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Pacific Region

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Science Advisory Report 2017/013

APPLICATION OF A FRAMEWORK TO ASSESS VULNERABILITY OF BIOLOGICAL COMPONENTS TO SHIP-SOURCE OIL SPILLS IN THE MARINE ENVIRONMENT IN THE PACIFIC REGION

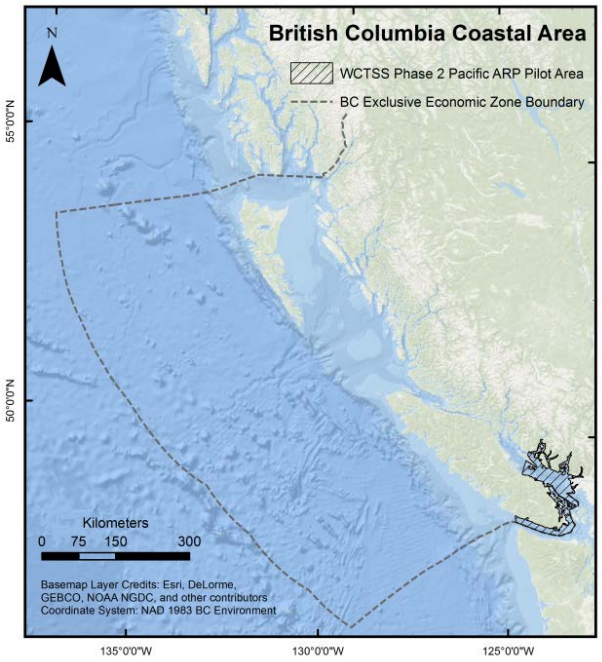

Figure 1. The British Columbia Pacific coastal region, the hatched area indicates the World Class Tanker Safety System (WCTSS) Area Response Plan pilot area for Western Canada.

Context:

'A National Framework to Assess the Vulnerability of Biological Components to Ship-source Oil Spills in the Marine Environment' (the framework) was developed by Fisheries and Oceans Canada (DFO),and reviewed in March 2016 through a Canadian Science Advice Secretariat (CSAS) National Peer Review (Thornborough et al., 2017).The framework contributes towards the development of a timely and informed response to ship-source oil spills by identifying biological sub-groups most vulnerable to spilled oil, and focusing data collection for spill response planning. The framework was determined to be appropriate for use in all Canadian regions with an allowance for regional flexibility - biological sub-groups were anticipated to require tailoring to reflect regional biota.

DFO's Oceans Branch requested that Science Branch provide a Pacific regional adaptation and application of the framework. The assessment and advice obtained from this CSAS Regional Peer Review, and the application of the adapted framework, will inform oil spill response planning for areas of interest within the Pacific Region (such as pilot areas for the World Class Tanker Safety System (WCTSS) initiative) (Fig. 1), and assist in identifying priority data relevant for those subgroups identified as being most vulnerable to oil.

This Science Advisory Report is from the September 14-15, 2016 Evaluation of Pacific Region application of a national framework to assess the vulnerability of biological components to ship-source oil spills in the marine environment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- In support of the development of a timely and informed response to ship-source oil spills in the Pacific region, DFO Science developed the 'National Framework to Assess the Vulnerability of Biological Components to Ship-source Oil Spills in the Marine Environment' (hereafter termed the 'framework') which was reviewed through a CSAS National Peer Review in March 2016 (Thornborough et al., 2017).
- The framework uses a structured method to identify the biological components most vulnerable to a ship-source oil spill utilising a suite of criteria and a screening and ranking process. DFO's Oceans Branch requested that Science Branch provide an adaptation and application of this framework to the Pacific region.
- The scope of the framework is limited to considering only the direct effects of oil. It was not designed to incorporate potentially significant indirect and food web effects such as consumption of contaminated food sources (e.g. contaminated plankton impacts on baleen whales), or cumulative effects from multiple stressors. Furthermore, this application is limited to marine biological components within DFO's jurisdiction in the Pacific region. However, it serves as an example of a method that could be applicable to biological components in other jurisdictions (e.g. marine birds).
- All marine biological components within DFO's mandate in the Pacific region are represented by sub-groups containing one or more species. The sub-groups described for the Pacific region application of the framework were developed through iterative changes in parallel with scoring. The proposed sub-groups are considered appropriate to represent the suite of on-shelf biota in the Pacific region, while also providing sufficient discrimination for scoring the vulnerability criteria.
- Some biological groups in the framework required considerable changes to sub-group breakdown when adapted for the Pacific region (i.e. marine fishes and marine algae/plants), whereas other biological groups required little to no changes (i.e. marine mammals, marine reptiles, marine invertebrates). Modifications to the sub-groups outlined in the framework were clearly stated and justified to facilitate comparable exercises in other regions.
- The following major changes were made to three of the vulnerability criteria in this pilot application of the framework to the Pacific region:
    1. Two criteria in the sensitivity category ('loss of insulation' and 'reduction of feeding/photosynthesis') were merged into a single criterion named 'mechanical sensitivity (reduction in feeding/ photosynthesis/insulation)' because both criteria capture impacts to energetics.
    2. Within the exposure category of criteria, site fidelity was moved from the aggregation/concentration criterion to the mobility criterion to capture mobile species with very limited home ranges.
    3. The name of a criterion within the exposure category was expanded from 'interaction with sediment' to 'seafloor or vegetation interacting' to address the fact that oil can also persist in consolidated sediments and result in exposure.
- Scoring the chemical sensitivity (impairment due to toxicity) criterion was challenging due to the breadth and conflicting nature of the literature on this topic. As a consequence, all sub-groups were given a precautionary score of 1*, based on a broad evaluation of toxicity on a whole oil basis, rather than a function of the constituents of the oil.

- The modified scoring criteria, and screening and ranking methods outlined were considered valid for use in the Pacific region to identify an appropriate list of sub-groups most vulnerable to a ship-source oil spill, and may also be applicable to framework adaptation in other regions.
- The screening and ranking method selected for this application required sub-groups to fulfil at least 1 exposure and 1 sensitivity criterion, and then be ranked based on the vulnerability score (total score over all criteria). The method was selected because the ranked complement of sub-groups was most consistent with the scientific literature. It differs from the framework method where scores were ranked based on recovery score.
- Relative vulnerability rankings of sub-groups were based on total additive scores across the three vulnerability criteria categories (exposure, sensitivity, and recovery). It is important to note that the unequal number of criteria in each of the vulnerability categories may result in unequal weighting of those categories in the total score (vulnerability score). It is recommended that further iterations of this approach look carefully at how the relative rankings are estimated to avoid unintentional bias in specific categories.
- Important knowledge gaps were identified throughout the application of the framework, and are summarized in a gap analysis.
- The geospatial representation of the outcomes of this framework will provide a foundation and a useful collaborative tool to inform marine spatial planning and response efforts in the Pacific region.

