an increased demand for fish protein as well as vitamin A-rich dogfish livers, there was a rapid rise in the number of vessels in the Canadian trawl fleet. Within Hecate Strait, landings of Spiny Dogfish, Pacific Cod and flatfish species dominated.

The demand for fish remained high after World War II, with an increased acceptance of fish previously designated as "scrap". This period is characterized by gradually increasing catches dominated by Pacific cod and decreased demand for dogfish (Forrester et al. 1978). Overall landings by Canadian vessels in the pilot study area ranged from a low of 2,228 t in 1954 to a high of 18,399 t in 1980. Vessels from the US continued to fish in the study area to some extent until 1977 when Canada declared its 200 nautical mile zone closed to all foreign fishing. US vessel activity was permitted to slowly phase out at this time, until, by 1981, all US landings from BC waters had ceased.

In 1978, annual quotas were first applied to the Canadian groundfish trawl fishery. A variety of management approaches were used in subsequent years including area-specific or grouped area quotas, single-species or species-aggregate quotas and pulsed fishing (Richards 1994). From 1989 until 1997, management consisted of a combination of grouped area quotas, trip limits, and area/time closures (Richards 1994). These management approaches were likely ineffective. Evidence showed that fishers found ways to circumvent these limits by misreporting catch areas, misreporting species, and discarding large portions of catch (Richards 1994).

In September 1995, when quotas for many species had been exceeded, DFO closed the trawl fishery coast-wide. The midwater portion of the trawl fishery was re-opened in October 1995 with the requirement for 100% observer coverage on all fishing trips. The bottom-trawl portion of the fishery reopened in February 1996 with the requirement of vessels to choose one of three options prior to licence issuance. Vessels choosing Option A and fishing with bottom trawl gear (which includes the pilot study fishery) were required to have user-paid 100% observer coverage. Most vessels choose to operate under Option A, and Option A has continued be most common through to 2011.

The next substantial change for the fishery occurred in April of 1997, when BC groundfish fisheries switched to an Individual Vessel Quota (IVQ) system. From this point, the total allowable catch (TAC) for those species under quota has been allocated among vessels as area- and species-specific IVQs. A suite of accompanying rules were put in place at this time for total holdings, individual species caps, and trading limits.

Geographic extent of fishery

Describe the geographic extent of the fishery and make note of any spatial closures. Maps of the managed area, distribution of fishing effort, and spatial closures should be included.

Hecate Strait is a channel between Haida Gwaii (formerly Queen Charlotte Islands) and the mainland of British Columbia on the west coast of Canada. It connects Queen Charlotte Sound to Dixon Entrance, which are both relatively deep, wide basins. The geographic extent of the pilot study encompasses Groundfish Management Areas 5C and 5D, which cover most of Hecate Strait as well as Dixon Entrance to the north of Haida Gwaii (Figure 2-1 and Figure 2-2). Hecate Strait is 130 km wide at its southern end, and 60 km wide at the north (Crawford et al. 1988). The strait is a shallow continental shelf region that is well mixed most of the year, with a strong northward current in the winter (Crawford et al. 1988). A return flow at the southwest side of the strait is believed to counteract the northward flow by re-circulating a large fraction of fish larvae back into the strait and enhancing recruitment (Crawford et al. 1990). Dixon Entrance runs east to west and connects the north end of Hecate Strait with the open Pacific Ocean to the west. Dixon Entrance is approximately 150 km long and 55-65 km wide (Carrasco 1998). Bottom trawl fishing effort currently focuses on Dixon Entrance and along the eastern and southern edges of Hecate Strait (Figure 2-3), and is restricted to depths less than 500 m. The areal extent of the commercial bottom trawl fishery footprint over the past three years within the pilot study area was calculated to be close to 13, 000 km^2 (or, 3800 nm^2) when a 6.85 km^2 (2 nm^2) grid was used to measure the footprint.

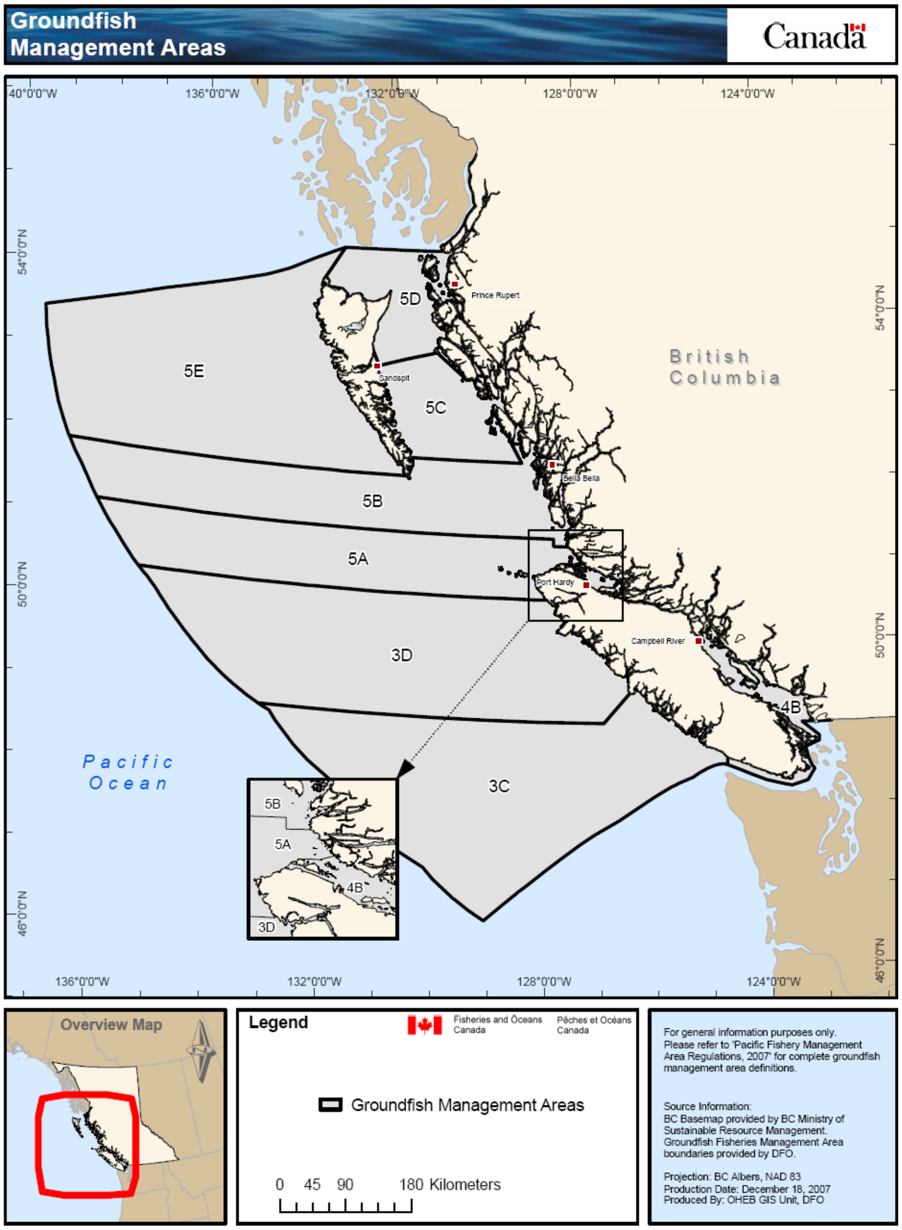


Figure 2-1. Commercial Groundfish Management Areas (4B, 5A to 5E). The pilot study area includes Areas 5C and 5D. Map taken from the Pacific Region Groundfish Integrated Fisheries Management Plan for 2011-2013 (http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm).

<u>Spatial Closures</u>

The following areas are excluded from the fishery year-round (based on 2010-11 fishing season).

- *Sponge Reef Closures:*
  The black areas on Figure 2-2 show two reefs within Hecate Strait that are closed to trawl fisheries year-round to provide protection for sponge reef ecosystems. These closures have been in place since the 2007 / 2008 fishing season. Sponge Reef Number 1 includes the waters entirely within Management Area 5C. Sponge Reef Number 2 includes waters within Management Areas 5C and 5B (the latter of which is not a part of this pilot study).

- *Queen Charlotte Spatial Closure:*
  The green area on Figure 2-2 is closed to bottom trawling year round to reduce harvesting pressure on localized stocks of fish and provide improved access to food, social, and ceremonial fish for the Haida First Nations.
- *McIntyre Bay/Masset Spatial Closures:*
  The red area on Figure 2-2 is closed to bottom trawling year round to reduce harvesting pressure on localized stocks of fish, minimize the catch of juvenile halibut, and provide improved access to food, social, and ceremonial fish for the Haida First Nations.
- *Rockfish Conservation Areas:*
  Groundfish bottom-trawl fishing is not permitted in several small-scale rockfish conservation areas located within the pilot study area. The locations of these closures are available from DFO's internet site: http://www.pac.dfo-mpo.gc.ca/fm-gp/rec/species-especes/conservation-eng.htm

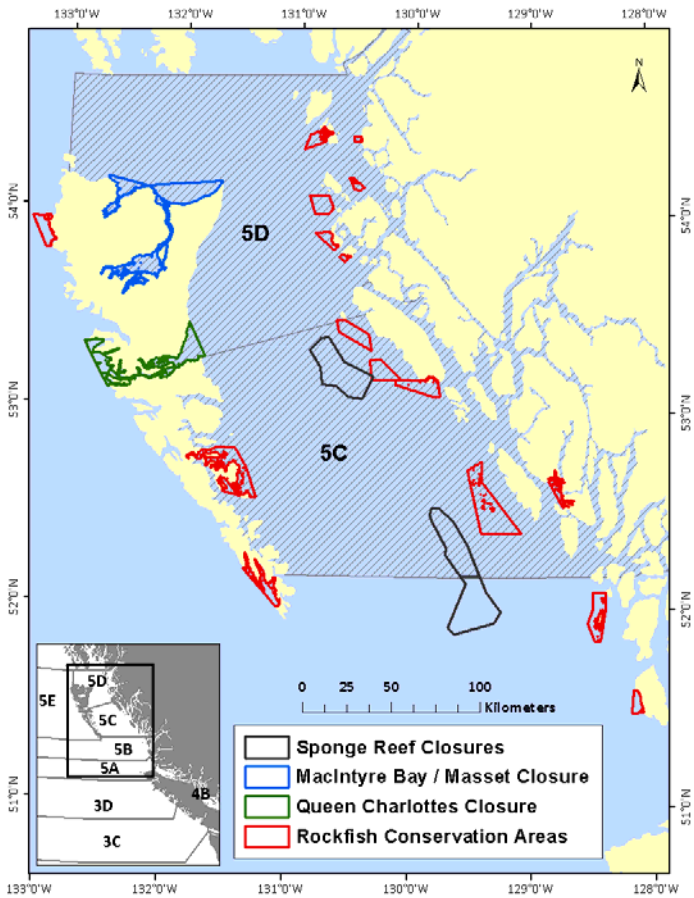


Figure 2-2. Pilot study area (grey shading) and locations of three spatial closures for the trawl fishery.

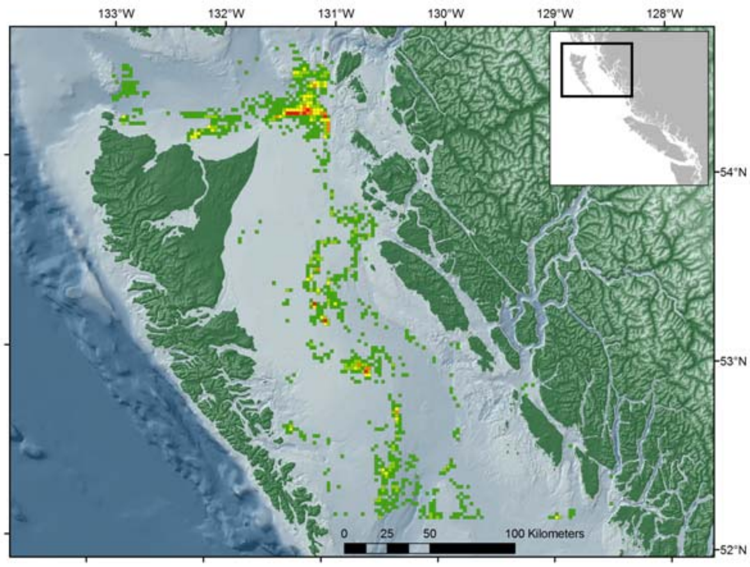


Figure 2-3. Distribution of trawl fishing effort in the pilot study area between 1996 and 2009 (quantified as number of trawl tracks). Effort intensity ranges from green (low) to yellow (moderate) to red (high).

Regions or Zones within the fishery
Describe the regions or zones used within the fishery for management purposes (e.g., Management Areas, Areas, and Subareas for BC groundfish fisheries).

The pilot study encompasses Groundfish Management Areas 5C and 5D. These areas are further delineated into the following areas and subareas:

Areas and subareas within Management Area 5C:
Areas 6, 106 and Subareas 2-1 to 2-19, 102-2 and 105-2 and 107-1.

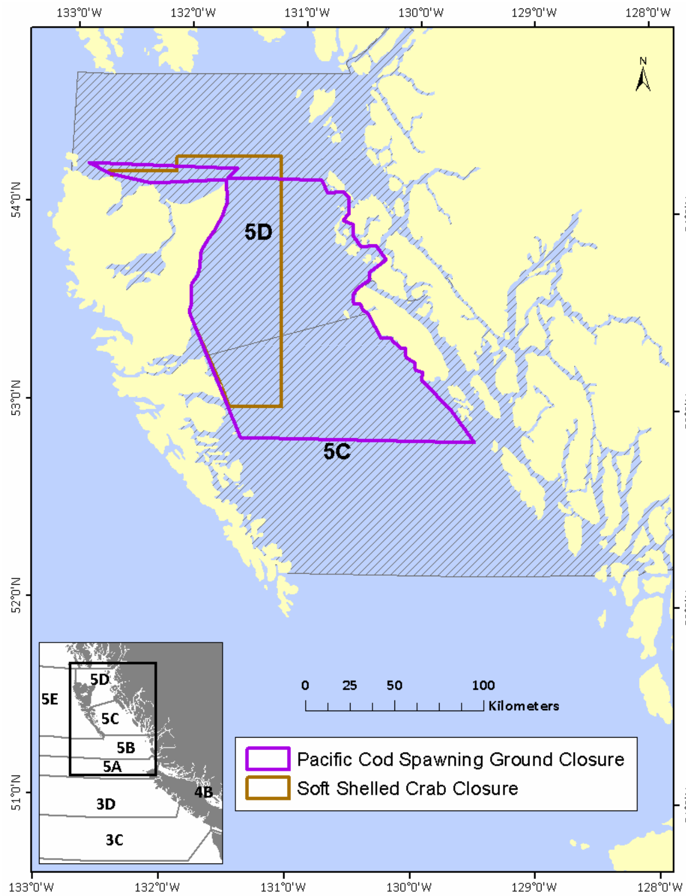
Areas and subareas within Management Area 5D:
Areas 3 to 5, 103, 104 and Subareas 1-2 to 1-5 and 101-4 to 101-10, 102-1 and 105-1.

Fishing season
What time of year does fishing occur? If seasonal closures are used in this sub- fishery, describe when and where these closures occur. Maps of seasonal closures should be included if they only apply to a portion of the geographic extent of the fishery.

For the 2010/11 fishing year, the groundfish fishing season extended from February 21, 2010 to February 20, 2011. The trawl fishery was open year round, with the following exceptions.

<u>Seasonal Closures</u>

- *Hecate Strait/Dixon Entrance – Protection of Pacific Cod*
  The purple area within Figure 2-4 was closed from January 1, 2010 to April 30, 2010 and from January 1, 2011 to April 30, 2011 to protect the spawning biomass of Pacific cod.
- *Hecate Strait/Dixon Entrance – Protection of Soft Shell Crabs*
  The brown area within Figure 2-4 was closed from June 1, 2010 through July 15, 2010 to bottom trawling to protect crabs during the soft-shell period.



;

Figure 2-4. Pilot study location (grey shading) and locations of seasonal closures. Closures are for Pacific cod spawning biomass (January 1 to April 30) and Dungeness crab soft shell phase (June 1 to July 15).

Directed species and stock status
Species targeted and, where known, stock status

Eleven directed species have been included in the pilot study. The most recent assessments of stock status for each species are described here:

- **Pacific Cod** (*Gadus macrocephalus*) were last assessed in 2005 (Sinclair and Starr 2005). The stock in the pilot study area was included in the Area 5C/D/E stock aggregate for the assessment, which was predicted to be at a historically low level of biomass in 2000/2001 (Sinclair et al. 2001). Some recovery for this stock aggregate was detected in the 2005 assessment. No trend is apparent in the three survey observations since 2005.
- **Walleye Pollock** (*Theragra chalcogramma*) were last assessed in 1997 (Saunders and Andrews 1998). The current status of this species is unknown. Recent trawl survey biomass trends are declining, although uncertainty in estimates is high.
- **Arrowtooth Flounder** (*Atheresthes stomias*) were last assessed in 2001 as a coastwide stock (Fargo and Starr 2001). At that time, analyses indicated the stock was being fished at a rate lower than F_{MSY}. Directed fishing in 2005 resulted in an apparent decline in the survey index in 2007, but Arrowtooth Flounder is still considered to be one on the most abundant groundfish species on the BC coast.
- **Dover Sole** (*Microstomus pacificus*) were last assessed in 1999 (Fargo 1999). The stock in the pilot study area was part of the 5C/D/E assessment unit. Stock status was deemed stable. Recent trawl survey biomass trends are flat or declining.

- **English Sole** (*Parophryrs vetulus*) were last assessed in 2006 (Starr 2009a). The stock in the pilot study area was part of the 5C/D/E assessment. Biomass levels were deemed to be within safe biological limits; however, results were sensitive to uncertain assumptions about changes in catchability over time. Recent trawl survey biomass trends are flat.
- **Petrale Sole** (*Eopsetta jordani*) were last assessed in 2006 as a coastwide stock (Starr 2009b). Biomass estimates suggested that the stock was continuing a rebuilding trend (first observed in 2003) from low levels throughout the 1980s and 1990s. Biomass levels were deemed to be within safe biological limits. However, results were sensitive to uncertain assumptions about changes in catchability over time. Recent trawl survey biomass trends are increasing or stable.
- **Rex Sole** (*Glyptocephalus zachirus*) have never been formally assessed. A 2003 analysis of trends in survey indices indicated a significant increase in biomass between 1984 and 2003 (Sinclair et al. 2007). Recent trawl survey biomass trends are flat.
- **Northern Rock Sole** (*Lepidopsetta polyxystrata*) have never been assessed in BC. However, they occur infrequently in BC fisheries. The species is primarily distributed in the Gulf of Alaska and the Bering Sea, although, one population is known to exist in Puget Sound, Washington. Recent assessments in Alaska indicate that stock has been stable since the 1990s. Data are lacking to make conclusive statements about the status of Northern Rock Sole in BC.
- **Southern Rock Sole** (*Lepidopsetta bilineata*) were last assessed in 2006 (Starr et al. 2006). The interpretation of status in Hecate Strait was dependent on which of two different methods was used to create the catch rate abundance index. Both methods predicted that the stock had experienced a decline since the early 1970s, although the timing of the decline and the stability of current levels differed between the two approaches. Both methods predicted that the stock has recently recovered from a particularly low level in the early 2000s. Recent trawl survey biomass trends are stable.
- **Sand Sole** (*Psettichthys melanostictus*) have never been formally assessed. A 2003 analysis of trends in survey indices indicated an overall increase in biomass between 1984 and 2003, as well as an expansion in occupied range (Sinclair et al. 2003). Recent trawl survey biomass trends are stable or increasing.
- **Big Skate** (*Raja binoculata*) was assessed in 2001 as part of a Phase 0 assessment intended to summarize known information about biology and status, as well as serve as a basis for future research and management action (Benson et al. 2001). Low data availability prevented the application of traditional stock assessment methods to estimate stock status. However, the authors suggested that the relatively high abundance of the large body sizes in the catch was an indication that the stock was healthy. Recent trawl survey biomass trends show a possible small decline.
- **Longnose Skate** (*Raja rhina*) was assessed in 2001 as part of a Phase 0 assessment intended to summarize known information about biology and status, as well as serve as a basis for future research and management action (Benson et al. 2001). Low data availability prevented the application of traditional stock assessment methods to estimate stock status. However, the authors suggested that the relatively high abundance of the large body sizes in the catch was an indication that the stock was healthy. Recent trawl survey biomass trends show a recent decline, although estimates have high uncertainty.

Bait collection and usage
Identify bait species and source of bait used in the sub-fishery. Describe methods of setting bait and trends in bait usage.

The bottom trawl fishery does not use bait.

Current entitlements
Provide the number of eligible licenses in the fishery, as well as the number of licenses that are currently active (i.e., number of vessels that have fished in recent years).

A groundfish trawl licence (category T) is required to commercially harvest groundfish species using trawl gear. Licence eligibilities are limited entry and are attached to an individual fishing vessel. Each vessel owner is required to choose one fishing option for a year. Option A allows license holders to fish with bottom trawl gear in all management areas except Area 4B and with midwater gear in all management areas including Area 4B, while Option B allows licence holders to fish only in Area 4B. The pilot study area falls within the jurisdiction of fishing Option A. There are currently 141 eligible licences for the Pacific groundfish trawl fishery, of which 106 selected fishing Option A in 2010. Of the 106 eligible license holders, there were 21, 17 and 19 vessels fishing in the pilot study area in 2007/08, 2008/09 and 2009/10, respectively.
Source: http://www-ops2.pac.dfompo.gc.ca/Ops/VRNdirectory/LicReportSelect.cfm

Current and recent quota trends by method
Summarize recent quota levels for directed species in the fishery by fishing method (sub-fishery).

Trends in annual TACs (in metric tonnes) for directed species are shown below, with the management areas for which the TAC applies shown in footnotes. Note that Rex Sole and Sand Sole are not subject to TACs. Rock sole TAC applies to both Northern and Southern Rock Sole since these species are not distinguished by markets or fishery management in BC. Morphological and genetic analyses show that Southern Rock Sole is the principle species harvested in BC.

Fishing Year	Pacific Cod [2]	Walleye Pollock [2]	Dover Sole [2]	Rock Sole [1]	English Sole [2]	Petrale Sole [3]	Arrowtooth Flounder [3]	Big Skate [1]	Longnose Skate [1]
1997/98	1620	825	1100	1045	605	479			
1998/99	1000	825	1100	1045	605	479			
1999/00	1000	1320	1100	1045	585	479			
2000/01	1000	1320	1100	1045	585	479			
2001/02	200	1320	1100	673	544	479			
2002/03	200	1320	1100	673	544	479		567	47
2003/04	200	1320	1100	673	544	479		567	47
2004/05	400	1320	1100	673	544	600		567	47
2005/06	800	1320	1100	673	544	600		567	47
2006/07	800	1320	1100	673	544	600	15000	567	47
2007/08	800	1320	1100	673	544	700	15000	567	47
2008/09	800	1320	1100	673	636	700	15000	567	47
2009/10	800	1320	1100	673	636	700	15000	567	47
2010/11	1200	1320	1100	673	636	700	15000	567	47

[1] 5C/D [2] 5C/D/E [3] Coastwide [4] Coastwide, excluding 4B

Current and recent fishery effort trends by method
Summarize recent effort levels in the fishery by fishing method (sub-fishery). Units of effort could include fishing hours per year, number of vessels per year, and/or number of sets/ hooks per year.

Annual fishing effort (hours and number of vessels) for the groundfish trawl fishery in the pilot study area (5C/D) since 1997.

Year	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04
Hours	6253	5462	5185	5568	4835	4138	4138
No. of vessels	27	28	26	26	24	21	21

Year	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Hours	5185	5568	4835	4138	3551	4115
No. of vessels	26	26	24	21	17	19

Current and recent landed catch trends by method
Summarize recent landed catch levels in the fishery by fishing method (sub-fishery). Include catch levels by directed species and non-directed species, as well as total landed catch summed over all directed / non-directed species.

The following two tables show annual landed catch (kg) of Directed and Non-directed species from the bottom-trawl fishery in the pilot study area (5C/D) since 1997. Horizontal blue bars represent the magnitude of annual catch values for a species relative to the largest catch in the time series for that species.

Directed Species:

Fishing year	Big skate	Longnose skate	Pacific cod	Walleye pollock	Arrowtooth flounder	Petrale sole	Rex sole	Rock sole	Dover sole	English sole	Sand sole
1997/98	474904	21651	1114288	121877	307659	24358	152213	654454	559549	521837	17059
1998/99	445451	10612	842675	104025	346979	18622	220356	576710	801403	519481	12039
1999/00	540724	39956	576575	206426	787441	43534	201279	713264	742020	574777	9912
2000/01	539102	71097	494340	103729	477772	48869	196251	707612	832591	492215	13400
2001/02	874966	53515	179554	48190	983867	34506	190423	561405	820907	396220	20970
2002/03	371143	14555	190562	41543	679157	52315	257765	628041	895853	527158	36564
2003/04	398711	23056	350483	21439	142404	45298	190031	603954	788905	480986	27650
2004/05	385142	11164	496680	70565	874642	46667	280396	715727	671151	491165	29625
2005/06	351736	17989	682509	341478	7028630	47700	224860	531450	641249	626737	13193
2006/07	404778	13592	666664	66762	1192048	48570	213125	632180	715588	504968	10058
2007/08	396477	13049	292860	62177	584316	46586	176360	569783	558220	498178	9382
2008/09	196399	7249	261887	70319	444430	49976	297066	491132	751319	452275	5998
2009/10	315244	7685	507778	63540	188050	92210	113859	774011	445703	457610	12861

Rock sole catches include both Northern and Southern Rock sole since these species are not distinguished by markets or fishery management in BC. The two species have occasionally been differentiated in fishery catch records in BC; however, it is unclear how often this distinction is made. Both morphological and genetic analysis has confirmed that Southern Rock Sole is the principle species harvested in BC.

Non-directed Species:

Fishing year	Brown cat shark	Spiny dogfish	Sandpaper skate	Pacific tomcod	Pacific sanddab	Speckled sanddab	Deepsea sole	Flathead sole	Butter sole	Slender sole	Starry flounder	C-O sole	Curlfin sole
1997/98	0	93	0	0	0	0	0	12069	4481	0	21524	33	4753
1998/99	0	20726	19	0	0	0	0	21051	5665	0	26889	113	5302
1999/00	0	116	707	0	0	0	0	20832	7244	0	23120	12	9286
2000/01	0	350	1200	0	0	0	0	17959	5909	0	31217	19	5769
2001/02	0	2989	469	0	2	0	0	12597	1755	0	46212	0	2625
2002/03	0	311	252	0	0	0	0	14314	813	0	8402	18	2340
2003/04	0	99	657	0	0	0	0	28136	445	0	11468	7	2346
2004/05	0	350	76	54	0	0	0	19417	5223	0	14797	6	2904
2005/06	0	1525	626	100	71	0	0	53283	4042	0	2818	15	3477
2006/07	0	261	405	0	0	0	0	17927	8733	0	16019	0	3215
2007/08	0	1432	209	0	195	0	0	12762	3441	0	8199	0	3023
2008/09	0	210	44	0	394	0	0	3710	1407	0	10129	15	4105
2009/10	0	4001	94	0	308	0	0	7625	1781	0	24650	6	5114

Current and recent value of the fishery ($)
Summarize current and recent value trends by fishing method (sub-fishery).

Estimated annual value for landings of the pilot study sub-fishery. Only landings for pilot study species caught by bottom-trawl gear in Areas 5C/D are included in this summary.

Fishing year	Value
1997/98	$5,358,927
1998/99	$5,099,105
1999/00	$5,859,791
2000/01	$5,979,293
2001/02	$4,885,339
2002/03	$6,282,683
2003/04	$5,001,147
2004/05	$4,960,135
2005/06	$6,563,658
2006/07	$5,493,005
2007/08	$4,026,364
2008/09	$3,836,775
2009/09	$4,505,189

Source: Applied estimated price per kg from the Regional Data Services Unit to landings from Official Catch tables in PacharvTrawl and GFFOS.

Relationship with other fisheries
List other commercial and recreational fisheries operating in the same region and note any interactions with assessed fishery.

Pacific Cod, Walleye Pollock, the two skate species, and all flatfish species can be caught and retained as non-directed catch by five other groundfish commercial sector groups: Halibut (L license), Sablefish (K license), Outside Rockfish (ZNO license), and the Lingcod and Dogfish Hook and Line fisheries that are licensed under Schedule II. All of the above sectors are subject to 100% at-sea monitoring, delivered in most cases using the Electronic Monitoring Program. In addition, flatfish bycatch in the Hecate Strait Dungeness crab fishery is often used as bait for crab traps.

First Nation and recreational harvest occurs coastwide. The level of First Nations' harvest of various groundfish species for food, social and ceremonial purposes is not fully known at this time. Catch monitoring programs are being developed in collaboration with some Aboriginal organizations. Recreational catches for species caught by the pilot study fishery are also not fully known, but are assumed to be low. None of the species of the pilot study are directly targeted by recreational fishers.

II. Gear

Fishing gear and methods
Provide a description of the methods and gear, as well as the average number days at sea / trip.

Vessels in the pilot study sub-fishery are permitted to fish using bottom trawl gear. Bottom trawling is a method of fishing in which a net is towed by a boat along, or just above, the ocean floor. Trawl nets are open at one end (called the mouth) and closed at the other end (called the cod end). Two large otter boards are connected to each side of the net mouth by cables (bridles and sweeplines) to keep the mouth spread horizontally open. Fish encountered by the gear are herded into the mouth of the net by otter boards and sweep lines attached to the front of the net, and become captured in the cod end. A heavy footrope is attached to the bottom of the net mouth to keep it in contact with the bottom. Large rollers are attached to the footrope to prevent the net from becoming snagged on ocean substrate, on more rocky bottom.

Fishing gear restrictions
Describe any restrictions on fishing gear (e.g., mesh size, hook size, etc).

Minimum mesh size requirements are in place to reduce the bycatch of small fish. The minimum mesh size in the last 100 meshes of the net is 140 mm. In all other parts of the net, the minimum mesh size is 76 mm.

Selectivity of gear and fishing methods
Describe the selectivity of fishing methods.

Trawling is generally considered to be a non-selective fishing method, in which multiple species with varying productivities are caught simultaneously. For BC bottom trawl fisheries, a minimum mesh size requirement is the only gear restriction used to control selectivity in fished areas. Trawl fishers have shown the ability to change the proportions on species in their catch by altering fishing gear, season, depth or location in order to avoid species subject to catch restrictions or limited quota (Branch 2006).

Spatial gear zone set
Describe where gear is set (e.g., continental shelf, shelf break, continental slope)

The pilot study area includes Hecate Strait and Dixon Entrance, both lying on the continental shelf. Trawl gear is rarely set in the narrow inlets and fjords along the mainland coast or Haida Gwaii due to unsuitable bottom-types for trawl gear. Most trawl sets within the pilot study area occur in the main channels of Dixon Entrance and Hecate Strait (Figure 2-3).

Depth range gear set
Provide the depth range gear is set at (in meters).

Gear is set between 0 and 500 m within the pilot study area.

How gear set
Describe how gear is set (e.g., pelagic in water column, benthic set (weighted) on seabed).

As described in the above *Fishing Gear and Methods* section, vessels deploy bottom trawl nets that are towed using trawl doors to maintain the mouth opening. The method of rigging the net, doors, sweeps, and bridles varies between vessels.

Area of gear impact per set or shot
Provide an estimate of area impacted by gear per set (square metres).

Using an assumed vessel speed of 3 knots, an average door spread of 70 m and an average tow length of 120 minutes results in an area of 0.78 km^2 per set.

Capacity of gear
For hook fisheries, provide number of hooks per set. For net or trap fisheries, provide net/ trap size and an average weight caught per set.

Size of net varies between vessels but it is assumed that the average door spread for the fishery is 70 m. Average annual catch per set in the pilot study area, averaged over a 10-year period between 1997 and 2006, ranged from approximately 2,000 to 4,500 kg.

Lost gear and ghost fishing
Describe how gear is lost, whether lost gear is retrieved, what happens to gear that is not retrieved, and impacts of ghost fishing.

Trawl gear is lost only rarely in Hecate Strait. Inspection of lost or discarded trawl nets has shown that this particular gear type does not ghost fish. The fabric of the meshes is too coarse to act like a gillnet. Instead, lost gear usually forms a mound that becomes habitat for benthic invertebrates and numerous groundfish species.

III. Issues

Directed species issues
List any directed species issues, including major uncertainties about species biology such as spawning season and spawning location.

Large sexual dimorphism for several flatfish species, most notably English Sole and Rock Sole, creates biased sex ratios in fisheries catch. The larger body size of females compared to males has led to females comprising up to 80% of the catch in some cases. This ratio likely has implications for the performance of stock assessment models and harvest strategies. However, these implications have not been examined.

Spawning and nursery locations are known for some, but not all, of the targeted flatfish species.

Northern Rock Sole and Southern Rock Sole were considered a single species prior to 1998. Southern Rock Sole occurs commonly in BC, while Northern Rock Sole are rare in BC waters. Northern rock sole are common in the Gulf of Alaska and Bering Sea, and a significant population has been identified in Puget Sound, Washington. Despite the existence of populations of Northern Rock Sole both to the north and south of Canadian waters, no significant number of verified specimens have been found in BC. Both morphological and genetic analysis has confirmed that Southern Rock Sole is the principle species harvested along the BC coast. The two species have occasionally been differentiated in fishery and survey catch records in BC, although it is unclear how often this distinction is made. In cases where time is not taken to distinguish between the two species, the default assignment within the pilot study area is Southern Rock Sole. Assessment work in BC has focussed on southern rock sole; the status of Northern Rock Sole in BC is unknown.

Rex Sole and Sand Sole have never had a stock assessment. There are currently no quotas or trip limits in place for these species.

Annual quotas for Pacific Cod decreased substantially in 2002 in response to the 2001 assessment which estimated the Hecate Strait population to be at a historically low level. As a result, the commercial industry adjusted fishing locations in order to avoid areas with high catch rates. The 2005 assessment indicated that stock size had increased in response to these restrictions. However, the population had not yet recovered to the long-term average biomass. TACs were increased in 2005. However, they still remain below historic catch levels. Seasonal closures to protect Pacific cod spawning aggregations in Hecate Strait and Dixon Entrance have been in place since 1996.

The two targeted skate species, Big Skate and Longnose skate, have never had a stock assessment. Life history and tagging studies in recent years have increased knowledge of species biology and distribution; however, quantitative estimates of stock status are not currently available for setting quotas. An assessment of Big Skate has recently been initiated, and is expected to be completed within the next two years.

Non-directed species issues and interactions
List any issues for non-directed species (includes retained and discarded), as was done for directed species above.

Nine flatfish species are included as non-directed species in the pilot study: Butter Sole (*Isopsetta isolepis*), C-O Sole (*Pleuronichthys coenosus*), Curlfin Sole (*Pleuronichthys decurrens*), Deepsea Sole (*Embassichthys bathybius*), Flathead Sole (*Hippoglossoides elassodon*), Pacific Sanddab (*Citharichthys sordidus*), Slender Sole (*Lyopsetta exilis*), Speckled Sanddab (*Citharichthys stigmaeus*), and Starry Flounder (*Platichthys stellatus*). All nine of these species are permitted to be retained as non-directed catch in all seven commercial groundfish sectors operating on the BC coast (Trawl, Halibut, Sablefish, Inside Rockfish, Outside Rockfish, and the Lingcod and Dogfish Hook and Line fisheries that are licensed under Schedule II). These non-directed flatfish species do not require IVQ and have no trip limit restrictions.

Three elasmobranch species, Spiny Dogfish (*Squalus acanthias*), Sandpaper Skate (*Bathyraja kincaidii*), and Brown Cat Shark (*Apristurus brunneus*), and one roundfish species, Pacific Tomcod (*Microgadus proximus*), have been included as non-directed species in the pilot study. Spiny Dogfish are subject to a coastwide quota (excluding area 4B, the Strait of Georgia) and fishers require IVQ to fish them. Brown cat shark, Sandpaper Skate and Pacific Tomcod do not require IVQ and have no trip limit restrictions.

Spiny Dogfish is caught as a directed species by the Dogfish Hook and Line fishery under the Schedule II license type. The Groundfish Trawl fishery is allocated 32% of the annual quota for dogfish, with the remaining 68% allocated to the Hook and Line fishery. Dogfish can also be caught and retained as non-directed catch by the five other non-Trawl sector groups listed above, so long as the vessel has obtained IVQ for the species.

Current status of all 13 non-directed species is unknown. Most of these species have never had a formal stock assessment, and the most recent examination of survey index trends in relative biomass and occupied area within Hecate Strait used data collected between 1984 and 2003 (Sinclair et al. 2007). Both relative biomass and occupied area were higher near the end of this time period compared to early years, suggesting that bycatch levels at that time were not negatively affecting population dynamics for any of these species (Sinclair et al. 2007).

Basic life history information, such as fecundity, age, mortality, and growth rates, have been estimated (or can be approximated) for most non-directed species. One notable exception is Brown Cat Shark, for which age at maturity is not known.

TEP issues and interactions
List any issues for Threatened, Endangered, and Protected species. Consider all TEP species groups: marine mammals, marine reptiles, seabirds. Include any key spawning/ breeding/ aggregation locations that might overlap with the fishery/sub-fishery.

No TEP issues or interactions are considered in the pilot study.

Habitat issues and interactions
List any issues for any of the habitat units identified in ***Scoping Form S2.3*** *(Section 2.2.2 of this report). This should include reference to any protected, threatened or listed habitats.*

There is increasing concern about the impacts of bottom trawling on sensitive benthic habitats throughout Canada (DFO 2010). One such habitat of particular concern in Hecate Strait is *Hexactinellida* sponge reefs (or glass sponges), which are endemic to BC waters. Large networks of these reefs occur primarily in Queen Charlotte Sound and Hecate Strait, with smaller reefs occurring in Queen Charlotte Strait and the Strait of Georgia. The skeleton of glass sponges are composed of silica, which make them fragile to physical interactions with fishing gear.

To help reduce the impact of fishing activities on sponge reef habitats, fishery closures have been in effect for three areas in northern BC since the 2002 fishing season. Two of these areas occur within the geographic range of the pilot study. Sponge reef closures appear to be effective in eliminating trawl fishing effort within their boundaries. An analysis of fishing events from DFO's GFFOS database shows that no bottom trawl tracks were recorded in sponge reef spatial closures between 2007 and 2009.

Community issues and interactions
List any issues for any of the community units identified in ***Scoping Document S1.2***

No community issues or interactions are considered in the pilot study.

