Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/038

National Capital Region

A framework to assess vulnerability of biological components to ship-source oil spills in the marine environment

Kate Thornborough[1], Lucie Hannah[1], Candice St. Germain[1], Miriam O[2]

[1] Institute of Ocean Sciences
Fisheries and Oceans Canada,
9860 West Saanich Road, P.O. Box 6000
Sidney, British Columbia V8L 4B2

[2] Ecosystems and Oceans Science
Fisheries and Oceans Canada
200 Kent Street
Ottawa, Ontario K1A 0E6

June 2017

Canada

Foreword

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

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

Published by:

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

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

ISSN 1919-5044

Correct citation for this publication:

Thornborough, K., Hannah, L., St. Germain, C., and O, M. 2017. A framework to assess vulnerability of biological components to ship-source oil spills in the marine environment. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/038. vi + 24 p.

TABLE OF CONTENTS

ABSTRACT

A structured, adaptable framework to assess the vulnerability of species groups to ship-source oil spills in the marine environment within the Department of Fisheries and Oceans (DFO's) mandate has been developed. The framework is needed to identify vulnerable biological components to inform oil spill response plans and contribute towards DFO's commitment to ensuring sustainable aquatic ecosystems. Vulnerability is assessed using a suite of criteria that are designed to be consistent enough to be applicable in different Canadian aquatic environments. There are two key phases:

1. Grouping of biological components based upon shared characteristics related to oil vulnerability; and
2. Scoring of biological groups against vulnerability criteria (exposure, sensitivity, and recovery) to identify those most vulnerable to oil.

Knowledge gaps are identified at each stage in the framework in order to highlight areas for prioritized research activities. While this framework was developed for marine environments, it did not consider areas with sea ice, but could be adapted to assess vulnerability of biological components in ice-edge areas and in the Arctic. It could also be adapted to consider freshwater biological components. The framework also has the potential to be adapted to assess other species outside of DFO's mandate. For validation purposes, this framework should be applied to various marine areas including Arctic sea ice conditions, and subsequently to a variety of aquatic environments across Canada.

Cadre d’évaluation de la vulnérabilité des composantes biologiques du milieu marin aux déversements d’hydrocarbures provenant de navires

RÉSUMÉ

Un cadre structuré et adaptable a été élaboré pour évaluer la vulnérabilité des groupes d’espèces aux déversements d’hydrocarbures provenant de navires dans le milieu marin selon le mandat du ministère des Pêches et des Océans (MPO). Ce cadre est nécessaire pour déterminer les composantes biologiques vulnérables et étayer les plans d’intervention en cas de déversement de pétrole tout en contribuant à la réalisation de l’engagement du MPO d’assurer des écosystèmes aquatiques durables. La vulnérabilité est évaluée à l’aide d’un ensemble de critères qui sont conçus de manière à être suffisamment conformes pour pouvoir s’appliquer dans différents milieux aquatiques canadiens. L’évaluation se fait en deux étapes principales :

1. Le regroupement des composantes biologiques en sous-groupes en fonction de caractéristiques semblables liées à la vulnérabilité aux hydrocarbures;
2. La notation des groupes biologiques par rapport aux critères de vulnérabilité (exposition, sensibilité et rétablissement) afin de déterminer ceux qui sont les plus sensibles aux hydrocarbures.

Les lacunes dans les connaissances sont relevées à chaque étape du cadre afin de mettre en lumière les secteurs d’activités de recherche prioritaires. Ce cadre a été élaboré pour les milieux marins, mais il n’a pas tenu compte des zones de glace de mer. Il peut cependant être adapté pour évaluer la vulnérabilité des composantes biologiques dans les zones à la lisière des glaces et dans l’Arctique. Il pourrait également être adapté afin de tenir compte des composantes biologiques en eau douce. Le cadre peut enfin être adapté afin d’évaluer d’autres espèces qui ne relèvent pas du mandat du MPO. Aux fins de validation, ce cadre devrait être appliqué à diverses zones marines, y compris l’état de la glace de mer dans l’Arctique, et, par la suite, à plusieurs environnements aquatiques dans l’ensemble du Canada.

1 INTRODUCTION

1.1 CONTEXT

The Department of Fisheries and Oceans (DFO) is committed to ensuring sustainable aquatic ecosystems. The development of a framework to assess vulnerability of biological components to ship-source oil spills in the marine environment represents an important contribution toward meeting this commitment. The proposed framework addresses the need for a rapid assessment of vulnerability to ship-source oil spills for marine biological components under DFO mandate and contributes to the ecological aspects of the ‘Resources at Risk’ component of oil spill planning and response (Figure 1.1). The framework was intended to be: nationally consistent; regionally flexible; grounded in science; and rapid and simple to implement, with the primary outcome being a concise list of biological components most vulnerable to oil. Currently, the assessment has been limited to components within DFO’s mandate, however the hope is that this framework may be more broadly applicable.

In this structured approach, biological components expected to be most affected by a ship-source oil spill are identified utilizing a suite of criteria to assess vulnerability. The term ‘vulnerability’ is an increasingly used concept in many disciplines; while often used interchangeably with ‘sensitivity’, it is generally accepted that vulnerability is the degree to which a system is susceptible to, and unable to cope with, injury, damage, or harm (De Lange et al. 2010). As such, 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). The proposed framework therefore divides criteria into three categories: exposure, sensitivity, and recovery, each encompassing a number of criteria which are envisaged to be consistent and broad enough to be applicable in a variety of aquatic environments. It is anticipated that this approach will be useful for identification of biological components most affected by ship-source oil spills in any aquatic environment.

This project aims to develop a structured ‘top-down’ framework to identify biological components most vulnerable to ship-source oil spills based on elements from sensitivity, vulnerability, and recovery. The framework should not be limited by data availability or heavily influenced, by or dependent on expert opinion at the onset, and should be applicable to any aquatic environment in Canada. The specific objectives of the framework are to:

1. Organize biological components into groups and sub-groups based upon similar characteristics with respect to factors important for vulnerability to oil; and,
2. Develop nationally consistent criteria for selection of vulnerable biological components for input into oil spill response plans that are flexible, yet general enough to be applied across Canada.