BACKGROUND

'A national framework to assess vulnerability of biological components to ship-source oil spills in the marine environment' was reviewed in 2016 (DFO, 2017), and is hereafter referred to as the "framework". The framework outlined a structured method to identify the biological sub-groups most vulnerable to a ship-source oil spill by utilising a suite of criteria and a screening and ranking process, and was an important contribution towards meeting DFO's commitment to ensuring sustainable aquatic ecosystems (Environment Canada, 2013). This paper describes a pilot application of this vulnerability framework to the Pacific region.

It is important to note that the output of this framework application (a ranked list of vulnerable sub-groups) is intended to be only one component of response preparedness. Within Canada's overall model of oil spill planning and response (Figure 2), the outputs of the vulnerability framework can be used to guide the process of data prioritization and collection necessary to fulfil DFO Science's contribution to the ecological component of "Resources at Risk" for oil spill planning.

This framework is not an all-inclusive approach for oil spill response; rather it is a template that can be adapted for different needs, by regions and groups for identifying what to provide to larger oil spill planning and response efforts. It is also not a risk assessment, but could be a framework for identifying the biological groups which should be considered within a future risk assessment.

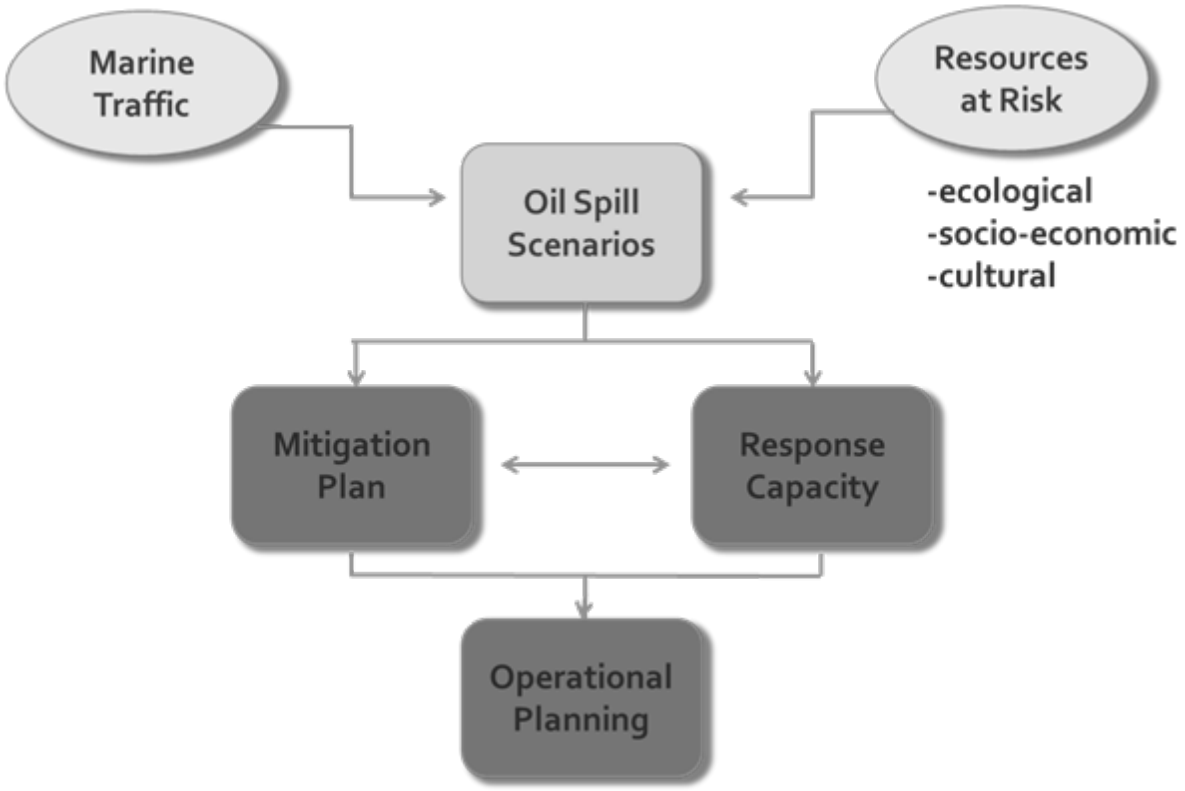

Figure 2. Overall model for oil spill planning and response. This framework identifies vulnerable biological sub-groups to address the ecological component of "Resources at Risk" (shown above).

Vulnerability is considered to be the degree to which a system is susceptible to, and unable to cope with, injury, damage, or harm (De Lange et al., 2010); however, the term 'vulnerability' has been used interchangeably with 'sensitivity'. In this framework, sensitivity is nested as a factor of vulnerability - where vulnerability is a function of exposure to a stressor, sensitivity (also termed effect or potential impact), and recovery potential (also termed adaptive capacity or resilience) (De Lange et al., 2010). Following this approach, the framework divides criteria into three categories: exposure, sensitivity, and recovery, each encompassing a number of criteria used to assess aspects of vulnerability in sub-groups. The most vulnerable biological components are identified through a scoring, screening, and ranking process described below (Figure 3).

The framework (Thornborough et al., 2017) consists of three key phases:

1. grouping of biological components into sub-groups based on similar characteristics related to oil vulnerability;
2. binary scoring of sub-groups against vulnerability criteria (under categories of exposure, sensitivity, and recovery); and
3. applying a screening and ranking method to identify the most vulnerable sub-groups.