Discarding
Summarize recent discarded catch levels in the sub- fishery. Include discard levels by directed species and non-directed species, as well as total landed catch summed over all directed / non-directed species. Describe discarding practices by sub-fishery, including non-directed species, juveniles of directed species, high-grading, and processing at sea.

Between 18 and 39 % of the catch taken each year in the pilot study area is discarded. This has generally included unmarketable species, unmarketable sizes of marketable species, and the mandatory discarding of prohibited species (none of which are included in the scope of the pilot study). Prohibited species include Pacific Halibut (*Hippoglossus stenolepis*), all salmon species (*Onchorhynchus sp.*), Pacific Herring (*Clupea harengus pallasi*), Green Sturgeon (*Acipenser medirostris*), White Sturgeon (*Acipenser transmontus*), Wolf-Eel (*Anarrhichthys* *ocellatus*), Pacific Basking Shark (*Cetorhinus maximus*), Tope Shark (*Galeorhinus zyopterus*), and Bluntnose Sixgill Shark (*Hexanchus griseus*). All species of groundfish, including non-Trawl IVQ, that are released at sea are deducted from IVQ holdings or annual TAC subject to marketable size limits and agreed-upon discard mortality rates as set out in Pacific Region Groundfish Integrated Management Plan (IFMP; available at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm)

The following two tables show estimated annual trawl fishery discards (kg) for Directed and Non-directed species in the pilot study area (5C/D) since 1997. Horizontal blue bars represent the magnitude of annual discard values for a species relative to the largest discard value in the time series for that species.

Directed Species:

Fishing year	Big skate	Longnose skate	Pacific cod	Walleye pollock	Arrowtooth flounder	Petrale sole	Rex sole	Rock sole	Dover sole	English sole	Sand sole
1997/98	285251	114875	78182	42629	825114	9104	107001	118887	86037	207249	20745
1998/99	166053	68058	32039	25377	1080432	4844	109226	74071	83874	170892	7744
1999/00	119416	30821	39445	14124	1566395	7423	101925	110579	80848	222474	33940
2000/01	92078	24301	19609	10421	1532589	7528	86412	116255	82693	132609	16178
2001/02	93801	28703	30389	17412	679085	3134	57993	91848	66783	64916	13255
2002/03	176631	26510	68809	13480	965229	2985	96615	103656	80400	98152	17651
2003/04	181541	25123	99616	7230	1029483	6515	91408	154262	62734	111494	26757
2004/05	146271	28392	59508	18279	1248285	4579	84973	186372	62906	118001	29866
2005/06	112503	22521	55764	33721	1092707	4860	85613	108483	62804	164636	21452
2006/07	67980	11645	17160	3344	486527	5306	61941	85847	52068	99166	15763
2007/08	79101	11864	8246	9688	493900	2154	56074	40696	48364	93924	8749
2008/09	22187	8003	3405	571	335455	2923	34945	32067	28399	40823	1325
2009/10	52385	4687	14879	843	693000	17716	43535	116123	22931	104182	6518

Rock sole catches include both Northern and Southern Rock sole since these species are not distinguished by markets or fishery management in BC. The two species have occasionally been differentiated in fishery catch records in BC; however, it is unclear how often this distinction is made. Both morphological and genetic analysis has confirmed that Southern Rock Sole is the principle species harvested in BC.

Non-directed Species:

Fishing year	Brown cat shark	Spiny dogfish	Sandpaper skate	Pacific tomcod	Pacific sanddab	Speckled sanddab	Deepsea sole	Flathead sole	Butter sole	Slender sole	Starry flounder	C-O sole	Curlfin sole
1997/98	0	235424	1168	0	2147	20	3	25244	31005	936	8458	1597	4768
1998/99	1	323137	1383	71	3788	692	2686	22229	11603	1657	16133	400	5017
1999/00	50	230240	6609	93	2295	179	0	24506	17091	1502	22920	1218	5731
2000/01	136	282108	8689	72	6980	23	27	48536	6043	855	17347	216	4798
2001/02	0	187567	8378	11746	4467	0	0	7861	9521	1040	15661	751	2619
2002/03	0	241671	9219	7562	11575	610	0	19648	11007	961	8452	76	1506
2003/04	94	120019	10523	9447	19202	510	127	26242	2986	2108	11383	44	4065
2004/05	18	175612	12531	6234	43310	191	18	20701	8668	2322	21310	176	3359
2005/06	0	95027	14954	997	4315	166	25	29328	13789	845	7800	467	3309
2006/07	5	92271	5825	343	6439	29	23	9804	9349	166	11931	233	2368
2007/08	29	69420	7135	409	7302	221	1	10767	4159	651	7968	39	1945
2008/09	12	64133	3138	65	1042	0	6	1599	57	50	8478	30	578
2009/10	0	165694	1460	1729	2482	220	0	1685	1436	137	8869	132	3271

IV: Management

Management objectives
Summarize management objectives from the most recent management plan.

Management objectives from the most recent management plan (IFMP):
There are five guiding principles for the commercial groundfish sector:

(i) All groundfish catch must be accounted for.
(ii) Groundfish catches will be managed according to established groundfish management areas.
(iii) Fish harvesters will be individually accountable for their catch.
(iv) New monitoring standards will be established and implemented to meet the above three objectives.
(v) Species and stocks of concern will be closely examined and actions such as reduction of TACs, and other catch limits will be considered and implemented to be consistent with the precautionary approach for management.

Fishery management plan
Is there a fisheries management plan? What are the key features?

There is an Integrated Fisheries Management Plan (IFMP) for Pacific Groundfish Fisheries. The purpose of the plan is to identify the main objectives and requirements for the Groundfish fishery in the Pacific Region, as well as the management measures that will be used to achieve these objectives. Within the plan there are individual harvest plans for the seven commercial groundfish fisheries on the Pacific coast. The relevant section to the pilot study is Appendix 8: Groundfish Trawl Commercial Harvest Plan. The current Groundfish IFMP can be downloaded from: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm

Input controls
Summarize any input controls in the fishery, (e.g. limited entry, area restrictions (zoning), vessel size restrictions, and gear restrictions).

Groundfish trawl licence eligibilities are limited entry with applications required annually to maintain licence eligibility. Prior to licence issue each year, the trawl vessel owner(s) is required to choose a fishing option (A or B) for the current fishing year, where Option A allows licence holders to fish in all management areas except Area 4B and Option B allows licence holders to fish only in Area 4B. All vessels fishing in the pilot study area must choose Option A.

Mesh size restrictions are in place to reduce bycatch of small fish, as described under the above heading "Fishing Gear Restrictions". Spatial and seasonal closures are shown in Figure 2-2 and Figure 2-4, respectively.

Output controls
Summarize any output controls in the fishery, (e.g. quotas).

Management of BC Groundfish fisheries is based on transferable individual vessel quotas (IVQ). Each trawl vessel is required to possess or acquire IVQ to account for mortality of all legal / marketable sized groundfish species managed under area- and species-specific TACs. Ten of the species considered in the current pilot study are subject to TACs (see above section on *Current* *and Recent Quota Trends* for a list of the directed species subject to TACs. Spiny Dogfish is the only non-directed species subject to a TAC). Trip limits are in place for some non-TAC rockfish species. None of the non-TAC species included in this pilot study are subject to trip limits.

Trawl vessels targeting groundfish stocks have been subject to 100% observer coverage since 1996. All fishing events are observed by an independent on-board observer, who records estimates of retained and discarded catch for quota species. Mortality from both landed and released-at-sea catch is deducted from IVQ.

Additional information on the integrated management of BC groundfish fisheries is available from the Pacific Region Groundfish IFMP (available at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm).

Technical measures
Summarize any technical measures in the fishery that have not yet been described (e.g. size limits, bans on females, mitigation measures such as bird-avoidance devices).

Most technical measures have been identified in previous sections. Consult current Pacific Region Groundfish IFMP for further information (available at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm).

Regulations
List regulations on fishing activities that have not yet been described in this form (e.g., rules about discarding offal and/or processing at sea, discarding of organic and inorganic waste, halibut bycatch caps).

Consult current Pacific Region Groundfish IFMP for further information (available at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm).

Initiatives and strategies
Identify any additional initiatives and strategies that have not yet described in this form (e.g., industry codes of conduct).

Consult current Pacific Region Groundfish IFMP for further information (available at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm).

Enabling processes
Briefly outline the processes that enable the fishery to operate including monitoring (logbooks, observer data, scientific surveys), assessment (stock assessments), management responses, decision rules, and, consultation processes.

<u>Monitoring</u> processes include logbooks, 100% observer coverage, and bi-annual fisheries independent research surveys. These programs are described in more detail below.

<u>Stock assessments</u> are usually initiated in response to a *Requests for Science Information and / or Advice* to the Groundfish Science Section from the Groundfish Management Unit. There is no set schedule for when assessments are completed; timing is usually based on a trade-off between the need for stock assessment advice by managers and available stock assessment resources and personal to respond to the request. These trade-offs are considered and priorities set through the Centre for Scientific Advice – Pacific (CSAP). Stock assessments must be peer-reviewed by the groundfish subcommittee of CSAP before they can be used to inform management. Invitations to

participate in a sub-committee are sent to experts from DFO, academia, First Nations, stakeholder groups, and other government or private institutions. The general public also has full participatory rights.

The DFO Sustainable Fisheries Framework provides the basis for fisheries management policy in Canada. Nested within the SFF is *A Fishery Decision-making Framework Incoprating the Precautionary Appraoch*, which identifies a decision-making rule for Canadian directed fisheries based on stock status relative to reference points. Both the SFF and the Decision-making Framework are available from: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/overview-cadre-eng.htm.

An Integrated Fisheries Management Plan (IFMP) for all Pacific Region Groundfish Fisheries is produced each year, as described in the above section on Fisheries Management Plans. The purpose of the plan is to identify the main objectives and requirements for the Groundfish fishery, as well as the management measures that will be used to achieve these objectives.

The Groundfish Integrated Advisory Board (GIAB) is a multi-interest forum for providing advice to DFO on management and policy issues relating to the groundfish fisheries in the Pacific Region. One of the mandates of GIAB is to provide advice on groundfish IFMPs.

Specific for the Groundfish trawl fishery, the Groundfish Trawl Advisory Committee (GTAC) (and its various subcommittees) is the trawl multi-stakeholder forum for providing pre-, post-, and in-season advice on the annual IFMP and the groundfish trawl harvest plan within the IFMP.

National or International Agreements
List national and international conventions or agreements that impact management of the fishery/sub-fishery.

National Legislation and Policies:

- The Fisheries Act
- The Oceans Act
- The Species at Risk Act
- Sustainable Fisheries Framework – including policies adopted and in development, such as “A Fishery Decision-making Framework Incorporating the Precautionary Approach”, “Managing Impacts of Fishing on Benthic Habitat, Communities and Species” and “Policy on New Fisheries for Forage Species”.

International Agreements:

- United Nations Fish Stocks Agreement (UNFSA)
- Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries
- FAO associated guidelines on applying the precautionary approach in fisheries
- UN Convention on Biological Diversity

V. Data

Logbook data
Describe program(s) in place for collecting verified logbook data.

All groundfish trawl licensed vessels are required to record fishing activities in a standardized information log provided by Fisheries and Oceans Canada. Information is recorded in the log at the end of each tow and submitted to Fisheries and Oceans Canada when fish are landed at the end of each trip. Recorded information includes the time, location, depth, and tow speed of each set, as well as the species-specific biomass of retained and released catch.

All vessels are also required to carry a DFO certified groundfish at-sea observer on each trip. Observers also record logbook information, as described below.

Observer data
Describe observer program, including, how many years in place, coverage, and data summaries obtained. Comment on factors related to reliability of data, including observer training and species identification skills.

The groundfish trawl fishery is subject to two mandatory catch monitoring and validation programs.

1. Dockside Monitoring – industry-funded one hundred percent dockside monitoring of landings has been in effect for all groundfish fisheries since 1994.

Purpose: to ensure that proper identification, sorting, weight, and enumeration by species occurs.

Data Collection: A service provider, under contract to the Canadian Groundfish Research and Conservation Society (CGRCS), is designated for this program and supplies certified observers to provide the dockside monitoring services. In addition DFO port samplers obtain biological samples (length, sex and ageing structures) for a sub-set of landed catch.

Data Collation: Data are faxed to the service provider's facility and scanned using optical character recognition (OCR). Following the completion of the trip, the service provider finalizes the catch record by assigning the catch to management areas fished.

Data Communication: Data is uploaded to the Department's Catch database (the Fishery Operations System or FOS) and then accessed by the Quota Management System and updated quota holdings are produced. The finalized catch record is forwarded to the vessel owner within 48 hours of the completion of the offload in the form of the Groundfish Quota Status Report. Data can also be accessed through the FOS database.

2. Groundfish At Sea Monitoring – the joint industry/Department funded program has been in effect since February 19, 2006.

Purpose: To strengthen stock assessment capabilities, to provide for effective area and species-specific management and to effectively monitor by-catch. Monitoring duties include determining retained and discarded catch amounts, as well as collecting biological data.

Data Collection: All vessels fishing in the pilot study area are required to choose Fishing Option A and as a requirement of this option must carry a DFO certified groundfish at sea observer on each trip. Observers are required to accurately record fishing activities on a set by set basis, including fishing locations (latitude/longitude), depths, gear, catch amounts by species and disposition (retained or discarded) of the catch. In addition the observers obtain biological samples (length, sex and ageing structures) for some species.

Data Collation: Data are recorded in waterproof notebooks and transcribed to data sheets. Upon landing datasheets are faxed to the Contractor's processing facility and scanned using optical character recognition. Data are then uploaded to the Contractor's database and subsequently uploaded to the Department's Catch database (the Fishery Operations System or FOS).

Data Communication: Data are accessed through the Department's FOS database.

Other data
Describe available data collected from surveys and other scientific studies.

Synoptic Groundfish Survey: Multispecies groundfish trawl survey conducted by DFO. Hecate Strait is one of four areas surveyed bi-annually (the other 3 are Queen Charlotte Sound, West Coast Haida Gwaii, and West Coast Vancouver Island). The first survey in the Hecate Strait pilot study area was initiated in 2005. The objectives of these surveys are to provide fishery independent relative abundance indices of as many benthic and near benthic fish species available to bottom trawling as is reasonable while obtaining supporting biological samples from selected species. The survey follows a random depth-stratified design.

Hecate Strait Multi-species Assemblage Surveys: This survey time series was initiated in 1984 and was conducted in 11 of the years between 1984 and 2003. Original purpose was to describe groundfish species distributions in the area and identify stable resident assemblages that would be amenable to multispecies production analysis and management. This survey was replaced by the Synoptic Groundfish Survey in 2005. Biomass estimates from the two surveys are not believed to be comparable due to expected differences in catchability.

Gear Impact Study: A National Science and Engineering Research Council (NSERC) supported gear impact study has been recently initiated to assess the potential impacts of bottom-fishing gear on seafloor habitat. This project is lead by Dr. Sean Cox and the Fisheries Science and Management Research Group at Simon Fraser University and is scheduled for completion in late 2011.

Big Skate Tagging Studies: From 2003-2006, over 18,000 big skate (*Raja binoculata*) were tagged and released in three regions in British Columbia to study movement patterns. Tagged individuals were recaptured in waters off of Oregon, Washington, throughout the Gulf of Alaska and the Bering Sea. In 2009, these data were published in King and McFarlane (Fisheries Research 101 (2010) 50–59).

End of Form S1

2.2. STEP 2: SELECTION OF UNITS OF ANALYSIS

2.2.1. Methods

Scoping Form S2 is broken down into 3 sub-forms for the BC pilot study; one for each of the three ecological components considered (Form S2.1 = Directed Species, Form S2.2 = Non-directed Species, and Form S2.3 = Habitats). Within each form, individual units of analysis are listed, where a unit of analysis is an individual species or habitat type. For example, within the Directed Species component, units of analysis are the list of species targeted by the fishery (e.g., Petrale Sole, Pacific Cod, etc.). The methods used to define units of analysis for each of the three ecosystem components considered in the pilot study are described below.

Directed Species

Completion of Scoping Form S2.1 required a clear definition of a "Directed Species". This definition may be difficult for some fisheries since quotas are set for 26 groundfish species in BC and quota allocations to individual vessels can be transferred within a sector and among sectors as part of an integrated fisheries management system. For the pilot study assessment of the BC groundfish trawl fishery, we choose to base our definition on an analysis of trawl captain's logbook information. Captains are asked in each tow to identify up to three directed species for that tow. We considered a "Directed Species" one that was identified as a target for at least five tows per year, on average, from 2001 to 2009. Although the selection of a threshold of five tows was somewhat arbitrary, it was deemed reasonable by the pilot study assessment team based on the grounds that the threshold should be larger than one to ensure that the designation of a Directed Species could not occur due to a single data entry error. Small specimens of directed species catch may still be subject to discarding due to market preference.

A decision was made at the initiation of the pilot study to limit the scope of analyses to 25 species in total; half of which would be Directed Species and half of which would be Non-directed Species. We therefore limited ourselves to selecting 12 units of analysis for the Directed Species component of out pilot study. An attempt was made to cover several life history types and levels of data availability when selecting these 12 species.

Non-directed Species

A Non-directed Species in the pilot study was defined as any species that is affected by the fishery, but that does not meet the definition of a Directed Species described above. Thus, Non-directed Species included both species that were discarded at sea and retained species that were not targeted, but that were kept for landing once captured. This definition is not necessarily limited to groundfish species; pelagic fish (including forage fish and salmon) and invertebrate species could also have been considered as Non-directed Species. However, all 13 of the Non-directed Species selected for the pilot study were groundfish species. As with the Directed Species component, an attempt was made to cover several life history types and levels of data availability when selecting the 13 non-directed species for the pilot study.

Habitats

The Habitat component of the pilot study was limited to habitats dominated by Hexactinellid (glass) sponge reefs. Sponge reefs were identified as a good starting point for evaluating the application of ERAEF to BC habitats since data on sponge reef distribution within the pilot study were readily available. Sponge reef formations can be easily identified using acoustic soundings due to unique backscatter signals produced by their siliceaous skeletons (Conway et al. 2004), and geo-referenced polygons for several sponge reef complexes have been previously compiled for Hecate Strait using this method. Further application of ERAEF to habitat types beyond sponge reefs will require the delineation of benthic substrates and fauna into multi-species complexes (e.g., crinoids, bioturbators, low encrustors) as well as the development of methods to map the distribution of each of these complexes. These research needs were determined to be beyond the scope of the current pilot study. We believe however that the sponge reef habitats we consider here provide a useful starting point for demonstrating how ERAEF methods can be applied to habitats in the same manner that they are applied to species.

In the Australian version of ERAEF, units of analysis for benthic habitats are defined based on a combination of geomorphology, substratum, and the dominant sessile benthic fauna (Hobday et al. 2007, Williams et al. 2011). Delineating the seafloor into distinct habitat types therefore requires the analysis and interpretation of several geological, biological and structural components of the seafloor. The preferred approach (Method 1) identified by Hobday et al. (2007) and applied by Williams et al. (2011) uses data from geo-referenced underwater photographic and video images to derive fine-scale lists of habitat types. These lists are based on observations within the fishery region of substrate type, geomorphology, and fauna. An example of a habitat type in this case would be *mud* substrate + *unrippled* geomorphology + *bioturbator* fauna (Williams et al. 2011). The distribution of each fine-scale habitat type is then extrapolated out to the fishery region based on the coarse-scale features of depth class (e.g., 100m – 200m) and geomorphic features (e.g., seamounts, canyons, sediment plains, patchy rocky bottom). An example of a final, derived unit of analysis for habitat types would thus be *mud* + *unrippled* + *bioturbators* + *100 – 200 m depth* + *canyon*. When fine-scale video or photographic observations are not available, Hobday et al. (2007) recommend a second method (Method 2) based on inferences made from geophysical data, GIS mapping of bathymetry, and whatever fauna observations are available from survey catches, fishery observer records, fishery logbooks, and photographic images from neighbouring areas.

The sample size of geo-referenced image data for Hecate Strait is relatively small, which limits the utility of these images for developing fine-scale lists of habitat types as required by Method 1. We therefore used a variation on the Method 2 described above for the pilot study. Acoustic data on sponge reef distributions were overlain with inferred distributions of geophysical attributes to identify unique combinations of attributes. Data on substrate and geomorphology were obtained from the *Province of British Columbia's* Marine Ecological Classification scheme (BCMEC), which are available online as compiled spatial data files (GeoBC 2010). Data on sponge reef distribution from acoustic bathymetric data was provided by the Geological Survey of Canada, Pacific (Kim Conway, Natural Resources Canada, pers. comm, 2010).

BCMEC was originally developed as a hierarchical classification scheme consisting of four nested divisions based on physiographic and oceanographic properties (Province of British Columbia 1997). Ecounits were subsequently added as a fifth level of subdivision based on systematic provincial coverages for depth, current, subsurface relief, substrate and wave exposure mapped at a 1:250,000 scale (AXYS 2001). The variables used to delineate eco-units were derived primarily from bathymetric and temperature/salinity data, each of which came from a compilation of various sources. Decisions about which of several candidate data sets represented the best available information was made at a workshop that included oceanographers, marine ecologists, and marine park specialists from a variety of provincial, federal, and U.S. agencies (AXYS 2001). Ecounits are the first example of a large-scale marine classification system applied to the BC coast. They were developed both for evaluation of the boundaries and homogeneity of the four larger BCMEC divisions and for application to coastal management and planning.

Each BCMEC ecounit is defined as a unique combination of seven variables: (i) Depth; (ii) Slope; (iii) Relief; (iv) Temperature; (v) Exposure; (vi) Current and (vii) Substrate (AXYS 2001). The Temperature variable was ignored when classifying ERAEF habitats for the pilot study because it was designed to represent an ecologically-significant temperature threshold that affected species composition, which would alternatively be addressed by the fauna layer used for ERAEF classification. Adjacent ecounit polygons distinguished only by differing temperature classes were effectively merged. The remaining six layers used in ecounit classification have been retained to represent physical habitat characteristics, substituting for the Substratum and Geomorphology components of the classification scheme. The classification criteria for each of these variables are shown in Table 2-1.

Table 2-1. Classification criteria used for the 6 BCMEC Eco-unit layers used to define habitat units for BC pilot study. Criteria developed by AXYS Environmental Consulting (2001).

Depth	Slope	Relief	Exposure	Current	Substrate
Shallow (0 - 20 m)	Flat (0 – 5%)	Low	Low (fetch < 50 km)	Low (≤ 3 kts)	Hard
Photic (20 - 50 m)	Sloping (6 – 20%)	Medium	Moderate (fetch = 50 - 500 km)	High (> 3 kts)	Mud
Mid-depth (50 - 200 m)	Steep (> 20%)	High	Low (fetch > 500 km)		Sand
Deep (200 - 1000 m)					Unknown
Abyssal (> 1000 m)					

When developing a list of units of analysis for sponge reef habitats, the BCMEC ecounits were overlaid with coverages of reef distribution (Figure 2-5). Sponge reef polygons were established using the closed area boundaries defined in the Integrated Fishery Management Plans (IFMP) for that portion of the North Reef Banks Island Sponge Complex and the Aristazabal Island Approach Sponge Complex that lie within pilot study area 5C and 5D. Sponge reef polygons for portions of reef that fell outside the spatial closures were delineated by establishing borders around the immediate area of the sponge reef fauna. All unique combinations of sponge reef polygon and ecounit polygon were considered a unit of analysis for the pilot study.

The approach used to define sponge reef habitats for our pilot study will not be practical for most species because we have less confidence that available records of species occurrences from underwater images and catch records adequately represent the distribution of these species. As a result, inferences will be required to create a complete coverage of habitat types throughout an area of interest before ERAEF can be applied to habitat types. A discussion of options and challenges for classifying habitat types is provided in Section 5 of this document.

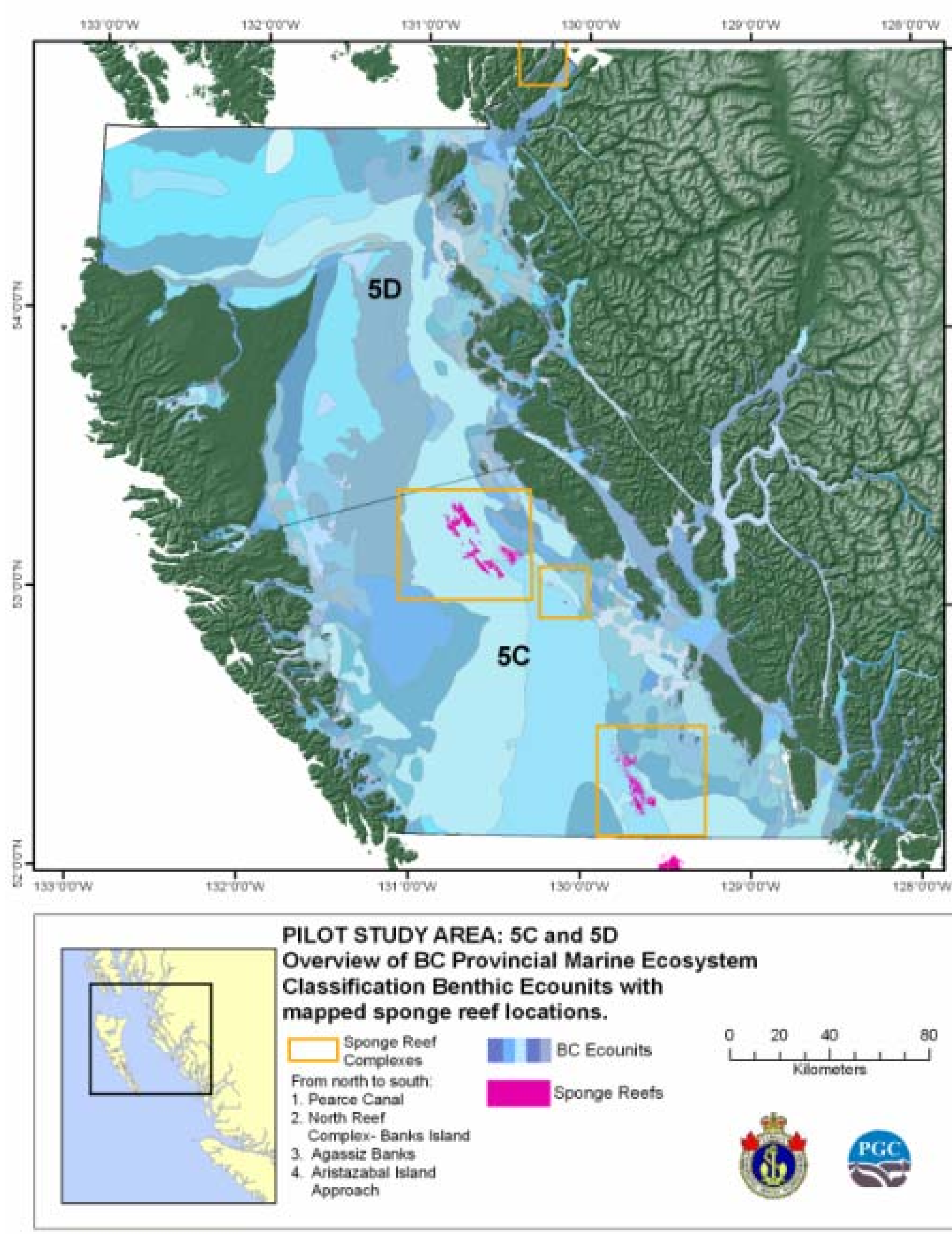


Figure 2-5. Distribution of BCMEC eco-units (with Temperature variable excluded, as described in text) and sponge reef complexes within the pilot study area. The different shades of blue show the boundaries of the 109 eco-units (with Temperature excluded). Orange boxes show the four sponge reef complexes that are commonly referred to when describing sponge reef distribution.

2.2.2. Results

Units of analysis included in the pilot study are shown below in Scoping Forms S2.1 (Directed Species), S2.2 (Non-directed Species), and S2.3 (Habitats). The total numbers of units of analysis selected for each component were: Directed Species = 12 units, Non-directed Species = 13 units, Habitats = 5 units. The distribution of habitat-types is shown in Figure 2-6 and the classifications schemes used to describe substrate, geomorphology and current/exposure are defined in Table 2-1.

Form S2.1: Units of Analysis for Directed Species

Species Type	Common Name	Scientific name
Flatfish	Arrowtooth Flounder	*Atheresthes stomias*
	Dover Sole	*Microstomus pacificus*
	English (Lemon) Sole	*Parophryrs vetulus*
	Northern Rock Sole	*Lepidopsetta polyxystrata*
	Southern Rock Sole	*Lepidopsetta bilineata*
	Petrale Sole	*Eopsetta jordani*
	Sand Sole	*Psettichthys melanostictus*
	Rex Sole	*Glyptocephalus zachirus*
Sharks / skates	Big Skate	*Raja binoculata*
	Longnose Skate	*Raja rhina*
Cods	Pacific Cod	*Gadus macrocephalus*
	Walleye Pollock	*Theragra chalcogramma*

Form S2.2: Units of Analysis for Non-directed Species

Species Type	Common Name	Scientific name
Flatfish	Butter Sole	*Isopsetta isolepis*
	C-O Sole	*Pleuronichthys coenosus*
	Curlfin Sole	*Pleuronichthys decurrens*
	Deepsea Sole	*Embassichthys bathybius*
	Flathead Sole	*Hippoglossoides elassodon*
	Pacific Sanddab	*Citharichthys sordidus*
	Slender Sole	*Lyopsetta exilis*
	Speckled Sanddab	*Citharichthys stigmaeus*
	Starry Flounder	*Platichthys stellatus*
Sharks / skates	Brown Cat Shark	*Apristurus brunneus*
	Sandpaper Skate	*Bathyraja kincaidii*
	Spiny Dogfish	*Squalus acanthias*
Cods	Pacific Tomcod	*Microgadus proximus*

Form S2.3: Units of Analysis for Habitats

ID	Depth	Substrate	Geomorphology	Current / Exposure	Fauna	Locale
1	Deep	Sand	Flat, Low relief	High exposure, Low current	Sponge	Agassiz Banks Aristazabal Approach Banks Island
2	Mid	Hard	Flat, Low relief	High exposure, Low current	Sponge	Agassiz banks Aristazabal Approach Banks Island
3	Mid	Sand	Flat, Low relief	High exposure, Low current	Sponge	Agassiz Banks Aristazabal Approach Banks Island
4	Mid	Hard	Flat, Medium relief	High exposure, Low current	Sponge	Aristazabal Approach
5	Mid	Mud	Sloping, Low relief	Low exposure, Low current	Sponge	Pearce Canal

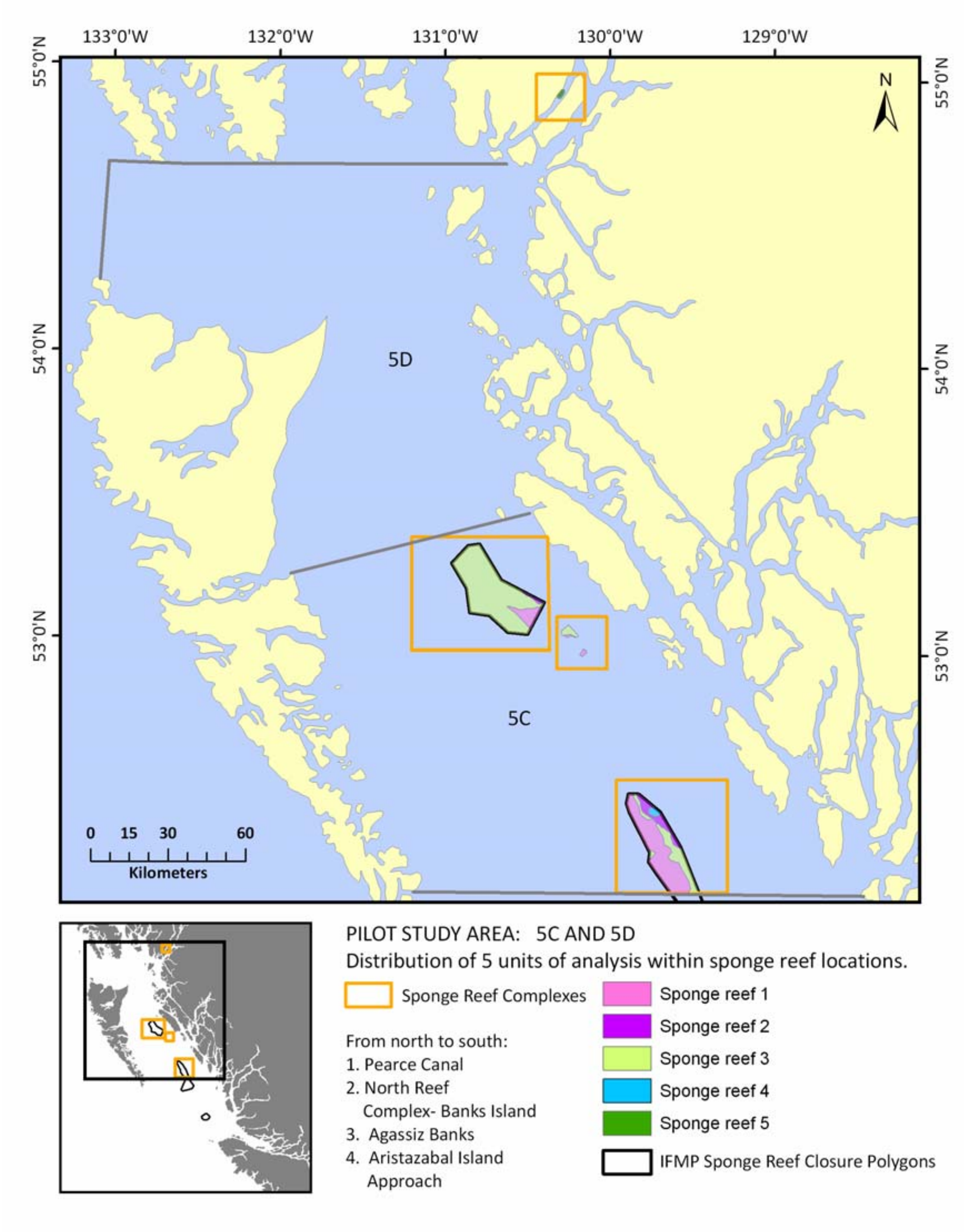


Figure 2-6. Distribution of 5 units of analysis identified for the Habitat component. A description of each unit of analysis is provided in Scoping Form S2.3.

2.3. STEP 3: SELECTION OF FISHERY OBJECTIVES

2.3.1. Methods

Step 3 of the scoping stage requires objectives to be identified for each ecological component. The operational objectives identified at this stage are referenced Level 1 Scale Intensity Consequence Analysis (SICA; Section 3.0). Completion of Scoping Form S3 requires assessors to select which objectives apply to the assessed fishery from a baseline set of objectives.

Objectives are classified in two stages. At the first stage, "core objectives" are stated for each of the five ecological components. Core objectives are broad-scale goals that represent a desired endpoint for the component, but may not be stated in terms that are measurable. For example, "to ensure a sustainable fishery" or "to prevent stock collapse" are core objectives. At the second stage, "operational objectives" that are specific to the fishery being assessed are identified for each sub-component within a component, where a sub-component is defined as a population, habitat, or community characteristic (Table 2-2). Operational objectives are required to (*i*) be associated with at least one measurable indicator, and (*ii*) identify limits to acceptable change. For example, an operational objective related to population size could be "biomass remains above 5,000 tonnes". More than one operational objective can be identified for a sub-component.

To ensure that the recommended baseline of core and operational objectives used for Australian applications of ERAEF (Hobday et al. 2007) were suitable for BC groundfish fisheries, we conducted a review of Canadian fisheries policy (Appendix A).

Table 2-2. Sub-components for each of the five ecological components. Only Directed Species, Non-directed Species, and Habitat components are considered in the current pilot study. TEP Species and Communities are only shown here for general interest.

Directed Species	Non-directed Species	TEP Species	Habitats	Communities
Population size	Population size	Population size	Substrate quality	Species composition
Geographic range	Geographic range	Geographic range	Water quality	Functional group composition
Genetic structure	Genetic structure	Genetic structure	Air quality	Distribution of community
Age/size/sex structure	Age/size/sex structure	Age/size/sex structure	Geographic Range	Trophic/size structure
Reproductive capacity	Reproductive capacity	Reproductive capacity	Habitat Structure and Function	Bio- and geo-chemical cycles
Behaviour / movement	Behaviour / movement	Behaviour / movement		
		Interactions with fishery		

2.3.2. Results

Core objectives identified for Australian fisheries were in line with Canadian fisheries policy (Appendix A), so baseline core and operational objectives identified by Hobday et al. (2007) were used for the current study. Scoping Form S3 shows the baseline set of core and operational objectives for Directed Species, Non-directed Species, and Habitats, as well as potential indicators that could be used to measure progress towards each objective (taken directly from Hobday et al. 2007).

Form S3: Objectives

Core objective	Sub-component	Operational objective	Potential indicators
Directed Species			
Avoid serious harm to reproductive capacity of directed species or population Avoid negative consequences for directed species or population sub-components	1. Population size	1.1 No trend in biomass 1.2 Maintain biomass above a specified level 1.3 Maintain catch at specified level 1.4 Species do not approach extinction or become extinct	Biomass Numbers Density CPUE Catch
	2. Geographic range	2.1 Geographic range of population, in terms of size and continuity, does not change outside of acceptable bounds	Presence of population across space
	3. Genetic structure	3.1 Genetic diversity does not change outside of acceptable bounds	Frequency of genotypes in population Effective population size Number of spawning units
	4. Age / size / sex structure	4.1 Age/size/sex structure does not change outside acceptable bounds (e.g. more than X% from reference structure)	Biomass, numbers, or relative proportion in age/size/sex classes Biomass of spawners Mean size Sex ratio
	5. Reproductive capacity	5.1 Fecundity of the population does not change outside acceptable bounds (e.g. more than X% from reference fecundity) 5.2 Recruitment to the population does not change outside acceptable bounds	Egg production of population Abundance of recruits
	6. Behaviour / movement	6.1 Behaviour and movement patterns of the population do not change outside acceptable bounds	Presence of population across space Movement patterns (e.g. attraction to bait, lights)

Form S3. – cont.

Core objective	Sub-component	Operational objective	Potential indicators
Non-directed Species			
Avoid serious harm to reproductive capacity of non-directed species or population Avoid negative consequences for non-directed species or population sub-components	1. Population size	1.1 No trend in biomass 1.2 Maintain biomass above a specified level 1.3 Maintain catch at specified level 1.4 Species do not approach extinction or become extinct	Biomass Numbers Density CPUE Catch
	2. Geographic range	2.1 Geographic range of population, in terms of size and continuity, does not change outside of acceptable bounds	Presence of population across space
	3. Genetic structure	3.1 Genetic diversity does not change outside of acceptable bounds	Frequency of genotypes in population Effective population size Number of spawning units
	4. Age / size / sex structure	4.1 Age/size/sex structure does not change outside acceptable bounds (e.g. more than X% from reference structure)	Biomass, numbers, or Relative proportion in age/size/sex classes Biomass of spawners Mean size Sex ratio
	5. Reproductive capacity	5.1 Fecundity of the population does not change outside acceptable bounds (e.g. more than X% from reference fecundity) 5.2 Recruitment to the population does not change outside acceptable bounds	Egg production of population Abundance of recruits
	6. Behaviour / movement	6.1 Behaviour and movement patterns of the population do not change outside acceptable bounds	Presence of population across space Movement patterns within the population (e.g. attraction to bait, lights)

Form S3. – cont.