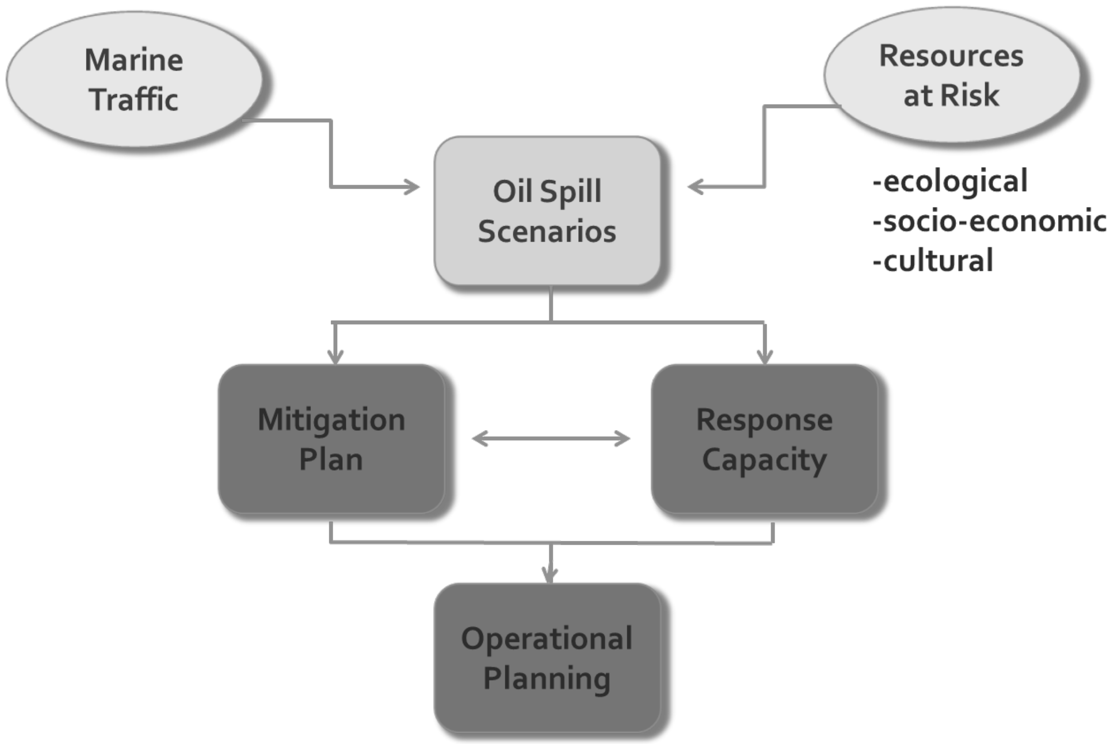

Figure 1.1: Overview of how the vulnerability framework fits in with the overall model for oil spill planning and response ("ecological" Resources at Risk)

1.2 SCOPE

Vulnerability within this framework is assessed based on *acute* effects from direct contact with oil and does not consider the effects of chronic exposure to spilled oil. Secondary impacts (higher level trophic) are not considered given the difficulty in assessment without knowledge of food webs and the impacts of oil on all biological components. The framework is not limited to spills of any specific oil type, but focuses on generalised impacts from the initial stages of a large-scale ship-based spill and does not consider mitigation measures such as the use of chemical dispersants.

This work focuses on marine biological components that fall within DFO's mandate; those at and below mean high water springs (MHWS), including mammals, reptiles, fish, invertebrates, and plants. However, in certain environments where perigean spring tides and storm surges can impact species in areas above or adjacent to DFO's jurisdictional boundaries, additional areas may be included in the assessment (e.g. low lying salt marshes).

Socio-economic and cultural values were not included in this framework as these are the responsibility of other sectors within our department. Fisheries species and species with conservation status (e.g. listed under the Species At Risk Act (SARA)) are captured only when their sub-group is assessed as highly vulnerable. While it is critical to capture these socio-economic and cultural species for oil-spill planning and response, their inclusion is the responsibility of other branches within our department and a separate assessment should be conducted to address other sensitivities.

Habitats are not directly assessed in this framework, but are included when associated with vulnerable biological components. In the context of this framework, habitats are defined as areas associated with important life stages and/or areas supporting high concentrations or aggregations of vulnerable species groups/sub-groups, and are assumed to be an underlying reason for aggregations of organisms or seasonal movements. While not directly assessed in this framework, habitats are included in the presentation of results as areas required to be mapped if they are associated with vulnerable biological components. Biogenic habitats (e.g. eelgrass beds, glass sponge reefs) are assessed on a species sub-group level, rather than as separate habitats (e.g. eelgrasses, Porifera).

Shoreline type is not considered in this framework, as there is an existing well-established shoreline classification system that ranks the physical shoreline types by sensitivity to spilled oil and potential mitigation measures (Howes et al. 1994). Since DFO does not collect this data it is also outside the department's jurisdiction to develop another system to assess shoreline for this purpose.

Ecologically and Biologically Significant Areas (EBSAs), Marine Protected Areas (MPAs), and other spatial planning areas are not assessed in this framework, but are considered important sources of supplementary information to be provided by DFO for oil spill planning and response purposes.

Lastly, this framework was developed for marine environments (including coastal and estuarine areas), but is sufficiently general to be relevant and applicable in freshwater, Arctic, and ice edge environments with minor adjustments.

2 FRAMEWORK

2.1 OVERVIEW

The framework to identify vulnerable marine biological components consists of two key phases:

1. Grouping of biological components based on similar characteristics related to oil vulnerability; and,
2. Scoring sub-groups against ecological vulnerability criteria (exposure, sensitivity, and recovery) to identify the most vulnerable sub-groups.

Built into this framework at every phase is the identification of knowledge gaps to feed into a gap analysis. The proposed framework was developed as a top-down approach, whereby at the start of the process, all species groupings present in an area are included regardless of data availability. This approach allows for the identification of knowledge gaps relating to biological components, which will inform future development of this framework. The structure of the framework is outlined in Figure 2.1.