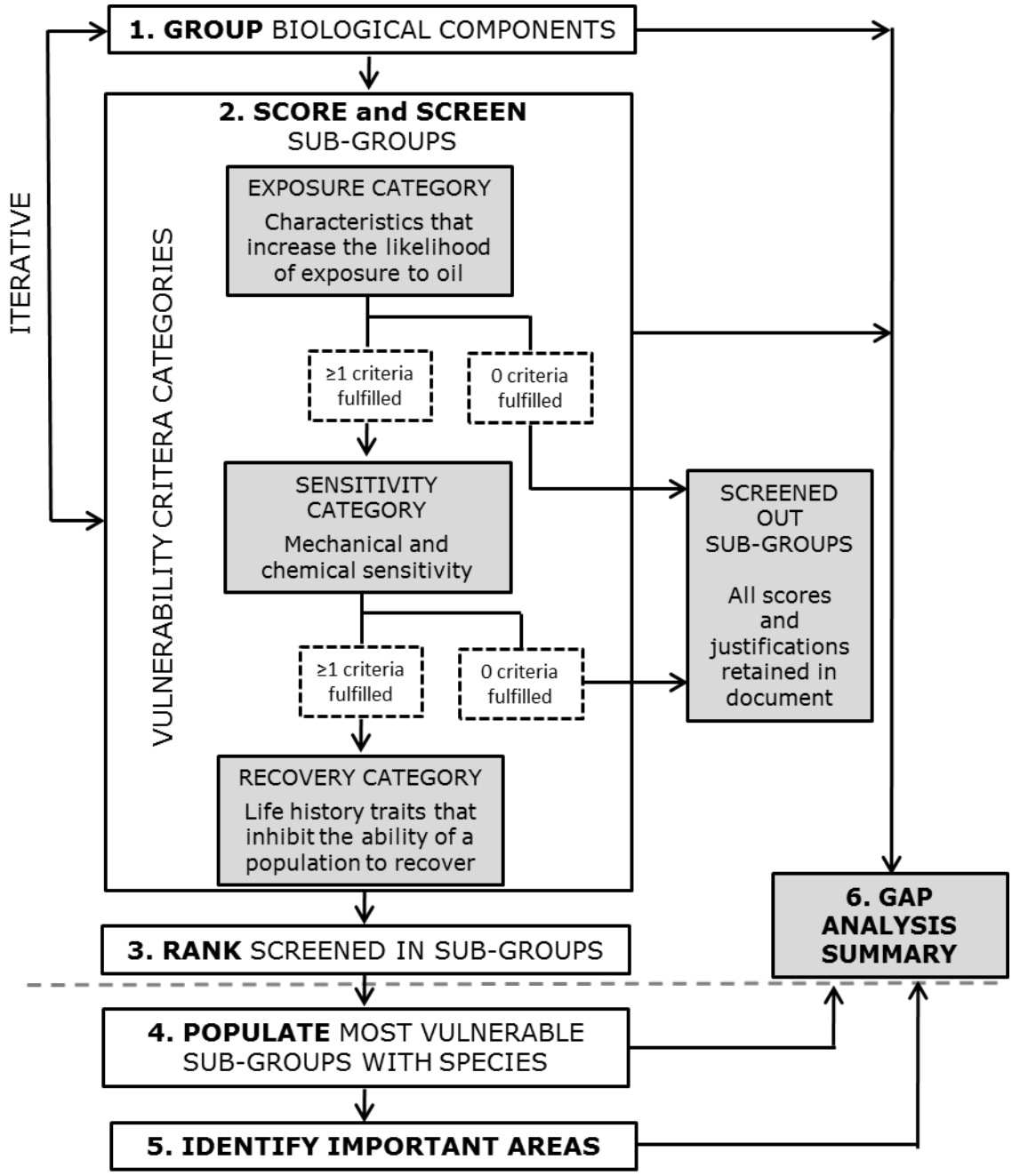

Figure 3. Overview of framework to identify vulnerable biological components (adapted from Figure 2.1 in Thornborough et al., 2017)

The framework utilises a top-down approach; at the start of the process, all sub-groups present in an area are included regardless of data availability. This approach allows for the identification of knowledge gaps to inform future development of this framework. These knowledge gaps are identified at every phase of the framework to inform a gap analysis. The flow chart developed for the framework (Thornborough et al., 2017) has been adapted to more clearly reflect how the framework was applied in the Pacific region (Figure 3). An iterative loop was included to reflect the fact that, though sub-group assessment and modification is the first step in the application of

the framework, in practice it occurs in an iterative way in parallel with the scoring process. In many cases it was not evident that sub-groups required further modification until attempting to score the sub-groups for vulnerability criteria. The Pacific region pilot application of the framework involved testing steps 1, 2 and 3 as outlined in Figure 3.

The framework was designed to be: nationally consistent but regionally flexible; grounded in science; and rapid and simple to implement. To assess vulnerability in a rapid and simple manner, the framework uses:

1. biological sub-groups rather than extensive species lists;
2. a simple binary scoring system; and
3. a screening and ranking process to assess vulnerability scores so that only the most vulnerable sub-groups are populated with species.

These three components facilitate a rapid and simple assessment to focus the provision of data of vulnerable biological components as part of oil spill planning for a specific area. This assessment, followed by data collection and mapping of the most vulnerable components, is intended to be completed in advance of an oil spill, rather than in response to it. This pilot application of the framework is intended to be relevant to all biota in the (on-shelf) Pacific region. Subsequent steps of the Pacific region application will focus on specific areas within this broader region, namely the Pacific Area Response Plan (ARP) pilot area (Figure 1), and will involve populating the sub-groups identified as most vulnerable with species and associated spatial data from within this area to guide oil spill planning efforts.

Objectives

The specific objectives of this Pacific pilot adaptation of the framework are to:

1. Assess, and where necessary, adapt sub-groups to the Pacific Region context, ensuring that sub-groups have been divided so that their vulnerabilities to oil can be discerned by the scoring criteria based on their biological and ecological traits.
2. Assess, and where necessary, adapt criteria and definitions through testing of the framework.
3. Score adapted sub-groups against all vulnerability criteria and, where necessary, adapt screening and ranking procedures in order to identify a list of sub-groups most vulnerable to ship-source oil spills in the Pacific region.

Scope

This scope of this pilot application is outlined in the framework document (DFO, 2017). Of particular note is that only marine biota within DFO's jurisdiction are assessed (i.e. not socio-economic and cultural values), as these will be considered by other sectors within DFO. In addition, the framework only considers the direct effects of oil, not indirect and food web effects such as consumption of contaminated food sources (e.g. contaminated plankton impacts on baleen whales), or cumulative effects from multiple stressors. Some of the limitations outlined in the framework scope are proposed as possibilities for future work in the next steps section of this document.

ASSESSMENT

Grouping Biological Components

The sub-groups outlined in the framework represent biota within five high-level biological groups:

1. Marine algae/plants;
2. Marine invertebrates;
3. Marine fishes;
4. Marine reptiles; and
5. Marine mammals.

Sub-groups in the high-level groupings above were created based on biological and ecological traits. For the Pacific region application, it was necessary to adapt these sub-groups in some cases to ensure that sub-groups were not only representative of the suite of on-shelf biota in the Pacific region, but also that they were divided in a way that allowed their vulnerability to oil to be discerned by the criteria. Most sub-group modifications addressed difficulties discerning between sub-groups when criteria were scored. In some cases, substantive changes were required to the sub-group organization (marine plants/algae and marine fishes); whereas, in other cases, very few changes were necessary (marine mammals). In total, there were 52 additional sub-groups in the Pacific region application, for a total of 118 sub-groups assessed.