Core objective	Sub-component	Operational objective	Potential indicators
Habitats			
Avoid negative impacts on the quality of the environment Avoid reduction in the amount and quality of habitat	1. Water quality	1.1 Water quality does not change outside of acceptable bounds	Water chemistry Noise levels Debris levels Turbidity levels Pollutant concentrations Light pollution
	2. Air quality	2.1 Air quality does not change outside of acceptable bounds	Air chemistry Noise levels Visual pollution Pollutant concentrations Light pollution
	3. Substrate quality	3.1 Sediment quality does not change outside of acceptable bounds	Sediment chemistry Stability Particulate size Debris Pollutant concentrations
	4. Geographic range	4.1 Relative abundance of habitat types does not vary outside of acceptable bounds	Extent and area of habitat types Percent cover
	5. Habitat structure and function	5.1 Size, shape, and condition of habitat types does not vary outside acceptable bounds	Size structure Species composition of biotic habitats Species morphology of biotic habitats

2.4. SETP 4: IDENTIFICATION OF FISHERY AND EXTERNAL STRESSORS

2.4.1. Methods

Step 4 of the scoping stage requires the identification of potential Stressors that arise from fishing activities associated with the assessed fishery or from external activities that also affect the ecosystem (e.g., coastal development, underwater oil or gas pipelines). Within the field of risk assessment, a stressor is generally defined as a biological, physical, or chemical event has the potential to cause an adverse effect on the ecosystem once it reaches a given level of intensity. Within ERAEF, a Stressor is represented using two components: (i) an Activity and (ii) a potentially adverse "Direct Impact" arising from the Activity (see Figure 1-2 and Table 2-3). Examples of activities include 'bait collection', 'fishing', and 'anchoring / mooring', while examples of Direct Impacts include 'capture', 'addition /movement of biological material', and 'disturbance of physical processes'.

The default set of Stressors identified by Hobday et al. (2007) was evaluated for the current pilot study, with each Stressor being assigned a score of 0 (absent) or 1 (present). Any additional Stressors considered to be present could also be added to the default list at this stage. Stressors assessed as present were then moved forward to the Level 1 SICA analysis. Definitions of the Stressors considered during scoping are provided in Table 2-3.

2.4.2. Results

The completed version of *Form S4: Stressor Identification Scoring Sheet* that identifies the list of fishery and external stressors included in the pilot study is shown below. A score of 1 indicates that a stressor was determined to apply to the pilot study fishery, while a score of 0 indicates that the stressor did not apply. Documentation is included for each assigned score for the pilot study.

Table 2-3. Descriptions of Activities and associated Stressors (taken directly from Hobday et al. 2007). For rows in which no "Fishing Activity" is provided, the description describes the general class of Activity that may give rise to a Direct Impact. For rows in which a Fishing Activity is provided, the description applies to the Stressor associated with the specific "Direct Impact" and "Activity".

Direct Impact	Activity	Description
Capture		Activities that result in the capture or removal of organisms. This includes unseen mortality due to organisms being caught but dropping out prior to the gear's retrieval.
	Bait collection	Capture of organisms due to bait gear deployment, retrieval, and bait fishing. This includes organisms caught but not landed.
	Fishing	Capture of organisms due to gear deployment, retrieval, and actual fishing. This includes organisms caught but not landed.
	Incidental behaviour	Capture of organisms due to crew behaviour incidental to primary fishing activities, possible in the crew's down time; e.g. crew may line fish while anchored.
Direct impact, without capture		This includes any actions that may result in direct impacts (damage or mortality) to organisms without actual capture.
	Bait collection	Direct impacts (damage or mortality) to organisms due to interactions (excluding capture) with bait gear during bait gear deployment, retrieval, and bait fishing. This includes: damage/mortality to organisms through contact with the gear that doesn't result in capture, e.g. Damage/mortality to benthic species by gear moving over them, organisms that hit nets but aren't caught.
	Fishing	Direct impacts (damage or mortality) to organisms due to interactions (excluding capture) with fishing gear during deployment, retrieval and fishing. This includes: damage/mortality to organisms through contact with the gear that doesn't result in capture, e.g. Damage/mortality to benthic species by gear moving over them, organisms that hit nets but are not caught.
	Incidental behaviour	Direct impacts (damage or mortality) without capture, to organisms due to behaviour incidental to primary fishing activities; e.g. the use of firearms on scavenging species, damage/mortality to organisms through contact with the gear that crew use to fish during their down time. This does not include impacts on predator species of removing their prey through fishing.
	Gear loss	Direct impacts (damage or mortality), without capture on organisms due to gear that has been lost from the fishing boat. This includes damage/mortality to species when the lost gear contacts them or if species swallow the lost gear.
	Anchoring / mooring	Direct impact (damage or mortality) that occurs and when anchoring or mooring. This includes damage/mortality due to physical contact of the anchor, chain or rope with organisms, e.g. An anchor damaging live coral.

Direct Impact	Activity	Description
	Navigation / steaming	Direct impact (damage or mortality) without capture may occur while vessels are navigating or steaming. This includes collisions with marine organisms or birds.
Addition/ movement of biological material		Any action that result in the addition or movement of biological material to the ecosystem.
	Translocation of species (boat movements, reballasting)	The translocation and introduction of species to the area of the fishery, through transportation of any life stage. This transport can occur through movement on boat hulls or in ballast water as boats move throughout the fishery or from outside areas into the fishery.
	On board processing	The discarding of unwanted sections of directed catch after on board processing introduces or moves biological material, e.g. heading and gutting, retaining fins but discarding trunks.
	Discarding catch	The discarding of unwanted organisms from the catch can introduce or move biological material. This includes individuals of directed and byproduct species due to damage (e.g. shark or marine mammal predation), size, high grading and catch limits. Also includes discarding of all non-retained bycatch species. This also includes discarding of catch resulting from incidental fishing by the crew. The discards could be alive or dead.
	Stock enhancement	The addition of larvae, juveniles or adults to the fishery or ecosystem to increase the stock or catches.
	Provisioning	The use of bait or berley in the fishery.
	Organic waste disposal	The disposal of organic wastes (e.g. food scraps, sewage) from the boats.
Addition of non-biological material		Any action that result in non-biological material being added to the ecosystem of the fishery, this includes physical debris, chemicals (in the air and water), lost gear, noise and visual stimuli.
	Debris	Non-biological material may be introduced in the form of debris from fishing vessels or mother ships. This includes debris from the fishing process: e.g. cardboard thrown over from bait boxes, straps and netting bags lost. Debris from non-fishing activities can also contribute to this e.g. Crew rubbish – discarding or food scraps, plastics or other rubbish. Discarding at sea is regulated by MARPOL, which forbids the discarding of plastics.
	Chemical pollution	Chemicals can be introduced to water, sediment and atmosphere through: oil spills, detergents other cleaning agents, any chemicals used during processing or fishing activities.
	Exhaust	Exhaust can be introduced to the atmosphere and water through operation of fishing vessels

Direct Impact	Activity	Description
	Gear loss	The loss of gear will result in the addition of non-biological material, this includes hooks, line, sinkers, nets, otter boards, light sticks, buoys etc.
	Navigation / steaming	The navigation and steaming of vessels will introduce noise and visual stimuli into the environment. Boat collisions and/or sinking of vessels. Echo-sounding may introduce noise that may disrupt some species (e.g. whales)
	Activity / presence on the water	The activity or presence of fishing vessels on the water will noise and visual stimuli into the environment.
Disturb physical processed		Any action that will disturb physical processes, particularly processes related to water movement or sediment and hard substrate (e.g. boulders, rocky reef) processes.
	Bait collection	Bait collection may disturb physical processes if the gear contacts seafloor-disturbing sediment, or if the gear disrupts water flow patterns.
	Fishing	Fishing activities may disturb physical processes if the gear contacts seafloor-disturbing sediment, or if the gear disrupts water flow patterns.
	Boat launching	Boat launching may disturb physical processes, particularly in the intertidal regions, if dredging is required, or the boats are dragged across substrate. This would also include foreshore impacts where fishers drive along beaches to reach fishing locations and launch boats. Impacts of boat launching that occurs within established marinas are outside the scope of this assessment.
	Anchoring/ mooring	Anchoring/mooring may affect the physical processes in the area that anchors and anchor chains contact the seafloor.
	Navigation/ steaming	Navigation /steaming may affect the physical processes on the benthos and the pelagic by turbulent action of propellers or wake formation.
External activity		Any outside actions that will result in an impact on the component in the same location and period that the fishery operates. The action as well as the mechanism for impact should be specified.
	Other capture fisheries	Take or habitat impact by other commercial, First Nations, or recreational fisheries operating in the same region as the fishery under examination
	Aquaculture	Capture of feed species for aquaculture. Impacts of cages on the benthos in the region
	Coastal development	Sewage discharge, ocean dumping, agricultural runoff
	Other extractive activities	Oil and gas pipelines, drilling, seismic activity

Direct Impact	Activity	Description
	Other non-extractive activities	Defense, shipping lanes, dumping of munitions, submarine cables
	Other anthropogenic activities	Recreational activities, such as scuba diving leading to coral damage, power boats colliding with marine mammals. Shipping, oil spills

Form S4: Stressor Identification Scoring Sheet			
Direct Impact of Fishing	**Fishing Activity**	**Score (0/1)**	**Documentation of Rationale**
Capture	Bait collection	0	This fishery does not currently directed or retain fish for bait purposes.
	Fishing	1	This fishery captures a suite of species managed using quotas and trip limits as well as numerous species that are neither retained nor managed using quotas or trip limits.
	Incidental behaviour	1	Crew may conduct some sport fishing (hook and line) while on commercial fishing trips; primarily for halibut when shut down for the night or when weathered in.
Direct impact without capture	Bait collection	0	This fishery does not currently directed or retain fish for bait purposes.
	Fishing	1	Direct impact from trawl gear without capture can occur during regular fishing activities or during site preparation for fishing. Bottom-trawl gear rolls or skids along the bottom allowing small fish or invertebrates to be crushed through interaction with trawl doors, sweep and bridle wires, and footgear. Small animals may also escape through the net mesh. Survival of animals that encounter gear without being caught is not well understood. Bottom trawl gear can also impact sessile benthic invertebrate communities.
	Incidental behaviour	1	Crew may conduct some sport fishing (hook and line) while on commercial fishing trips; primarily for halibut when shut down for the night or when weathered in. There could be some hook mortality of escaped fish.
	Gear loss	1	Although rare, trawl gear can be lost in Hecate Strait and Dixon Entrance.
	Anchoring / mooring	1	Vessels tend to moor at docks and use the same anchorages repeatedly; however, when anchoring at sea occurs, anchors and chains may have an impact on habitat forming invertebrates (e.g., sponges, sea pens, and sea whips) and non non-habitat forming invertebrates (e.g., bivalves, decapods, and numerous smaller infaunal invertebrates).
	Navigation / steaming	0	Vessels can strike animals while steaming. Seabirds occasionally collide with vessels during bad weather; however, there are no known collisions between steaming vessels and the three ecosystem components included in the pilot study (Directed species, Non-Directed Species, and Habitats).

Addition / movement of biological material	Discarding catch	1	Undersize directed species and bycatch species are generally discarded at or near the sight of capture.
	On board processing	0	There is no permitted processing at sea in this fishery.
	Translocation of species (boat launching, reballasting)	1	Invasive species could be introduced through fouling of trawl vessel hulls or fishing gear, or in the ballast water of ships. Introductions could be from other countries via vessels conducting foreign charters or from non-native populations in BC (e.g., invasive tunicate or green crab populations in Strait of Georgia).
	Stock enhancement	0	No groundfish stock enhancement is being pursued.
	Provisioning	0	Provisioning is not permitted for this fishery.
	Organic waste disposal	1	Very few commercial fishing vessels have sewage treatment plants or holding tanks; most sewage is flushed directly into the surrounding waters. Food waste is generally discarded at sea with non-compostable materials retained for disposal on land.
Addition of non-biological material	Debris	1	Most inorganic waste is retained for disposal on land. Some pieces of twine, packaging, metal parts like trawl wire, shackles, and pieces of chain may be disposed of at sea.
	Chemical pollution	1	Detergents are used to wash down the vessel, but vessels are mandated to use a biodegradable detergent; vessels do have occasional oil or fuel leaks; some vessels have changed to organic, non-toxic hydraulic oils.
	Exhaust	1	Some exhaust is emitted from vessels.
	Gear loss	1	Lost gear introduces non-biological debris. Some modern trawl nets are composed entirely of non-organic material, steel, rubber and plastic.
	Navigation / steaming	0	Navigation/steaming activities do not introduce any additional non-biological materials into the environment that have not already been covered under chemical pollution, exhaust, and activity/presence on water.
	Activity / presence on water	1	Most vessels involved in this fishery are large, diesel-powered, and steel hulled; as well they are equipped with modern depth sounders and as such are a source of noise or acoustic pollution for the local environment. Vessel lights may cause light pollution. Birds often are attracted by bright lights and land on the deck where they may get covered in oil and eventually die
Disturb physical processes	Bait collection	0	This fishery does not currently directed or retain fish for bait purposes.
	Fishing	1	Trawl gear can impact the benthic physical environment: disks or rollers of the foot gear scour

			the bottom, trawl doors create furrows with their passage, and all parts of the gear in contact with bottom (doors, sweeps, lower bridle, footgear, codend chafing gear) introduce sediment into the water column as they move along the bottom.
	Boat launching	0	All vessels involved are moored.
	Anchoring / mooring	1	Vessels tend to moor at docks and use the same anchorages repeatedly; however, when anchoring at sea, anchors and chains can disturb the bottom environment by scouring the bottom and introducing sediment into the water column.
	Navigation / steaming	1	Navigation / steaming occurs in deep water, so it is not expected to impact benthic physical processes. On a very small scale, steaming may increase surface water temperature.
External Stressors	Other capture fisheries	1	All ecosystem components will be impacted by numerous other commercial fisheries that operate in the area including: (1) a large Dungeness crab fishery that often retains bycaught flatfish and cod as bait, (2) hook and line fisheries for halibut, dogfish, lingcod and rockfish (impact fish species through capture or possibly though gear interactions that do not result in capture), (3) prawn trawl fishery, and (4) salmon troll fisheries. Aboriginal subsistence fisheries and large recreational fisheries also occur in the area, primarily directed at salmon, halibut, and prawns.
	Aquaculture	1	Net pen aquaculture does occur in near shore environments within this area.
	Coastal development	1	Development in this area is limited, but communities are expanding and most sewage is dumped directly into the sea.
	Logging	1	Logging activities and sawmill operations (including the Skeena River Watershed) can introduce sediment into the marine environment. Log dumping may impact marine fauna as well as benthic physical processes.
	Oil and gas extraction / pipelines	0	No offshore oil or mineral extraction is currently permitted in the area.
	Shipping traffic	1	High seas commercial traffic transiting through the area may be a source of species translocations.
	Wind turbines		A large wind farm is proposed for Northern Hecate Strait, but has not yet been built. The pylons for these windmills may alter currents and create new habitat types.
	Other anthropogenic activities	0	Included within the other external stressors listed.

3. LEVEL 1 RISK ASSESSMENT: SICA

Purpose of Analysis

The Scale, Intensity, Consequence Analysis (SICA) method is a rapid screening tool that relies on expert opinion to assess potential risk on a six-point scale (1 = negligible; 6 = catastrophic). The scope of SICA should always be restricted to the bounds specified during the Scoping stage of ERAEF. The primary goal at this level of ERAEF is to identify low-risk impacts that can be eliminated from further analysis at Level 2.

SICA focuses on assessing the impacts of stressors at the level of an ecosystem component (e.g. Directed species, Habitats) rather than on the individual units of analysis within each component. This approach is necessary at this early stage of ERAEF because assessing impacts of each stressor on all units of analysis would be too cumbersome and time-consuming. For each combination of stressor and ecosystem component, a plausible worst case scenario is used to assess the risk. The worst case scenario is identified by selecting the unit of analysis within a given component that is expected to be most negatively impacted by a stressor (e.g., the most vulnerable species or habitat type). Scale, intensity, and consequence are then assessed for only the selected unit of analysis using the scoring criteria described below, and the risk score assigned to the unit of analysis is used to represent risk for the entire ecosystem component. The rationale for this approach is that if the worst case scenario is deemed to be a low risk, all other units of analysis within the component are also likely to be low risk. When this is the case, analysts can be confident in their decision to exclude the entire ecosystem component from more intensive risk analyses at Levels 2 and 3 of ERAEF.

Expected Outcomes

At the end of the Level 1 SICA assessment, a decision must be made about whether each ecosystem component will be moved forward to a Level 2 assessment. We use the same threshold level of risk as Hobday et al. (2007) used for Australian fisheries: if an ecosystem component has at least one stressor with a risk that scored moderate or higher (≥ 3 on six-point scale), the entire component will be moved forward to a Level 2 Productivity Susceptibility Assessment (PSA). Previous applications in Australia have found that all five components usually proceed forward, but that only a handful of stressors will remain at the end of the SICA stage (e.g., Daley et al. 2007, Griffiths et al. 2007). The most common advantage SICA is thus the ability to screen out low risk stressors, rather than low risk ecosystem components.

Occasionally, an entire ecosystem component will be assessed as low risk during the SICA stage and will not be required to proceed to the more time-intensive PSA. For example, the SICA for the Eastern Australia tuna and billfish pelagic longline fishery eliminated the Habitat component, since all impacts on habitats were assessed as low risk

(Webb et al. 2007). Similarly, the Torres Strait rock lobster trap fishery eliminated the Non-directed Species component since fishery bycatch in the trap gear was minimal (Furlani et al. 2007).

The following sections 3.1 and 2.3 describe the methods and results, respectively, for our pilot study application of SICA to a portion of the Hecate Strait bottom-trawl fishery.

3.1. METHODS

Expert Panel Workshop

In practice, SICA risk scores should be determined in a workshop setting by an expert panel that includes representatives from all stakeholder groups, fishery scientists, managers, and academics with expertise in required areas. For the purpose of this pilot study, the expert panel was limited to the authors of this report, all of whom are part of the Pacific Region Groundfish Science Section of DFO. As a result, the SICA consequence scores presented here do not reflect the best expert opinion available, and should be viewed as the product of a preliminary exercise. Despite this limitation, we feel that the results obtained from the pilot study are adequate to provide insight into the benefits and limitations of applying SICA to a BC groundfish fishery. In addition, the exercise of working through a SICA analysis helps provide understanding of how SICA outcomes inform the scope of the Level 2 PSA analysis. Future applications of SICA to an entire fishery (as opposed to the limited scope of this pilot study) should include a representative list of stakeholders.

Steps to Analysis

Clear documentation of the rationale used to assign risk scores within the workshop must be recorded by the expert panel. This documentation is essential to ensuring consistent application of SICA among fisheries and through time (e.g., repeatability). The SICA scoring form (Table 3-1) should be used to guide participants through the steps of the analysis, as well as to ensure that all steps and decisions are clearly documented.

The SICA method used in the pilot study closely followed the methodology developed by Hobday et al. (2007) for Australian fisheries. The following eight steps describe the methods that were used in the pilot study to complete the SICA scoring sheet. These steps were completed for each combination of stressor and ecosystem component. Each step corresponds to a column in the SICA scoring form, and each row represents the scenario considered for each stressor (Table 3-1). A separate copy of this form was completed for each ecological component.

A web-based data entry tool was developed for the pilot study that allowed users to easily reference SICA selection options and scoring criteria from a series of pull-down menus. This format reduced the need for workshop participants to constantly consult the scoping forms and scoring tables referenced in the following steps.

The time period used when scoring scale and intensity was “the most recent three year period”; however, historical information from earlier periods was often be used to provide a context for decisions. For example, information about the ability of various fish species to recover from low abundances in the past was used to help select a most vulnerable unit of analysis for directed species. In contrast, the time period used when selecting consequence scores was “before the next scheduled ERAEF assessment”.

Table 3-1. Blank SICA scoring form.

Ecological Component: *{Specify one of the following: Directed species, Non-directed species, TEP species, Habitat, or Community}*											
Stressor		**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Operational objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
Direct impact	**Activity**										
Capture (Removal of species/habitats)	Bait collection										
	Fishing										
	Incidental behaviour										
Direct impact without capture	Bait collection										
	Fishing										
	Incidental behaviour										
	Gear loss										
	Anchoring / mooring										
	Navigation / steaming										
Addition or movement of biological material	Discarding catch										
	Onboard processing										
	Translocation of species										
	Stock enhancement										
	Provisioning										
	Organic waste disposal										
Addition of non-biological material	Debris										
	Chemical pollution										
	Exhaust										
	Gear loss										

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Operational objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
	Navigation / steaming										
	Activity / presence										
Disturbance of physical processes	Bait collection										
	Fishing										
	Boat launching										
	Anchoring / mooring										
	Navigation / steaming										
External activities	*{Fill-in as needed}*										
	{Fill-in as needed} …										

The eight steps taken in the pilot study (which follow closely the steps of Hobday et al. (2007)) were as follows:

Step 1. Record the stressor identification score: absence (0) presence (1)

A stressor is defined as an activity that is associated with a potential direct impact. Record the stressor identification score that was assigned to each stressor in Scoping Form S4 (i.e., 0 = absence, 1 = presence) into the first column of the SICA scoring form (Table 3-1). Only those stressors that scored a 1 (presence) will be analysed. Stressors that scored a 0 do not proceed through the remaining steps.

Step 2. Score spatial scale of activity

Assign a score to the spatial scale of the activity using the scoring scheme in Table 3-2. Spatial scale is based on the total areal extent of an activity over the past three years. The longest dimension of the estimated areal extent (i.e., length or width) should be used when assigning the score. Note that spatial scale applies to the scale of the activity on its own rather than on the scale of the interactions between the activity and the worst case scenario under consideration. The intensity of the activity is not considered at this stage, so it does not matter whether an area has been exposed to an activity 1 or 100 times over the specified time period. This type of information gets included at Step 5. For example, for the activity of fishing, areal extent will be calculated as the proportion of the total study area that has been exposed to fishing gear one or more times over the past three years. Maps or calculations describing the distribution of an activity can be used to inform this step. Since multiple stressors can arise from a single activity, this score will not need to be calculated for each individual stressor. In many cases, a previously calculated score can be applied.

Table 3-2. Criteria for assigning spatial scale scores to stressors based on nautical miles (nm).

< 1 nm	1-10 nm	10-100 nm	100-500 nm	500-1000 nm	> 1000 nm
1	2	3	4	5	6

The aerial coverage of the commercial bottom trawl fishery footprint within the pilot study area was calculated to be on the scale of approximately 140 nm long x 80 nm wide when a 2 nm^2 grid was used to measure the footprint.

Step 3. Score temporal scale of activity

Assign a score to the temporal scale of the activity (i.e., the frequency) using the scoring scheme in Table 3-3. For stressors that occur at multiple locations on different days throughout the year, such as fishing, the aggregate number of days that a stressor occurs should be used. For example, if 10 boats each spend 30 days fishing, and the days do not overlap, the aggregate number of days would be 300. If however the same 10 boats all fished the same 30 days, the aggregate number of days would be 30. Only the frequency of the initial event should be scored at this stage. The number of days that a stressor can continue to affect a component after the initial event (e.g., ghost fishing after gear loss) will be considered when assigning intensity scores.

Table 3-3. Criteria for assigning temporal scale scores to stressors.

Decadal (1 day every 10 years)	Every several years (1 day every several years)	Annual (1 – 100 days per year)	Quarterly (100-200 days per year)	Weekly (200-300 days per year)	Daily (300-365 days per year)
1	2	3	4	5	6

Step 4. Choose the plausible worst case scenario for stressor

The selection of the plausible worst case scenario is divided into 3 sub-steps, labelled Steps 4a, 4b, and 4c. The expert panel may wish to draw from a wide range of sources when selecting the worst case scenario, including previous experience (e.g., which species / habitats have shown the highest susceptibility to stressors in the past?) and scientific literature.

Step 4a. Choose the sub-component most likely to be affected by stressor

Identify and record the most vulnerable sub-component for the ecosystem component being assessed. Sub-components are traits associated with each of the five main ecological components. A full list of sub-components for each of the five ecosystem components is given in the following table:

Sub-components for each of the three ecosystem components included in the pilot study (repeated from Table 2-2):

Directed Species	**Non-directed**	**Habitats**
Population size	Population size	Substrate quality
Geographic range	Geographic range	Water quality
Genetic structure	Genetic structure	Air quality
Age/size/sex structure	Age/size/sex structure	Geographic Range
Reproductive capacity	Reproductive capacity	Habitat Structure and Function
Behaviour / movement	Behaviour / movement	

Selection of the most vulnerable sub-component must be made on the basis of highest expected risk for the stressor being assessed. The time period that should be considered when making this choice extends from the current time to the next scheduled ERAEF assessment. The justification for selecting a given sub-component is recorded in the rationale column of the SICA scoring form.

Step 4b. Choose the unit of analysis most likely to be affected by stressor

Choose the most vulnerable unit of analysis for the sub-component selected in Step 4a (i.e. the species, habitat-type or community expected to have the highest consequence score for the selected sub-component). This selection must be made on the basis of highest expected risk for the stressor being assessed. The species, habitat-type, or community (depending on which ecosystem component is being analysed) must be selected from the completed Scoping Form S2. The justification for choosing the unit of analysis should be recorded in the rationale column. Guidance for choosing the most vulnerable unit of analysis for habitat types is provided in Box 1.

Box 1: Identifying Vulnerable Habitat Types

The following factors should be considered when choosing the most vulnerable habitat-type in Step 4b of SICA:

1) **Benthic fauna associated with habitat.** The presence of slow-growing bioengineers, such as coral or sponge reefs, usually indicates a vulnerable habitat that will take decades or centuries to recover from structural damage.

2) **Specific features of seafloor habitats that make them vulnerable, including geomorphology, substrate-type, and natural disturbance regime.** For example, bottom-contacting gears have greater impacts on low energy sites (i.e., low frequency of natural disturbance) than on high-energy sites. In addition, the impacts of bottom trawl gears are initially greater on sandy and muddy bottoms than on hard, complex bottoms. However, the duration of impacts is usually greater on hard-complex bottoms than on sandy or muddy bottoms.

3) **The frequency with which habitat-types are impacted by the stressor.** For habitats that have similar benthic fauna, seafloor structures, and natural disturbance regimes, those that are impacted more frequently by a stressor are likely to be the most vulnerable.

Step 4c. Select the most appropriate operational objective

To provide linkage between the SICA consequence score and the management objectives, the most appropriate operational objective for each sub-component is chosen. The most relevant operational objective from Scoping Form S3 is recorded in the 'operational objective' column in the SICA scoring form (Table 3-1). SICA can only be performed on operational objectives agreed as important for the fishery and entered into Scoping Form S3 during the scoping stage.

As an example of how steps 4a – 4c are used to identify a plausible worst case scenario, we consider the stressor of 'capture due to fishing' on directed species. The expert panel workshop for the pilot study first identified population size as the most vulnerable sub-component at step 4a because it is well established that fish population sizes can be reduced by high catch rates. At step 4b, Pacific Cod was identified as the most vulnerable unit of analysis because it is one of the most heavily targeted species, as shown by high landed catch. Furthermore, the stock has been a conservation concern in the past which demonstrates high susceptibility. At step 4c, the maintenance of biomass above biological reference points was identified as the most appropriate objective because this objective has been identified by Fisheries and Aquaculture Management in DFO as a key operational objective for directed species under the Sustainable Fisheries Framework.

Step 5. Score the intensity of the stressor for the plausible worst case scenario

Intensity is a measure of the acuteness of the expected negative impact on the most vulnerable unit of analysis (Step 4b), and should be assessed in relation to the selected operational objective (Step 4c). Depending on the nature of a stressor, it may be related to the level of effort, density, amount of an activity, or the strength of the stressor. Intensity is scored based on three components: (i) the level of impact imposed on the plausible worst case scenario by the stressor, (ii) the temporal scale of the interaction, and (iii) the spatial scale of the interaction. Thus, if the stressor was 'capture due to fishing' and the plausible worst case scenario was the maintenance of Pacific Cod population size above a given threshold, intensity should be thought of in terms of the impact all trawl fishing could have on population size given current levels of fishing effort. An intensity score should be selected from Table 3-4 and recoded in the SICA scoring form (Table 3-1). A rationale for the selected score should be included in the "Rationale" column of the form.

Table 3-4. Criteria for selecting intensity scores. Where two rows are given under for single score, the score can be selected if either row is appropriate.

		Description		
Level	**Score**	**Level of impact**	**Temporal scale**	**Spatial scale**
Negligible	1	Low	Rare	Few restricted locations
Minor	2	Low	Rare	Widespread
		Low	Reasonably often	Few restricted locations
Moderate	3	Moderate	Reasonably often	Widespread
		High	Reasonably often	Localized
Major	4	High	Reasonably often	Widespread
Intense	5	High	Frequent	Widespread
		Very high	Reasonably often	Localized
Very Intense	6	Very high	Continual	Widespread

Step 6. Score the consequence of intensity for that component

Adverse effects and their consequence on selected indicators are components of risk. Within ERAEF, the potential risk associated with a stressor is assessed using the consequence scoring criteria provided in Table 3-5 and Table 3-6. Consequence scores provide a qualitative measure of risk incurred by an ecological component as a result of a fishery or external stressor. They are based on the expected magnitude of impact that will occur as a result of a stressor. For each plausible worst case scenario evaluated (i.e., each row in the SICA scoring sheet), the expert panel must identify which consequence score they believe best characterizes the level of risk caused by the stressor. The time period considered when making this selection should extend from the current time to the next scheduled assessment. Assigned scores will be based on existing information and/or the expertise of the assessment panel. The scale and intensity scores assigned in Steps 1 to 5 are not directly used to select a consequence score in Step 6. Rather, the first six steps are intended to provide the assessors with a general context for selecting consequence scores. In many senses, this is the most important step in the Level 1 analysis, since the consequence scores alone are the final determinant of whether the ecosystem component advances to Level 2.

Table 3-5 provides the general six-point scale used to score consequence (common to all ecological components). Table 3-6 provides more specific criteria that have been tailored to individual sub-components and operational objectives. The more detailed criteria in Table 3-6 are used by the expert panel to assign a consequence score. The rationale for assigning each consequence score must be documented on the SICA scoring form (Table 3-1). The rationale should be used to link impact to consequence by showing the pathway that was considered. In the absence of agreement by the expert panel or information, the highest consequence score considered plausible (i.e., the worst case scenario) is applied to the stressor.

Table 3-5. General consequence criteria used to score potential risk. A more detailed list of criteria specific to individual sub-components and operational objectives are provided in Table 8.

Level	Score	Description
Negligible	1	Negligible impact on stock/habitat/community
Minor	2	Minimal impact on stock/habitat/community structure or dynamics
Moderate	3	Maximum impact that still meets an objective (e.g. sustainable level of impact such as full exploitation rate for a target species).
Major	4	Wider and longer term impacts (e.g. long-term decline in CPUE)
Severe	5	Very serious impacts occurring, with relatively long time period likely to be needed to restore to an acceptable level (e.g. serious decline in spawning biomass limiting population increase)
Critical	6	Widespread and permanent/irreversible damage or loss will occur-unlikely to ever be fixed (e.g. extinction)

Table 3-6A. Directed & Non-directed Species Components: consequence criteria used to score potential risk for specific operational objectives related to each sub-component. The time period used when scoring consequences is "until next scheduled assessment".

Sub-component	Score / level					
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Population size*	**1. Population size** Negligible impact on population size.	**1. Population size** Stressor may contribute to small, short-term fluctuations in population size, but no long-term declines observed.	**1. Population size** Population size has been reduced to a level associated with exploitation rates at MSY, but long-term recruitment dynamics not adversely damaged.	**1. Population size** Population size is reduced enough that declines are affecting recruitment state of stocks and/or their capacity to increase.	**1. Population size** Likely to cause local extinctions if continued in longer term.	**1. Population size** Local extinctions are imminent/ immediate.
Geographic range	**2. Geographic range** Negligible impact on geographic range.	**2. Geographic range** Change in geographic range due to Stressor is most likely to be < 5% of original range.	**2. Geographic range** Change in geographic range due to Stressor is most likely to be 5% - 10% of original range.	**2. Geographic range** Change in geographic range due to Stressor is most likely to be 10% - 25% of original range.	**2. Geographic range** Change in geographic range due to Stressor is most likely to be 25 - 50% of original range.	**2. Geographic range** Change in geographic range due to Stressor is most likely to be > 50% of original range.
Genetic structure	**3. Genetic structure** Negligible impact on genetic structure.	**3. Genetic structure** Change in frequency of genotypes, effective population size or number of spawning units due to Stressor is most likely to be < 5% of original.	**3. Genetic structure** Change in frequency of genotypes, effective population size or number of spawning units due to Stressor is most likely to be 5% - 10% of original.	**3. Genetic structure** Change in frequency of genotypes, effective population size or number of spawning units due to Stressor is most likely to be 10% - 25% of original.	**3. Genetic structure** Change in frequency of genotypes, effective population size or number of spawning units due to Stressor is most likely to be 25% - 50% of original.	**3. Genetic structure** Change in frequency of genotypes, effective population size or number of spawning units due to Stressor is most likely to be > 50% of original.
Age / size / sex structure	**4. Age/size/sex structure** Negligible impact on age/size/sex structure.	**4. Age/size/sex structure** Change in age / size / sex structure is possible due to Stressor, but change is unlikely to have an	**4. Age/size/sex structure** Change in age / size / sex structure is almost certain to occur as a result of Stressor; but	**4. Age/size/sex structure** Change in age / size / sex structure is almost certain to occur as a result of Stressor.	**4. Age/size/sex structure** Change in age / size / sex structure is almost certain to occur as a result of	**4. Age/size/sex structure** Change in age / size / sex structure is almost certain to occur as a result of

* Modified from Hobday et al. (2007) version.

Sub-component	Score / level					
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
		impact on population dynamics.	adverse impacts on long-term recruitment dynamics are unlikely.	Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original structure is likely 1 - 5 generations.	Stressor. Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original structure is likely 5 - 10 generations.	Stressor. Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original structure is likely > 10 generations.
Reproductive capacity	**5. Reproductive capacity** Negligible impact on reproductive capacity.	**5. Reproductive capacity** Change in reproductive capacity is possible due to Stressor, but change is unlikely to have an impact on population dynamics.	**5. Reproductive capacity** Change in reproductive capacity is almost certain to occur as a result of Stressor; but adverse impacts on long-term recruitment dynamics are unlikely.	**5. Reproductive capacity** Change in reproductive capacity is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original capacity is likely 1 – 5 generations.	**5. Reproductive capacity** Change in reproductive capacity is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original capacity is likely 5 - 10 generations.	**5. Reproductive capacity** Change in reproductive capacity is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Time to recover to original capacity is likely > 10 generations.
Behaviour / movement	**6. Behaviour/ movement** Negligible impact on behaviour / movement. Time taken to recover to pre-disturbed state likely to be on the scale of hours.	**6. Behaviour/ movement** Change in behaviour / movement due to Stressor is possible, but is unlikely to have an impact on population dynamics. Time to return to original behaviour is likely on the scale of days to weeks.	**6. Behaviour/ movement** Change in behaviour / movement is almost certain. Adverse effects on long-term dynamics are plausible but unlikely. Time to return to original state likely weeks to months.	**6. Behaviour/ movement** Change in behaviour / movement is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Time to return to original behaviour likely months to years.	**6. Behaviour/ movement** Change in behaviour / movement is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Time to return to original behaviour likely years to decades.	**6. Behaviour/ movement** Change in behaviour / movement is almost certain. Adverse impacts on long-term recruitment dynamics are likely. Population unlikely to return to original behaviour.

Table 3-6-B. Habitat Component: consequence criteria used to score potential risk for specific operational objectives related to each sub-component for Habitats. The time period used when scoring consequences is "until next scheduled assessment".

Sub-component	Score / level					
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Substrate quality	**1. Substrate quality** Negligible impact on substrate quality. Time to recover to pre-disturbed state likely on the scale of hours.	**1. Substrate quality** Change in substrate quality is possible due to Stressor, but long-term effects are likely negligible. Time to recover from local impact likely on the scale of days to weeks. At larger spatial scales, recovery time likely hours to days.	**1. Substrate quality** Change in substrate quality due to Stressor is almost certain, and may be widespread. Magnitude of change is likely moderate given (i) percent of area affected, (ii) intensity of impact, and (iii) recovery capacity of substrate. Time to recover from local impact likely weeks to months. At larger spatial scales, recovery time likely days to weeks.	**1. Substrate quality** Change in substrate quality is almost certain, and may be widespread. Magnitude of change may be enough to reduce internal dynamics of substrate and prevent recovery. Possible loss of ecosystem function. Time to recover from local impact likely months to years. At larger spatial scales, recovery time likely weeks to months.	**1. Substrate quality** Widespread change in substrate quality is almost certain with 50-95% of the habitat affected or removed by the Stressor. Magnitude may be severe enough to endanger long-term survival of habitat, and will likely cause changes in ecosystem function. Time to recover likely years to decades.	**1. Substrate quality** Widespread change in substrate quality is almost certain with > 90% of the habitat destroyed or dynamics changed in a major way by Stressor.
Water quality	**2. Water quality** Negligible impact on water quality. Time taken to recover to pre-disturbed state likely on the scale of hours.	**2. Water quality** Change in water quality is possible due to Stressor, but long-term effects are likely negligible. Time to recover from local impact likely on the scale of days to weeks. At larger spatial scales, recovery time likely hours to days.	**2. Water quality** Change in water quality due to Stressor is almost certain. Magnitude of change is likely moderate. Time to recover from local impact likely weeks to months. At larger spatial scales, recovery time likely days to weeks.	**2. Water quality** Change in water quality due to Stressor is almost certain. Magnitude of change is likely moderate to high. Time to recover from local impact likely on the scale of months to years. At larger spatial scales, recovery time likely weeks to months.	**2. Water quality** Widespread change in water quality is almost certain with 50-95% of the habitat affected or removed. Magnitude may be severe enough to endanger long-term survival of habitat, and will likely cause changes in ecosystem function. Time to recover likely years to decades.	**2. Water quality** Widespread change in water quality is almost certain with > 90% of the habitat destroyed or dynamics changed in a major way by Stressor.