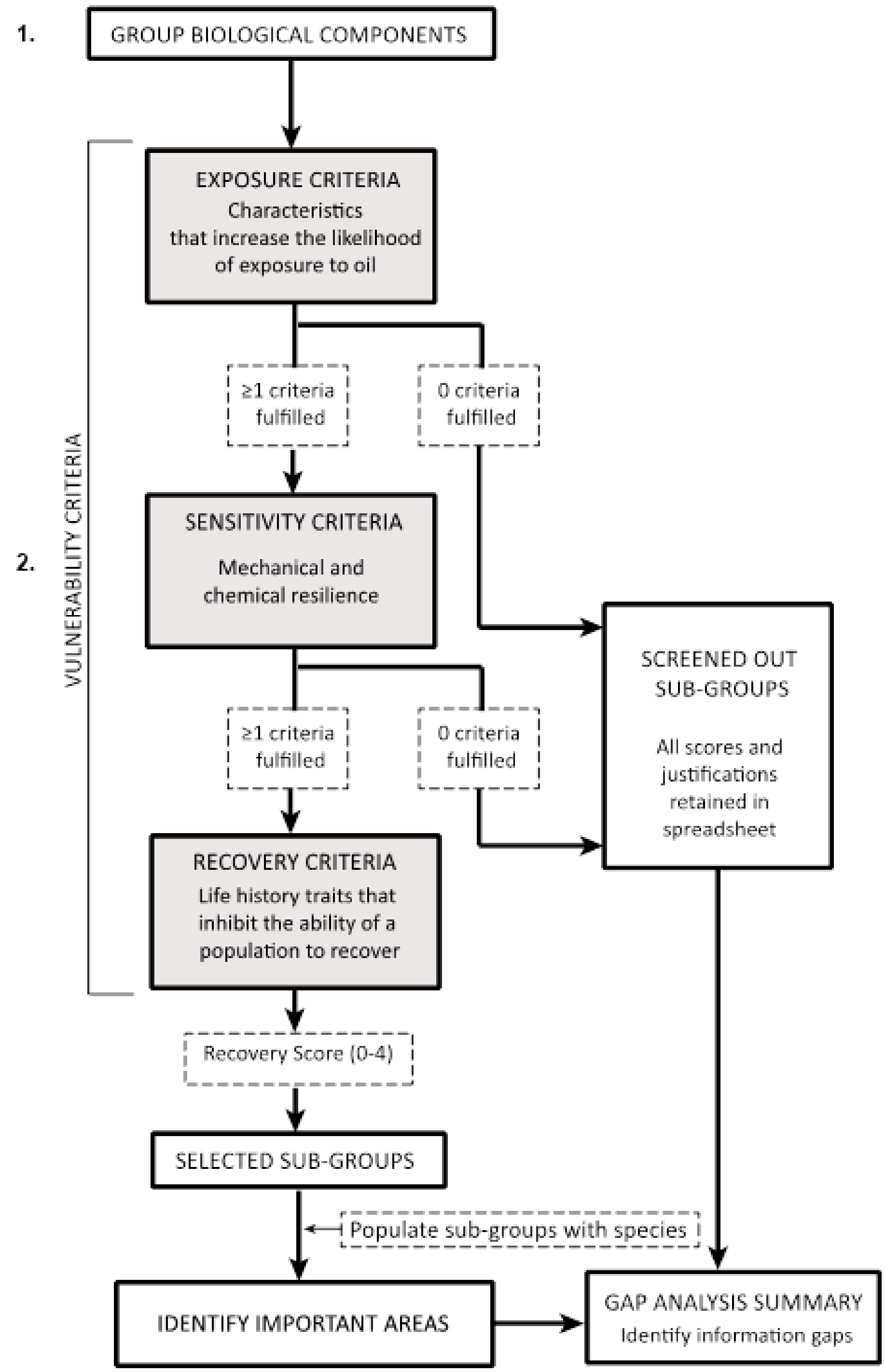

Figure 2.1: Overview of framework to identify vulnerable biological components.

2.2 GROUPING BIOLOGICAL COMPONENTS

The use of species sub-groups eliminates the need to assemble lists of all available species for a geographic area at the study onset. An assessment that does not rely on gathering extensive species data at the start is expected to be a faster and more streamlined process suited to oil spill response. In the proposed framework, only sub-groups identified as most vulnerable are populated with species. Sub-groupings were developed for five high-level groups: marine algae/plants; marine invertebrates; marine reptiles; marine fish and marine mammals, based upon biological expertise and available literature.

Members of a sub-group should share similar characteristics with respect to their vulnerability to oil to enable them to be distinguished from one another and so be effectively assessed by the criteria. For example, baleen whales are likely to experience greater impact from an oil spill compared to toothed whales, because their baleen plates can be clogged by oil.

There are seventy-five proposed sub-groups. The following sections describe how sub-groups were broken down for each group and Tables 2.1-2.5 outline the proposed sub-groups.

2.2.1 Marine Algae/Plant Groupings

Sub-groups for marine algae/plants were based upon a report from an expert workshop (Ban et al. 2007) and were refined for relevance to oil impacts by incorporating discussions with an expert (Joanne Lessard, DFO, Feb 2016). The first sub-groups separate pelagic from benthic to distinguish phytoplankton (which was not further divided). The benthic sub-group was separated into five sub-groups: vascular; canopy forming; understory; turf; and encrusting. These divisions can be in response to a number of factors, including characteristics linked to oil adherence. For example branching in the turf group and the rough edges of eelgrass may indicate a tendency to retain oil compared to understory and canopy types which tend to have smoother blades slick with mucous. The vascular sub-group is further separated into eelgrass, surfgrass, and saltmarsh grasses (e.g. *Spartina*) due to their presence in very different habitats (surfgrass attaches to rocks in high energy intertidal areas, eelgrass grows in soft sediment in lower energy areas, and saltmarsh grasses grow in the high intertidal). There are eight sub-groups identified for marine algae/plants.

Table 2.1: Proposed sub-group breakdown for marine algae/plants.

Sub-group breakdown		
Sub-group 1	**Sub-group 2**	**Sub-group 3**
Pelagic	N/A	Phytoplankton
Benthic	Vascular	Eelgrasses
		Surf grasses
		Saltmarsh grasses
	Non-vascular	Canopy forming kelps
		Understory
		Turf
		Encrusting

2.2.2 Marine Invertebrate Groupings

The marine invertebrate sub-groups were developed using a taxonomic guild classification publication as a guide (MacDonald et al. 2010), and with additional expert input (Lucie Hannah; Candice St-Germain, DFO, January, 2016). The first sub-groups separate marine invertebrates, based on location in order to capture exposure (intertidal/sub-tidal). The second sub-groups separate these species using a substrate factor (e.g. sediment in-fauna, sediment epifauna), to capture factors of exposure and recovery. The third sub-groups capture mobility (sessile/low mobility/high mobility) to identify sub-groups lacking the ability to move away from spilled oil (note: the mobility factors do not reflect if an organism will avoid oil, only that it has the ability). The distinction between what constitutes ‘low’ and ‘high’ mobility is captured in the fourth sub-group division. For example, within the pelagic invertebrates, zooplankton and jellyfish are low mobility as they have limited ability to move against the currents, whereas squid are high mobility as they can move against currents. The fourth sub-groups are based upon taxonomic divisions that can be linked to a number of factors important for assessing vulnerability to oil such as feeding types (e.g. sub-groups with feeding structures susceptible to clogging such as filter feeders), and reproductive strategies. Using taxonomic groups also simplifies comparisons to published toxicity studies. Due to the diversity of marine invertebrates, only major taxonomic groups are included to meet the need for a relatively rapid assessment. Other minor taxonomic groups are expected to be captured through the habitat shared with other sub-groups being assessed. Thirty-seven sub-groups are identified for marine invertebrates.

Table 2.2: Proposed sub-group breakdown for marine invertebrates.

Sub-group breakdown			
Sub-group 1	**Sub-group 2**	**Sub-group 3**	**Sub-group 4**
Intertidal	Rock and rubble dwellers	Sessile (attached to hard substrate)	Crustacea (*e.g. barnacles*)
			Mollusca (*e.g. oysters*)
			Cnidaria (*e.g. sea anemones*)
			Porifera (e.g. *demosponges*)
			Worms (*e.g. tube worms*)
			Ascidia (*e.g. sea squirts*)
		Low mobility	Worms (*e.g. annelids*)
			Echinoderms (*e.g. sea urchins*)
			Mollusca (*e.g. gastropods*)
		High mobility	Crustacea (*e.g. crabs*)
			Mollusca (*e.g. octopus*)
	Sediment infauna	Low mobility	Mollusca (*e.g. clams*)
			Worms (*e.g. annelids*)
	Sediment epifauna	Low mobility	Mollusca (*e.g. gastropods*)
			Cnidaria (*e.g. sea pens*)
			Echinoderms (*e.g. sea stars*)
		High mobility	Crustacea (*e.g. crabs*)
Subtidal benthic	Rock and rubble dwellers	Sessile (attached to hard substrate)	Crustacea (*e.g. barnacles*)
			Mollusca (*e.g. mussels*)
			Cnidaria (*e.g. coral*)
			Porifera (*e.g. glass sponges*)
			Worms (*e.g. tube worms*)
			Ascidia (*e.g. sea squirts*)
		Low mobility	Worms (*e.g. annelids*)
			Echinoderms (*e.g. sea urchins*)
			Mollusca (*e.g. gastropods*)
		High mobility	Crustacea (*e.g. crabs*)
			Mollusca (*e.g. octopus*)
	Sediment infauna	Low mobility	Mollusca (*e.g. clams*)
			Worms (*e.g. annelids*)
	Sediment epifauna	Low mobility	Mollusca (*e.g. gastropods*)
			Cnidaria (*e.g. sea pens*)
			Echinoderms (*e.g. sea stars*)
		High mobility	Crustacea (*e.g. crabs*)
Pelagic	N/A	Low mobility	Zooplankton
			Cnidaria (*e.g. jellyfish*)
		High mobility	Mollusca (*e.g. squid*)

2.2.3 Marine Reptile Groupings

Sea turtles, such as migratory loggerhead and leatherback sea turtles, which use Canada's Atlantic and Pacific waters for foraging (Gregr et al. 2015), are the only marine representatives of this group in Canada. As all sea turtles are expected to be impacted in similar ways, this is the only sub-group identified for this group.