Changes made to sub-groups were of three major types:

- Inclusion of location/habitat descriptors – to improve consistency across sub-groups by including descriptors for intertidal/ subtidal and benthic/ non-benthic/pelagic. Marine plants/algae had additional descriptors;
- Addition of missing sub-groups – Inclusion of sub-groups identified as missing by reviewers, and juvenile stages/pelagic larvae that did not fit the sub-group descriptions for adults (31 additional sub-groups overall); and
- Reorganisation - In many cases, sub-groups required restructuring to allow for clearer differentiation for scoring criteria once scoring began. This was an iterative process that occurred in parallel with scoring.

Vulnerability Criteria

In the framework (DFO, 2017), it was recommended that vulnerability criteria be used without modifications in order to facilitate comparisons (DFO, 2017). However, challenges encountered during the pilot application of the framework in the Pacific region resulted in a number of modifications to the criteria and their definitions. Most of these proposed changes are recommended as improvements to the framework rather than specific changes required for the Pacific region exclusively.

Exposure Criteria

During a large ship-source oil spill, all marine biological components have the potential to be exposed to some degree. However, species that are more likely to encounter spilled oil are assumed to be more vulnerable. Criteria in the exposure category identify characteristics that increase the likelihood of exposure to oil.

For the Pacific region pilot framework application, the following modifications were made to criteria in the exposure category:

1. Site fidelity was moved from the concentration criterion to mobility criterion, so that it became ‘‘mobility and/or site fidelity’ and the definition for site fidelity was refined;
2. The sea surface layer was defined as the top 1 metre of the water column; and
3. The ‘sediment interaction’ criterion was expanded to include interactions with any seafloor substrate (‘seafloor and/or vegetation interacting’).

A comparison of the exposure criteria proposed in the framework and the criteria used in the Pacific region pilot application is provided in Table 1.

Table 1. A comparison of framework criteria within the ‘Exposure’ category with those used in the Pacific region pilot application.

Framework criteria (DFO, 2017)	Pacific region pilot criteria
• Concentration (aggregation) and/or site fidelity • Mobility • Sea surface interaction • Sediment interaction	• Concentration (aggregation) • Mobility and/or site fidelity • Sea surface interacting • Seafloor and/or vegetation interacting

Sensitivity Criteria

Sensitivity criteria examine both mechanical and chemical sensitivity based on physiological characteristics that may influence the magnitude of impact from exposure to oil.

Mechanical sensitivity identifies physiological characteristics that are vulnerable to mechanical impairment by oil. There are two framework criteria that deal with mechanical sensitivity in the framework, for the Pacific region pilot application these were combined into a single criterion, as both address aspects of energetics, and when combined provide broader coverage across biological groups. The single criterion was named ‘mechanical sensitivity (reduction in feeding/photosynthesis/insulation)’.

The single chemical sensitivity criterion (impairment due to toxicity) identifies physiological characteristics more vulnerable to chemical impairment by oil. Changes to this criterion relate to how it was applied during scoring, and are outlined in the “Scoring of sub-groups” section.

A comparison of the framework criteria for sensitivity and the criteria used in the Pacific region pilot application is provided in Table 2.

Table 2. A comparison of framework criteria within the ‘Sensitivity’ category with those used in the Pacific region pilot application.

Framework criteria (DFO, 2017)	Pacific region pilot criteria
• Reduced feeding/photosynthesis (e.g. oiled filter feeding structures) • Loss of insulation (e.g. oiled fur)	• Mechanical sensitivity (reduction in feeding/photosynthesis/insulation)’
• Impairment due to toxicity (chemical sensitivity)	• Chemical sensitivity (impairment due to toxicity)

Recovery Criteria

Recovery criteria examine the life history traits that impact the ability of a population to recover. Two minor modifications were made to these criteria with respect to scoring guidance in the Pacific region pilot application as summarised in Table 3. Firstly, the definition of 'low reproductive capacity' was expanded to include 'or have life history traits that can lead to low reproductive potential (e.g. delayed maturity, infrequent reproductive success)'. The fourth criterion was also revised from 'close association with sediments' to 'close association with unconsolidated substrates' to better align with the intention of this criterion, which was to identify species that associate with soft substrates such as sand and mud that are known to retain oil.

Table 3. A comparison of framework criteria within the 'Recovery' category with those used in the Pacific region pilot application.

Framework criteria (DFO, 2017)	Pacific region pilot criteria
• Population status • Reproductive capacity • Endemism or isolation • Close association with sediments	• Population status • Reproductive capacity • Endemism or isolation • Close association with unconsolidated substrates

Scoring of Sub-groups

A binary system is used in the framework to score sub-groups against vulnerability criteria as either (1) criterion fulfilled, or (0) criterion not fulfilled. Scoring decisions were aided by consulting general guidance tables and supplemental guidance tables for each biological group, in addition to subject matter expertise and publications. Referenced justifications were provided for each score where applicable. All scores were based on the assumption of direct contact with oil. To ensure that the final total vulnerability scores were comparable across sub-groups and could be used to produce a ranked list of relative scores, sub-groups were scored in a consistent and relative manner across all major groupings.

Scoring was precautionary in a number of ways. For example, when assigning scores, a worst case scenario involving whole oil (rather than individual oil constituents) was assumed. Also, if at least one species within a sub-group was known to fulfill the criterion, then the whole sub-group was scored as fulfilling the criterion. Furthermore, sub-groups were scored based on the life stages most sensitive to impacts from oil (e.g. juveniles vs. adults). This ensured that sub-groups containing species where the adults may be relatively unaffected while juveniles may be highly affected were screened into the assessment. This was most relevant for the marine invertebrate and marine fishes groups.

The chemical sensitivity criterion (impairment due to toxicity) was difficult to assess accurately and rapidly for all sub-groups due to the breadth of literature review required to arrive at a clear score for the large number of sub-groups assessed. Consequently, in this pilot application, all sub-groups were given a precautionary score of 1 (1*) for this criterion until a detailed literature review on all groups can be completed.