Sub-component	Score / level					
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Air quality	**3. Air quality** Negligible impact on air quality. Time to recover to pre-disturbed state likely on the scale of hours.	**3. Air quality** Change in air quality is possible due to Stressor, but long-term effects are likely negligible. Time to recover from local impact likely on the scale of days to weeks. At larger spatial scales, recovery time likely hours to days.	**3. Air quality** Change in air quality due to Stressor is almost certain. Magnitude of change is likely moderate. Time to recover from local impact likely weeks to months. At larger spatial scales, recovery time likely days to weeks.	**3. Air quality** Change in air quality due to Stressor is almost certain. Magnitude of change is likely moderate to high. Time to recover from local impact likely on the scale of months to years. At larger spatial scales, recovery time likely weeks to months.	**3. Air quality** Widespread change in air quality is almost certain with 50-95% of the habitat affected or removed. Magnitude may be severe enough to endanger long-term survival of habitat, and will likely cause changes in ecosystem function. Time to recover likely years to decades.	**3. Air quality** Widespread change in air quality is almost certain with > 90% of the habitat destroyed or dynamics changed in a major way by Stressor.
Geographic range	**4. Geographic range** Negligible impact on geographic range or distribution of habitat type. Time to recover to pre-disturbed state likely on the scale of hours.	**4. Geographic range** Reduction in geographic range of habitat type is possible due to Stressor, but changes are temporary. Time to recover from local impact on the scale of days to weeks. At larger spatial scales, recovery time of days to months.	**4. Geographic range** Reduction in geographic range of habitat type is almost certain. Magnitude of reduction is likely moderate. Time to recover from local impact on the scale of weeks to months. At larger spatial scales recovery time of months to one year.	**4. Geographic range** Reduction in geographic range of habitat type is almost certain. Magnitude of reduction may be large enough to threaten ability to adequately recover to original distribution. Possible loss of some ecosystem functions. Time to recover from impact most likely between one year and a decade.	**4. Geographic range** Reduction in geographic range of habitat type is almost certain. Magnitude of reduction likely to cause severe changes in ecosystem function. Time to recover from impact most likely to be > decadal.	**4. Geographic range** Reduction in geographic range of habitat type likely large enough to shift the distribution away from original spatial pattern. Magnitude of impact likely to change dynamics of habitat type in a catastrophic way. Possible that impacts are irreversible. If impacts reversible, recovery period will likely be decades to centuries.

Sub-component	Score / level					
	1 Negligible	2 Minor	3 Moderate	4 Major	5 Severe	6 Intolerable
Habitat structure and function	**5. Habitat structure and function** Negligible change to the internal dynamics of the habitat type (including populations of species making up the habitat type). No detectable change to the internal dynamics of habitat or populations of species making up the habitat. Time taken to recover to pre-disturbed state likely hours to days.	**5. Habitat structure and function** Change in habitat structure and function due to Stressor is possible, but changes are temporary. Time to recover to original state is days to weeks, regardless of spatial scale.	**5. Habitat structure and function** Change in habitat structure and function due to Stressor is likely. To remain in this category, < 50% of total habitat area experiences reductions in structure or function (must be <20% for slow-growing, fragile habitat structures such as reefs) AND time to recover to original state is weeks to months on a local scale, or months to one year on a habitat-wide scale.	**5. Habitat structure and function** Change in habitat structure and function due to Stressor is almost certain. Magnitude of change may be large enough to threaten ability to recover adequately. To remain in this category, < 50% of total habitat area experiences reductions in structure or function (must be <25% for slow-growing, fragile habitat structures such as reefs) AND time to recover to original state is most likely one-year to a decade, regardless of spatial scale.	**5. Habitat structure and function** Change in habitat structure and function due to Stressor is almost certain. Impact on habitat function arises from severe changes to internal dynamics over > 50% of the total habitat area (> 25% for slow-growing, fragile habitat structures such as reefs). Time to recover from impact likely to be > decadal.	**5. Habitat structure and function** Change in habitat structure and function due to Stressor is almost certain. Magnitude of impact likely to change dynamics of habitat in a catastrophic way. Possible that impacts to habitat structure and function are irreversible. Some elements of habitat function may remain, but will require a long-term recovery period on the scale of decades to centuries.

Step 7. Record confidence/uncertainty for the consequence scores

The information used at this level is qualitative and each step is based on expert judgment from industry, managers, conservationists, and scientists. The confidence rating for the consequence score is rated as 1 (low confidence) or 2 (high confidence) using the definitions in Table 3-7.

Table 3-7. Confidence scores.

Confidence	Score	Rationale for the confidence score
Low	1	• Data exist, but are considered poor or conflicting, or • No data exist, or • Substantial disagreement among experts.
High	2	• Data exist and are considered sound, or • Consensus between experts, or • Consequence is constrained by logical consideration.

Step 8. Document rationale for each of the above steps

The rationale forms a logical pathway to the consequence score. It should describe the thought process followed by the panel at each step of the SICA analysis.

3.2. RESULTS

Completed SICA forms for Directed Species, Non-directed Species, and Habitat components are shown in Table 3-8, Table 3-9, and Table 3-10, respectively. A brief overview of key results for each of the three components is provided after these tables.

Table 3-8. SICA form for Directed Species component.

Ecological Component: Directed species											
Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
Capture (Removal of species/ habitats)	Bait collection	0									
	Fishing	1	4	6	Population size	Pacific Cod	1.2	4	3	2	Scale: Areal extent of fishery is approximately 140 nm by 80 nm; fishing occurs >300 days per year. Sub-component: Population size can be reduced by high catch rates. Unit of Analysis: Pacific Cod is one of the most heavily targeted species, as shown by high landed catch. Biomass is believed to be increasing, but the stock has been a conservation concern in the past which demonstrates high susceptibility. Objective: Maintenance of biomass above biological reference points has been identified by *Fisheries and Aquaculture Management* in DFO as a key operational objective for directed species. Intensity: major, fishing mortality is widespread, frequent, and high intensity, although seasonal closures to protect spawning aggregation are expected to reduce impacts. Consequence: moderate, likely that population is fished near MSY levels. Confidence: high, agreement among experts on scenario.
	Incidental behaviour	1	4	6	Population size	Arrowtooth Flounder	1.2	2	1	2	Scale: Sport fishing from trawl boats occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Sub-component: Population size could be reduced due to capture. Unit of Analysis: Arrowtooth Flounder is most likely to be intercepted while targeting Pacific Halibut and has high post-release mortality. Intensity: minor, sport fishing only occurs when anchored so impact is low. Consequence: negligible, catch is very low compared to population size. Confidence: high, agreement among experts on this scenario.

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
Direct impact without capture	Bait collection	0									
	Fishing	1	4	6	Population size	Rex Sole	1.2	3	2	1	Scale: Some uncaught organisms will be impacted by gear for each fishing event due to escapement from the net or interactions with gear. Sub-component: Population size could be reduced due to unobserved fishing mortality. Unit of Analysis: Rex Sole may be particularly vulnerable to escapement mortality because it is a delicate species that does not survive handling well. It also has the smallest body size of directed species in the pilot study, and small body size can increase escapement mortality. Intensity: moderate, most Rex Sole encountering the net are likely captured, so mortality is counted as observed. Consequence: minor, mortality from indirect gear impacts is likely small compared to population size. Confidence: low, no data or expertise to support this scenario.
	Incidental behaviour	1	4	6	Behaviour / movement	Arrowtooth Flounder	6.1	2	1	2	Scale: Sport fishing from trawl boats likely occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Sub-component: behaviour / movement of fish species may be affected due to bait attraction. Unit of Analysis: Arrowtooth Flounder most likely to be affected since they have similar feeding preferences as targeted Pacific Halibut. Intensity: minor, only individuals in the immediate vicinity of anchored boats will be attracted. Consequence: negligible, behaviour / movement would return to normal within a few hours. Confidence: high, agreement among experts of negligible impact.
	Gear loss	0									
	Anchoring / mooring	1	4	4	Behaviour / movement	Southern Rock Sole	6.1	2	1	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal scale is limited because most vessels drift at night while at sea. Sub-component: fish in the vicinity of an anchor or mooring lines may move away. Unit of Analysis: Rock Sole occurs in shallow sandy habitat where there is good anchorage. Intensity is minor because most

Stressor											
Direct impact	Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											vessels moor at docks or use the same anchorage repeatedly. Consequence: negligible, changes in movement / behaviour would only last minutes to hours. Confidence: high, logical consideration suggests minimal interactions.
	Navigation	0									No directed species are expected to collide with boats.
Addition or movement of biological material	Discarding catch	1	4	6	Behaviour / movement	Arrowtooth Flounder	6.1	4	2	2	Scale: Discarding is associated with all fishing events. Sub-component: species that consume discarded organisms (e.g., under-sized or unmarketable directed catch or non-directed catch) may display changes in feeding behaviour and movement patterns. Arrowtooth Flounder are large piscivorous flatfish - they are the highest trophic level of all directed species and thus most likely to feed on discarded fish. Intensity: major, discarding is associated with all fishing events. Consequence: minor, consumption of discarded organisms is expected to have only minor impacts on behaviour / movement, with normal behaviour resuming within a few days. Confidence: high, agreement among experts that impact from feeding on discarded catch is minor.
	Onboard processing	1	4	6	Behaviour / movement	Arrowtooth Flounder	6.1	2	1	2	Scale: On-board processing can occur for all fishing events. Sub-component: species that consume material from on-board processing (e.g., heading and gutting of retained catch) may display changes in feeding behaviour and movement patterns. Unit of Analysis: Arrowtooth flounder are large piscivorous flatfish - they are the highest trophic level of all directed species and thus most likely to feed on waste from on-board processing. Intensity: minor, on-board processing is limited to catches of skate and Pacific cod in the pilot study. Consequence: negligible, high rates of flushing in Hecate Strait are expected to disperse discarded body parts, so impacts on behaviour / movement are likely low. Confidence: high, agreement among experts that impact from feeding on discarded catch waste is minor.

Stressor											
Direct impact	Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
	Translocation of species	1	4	5	Population size	Southern Rock Sole	1.2	3	3	1	Scale: Temporal scale is limited because vessels don't travel between countries or up and down the BC coast on a daily basis. Sub-component: population size could be reduced if introduced benthic invasive species (e.g., tunicates, green crab) affected the native species composition of forage fish or invertebrate prey, or if invasive species were direct predators or competitors. Unit of Analysis: A flatfish species such as Rock Sole that feeds on benthic invertebrates (molluscs, polychaetes) could be impacted. Intensity: moderate, recent risk assessments on invasive tunicates estimate that impacts will likely be limited to coastal regions (Therriault and Herborg 2008b, Herborg et al. 2009, Gillespie et al. 2007 for green crabs) and that commercial fishing vessels are of low - medium importance as a transport vector (Therriault and Herborg 2008a). Consequence: moderate, potential for impacts to alter population size. Confidence: low, potential extent of colonization unknown.
	Stock enhancement	0									
	Provisioning	0									
	Organic waste disposal	1	4	6	Population size	Rex Sole	1.2	2	1	2	Scale: Disposal of organic wastes from boats (e.g., food scraps, sewage) is associated with all fishing trips. Sub-component: Population size and productivity of directed species could be affected if organic wastes caused meiofaunal disturbance that reduced the availability of prey species. Unit of Analysis: A flatfish species with specific habitat requirements, such as rex sole (sand, mud or gravel substrate over 300m deep), may be especially susceptible to benthic meiofaunal disturbance. Intensity: minor, small portions of waste released at a time. Consequence: negligible impact against background of other organic input and high flushing; impacts expected to last hours to days. Confidence: high, constrained by logical considerations.

Stressor											
Direct impact	Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Addition of non-biological material	Debris	1	4	4	Behaviour / movement	Southern Rock Sole	6.1	1	1	2	Scale: Debris (pieces of net, rope, etc.) could be released across the entire fishery footprint and on any given day, but frequency is rare and often accidental. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from garbage in the water column or sea floor. Unit of Analysis: Flatfish species with small ranges and specific habitat requirements, such as Southern Rock Sole, may be more impacted by garbage in the benthic habitat. Intensity of garbage disposal is likely negligible due to improved garbage handling practices and the presence of on-board observers. Consequence: negligible because changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.
	Chemical pollution	1	4	6	Population size	Dover Sole	1.2	2	1	1	Scale: Chemical pollution such as oil leaks can occur across the entire fishery range and on any given day. Sub-component: Population size may be impacted by harm to pelagic eggs or larvae. Unit of Analysis: For flatfish species, year-class strength is highly dependent on mortality during the pelagic stage; Dover Sole have a particularly long pelagic larval stage. Intensity: minor, trawl fleet is small and many boats are moving towards biodegradable hydraulic oils. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait. Confidence: low, no data to support this scenario.
	Exhaust	1	4	6	Population size	Dover Sole	1.2	1	1	2	Scale: Boat exhaust can be emitted across the entire fishery footprint and on any given day. Sub-component: Population size may be impacted by harm to pelagic eggs or larvae. Unit of Analysis: For flatfish species, year-class strength is highly dependent on mortality during the pelagic stage; Dover sole have a particularly long pelagic larval stage. Intensity: negligible, a very small portion of exhaust is expected to settle in water. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait. Confidence: high, logical consideration suggests minimal

Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
											impacts.
	Gear loss	1	4	3	Behaviour / movement	Southern Rock Sole	6.1	1	1	2	Scale: Trawl gear could be lost across the entire study area, but frequency of gear loss is low. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from pieces of gear in the water column or on the sea floor. Unit of Analysis: Flatfish species with small ranges and specific habitat requirements, such as Southern Rock Sole, may be more impacted by gear in benthic habitats. Intensity is negligible because in most cases only a small piece of net is lost; loss of an entire net is uncommon. Consequence: negligible, changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.
	Navigation	1	4	6	Behaviour / movement	Pacific Cod	6.1	2	1	2	Scale: Trawl boats can navigate across the study area and on any day of the year. Sub-component: Behaviour / movement may be impacted if fish avoid noise and lights from boats while they are steaming. Unit of Analysis: Atlantic Cod in the water column are known to dive in response to boats, so Pacific Cod may too. Intensity: minor, Pacific Cod spend most of their time at the bottom where interaction with boats at the surface is minimal. Consequence: negligible, normal behaviour would likely resume within minutes or hours. Confidence: high, agreement among experts of minimal interaction.
	Activity / presence	1	4	6	Behaviour / movement	Pacific Cod	6.1	2	1	2	Scale: Trawl boats can occur across the study area and on any day of the year. Sub-component: Behaviour / movement may be impacted if fish avoid boats. Unit of Analysis: Atlantic cod in the water column are known to dive in response to boats, so Pacific cod may too. Intensity: minor, Pacific cod spend most of their time at the bottom where interactions with boats at the surface are minimal. Consequence: negligible, normal behaviour would likely resume within minutes or hours. Confidence: high, agreement among experts of minimal interaction.

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
Disturbance of physical processes	Bait collection	0									
	Fishing	1	4	6	Population size	Dover Sole	1.2	4	2	1	Scale: Disturbance of physical processes can occur over the same spatial and temporal scale as the fishery. Sub-component: Size of fish populations could be affected due to increased turbidity in the water column affecting feeding behaviour and / or an overall reduction in the productivity of feeding habitats. Unit of Analysis: Dover Sole may be particularly sensitive to benthic disturbance since they inhabit muddy habitats that are most likely to be disturbed by trawling. Intensity: major, disturbance can occur over broad temporal and spatial scales. Consequence: minor - despite a 50 year history of trawl fishing in the study area, Dover sole still maintain a viable population size. Confidence: low, no data or expertise to support scenario.
	Boat launching	0									
	Anchoring / mooring	1	4	4	Behaviour / movement	Southern Rock Sole	6.1	1	1	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal Scale is limited because most vessels drift at night while at sea. Sub-component: Fish may move away from bottom habitat that has been disturbed by anchors. Unit of Analysis: Rock Sole occurs in shallow sandy habitat where there is good anchorage. Intensity: negligible, most vessels moor at docks or use the same anchorage repeatedly and only a very small portion of bottom habitat would be affected by anchoring. Consequence: negligible, changes in movement / behaviour would only last minutes to hours. Confidence: high, agreement among experts of minimal interaction.
	Navigation	0									
External activities	Other capture fisheries	1	4	6	Population size	Pacific Cod	1.2	3	3	1	Scale: Other commercial fisheries, as well as aboriginal and recreational fisheries, catch species that are directed catch for the trawl fishery.

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
											Combined, these fisheries occur year round and cover almost all of the study area. Sub-component: Population size is most likely to be affected by the removal of individuals by other fisheries. Unit of Analysis: The Pacific Cod stock in this area has been a conservation concern in the past, which suggests that it may be more vulnerable to non-directed catch by other fisheries. Intensity: moderate, Pacific Cod are not targeted by other commercial fisheries. Consequence: moderate, non-directed harvest of Pacific Cod could cause a notable decline in population size. Confidence: low, Pacific cod populations are highly variable and stock assessment has not been updated since 2005. Little data available on recreational or First Nations catch.
	Aquaculture	1	2	6	Behaviour / movement	Southern Rock Sole	6.1	3	1	1	Scale: Shellfish and finfish aquaculture operations in this area are restricted to localized sites along shore. Sub-component: The accumulation of organic wastes (food, feces) under or near aquaculture operations can alter substrate and water quality (DFO 2004). For species included in this pilot study, behaviour and movement are most likely affected due to attraction or repulsion from the area under aquaculture operations. Unit of Analysis: Southern Rock Sole may be most affected because they have specific habitat requirements for shallow, sandy bottom, and are thus distributed closer to shore. Intensity: moderate, potentially intense impacts on a localized scale. Consequence: moderate, only a small portion of the population is expected to interact with localized aquaculture facilities; time taken to recover to original feeding behaviour is expected to be days to weeks. Confidence: low, no data or expertise to support scenario.
	Coastal development	1	3	6	Population size	Southern Rock Sole	1.2	2	2	1	Scale: Coastal development in this area includes infrastructure associated with four small townships (< 20,000 residents in total), ferry terminals, airports, port development, fish processing plants, a cruise ship

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											dock, and logging infrastructure. Sub-component: Population size could be affected if disposal of sewage and other waste caused meiofaunal disturbance that reduced the availability of prey species. Unit of Analysis: Southern Rock Sole may be most affected because they have specific habitat requirements for shallow, sandy bottom, and are thus distributed closer to shore. Intensity: moderate, potentially intense impacts on a localized scale. Consequence: minor, only a small portion of the population is expected to interact with coastal developments. Confidence: low, no data or expertise to support scenario.
	Logging	1	2	6	Population size	Southern Rock Sole	1.2	2	1	2	Scale: Pulp mills and log sorting, dumping, and storage operations occur in marine environments within the study area, but are restricted to coastal sites. Sub-component: The activity can result in considerable accumulation of pulp, wood, and bark debris on the seafloor near sites (within a few hundred meters for log dumps; Williamson et al. 2000). Physical and chemical changes to substrate quality may affect fish population size due to reduced habitat productivity in these areas. Unit of Analysis: Southern Rock Sole may be most affected because they have specific habitat requirements for shallow, sandy bottom, and are thus distributed closer to shore. Intensity: minor, impacts of log dumps are localized and impacts likely low as fish can move to other areas. Consequence: negligible, at current scale of activity, impacts are unlikely to cause population size to decline. Confidence: high, agreement among experts of minimal interaction.
	Shipping traffic	1	4	6	Behaviour / movement	Southern Rock Sole	6.1	2	1	2	Scale: Marine traffic, including cruise ships, ferries, and cargo shipping occurs year-round throughout the pilot study area. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from oil spills and gray water or debris disposal in the water column or on the sea floor. Unit of Analysis: Flatfish species with small ranges and

Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
											specific habitat requirements, such as Southern Rock Sole, may be more impacted by shipping waste products in the benthic habitat. Intensity of waste disposal of spillage is minor due to infrequency of events and small amounts of materials released on a regular basis. Tanker ship traffic within the area is rare due to a voluntary tanker exclusion zone. Consequence: negligible, changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.

Table 3-9. SICA form for Non-directed Species component.

Ecological Component: Non-directed species

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Capture (Removal of species/ habitats)	Bait collection	0									
	Fishing	1	4	6	Population size	Flathead Sole	1.2	4	3	1	Scale: Areal extent of fishery is approximately 140 nm long by 80 nm wide; fishing occurs >300 days per year. Sub-component: Population size can be reduced due to high catch rates. Unit of Analysis: Landings of Flathead Sole have been high compared to other non-directed species over the past 15 years, with landings greater than 55, 000 kg in 2005. Intensity: major, fishing activity is widespread, frequent, and high intensity. Consequence: moderate, fishery overlap with species range is relatively high and a slight decline in Flathead Biomass is apparent in the Hecate Strait synoptic survey since 2005. Confidence: low, a stock assessment for Flathead Sole has never been done in BC.
	Incidental behaviour	1	4	6	Population size	Spiny Dogfish	1.2	1	1	2	Scale: Sport fishing from trawl boats likely occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Unit of Analysis: For the limited non-directed species list in the pilot study, Spiny Dogfish is most likely caught. Intensity is low because sport fishing only occurs when anchored and dogfish are not the species being targeted. Consequence: negligible because catch of Spiny Dogfish from sport fishing off trawl boats is very low and release mortality is low. Confidence: high, agreement among experts.
Direct impact without capture	Bait collection	0									
	Fishing	1	4	6	Population size	Slender Sole	1.2	3	2	1	Scale: Some uncaught organisms will be impacted by trawl fishing gear for each fishing event due to escapement from the net or interactions with gear. Sub-component: Population size could be reduced due to unobserved fishing mortality. Unit of Analysis: Slender Sole may be

Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
											particularly vulnerable to escapement mortality because it is a delicate species that does not survive handling well. It is also has a small body size, which can increase escapement mortality. Intensity: moderate, most Slender Sole encountering the net are likely captured, so mortality is counted as observed. Consequence: minor, mortality from indirect gear impacts is likely small compared to population size. Confidence: low, no data or expertise to support this scenario.
	Incidental behaviour	1	4	6	Behaviour / movement	Spiny Dogfish	6.1	1	1	2	Scale: Sport fishing from trawl boats likely occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Sub-component / Unit of Analysis: behaviour and movement of opportunistic feeders such as Spiny Dogfish may be affected due to bait attraction. Intensity: minor, only individuals in the immediate vicinity of anchored boats will be attracted. Consequence: negligible, behaviour / movement would return to normal within a few hours. Confidence: high, agreement among experts of negligible impact
	Gear loss	0									
	Anchoring / mooring	1	4	4	Behaviour / movement	Butter Sole	6.1	2	1	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal scale is limited because most vessels drift at night while at sea. Sub-component: fish in the vicinity of an anchor or mooring lines may move away. Unit of Analysis: Butter Sole occurs in shallow, mud or silt habitat where there is good anchorage. Intensity is minor because most vessels moor at docks or use the same anchorage repeatedly. Consequence: negligible, changes in movement / behaviour would only last minutes to hours. Confidence: high, logical consideration suggests minimal interactions.
	Navigation	0									

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
Addition or movement of biological material	Discarding catch	1	4	6	Behaviour / movement	Spiny Dogfish	6.1	4	2	2	Scale: Discarding is associated with all fishing events. Sub-component: species that consume discarded organisms (e.g., under-sized or unmarketable directed catch or non-directed catch) may display a change in normal feeding and movement patterns. Unit of Analysis: Spiny Dogfish are high level predators with well-developed prey detection skills, are thus most likely to feed on discarded individuals. Intensity: major, discarding is associated with all fishing events. Consequence: minor, consumption of discarded organisms is expected to have only minor impacts on behaviour and movement; feeding patterns will likely resume within a few days. Confidence: high, agreement among experts that impacts will be minor.
	Onboard processing	1	4	6	Behaviour / movement	Spiny Dogfish	6.1	2	1	2	Scale: On-board processing can occur for all fishing events. Sub-component: species that consume material from on-board processing (e.g., heading and gutting of retained catch) may display a change in normal feeding and movement patterns. Unit of Analysis: Spiny Dogfish are high level predators with well-developed prey detection skills, are thus most likely to feed on waste from on-board processing. Intensity: minor, on-board processing is limited to catches of skate and Pacific Cod in the pilot study. Consequence: negligible, high rates of flushing in Hecate Strait likely disperse discarded body parts so that impacts on behaviour are negligible. Confidence: high, agreement among experts that impacts will be negligible.
	Translocation of species	1	4	5	Population size	Butter Sole	1.2	3	3	1	Scale: Temporal scale is somewhat limited because vessels don't travel between countries or up and down the BC coast on a daily basis. Sub-component: Population size could be reduced if introduced benthic invasive species (e.g., tunicates, green crab) affected the native species composition of forage fish or invertebrate prey, or if invasive species were direct predators or competitors. Unit of Analysis: A flatfish species such

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
											as Butter Sole that feeds on benthic invertebrates (sand dollars, polychaete worms, shrimp) could be impacted. . Intensity: moderate, recent risk assessments on invasive tunicates estimate that impacts will likely be limited to coastal regions (Therriault and Herborg 2008b, Herborg et al. 2009, Gillespie et al. 2007 for green crabs) and that commercial fishing vessels are of low - medium importance as a transport vector (Therriault and Herborg 2008a). Consequence: moderate, potential for impacts to alter population size. Confidence: low, potential extent of colonization unknown.
	Stock enhancement	0									
	Provisioning	0									
	Organic waste disposal	1	4	6	Population size	Butter Sole	1.2	2	1	2	Scale: Disposal of organic wastes from boats (e.g., food scraps, sewage) is associated with all fishing trips. Sub-component: Population size and productivity of directed species could be affected if organic wastes caused meiofaunal disturbance that reduced the availability of prey species. Unit of Analysis: A flatfish species with specific habitat requirements, such as Butter Sole, may be especially susceptible to benthic meiofaunal disturbance. Intensity: minor, small portions of waste released at a time. Consequence: negligible impact against background of other organic input and high flushing; impacts expected to last hours to days. Confidence: high, constrained by logical considerations.
Addition of non-biological material	Debris	1	4	4	Behaviour / movement	Butter Sole	6.1	1	1	2	Scale: Debris (pieces of net, rope, etc.) could be released across the fishery footprint on any given day, but frequency is rare and often accidental. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from garbage in the water column or sea floor. Unit of Analysis: Flatfish species with small ranges and specific habitat requirements, such as Butter Sole, may be more impacted by garbage in

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											the benthic habitat. Intensity of garbage disposal is likely negligible due to improved garbage handling practices and the presence of on-board observers. Consequence: negligible because changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.
	Chemical pollution	1	4	6	Population size	Speckled Sanddab	1.2	2	1	1	Scale: Chemical pollution such as oil leaks can occur across the entire fishery range and on any given day. Sub-component: Population size may be impacted by harm to pelagic eggs or larvae. Unit of Analysis: Speckled Sanddab have a particularly long pelagic larval stage (300+ days, Love 1996). Intensity: minor, trawl fleet is small and many boats are moving towards biodegradable hydraulic oils. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait. Confidence: low, no data or expertise to support this scenario.
	Exhaust	1	4	6	Population size	Speckled Sanddab	1.2	2	1	1	Scale: Boat exhaust can be emitted across the entire fishery range and on any given day. Sub-component: Population size may be impacted by harm to pelagic eggs or larvae. Unit of Analysis: Speckled Sanddab have a particularly long pelagic larval stage (300+ days, Love 1996). Intensity: negligible, a very small portion on exhaust is expected to settle in water. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait. Confidence: high, logical consideration suggests minimal impacts.
	Gear loss	1	4	3	Behaviour / movement	Butter Sole	6.1	1	1	2	Scale: Trawl gear could be lost across the entire study area, but frequency of gear loss is low. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from pieces of gear in the water column or on the sea floor. Unit of Analysis: Flatfish species with small ranges and specific habitat requirements, such as Butter Sole, may be more impacted by gear in benthic habitats. Intensity is negligible because in most cases only a small piece of net is lost; loss of an entire

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
											net is uncommon. <u>Consequence</u>: negligible, changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.
	Navigation	1	4	6	Behaviour / movement	Spiny Dogfish	6.1	2	1	2	<u>Scale:</u> Trawl boats can occur across the study area and on any day of the year. <u>Sub-component</u>: Behaviour / movement may be impacted if fish noise and lights from steaming boats. <u>Unit of Analysis</u>: Spiny Dogfish can occur higher up in the water column than other groundfish species, and thus may be more affected by steaming boats. <u>Intensity</u>: minor, Spiny Dogfish interactions with boats at the surface are likely minimal. <u>Consequence</u>: negligible, normal behaviour would likely resume within minutes or hours. <u>Confidence</u>: high, agreement among experts of minimal interaction.
	Activity / presence	1	4	6	Behaviour / movement	Spiny Dogfish	6.1	2	1	2	<u>Scale</u>: Trawl boats can occur across the study area and on any day of the year. <u>Sub-component</u>: Behaviour / movement may be impacted if fish avoid boats. <u>Unit of Analysis</u>: Spiny Dogfish can occur higher up in the water column than other groundfish species, and thus may be more affected by boat presence. <u>Intensity</u>: minor, Spiny Dogfish interactions with boats at the surface are likely minimal. <u>Consequence</u>: negligible, normal behaviour would likely resume within minutes or hours. <u>Confidence</u>: high, agreement among experts of minimal interaction.
Disturbance of physical processes	Bait collection	0									
	Fishing	1	4	6	Population size	Butter Sole	1.2	4	2	1	<u>Scale</u>: Disturbance of physical processes can occur over the same spatial and temporal scale as the fishery. <u>Sub-component</u>: Size of fish populations could be affected due to increased turbidity in the water column affecting feeding behaviour and / or an overall reduction in the productivity of feeding habitats. <u>Unit of Analysis</u>: Butter Sole may be particularly sensitive to benthic disturbance since they inhabit mud, silt, and sand habitats that are most likely to be disturbed by trawling.

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
											Intensity: major, disturbance can occur over broad temporal and spatial scales. Consequence: minor - despite a 50 year history of trawl fishing in the study area, butter sole still maintain a viable population size. Confidence: low, no data or expertise to support scenario.
	Boat launching	0									
	Anchoring / mooring	1	4	4	Population size	Butter Sole	1.2	1	1	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal scale is limited because most vessels drift at night while at sea. Sub-component: Fish may move away from bottom habitat that has been disturbed by anchors. Unit of Analysis: Butter Sole occurs in shallow sandy habitat where there is good anchorage. Intensity: negligible, most vessels moor at docks or use the same anchorage repeatedly and only a very small portion of bottom habitat would be affected by anchoring. Consequence: negligible, changes in movement / behaviour would only last minutes to hours. Confidence: high, agreement among experts of minimal interaction.
	Navigation	0									
External activities	Other capture fisheries	1	4	6	Population size	Spiny Dogfish	1.2	3	3	2	Scale: Other commercial fisheries, as well as aboriginal and recreational fisheries, catch species that are non-directed catch for the trawl fishery. Unit of Analysis: Spiny Dogfish are targeted by a commercial hook and line fishery, which is allocated 68% of the coastwide dogfish quota in BC. Intensity: moderate, other fisheries are widespread and occur often. Consequence: moderate, directed harvest of Spiny Dogfish by other fisheries could cause a decline in population size; however, a recent assessment suggests quota are near MSY levels. Confidence: high, agreement among experts that other fisheries contribute significantly to Spiny Dogfish catch.

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
	Aquaculture	1	1	6	Behaviour / movement	Starry Flounder	6.1	3	1	1	<u>Scale:</u> Shellfish and finfish aquaculture operations in this area are restricted to localized sites along shore. <u>Sub-component</u>: The accumulation of organic wastes (food, feces) under or near aquaculture operations can alter substrate and water quality (DFO 2004). For species included in this pilot study, behaviour and movement are most likely affected due to attraction or repulsion from the area under aquaculture operations. <u>Unit of Analysis</u>: Starry Flounder may be most affected because they inhabit shallow, nearshore waters during both adult and juvenile stages. <u>Intensity</u>: moderate, potentially intense impacts on a localized scale. <u>Consequence</u>: negligible, only a small portion of the population is expected to interact with localized aquaculture facilities; time taken to recover to original behaviour and movement is expected to be hours to days. <u>Confidence</u>: low, no data or expertise to support scenario.
	Coastal development	1	3	6	Population size	Butter Sole	1.2	3	2	1	<u>Scale:</u> Coastal development in this area includes infrastructure associated with four small townships (< 20,000 residents in total), ferry terminals, airports, port development, fish processing plants, a cruise ship dock, and logging infrastructure. <u>Sub-component</u>: Disposal of sewage and other waste could affect population size if wastes caused meiofaunal disturbance that reduced the availability of prey species, or if pollution affected survival rates of egg or larval stages. <u>Unit of Analysis</u>: Butter Sole may be most affected because individuals in Hecate Strait are a single population with a specific spawning habitat in Skidegate Inlet. <u>Intensity</u>: moderate, potentially intense impacts on a localized scale. <u>Consequence</u>: minor, only a small portion of the population is expected to interact with coastal developments. <u>Confidence</u>: low, no data or expertise to support scenario.
	Logging	1	2	6	Population size	Starry Flounder	1.2	2	1	2	<u>Scale:</u> Pulp mills and log sorting, dumping, and storage operations occur in marine environments within the study area, but are restricted to coastal

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	**Activity**										
											sites. Sub-component: The activity can result in considerable accumulation of pulp, wood, and bark debris on the seafloor near sites (within a few hundred meters for log dumps; Williamson et al. 2000). Physical and chemical changes to substrate quality may affect fish population size due to reduced habitat productivity in these areas. Unit of Analysis: Starry Flounder inhabit shallow, nearshore waters. Intensity: minor, impacts of log dumps are localized and impacts likely low as fish can move to other areas. Consequence: negligible, at current scale of activity, impacts are unlikely to cause population size to decline. Confidence: high, agreement among experts of minimal interactions.
	Shipping traffic	1	4	6	Behaviour / movement	Butter Sole	6.1	2	1	2	Scale: Marine traffic, including cruise ships, ferries, and cargo shipping occurs year-round throughout the pilot study area. Sub-component: Behaviour / movement could be affected due to attraction or repulsion from oil spills and gray water or debris disposal in the water column or on the sea floor. Unit of Analysis: Flatfish species with small ranges and specific habitat requirements, such as Butter Sole, may be more impacted by shipping waste products in the benthic habitat. Intensity of waste disposal of spillage is minor due to infrequency of events and small amounts of materials released on a regular basis. Tanker ship traffic within the area is rare due to a voluntary tanker exclusion zone. Consequence: negligible, changes to behaviour / movement would likely only last hours to days. Confidence: high, agreement among experts of minimal interaction.

Table 3-10. SICA form for Habitat component.