2.2.4 Marine Fish Groupings

Marine fish sub-groups were developed following discussions with a DFO fish expert (Dana Haggarty, DFO, February 2016) and further adjusted with expert input from review meeting participants (CSAS meeting in March 2016). The first two sub-groups considers factors of exposure; the first separates fish sub-groups that primarily inhabit different areas (e.g. intertidal, estuarine, on and off shelf) and the second captures broad vertical location in the water column. The latter sub-group discerning between fish present mostly at the surface, mid-water or seabed, for example, between mid-water rockfish sub-groups and demersal rockfish sub-groups, which are more closely associated with the seabed. The third sub-groups are taxonomic, and can discern a number of differences between sub-groups related to oil vulnerability such as toxic effects and behavioural factors. Twenty sub-groups are identified for marine fish.

Table 2.3: Proposed sub-group breakdown for marine fish.

	Sub-group breakdown		
	Sub-group 1	**Sub-group 2**	**Sub-group 3**
Marine Fish	Diadromous	Anadromous	Lampreys
			Acipenseridae
			Clupeidae
			Osmeridae
			Salmonidae
		Catadromous	Anguillidae
	Estuarine (*excluding migrating groups*)	Demersal/ Semi-demersal	Roundfish
			Rockfish/Redfish
			Flatfish
			Elasmobranchs
	Intertidal	Demersal/ Semi-demersal	Roundfish
			Rockfish/Redfish
			Flatfish
			Elasmobranchs
	On shelf	Demersal/ Semi-demersal	Roundfish
			Rockfish/Redfish
			Flatfish
			Elasmobranchs
		Small pelagics/ Forage fish	Ammodytidae (*e.g. sandlance*)
			Embiotocidae (*e.g. perch*)
			Clupeidae (*e.g. herring*)
			Osmeridae (*e.g. smelt, eulachon*)
		Large pelagics	Elasmobranchs
			Scombrids
	Off shelf	Demersal/ Semi-demersal	Roundfish
			Rockfish/Redfish
			Flatfish
			Elasmobranchs
		Small pelagics/ Forage fish	Clupeidae (*e.g. sardines*)
		Large pelagics	Elasmobranchs

2.2.5 Marine Mammal Groupings

Marine mammal sub-groups were developed using feedback from experts (Miriam O, DFO, January 2016; Peter Ross, Vancouver Aquarium, March 2016). The first sub-groups separate marine mammals into cetaceans (whales and dolphins), pinnipeds (seals and sea lions) and mustelids (otters). The second sub-groups are separated based on physical characteristics related to increased oil vulnerability; baleen for whales, and fur for mustelids and some pinnipeds (those that rely on fur for thermoregulation - a crucial function that can be impaired by oil fouling). The third sub-groups (only for cetaceans and pinnipeds) address whether a group is discrete or dispersed, which may have implications for exposure criteria. For example, the sub-group 'marine mammals: toothed cetaceans (dispersed)' distinguishes dispersed groups such as dolphins from discrete groups such as Harbour porpoises which would be captured in 'toothed cetaceans (discrete)'. There are nine sub-groups identified for marine mammals.

Table 2.4: Proposed sub-group breakdown for marine mammals.

Sub-group breakdown		
Sub-group 1	**Sub-group 2**	**Sub-group 3**
Cetaceans	Toothed	Discrete
		Dispersed
	Baleen	Discrete
		Dispersed
Pinnipeds	Thermoregulate with fur	Discrete
		Dispersed
	Other pinnipeds	Discrete
		Dispersed
Mustelids	-	-

2.2.6 Other Grouping Options

The proposed groupings were developed to be broadly applicable for incorporation into a rapid assessment. As this framework has a national scope, proposed groupings were developed to be general enough to be applicable across Canada by allowing flexibility in sub-groups division to account for differences between regions. Modifications to sub-groups are likely to be needed for the framework to be applicable in other aquatic environments such as freshwater, Arctic, and ice edge environments.

There are a number of options to divide biological components into sub-groups; some examples of factors considered during the development of this work include:

- Feeding guilds [all groups]
- Discriminate vs. indiscriminate feeders [marine mammals, fish, invertebrates]
- Reproductive strategy [investment, dispersal]
- Diel vertical migration [fish, invertebrates]
- Ability to close off the body (e.g. clams) [invertebrates]

Groupings could also be adjusted for specific needs, for example if the assessment wanted to focus on only a specific type of oil being transported in an area, groupings could be tailored to better discern impacts from that oil type.

2.3 ECOLOGICAL VULNERABILITY CRITERIA

All marine biological components are assumed to be vulnerable to oil to some degree. In order to provide area response coordinators with guidance on only the most vulnerable biological components, criteria are used to determine the vulnerability of each sub-group. The use of selection criteria creates a structured approach to a top-down selection process, making results comparable across regions.

A literature search was conducted to assess other approaches that may be suitable to base our framework upon and found that National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) mapping, and recent risk and vulnerability assessment methodologies (specifically, O et al. 2015; Reich et al. 2014) were well established and tested in identifying vulnerabilities (and sensitivities) in marine biological components. Therefore, the development of criteria was based primarily on NOAA ESI (NOAA 2002; Table 2.6) mapping considerations, vulnerability criteria in Reich et al. (2014), and recovery criteria from the Ecological Risk Assessment Framework (ERAF) (O et al. 2015).

Table 2.5: National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) considerations to select vulnerable biological components.

NOAA considerations	
1	Many individuals are concentrated in a small area, such as a seal haul out area or a bay where waterfowl concentrate during migration.
2	Early life stages are present in certain areas, such as seabird rookeries, spawning beds used by anadromous fish, or turtle nesting beaches.
3	Oil affects areas important to specific life stages or important for migration, such as foraging or over-wintering sites.
4	Specific areas are critically important for propagation of a species.
5	A particular species is threatened or endangered.
6	A substantial percentage of an animal or plant population is likely to be exposed to oil.

These considerations/criteria are based on the same broad principles: potential exposure to spilled petroleum products; sensitivity to petroleum products; and, recovery potential. As a result, vulnerability criteria were divided into three types: exposure (Table 2.7), sensitivity (Table 2.8), and recovery (Table 2.9). Criteria were developed to be applicable at the sub-group level and relevant to all regions across Canada. These criteria identify vulnerable sub-groups based on direct contact with spilled oil; secondary (food web) impacts resulting from contact with oil are not addressed in this framework. Additional research will be required to capture and study long-term effects.

Each criterion is presented with justifications and guidance for scoring in Sections 2.3.1, 2.3.2, and 2.3.3. Additional guidance for scoring, with information specific to each species sub-group, is presented in Appendix A. Guidance for the scoring and filtering process to select vulnerable species sub-groups is presented in Section 2.4.

In some cases criteria may appear to be biased toward certain groups, but those groups have characteristics that make them relatively more vulnerable to oil than other groups (e.g. mammals that lose the ability to thermoregulate when their fur becomes oiled; sessile invertebrates that cannot move away from spilled oil). We have attempted to capture these characteristics using the following criteria.