To ensure the pilot application was scientifically valid and relevant to the Pacific region, the breakdown of sub-groups and all scores were subjected to peer-review by at least one subject matter expert for each of the major biological groups assessed.

Screening and Ranking of Sub-groups

The screening and ranking method outlined in the framework, whereby all sub-groups are first scored for exposure criteria, and only those sub-groups fulfilling one or more exposure criteria are retained to be scored for sensitivity criteria was applied in the Pacific region pilot application. Only sub-groups which fulfilled at least 1 sensitivity criterion were retained and scored for recovery. The final list of screened sub-groups was then scored for recovery criteria and ranked based on cumulative recovery scores (0-4) to produce a list of vulnerable sub-groups ranked by recovery potential (sub-groups with the lowest potential for recovery ranked at the top of the list).

When applied to the Pacific region, the screening and ranking method in the framework was determined to be ineffective, as the ranked list it produced was not consistent with the scientific literature. In addition, it resulted in only minimal screening of sub-groups at the exposure screening stage (2 of 118 sub-groups screened out), and no screening at the sensitivity screening stage, resulting in the need to fully score all but 2 sub-groups.

To identify a more effective screening and ranking method, eight alternative screening and ranking methods were explored, each with a variation in the number of fulfilled criteria required at each screening step, as well as in the ranking procedure to assess the final screened list of sub-groups. To be able to compare these methods it was necessary to score all biological sub-groups (118) for all criteria (10).

The screening and ranking method identified as the most appropriate among those tested used the same screening method as the framework, but had a different ranking procedure. For the Pacific region pilot application, the final list of sub-groups was ranked using the total scores for all criteria (vulnerability scores), rather than by total recovery score (as in the framework). Though this method only screened out a limited number of sub-groups, the ranked complement of sub-groups it produced was the most consistent with the scientific literature.

List of Most Vulnerable Sub-groups Identified for the Pacific Region

Table A-1 summarises the ranked list of sub-groups identified as most vulnerable following the Pacific region pilot application of the framework. Of 118 sub-groups, 2 were screened out in the exposure screening stage (highlighted in grey at the bottom of the table). Most major groups (e.g. marine invertebrates) were represented across the range of vulnerability scores from 1-9, and no sub-group had a vulnerability score greater than 9 (out of a possible 10).

Marine plant and algae vulnerability scores ranged from 4 to 9. The highest vulnerability scores for this group included three sub-groups with scores of 9, one with a score of 8, and two with scores of 7. The lowest vulnerability scores for this group included four sub-groups with scores of 4.

Marine invertebrate vulnerability scores ranged from 3 to 8. The highest vulnerability scores for this group included three sub-groups with scores of 8, and eleven sub-groups with scores of 7. The lowest vulnerability scores included two marine invertebrate sub-groups with scores of 3.

Marine fish vulnerability scores ranged from 1-8. The highest vulnerability scores for this group included one sub-group with a score of 8 and three sub-groups with scores of 7. The lowest vulnerability scores included ten fish sub-groups with scores of 3, one with a score of 2, and two with scores of 1, both of which were screened out at the exposure screening step.

The marine reptiles group is comprised of only one sub-group, sea turtles, which received a vulnerability score of 6.

Marine mammal vulnerability scores ranged from 4 to 9. The highest vulnerability scores for this group included two sub-groups with scores of 9 and one with a score of 7. The lowest vulnerability scores for this group included two sub-groups with scores of 4.

Discussion

The Pacific region pilot adaptation of the framework assessed the suitability of the framework as a simple and rapid method to assess vulnerability of marine biological components to ship-source oil spills in the marine environment.

Development of biological sub-groups

Two requirements were considered when adapting sub-groups:

(i) ensuring sub-groups were representative of the on-shelf biota of the Pacific region; and

(ii) that sub-groups were divided so that differences in vulnerability between sub-groups could be discerned when scored by vulnerability criteria.

In some cases, few modifications were needed to sub-groups to fulfill the requirements outlined above (e.g. marine mammals), but in others, more significant changes were required (e.g. marine fishes). Expert consultation ensured that sub-groups were developed appropriately based on these two requirements. Ultimately, all sub-groups were able to be effectively scored for each of the vulnerability criteria after this process, indicating their suitability (Appendix Table A-1).

Suitability of the list of most vulnerable sub-groups for the Pacific Region

The list of most vulnerable sub-groups identified for the Pacific region contained 116 sub-groups screened for vulnerability to oil (exposure and sensitivity), and then ranked by their vulnerability scores (total scores for all vulnerability criteria combined). To assess the validity of this ranked list, results were compared to other studies examining the impacts of oil spills on marine organisms.

Overall, the outcomes of the trial application to the Pacific region aligned well with findings from previous studies. Notable exceptions occurred with the following groups (vulnerability scores in brackets):

- Phytoplankton (4): phytoplankton received a relatively low vulnerability score. However, findings for phytoplankton in the literature are variable, with some studies reporting local short term decreases in abundance and productivity of phytoplankton, while others report increases in primary productivity (Duval et al. 1989). A main driver for the low vulnerability score in this analysis was recovery, as phytoplankton are expected to have high recovery regardless of their exposure or sensitivity.
- High mobility arthropods sub-groups (5,4,3): Most high mobility invertebrate sub-groups (including arthropods) received relatively low vulnerability scores. This is in contrast with findings following the *Nestucca* oil spill off the coast of Washington and BC, where crabs appeared to be highly impacted (Duval et al. 1989). However, these results were based on observations following within months of a spill and did not take into account recovery. Given their life history characteristics, arthropods are expected to have high recovery potential.
- Sea turtles (4): sea turtles received a relatively low vulnerability score. This score is considered acceptable as sea turtle sightings are infrequent in the Pacific region of Canada (British Columbia) making it difficult to draw conclusions about the distribution and habitat use of sea turtles in BC waters.

Challenges and Limitations

A number of challenges and limitations were encountered during the adaptation and application of the framework to the Pacific region. These challenges and limitations are outlined in detail in the research document (Hannah et al. 2017, in prep[1]) and are also incorporated throughout this document in the section most pertinent to each.

Sources of Uncertainty

A key result of the pilot application was the identification of knowledge gaps, including a lack of information or conflicting information, during two main stages of the framework adaptation and application processes:

1. Grouping biological components into sub-groups, and
2. Scoring sub-groups against the suite of vulnerability criteria. Gaps may be used to prioritize future research.