Ecological Component: Habitat

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Capture (Removal of species/ habitats)	Bait collection	0									
	Fishing	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	2	2	1	Scale: Some level of habitat impact is expected for all bottom trawl events. Sub-component: The removal of bioengineer habitat formations by fishery capture could reduce habitat structure and function. Unit of Analysis: The removal of sponge reef structures by bottom trawl has been common in the past (Ardron and Jamieson 2006). Sponge Reef Habitat 3 was selected as the most vulnerable because a portion is outside closed areas. Intensity: low, > 97.5 % of the known area for this habitat type is within closed areas, and closures have been effective in eliminating trawl fishing effort within their boundaries. Consequence: minor, although sponge reef growth is slow (< a few cm / year, Leys and Lauzon 1998) and biogenic matrices may take decades to centuries to recover, further impacts on the overall structure and function of Sponge Reef Habitat 3 is expected to be low given that < 2.5% of current areal extent is vulnerable to capture. Confidence: low, additional undiscovered sponge reef structures may exist within coastal fjords.
	Incidental behaviour	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	1	1	2	Scale: Sport fishing from trawl boats likely occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Sub-component: Recreational hook or trap gear may come in contact with structural habitat formations and inadvertently pull pieces to the surface. Unit of Analysis: Sponge Reef Habitat 3 was selected as the most vulnerable because it is mid-depth and has a sandy bottom, which may be preferable for Pacific Halibut sport fishing. Intensity: negligible, occurs infrequently in a few restricted locations, and chance of gear pulling up a

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
											piece of sponge reef is low. Consequence: negligible, capture by sport fishing gear is not affected to reduce the structure and function of habitat. Confidence: high based on logical constraints.
Direct impact without capture	Bait collection	0									
	Fishing	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	2	2	1	Scale: Some level of habitat impact is expected for all bottom trawl events. Sub-component: Sponge reef structures are brittle and prone to fragmentation with physical contact. Bottom trawl gear has been shown to mechanically damage reef complexes, resulting in pieces of broken skeleton on the seafloor and little to no standing dead sponge (Cook 2008). When large areas are affected, recolonization may be reduced or prevented if sponge larvae are unable to find a substrate of standing dead sponge to settle on (Conway et al. 2001). Unit of Analysis: Sponge Reef Habitat 3 was selected as the most vulnerable because a portion is outside closed areas. Intensity: low, > 97.5 % of the known area for this habitat type is within closed areas, and closures have been effective in eliminating trawl fishing effort within their boundaries. Consequence: minor, although sponge reef growth is slow (< a few cm / year, Leys and Lauzon 1998) and biogenic matrices may take decades to centuries to recover, further impacts on the overall structure and function of Sponge Reef Habitat 3 is expected to be low given that < 2.5% of current areal extent is vulnerable to direct imapacts. Confidence: low, additional undiscovered sponge reef structures may exist within coastal fjords.
	Incidental behaviour	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	2	2	2	Scale: Sport fishing from trawl boats likely occurs across the fishery footprint, and there is likely someone sport fishing on any given evening. Sub-component: Mechanical damage to structural habitats from line gear (including weights) and invertebrate trap gear may occur, which could compromise habitat structure and function. Unit of Analysis: Sponge Reef Habitat 3 was selected as the most vulnerable because it is mid-

Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
											depth and has a sandy bottom, which may be preferable for halibut sport fishing. Intensity: minor, occurs infrequently in a few restricted locations. Consequence: minor, sport fishing from trawl boats occurs infrequently in sponge reef habitats, and impacts are expected to be localized. Confidence: high based on logical constraints.
	Gear loss	0									
	Anchoring / mooring	1	4	4	Habitat structure and function	Sponge Reef 3	5.1	2	2	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal scale is limited because most vessels drift at night while at sea. Sub-component: Anchors and chains that come in contact with rigid habitat structures could cause pieces to break-off main structure, which could affect overall habitat structure and function. Unit of Analysis: Sponge Reef Habitat 3 (mid-depth, low relief, and sandy bottom) likely provides the best anchorage. Intensity: minor, most vessels drift at night when at sea; especially when in deep, open waters such as sponge reef habitats. Consequence: minor, trawl boats anchoring within sponge reef habitat is believed to be infrequent enough that it does not pose a threat to habitat structure and function. Confidence: low, data on anchor sites was not examined.
	Navigation	0									
Addition or movement of biological material	Discarding catch	1	4	6	Water quality	Sponge Reef 3	1.1	1	1	2	Scale: Discarding of live or dead individuals can occur for all fishing events. Sub-component: Discards could accumulate in benthic habitats and affect water quality as they break down. Unit of Analysis: A large portion of Sponge Reef Habitat 3 is located within the North Reef Complex near Banks Island, and has a higher density of trawl activity in neighboring areas than other reefs. Intensity: negligible, benthic habitats unlikely to be affected as discarded materials are most likely rapidly taken up by predators. Consequence: negligible impacts expected on water quality near sponge reef habitats. Confidence: high; constrained by

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											logical considerations.
	Onboard processing	1	4	6	Water quality	Sponge Reef 3	1.1	1	1	2	Scale: On-board processing can occur for all fishing events. Sub-component: Discarded materials could accumulate in benthic habitats and affect water quality as they break down. Unit of Analysis: A large portion of Sponge Reef Habitat 3 is located within the North Reef Complex near Banks Island, and has a higher density of trawl activity in neighboring areas than other reefs. Intensity: negligible, benthic habitats unlikely to be affected as discarded materials are most likely rapidly taken up by predators. Consequence: negligible impacts expected on water quality near sponge reef habitats. Confidence: high; constrained by logical considerations.
	Translocation of species	1	4	5	Habitat structure and function	Sponge Reef 5	5.1	2	1	1	Scale: Temporal scale is limited because vessels don't travel between countries or up and down the BC coast on a daily basis. Sub-component: Invasive tunicates, or other not-yet apparent encrusting invasive species, could overgrow and smoother living sponges, resulting in reductions in habitat function. Unit of Analysis: Recent risk assessments on invasive tunicates estimate that impacts will likely be limited to coastal regions (Therriault and Herborg 2008b, Herborg et al. 2009). Sponge Reef Habitat 5 may be most vulnerable because it is located within a costal inlet. Intensity: minor, commercial fishing vessels have been estimated to be of low - medium importance as a transport vector (Therriault and Herborg 2008a). Furthermore, the known depth distribution of invasive tunicates on the North American Pacific coast (intertidal to 65 m) does not overlap with that of sponge reefs habitats in the Queen Charlotte Basin (140 to 200 m). Consequence: negligible, a pathway through which invasive tunicate species introduced by trawl vessels could impact sponge reef habitats within the study area is not apparent based on current knowledge. Confidence: low, the true risk to sponges from

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
											invasive species is not known due to lack of past experience.
	Stock enhancement	0									
	Provisioning	0									
	Organic waste disposal	1	4	6	Water quality	Sponge Reef 3	1.1	2	1	2	Scale: Disposal of organic wastes from boats (e.g., food scraps, sewage) is associated with all fishing trips. Sub-component: Overall volume of waste to reach / accumulate in benthos is likely small, however, if it did, it could affect meiofaunal communities and re-suspended sediments taken up by suspension feeding sponges. Intensity: minor, small portions of waste released at a time. Consequence: negligible impact against background of other organic input and high flushing; impacts expected to last hours to days. Confidence: high; constrained by logical considerations.
Addition of non-biological material	Debris	1	4	4	Substrate quality	Sponge Reef 3	3.1	1	1	2	Scale: Debris (pieces of net, rope, etc.) could be released across the entire study area and on any given day, but frequency is rare and often accidental. Sub-component: Substrate quality for sponge reef larval settlement could be reduced or enhanced by debris. Intensity: negligible, gear is not deployed within sponge reef closures and negative impacts of lost gear expected to be low. Consequence: negligible. Confidence: high, agreement among experts of minimal impact.
	Chemical pollution	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	2	1	1	Scale: Chemical pollution such as oil or gas leaks can occur across the entire fishery range and on any given day. Sub-component: Habitat structure and function for habitats dominated by filter feeders could be compromised due to feeding on chemically contaminated particles. Intensity: minor, trawl fleet is small and many boats are moving towards biodegradable hydraulic oils and accidental oil leaks are likely small. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait. Confidence: low, no data or expertise to support this

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											scenario.
	Exhaust	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	1	1	2	Scale: Boat exhaust can be emitted across the entire fishery range and on any given day. Sub-component: Habitat structure and function for habitats dominated by filter feeders could be compromised due to feeding on chemically contaminated particles. Intensity: negligible, a very small portion on exhaust is expected to settle in water. Consequence: negligible due to low intensity and high rates of flushing in Hecate Strait; impacts on population size are likely very small. Confidence: high, logical consideration suggests minimal impacts.
	Gear loss	1	4	3	Substrate quality	Sponge Reef 3	3.1	1	1	2	Scale: Gear could be lost across the entire study area, but frequency of trawl fishery gear loss is low. Snagging of mesh nets caught in sponge structure may occur, but mesh more likely to tear than remain in habitat. Sub-component: Substrate quality for larval settlement of benthic species could be reduced or enhanced by a lost trawl net. Unit of Analysis: Sponge Reef Habitat 3 has the highest density of trawl activity in neighbouring areas. Intensity: negligible, gear is not deployed within sponge reef closures and negative impacts of lost gear expected to be low. Consequence: negligible. Confidence: high, agreement among experts of minimal interaction.
	Navigation	0									
	Activity / presence	1	4	6	Habitat structure and function	Sponge Reef 5	5.1	1	1	2	No clear mechanism through which the presence of fishing vessels alone would affect sponge reef structure or function. High confidence in negligible effect.
Disturbance of physical processes	Bait collection	0									
	Fishing	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	3	3	1	Scale: Rates of sedimentation are increased temporarily after bottom-trawl gear passes over an area; this impact is expected for all bottom trawl fishing events. Sub-component: Suspended sediments in the water column can be trapped and retained on sponge reefs. Sponge reef

Stressor: Direct impact	Stressor: Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
											habitat is typically stable, with low levels of natural disturbance and sediment input (Conway et al. 2007). It is unknown if the introduction of an additional sediment load could exceed a maximum tolerable limit (Jamieson et al. 2007). Since larval attachment requires solid surfaces, too much sediment could restrict colonization. Unit of Analysis: A large portion of Sponge Reef Habitat 3 is located within the North Reef Complex near Banks Island, and has a higher density of trawl activity in neighboring areas than other reefs. Intensity: moderate, most (but not all) trawl activity in recent years has been several kilometers from known sponge reef complexes, and it is expected that much of the sediment load would dissipate within the water column before reaching sponges. Consequence: moderate. Confidence: low, no data or expertise to inform this scenario.
	Boat launching	0									
	Anchoring / mooring	1	4	4	Habitat structure and function	Sponge Reef 3	5.1	1	1	2	Scale: Vessels could drop anchor at any position across the pilot study area. Temporal scale is limited because most vessels drift at night while at sea. Sub-component: Impact and movement of anchors and chains on the seafloor could introduce sediments to the water column that become trapped or retained on sponge reefs. Increased sediment loads on reefs may interfere with sponge larvae colonization. Unit of Analysis: Sponge Reef Habitat 3 (mid-depth, low relief, and sandy bottom) likely provides the best anchorage. Intensity: negligible, most vessels moor at docks or use the same anchorage repeatedly, and minor increases in sediment load likely to dissipate before reaching reefs. Consequence: negligible, no change to the internal dynamics of the habitat type expected. Confidence: high, logical consideration suggests minimal interactions.
	Navigation	0									

Stressor											
Direct impact	Activity	Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
External activities	Other capture fisheries	1	4	6	Habitat structure and function	Sponge Reef 3	5.1	3	5	1	Scale: Other capture fisheries operating in the vicinity of sponge reef habitats include demersal fisheries that don't use trawl gear (e.g. prawn by trap, hook and line) and various pelagic fisheries (mid-water trawl, salmon trolling). A recommended closure for the prawn by trap fishery in sponge reef areas has been included in the Integrated Fisheries Management Plan since 2009. Sub-component: Potential reductions in habitat structure and function could occur due to other bottom contact gear (e.g., longline, trap) breaking reef structures or mid-water trawl gear coming in contact with the bottom and breaking structures or increasing sedimentation. Unit of Analysis: A recent draft analysis of catch data to support consultations on a Sponge Reef Marine Protected Area in Hecate Strait found that the majority of demersal fishing activity was halibut longline, and was concentrated on the most northern reef complex (Hemerra 2010). This area is primarily within Sponge Reef Habitat 3. Intensity: moderate, impacts very intense and potentially widespread, but infrequent. Consequence: severe, although impacts are currently believed to be rare and localized, time scale to recover could be decades to centuries.
	Aquaculture	1	2	6	Substrate quality	Sponge Reef 3	3.1	1	1	2	Scale: Shellfish and finfish aquaculture operations in this area are restricted to localized sites along shore. Sub-component: The accumulation of organic wastes (food, feces) under or near aquaculture operations can alter substrate quality (DFO 2004). Unit of Analysis: Sponge reef habitat 3 is closest to coastal areas. Intensity: negligible, no aquaculture sites occur in open waters near known sponge reef complexes (Hemerra 2010). Consequence: negligible impacts on substrate quality of sponge reef habitat due to distance from activity. Confidence: High confidence due to logical constraints.
	Coastal	1	3	6	Water quality	Sponge	1.1	2	1	2	Scale: Coastal development in this area includes infrastructure

Stressor											
Direct impact	**Activity**	**Presence (1) Absence (0)**	**Spatial scale (1-6)**	**Temporal scale (1-6)**	**Sub-component**	**Unit of analysis**	**Objective**	**Intensity score (1-6)**	**Consequence (1-6)**	**Confidence (1-2)**	**Rationale**
	development					Reef 3					associated with four small townships (< 20,000 residents in total), ferry terminals, airports, port development, fish processing plants, a cruise ship dock, and logging infrastructure. Sub-component: Disposal of sewage and other waste could affect water quality. Unit of Analysis: Sponge reef habitat 3 is closest to the town of Prince Rupert. Intensity: minor, impacts on water quality from coastal development are likely low intensity because reef complex are located in the open waters of Hecate Strait where rates of flushing are high. Consequence: negligible impacts of water quality expected. Confidence high, agreement among experts and logistical considerations.
	Logging	1	2	6	Habitat structure and function	Sponge Reef 3	5.1	1	1	2	Scale: Pulp mills and log sorting, dumping, and storage operations occur in marine environments within the study area, but are restricted to coastal sites. Sub-component: The activity can result in considerable accumulation of pulp, wood, and bark debris on the seafloor near sites (within a few hundred meters for log dumps; Williamson et al. 2000). Increased sediment loading from these activities could lead to sponge reef mortality through smothering and oxygen deficits (Leyes et al. 2004). Unit of Analysis: Sponge reef habitat 3 has the largest portion of reef near coastal areas. Intensity: negligible, no pulp mill or log dump / sorting sites occur near known sponge reef complexes; reefs occur further offshore than these activities. Consequence: negligible, at current scale of activity, impacts are unlikely to impact substrate quality near sponge reefs. Confidence high, agreement among experts and logistical considerations.
	Shipping traffic	1	4	6	Water quality	Sponge Reef 3	1.1	1	1	2	Scale: Marine traffic, including cruise ships, ferries, and cargo shipping occurs year-round throughout the pilot study area. Sub-component: Oil spills, gray water or debris disposal, and changes in wave action can impact the water quality of marine habitats. Unit of Analysis: The location

Stressor		Presence (1) Absence (0)	Spatial scale (1-6)	Temporal scale (1-6)	Sub-component	Unit of analysis	Objective	Intensity score (1-6)	Consequence (1-6)	Confidence (1-2)	Rationale
Direct impact	Activity										
											of Sponge Reef Habitat 3 receives the highest amount of marine traffic (based on map of 2007 vessel movement trends from Hemmera 2010). Intensity: negligible, the level of marine traffic travelling over reefs is low as most tankers and large shipping vessels transiting past the BC coast travel along the west coast of Haida Gwaii, and vessels that do access ports in Hecate Strait appear to follow a path inside islands along the east coast of the strait (Hemerra 2010). Tanker ship traffic within the area is rare due to a voluntary tanker exclusion zone. Impacts at the depth of sponge reefs are expected to be low intensity. Consequence: negligible impacts on water quality of sponge reef habitats expected. Confidence: high confidence due to logistical considerations.

Directed Species

Nine of the 31 stressors evaluated for Directed species were identified as "not present" during the scoping stage and were assigned consequence scores of zero. These stressors were mostly related to activities that were not undertaken during trawl fishing (e.g., bait collection, provisioning, stock enhancement; Table 3-8). Of the remaining 22 stressors that were determined to be present, 15 were assigned consequence scores of 'negligible' (score = 1), four were assigned consequence scores of minor (score = 2), and three were assigned consequence scores of moderate (score = 3) (Figure 3-1). The expert panel generally had high confidence in assessing stressors as negligible, with 13 of the 15 negligible scores assessed as high confidence. Confidence decreased with increasing consequence scores (Figure 3-1). Three stressors were assigned consequence scores of ≥ 3, which lead to the Directed Species component progressing to a Level 2 assessment in the ERAEF hierarchy (Table 3-11).

Non-directed Species

The final distribution of consequence scores for Non-directed Species was the same as that of Directed Species, although there were slight variations in the confidence scores assigned to individual stressors (Figure 3-2; Table 3-9). For example, risk due to capture by the fishery was assessed as 'consequence = major' for both Directed and Non-directed Species, but Directed Species was assigned a confidence score of high while Non-directed Species was assigned a confidence score of low. Three stressors were assigned consequence scores of ≥ 3, which lead to the Non-directed Species component progressing to a Level 2 assessment in the ERAEF hierarchy (Table 3-11).

Habitats

Note that when assigning SICA scores for the spatial and temporal scales of activities for the Habitat component, the impact of the activity on <u>all</u> habitats within the pilot study area was used rather than on sponge reef habitats alone. The limited scope of the pilot study to sponge reef habitats was introduced when choosing the worst case scenario for each stressor since only five units of analysis were available rather than the full list of habitats that would be expected for a full-scale habitat assessment.

Ten of the 31 stressors evaluated for Habitats were identified as "not present" during the scoping stage and were assigned consequence scores of zero. As with Directed and Non-directed Species, these stressors were mostly related to activities that were not undertaken during trawl fishing (e.g., bait collection, provisioning, stock enhancement; Table 3-10). Of the remaining 21 stressors that were determined to be present, 15 were assigned consequence scores of 'negligible' (score = 1), four were assigned consequence scores of minor (score = 2), one was assigned a consequence score of moderate (score = 3), and one was assigned a consequence score of severe (score = 5) (Figure 3-3). Confidence decreased with increasing consequence scores (Figure 3-3).

Two stressors were assigned consequence scores of ≥ 3, which lead to the Habitat component progressing to a Level 2 assessment in the ERAEF hierarchy (Table 3-11).

Advancement to Level 2 Analysis

A total of 66 combinations of ecosystem component and stressor were determined to be present in the pilot study area and were evaluated at Level 1 using SICA. Results from this analysis identified eight of the 66 component-stressor combinations as needing further analysis at Level 2 based on the criteria of a SICA consequence score of ≥ 3 (summarized in Table 3-11). The remaining 58 component-stressor combinations were identified as posing only negligible or minor risk, and were thus excluded from further consideration at Level 2.

While ERAEF requires that all eight component-stressor combinations with scores ≥ 3 be moved forward to a Level 2 analysis, only two of these are carried forward in our pilot study: (i) the impact of bottom-trawl fishery capture on Directed Species and (ii) the impact of bottom-trawl fishery capture on Non-directed Species (Table 3-11). The primary rationale for our limited scope at Level 2 is that the development of PSA methods to date has focused solely on mortality due to fishery capture (i.e., removal of species or habitats), which has consistently been identified as one of the most high risk impacts during SICA (e.g., Hobday et al. 2010, Williams et al. 2011). The development of PSA methods for non-capture impacts has not yet been completed (Hobday et al. 2007).

While methodological gaps were our primary reason for excluding five 'high risk' component-stressor combinations from further consideration at Level 2, several of these impacts are also being addressed by other risk assessment processes. Risk assessments of invasive tunicate species on the BC coast (Herborg and Therriault 2007, Therriault and Herbog 2008) and of fishery and other anthropogenic impacts on Hecate Strait / Queen Charlotte Sound glass sponge reefs (Hemmera 2010) have recently been completed. Fisheries and Oceans Canada is also in the process of developing a Ecological Risk Assessment methodology for fishery impacts on sensitive benthic areas (DFO 2010), which would include glass sponge reef habitats. Short-term information gains from a Level 2 PSA analysis of these impacts may therefore be small given that existing risk assessments exist.

In the longer-term however, we believe that there are expected benefits from developing PSA methods for impacts other than fishery capture. A consistent approach to risk classification across multiple activities and ecosystem components, such as that potentially provided through an analysis such as PSA, will better support the assessment of cumulative impacts within an ecosystem. We further expand on this topic in Section 5.0.

Table 3-11. List of combinations of ecological component and stressor that were identified as needing further evaluation at Level 2 based on SICA consequence (risk) scores of moderate or higher. Bold font is used to identify the two combinations that were actually evaluated at Level 2 for the current pilot study. The other five combinations were not evaluated at Level 2.

Ecological Component	Stressor		Consequence score	Confidence score
	Direct Impact	Activity		
Directed species	**Capture (removal of species)**	**Fishing**	Moderate (3)	High
	Addition / movement of biological material	Translocation of species (i.e., invasive species)	Moderate (3)	Low
	Capture (removal of species)	Other capture fisheries	Moderate (3)	Low
Non-directed species	**Capture (removal of species)**	**Fishing**	Moderate (3)	Low
	Addition / movement of biological material	Translocation of species	Moderate (3)	Low
	Capture (removal of species)	Other capture fisheries	Moderate (3)	Low
Habitats	Disturbance of physical processes	Fishing	Moderate (3)	Low
	Capture (removal of habitats)	Other capture fisheries	Severe (5)	Low

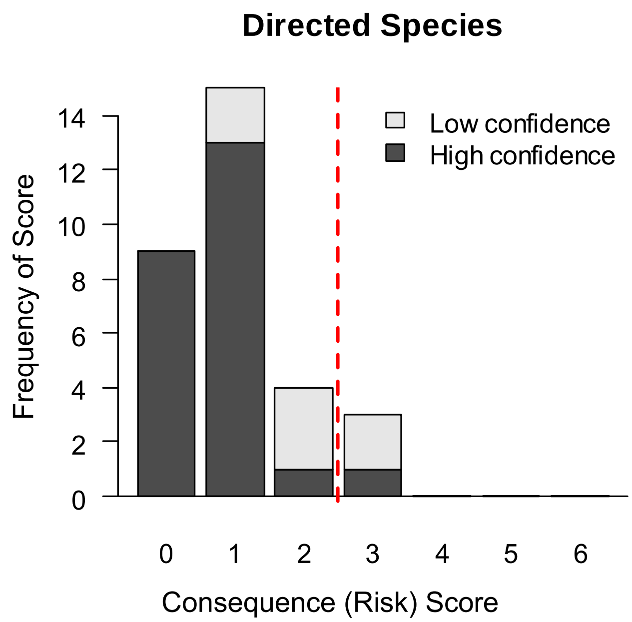


Figure 3-1. Distribution of SICA consequence scores assigned to stressors for Directed Species. Low and high confidence reflects the level of certainty that the expert panel placed on the consequence score they assigned to a stressor. The red dashed line shows the threshold used to identify whether the Directed species component should be moved forward to a Level 2 analysis for one or more stressors.

Figure 3-2. Distribution of SICA consequence scores assigned to stressors for Non-directed Species. Low and high confidence reflects the level of certainty that the expert panel placed on the consequence score they assigned to a stressor. The red dashed line shows the threshold used to identify whether the Non-directed species component should be moved forward to a Level 2 analysis for one or more stressors.

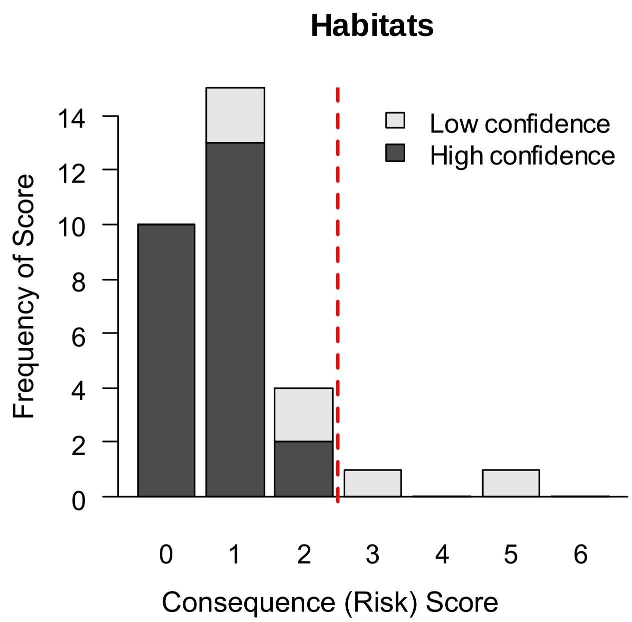


Figure 3-3. Distribution of SICA consequence scores assigned to stressors for the Habitat component. Low and high confidence reflects the level of certainty that the expert panel placed on the consequence score they assigned to a stressor. The red dashed line shows the threshold used to identify whether the Habitat component should be moved forward to a Level 2 analysis for one or more stressors.

4. LEVEL 2 RISK ASSESSMENT: PSA

Productivity Susceptibility Analysis (PSA) was first developed to measure the vulnerability (or risk) of bycatch species to overfishing in Australia (Milton 2001, Stobutzki et al. 2001). The original PSA methodology was expanded within EREAF to include methods for habitats and ecological communities so that it could be applied to ecosystem components beyond single species (Hobday et al. 2007, 2011). PSA measures ecological risk based on two characteristics: 1) the productivity of the impacted unit (i.e., the unit of analysis in ERAEF); and 2) the susceptibility of the unit to harmful fishery impacts. As described in the scoping section, a unit of analysis can refer to a species population, a habitat, or ecological community. For readability, we will refer to units of analysis as species in this section since we only apply PSA to Directed and Non-Directed species in the pilot study. Note however that the same approach would apply to habitats and ecological communities that were assessed at Level 2. Williams et al. (2010) demonstrates the application of PSA to habitat units of analysis and Hobday et al. (2007) identify metrics that could be used for a PSA of ecological communities.

The characterization of risk based on productivity and susceptibility follows the exposure-effects approach to risk assessment used in toxicology rather than a likelihood-consequence approach (Smith et al. 2007). Productivity measures the ability of a species to recover from a depleted state (i.e., resilience). Low productivity indicates high risk because, once impacted, a low productivity species will take longer to recover than a high productivity species. Susceptibility measures the magnitude of negative impact that an activity is expected to have on a species based on the scale and intensity of interactions. In ERAEF, the effects component of the expose-effects approach is represented by productivity, while the exposure component is represented by susceptibility.

4.1. METHODS

For each species, indices of productivity and susceptibility are calculated based on a combination of attributes ranked on a 3-tier scale (1 = low, 2 = medium, 3 = high). The productivity index is calculated as the average of the scores assigned to nine productivity attributes (see below and Table 4-1), while the susceptibility index is calculated as the average of scores assigned to the 11 susceptibility attributes (Table 4-2). An overall index of potential risk is obtained by plotting the resulting productivity and susceptibility index scores against each other (Figure 4-1), and calculating relative risk as the Euclidean distance from the point of origin (Hobday et al. 2007).

An expanded version of PSA has recently been adopted as an assessment tool for fish species captured in US fisheries. Patrick et al. (2009, 2010) made several modifications to the PSA methods developed in Australia (Stobutzki et al. 2001, Milton 2001, Hobday et al. 2007) to better meet the needs of US regulatory agencies. These modifications included: (i) redefining the scoring thresholds used to calculate productivity to be more representative of life history traits of US fish species; (ii) increasing the number of productivity and susceptibility attributes to include more data-intensive measures; (iii) developing a data-quality index that allowed a comparison of uncertainty in risk scores among species; (iv) eliminating the requirement that missing data be assigned a precautionary score of high risk; and (v) developing an attribute weighting system that allows users to modify the weights assigned to each attribute for a given fishery analysis. Rosenberg et al. (2007, 2009) have also made recommendations about PSA methodology for US fisheries. Their recommendations incorporated the new scoring thresholds developed by Patrick et al. (2009, 2010), but retained most other elements of the Hobday et al. (2007) methodology.

We use a slightly modified version of the Patrick et al. (2010) PSA method to assess risk for two of the ecosystem component–stressor combinations that were identified as moderate risk in the Level 1 SICA: (i) the impact of bottom-trawl fishery capture on Directed Species; and (ii) the impact of bottom-trawl fishery capture on Non-directed Species. Since fish species in Canada are similar to or the same as those in many parts of the US, we adopt the attribute scoring thresholds of Patrick et al. (2010). We also adopt the data quality index because it matches well with the types of data sources we used to parameterize our analysis (Table 4-3). We do not apply the attribute weighting option suggested by Patrick et al. (2010). Rather, we allow for equal weighting in order to maintain consistency and transparency among different fishery applications and though time. All modifications we made to the methods of Patrick et al. (20010) are noted in the following descriptions of productivity and susceptibility attributes. Patrick et al. (2010) demonstrated consistency among attributes in each of the productivity and susceptibility indices using correlation analyses between individual attributes and the overall index (with the attribute being evaluated removed). Since the changes we make to the scoring attributes of Patrick et al. (2010) are minor, we do not duplicate these analyses.

We use the three risk status zones (low, moderate, and high) used by Hobday et al. (2007) to identify species that should be moved forward to a Level 3 ERAEF assessment (Figure 4-1). Only species that fall in the high risk zone in Figure 4-1 were moved forward to Level 3. PSA was originally designed as a means to assess relative risk among species, and did not include the three stock status zones (Milton 2001, Stobutzki et al. 2001). The version of PSA developed by Patrick et al. (2010) also focussed on relative risk and did not delineate zones. However, the hierarchical assessment framework of ERAEF requires some threshold level of risk beyond which further assessment work is required at Level 3. We therefore adopt the three zones used by Hobday et al. (2007) to demonstrate how PSA can screen out low-risk units of analysis. A more thorough examination of the acceptability of these boundaries will be necessary prior to a broader-scale application of ERAEF to BC fisheries.

Data sources used to assign scores to productivity and susceptibility attributes include DFO Pacific Region Groundfish databases and various literature sources. Values used to score attributes for each species, as well as the data source used to obtain the value, are summarized in Appendix B.

Table 4-1. Productivity attributes and scoring thresholds. [Reproduced from Patrick et al. (2010), but with the 'intrinsic rate of growth' attribute used by Patrick et al. (2010) excluded. See text for rationale for exclusion.]

		Ranking		
Productivity Attribute	Definition	High (3)	Moderate (2)	Low (1)
Maximum age	Maximum age is a direct indication of the natural mortality rate (M), where low levels of M are negatively correlated with age.	< 10 years	10 – 30 years	> 30 years
Maximum size	Maximum size is correlated with productivity, with large fish tending to have lower levels of productivity, although, this relationship tends to degrade at higher taxonomic levels.	< 60 cm	60 – 150 cm	> 150 cm
Von Bertalanffy growth coefficient (*k*)	The von Bertalanffy growth coefficients measures how rapidly a fish reaches its maximum size, where long-lived, low productivity stocks tend to have low values of *k*.	> 0.25	0.15 - 0.25	< 0.15
Estimated natural mortality (M)	Natural mortality rate directly reflects population productivity; stocks with high rates of natural mortality will require high levels of production in order to maintain population levels.	> 0.40	0.20 – 0.40	< 0.20
Measured fecundity	Fecundity (i.e., the number of eggs produced by a female for a given spawning event or period) is measured here at the age of first maturity.	> 100,000	1000 –10,000	< 1000
Breeding strategy	Breeding strategy (indexed using Winemiller's (1989) method, Table 4-4) provides an indication of the level of mortality that may be expected for offspring in the first stages of life.	0	1 - 3	> 3
Recruitment pattern	Stocks with sporadic and infrequent recruitment success often are long-lived and thus may be expected to have lower levels of productivity. Recruitment success is defined as recruitment greater than the long-term average level.	Highly frequent success (>75% of year classes are successful)	Moderately frequent success (between 10 and 75% of year classes successful)	Infrequent success (< 10% of year classes are successful)
Age at maturity	Age at maturity tends to be positively related with maximum age (tmax); long-lived, lower productivity stocks will have higher ages at maturity than short-lived stocks.	< 2 years	2 – 4 years	> 4 years
Mean trophic level	The position of a stock within the larger fish community can be used to infer stock productivity; lower-trophic-level stocks generally are more productive than higher-trophic-level stocks.	< 2.5	2.5 – 3.5	> 3.5

Table 4-2. Susceptibility attributes and scoring thresholds. [Reproduced from Patrick et al. (2010), but with the ‘impact of fisheries on essential fish habitat’ attribute used by Patrick et al. (2010) excluded. See text for rationale for exclusion.]

Susceptibility Attribute	Definition	Low (1)	Moderate (2)	High (3)
Areal overlap	The extent of geographic overlap between the known distribution of a stock and the distribution of the fishery	< 25% of stock present in area fished	Between 25% and 50% of the stock present in the area fished	> 50% of stock present in the area fished
Geographic concentration	The extent to which the stock is concentrated in small areas	Stock is distributed in >50% if its total range	Stock is distributed in 25% to 50% of its total range	Stock is distributed in <25% of its total range
Vertical overlap	The position of the stock within the water column (i.e., whether demersal or pelagic) in relation to the fishing gear	< 25% of stock is present in the depths fished	Between 25% and 50% of stock is present in the depths fished	> 50% of stock is present in the depths fished
Seasonal migration	Seasonal migrations (i.e. spawning or feeding migrations) either to or from the fishery area could affect the overlap between the stock and the fishery	Seasonal migrations decrease overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations increase overlap with the fishery
Schooling, aggregation, & behavioural responses	Behavioural responses of both individual fish and the stock to overfishing	Behavioural responses of fish decrease catchability of the gear	Behavioural responses of fish do not substantially affect catchability of the gear	Behavioural responses of fish increase catchability of the gear (i.e., hyperstability of catch per unit effort with schooling behaviour)
Morphological characteristics affecting capture	The ability of the fishing gear to capture fish based on their morphological characteristics (e.g., body shape, spiny vs. soft ray fins, etc.)	Species shows a low susceptibility to gear selectivity	Species shows moderate susceptibility to gear selectivity	Species shows high susceptibility to gear selectivity

Table 4-2-cont. Susceptibility attributes and scoring thresholds.

Susceptibility Attribute	Definition	Low (1)	Moderate (2)	High (3)
Desirability or value of the fishery	The assumption that highly values fish stocks are more susceptible to overfishing or becoming overfished by recreational or commercial fisherman owing to increased effort	Stock is not highly valued or desired by the fishery (0% retained; or <12% retained and < \$0.21/ lb) *	Stock is moderately valued or desired by the fishery (13% - 73% retained; \$0.22 - \$0.36 / lb) *	Stock is highly desired or valued by the fishery (> 73% retained; > \$0.37 / lb) *
Management strategy	The susceptibility of a stock to overfishing may largely depend on the effectiveness of fishery management procedures used to control catch	Targeted stocks have catch limits and proactive accountability measures; non-directed stocks are closely monitored	Targeted stocks have catch limits and re-active accountability measures	Targeted stocks do not have catch limits or accountability measures; non-directed stocks are not closely monitored
Fishing rate relative to M	As a conservative rule of thumb, it is recommended that M should be the upper limit of F so as to conserve the reproductive potential of a stock	< 0.5	0.5 – 1.0	> 1.0
Biomass of spawners (SSB) or other proxies	The extent to which fishing has depleted the biomass of a stock in relation to expected unfished levels offers information on realized susceptibility	B is > 40% of B_0 (or maximum observed from time series of biomass estimates)	B is between 25% and 40% of B_0 (or maximum observed from time series of biomass estimates)	B is < 25% of B_0 (or maximum observed from time series of biomass estimates)
Survival after capture and release	Fish survival after capture and release varies by species, region, and gear type, and thus can affect the susceptibility of the stock	Probability of survival > 67%	Probability of survival between 33% and 67%	Probability of survival < 33%

* Scoring thresholds for 'desirability or value of the fishery' attribute have been modified from those of Patrick et al. (2010) to better represent the portion of the BC trawl fishery used in the pilot study. See text for a description of changes.

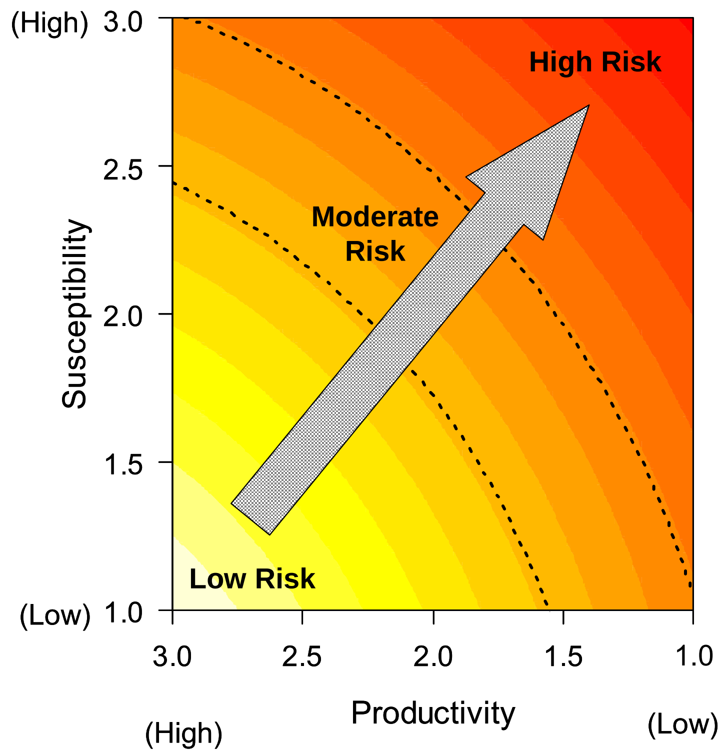


Figure 4-1. Representation of potential risk (i.e., vulnerability) in the Productivity Susceptibility Analysis. The grey arrow and coloured contour lines indicate the axis of increasing risk. Risk is assumed to be lowest for high productivity species with low susceptibility to fishing mortality, and highest for low productivity species with high susceptibility to fishing mortality. Black dotted lines delineate the low, moderate, and high risk zones used by Hobday et al. (2007).

Table 4-3. The five tiers of data quality used when evaluating the productivity and susceptibility of an individual stock. [Reproduced from Patrick et al. (2010)]

Data quality tier	Description	Example
1	Best data. Information is based on collected data for the stock and area of interest that is established and substantial.	Data-rich stock assessment; published literature for which multiple methods are used, etc.
2	Adequate data. Information is based on limited coverage and corroboration, or for some reason is deemed not as reliable as tier-1 data.	Limited temporal or spatial data, relatively old information, etc.
3	Limited data. Estimates with high variation and limited confidence and may be based on studies of similar taxa or life history strategies.	Similar genus or family, etc.
4	Very limited data. Information based on expert opinion or on general literature reviews from a wide range of species, or outside of region.	General data not referenced.
5	No data. When there are no data on which to make even an expert opinion, the person using the PSA should give this attribute a "data quality" score of 5 and not provide a productivity or susceptibility score so as not to bias those index scores. When plotted, the susceptibility or productivity index score will be based on one less attribute, and will be highlighted as such by its related data quality score.	

4.1.1. Productivity Attributes

Productivity refers to the capacity of a stock to recover rapidly from a depleted state. We included nine of the 10 attributes used by Patrick et al. (2010) when calculating a productivity index for Directed and Non-directed pilot study species (Table 4-1).

The intrinsic rate of population growth, *r*, was excluded from the pilot study based on the premise that, when available, estimates should be treated as direct measures of productivity rather than as one of 10 attributes contributing to a productivity index. The intrinsic rate of population growth represents the maximum per capita population growth rate that can occur in the absence of fishing and at the lowest population size (i.e., in the absence of density dependent processes). For most species (especially data-poor species), *r* is difficult to measure (Jennings 2001, Gedamke et al. 2007), but understood to be correlated with key life history taits (Jennings et al. 1998, Denney et al. 2002, Dulvy et al. 2004). The productivity index of the PSA analysis was originally intended to approximate *r* using a suite of well-known life history correlates (Smith et al. 2007). Patrick et al. (2010) suggested that when estimates of the intrinsic rate of population growth are available, the attribute should be heavily weighted so that it would over-ride all other attributes. Since we do not use a weighting scheme and do not have independent estimates of *r* for most species (i.e., our estimate of *r* would likely be derived from the other attributes), we have chosen to eliminate this parameter from the index entirely.

A comparison of the productivity index used for the pilot study (i.e., based on nine attributes) with the productivity index that would have been calculated using only an estimate of *r* (i.e., based on the excluded 10^{th} attribute) for a sub-set of five species showed that the two indices were consistent (Appendix C). This result supports the decision to exclude estimates of *r* from the productivity index; the life history correlates used to approximate *r* in the productivity index appear adequate.

The nine attributes used to score productivity are defined below, along with a brief description of how the estimates of productivity parameters were obtained for each attribute. Of the productivity attributes used within PSA, the natural mortality rate *M* is expected to provide the most reliable approximation of *r*. However, independent estimates of this parameter are rarely available. As a result, productivity indices tend to rely heavily on available estimates of other life history traits (e.g., body size, growth rates). A data-quality score, which is explained below and in Table 4-3, was assigned to each attribute based on the estimation method used. Scoring thresholds used to score productivity attributes as high, moderate, or low, are shown in Table 1.

Maximum age (t_{max}) – Within the productivity index, high maximum age is an indictor of low productivity. Estimates of t_{max} were obtained from the literature, with estimates from the pilot study area being preferable. Estimates for females where used when sex-specific estimates were provided. For species with no published estimates, t_{max} was approximated using a similar species, and the data-quality score was reduced (Table 4-3).

Scoring criteria for t_{max}:

High productivity	Moderate productivity	Low productivity
< 10 years	10 – 30 years	> 30 years

Maximum size – Large body size is used as an indicator of low productivity within the productivity index. Maximum size for stocks within BC was estimated as the 99^{th} percentile of all available length records in the DFO Groundfish GFBio database, which includes biological samples from commercial catch and research surveys. Maximum length could be underestimated if sustained exploitation prior to the observation period reduced the number of big individuals in the population. We don’t believe this concern applies to our pilot study however, since records for the more heavily exploited species (Pacific cod, Dover sole, Petrale sole) extend back to the 1940s and 1950s, which coincides with the development of the BC groundfish trawl fishery. Total length was used for all species except four. Fork length was used for Pacific Cod, Walleye Pollock, Pacific Tomcod, and Arrowtooth Flounder.