2.3.1 Exposure Criteria

While it is possible that all marine biological components may be exposed to some degree during a large ship-source oil spill, species that are more likely to encounter spilled oil are assumed to be more vulnerable (Reich et al. 2014). Exposure criteria identify characteristics that increase the likelihood of exposure to oil, including: concentration (aggregation); sessile/low mobility; and surface and sediment interaction (Table 2.7). Exposure criteria were developed with reference primarily to on ESI mapping considerations (NOAA 2002; Table 2.6), and Reich et al. (2014).

Table 2.6: Proposed exposure criteria and guidance for scoring.

Concentration (aggregation) and/or site fidelity	
Question	Does the sub-group contain species that concentrate or aggregate in areas linked to fixed/transient habitat within the study area and/or exhibit site fidelity?
Justification	Organisms that live in high concentrations or aggregate in large numbers in fixed/transient locations have an increased likelihood of exposure to oil. Organisms exhibiting site fidelity may try to remain in, or return to a specific area, even if they were to become exposed to oil.
Scoring guidance	Sub-groups containing species that concentrate in fixed/transient locations for habitat, feeding, or breeding; Sub-groups containing species that exhibit site fidelity.
Mobility	
Question	Does the sub-group contain species with low or no mobility?
Justification	Organisms that are unable to, or have limited ability to move away from spilled oil, or are known to be attracted to spilled oil are likely to have higher exposure to spilled oil.
Scoring guidance	Sub-groups containing species with sessile life-stages (e.g. sponges, corals, kelp, sea grass, etc.); sub-groups containing species with low mobility (e.g. echinoderms); sub-groups containing species with evidence of attraction to spilled oil.
Sea surface interacting	
Question	Does the sub-group contain species that are reliant on or have regular interaction with the air/near sea surface, including intertidal areas?
Justification	The sea surface is the first point of contact in a ship-sourced spill. Therefore, organisms reliant on or with regular interaction with the sea surface have an increased likelihood of exposure to spilled oil. The intertidal zone is likely to experience significant exposure from floating oil spills as tidal movements bring species in direct contact with oil (Chang et al., 2014).
Scoring guidance	Sub-groups containing species that are reliant on or have regular interaction with the near-surface of the ocean (e.g. marine mammals, basking sharks). This includes intertidal species as intertidal areas regularly interact with the surface. The depth of the surface layer (e.g. sea-air interface or -10 m) should be defined by regional conditions (i.e. localized hydrodynamics).
Sediment interacting	
Question	Does the sub-group contain species closely associated with types of sediment that can retain oil for long periods?
Justification	Reoccurring direct exposure due to persistence of oil in sediments. Contaminated sediments can expose individuals in a population repeatedly. This is still considered an acute impact since it is not due to chronic (or multiple exposures) to a single individual. Rather this type of reoccurring exposure impacts a greater proportion of the population through direct contact.
Scoring guidance	Sub-groups containing species that inhabit sediment such as eelgrass and other sediment dwellers such as clams; Sub-groups containing species which spend a significant proportion of time in close association with sediment (e.g. grey whales feeding within sediments).

2.3.2 Sensitivity Criteria

This suite of criteria examines both mechanical and chemical sensitivity based on physiological characteristics that may influence the magnitude of impact from exposure to oil (Table 2.8).

Mechanical sensitivity identifies physiological characteristics more vulnerable to mechanical impairment by oil (e.g. loss of insulation when fur becomes oiled and reduction of feeding when feeding structures become oiled). Impairment of breathing was considered for inclusion in this criterion but was excluded due to it being almost universally applicable to sub-groups.

Chemical sensitivity identifies physiological characteristics more vulnerable to chemical impairment by the oil (e.g. pathologies developed as a result of contact with the toxic components of oil). The pathways of exposure to oil are through adhesion, ingestion, absorption, and/or inhalation. Sensitivity criteria were developed with reference primarily to work by Reich et al. (2014).

Table 2.7: Proposed sensitivity criteria and guidance for scoring

MECHANICAL SENSITIVITY	
Loss of insulation	
Question	Does contact with oil result in a loss of insulation/ability to thermoregulate for species in the sub-group?
Justification	Oil causes a substantial decrease in the insulative value of fur, inhibiting the ability of affected organisms to thermoregulate (Reich et al. 2014).
Scoring guidance	Sub-groups containing species reliant on fur as their primary means of thermoregulation
Reduction of feeding/photosynthesis	
Question	Does direct contact with oil result in the mechanical impairment of feeding structures for species in the sub-group?
Justification	Fouling of feeding structures by oil may reduce the ability of organisms to feed, reducing their condition and reproductive capacity and increasing time spent feeding (Reich et al. 2014).
Scoring guidance	Sub-groups that contain species that feed by filtering water through their systems and removing particles (filter-feeders); sub-groups containing species that photosynthesize (smothering effects reducing photosynthesis).
CHEMICAL SENSITIVITY	
Impairment due to toxicity	
Question	Does direct contact with oil result in severe, irreversible effects or death for species in the sub-group?
Justification	Organisms that are more sensitive to toxic effects of oil are more likely to experience irreversible effects or death.
Scoring guidance	Sub-groups containing species that display severe, irreversible effects or death due to oil toxicity. Acute effects from direct contact include: the inability of animals to digest and absorb foods; reproductive failure; respiratory failure; lesions; hemorrhaging; neurological impairment; and mortality.

2.3.3 Recovery Criteria

Recovery (often referred to as adaptive capacity) criteria examine the life history traits that impact the ability of a population to recover (Table 2.9), including: population status; reproductive capacity; endemism; and close association with sediments. These criteria were developed with reference primarily to work by O et al. (2015) and Reich et al. (2014). Recovery criteria address long-term recovery from a single oil spill event. For this framework, population is is defined as a Designatable Unit (DU). DUs are defined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as a species, subspecies, variety, or geographically or genetically distinct population that are both discrete and evolutionarily significant.

Table 2.8: Proposed recovery criteria and guidance for scoring

Population status	
Question	Does the sub-group contain species with reduced or declining population levels?
Justification	Sub-groups containing species with greatly reduced or declining population numbers (in particular breeding population numbers) are compromised in their ability to recover from an impact, in contrast to those with healthy population levels which are most capable of recovering (Reich et al. 2014). Conservation status can be used as a proxy for reduced or declining population levels.
Scoring guidance	Sub-groups containing species with: low population levels relative to historic levels (incorporates groups underrepresented/not assessed in conservation indices) (e.g. stock assessment zones – healthy/cautious/critical); greatly reduced breeding population numbers relative to historic levels; special conservation status (a proxy for a low population status), e.g. Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recommended, Species at Risk Act (SARA) listed, International Union for Conservation of Nature (IUCN) listed; Provincially listed.
Reproductive capacity	
Question	Does the sub-group contain species with low reproductive capacity?
Justification	Reproductive capacity of a species is a key contributor to population recovery. Sub-groups containing species with low reproductive capacity can be slow to recover from impact even with high population levels, whereas species with relatively high reproductive capacity are inherently more capable of population recovery from oil spill impacts (Reich et al. 2014).
Scoring guidance	Sub-groups that contain K-strategist species (i.e. have a longer life expectancy, grow and mature more slowly, and have fewer progeny with higher reproductive investment); Sub-groups that contain species with sporadic, infrequent, or density dependent recruitment success.
Endemism or isolation	
Question	Does the sub-group contain endemic species or isolated populations that have limited distribution within the region?
Justification	Sub-groups that contain species or populations endemic or isolated in the area are more likely to have a greater proportion of the population impacted by an oil spill, as well as decreased ability of the population to recolonize an area (Reich et al. 2014).
Scoring guidance	Sub-groups containing endemic or isolated populations with limited distribution within the region. Assessed only for the period the species was present in the area of interest (e.g. seasonal abundances of species at certain times of the year).
Close association with sediments	
Question	Does the subgroup contain species that are closely associated with sediments types that can retain oil for long periods of time?
Justification	Sediments retaining oil can expose associated organisms for decades after a spill hindering their recovery. Aliphatic and polycylic aromatic hydrocarbon fractions of dissolved petroleum accumulate in sediments and can affect benthic organisms long after spill events (Gunster et al. 1993; Kennish 1996)
Scoring guidance	Sub-groups containing species that inhabit sediment such as eelgrass and other sediment dwellers such as clams, worms; sub-groups containing species which spend a significant proportion of time in close association with sediment (e.g. grey whales feeding within sediments).