Major gaps included:

- Scores were affected by limited knowledge of the fate and behaviour of oil in environment (e.g. persistence in different habitats)
- For some biological groups (e.g. marine plants/algae and invertebrates) there was a lack of specific biological information (e.g. life history) to guide sub-group breakdown and scoring.
- Lacking or conflicting information characterising the toxicity of oil to marine biological components limited the ability to effectively score the chemical sensitivity (impairment due to toxicity) criterion.

Next Steps

This application has produced a list of most vulnerable sub-groups for the Pacific region through an application of the framework. The next stage in the evaluation process will be the provision of appropriate geospatial representation for planning and response purposes. This will be done by populating sub-groups identified as most vulnerable with species inhabiting an area of interest, and identifying spatial data layers for those species within each vulnerable sub-group. For each species, important areas and associated datasets will be identified for mapping, such as areas of high concentration, and/or areas important for the most sensitive life-stages. It is expected that datasets for all species within a vulnerable sub-group will be rolled up into a single sub-group representation, consisting of multiple layers of datasets. An assessment of data gaps will be carried out at this stage.

This application of the framework was designed to provide the basic building blocks for assessing vulnerability to oil-spills that can be built upon in the future. Options for future work that would complement the application presented here include:

- Comparisons with outcomes from pilot applications underway in Quebec and Maritimes regions;

[1] Hannah, L., St. Germain, C., Jeffery, S., Patton, S., and M.O. 2017. Application of a framework to assess vulnerability of biological components to ship-source oil spills in the marine environment in the Pacific Region. DFO Can. Sci. Advis. Sec. Res Doc. In prep.

- Adapting components of the framework to assess spills of specific oil types;
- Assessing higher trophic effects within the framework (e.g. killer whale mother passing contaminants to a calf through milk); and
- Using a multi-level scoring rubric (e.g. scores of 1-4 rather than 0 or 1) and incorporating uncertainty for each score.

CONCLUSIONS AND ADVICE

- A framework was applied to the Pacific region to assess vulnerability of biological components to ship-source oil spills in the marine environment. The structured method comprised three major components:
  1. Grouping of biological components into sub-groups;
  2. Scoring of sub-groups against criteria in three categories (exposure, sensitivity and recovery); and
  3. Screening and ranking of scored sub-groups to produce a list of biological components ranked for vulnerability.
- The sub-groups proposed for the Pacific application of the framework represent the suite of on-shelf biota in the Pacific region, while also providing sufficient discrimination for effective scoring of vulnerability criteria.
- Some biological groups required considerable changes to sub-group breakdown for the regional application (i.e. marine fishes and marine algae/plants), whereas other biological groups required few to no changes (i.e. marine mammals, marine reptiles, marine invertebrates). Modifications to sub-groups were clearly stated and justified to facilitate comparable re-assessments in other regions.
- Scoring all sub-groups against all criteria in this pilot application allowed for a detailed evaluation of the outcomes of a range of different screening and ranking methods, and provided justification for recommending the chosen method. However, this approach may not be feasible for future applications if resources are limited.
- At present, the chemical sensitivity (impairment due to toxicity) criterion was not effective at differentiating between sub-groups based on vulnerability to chemical impacts of oil due to the scoring methods used. If future iterations of this framework application include this criterion, it is recommended that further investigation is needed to better characterize chemical vulnerability of sub-groups.
- The screening method used in the framework (requiring sub-groups to fulfil 1 exposure and 1 sensitivity criteria) was retained in the Pacific application, but the ranking method was modified so that sub-groups were ranked based on vulnerability scores (total score over all criteria), rather than on recovery scores. With the incorporation of this modification, the proposed screening and ranking method appears to function effectively to identify a ranked list of vulnerable sub-groups for the Pacific region that is most consistent with literature on oil impacts to marine organisms.
- This application of the framework will result in more focused data collection and expert advice on those biological components identified as most vulnerable to ship-source oil spills in the Pacific region

- Throughout the framework application, knowledge gaps were documented and included in a gap analysis which can be used to guide future work to address these gaps.
- The importance of expert input throughout all phases of regional framework development is emphasised, and is an appropriate approach for quality control. It is recommended that expert input on scoring and sub-group modifications be considered for future iterations of the framework adaptation.
- The geospatial products that will be produced based on the outputs of this framework will provide a foundation for coordinated planning and response across various organizations

The overall recommendations from this pilot application are outlined below.

- It is recommended that further iterations of this approach look carefully at how the relative rankings are calculated to avoid unintentional bias in specific categories of vulnerability criteria (exposure, sensitivity and recovery).
- The development of accessible and comprehensive geospatial databases is recommended as a next step, incorporating collaboration among DFO programs and other agencies engaged in marine spatial planning and response initiatives to avoid duplication of efforts and ensure efficiencies.
- Future iterations could examine alternative scoring and ranking methodologies, for example, scoring methods that are non-binary to provide gradient, and methods that could illustrate confidence in the score based on the data/info used to score.
- Phytoplankton and non-larval zooplankton were not assessed at sufficient resolution to assist decision making. It is recommended that the development of these two groups be included in future iterations of the framework.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 14-15, 2016 Evaluation of Pacific Region application of a National Framework to assess the vulnerability of biological components to ship-source oil spills in the marine environment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX: FINAL RANKED LIST OF VULNERABLE SUB-GROUPS

Table A-1. Final ranked list of screened sub groups for the Pacific regional application of the vulnerability framework. Separations between vulnerability scores (e.g. between those sub-groups scoring 9 and those scoring 8) are highlighted using alternating light grey shading. Sub-groups that were screened out are highlighted in dark grey shading.