Scoring criteria for maximum size:

High productivity	Moderate productivity	Low productivity
< 60 cm	60 – 150 cm	> 150 cm

von Bertalanffy growth coefficient (*k*) – The *k* parameter of the von Bertalanffy length-at-age relationship measures how quickly an individual reaches its maximum size. Within the productivity index, low values indicate a less productive species. Estimates of *k* were obtained from the literature, with estimates from the pilot study area being preferable. Estimates for females where used whenever separate sex-specific estimates were provided. For species with no published estimates, *k* was approximated using a similar species. For the few species in which estimates from similar species were also not available, *k* was approximated based on Froese and Binhlan's (2000) empirical relationship $k = 3/t_{max.}$

Scoring criteria for growth rate *k*:

High productivity	Moderate productivity	Low productivity
> 0.25	0.15 – 0.25	< 0.15

Natural mortality (*M*) – Within the productivity index, a low value of M is an indicator of low productivity. Species-specific estimates of M were obtained from the literature when possible. In some cases these came from empirical studies, while in others they were estimated by population dynamic models as part of a stock assessment. When species-specific estimates were not available, the next best option was to use an estimate from a similar species. Estimates taken from stock assessments that assumed fixed values of *M* (as opposed to estimating *M*) were assumed to be based on a review of similar species. When no suitable proxy species was available, *M* was approximated using Hoeing's (1983) empirical relationship between *M* and t_{max} [$M = 4.306 / (tmax^{1.01})$]. In this case, a data quality score of 4 was assigned to reflect a value that was based on expert opinion or on a general review from a wide range of species (Table 4-3).

Scoring criteria for *M*:

High productivity	Moderate productivity	Low productivity
> 0.40	0.20 – 0.40	< 0.20

Fecundity - Fecundity is defined as the number of eggs (or live young) produced by a female per spawning event. Within the productivity index of Patrick et al. (2010), low fecundity is an indicator of low productivity. While fecundity has been identified as a potential indicator of productivity, several empirical studies have failed to show that high fecundity indicates increased resilience (Denney et al. 1998; Reynolds et al. 2002). We discuss this inconsistency further in the Section 4.2. All fecundity values in the current analysis were taken from the literature. We followed the convention of Patrick et al. (2010) of using fecundity at the age of first maturity; however, detailed estimates of age-specific fecundity were not available from the literature for most species. When a range of fecundity values were given, we selected the lowest end of the range to represent the value expected from a young individual.

Scoring criteria for fecundity:

High productivity	Moderate productivity	Low productivity
> 100, 000	1000 – 10, 000	< 1000

Breeding Strategy – An adapted version of an index of parental investment developed by Winemiller (1989) was used to represent the level of mortality experienced by offspring in the first stages of life (Table 4-4).

Table 4-4. Adapted version of Winemiller (1983) index used to score parental investment. An index of parental investment is calculated by selecting a value for each of the three components, and then summing the three values. Table format reproduced from King and McFarlane (2003).

Component	Attribute	Value
1. Placement of zygotes or larvae	No placement	0
	Zygotes or larvae placed in a special habitat	1
	Zygotes or larvae maintained in a nest	2
2. Parental protection of zygotes or larvae	No parental protection	0
	Brief protection (< 1 month) by one parent	1
	Lengthy protection (> 1 month) by one parent	2
	Brief protection (<1 month) by both parents	2
	Lengthy protection (> 1 month) by both parents	4
3. Nutritive contribution to larvae	No contribution (excluding yolk sac)	0
	Gestation period < 1 month	2
	Gestation period 1 – 2 months	4
	Gestation period > 2 months	8

High parental investment (low juvenile mortality) is used as an indicator of low productivity within the productivity index. King and McFarlane (2003) calculated the Winemiller index for 42 Pacific fish species occurring in BC. When possible, values were taken directly from this study. For species not covered in King and McFarlane (2003), we either assumed an index value based on a similar species or calculated the Winemillar index based on available reproductive information.

Scoring criteria for breeding strategy:

High productivity	Moderate productivity	Low productivity
0	1 - 3	> 3

Recruitment pattern – Fish species with high recruitment variability (i.e., erratic and infrequent recruitment success) tend to have high longevity in order to maintain fitness (Musik 1999). Since high longevity is an indicator of low productivity, the productivity index assumes that high recruitment variability is an indicator of low productivity.

Following the approach of Patrick et al. (2010), recruitment variability was measured as the proportion of years in which recruitment was "successful", where successful is defined as being above the long-term average recruitment level. The theory that high recruitment variability is an indicator of low productivity was developed for teleost fish with high juvenile mortality (Longhurst 2002). High recruitment variability is not expected to be a good indicator of productivity for sharks and skates because they have higher levels of parental investment, and thus, lower levels of juvenile mortality. As a result, we excluded the recruitment pattern attribute when calculating productivity for shark and skate species. This attribute also may not apply to some short-lived, high productivity species that show high recruitment variability (e.g., sardines, herring), and should be more closely evaluated before applying to these species.

Scoring criteria for recruitment pattern:

High productivity	Moderate productivity	Low productivity
Highly frequent success (>75% of year classes are successful)	Moderately frequent success (10 - 75% of year classes are successful)	Infrequent success (< 10% of year classes are successful)

Age-at-maturity (t_{mat}) – A late age-at-maturity is an indictor of low productivity within the productivity index. Estimates of age-at-maturity were taken from the literature. When age-at-maturity was reported as both the age associated with 50% of individuals being mature ($t_{mat50\%}$) and that associated with 100% of individuals being mature ($t_{mat100\%}$), we used $t_{mat50\%}$. Estimates for females where used whenever separate sex-specific estimates were provided.

Scoring criteria for t_{mat}:

High productivity	Moderate productivity	Low productivity
< 2 years	2 – 4 years	> 4 years

Trophic level – The inclusion of this attribute is based on the assumption that species with high trophic levels tend to be less productive than species with low trophic levels. All estimates of trophic level were taken from Froese and Pauly (FishBase 2010). The scoring thresholds applied roughly categorize piscivores to higher trophic levels, omnivores to intermediate trophic levels, and planktivores to lower trophic levels (Patrick et al. 2010).

Scoring criteria for trophic level:

High productivity	Moderate productivity	Low productivity
< 2.5	2.5 – 3.5	> 3.5

4.1.2. Susceptibility Attributes

We measure susceptibility in the same way as Patrick et al. (2010), which expands the definition of susceptibility beyond early PSA applications by including information on fishery management (Table 4-2, Appendix B). Previous applications focussed on the susceptibility of a stock to fishing mortality due to capture (Stobutski et al. 2001, Hobday et al. 2007). For these cases, all susceptibility attributes were related to catchability (i.e., the likelihood of a given species being captured by the gear) and post-capture survival. Patrick et al. (2010) define susceptibility more broadly as the susceptibility of a species to overfishing, which is also dependent on the current status of a species and the management measures in place. Under the Australian ERAEF framework, management effectiveness was dealt with in a post-hoc analysis step called as "Residual Risk Analysis" in which a set of guidelines was used to reduce risk scores for species with mitigating management measures in place (Hobday et al. 2007). We favour the Patrick et al. (2010) approach because it simplifies the number of analyses required. Species with management measures in place that reduce the risk of overfishing (e.g., fishing mortality rates < natural mortality, catch limits, frequent monitoring of stock status) will be assigned lower PSA risk scores. As a result, the intent of the Residual Risk Analysis Stage is embedded in Patrick et al.'s (2010) expanded definition of susceptibility.

We included 11 of the 12 attributes used by Patrick et al. (2010) when calculating a susceptibility index for Directed and Non-directed pilot study species. The 11 attributes used to score susceptibility are defined below, along with a brief description of how values were estimated. Scoring thresholds used to score each attribute as high, moderate, or low, are shown in Table 4-2.

Areal Overlap - Areal overlap measures the proportion of a species distribution within the pilot study area that is impacted by the fishery footprint (i.e., the proportion of the distribution of the species that overlaps with the distribution of the fishery). Greater overlap indicates a higher susceptibility to fishing mortality within the susceptibility index. Patrick et al. (2010) suggest that when records of species occurrence are sparse, inferences of areal overlap can be made using knowledge of depth distributions. This approach was taken for our pilot study because an initial examination of species occurrence based on available records from biological surveys and commercial fisheries showed patchy distributions when mapped using a 2 km x 2 km grid. Not all grids had samples, which meant that a large amount of infilling would have been required to estimate species distribution directly from catch records.

The following steps were taken to infer areal overlap based on depth distribution for each species in the pilot study:

1) Calculate the observed depth range of the species as the 2.5th and 97.5th quantiles of bottom trawl fishery catches along the BC coast between 2007 and 2010.
2) Approximate potential species distribution within the pilot study area based solely on the 95th percentiles of their observed depth range. A 2 km x 2 km grid was used to map species distribution. All grids with bottom depths within the

observed depth range were considered to be part of the potential species distribution.

3) Map the total bottom-trawl fishery footprint in the pilot study area over the past three years using the same 2 km x 2 km grid that was used to map species distribution.
4) Overlay the potential species distribution and fishery footprint maps and calculate the percentage of grids occupied by the species distribution that also contain fishing activity.

The measure of potential species distribution is likely an overestimate of the true species distribution. Preferences for specific habitat types (e.g., sandy bottom, rocky bottom) mean that not all of the observed depth range will be occupied habitat. Despite this potential bias, the approach taken is believed reasonable enough to inform the coarse-scale scoring criteria for the pilot study.

Scoring criteria for areal overlap:

Low susceptibility	Moderate susceptibility	High susceptibility
< 25% of stock present in area fished	25% - 50% of stock present in area fished	> 50% of stock present in area fished

Geographic concentration - Geographic concentration measures the degree to which a species is concentrated into small areas. High geographic concentration, or aggregation, indicates a higher susceptibility to fishing mortality because a small number of fishing events could impact a large proportion of the stock. Patrick et al. (2010) used an index of species distribution first developed by Swain and Sinclair (1993) to quantify geographic concentration. This method estimates the proportion of available area occupied by a stock, with a smaller proportion indicating greater geographic concentration. Fishery-independent survey catch data is used to estimate both the area occupied by the stock (i.e., the survey area covered by 95% of the stock) and the total available area (i.e., the total survey area) using equations 1 to 3 below.

Survey data from the Hecate Strait groundfish synoptic trawl survey (Olsen et al. 2009) was used for the current analysis. The biennial survey is relatively new, with existing time series only including the years 2005, 2007, and 2009. Tows from all years were combined for the analysis. For each species, the 5th percentile of catch density (i.e., the level below which only 5% of all density values occur) was calculated using available survey data. Catch density was measured in units of biomass per area swept by the gear. The 5th percentile of catch density is denoted $c_{5\%}$ in the following equations. The cumulative survey area associated with that 5th percentile, $F(c_{5\%})$, was then calculated as:

(1) $$F(c_{5\%}) = \sum_{i=1}^{h} \sum_{j=1}^{n_i} \frac{A_i}{n_i} I \quad \text{where} \quad I = \begin{cases} 1 & \text{if } y_{ij} \le c_{5\%} \\ 0 & \text{otherwise} \end{cases}$$

where, i is an index for survey stratum, j is an index for survey tow, h is the number of stratum, n_i is the number of tows in stratum i, A_i is the area of stratum i, and y_{ij} is catch density from tow j in stratum i. $F(c_{5\%})$ is thus the area over which catch density is at or below the 5th percentile level of $c_{5\%}$. Strata used to calculate $F(c_{5\%})$ in equation 1 were based on the four depth strata used to design the survey: 10 – 70 m, 70 – 130 m, 130 – 220 m, and 220 – 500 m. The area corresponding to the 95th percentile was calculated from equation 1 as:

(2) $$D_{95\%} = A_T - F(c_{5\%})$$

where, A_T is the total area surveyed. The proportion of survey area occupied by 95% of the stock was then calculated as:

(3) $$\text{Proportion of survey area occupied} = D_{95\%} / A_T .$$

Scoring criteria for geographic concentration:

Low susceptibility	Moderate susceptibility	High susceptibility
Stock is distributed in > 50% of its total range	Stock is distributed in 25% - 50% of its total range	Stock is distributed in < 25% of its total range

Vertical overlap - Vertical overlap is intended to characterize the position of a species in the water column (e.g., demersal vs. pelagic) in relation to the position at which gear is deployed. While some pelagic species may occasionally be caught by bottom trawl gear, their susceptibility to capture is expected to be lower than demersal species which spend most of their time at the ocean floor. Patrick et al. (2010) base their scoring thresholds for vertical overlap on the percentage of the stock present in the depths fished.

We used a comparison on commercial CPUE from bottom trawl and mid-water trawl tows to get a coarse index vertical overlap. The proportion of a species at depths fished by bottom trawl gear was estimated as,

(4) $$\text{Proportion fished depth} = \frac{CPUE_B}{(CPUE_B + CPUE_M)}$$

where, $CPUE_B$ is the average CPUE from bottom trawl tows in the pilot study area and $CPUE_M$ is the average CPUE from mid-water trawl tows in the pilot study area.

This approach has several sources of uncertainty that may limit the reliability of calculated metrics of vertical overlap. Mid-water tows within the pilot study area specifically target hake stocks using acoustic technology, which likely results in a different catchability coefficient than bottom trawl gear for a given species. Fish may also be more likely to aggregate when they are off the bottom, which could also affect catchability if it is a density-dependent process. Despite these limitations, the method we adopt here is expected to provide some coarse indication of whether a given species is ever caught off the bottom, and thus, could have a reduced susceptibility to bottom trawl mortality.

Scoring criteria for vertical overlap:

Low susceptibility	Moderate susceptibility	High susceptibility
< 25% of stock present in the depths fished	25% - 50% of stock present in the depths fished	> 50% of stock present in the depths fished

Seasonal migrations - This attribute characterizes temporal overlap between a species distribution and the fishery distribution. Species with seasonal migration patterns that increase their areal overlap with the fishery compared to the areal overlap attribute described above (e.g., a large portion of the population moves onto the fishing grounds to spawn) are assumed to have an increased susceptibility to fishing mortality. Species with seasonal migration patterns that decrease their areal overlap with the fishery compared to the areal overlap attribute (e.g., most of the population leaves the fishing grounds when spawning) will have a decreased susceptibility. Although quantitative data about fish movement may be used to inform this metric, scores are assigned qualitatively with analysts deciding which of three statements best describes the migration pattern of a species (Table 4-2). When possible, empirical data or published literature on fish movements have been used to inform scores assigned for this metric.

Scoring criteria for seasonal migration:

Low susceptibility	Moderate susceptibility	High susceptibility
Seasonal migrations decrease overlap with fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations increase overlap with fishery

Schooling, aggregation, and other behaviours - Behavioural responses of fish to fishing gear can affect susceptibility to fishing mortality. These responses can include both the individual response of a single fish and the collective response of a stock. Schooling, aggregation and herding behaviour can increase catchability, while gear avoidance behaviour, such as diving or moving up in the water column, could decrease the chance of capture. This attribute is scored qualitatively using empirical information on species behaviour. When species-specific information is not available, inferences can often be made from similar species.

Scoring criteria for schooling, aggregation, and other behaviours:

Low susceptibility	Moderate susceptibility	High susceptibility
Behavioural responses of fish decrease catchability of gear	Behavioural responses of fish do not substantially affect catchability of gear	Behavioural responses of fish increase catchability of gear (i.e., hyperstability of catch per unit effort due to schooling behaviour)

Morphological characteristics - Morphological characteristics can increase or decrease the probability of capture once an individual has encountered gear. Patrick et al. (2010) recommend that the portion of the population size or age composition that is accessible to the gear should be considered when scoring this attribute, with particular attention being paid to morphology at the age or size of maturity. Two steps were used to score morphological susceptibility for the current analysis. First, a set of guidelines for net fisheries established by Hobday et al. (2007, 2011) were applied:

- Low susceptibility = body size < mesh size
- Moderate susceptibility: body size < 2 times mesh size; or body size = 4–5 m
- High susceptibility: body size > 2 times mesh size; or body size > 5 m

Relationships such as this between body size and catchability are well-supported (Walsh 1992, Fraser et al. 2007). In the second step, adjustments to scores were made by taking into account documented effects of body shape / type on fishery selectivity. The broad scoring guidelines of Patrick et al. (2010) were used for this second step: a score is increased if morphology increases catchability and a score is decreased if morphology decreases susceptibility. For example, the potential for trawl gear to pass over flat-bodied animals such as skates and flatfish was considered as part of this second step.

Scoring criteria for morphological characteristics:

Low susceptibility	Moderate susceptibility	High susceptibility
Species shows a low susceptibility to gear selectivity	Species shows moderate susceptibility to gear selectivity	Species shows high susceptibility to gear selectivity

Desirability or value of the fishery - Scoring for this attribute is based on the assumption that species that are more desirable as target species or are retained as non-directed catch are more susceptible to fishing mortality. Patrick et al. (2010) suggest three metrics of fishery value: market value per unit sold (e.g., $ / lb); total value of annual landings (e.g., $ / year for entire fishery); and percent retention in recreational fisheries. We adopt a modified approach for the current analysis that combines market value ($ / lb) and the percent of commercial catch that is retained for landing. Scoring thresholds for both market value and percentage retention that are specific to the portion of the BC trawl fishery considered in the pilot study were developed by dividing observed ranges of values into thirds. Overall scores for desirability were assigned as the highest of the market value and percentage retention scores for each species. The only exception to this rule was that species with zero percent retention were always assigned a desirability of low. Fishery value ($ / lb) was calculated as the average of estimates obtained from the Regional Data Service Unit, DFO for the last three fishing seasons (2007/08, 2008/09 and 2009/10). Percent retention was calculated as the average of annual percentages over the last three fishing seasons.

Scoring criteria for desirability or value of fishery:

Low susceptibility	Moderate susceptibility	High susceptibility
Species is not highly valued or desired by the fishery (0% retained; or <12% retained and < $0.21 / lb)	Species is moderately valued or desired by the fishery (13 - 73% retained; $0.22 - $0.36 / lb)	Species is highly valued or desired by the fishery (>73% retained; > $0.37/ lb)

Management strategy - The type of management strategy applied to a species can impact the susceptibility of a stock to overfishing, with species for which effective management mechanisms are in place being less susceptible. Effective management mechanisms considered when assigning scores for this attribute include annual catch limits, timely monitoring of catch levels, and the ability to restrict catch in-season once limits are reached. Management measures for all groundfish species in BC are summarized annually in the Groundfish Integrated Fisheries Management Plan (IFMP) for the Pacific Region.

Scoring criteria for management strategy:

Low susceptibility	Moderate susceptibility	High susceptibility
Directed stocks have catch limits and proactive accountability measures; non-directed stocks are closely monitored	Directed stocks have catch limits and reactive accountability measures	Directed stocks do not have catch limits or accountability measures; non-directed stocks are not closely monitored

Fishing mortality rate - For this attribute, the susceptibility of a stock to overfishing is scored based on the current fishing mortality relative to natural mortality (F / M). Scoring thresholds are based on the rule of thumb that the rate of fishing mortality should not exceed the rate of natural mortality. A ratio of F/M > 1.0 indicates that a stock has a high susceptibility to overfishing, while a ratio of < 0.5 indicates that a stock has a low susceptibility (Patrick et al. 2010). This attribute was only applied to pilot study species that have recently has a stock assessment analysis conducted that provided an estimate of F for stocks within the pilot study area. This attribute was excluded from the calculation of a susceptibility index for all other species, with a data quality score of 5 (no data) being assigned to reflect this exclusion (see below for explanation of the data quality index).

Scoring criteria for F:M ratio:

Low susceptibility	Moderate susceptibility	High susceptibility
< 0.5	0.5 - 1.0	> 1.0

Biomass of spawners – The current level of spawning stock biomass ($B_{CURRENT}$) relative to the expected unfished level (B_0) is used to represent susceptibility to overfishing, with lower ratios of $B_{CURRENT}$ / B_0 indicating a higher susceptibility. The preferred method for estimating $B_{CURRENT}$ / B_0 is from a quantitative stock assessment model. For the current pilot study, we only used estimates of $B_{CURRENT}$ / B_0 from stock assessments done in the past five years. Estimates from older assessments were deemed out of date, and the attribute was designated as "missing". The five-year threshold is arbitrary; however, some cut-off point was necessary and five years seemed reasonable. Most regularly assessed species in the pilot study had an estimate available from a stock assessment within the past five years (Rock Sole, Petrale Sole, English Sole, Pacific Cod, Spiny Dogfish), with the exception of Dover Sole. Patrick et al. (2010) suggest that when estimates of B_0 are not available, a long time series of reliable biomass indices (e.g., research surveys) could be used to approximate $B_{CURRENT}$ / B_0 as the current index value divided by the maximum observed value. Since the current groundfish mutli-species research trawl survey has only three observations over the last six years, it was deemed to short to use at this time. As a result, most pilot study species were assigned scores of "missing" for this attribute.

Scoring criteria for biomass of spawners:

Low susceptibility	Moderate susceptibility	High susceptibility
Biomass is >40% of B_0 (or maximum observed from time series of biomass estimates)	Biomass is 25% - 40% of B_0 (or maximum observed from time series of biomass estimates)	Biomass is < 25% of B_0 (or maximum observed from time series of biomass estimates)

Survival after capture and release - The survival rate of released individuals is an indicator of susceptibility for fisheries with high levels of non-retained catch (both non-directed and sub-legal catch). Survival rates can vary among species and fisheries due to barotraumatic effects, body-type, fish handling methods, and the invasiveness of the gear-type. Estimates of post-capture survival rates for the pilot study were obtained from a review of the literature. All estimates used in our analysis were specific to trawl gear; however, species-specific estimates were rarely available for our pilot study species. Estimates from similar species (e.g., other flatfish, skate, or cod species) captured in trawl fisheries in other parts of the world were applied instead.

Scoring criteria for survival after capture and release:

Low susceptibility	Moderate susceptibility	High susceptibility
Probability of survival > 67%	Probability of survival between 33 and 76%	Probability of survival < 33%

4.1.3. Data-Quality Index

Uncertainty in attribute scores is represented using the five tier index of data quality developed by Patrick et al. (2010), and shown in Table 4-3. Each attribute scored for each species gets assigned an individual score.

4.2. RESULTS

Relative risk scores: Directed and Non-directed species

A PSA summary sheet for each of the 25 species in the pilot study is presented in Appendix B. Each page contains a table documenting the attribute values used to derive productivity and susceptibility indices, as well as data quality scores and associated data sources. Numerical values for the overall productivity index, susceptibility index, and risk (vulnerability) index are summarized at the bottom of each species sheet, along with the associated data quality scores for the indices. The relative risk ranking for each species is also given.

Elasmobranch species (Class *Chondrichthyes*, Subclass *Elasmobranchii*) tended to have the highest risk scores, with the four highest ranked species being (in order of highest to lowest risk) Brown Cat Shark, Big Skate, Spiny Dogfish, and Longnose Skate (Appendix B). Sandpaper skate ranked 10th. The species with the 5th and 6th highest risk rankings were both Non-directed flatfish species: Flathead Sole and Starry Flounder. The species with the lowest risk scores were Speckled Sanddab, Pacific Cod, and Walleye Pollock.

PSA plots for Directed and Non-directed species (Figure 4-2 and Figure 4-3, respectively) show that the high risk scores for elasmobranch species were due primarily to the low productivity scores. Brown Cat Shark had the highest risk ranking because in addition to having a low productivity score, it received a high susceptibility score. The susceptibility score for this species was likely inflated compared to other species due to the large amount of missing data and the resulting poor data quality scores (Figure 4-5). Four of the 11 susceptibility attributes were missing data, and were thus excluded for the calculation of the index (Appendix B). Of the remaining seven attributes, four received high susceptibility scores. These high scores were based on high vertical overlap between depths occupied by Brown Cat Shark and depths fished within the pilot study area, high morphological susceptibility based-one the ratio of body size to mesh size, the lack of a management strategy for brown cat shark, and low post-release survival. In reality, catches of Brown Cat Shark in the pilot study area are rare events, which suggests low susceptibility is a possibility.

The high risk scores assigned to Flathead Sole and Starry Flounder were due to a combination of moderate productivity scores and high susceptibility scores (Figure 4-3).

Both are occasionally monitored, non-quota species with high fishery desirability based on market value.

Despite being desirable species with directed fisheries, Pacific Cod and Walleye Pollock tied for the second lowest risk score of the pilot study due to low susceptibility scores. Suscpetibility scores based on the seasonal migration attribute were low for both species. For Pacific Cod, the low score was due to the current seasonal closure for Pacific Cod spawning aggregations. For Walleye Pollock, the low score was due to the documented spawning migration to inlets within the pilot study area, which are outside of the fishery footprint. Susceptibility for Pacific cod was also reduced due to high post-release survival, while susceptibility for Walleye Pollock was reduced due to low vertical overlap with the bottom-trawl fishery.

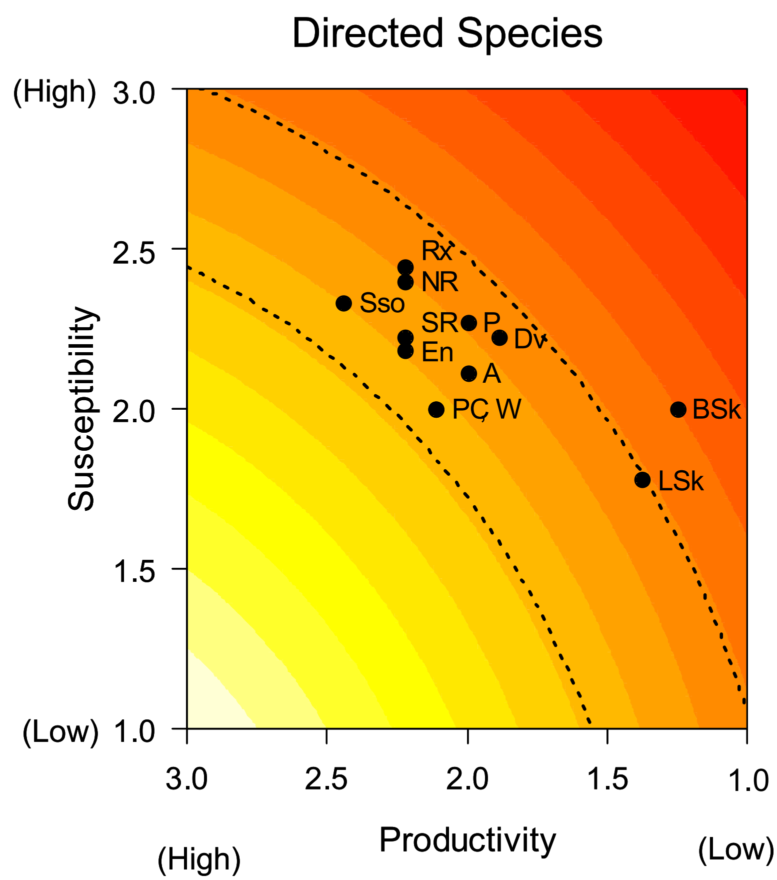


Figure 4-2. Results from Productivity Susceptibility Analysis for directed species, where points represent the vulnerability score for one or more species and letters indicate the species associated with the point to the left of the letters (SSo = Sand Sole, RX = Rex Sole, NR = Northern Rock Sole, SR = Southern Rock Sole, EN = English Sole, PT = Petrale Sole, DV = Dover Sole, A = Arrowtooth Flounder, PC = Pacific Cod, W = Walleye Pollock, BSk = Big Skate, LSk = Longnose Skate). The vulnerability scores for Pacific Cod and Walleye Pollock overlap, and appear as one point on the plot. Black dotted lines delineate the low, moderate, and high risk zones used by Hobday et al. (2007).

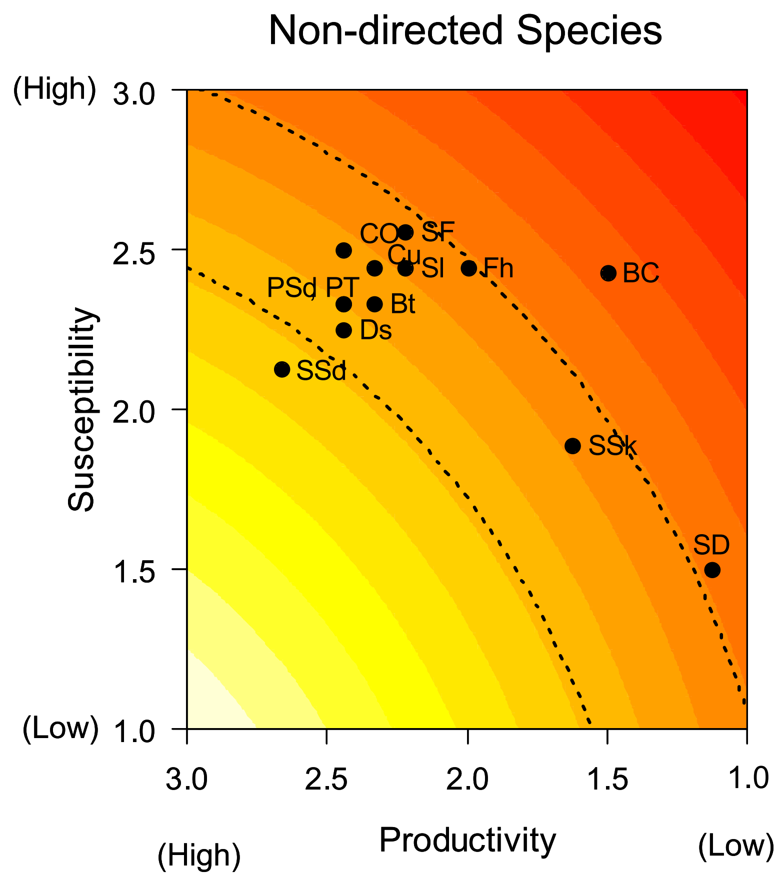


Figure 4-3. Results from Productivity Susceptibility Analysis for non-directed species, where points represent the vulnerability score for one or more species and letters indicate the species associated with the point to the left of the letters (SSD = Speckled Sanddab, CO = C-O Sole, CU = Curlfin Sole, PSd = Pacific Sanddab, PTd = Pacific Tomcod, Bt = Butter Sole, Ds = Deepsea Sole, SF = Starry Flounder, Sl = Slender Sole, Fh = Flathead Sole, BC = Brown Cat Shark, SSk = Sandpaper Skate, SD = Spiny Dogfish). The vulnerability scores for Pacific Sanddab and Pacific Tomcod overlap with each other, and appear as one point on the bottom right side of the letter symbols. Black dotted lines delineate the low, moderate, and high risk zones used by Hobday et al. (2007).

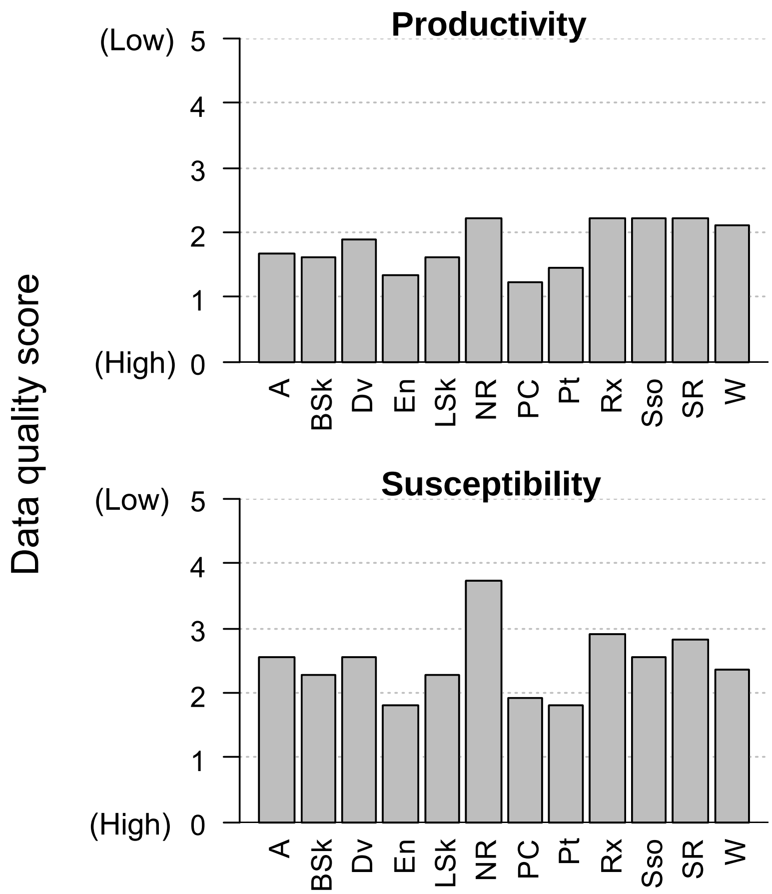


Figure 4-4. Average data quality scores for productivity and susceptibility indices for directed species (A = Arrowtooth Flounder, BSk = Big Skate, DV = Dover Sole, EN = English Sole, LSk = Longnose Skate, NR = Northern Rock Sole, PC = Pacific Cod, PT = Petrale sole, RX = Rex Sole, SSo = Sand Sole, SR = Southern Rock Sole, W = Walleye Pollock). See Table 4-3 for definition of scores.

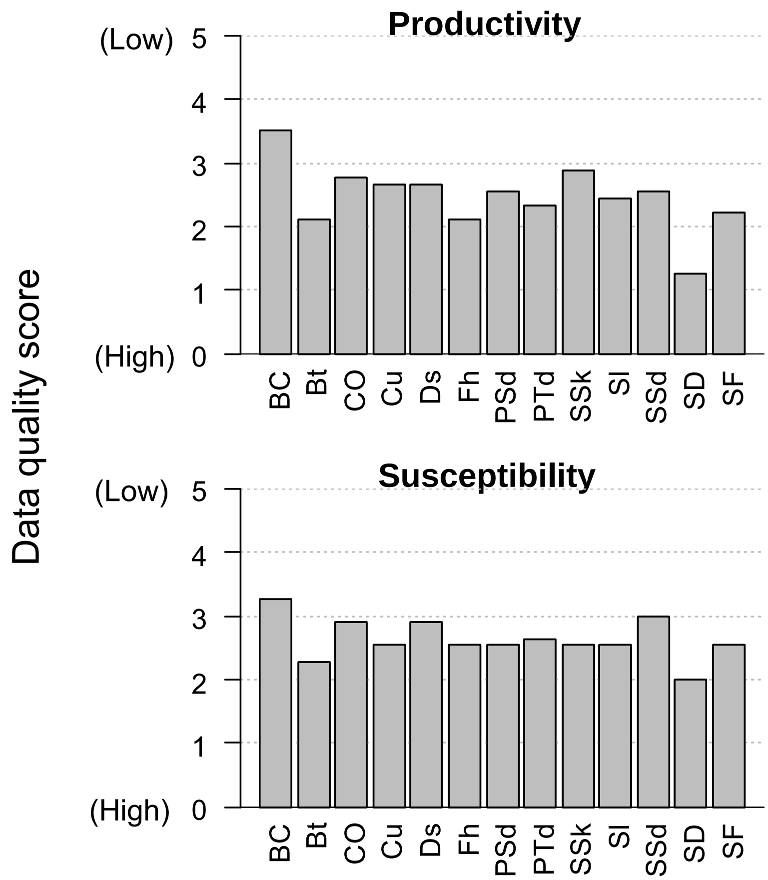


Figure 4-5. Average data quality scores for productivity and susceptibility indices for non-directed species (BC = Brown Cat Shark, Bt = Butter Sole, CO = C-O Sole, CU = Curlfin Sole, Ds = Deepsea Sole, Fh = Flathead Sole, PSd = Pacific Sanddab, PTd = Pacific Tomcod, SSk = Sandpaper Skate, Sl = Slender Sole, SSd = Speckled Sanddab, SD = Spiny Dogfish, SF = Starry Flounder). See Table 4-3 for definition of scores.

Advancement to Level 3 Analysis

Four of the 25 species evaluated at Level 2 using PSA were identified as needing further analysis at Level 2 based on the criteria of risk scores falling on or above the "high risk" threshold on PSA plots. Of these four species, two were Directed Species (Big Skate and Longnose Skate) and two were Non-directed species (Brown Catshark and Spiny Dogfish). All four species were elasmobranchs, and were moved forward to Level 2 based primarily on low productivity scores. Flathead sole was just below the cut-off for advancement to a Level 3 analysis due to a combination of moderate productivity and moderate-high susceptibility.

The identification of Spiny Dogfish as a "high risk" species highlights a previously recognized limitation of PSA. Because PSA measures potential risk, it does not necessarily represent all available information on actual risk. As a result, PSA has a tendency to give false positive results (Hobday et al. 2011). A recent stock assessment of the offshore Spiny Dogfish population in British Columbia (which includes the pilot study area) indicated that the population was most likely being fished within safe biological limits in 2008 (Gallucci et al. 2011), which contradicts the PSA result.

The tendency towards false positives is dealt with in the Australian ERAEF framework using a Residual Risk Analysis step between Levels 2 and 3. Residual Risk Analysis attempts to adjust potential risk scores from Level 2 to actual risk scores by allowing high risk scores to be down-graded to moderate or low using a pre-defined set of decision rules (Hobday et al. 2007). For example, if a Residual Risk Analysis had been applied to the pilot study, Spiny Dogfish could have been downgraded from high to moderate risk based on the decision rule: *If an additional scientific assessment for a species has been published that provides a more quantitative analysis than the Level 2 assessment, then the risk score from the additional assessment may be adopted*.

We did not apply the Residual Risk Analysis step in the pilot study based on our selection of the Patrick et al. (2010) version of PSA. The inclusion of management attributes in the susceptibility index was expected to reduce the need for the additional analysis step. For example, information from the 2008 Spiny Dogfish stock assessment was used when scoring the susceptibility index; attributes for both the ratio of F:M and the ratio of current biomass relative to unfished biomass were assigned susceptibility scores of low. However, Spiny Dogfish was labeled a high risk species based on its low productivity index (Figure 4-3). This result suggests that a Residual Risk Analysis step could still be needed when PSA is applied to decide whether to move species forward to Level 3. The position of the boundary between the high and moderate risk zones is such that extremely low productivity species have a high tendency to be moved forward to a Level 3 analysis, regardless of their susceptibility score (Table 4-1). Future applications of ERAEF should consider the inclusion of an additional analysis step at the end of Level 2 to evaluate additional information. The utility of such a step will depend on how the outcomes of ERAEF are being used to affect the setting of science priorities and management decision making.