2.4 SCORING PROCESS

The current framework proposes to assess species sub-groups by scoring them against three categories of criteria (exposure, sensitivity, and recovery) in a sequential manner (Figure 2.1). This sequential application of criteria is hoped to provide a rapid and efficient guided scoring process to differentiate those species sub-groups that are relatively more vulnerable to oil spills.

2.4.1 Scoring and Screening

A binary system is employed to score species sub-groups against criteria as either (1) criterion fulfilled, or (0) criterion not fulfilled. Each criterion is scored against the lowest level of grouping for each biological category (i.e. Sub-group 3 for Marine Algae/Plants, Sub-group 4 for Marine Invertebrates, Sub-group 3 for Marine Fish, Sub-group 3 for Marine Mammals). Scoring decisions are explored in detail by consulting publications and subject matter experts. Referenced justifications are provided for each score, maintaining scoring consistency.

Exposure criteria are scored first, as these criteria are straightforward and rapid to evaluate using the biological expertise of the scorers. While each exposure criterion is scored per sub-group, only those sub-groups that fulfill at least one exposure criterion move on to be scored against sensitivity criteria (Figure 2.1).

Sensitivity criteria are scored second. These evaluations can often require the biological expertise of the scorers, literature review, and consultation with experts; and are therefore more time consuming to score. For example, the use of fur as the primary means of thermoregulation can be scored using biological expertise, but toxicity effects to a sub-group may require the use of subject matter experts/publications. As with the exposure criteria, all sensitivity criteria are scored, but only those sub-groups that fulfil at least one sensitivity criterion move on to be scored against recovery criteria (Figure 2.1). These sub-groups are then ranked according to their cumulative recovery score (which ranges from 0-4).

Note that sub-groups that do not fulfill any exposure and/or sensitivity criteria are removed from the analysis, but are included in a spreadsheet with justifications.

Recovery criteria are scored at a species level, and require biological expertise, research and expert opinion to evaluate as each criterion should be scored based on the life stage most likely to be impacted where possible. The potential drawback of this approach is that it may prolong the assessment, which is designed to be rapid. In addition, this precautionary scoring may not be feasible for some organisms, and this should be highlighted in the gap analysis. For example, planktonic juvenile stages may be the most sensitive life stage for most invertebrates, but it may be difficult to produce a ranked list of sub-groups, as most would receive similar scores. In addition, planktonic stages would be difficult or impossible to map for the purposes of spill response.

Sub-groups should be scored in a precautionary way, which means that if at least one species within a sub-group is known to fulfill the criterion, then the sub-group fulfills the criterion. One drawback to this approach is that the score for a whole sub-group may be driven by one species. However, further in the process if resources are available, regions can populate identified sub-groups with species and score each species to identify the most vulnerable species within those groups.

The end result of the sequential application of criteria is a list of vulnerable species sub-groups (those that fulfil a minimum of one criterion for both exposure and sensitivity criteria) ranked by recovery potential (those with the lowest potential for recovery ranked at the top of the list). Sub-groups in this list are considered more vulnerable to oil spills as they have a higher likelihood of exposure, a higher sensitivity to oil and, for those ranked near the top of the list, a lower potential for recovery.

Two types of uncertainty are inherent in the scoring of sub-groups against criteria: the amount of information available on the interaction between the species sub-group and spilled oil, and the scientific consensus as to the impact of spilled oil on species sub-groups. In some cases, there is a wealth of scientific information but no agreement about the impact. This second type of uncertainty is implicitly considered when scoring the sub-group against the criteria, whereby a precautionary approach is taken and the sub-group is scored as 1* for the criterion; this uncertainty is then flagged in the gap analysis.

While it is recognized that available information to inform scoring may be limited in some cases, a standard guide of three or more peer-reviewed papers should be consulted for each component, where possible. When available literature is lacking, this should be captured by the gap assessment. During application of this framework, tables with justifications for the scoring of each criterion should be provided, with references.

2.4.2 Scoring Resources

A database is currently being developed by DFO Pacific Region that compiles information on marine biological components and their vulnerabilities to ship-source oil spills. This database is being built to be searchable by species, region, etc., for easy referral while scoring. The focus of the database is currently on BC species sub-groups, however, it can be built upon and updated with information from other regions. In addition to this, a literature review on the sensitivities of species is currently being developed that will be accessible to all regions to assist with scoring. Again, this literature review focuses on BC species sub-groups but contains information that will be relevant to similar sub-groups irrespective of a specific area.

2.5 POPULATING SUB-GROUPS AND IDENTIFYING IMPORTANT AREAS

In order to provide an appropriate geospatial representation of vulnerable biological components to first responders, data layers for each sub-group must be identified. Each sub-group must be populated with area specific species lists, and areas representing high concentrations and/or important for sensitive life stages identified and mapped.

2.5.1 Populating Sub-Groups with Species

Once the most vulnerable species sub-groups are selected, area-specific species lists need to be compiled and associated datasets need to be identified in order to determine the most appropriate spatial representation. Datasets are rarely grouped by species sub-groups and are usually at the species, habitats, or population level. Therefore, it is assumed that datasets will need to be rolled up into a single sub-group representation, consisting of multiple layers of datasets. Species are selected from available literature and species databases.

Where no species information is found for a species sub-group for the region, it is assumed that no species under that sub-group is currently in the focus area, and the sub-group is removed from the analysis.

2.5.2 Identifying Important Areas

The entire distribution of multiple biological components would not appropriately inform responders setting protection priorities in the event of a spill. Therefore, only areas of high concentrations and those important for the most sensitive life-stages are suggested for the purpose of identifying important areas. A list of suggested area types to be mapped for each species group is presented in Table 2.9.

Table 2.9: Suggested areas of importance for species groups, adapted from ESI guidelines (NOAA 2002). Only those areas specific to Canada are included as examples.

Group	Important areas
Marine mammals	Migratory routes Rubbing beaches Feeding areas Haul-outs Pupping sites Calving sites Nursery sites Other concentration areas
Marine reptiles	Any concentration areas
Fish	Spawning areas/runs Nursery areas Feeding areas Estuaries Other concentration areas
Marine invertebrates	Spawning areas Nursery areas Other concentration areas (e.g. mussel beds)
Marine plants	Seagrass beds Kelp beds/forests Other concentration areas

2.5.3 Accompanying Data Tables

The geospatial dataset for each species is accompanied by data tables that include information on the seasonality and estimated densities of the species such as the life stage(s) present at a particular location, for each month of the year, and the estimated start and end dates for specific breeding activities associated with a specific location or area. This format aligns with the NOAA ESI data table format. An example template for the accompanying data tables is presented in Appendix B.