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
MARINE PLANTS & ALGAE	Intertidal	Vascular Plants	Low energy unconsolidated shore	Seagrasses	e.g. *Zostera marina, Z. japonica, Ruppia maritima*	9
				Salt marsh grasses	e.g. *Carex lyngbyei, Leymus mollis*	
				Salt marsh succulents	e.g. *Sarcocornia pacifica, S. pacifica, Glaux maritima, Plantago maritima*	
MARINE MAMMALS	Mustelids	N/A	N/A	N/A	e.g. sea otter	
	Cetaceans	Baleen	Discrete	N/A	e.g. humpback whales; grey whales	
MARINE PLANTS & ALGAE	Intertidal	Vascular Plants	High energy, rocky shore	Seagrasses	*e.g. Phyllospadix scouleri, P. torreyi, P. serrulatus*	8
MARINE INVERTEBRATES	Intertidal	Sediment epifauna	Low mobility	Mollusca	e.g. snails [Cl. Gastropoda]	8
				Cnidaria	e.g. sea pens	
				Echinodermata	e.g. sea stars	
MARINE FISHES	Estuarine	Transient	N/A	Salmon (Salmonidae)	e.g. juvenile and adult salmon & steelhead	
	Intertidal	Benthic	Associated with unconsolidated substrates (Silt/Sand/Gravel) (including eelgrass environments)	Salmonidae (juvenile)	e.g. pink, chum, coho, chinook salmon	
MARINE PLANTS & ALGAE	Intertidal	Understory / Turf Algae	High energy, rocky shore	N/A	e.g. *Pelvetiopsis limitata, Cymathere triplicata, Postelsia palmaeformis, Corallina vancouveriensis, Alaria fistulosa*	7
	Subtidal	Canopy Algae	Low – moderate energy rocky habitat	N/A	e.g. Macrocystis integrifolia	
MARINE	Intertidal	Rock and rubble	Sessile (attached to hard substrate)	Mollusca	e.g. oysters [Bivalvia]	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
INVERTEBRATES		dwellers	Low mobility	Echinodermata	e.g. sea urchins [Echinoidea];sea cucumbers [Holothuroidea];sea stars [Asteroidea]	
MARINE INVERTEBRATES	Intertidal	Sediment infauna	Low mobility	Mollusca	e.g. clams [Bivalvia]; snails [Gastropoda]	7
				Worms	e.g. burrowers	
				Arthropoda	e.g. sand crabs [Emerita]	
				Lophophorates	e.g. horseshoe worms [Phoronida]; lampshells [Brachiopoda]	
MARINE INVERTEBRATES	Subtidal benthic	Rock and rubble dwellers	Sessile (attached to hard substrate)	Porifera	e.g. glass sponges	
			Low mobility	Echinodermata	e.g. sea urchins, sea stars	
		Sediment infauna	Low mobility	Mollusca	e.g. clams	
		Sediment epifauna	Low mobility	Cnidaria	e.g. sea pens	
				Echinodermata	e.g. sea stars	
MARINE FISHES	Estuarine	Transient	N/A	Sturgeon (Acipenseridae)	e.g. green sturgeon, white sturgeon	
	Intertidal	Benthic	Associated with unconsolidated substrates (Silt/Sand/Gravel) (including eelgrass environments)	Herring (Clupeidae)	e.g. Pacific herring	
MARINE MAMMALS	Cetaceans	Toothed	Discrete	N/A	e.g. killer whales: residents (Northern and Southern) and offshore populations; Pacific white sided dolphin	
MARINE PLANTS AND ALGAE	Intertidal	Understory / Turf Algae	Mod to low energy rocky shores	N/A	e.g. *Fucus gardneri, Neorhodomela larix, Desmarestia sp., Laminaria saccharina, Calliarthron* spp.	6
	Subtidal	Canopy Algae	High energy, rocky habitat	N/A	e.g. *Nereocystis leutkeana, Egregia menziesii*	
		Understory Algae	Rocky habitat	With tall, woody stipes or floats	e.g. *Pterygophera californica, Sargassum muticum, Lessoniopsis littoralis*	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
MARINE INVERTEBRATES	Intertidal	Rock and rubble dwellers	Sessile (attached to hard substrate)	Arthropoda	e.g. barnacles [Cirripedia]	
				Cnidaria	e.g. coral	
				Porifera	e.g. demosponges	
				Worms	e.g. tube worms [Polychaeta: Sedentaria]	
				Urochordata	e.g. sea squirts	
				Lophophorates	e.g.bryozoans [Ectoprocta]; lampshells [Brachiopoda]	
			Low mobility	Arthropoda	e.g. isopods [Isopoda]	
MARINE INVERTEBRATES	Intertidal	Rock and rubble dwellers	Low mobility	Cnidaria	e.g. sea anemones	6
	Subtidal benthic	Rock and rubble dwellers	Sessile (attached to hard substrate)	Cnidaria	e.g. coral	
		Sediment infauna	Low mobility	Worms	e.g. annelids	
				Lophophorates	e.g. horseshoe worms [Phoronida]; lampshells [Brachiopoda]	
		Sediment epifauna	Low mobility	Mollusca	e.g. snails [Cl. Gastropoda]	
MARINE INVERTEBRATES	Pelagic	Larvae	N/A	Mollusca	N/A	
				Echinodermata	N/A	
MARINE FISHES	Subtidal	Benthic	Associated with unconsolidated substrate (Silt/Sand/Gravel)	Elasmobranchs	e.g. big skate	
MARINE PLANTS & ALGAE	Intertidal	Canopy Algae	N/A	N/A	e.g. *Egregia menziesii*	5
		Encrusting Algae	Rocky habitat	N/A	e.g. Coralline algae, *Codium setchellii, Hildenbrandia* sp., *Mastocarpus* (crust form), *Ralfsia pacifica*	
MARINE INVERTEBRATES	Intertidal	Rock and rubble dwellers	Low mobility	Worms	e.g. polychaetes [Errantia]; nemerteans	5
				Mollusca	e.g. chitons [Cl. Polyplacopora]; snails [Cl. Gastropoda]	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
			High mobility	Arthropoda (filter feeders)	e.g. porcelain crabs	
				Mollusca	e.g. octopuses	
		Sediment epifauna	High mobility	Arthropoda	e.g. crabs	
MARINE INVERTEBRATES	Subtidal benthic	Rock and rubble dwellers	Sessile (attached to hard substrate)	Arthropoda	e.g. barnacles [Cirripedia]	
				Mollusca	e.g. rock scallops [Bivalvia]	
				Worms	e.g. tube worms [Polychaeta: Sedentaria]	
				Urochordata	e.g. sea squirts	
				Lophophorates	e.g.bryozoans [Ectoprocta]; lampshells [Brachiopoda]	
			Low mobility	Worms	e.g. annelids	
				Cnidaria	e.g. sea anemones	
	Pelagic	N/A	Low mobility	Zooplankton (other than larvae)	N/A	
MARINE INVERTEBRATES	Pelagic	N/A	Low mobility	Cnidaria	e.g. jellyfish	5
		Larvae	N/A	Cnidaria	N/A	
				Worms	N/A	
				Arthropoda	N/A	
				Lophophorates	N/A	
MARINE FISHES	Estuarine	Resident	N/A	Surfperches (Embiotocidae)	e.g. shiner perch	
		Transient	N/A	Osmeridae	e.g. eulachon	
	Intertidal	Benthic	Associated with unconsolidated substrates (Silt/Sand/Gravel) (including eelgrass environments)	Ammodytidae & Osmeridae	e.g. Pacific sand lance, surf smelt	
				Other species (e.g. sculpins , gobies)	e.g. staghorn sculpin, plainfin midshipmen	
	Subtidal	Benthic	Associated with consolidated substrates (cobble, boulder, bedrock)	Rockfishes (Scorpaenidae)	e.g. quillback, yelloweye, tiger & china rockfish	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
			Associated with unconsolidated substrate (Silt/Sand/Gravel)	Rockfishes (Scorpaenidae)	e.g. dark-blotched rockfish, canary rockfish	
MARINE FISHES	Subtidal	Non-benthic (pelagic, midwater and demersal)	N/A	Rockfishes (Scorpaenidae)	e.g. yellowtail, blue, widow rockfishes, bocaccio	5
				Elasmobranchs	e.g. spiny dogfish, sixgill sharks	
				Chimaeridae	e.g. spotted ratfish	
				Elasmobranchs filter feeder	e.g. basking shark	
MARINE MAMMALS	Cetaceans	Baleen	Dispersed	N/A	e.g. sei whale; blue whale; fin whale; North Pacific right whale; common minke whale	
	Pinnipeds	Thermoregulate with fur	N/A	N/A	e.g. northern fur seal	
		Other pinnipeds	Discrete	N/A	e.g. Steller sea lion, harbour seal	
MARINE PLANTS & ALGAE	Pelagic	Phytoplankton	N/A	N/A	N/A	4
	Subtidal	Understory Algae	Rocky habitat	Without tall, woody stipes or floats	e.g. *Desmarestia* sp, *Agarum fimbriatum, Laminaria* sp., *Prionitis lyallii*	
		Turf Algae	Rocky habitat	N/A	e.g. *Callophyllis* sp.; *Dictyota binghamiae, Sarcodiotheca furcata, Rhodymenia pacifica*	
		Encrusting Algae	Rocky habitat	N/A	e.g. Coralline algal crusts, *Hildenbrandia* sp.	
MARINE INVERTEBRATES	Intertidal	Rock and rubble dwellers	High mobility	Arthropoda	e.g. crabs [Decapoda]	4
	Subtidal benthic	Rock and rubble dwellers	Low mobility	Mollusca	e.g. snails [Cl. Gastropoda]	
			High mobility	Mollusca	e.g. octopuses	
		Sediment epifauna	High mobility	Arthropoda	e.g. crabs	
	Pelagic	Larvae	N/A	Porifera	N/A	
				Chordata	N/A	
MARINE FISHES	Estuarine	Transient	N/A	Sticklebacks (Gasterosteidae)	e.g. threespine stickleback	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
	Intertidal	Benthic	Associated with consolidated substrates (cobble, boulder, bedrock)	Snailfishes (Liparidae)	e.g. tidepool snailfish	
				Clingfishes (Gobiesocidae)	e.g. northern clingfish	
				Blennies (Stichaeidae & Pholidae)	e.g. penpoint gunnel, crescent gunnel, high cockscomb	
			Associated with unconsolidated substrates (Silt/Sand/Gravel) (including eelgrass environments)	Pipefish (Sygnathidae)	e.g. bay pipefish	
				Greenlings (Hexagrammidae)	e.g. lingcod- juvenile	
		Non-benthic (pelagic and demersal)	N/A	Surfperch (Embiotocidae)	e.g. shiner perch, striped perch, pile perch	
				Rockfishes (juvenile)	e.g. black rockfish, copper rockfish	
MARINE FISHES	Subtidal	Benthic	Associated with consolidated substrates (cobble, boulder, bedrock)	Wolf fish (Anarhichadidae)	e.g. wolf-eel	4
				Greenlings (Hexagrammidae) & Sculpins (Cottidae)	e.g. lingcod (adult), cabezon	
			Associated with unconsolidated substrate (Silt/Sand/Gravel)	Flatfishes (Pleuronectidae)	e.g. English sole, starry flounder, Pacific halibut	
		Non-benthic (pelagic, midwater and demersal)	N/A	Ammodytidae	e.g. Pacific sand lance	
				Engraulidae	e.g. northern anchovy	
MARINE MAMMALS	Pinnipeds	Other pinnipeds	Dispersed	N/A	e.g. northern elephant seal; California sea lion	
	Cetaceans	Toothed	Dispersed	N/A	e.g. sperm whales, killer whales (W.Coast transients); false killer whale; beaked whales (Baird's, Hubbs' and Stejneger's) harbour porpoise; Dall's porpoise	
MARINE REPTILES	Sea turtles	N/A	N/A	N/A	e.g. leatherback sea turtle; green sea turtle; olive ridley	
MARINE INVERTEBRATES	Subtidal benthic	Rock and rubble dwellers	High mobility	Arthropoda	e.g. crabs	3
	Pelagic	N/A	High mobility	Mollusca	e.g. squid	