Additional Considerations for Future PSA

We followed the PSA scoring of Patrick et al. (2010) for our pilot study because it was developed for species with similar life history characteristics as BC species, and because the authors had already demonstrated consistency among the attributes used within productivity and susceptibility indices. However, we note concerns with a few of the attributes used that should be considered prior to further application. First, the use of fecundity as an indicator of productivity has been discredited for teleost species in recent years due to lack of empirical support (Denney et al. 1998, Reynolds et al. 2005). Egg and juvenile survival rates can confound this indicator, such that high fecundity does not necessarily translate into high recruitment. Second, as noted in its description above, the recruitment variability attribute is likely not appropriate for species with high parental investment (e.g., sharks and skates) or short-lived, high productivity species with high recruitment variability (e.g., herring and sardine). Given the limited range of life history types that this attribute can be applied to and the difficulty in determining the frequency of recruitment success for data-poor species, it may not be worth pursuing in the future. Finally, the susceptibility attribute of F:M may be appropriate for all cases. For fisheries in which individuals are able to contribute substantially to spawning before fish become vulnerable to the fishery, a ratio of F:M > 1 could be within safe biological limits.

One further concern with the pilot study PSA arises from our decision to use empirically-based approximations to estimate natural mortality (Hoeing 1983) and growth coefficients (Froese and Binhlan 2000) for some data-poor species. In these cases, parameter estimates were based on the maximum age of the species, which is itself an attribute used to score productivity. As a result, attributes used to calculate productivity for the pilot study were not necessarily independent estimates. Future ERAEF applications should consider assigning natural mortality and growth coefficient attributes missing scores rather than using these approximations so that twice as much weight is not assigned to estimates of maximum length.

5. DISCUSSION AND CONCLUSIONS

5.1. SUMMARY OF PILOT STUDY RESULTS

Our pilot study application of ERAEF to a portion of the bottom trawl fishery in Hecate Strait resulted in several low-risk stressors and species being screened out from more intensive analyses at Levels 2 and 3. An overview of stressors and species that were screened out versus moved forward at each level of the ERAEF hierarchy is shown in Figure 5-1. Note that risk scores assigned in this pilot study do not necessarily reflect realistic risk scores for the fishery because only a portion of species and habitats in Hecate Strait were included. Furthermore, the SICA expert panel workshop at Level 1 only included participants from within the DFO groundfish science section, and therefore does not reflect as diverse of a set of opinions as it would in a real application.

The initial scoping stage identified 22 Stressors for the three ecosystem components considered (Directed Species, Non-directed Species, and Habitats). In addition, several units of analysis were identified within each ecosystem component. Directed Species had 12 units of analysis, Non-directed Species had 13 units of analysis, and Habitats had 5 units of analysis. As a result, the total number of issues to be evaluated in the pilot study (i.e., combinations of stressor x unit of analysis) was 660.

The most apparent advantage of SICA at Level 1 was its ability to efficiently identify low-risk stressors that could be screened out from further analysis levels (Figure 5-1). Because SICA is applied at the level of ecosystem components using a worst-case scenario approach, only 66 combinations of stressor and component were actually analysed at Level 1 (as opposed to the original sample of 660 combinations of stressor and unit of analysis). Fifty-five of the initial 66 component-stressor combinations were assessed to pose only a negligible or minor potential risk, and were thus excluded from further consideration at Level 2. The remaining eight combinations of stressor and ecosystem component to be moved forward to Level 2 are summarized in Table 5-1.

Table 5-1. Issues identified at Level 1 as needing further analysis.

Ecosystem Component	Stressors
Directed species	• Capture by fishery (removal of species) • Translocation of species (i.e., introduction of invasive species) • Capture by other fisheries
Non-directed species	• Capture by fishery (removal of species) • Translocation of species (i.e., introduction of invasive species) • Capture by other fisheries
Habitats	• Disturbances of physical processes due to fishing (i.e., sedimentation) • Capture by other fisheries (removal of habitats)

All three ecological components had at least one stressor that was scored ≥ moderate risk, so no ecological components were screened out at Level 1.

While ERAEF requires that all eight component-stressor combinations with scores ≥ moderate be moved forward to a Level 2 analysis using PSA, only two of these were carried forward in the pilot study: (i) the impact of fishery capture on Directed Species and (ii) the impact of fishery capture on Non-directed Species. All other pathways (tanslocation of species, other capture fisheries, and disturbance of physical processes) were prematurely terminated at Level 2 (Figure 5-1) because detailed methods for PSA of stressors other than fishery capture have not yet been developed (see Hobday et al. 2007 for reference to ongoing development of these methodologies).

The focus of the Level 2 PSA on impact of fishery capture on individual units of analysis allowed 21 of the 25 groundfish species to be screened out from proceeding to a quantitative, model-based Level 3 assessment (Figure 5-1). Of the four species that were identified as needing a Level 3 assessment, two were Directed Species (Big Skate and Longnose Skate) and two were Non-directed species (Brown Catshark, and Spiny Dogfish).

Our pilot application of ERAEF both supported some of our current risk perceptions for bottom-trawling in Hecate Strait and identified new issues to be evaluated in more detail. All four of the species identified as high potential risk at Level 2 were elasmobranch species with extremely low productivity scores. The high potential risk scores for elasmobranches in the pilot study are supported by the PSA results of Patrick et al. (2009, 2010) for US fish species, as well a general consensus within the literature that shark and skates are highly vulnerable to fishing mortality (Musik et al. 2000, Frisk et al. 2002). Not all elasmobranchs were identified as high potential risk in the pilot study. Sandpaper skate was classified as moderate risk. It is interesting to note that, at Level 2, species that scored the highest risk scores from fishery capture were not necessarily species that receive the highest level of stock assessment effort. Flathead Sole and Starry Flounder, both of which have never had a stock assessment, had higher PSA risk scores than more commonly assessed species such as Southern Rock Sole and English Sole. This result suggests that, from a purely ecological risk-based point of view, Flathead Sole and Starry Flounder should be a higher priority for further research than Southern Rock Sole and English Sole. Note that this order of prioritization could change once socio-economic factors affecting prioritization are accounted for.

The Level 1 SICA supported current perceptions that capture by fisheries (both bottom-trawl and other fisheries) is the largest threat to fish species in Hecate Strait. This perception is already implicit in the current focus on single-species stock assessments for groundfish species, in which the effects of fishing mortality on population dynamics are modelled to help identify sustainable harvest levels. Similarly, the impact of invasive species introductions from trawl vessels was also identified as a potentially high-risk impact for fish species. This risk has also been previously identified and studied (Therriault and Herborg 2008a, Herborg and Therriault 2009).

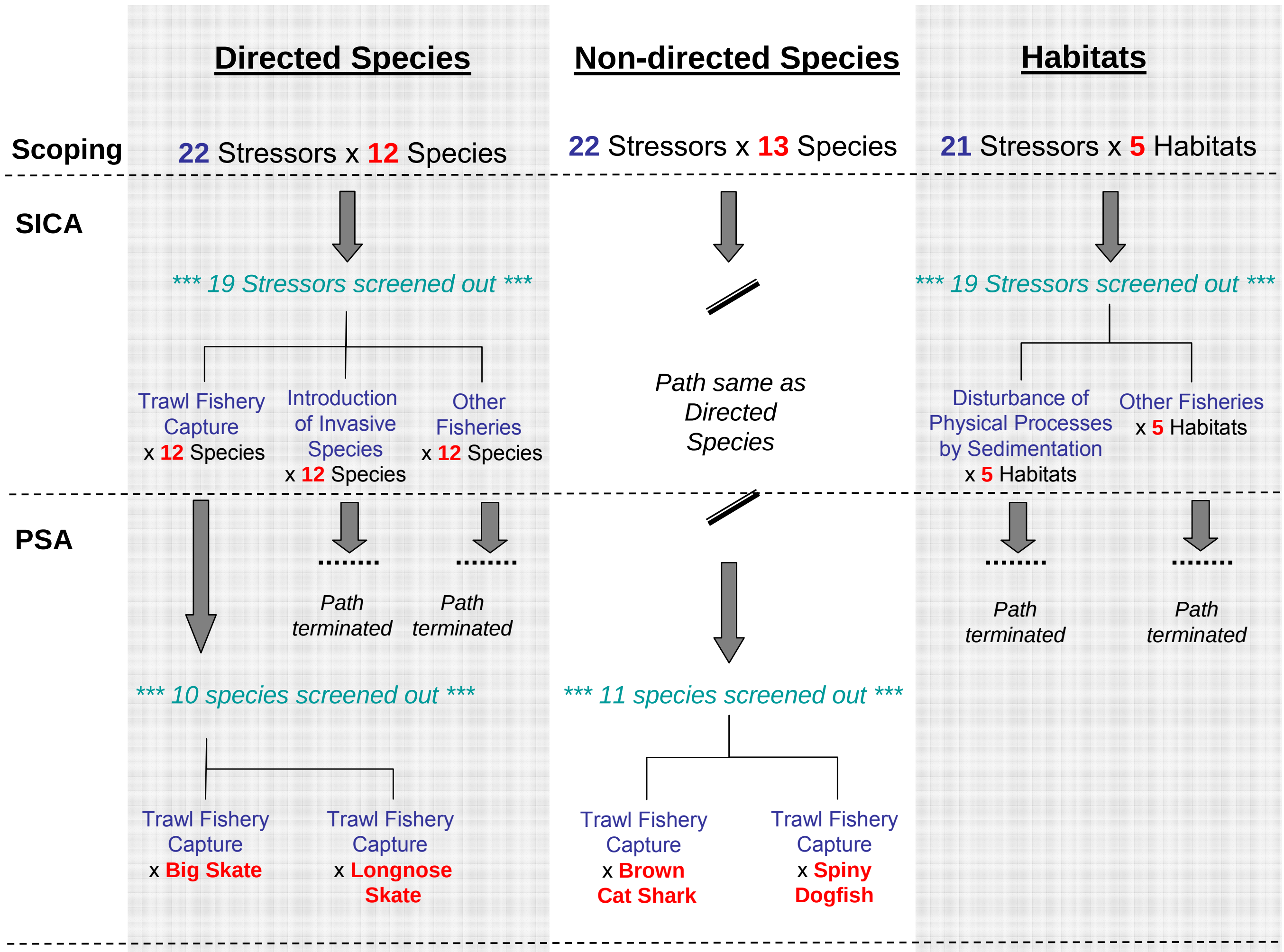


Figure 5-1. Summary of hierarchical risk screening for pilot study ERAEF. At the end of each analysis step, only impacts with risk scores ≥ moderate are shown as progressing to the next analysis level (i.e., the impacts that are not screened out). Red text indicates Units of Analysis and blue text indicates Stressors.

5.2. ADVANTAGES OF ERAEF

Several advantages of ERAEF are apparent from the Australian applications and from our British Columbia pilot study.

The hierarchical structure of ERAEF allows one of the key challenges to ecosystem-based fisheries management to be addressed: how is ecological risk for the hundreds of fisheries impacts on species, habitats, and communities to be assessed, given realistic time and resource constraints? By breaking the assessment down into a series of discrete relationships between the fishery and ecosystem features, ERAEF provides a framework within which existing knowledge, information, and data can be used to identify the impacts that pose the greatest ecological threat. In the process, ERAEF can also serve as a gap analysis to identify areas where further work is needed to reduce uncertainty. Hobday et al. (2011) observed that many stakeholder participants appreciate that ERAEF allows issues to be brought forward that are not normally thought about (e.g., impacts of oil leaks on larval fish habitat). In our pilot study, one of the most apparent advantages of ERAEF was its ability to identify ongoing management and science concerns (impacts of fishery capture, invasive species) as those with the highest risk from an ecological point of view, while at the same time identifying additional high-risk ecological issues that warrant further work (fishery capture of Flathead Sole, sedimentation effects on sponge reef habitats).

A second advantage of ERAEF was in its use of clearly defined ecological objectives for all fishery and non-fishery activities. These objectives, as well as the associated scoring criteria used to estimate risk (defined as the risk of failure to achieve objectives), allow all activities to be assessed on the same scale. Impacts of fishing mortality on non-directed species can be readily compared to gear impacts on benthic habitats. ERAEF thus promotes a consistent approach to assessing risk across all aspects of managing a fishery.

The flexibility of the ERAEF framework is also an important advantage. The hierarchical framework is not specific to a given tool or analysis method. Rather, each level is defined by the complexity and focus of the analysis (Hobday et al. 2011). As a result, new or alternative tools can be "plugged-in" at any level. Similarly, the list of evaluated stressors can be revised to include as many non-fishery impacts as can be identified by the assessment team. When thought of this way, the hierarchical ERAEF framework becomes an umbrella under which several different risk assessment tools can be linked together to communicate a broader view of anthropogenic impacts on ecosystem features than that given by traditional assessment approaches that consider individual issues in isolation.

Finally, the extensive documentation required for an ERAEF assessment helps ensure that results can be readily reviewed and critiqued. In addition, the detailed instructions for conducting each stage of the analysis attempt to make the methods as transparent and repeatable as possible. These features are beneficial because they can help justify why certain stressors or ecosystem components are allocated more research and management attention compared to others.

5.3. CHALLENGES TO FURTHER IMPLEMENTATION IN BRITISH COLUMBIA

Identification of Habitat Units of Analysis

A broader and more meaningful application of SICA and PSA analyses to the Habitat component of the BC coast will require further development of the methods used to classify both benthic and pelagic habitat-types. Defining units of analysis for habitats is more complicated than for species. Taxonomic conventions exist for defining a single species; however, defining habitats requires an integration of multiple species (both plant and animal) and abiotic variables (e.g., substrate type, slope) into a single assessment unit, followed by the mapping of each of these assessment units to describe their distribution and extent. Delineating habitats in this way will thus require a clear definition of which relationships between benthic species and their seafloor environments are of primary interest for management and conservation actions.

For the purposes of this pilot study, we chose to base our habitat units of analysis on a single identifiable faunal type (sponge reefs) rather than on a less well-defined integration of multiple species (e.g., echinoderms, infauna in mud substrate). We also chose to rely solely on direct observations of sponge reef presence (via acoustic methods) and mapped distributions of abiotic features (i.e., BCMEC ecounits) as a basis for defining units of analysis. This approach will not be practical for most species however, because we have less confidence that the patchy records of species occurrences available from underwater images and catch records adequately represent the distribution of these species. As a result, inferences will be required to create a complete coverage of habitat types throughout an area of interest.

While the continued collection of seabed image samples in BC will provide useful data on the distribution of benthic species relative to substrate and geomorphology, there is likely enough information available at present to undertake some level of habitat classification and mapping, be it based on quantitative predictive models, expert opinion, or a combination of both. At the simplest level, this mapping could involve a top-down approach to habitat classification in which each BCMEC ecounit is assigned a "multi-species assemblage" based on documented patterns of co-occurrence between ecounits and sessile benthic fauna observed from available samples. While this approach would be most efficient in the short-term, it is increasingly recognized that top-down approaches like this fail to represent ecologically meaningful relationships between abiotic and biotic components of the seafloor (Eastwood et al. 2006, Shumchenia and King 2010). Alternatively, a bottom-up approach to habitat classification could be undertaken in which relationships between abiotic and biotic variables of interest are identified first. These relationships are then used to interpolate between available biotic samples to predict the spatial extent of various habitat types (Rooper and Zimmerman 2007, Shumchenia and King 2010).

Regardless of the method chosen to delineate habitat types for the BC coast, inferences will be required based on assumed relationships between species and their abiotic environments. As a result, the habitat maps created will need to be viewed as best-available estimates of the distribution of habitat types, with these estimates being subject to ongoing changes as more data becomes available over time. Top-down or bottom-up, analyses such as this would require expertise beyond that currently available among scientists in the Groundfish Science section, highlighting the importance of collaborative relationships when taking a whole-ecosystem approach to assessing risk and managing fisheries.

Identification and Assessment of Community Units of Analysis

As with Habitats, application of ERAEF to the Community component for BC fisheries will require the development of a classification scheme to delineate boundaries between community units of analysis. In Australia, the geographic boundaries of communities are based on a set of nationally agreed upon bioregions and biotic provinces (IMCRA Technical Group, 1998), combined with depth class. Communities are then defined as the species assemblages that occupy each identified region (Hobday et al. 2007).

Existing bio-regionalization projects may provide a basis for identifying ecological communities in British Columbia. For example, a 2004 *Canadian Marine Ecoregion Workshop* reviewed previous Canadian initiatives to classify marine ecoregions, and then put forward a new scheme to use as a basis for Integrated Coastal Management in Canada (Powles et al. 2004). The marine ecoregions identified at the workshop were based on geology, physical oceanography, biology, and administrative / management considerations. Our ERAEF pilot study area falls within the Northern Shelf ecoregion of the Pacific Ocean under the *Canadian Marine Ecoregion* classification scheme. This region has been the focus of a pilot study for a new approach to integrated fisheries governance under the Pacific North Coast Integrated Management Area (PNCIMA 2011), and has recently been the subject of an ecosystem overview as part of this initiative (Lucas et al. 2007). Thus, while the Community component of ERAEF was specified as beyond the scope of our pilot study, PNCIMA boundaries may have been a useful starting point for identifying community boundaries had it been included. Future ERAEF applications to the Community component should further evaluate the suitability of the *Canadian Marine Ecoregion* classification scheme as a basis for conducting community-level risk assessments under ERAEF, as well as other classification schemes that have emerged more recently (e.g., Spalding et al. 2007). Once a regionalization scheme has been identified as a geographical basis for defining community units of analysis, additional work will be required to delineate the area into meaningful depth zones and compile lists of species assemblages associated with each combination of ecoregion and depth zone.

Risk assessment methods for the Level 2 PSA analysis of Communities will also require further development before ERAEF can be applied at this level. The objective of the community risk assessment is to estimate the potential risk of fishing to a community through examining changes to community properties such as species composition, trophic structure, and distribution. Objectives and indicators for assessing risks to communities have been identified and applied for Level 1 SICA assessments in Australia (e.g., Daley et al. 2007). However, methods for applying PSA to communities at Level 2 are still in progress. A list of potential productivity and susceptibility attributes for communities have been identified for Australian applications (Hobday et al. 2007); however, scoring thresholds (for high, medium, low categories) have not been established for many of these attributes. Furthermore, methods for combining attributes into a single index for productivity and susceptibility have not yet been developed. Other sets of objectives and indicators have been identified for monitoring and assessment of marine communities in Canada and in other jurisdictions (e.g., Jamieson et al. 2001 for Canada, Boldt and Zador 2009 for Alaska), and could alternatively be considered for future Level 1 and Level 2 assessments in BC. Application of ERAEF to communities will thus require a substantial amount of development of methodologies by scientists with relevant expertise.

Identification of Stressors for Non-fishery Activities

The occurrence of risks from non-fishery (external) activities is recognized within ERAEF. However, the assessment of potential risks from these activities is weak compared to the level of analysis afforded to fishery impacts. The list of stressors put forward for evaluation during Scoping contains 25 stressors nested within the fishing activity of interest (e.g. bait collection, fishing, gear loss, anchoring; Figure 1-2). In comparison, each non-fishery activity is assessed as a single stressor (e.g., aquaculture, coastal development, wind farms). However, non-fishery activities occur at the same level as the fishery in Figure 1-2, and the list of stressors related to each non-fishery activity is as varied as that of a fishing activity. For example, in a more complete assessment, the non-fishery activity of wind farm development would have several activities nested under it including, for example: (i) wind farm construction (drilling, dredging, and trenching of seafloor habitats, geophysical surveys, increased boat traffic, noise pollution); (ii) turbine operation (vibrations from turbines, seabird mortality from collisions with rotors, noise pollution effects on fish and marine mammals); and (iii) foundation attachment to seafloor (increased sediment turbidity as the result of scour of the seabed, change of community structure of benthic habitats) (Kannen 2005, Fox et al. 2006, Kikuchi 2010).

The scope of stressors should depend on the purpose of the assessment. While the limited scope of non-fishery stressors is a deliberate feature of ERAEF given that the method was developed as a tool for assessing fishery impacts, the current list of stressors limits the ability of ERAEF to provide a comprehensive assessment of all human-induced risks to marine ecosystems. Further identification of stressors for non-fishery impacts is needed before ERAEF could be adapted to provide risk-based science advice for non-fishery impacts to groundfish resources, or more broadly, to marine ecosystems.

Stakeholder Participation

Participation of stakeholders in the risk assessment is a key element of ERAEF, especially in the Scoping and Level 1 SICA stages that require inputs from stakeholders with a range of expertise (Hobday et al. 2011). For example, stakeholders for an application of ERAEF to a commercial fishery may include commercial fishers, First Nations groups, recreational fishers, environmental non-governmental organizations, fisheries managers, fisheries scientists, and experts in relevant taxa or oceanographic processes. Lessons learned from Australian assessments as well as this pilot study provide insight into expected challenges in communicating methods, extracting opinions, and building consensus among diverse groups such as this.

First, ERAEF methods can be difficult to understand initially due to the new terminology, broad scope, and multiple levels of analysis (Hobday et al. 2011). In Australia, it often took as many as three workshops before stakeholders were comfortable with the approach. Clear and consistent presentation of the methodology and the use of practical examples will be necessary to facilitate communication. An initial focus on the expected outcomes of ERAEF in BC rather than on technical aspects of the methods may help build an appreciation of how the comprehensive nature of ERAEF can benefit fisheries management (e.g., tabling of a broader range of conservation concerns, science support for eco-certification), thereby making participants more willing to invest the time in learning and applying the method.

A second set of expected challenges to stakeholder participation in ERAEF centres on organization of the Level 1 SICA workshops in which expert panels debate and assign risk scores. One commonly expressed concern is that the results of the SICA workshop may not be repeatable due to the qualitative, and potentially subjective, nature of the assessment. Hobday et al. (2011) suggest that this concern can be addressed by ensuring a representative group of stakeholders is included so that a wide range of views are present. In addition, Australian assessment teams learned that having an experienced ERAEF assessor on hand to provide guidance on the interpretation of SICA methods helped ensure consistent applications among fisheries. Concerns have also been expressed that it may be difficult to build consensus in a workshop setting, especially if a few individuals with agendas have different viewpoints than the rest of the panel. Hiring a professional meeting facilitator for BC ERAEF applications who is trained in consensus decision-making may help resolve these issues. Finally, Hobday et al. (2011) note that some stakeholders became frustrated by the comprehensive nature of SICA (i.e., "why are we wasting time on this issue if we already know it's not a problem?"). For the current pilot study, we attempted to address this concern by providing the pilot study working group with a draft copy of a completed SICA table that could be revised in the workshop rather than a blank form. While the draft table was beneficial in increasing efficiency and demonstrating the intended purpose of SICA (i.e., to eliminate stressors due to low potential risk), it also appeared to limit the amount of debate. In the face of large amounts of uncertainty about worst case scenarios, participants were unlikely to voice opposition to the draft version if they had low confidence in alternative scenarios. It seems likely that this effect would be reduced in a real workshop setting in which the expert panel had broader representation and assessment outcomes were linked to management actions, although, this will likely need to be further explored through real world applications.

While the specific methodology used for the expert workshop component of SICA will likely be subject to frequent initial updates as assessment teams learn how best to ensure a fair process for reaching consensus, expertise and software tools required to support this exercise have been developed through this pilot study.

Quantification of Cumulative Impacts

A cumulative impact is defined as the combined, incremental effects that multiple human activities through space and time can have on an environment. Interactions and feedback mechanisms among different impacts on ecosystem components mean that cumulative impacts do not necessarily increase linearly with increases in the number of human activities or stressors (Halpern et al. 2008). As a result, a complex analytical framework that can account for these interactions is needed to properly assess the magnitude of cumulative impacts (Rosenberg and McLeod 2005).

While ERAEF is comprehensive in the range of fishery and non-fishery impacts assessed, the framework only considers risk on an impact-by-impact basis. It does not address cumulative impacts by combining risk across multiple stressors within a single fishery, or across all fisheries and marine activities within a given area. As a result, assessors using ERAEF cannot definitively conclude that a given stressor will not harm a unit of analysis, since the actual level of impact a unit of analysis can withstand from one stressor will depend on the magnitude of impacts imposed by other stressors. Similarly, ERAEF is limited in its ability to make complete statements about the total risk incurred by a single species, habitat, or community across all activities. Instead, ERAEF simply enables assessors to identify the individual impacts on ecosystem components that pose the highest potential risk compared to all other individual impacts.

The development of assessment tools that integrate across a range of fisheries or ecosystem components has been identified as an outstanding challenge before ERAEF can be fully used to inform Ecosystem-Based Management in Australia (Hobday et al. 2011). The complex analytical framework needed to assess cumulative impacts suggests that the integration of risks across activities and ecosystem components is best dealt with at Level 3 of ERAEF. Hobday et al. (2011) use the relatively simple example of the effects of fishery capture on a single species to emphasize this point. Traditional fisheries stock assessment models combine estimates of fishing mortality across multiple fisheries. In some cases, these models have also been expanded to incorporate environmental impacts and predation mortality. More complicated interactions than this example, such as the assessment of multiple activities on the structure and function of the community component of ERAEF, will require the development of much more complex ecosystem models than those traditionally used for single-species assessments (Smith et al. 2007, Levin et al. 2009). Uncertainty associated with outputs of these models may be very large.

It is possible that the problem of cumulative impacts among individual groundfish fisheries in BC could be eliminated by re-defining the assessed fishery as the entire integrated groundfish fishery rather than as a single gear type. In this case, the scope of the pilot study would have extended beyond the bottom-trawl fishery in Hecate Strait to also include the mid-water trawl fishery, the Halibut fishery (licence L), the Sablefish fishery (licence K), the outside Rockfish fishery (licence ZNO), and the Lingcod and Dogfish Hook and Line fisheries that are licensed under Schedule II. While this approach would eliminate the problem of assessing cumulative impacts among groundfish fisheries, several new challenges would emerge when trying to assess risk across the multiple gear types and fishery distributions. Furthermore, estimated cumulative impacts would not include non-groundfish fisheries (e.g., crab, salmon, prawn) and non-fishery activities (e.g., aquaculture, coastal development).

Linking ERAEF to an Ecosystem Approach to Management

DFO has committed to moving towards an Ecosystem Approach to Fisheries Management (EAFM), which DFO policy defines as management decisions that "consider the impact of the fishery not only on the directed species, but also on non-directed species, seafloor habitats, and the ecosystems of which these species are a part" (DFO 2009c). Closely linked to DFO's commitment to move towards an EAFM is DFO's requirement under Canada's Oceans Act (1997) to adopt a more integrated approach to the management of marine ecosystems in which management decisions for all marine-use activities consider trade-offs between physical, biological, and socio-economic objectives (O'Boyle and Jamieson 2006). EAFM, or more simply an Ecosystem Approach to Management (EAM), is seen as one component of this broader Integrated Management (IM) process for all ocean activities.

ERAEF results could inform both EAM and IM by providing consistent and transparent estimates of potential ecological risk for a wide range of fishery and non-fishery impacts on the ecosystem elements identified in the above DFO definition of an EAFM (i.e., "directed species, non-directed species, seafloor habitats, and the ecosystems of which these species are a part"). However, simply comparing ecological risk scores for isolated impacts is not enough to inform EAM. It is widely cited that an evaluation of cumulative impacts on ecosystem services should form the basis of EAM (Rosenberg and McLeod 2005, Halpern et al. 2008, Levin et al. 2009). Rice (2011) notes that a major challenge in attempting to manage for the full fishery footprint is portioning accountability for ecosystem degradation among various fishing sectors and activities. As discussed above, ERAEF analysis methods at Level 1 and 2 do not explicitly consider cumulative impacts over all fisheries within an area. In addition, both EAM and IM require socio-economic considerations to be fully integrated into management decisions (Pikitch et al. 2004, Levin et al. 2009). Since ERAEF only assesses ecological risk, it cannot provide all of the information needed to balance trade-offs between ecological and social-economic objectives.

Various methods have been developed in Australia to combine risk scores over multiple fisheries and integrate socio-economic factors with ecological risk as part of a larger, integrated risk management process (Fletcher et al. 2010, Hobday et al. 2011). However, these methods require co-operation among multiple stakeholder groups and levels of government, and extend well beyond a science input to management. Ultimately, the extent to which ERAEF can help inform an EAM for BC groundfish fisheries will depend on the science needs of the EAM framework used to guide decision-making.

5.4. CONCLUSIONS RELATIVE TO PILOT STUDY OBJECTIVES

<u>Objective 1:</u> *To evaluate the ability of ERAEF to provide timely advice on the impacts of BC fisheries on marine ecosystems using risk-based triage*

At present, ERAEF can be readily used to assess the potential risk of individual fisheries on some (but not all) components of the marine ecosystem in BC (limitations are discussed below). It is important to recognize however that ERAEF cannot provide timely advice on the <u>status</u> of a given unit of analysis; rather it provides advice on the <u>potential risks imposed by an activity</u> on a unit of analysis. For example, ERAEF results will not provide an indication of whether Spiny Dogfish populations in BC are at a healthy level of abundance. Instead, the results can tell us, for example, whether Spiny Dogfish populations have a high potential risk of harm by trawl fishery capture. This distinction means that when evaluating this objective, we define 'advice' at a higher level than the harvest advice that is traditionally considered for science input to management. Rather than providing advice in terms of what level of quota to apply, ERAEF provides advice on what issues science staff should work on. We note that Eco-certification bodies that evaluate whether fishing practices are sustainable, such as the Marine Stewardship Council (MSC), are interested in ERAEF specifically because it addresses the potential risks imposed by a fishing activity (MSC 2009). Small-scale versions of SICA and PSA were recently used in the assessment of Spiny Dogfish fisheries in British Columbia as part of an MSC assessment process.

ERAEF could be a useful tool for implementing the DFO Bycatch Policy that is currently being developed under the Sustainable Fisheries Framework (DFO 2009d) by assessing the potential risk of a fishery to non-directed catch of fish species. Regularly scheduled ERAEF assessments (e.g., every 4 years) could act as a triage process to rapidly identify the species at highest potential risk from a fishery. In doing so, ERAEF could identify areas where further bycatch risk reduction is needed, as well as show that the potential risks posed to all other species encountered by the fishery are at acceptable levels.

There are two current limitations to the ability of ERAEF to fully assess the footprint of a fishery in BC. The first limitation is that prior to the Level 1 SICA, more work is needed to identify units of analysis for habitats and communities. Currently, only impacts on species can be readily assessed by applying SICA to available data. However, our limited application of SICA to sponge reef habitats suggests that SICA could also be a useful tool for assessing habitat impacts once units of analysis are identified. The second limitation is at the Level 2 PSA, where more work is needed to develop methods to assess non-capture impacts. At the present time, only impacts of fishery capture on Directed species, Non-directed species, and TEP species can be readily assessed for BC fisheries. PSA methods have been developed for assessing the impact of fishery capture on Habitats (Williams et al. 2011), but these methods have not yet been tested for BC. The impacts of fishery capture have consistently been identified as high risk at Level 1 for Australian fisheries, so the limited PSA methods currently available are still expected to provide useful information for fisheries management. Management agencies in the United States have opted to only use PSA methods (as opposed to the entire ERAEF framework) to assess the vulnerability of species to fishery mortality (Patrick et al. 2010).

<u>Objective 2:</u> *To evaluate the ability of ERAEF to provide timely advice on the impacts of non-fishing activities in BC on marine ecosystems using risk-based triage*

ERAEF could be a useful tool for assessing the impacts of non-fishery activities on species, habitats, and communities, especially the Scoping and Level 1 SICA stages, which could be easily adapted to focus more specifically on non-fishery impacts. For example, it could be used to address questions such as "What are the potential risks of an expansion of shellfish aquaculture on groundfish species?" As with traditional ERAEF assessment for fishing effects, the ability of assessors to produce risk statements for habitats and communities is subject to further development of methods to identify units of analysis for these components.

The Scoping stage of ERAEF would be a valuable tool for defining concerns with non-fishery activities for which fisheries scientists, managers, and stakeholders have little experience. For example, if the purpose of the assessment was to evaluate potential risk for a proposed offshore wind farm, assessors would first need to come up with a detailed list of stressors and propose pathways through which the stressors could affect ecosystem components. Identified stressors could then be assessed at Level 1 using the plausible worst case scenario approach of SICA to produce a completed SICA form for the activity of interest.

Future requests for science advice on the impacts of a non-fishery activity on groundfish species (e.g., aquaculture, a proposed offshore wind farm) can consider SICA (combined with a Scoping step) as a potential tool for providing science advice. The development of Level 2 PSA methods for non-fishery impacts is also possible, although it would require a larger time commitment than SICA to develop a scientifically-defensible methodology.

<u>Objective 3:</u> To determine whether risk-based outputs from ERAEF could help prioritize scheduling of science advice related to groundfish species and fisheries.

ERAEF can help with the prioritization of groundfish science advisory activities by indicating the types of issues that science effort should focus on based on ecological risk (e.g., fishery capture versus benthic impacts versus gear loss). However, once a decision is made to allocate science effort towards an issue, several challenges exist to using ERAEF risk scores a sole basis for prioritizing which unit of analysis gets assessed when. Our original perception that ERAEF risk scores could be used as a basis for prioritizing single-species assessments therefore appears misguided.

One challenge to using ERAEF to prioritize the assessment of individual species is that ERAEF assesses potential ecological risk from a single fishing activity. However, ecological risk is just one of several criteria typically used to prioritize stock assessment advice. Other factors of interest include the identification of a species for assessment under the Canadian Species at Risk Act, the level of uncertainty in previous advice, time elapsed since advice was last provided, and the cultural, economic or social importance of a species or activity. Thus, ERAEF risk scores would only be one of several pieces of information to be considered when assigning priority. Developing formal scoring criteria for some of these other factors, as well as methods for comparing scores among the different factors, would be a significant undertaking. Fletcher et al. (2010) describe a multi-level decision-making framework that attempts to prioritize issues based on qualitative estimates of ecological and social risk while aligning fisheries management with regional marine planning processes. While such a framework may help in the long-term, it would take several years and a substantial amount of consultation to establish.

A second challenge to using ERAEF to prioritize the assessment of individual species is that ERAEF is intended to inform and document decision-making processes for a single fishery, which does not line up well with the individual species quotas assigned to the integrated multi-gear groundfish fishery in BC. For example, the ecological risk scores obtained for individual species in the Level 2 PSA analysis of this pilot study only represent the potential risk imposed by the bottom-trawl fishery in Hecate Strait. A separate ERAEF analysis for all other fisheries operating in Hecate Strait, as well as for all non-fishery impacts in the area, would be needed to give a complete picture of the total ecological risk incurred by each fish species. Multiple ERAEF analyses for each gear type leads to the problem of how to combine risk scores across fisheries.

We thus see prioritization of science advice related to groundfish species and fisheries as a two-stage process. At stage 1, ERAEF can provide advice on the types of issues science staff should work on. For example, if the impact of fishery capture on Directed species was consistently scored the highest potential risk, we would be justified in continuing to focus on single-species assessments that recommend a quota using population models that predict the response of fish stocks to harvest. If however gear impacts on benthic habitats was scored as equally high risk, a more equal allocation of science advisory activities between single-species assessment and gear impact studies would be warranted. At stage 2, we suggest that a consultative workshop aimed at prioritizing single-species assessments based on perceived risk by managers, scientists, and stakeholders be used. In this case, ERAEF risk scores would be just one piece of information used at the workshop. Prioritization could also be informed by information on recent trends in relative abundance indices, recent trends in retained and non-retained catch, changes in species distribution, changes in the fishery footprint, SARA status, and cultural, social, and economic considerations. While the stakeholder workshop at stage 2 will be more subjective that using ERAEF scores alone, it provides a more practical and efficient means of prioritizing work at the species level in the short-term.

Objective 4: *To demonstrate a potential format for science input to an Ecosystem Approach to Management*

Examples of formats that could be used to provide ERAEF-based science advice to fisheries managers are provided in the completed SICA scoring forms (Figures 3-8 to 3-10), the SICA summary table (Table 3-11), the SICA summary figures (Figures 3-1 to 3-3), and the PSA plots (Figures 4-2 and 4-3). The utility of these types of summaries to fisheries management will depend on how well they align with the information needs of decision-making under an EAM, which may include information on cumulative impacts and socio-economic risks. Determination of how fisheries decisions under an EAM will be made in Canada is still under development, so information needs may not yet be clear. At the very least, ERAEF can inform EAM by providing a comprehensive summary of existing knowledge, information, and data on the ecological impacts of fisheries on ecosystem components, as well as by identifying areas in which information is lacking (e.g., Figure 5-1).

5.5. GENERAL CONCLUSIONS

The results from this pilot study demonstrate that ERAEF provides a means to organize the pursuit of science-based advice of fishery impacts on a diverse ecosystem.

Examples for Directed Species, Non-Directed Species, and sponge reef Habitats in the current pilot study indicate that the Level 1 SICA analysis could be useful for directing research and management actions towards potentially high-risk issues. However, further development of methods for classifying Community and Habitat components in BC will be needed before ERAEF can be fully applied. The inclusion of expert opinion and the detailed documentation for SICA could help ensure that decisions on where to focus science and management are inclusive, transparent, and repeatable. While the Level 2 PSA analysis is narrower in the scope of fishery impacts it can currently assess (only fishery capture), it demonstrates one type of tool that could be used for a more intensive analysis of potential risk at Level 2. Further development of PSA methodology is possible, as is the substitution of alternative rapid assessment methods that are better suited to the specific issue at hand for BC fisheries. The key advantage of ERAEF lays in its hierarchical approach to assessment that allows analysis methods to progress from a comprehensive assessment using qualitative data to more intensive assessments of high risk issues using quantitative data.

With regard to the four specific objectives that were identified for this pilot study, we found that ERAEF could address the first two: timely advice on the impacts of BC fisheries on marine ecosystems and timely advice on the impacts of non-fishing activities on marine ecosystems. However, further method development would be needed before either of these needs could be fully met for all ecosystem components. The ability of ERAEF to address the third objective of prioritizing science advice related to groundfish species and fisheries is also possible, but not at the level of individual units of analysis that we originally envisioned. ERAEF risk scores alone are not adequate for providing advice on which species (or habitats or communities) to assess when. The need to combine ERAEF scores of ecological risk over all fisheries and external activities to assess total risk for a unit of analysis, as well as the need to combine ecological risk with cultural, social, and economic considerations, is believed to be too onerous in the short-term. Instead, ERAEF can provide advice at a higher level by advising on how much time science should allocate to single-species assessments versus other ecosystem concerns. Finally, the results figures and tables presented in this document meet our fourth objective for the pilot study, which was to demonstrate a potential format for science input to an Ecosystem Approach to Management. These results demonstrate that ERAEF has the ability to inform EAM by providing a comprehensive summary of existing knowledge, information, and data on the ecological impacts of anthropogenic activities on ecosystem components, as well as to identify areas in which information is lacking. Outstanding issues that are necessary for EAM but that are not addressed by ERAEF at Levels 1 and 2 include the assessment of cumulative impacts over multiple activities and the consideration of socioeconomic benefits and risks when making management decisions.