In addition to the seasonality and density considerations for each species, a depth component may be included that could also be cross-referenced with oil type, i.e., surface, mid-water, seafloor, and intertidal/shoreline, and scored as present or absent. This cross-referencing allows for rapid dataset selection in the event of a spill by oil type. The American Petroleum Institute (API) divides oil type into five categories based on the petroleum density compared to water (buoyancy). If the API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks. Using the API gravity, the potential depth overlap of oil types can also be divided into surface, mid-water, seafloor, and intertidal/seafloor, and scored as present or absent (example in Appendix B).

2.5.4 Data Considerations

Data feeding into the assessment of important areas should be based upon best available science. DFO holds the greatest quantity of marine biological data, and will be key in providing data on the screened in sub-groups. In addition, consulting other data providers and generators, such as other agencies and non-government organisations should ensure that the most current and complete datasets are provided. Some examples of existing datasets that could also be incorporated include the ‘Important Areas’ identified for Ecologically or Biologically Significant Areas (EBSA) projects and similar expert knowledge information from Traditional Ecological Knowledge (TEK) and Local Ecological Knowledge (LEK) databases.

There are several challenges associated with datasets, including: range/distribution only datasets; data of varying scales; data of varying specificity; appropriate number and type of species mapped; level of detail (by species or sub-group); and too much data or not enough detail. For example, areas of varying size and scale representing a single species or several species combined into a sub-group may exist, and each area may include seasonal presence and life stage associated for each species occurring within the polygon. The challenge is to choose the best representation of a species or sub-group to address the question at hand, i.e., which areas are most important for the survival of a species or sub-group that has been deemed vulnerable to a ship-source oil spill.

2.6 GAP ANALYSIS

A key output of the framework is the identification of knowledge gaps, as they can be used to prioritize research moving forward. Knowledge gaps are identified throughout the framework, and are flagged for inclusion in the gap analysis. Areas in the framework where knowledge gaps should be identified include: during grouping, when there is uncertainty in the breakdown for a given sub-group due to lack of information; during scoring, when a sub-group is given a precautionary score of 1* for a given criterion due to lacking or conflicting information; and, when populating sub-groups with area specific species if there is a lack of knowledge of species within an area.

Once knowledge gaps have been summarized, they should be organized into short-term and long-term goals to prioritize research to inform the gaps moving forward. Examples of short-term goals to address knowledge gaps include: a more extensive literature search, and/or short-term research using previously collected data.

2.7 FRAMEWORK FLEXIBILITY

The proposed framework was designed to be applicable to a range of aquatic environments across Canada but also to have the ability to compare outputs between regions. For this purpose, the vulnerability criteria outlined are designed to be fixed and to be used without adjustments. However, regional differences have been accounted for by providing flexibility in the breakdown of biological sub-groupings that will be scored against the vulnerability criteria. For example, adapting biological groupings to capture freshwater species would be necessary for the framework to be applicable in regions with high freshwater input such as Quebec. The incorporation of this flexibility makes it critical that any adaptations made to sub-groups are clearly outlined in the framework application to facilitate comparable re-assessments.

2.8 CHALLENGES AND LIMITATIONS

The framework has been designed to be consistent, but with some flexibility, to enable it to be applicable across a range of aquatic environments. However, there are some limitations in the framework that cannot yet be addressed due to the current state of knowledge.

The framework does not consider indirect effects or food web impacts (e.g. toxicity from a seal pup ingesting contaminated milk) due to a lack of consistency in available information on oil toxicity effects, as well as a lack of information on ecosystem/food web dynamics. Increased vulnerabilities due to impacts from multiple stressors (i.e. cumulative effects) are not considered in this framework, nor are compounding impacts, including sink-source dynamics. Again, although these are important considerations for a comprehensive assessment of impacts to a system, it is not practical to include these at this stage in our understanding of impacts from oil.

The intent of the proposed framework is that it provides a rapid scoring and selection process, and assessing factors such as those mentioned above can be very complicated and time consuming. However, that is not to say that understanding food web impacts, cascading trophic effects, and ecosystem dynamics are not critical to our evaluation of potential effects, only that it is beyond the scope of this proposed framework. This framework aims to provide the basic building blocks upon which more criteria can be added in future iterations to include considerations such as indirect impact, freshwater species, and species beyond DFO's mandate (e.g. sea birds).

2.9 FUTURE WORK

2.9.1 Regional Application of Framework

The functionality of this framework will not be fully realized until it has been applied in multiple regions to evaluate the criteria and determine if and how species groupings need to be adjusted to be applicable in different aquatic environments. A full application of the framework is currently underway in the Pacific, Maritimes and Quebec Regions of Canada, and the outcomes of these applications are expected to allow further refinement of the framework and to highlight any required modifications.

2.9.2 Scoring Rubric and Incorporation of Uncertainty

The scoring of criteria is currently limited to a binary system of criterion fulfilled (1) or not fulfilled (0) in order for this to be a rapid scoring assessment. However, a more complex scoring rubric such as that in O et al. (2015) and Reich et al. (2014), where multiple options are available per criterion may be incorporated into the framework in the future. This would allow for further differentiation between sub-groups, but would require a method to normalize the scores on a relative scale between criteria.

Additionally, uncertainty could be incorporated into a more complex scoring rubric, meaning that that an uncertainty score would be assigned to each scored criterion. While the incorporation of uncertainty is not feasible for a rapid assessment, for more detailed assessments the uncertainty score can highlight information and data gaps, and increase the accuracy of the gap analysis.

2.9.3 Life Stages

The proposed framework provides guidance to score sub-groups based on the life stages most sensitive to impact (Section 2.4.1). This is a precautionary approach to ensure that sub-groups consisting of species where the adult population may be relatively unaffected while juveniles may be highly affected (based on differing sensitivities and distributions) are not excluded from this assessment. However, this approach is very difficult to apply consistently across all species groups. This is particularly the case for invertebrates, where the most sensitive life stage is often their planktonic form. This leads to little differentiation in scores between sub-groups, and elevates the vulnerabilities of invertebrates higher than other species groups. A potential solution to this problem would be to separate all life stages for each species sub-group and score each separately. While this approach is not feasible for a rapid assessment of vulnerabilities, it may be incorporated into more detailed assessments for other purposes.

2.9.4 Framework Usage in Different Environments

The framework was designed to assess vulnerabilities of biological components in marine environments (below mean high water springs). As such, the species sub-groupings are specific to marine biological components. However, this framework could be adapted in the future for freshwater, arctic, or ice edge environments of Canada by modifying biological sub-groupings.

The species groupings and sub-groupings would need to be expanded to include different species, and could be added to the existing species groupings.

2.9.5 Framework Usage for Other Stressors

This framework was designed to assess vulnerabilities of biological components to ship source oil spills, however, it could be adapted to assess vulnerabilities from other stressors such as chemical spills. This could be achieved by adapting or adding criteria and adjusting the way that the sub-groups are broken down.