Biological group	Sub-groups				Pacific example species	Vulnerability score (0-10)
	Sub-group level 1	Sub-group level 2	Sub-group level 3	Sub-group level 4		
MARINE FISHES	Estuarine	Transient	N/A	Lampreys	e.g. river & Pacific lamprey	
				Sculpins (Cottidae)	e.g. prickly sculpin	
MARINE FISHES	Estuarine	Transient	N/A	Flatfishes (Pleuronectiformes)	e.g. starry flounder, juvenile English sole	3
		Resident	N/A	Salmonidae	e.g. cutthroat trout and Dolly Varden	
				Sculpins (Cottidae)	e.g. staghorn sculpin	
	Intertidal	Benthic	Associated with unconsolidated substrates (Silt/Sand/Gravel) (including eelgrass environments)	Flatfishes- juvenile (Pleuronectidae)	e.g. English sole, starry flounder	
	Subtidal	Benthic	Associated with unconsolidated substrate (Silt/Sand/Gravel)	Hagfishes (Myxinidae)	e.g. Pacific hagfish	
		Non-benthic (pelagic, midwater and demersal)	N/A	Molidae	e.g. ocean sunfish	
				Cod (Gadidae)	e.g. Pacific cod, hake, Pacific tomcod, walleye pollock	
		Non-benthic (pelagic, midwater and demersal)	N/A	Misc species	e.g. sablefish (Anaplopomatidae), salmon (Salmonidae), surfperch (Embiotocidae), herring (Clupeidae)	
MARINE FISHES	Estuarine	Transient	N/A	Cod (Gadidae)	e.g. Pacific tomcod, walleye pollock *(juveniles)*	1
MARINE FISHES	Subtidal	Non-benthic (pelagic, midwater and demersal)	N/A	Scombrids	e.g. mackerel	1

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