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APPENDIX A

Assessing suitability of Australian ERAEF objectives for BC Groundfish Fisheries

To ensure that the recommended core and operational objectives used for Australian applications of ERAEF (Hobday et al. 2007) were suitable for BC groundfish fisheries, we conducted a review of Canadian Fisheries policy. Canada is a signatory to several international agreements including the United Nations Fish Stocks Agreement (UNFSA, United Nations 1995), the UN Convention on Biological Diversity (United Nations 1992), and the 2002 World Summit on Sustainable Development in Johannesburg, the latter of which was reaffirmed by Canada at the International Conference on the Governance of High Seas Fisheries, and the United Nations Fish Agreement (Fisheries and Oceans Canada 2005a). The principles of these international agreements are reflected in Canadian domestic laws and policies.

We reviewed three key pieces of Canadian legislation that influence fisheries management, the *Fisheries Act*, the *Oceans Act*, and the *Species at Risk Act* (SARA), to identify Canadian objectives for fisheries management. The *Fisheries Act* assigns Fisheries and Oceans Canada the legal responsibility to conserve and protect fish and fish habitat. The *Oceans Act* promotes application of precautionary and ecosystem approaches to conservation, management, and exploitation of marine resources in order to maintain biological diversity and productivity in the marine environment. The *Species at Risk Act* (SARA) is intended to prevent wildlife species from becoming extinct and allow for their recovery when needed. In addition to these three pieces of legislation, we reviewed several emerging domestic policy platforms developed to support their implementation. These platforms include *A Fishery Decision-Making Framework Incorporating the Precautionary Approach (*Harvest Strategy), *Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas* (Benthic Areas), *Policy on New Fisheries for Forage Species* (Forage Species), and *Canada's Oceans Strategy* (COS), which was developed to support implementation of Canada's Oceans Act.

The results of this review showed that core objectives identified for Australian fisheries were in line with Canadian fisheries policy (Table A-1). Statements about operational objectives were rarely included in the high-level Canadian policy documents we reviewed, with the exception of the *Fishery Decision-Making Framework Incorporating the Precautionary Approach*. In the case of the latter, operational objectives related to the desired status of harvested fish stocks relative to fishery reference points based on Maximum Sustainable Yield are provided; however, the methods used to assess performance relative to these objectives are more intensive than we believe is intended for the Level 1 SICA Analysis. We have therefore chosen to use the operational objectives identified by Hobday et al. (2007), which were developed to correspond to the core objectives identified in both Australia and Canada.

Table A-1: Identification of core objectives in Canadian fisheries policy, and comparison with core objectives used in Australian ERAEF. Abbreviations for Canadian Acts and Policies are provided in the text above.

Component	**Relevant Objectives from Canadian Policy**	**ERAEF Core Objective**
Directed Species	Harvest Strategy: Avoid serious harm to reproductive capacity of harvested stock SARA: Prevent Canadian indigenous species, subspecies, and distinct populations from becoming extirpated or extinct Forage Species: Maintenance of full reproductive potential of forage species, including genetic diversity and geographic population structure	Avoid serious harm to reproductive capacity of directed species or population Avoid negative consequences for directed species or population sub-components
Bycatch	Harvest Strategy: Avoid serious harm to reproductive capacity of harvested stock SARA: Prevent Canadian indigenous species, subspecies, and distinct populations from becoming extirpated or extinct Forage Species: Maintenance of full reproductive potential of forage species, including genetic diversity and geographic population structure	Avoid serious harm to reproductive capacity of bycatch species or population Avoid negative consequences for bycatch species or population sub-components
TEP	SARA: Prevent Canadian indigenous species, subspecies, and distinct populations from becoming extirpated or extinct SARA: Provide for the recovery of endangered or threatened species	Avoid serious harm to reproductive capacity of TEP species or population Avoid negative consequences for TEP species or population sub-components Avoid negative impacts on the population from fishing

Habitats	Benthic areas: Avoid impacts of fishing that are likely to cause serious or irreversible harm to sensitive marine habitat, communities and species COS: Ensure protection of the marine environment, where protection must consider the degradation of the marine environment including, physical alteration and destruction of marine habitat	Avoid negative impacts on the quality of the environment Avoid reduction in the amount and quality of habitat
Communities	Benthic areas: avoid impacts of fishing that are likely to cause serious or irreversible harm to sensitive marine habitat, communities and species Forage species: Maintenance of ecological relationships (e.g predator-prey and competition) among species affected directly or indirectly by the fishery within the bounds of natural fluctuations in these relationships	Avoid negative impacts on the composition / function / distribution / structure of the community

APPENDIX B

Box B1: Interpreting PSA Summary Sheets

- A PSA summary sheet for each of the 25 species in the pilot study is presented in this appendix. Each page contains a table documenting the attribute values used to derive productivity and susceptibility indices for a single species, as well as data quality scores and associated data sources.

- Summaries of productivity and susceptibility scoring criteria used to assign scores are provided in Table 4-1 and Table 4-2, respectively.

- A reference code for data sources is provided for literature sources used to score an attribute (e.g., A-2006). The citation associated with each code is provided at the end of the appendix.

- Numerical values for the overall productivity index, susceptibility index, and risk (vulnerability) index are summarized at the bottom of each species sheet, along with the associated data quality scores for the indices.

- The relative risk ranking for each species is also given. A ranking of 1/25 indicates that a species had the highest risk score for the pilot study, while a ranking of 25 / 25 indicates that a species had the lowest risk score.

ARROWTOOTH FLOUNDER *(Atheresthes stomias)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	24 years	Mod. (2)	1	Arrowtooth flounder in BC (FS-2001)
Maximum size	71 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.192	Mod. (2)	1	Arrowtooth flounder in BC (FS-2001)
M	0.20	Mod. (2)	3	Assumed in a stock assessment (FS-2001).
Fecundity	1.3×10^6	High (3)	2	Arrowtooth flounder in Gulf of Alaska (cited within KM-2003)
Breeding	0	High (3)	1	Calculated by KM-2003
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	5	Low (1)	1	Arrowtooth flounder in BC (FS-2001)
Trophic level	4.26	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	87%	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	91%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour and swim off the bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.13 / lb 44% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Catch limits	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	An estimate of *F* for Arrowtooth flounder is BC has not been updated since 2000.
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.00	Data quality: 1.67

Susceptibility	Average score: 2.11	Data quality: 2.55

Risk / Vulnerability	Score: 2.91 Risk ranking: **15 / 25** (1 = Highest risk)	Data quality: 2.15

BIG SKATE *(Raja binoculata)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	26 years	Mod. (2)	1	Big skate in B.C. (MK-2006)
Maximum size	171 cm	Low (1)	1	Extracted from DFO groundfish database
Growth coeff.	0.04	Low (1)	1	Big skate in B.C. (MK-2006)
M	0.16	Low (1)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	5	Low (1)	2	Big skate on the Pacific coast of North America (cited in KM-2003)
Breeding	2	Mod. (2)	1	Calculated by KM-2003
Recruitment	-	-	-	Attribute not applied to sharks and skates
Age-maturity	7.5	Low (1)	1	Big skate in B.C. (MK-2006)
Trophic level	3.92	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	15%	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	99%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	1	No seasonal migration patterns found for BC stocks (KM-2009)
Behavioural responses	Decreased catchability	Low (1)	3	Assumed based on observations that thorny skates in Newfoundland escape under trawl gear (W-1992)
Morphological susceptibility	Low	Low (1)	3	Based on a study of skates in another demersal trawl fishery (F-2007)
Desirability	$0.13 / lb 86% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality exist for Big skate
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	41 – 60 %	Mod. (2)	3	Based on a study of skate species in other bottom trawl fisheries (L-2004; S-2002)

Productivity	Average score: 1.25	Data quality: 1.63

Susceptibility	Average score: 2.00	Data quality: 2.27

Risk / Vulnerability	Score: 3.40 Risk ranking: **2 / 25** (1 = Highest risk)	Data quality: 2.00

BROWN CAT SHARK *(Apristurus brunneus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	-	-	5	
Maximum size	65 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	-	-	5	
M	-	-	5	
Fecundity	2	Low (1)	2	Brown cat shark in North East Pacific (C-2000)
Breeding	1	Mod. (2)	3	Calculated based on observation that egg cases are placed in special habitats (attached to rocks, weeds, crevices)
Recruitment	-	-	-	Attribute not applied to sharks and skates
Age - maturity	-	-	5	
Trophic Level	3.58	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	33%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	-	-	5	Not enough survey catch records in DFO groundfish database to calculate
Vertical overlap	100%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	-	-	5	Not enough catch records in DFO groundfish database to calculate
Morphological susceptibility	High	High (3)	4	Assumed based ratio of body size to mesh size > 2.
Desirability	$0.00 / lb 0% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; not monitored	High (3)	1	Considered 'not monitored' because it was not included in S-2007.
F : M	-	-	5	No estimates of fishing mortality exist for brown cat shark
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	<10 %	High (3)	4	Assumed due to trauma from bringing deepwater species to surface; delicate body

Productivity	Average score: 1.50	Data quality: 3.50

Susceptibility	Average score: 2.43	Data quality: 3.27

Risk / Vulnerability	Score: 3.49 Risk ranking: **1 / 25** (1 = Highest risk)	Data quality: 3.37

BUTTER SOLE *(Isopsetta isolepsis)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	11 years	Mod. (2)	2	Butter sole on the Pacific coast (H-1973)
Maximum size	40 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.30	High (3)	2	Butter sole in BC; old reference (H-1948)
M	0.40	Mod. (2)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	350,000	High (3)	2	Butter sole on the Pacific coast (L-1996)
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age - maturity	2	Mod. (2)	1	Butter sole in BC; old reference (H-1948)
Trophic level	3.59	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	40%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	12%	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	100%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	Decreased overlap	Low (1)	1	Decreased overlap with fishery footprint during spawning in Skidigate inlet.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.32 / lb 66% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimate of fishing mortality for BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.33	Data quality: 2.11

Susceptibility	Average score: 2.33	Data quality: 2.27

Risk / Vulnerability	Score: 1.49 Risk ranking: **16 / 25** (1 = Highest risk)	Data quality: 2.20

C-O SOLE *(Pleuronichthys coenosus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	11 years	Mod. (2)	3	Approximated based on butter sole (same taxonomic family, similar maximum size)
Maximum size	36 cm	High (3)	2	C-O sole on the Pacific coast (H-1943)
Growth coeff.	0.30	High (3)	3	Approximated based on butter sole
M	0.40	Mod. (2)	4	Approximated based on maximum age of Butter sole using Hoeing's (1983) method
Fecundity	350,000	High (3)	3	Approximated based on butter sole
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age- maturity	2	Mod. (2)	3	Approximated based on butter sole
Trophic level	3.16	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	41%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	-	-	5	Not enough survey catch records in DFO groundfish database to calculate
Vertical overlap	100%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour and swim off the bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.35 / lb 12% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Non-target stock; not monitored	High (3)	1	Considered 'not monitored' because it was and it was not included in S-2007.
F : M	-	-	5	No estimate of fishing mortality for BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.44	Data quality: 2.78

Susceptibility	Average score: 2.50	Data quality: 2.91

Risk / Vulnerability	Score: 2.87 Risk ranking: **14 / 25** (1 = Highest risk)	Data quality: 2.85

CURLFIN SOLE *(Pleuronichthys decurrens)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	11 years	Mod. (2)	3	Approximated based on butter sole (same taxonomic family, similar maximum size)
Maximum size	42 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.30	High (3)	3	Approximated based on butter sole
M	0.40	Mod. (2)	4	Approximated based on maximum age of Butter sole using Hoeing's (1983) method
Fecundity	350,000	High (3)	3	Approximated based on butter sole
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	2	Mod. (2)	3	Approximated based on butter sole
Trophic level	3.85	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	39 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	25 %	Mod. (2)	1	Calculated from DFO groundfish database
Vertical overlap	100%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.39 / lb 70% retain.	High (3)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality for BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.33	Data quality: 2.67

Susceptibility	Average score: 2.44	Data quality: 2.55

Risk / Vulnerability	Score: 2.96 Risk ranking: **13 / 25** (1 = Highest risk)	Data quality: 2.60

DEEPSEA SOLE *(Embassichthys bathybius)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	11 years	Mod. (2)	3	Approximated based on butter sole (same taxonomic family, similar maximum size)
Maximum size	44 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.30	High (3)	3	Approximated based on butter sole
M	0.40	Mod. (2)	4	Approximated based on maximum age of Butter sole using Hoeing's (1983) method
Fecundity	350,000	High (3)	3	Approximated based on butter sole
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	2	Mod. (2)	3	Approximated based on butter sole
Trophic Level	3.26	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	9 %	Low (1)	1	Calculated from DFO groundfish database
Geographic concentration	-	-	5	Not enough survey catch records in DFO groundfish database to calculate
Vertical overlap	100%	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour and swim off the bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.00 / lb 0% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; not monitored	High (3)	1	Considered 'not monitored' because it was not included in S-2007.
F : M	-	-	5	No estimates of fishing mortality for BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.44	Data quality: 2.67

Susceptibility	Average score: 2.25	Data quality: 2.91

Risk / Vulnerability	Score: 2.74 Risk ranking: **24 / 25** (1 = Highest risk)	Data quality: 2.80

DOVER SOLE *(Microstomus pacificus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	49 years	Low (1)	1	Dover sole in BC (cited within KM-2003)
Maximum size	59 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.09	Low (1)	1	Dover sole in BC (cited within KM-2003)
M	0.085	Low (1)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	1.5×10^6	High (3)	2	Dover sole on the Pacific coast of North America (cited in KM-2003)
Breeding	0	High (3)	1	Calculated by KM-2003
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	5.6	Low (1)	2	Dover sole in southern BC (BM-2000)
Trophic level	3.27	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	72 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.44 / lb 94% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	An estimate of *F* for Dover sole in Hecate Strait has not been updated since 1998.
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 1.89	Data quality: 1.89

Susceptibility	Average score: 2.22	Data quality: 2.55

Risk / Vulnerability	Score: 3.07 Risk ranking: **7 / 25** (1 = Highest risk)	Data quality: 2.25

ENGLISH SOLE *(Parophrys vetulus)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	23 years	Mod. (2)	1	English sole in BC (cited within KM-2003)
Maximum size	47 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.21	Mod. (2)	1	English sole in Hecate Strait (S-2009b)
M	0.22-0.24	Mod.(2)	2	Estimated by fitting a stock assessment model (S-2009a)
Fecundity	913,800	High (3)	2	English sole on the Pacific coast of North America (cited in KM-2003)
Breeding	0	High (3)	1	Calculated by KM-2003
Recruitment	Moderate (34% successful)	Mod. (2)	1	Calculated that 34% of year classes in Hecate Strait have successful recruitment (data from SS-2009a).
Age-maturity	4.5	Low (1)	1	English sole in BC (F-2000)
Trophic Level	3.39	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	60 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour and swim off the bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.44 / lb 86% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	0.42-0.68	Mod. (2)	1	Based on 2006 assessment (S-2009a)
Relative biomass	0.31	Mod. (2)	1	Based on 2006 assessment (S-2009a)
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 1.33

Susceptibility	Average score: 2.18	Data quality: 1.82

Risk / Vulnerability	Score: 2.81 Risk ranking: **18 / 25** (1 = Highest risk)	Data quality: 1.60

FLATHEAD SOLE *(Hippoglossoides elassodon)*

Attribute	Value	Score	Data quality	Data source
PRODUCTIVITY ATTRIBUTES				
Maximum age	20 years	Mod. (2)	2	Flathead sole in Gulf of Alaska (S-2004)
Maximum size	39 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.115	Low (1)	2	Flathead sole in Gulf of Alaska (S-2004)
M	0.2	Mod. (2)	3	Assumed for Gulf of Alaska (T-2009)
Fecundity	72,800	Mod. (2)	2	Flathead sole in Pacific Ocean (H-1973)
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	8.75	Low (1)	2	Flathead sole in Gulf of Alaska (S-2004)
Trophic Level	3.64	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	39 %	Mod. (2)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.48 / lb 69% retain.	High (3)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.00	Data quality: 2.11

Susceptibility	Average score: 2.44	Data quality: 2.55

Risk / Vulnerability	Score: 3.16 Risk ranking: **5 / 25** (1 = Highest risk)	Data quality: 2.35

LONGNOSE SKATE *(Raja rhina)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	26 years	Mod. (2)	1	Longnose skate in B.C. (MK-2006)
Maximum size	131 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.06	Low (1)	1	Longnose skate in B.C. (MK-2006)
M	0.16	Low (1)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	1	Low (1)	2	Longnose skate on the Pacific coast of North America (cited in KM-2003)
Breeding	2	Mod. (2)	1	Calculated by KM-2003
Recruitment	-	-	-	Attribute not applied to sharks and skates
Age-maturity	13.5	Low (1)	1	Longnose skate in B.C. (MK-2006)
Trophic level	3.85	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	29 %	Mod. (2)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	1	No seasonal migration patterns found for BC stocks (KM-2009)
Behavioural responses	Decreased catchability	Low (1)	3	Assumed based on observations that thorny skates in Newfoundland escape under trawl gear (W-1992)
Morphological susceptibility	Low	Low (1)	3	Based on a study of skates in another demersal trawl fishery (F-2007)
Desirability	$0.20 / lb 54% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality exist for longnose skate
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	41 – 60 %	Mod. (2)	3	Based on a study of skate species in other bottom trawl fisheries (L-2004; S-2002)

Productivity	Average score: 1.38	Data quality: 1.63

Susceptibility	Average score: 1.78	Data quality: 2.27

Risk / Vulnerability	Score: 3.17 Risk ranking: **4 / 25** (1 = Highest risk)	Data quality: 2.00

NORTHERN ROCK SOLE *(Lepidopsetta polyxystra)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	22 years	Mod. (2)	2	Northern rock sole in Gulf of Alaska (GOA) (SS-2002)
Maximum size	50 cm	High (3)	2	Northern rock sole in GOA (SS-2002)
Growth coeff.	0.236	Mod. (2)	2	Northern rock sole in GOA (SS-2002)
M	0.20	Mod. (2)	2	Assumed for GOA assessment (T-2009).
Fecundity	400,000	High (3)	3	Assumed same as southern rock sole in BC
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	6.4	Low (1)	2	Northern rock sole in GOA (SS-2002)
Trophic level	3.21	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	-	-	5	
Geographic concentration	-	-	5	Not enough survey catch records in DFO groundfish database to calculate
Vertical overlap	-	-	5	
Seasonal migration	-	-	5	Few reports of northern rock sole in BC; hard to distinguish from southern species
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.55 / lb 91% retain.	High (1)	1	Calculated from DFO data; not differentiated from southern rock
Management strategy	Catch not distinguished	High (3)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No reliable index of relative biomass for northern rock sole in Hecate Strait
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 2.22

Susceptibility	Average score: 2.40	Data quality: 3.73

Risk / Vulnerability	Score: 2.99 Risk ranking: **12 / 25** (1 = Highest risk)	Data quality: 3.05

PACIFIC COD *(Gadus macrocephalus)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	11 years	Mod. (2)	1	Pacific cod BC (W-1996)
Maximum size	80 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.203	Mod. (2)	1	Pacific cod BC (W-1996)
M	0.40	High (3)	2	Average estimate for Hecate Strait stock, as summarized in ON-2009
Fecundity	148,250	High (3)	1	Pacific cod in BC (W-1996)
Breeding	0	High (3)	1	Calculated by KM-2003
Recruitment	Moderate (33 % successful)	Mod. (2)	1	Calculated that 33% of year classes in Hecate Strait have successful recruitment (data from SS-2005).
Age-maturity	4	Low (1)	1	Pacific cod in BC (cited within W-1996)
Trophic level	4.01	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	62 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	Decreases overlap	Low (1)	1	A seasonal closure for Pacific cod spawning aggregations is in place that limits potential overlap during this time
Behavioural responses	Increased catchability	High (3)	3	Based on a study of Atlantic cod which found horizontal herding of cod into the path of trawl nets (HT-2005).
Morphological susceptibility	High	High (3)	4	Assumed based on ratio of body size to mesh size > 2.
Desirability	$0.61 / lb 98% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	< 0.5	Low (1)	2	Ratio was 0.1 in 2005 (SS-2005). Quota since has increased from 400 to 800 tonnes.
Relative biomass	25 – 68%	Mod. (2)	2	Based on 2005 assessment of Pacific cod in Hecate Strait – Dixon Entrance (SS-2005)
Post-release survival	70 %	Low (1)	4	Based on an un-published estimate for an Atlantic cod beam trawl fishery

Productivity	Average score: 2.11	Data quality: 1.22

Susceptibility	Average score: 2.00	Data quality: 1.91

Risk / Vulnerability	Score: 2.75 Risk ranking: **23 / 25** (1 = Highest risk)	Data quality: 1.60

PACIFIC SANDDAB *(Citharichthys sordidus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	9 years	High (3)	2	Pacific sanddab in US (RP-1987)
Maximum size	33 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.33	High (3)	4	Approximated based on maximum age using Froese and Binohlan (2000) method
M	0.47	Mod. (2)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	4200	Mod. (2)	3	Assumed same as speckled sanddab
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	3	Mod. (2)	2	Pacific sanddab in US (RP-1987)
Trophic level	3.45	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	44 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	38 %	Mod. (2)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off the bottom in front trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.26 / lb 14% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.44	Data quality: 2.56

Susceptibility	Average score: 2.33	Data quality: 2.55

Risk / Vulnerability	Score: 2.80 Risk ranking: **21 / 25** (1 = Highest risk)	Data quality: 2.55

PACIFIC TOMCOD *(Microgadus proximus)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	3 years	High (3)	3	Approximated based on Atlantic tomcod (same genus and maximum size; SA-1987)
Maximum size	28 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	1.00	High (3)	4	Approximated based on maximum age using Froese and Binohlan (2000) method
M	> 0.4	High (3)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	1000	Mod. (2)	1	Pacific tomcod on Pacific coast (L-1996)
Breeding	0	High (3)	2	Assumed same as walleye pollock and Pacific cod (same genus); high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Assumed same as walleye, Pacific cod
Age-maturity	2	Mod. (2)	1	Pacific tomcod on Pacific coast (L-1996)
Trophic Level	3.58	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	24 %	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed same as Pacific cod and walleye pollock
Morphological susceptibility	Moderate	Mod. (2)	4	Assumed based on body size ratio of 1 – 2 times mesh size.
Desirability	\$0.35 / lb 0% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	0 %	High (3)	3	Assumed same as juvenile walleye pollock (O-1997)

Productivity	Average score: 2.44	Data quality: 2.33

Susceptibility	Average score: 2.33	Data quality: 2.64

Risk / Vulnerability	Score: 2.80 Risk ranking: **21 / 25** (1 = Highest risk)	Data quality: 2.50

PETRALE SOLE *(Eopsetta jordani)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	36 years	Mod. (2)	1	Petrale sole in BC (S-2009)
Maximum size	57 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.17	Mod. (2)	1	Petrale sole in Hecate Strait (S-2009b)
M	0.18	Low (1)	2	Estimated from assessment (S-2009b)
Fecundity	800,000	High (3)	2	Petrale sole on Pacific coast (cited in KM-2003)
Breeding	0	High (3)	1	Calculated by KM-2003
Recruitment	Moderate (46% successful)	Mod. (2)	1	Calculated that 46% of year classes in Hecate Strait have successful recruitment (data from SS-2009b).
Age-maturity	5	Low (1)	2	Petrale sole in Oregon (H-2002)
Trophic Level	4.05	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43%	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	54 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour and swim off the bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$1.16 / lb 91% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	0.88-1.07	High (3)	1	Estimated by fitting a stock assessment model (S-2009b)
Relative biomass	0.35	Mod. (2)	1	Based on 2006 assessment (S-2009a)
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.00	Data quality: 1.44

Susceptibility	Average score: 2.27	Data quality: 1.82

Risk / Vulnerability	Score: 3.03 Risk ranking: **9 / 25** (1 = Highest risk)	Data quality: 1.65

REX SOLE *(Glyptocephalus zachirus)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	29 years	Mod. (2)	2	Rex sole in Gulf of Alaska (TA-2005)
Maximum size	42 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.388	High (3)	2	Rex sole in Gulf of Alaska (A-2006)
M	0.17	Mod. (2)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	3900	Mod. (2)	2	Rex sole on the Pacific coast of North America (L-1996)
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	5.1	Low (1)	2	Rex sole in Gulf of Alaska (A-2006)
Trophic Level	3.24	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	88 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.36 / lb 79% retain.	High (3)	1	Calculated from DFO data
Management strategy	Targeted species; no catch limit	High (3)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 2.22

Susceptibility	Average score: 2.44	Data quality: 2.91

Risk / Vulnerability	Score: 3.02 Risk ranking: **11 / 25** (1 = Highest risk)	Data quality: 2.60

SAND SOLE *(Psettichthys melanostictus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	10 years	Mod. (2)	2	Sand sole in California (PM-2005)
Maximum size	49 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.79	High (3)	2	Sand sole in California (PM-2005)
M	0.4	Mod. (2)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	900,000	High (3)	2	Sand sole in California (PM-2005)
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	< 2	High (3)	2	Sand sole in California (PM-2005)
Trophic level	4.06	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	39 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	26 %	Mod. (1)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.31 / lb 67% retain.	Mod. (2)	1	Calculated from DFO data
Management strategy	Targeted species; no catch limit	High (3)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.44	Data quality: 2.22

Susceptibility	Average score: 2.33	Data quality: 2.55

Risk / Vulnerability	Score: 2.80 Risk ranking: **21 / 25** (1 = Highest risk)	Data quality: 2.40

SANDPAPER SKATE *(Bathyraja kincaidii)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	17 years	Mod. (2)	3	Approximated based on Alaska skate in the Bering Sea (same genus; MG-2007)
Maximum size	106 cm	Mod. (2)	3	Extracted from DFO groundfish database
Growth coeff.	0.087	Low (1)	3	Assumed same as Alaska skate (MG-2007)
M	0.25	Mod. (2)	4	Approximated based on maximum age of Alaska skate using Hoeing (1983) method
Fecundity	21	Low (1)	3	Assumed same as Alaska skate (MG-2007)
Breeding	2	Mod. (2)	2	Assumed same as other skates; high confidence in assumption
Recruitment	-	-	-	Attribute not applied to sharks and skates
Age-maturity	9.7	Low (1)	3	Assumed same as Alaska skate (MG-2007)
Trophic level	3.44	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	7 %	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Assumed based on lack of a documented seasonal mirgation
Behavioural responses	Decreased catchability	Low (1)	3	Assumed based on observations that thorny skates in Newfoundland escape under trawl gear (W-1992)
Morphological susceptibility	Low	Low (1)	3	Based on a study of skates in another demersal trawl fishery (F-2007)
Desirability	$0.16 / lb 3% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality exist for sandpaper skate
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	41 – 60 %	Mod. (2)	3	Based on a study of skate species in other bottom trawl fisheries (L-2004; S-2002)

Productivity	Average score: 1.63	Data quality: 2.88

Susceptibility	Average score: 1.89	Data quality: 2.55

Risk / Vulnerability	Score: 3.04 Risk ranking: **8 / 25** (1 = Highest risk)	Data quality: 2.68

SLENDER SOLE *(Lyopsetta exilis)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	20 years	Mod. (2)	2	Slender sole on Pacific coast (E-1983).
Maximum size	31 cm	High (3)	1	Extracted from DFO groundfish database
Growth coeff.	0.115	Mod. (2)	3	Approximated based on Flathead sole (similar maximum size and maximum age)
M	0.21	Mod. (2)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	72,000	Mod. (2)	3	Approximated based on Flathead sole
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	4	Mod. (2)	2	Slender sole on the Pacific coast (L-1996)
Trophic level	3.44	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	24 %	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in a demersal trawl fishery (F-2007)
Desirability	$0.26 / lb 0% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; not monitored	High (3)	1	Considered 'not monitored' because it was not included in S-2007.
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 2.44

Susceptibility	Average score: 2.44	Data quality: 2.55

Risk / Vulnerability	Score: 3.02 Risk ranking: **11 / 25** (1 = Highest risk)	Data quality: 2.50

SPECKLED SANDDAB *(Citharichthys stigmaeus)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	3.5 years	High (3)	2	Speckled sanddab in Washington to California (RP-1987; AL-2001)
Maximum size	17 cm	High (3)	2	Speckled sanddab, Pacific coast (H-1973)
Growth coeff.	0.857	High (3)	4	Approximated based on maximum age using Froese and Binohlan (2000) method
M	> 0.4	High (3)	4	Approximated based on maximum age using Hoeing's (1983) method
Fecundity	4200	Mod. (2)	2	Speckled sanddab in RP-1987; AL-2001
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	1	High (3)	2	Speckled sanddab in California (AL-2001)
Trophic Level	3.40	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	44 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	-	-	5	
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on flatfish herding behaviour (R-2008)
Morphological susceptibility	Low	Low (1)	4	Assumed based on small body size (rarely > 13 cm in length, which is < mesh size)
Desirability	$0.00/ lb 0% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.67	Data quality: 2.56

Susceptibility	Average score: 2.13	Data quality: 3.00

Risk / Vulnerability	Score: 2.51 Risk ranking: **25 / 25** (1 = Highest risk)	Data quality: 2.80

SOUTHERN ROCK SOLE *(Lepidopsetta bilineata)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	22 years	Mod. (2)	2	Rock sole in Hecate Strait (S-2011)
Maximum size	50 cm	High (3)	2	Extracted from DFO groundfish database; sample may include northern rock sole
Growth coeff.	0.203	Mod. (2)	2	Rock sole in Hecate Strait (S-2011); sample may include northern rock sole
M	0.20	Mod. (2)	3	Assumed in a stock assessment for BC rock sole (F-2000).
Fecundity	400,000	High (3)	2	Rock sole in BC (cited in KM-2003)
Breeding	0	High (3)	2	Calculated by KM-2003
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	6	Low (1)	2	Rock sole in Hecate Strait (S-2011)
Trophic Level	3.21	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	41 %	Mod. (2)	2	Calculated from DFO groundfish database
Geographic concentration	49 %	Mod. (2)	2	Calculated from DFO groundfish database; sample may include northern rock sole
Vertical overlap	100%	Mod. (2)	2	Calculated from DFO groundfish database; sample may include northern rock sole
Seasonal migration	No change	Mod. (2)	4	Based on expert opinion and no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour; swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	\$0.55 / lb 91% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 2.22

Susceptibility	Average score: 2.22	Data quality: 2.82

Risk / Vulnerability	Score: 2.85	Data quality: 2.55
	Risk ranking: **17 / 25** (1 = Highest risk)	

SPINY DOGFISH *(Squalus acanthias)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	100 years	Low (1)	2	Global review of spiny dogfish (cited by KM-2003)
Maximum size	111 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.044	Low (1)	1	Spiny dogfish in BC (cited within KM-2003)
M	0.094	Low (1)	1	Spiny dogfish in BC (W-1979)
Fecundity	9	Low (1)	1	Spiny dogfish in BC (cited in KM-2003)
Breeding	12	Low (1)	1	Calculated by KM-2003
Recruitment	-	-	-	Attribute not applied to sharks and skates
Age-maturity	35	Low (1)	1	Spiny dogfish in BC (cited within KM-2003)
Trophic Level	4.30	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	43 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	67 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	89 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	Decreased overlap	Low (1)	2	Old mature females are not available to fishery in Hecate Strait and Dixon entrance during summer; moderate confidence because old reference (H-1943)
Behavioural responses	-	-	5	
Morphological susceptibility	High	High (3)	3	Assumed based on ratio of body size to mesh size > 2.
Desirability	$0.14 / lb 4% retain.	Low (1)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	0.06-0.15	Low (1)	2	Based on 2008 assessment of spiny dogfish for entire outside BC stock (G-2011)
Relative biomass	67 – 96%	Low (1)	2	Based on 2008 assessment of spiny dogfish for entire outside BC stock (G-2011)
Post-release survival	71 %	Low (1)	3	Based on studies of spiny dogfish from bottom trawl fisheries (L-2004; S-2002)

Productivity	Average score: 1.13	Data quality: 1.25

Susceptibility	Average score: 1.50	Data quality: 2.00

Risk / Vulnerability	Score: 3.24 Risk ranking: **3 / 25** (1 = Highest risk)	Data quality: 1.68

STARRY FLOUNDER *(Platichthys stellatus)*

Attribute	**Value**	**Score**	**Data**	**Source**
PRODUCTIVITY ATTRIBUTES				
Maximum age	24 years	Mod. (2)	2	Cited within KM - 2003
Maximum size	69 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.190	Mod. (2)	2	Starry flounder in California (in KM-2003)
M	0.2	Mod. (2)	3	Assumed in a stock assessment for Gulf of Alaska starry flounder (T-2009)
Fecundity	1.5×10^6	High (3)	3	Approximated based on Kamchatka flounder (cited in KM-2003)
Breeding	0	High (3)	2	Assumed same as other flatfish; high confidence in assumption
Recruitment	Moderate	Mod. (2)	3	Based on a CV for flatfish recruitment of approximately 0.5 (VL-2005).
Age-maturity	3	Mod. (2)	2	Starry flounder on Pacific coast (L-1996)
Trophic level	3.32	Mod. (2)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	38 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	2 %	High (3)	1	Calculated from DFO groundfish database
Vertical overlap	100 %	High (3)	1	Calculated from DFO groundfish database
Seasonal migration	No change	Mod. (2)	4	Based on no recorded observations of a large seasonal migration.
Behavioural responses	Increased catchability	High (3)	3	Assumed based on observations that flatfish display herding behaviour, swim off bottom in front of trawl nets (R-2008)
Morphological susceptibility	Moderate	Mod. (2)	3	Based on a study of sole in another demersal trawl fishery (F-2007)
Desirability	$0.51 / lb 60% retain.	High (3)	1	Calculated from DFO data
Management strategy	Non-target stock; somewhat monitored	Mod. (2)	1	Species-specific catch statistics and biomass indices are compiled (e.g., S-2007); but no rules to guide management
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	10 – 34 %	High (3)	3	Based on a study of flatfish species in North Sea bottom trawl fisheries (V-1990)

Productivity	Average score: 2.22	Data quality: 2.22

Susceptibility	Average score: 2.56	Data quality: 2.55

Risk / Vulnerability	Score: 3.11 Risk ranking: **6 / 25** (1 = Highest risk)	Data quality: 2.40

WALLEYE POLLOCK *(Theragra chalcogramma)*

Attribute	Value	Score	Data	Source
PRODUCTIVITY ATTRIBUTES				
Maximum age	12 years	Mod. (2)	3	Walleye pollock in BC (SG-1983)
Maximum size	64 cm	Mod. (2)	1	Extracted from DFO groundfish database
Growth coeff.	0.414	High (3)	4	Walleye pollock in BC (SG-1983)
M	0.30-0.38	Mod. (2)	2	Walleye pollock in Gulf of Alaska (GOA) (H-2000)
Fecundity	307,564	High (3)	1	Walleye pollock in BC (M-1985)
Breeding	0	High (3)	2	Calculated by KM-2003
Recruitment	Moderate (68% successful)	Mod. (2)	2	Calculated that 68% of year classes in GOA have successful recruitment (based on D-2005).
Age-maturity	4.3	Low (1)	1	Walleye pollock in BC (SG-1983)
Trophic level	3.45	Low (1)	2	Fishbase (F-2010)
SUSCEPTIBILITY ATTRIBUTES				
Areal overlap	42 %	Mod. (2)	1	Calculated from DFO groundfish database
Geographic concentration	66 %	Low (1)	1	Calculated from DFO groundfish database
Vertical overlap	24 %	Low (1)	1	Calculated from DFO groundfish database
Seasonal migration	Decreases overlap	Low (1)	1	Spawning locations within pilot study are mostly inlets (Portland inlet, east coast of Moresby Island, mainland inlets; SM-1983), which are outside fishery footprint.
Behavioural responses	Increased catchability	High (3)	3	Assumed same as Pacific cod
Morphological susceptibility	High	High (3)	4	Assumed based on ratio of body size to mesh size > 2.
Desirability	$0.21 / lb 95% retain.	High (3)	1	Calculated from DFO data
Management strategy	Catch limits & pro-active	Low (1)	1	DFO Integrated Fisheries Management Plan for Pacific Groundfish 2010/11
F : M	-	-	5	No estimates of fishing mortality in BC
Relative biomass	-	-	5	No consistent, long-term series of biomass estimates extending to the current year
Post-release survival	<33 %	High (3)	3	Based on estimate of 0 % survival after 10 minutes of air exposure for juvenile walleye pollock (14-21 cm) (O-1997)

Productivity	Average score: 2.11	Data quality: 2.00

Susceptibility	Average score: 2.00	Data quality: 2.36

Risk / Vulnerability	Score: 2.75 Risk ranking: **23 / 25** (1 = Highest risk)	Data quality: 2.22

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APPENDIX C

We excluded the intrinsic rate of population growth, *r*, from the productivity index developed by Patrick et al. (2010) based on the premise that, when available, estimates should be treated as direct measures of productivity rather than as 1 of 10 attributes contributing to a productivity index. As a result, our index was based on 9 attributes instead of 10. To examine the effect of our decision to exclude estimates of *r* in cases where they are available, we compared the productivity index used for the pilot study (i.e., based on nine attributes) with the productivity index that would have been calculated using only an estimate of *r* (i.e., based on the excluded 10th attribute) for a sub-set of species.

Estimates of *r* were readily available for six pilot study species. Five of these species (English Sole, Pacific Cod, Petrale Sole, Southern Rock Sole, and Walleye Pollock) had sufficient information on life history parameters to estimate *r* using a demographic analysis based on the Euler-Lotka equation (McAllister et al. 2001, Stanley et al. 2009). A range of estimates for the sixth species, Spiny Dogfish, was available from multiple literature sources (summarized in Gallucci et al. 2011).

Productivity index scores based on the 9 attributes described in Table 4-1 were taken from Appendix B. Productivity index scores based on estimates of *r* alone were assigned using the scoring criteria of Patrick et al. (2010) for this attribute:

Scoring criteria for *r*:

High productivity (3)	Moderate productivity (2)	Low productivity (1)
< 0.5	0.16 – 0.5	< 0.16

Results show that the nine-attribute index was consistent with an index based on *r* alone (Table C-1). This result supports the decision to exclude estimates of *r* from the productivity index even when they are available because the life history correlates used to approximate *r* in the productivity index appear adequate.

Table C-1. Comparison of the productivity index used for the pilot study (i.e., based on nine life history attributes) with the productivity index that would have been calculated using the estimated intrinsic rate of population growth, *r*, as well as the estimated value of r used to assign a score for the former.

Species	Estimated *r*	Index based on *r* attribute	Index based on nine life history attributes
English Sole	0.40	2	2.22
Pacific Cod	0.46	2	2.11
Petrale Sole	0.33	2	2.00
Southern Rock Sole	0.34	2	2.22
Spiny Dogfish	0.017 – 0.07	1	1.13
Walleye Pollock	0.28	2	2.11