3 CONCLUSIONS/RECOMMENDATIONS

- Marine biological components are divided into groups and sub-groups by taxonomy and similar responses to spilled oil. These groupings aim to be applicable across Canada, but may need adjusting to accommodate regional differences.
- A sequential application of criteria grouped into three types (exposure, sensitivity, and recovery) allows for a rapid assessment to identify species sub-groups with higher vulnerabilities to ship-source oil spills and for filtering out sub-groups that do not fulfill those criteria. Criteria are broad and aim to be adaptable to all species sub-groupings across Canada.
- The selection of species to populate vulnerable species sub-groups is regionally specific. Species lists should be compiled from available databases, literature, and expert opinion, in that order of preference.
- Once the scoring and filtering steps have been applied, and selected sub-groups have been populated with species, all components that were flagged for inclusion in the gap analysis should be compiled into a gap analysis summary. Identifying gaps at every step in the process allows us to understand what is driving these gaps and make recommendations as to how these gaps can be addressed.
- The flexibility for biological sub-group breakdown provided by this framework makes it critical that the sub-groups and justifications are clearly stated in the application of this framework, resulting in comparable re-assessments.
- The effectiveness of the proposed framework will not be fully realized until after it has been applied to multiple regions of Canada.

4 REFERENCES

Ban, N., Bodtker, K., Conley, K., Cripps, K., Day, A., Haggarty, D., Hrabok, C., Lee, L., Nicolson, D., Royle K., and Short C. 2007. Marine Plants Expert Workshop. British Columbia Marine Conservation Analysis. 34 pp.

De Lange, H.J., Sala, S., Vighi, M., and Faber, J.H. 2010. Ecological vulnerability in risk assessment – A review and perspectives. Science of the Total Environment. 408: 3871-3879.

Chang, S. E., J. Stone, K. Demes, and Piscitelli, M. 2014. Consequences of oil spills: a review and framework for informing planning. Ecology and Society 19(2): 26.

Gregr, E.J., Gryba, R., James, M.C., Brotz, L., and Thornton, S.J. 2015. Information relevant to the identification of critical habitat for Leatherback Sea Turtles (*Dermochelys coriacea*) in Canadian Pacific waters. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat. Research Document 2015/079. 39 pp.

Gunster, D.G., Gillis, C.A., Bonnevie, N.L., Abel., T.B., and Wenning, R.J. 1993. Petroleum and hazardous chemical spills in Newark Bay, New Jersey, U.S.A. from 1982 to 1991. Environ. Pollut., 82, 245.

Howes, D., Harper, J.R., and Owens E.H. 1994. Physical shore-zone mapping system for British Columbia. B.C. Resources Inventory Committee, Victoria, B.C. 70 pp.

Kennish, M.J. 1996. Practical Handbook of Estuarine and Marine Pollution. CRC Press, Boca Raton, FL. 554 pp.

MacDonald, T.A., Burd, B.J., MacDonald, V.I., and van Roodselaar, A. 2010. Taxonomic and feeding guild classification for the marine benthic macroinvertebrates of the Strait of Georgia, British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences. 2874: iv + 63 p.

NOAA (National Oceanic and Atmospheric Administration), 2002. Environmental Sensitivity Index Guidelines, version 3.0. NOAA Technical Memorandum NOS OR&R 11. Seattle: NOAA, Office of Response and Restoration, Hazardous Materials Response and Assessment Division, 129 p.

O, M., Martone R., Hannah, L., Grieg, L., Boutillier, J., and Patton, S. 2015. An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat. Research Document 2014/072. vii + 59 p.

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E. and Irons, D.B. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302 (5653): 2082-2086.

Reich, D.A., Balouskus, R., French McCay, D., Fontenault, J., Rowe, J., Singer-Leavitt, Z., Etkin, D.S., Michel, J., Nixon, Z., Boring, C., McBrien, M., and Hay, B. 2014. Assessment of marine oil spill risk and environmental vulnerability for the state of Alaska. Prepared by RPS ASA, Environmental Research Consulting, Research Planning, Inc., and The Louis Berger Group, Inc. for the National Oceanic and Atmospheric Administration. NOAA Contract Number: WC133F-11-CQ-0002.

APPENDIX A: SCORING GUIDANCE FOR CRITERIA APPLICATION BY SPECIES GROUP

The tables below (A1-5) provide some scoring guidance for each major biological group. Note, if at least one species in that sub-group fulfills a criterion, the entire sub-group is scored as fulfilling the criterion.

A1. MARINE MAMMALS

Criterion type	Criterion name	Guidance for this group
Exposure	Concentration (aggregation) and/or site fidelity	For example, those living in high concentrations or aggregating in specific locations (e.g. haul-outs), and/or those likely to return to or not leave particular areas (site fidelity).
Exposure	Mobility	All marine mammals are highly mobile.
Exposure	Sea surface interacting	Marine mammals must regularly pass through the air-water interface to breathe making them particularly vulnerable to oil exposure (Peterson et al. 2003),
Exposure	Sediment interacting	Marine mammals that forage in sediment for food.
Sensitivity	Loss of insulation	Marine mammals that depend on fur for thermoregulation (e.g. fur seals, sea otters).
Sensitivity	Reduction of feeding/ photosynthesis	Marine mammals with feeding structures vulnerable to clogging (e.g. baleen whales)
Sensitivity	Impairment due to toxicity	Marine mammals identified in the literature as experiencing severe toxic impacts.
Recovery	Population status	Many marine mammals have reduced population levels, and may be indicated by conservation status.
Recovery	Reproductive capacity	All marine mammals are K-strategists with low reproductive capacity.
Recovery	Endemism or Isolation	Those marine mammals endemic to the region or with isolated populations.
Recovery	Close association with sediments	Marine mammals that forage in sediment for food.

A2. MARINE REPTILES

Sea turtles are the only sub-group of marine reptiles considered in the framework.

Criterion type	Criterion name	Guidance for this group
Exposure	Concentration (aggregation) and/or site fidelity	Sea turtles are not known to concentrate / aggregate in Canadian waters (e.g. for nesting)
Exposure	Mobility	Sea turtles are highly mobile
Exposure	Sea surface interacting	Sea turtles have to interact with the surface to breathe.
Exposure	Sediment interacting	Sea turtles are not known to forage and dig in sediments in Canadian waters
Sensitivity	Loss of insulation	Not relevant for sea turtles
Sensitivity	Reduction of feeding/ photosynthesis	Feeding structures are not expected tobecome clogged with oil
Sensitivity	Impairment due to toxicity	There is evidence in the literature that sea turtles experience severe toxic impacts
Recovery	Population status	Some species in Canada have reduced overall population levels (e.g. the SARA listed Leatherback)
Recovery	Reproductive capacity	Have features of both r and k strategists – long lived with slow

Criterion type	Criterion name	Guidance for this group
		development but with many offspring
Recovery	Endemism or Isolation	None endemic to Canada or with isolated populations
Recovery	Close association with sediments	Sea turtles are not known to forage and dig in sediments to find food in Canadian waters

A3. MARINE FISH

Criterion type	Criterion name	Guidance for this group
Exposure	Concentration (aggregation) and/or site fidelity	For example, fish that concentrate to spawn in specific areas (e.g. eelgrass), and seasonal estuarine aggregations (e.g. salmon).
Exposure	Mobility	Fish are highly mobile.
Exposure	Sea surface interacting	For example intertidal, and anadromous fish will have regular interaction with the sea surface compared to benthic fish.
Exposure	Sediment interacting	Fish that forage in the sediment, or who closely associate with sediment for shelter or camouflage.
Sensitivity	Loss of insulation	Not relevant for fish.
Sensitivity	Reduction of feeding/ photosynthesis	Filter feeding fish such as basking sharks have feeding structures that can become clogged with oil.
Sensitivity	Impairment due to toxicity	Fish sub-groups identified in the literature as experiencing severe toxic impacts.
Recovery	Population status	Sub-groups of fish with reduced population levels indicated by conservation status.
Recovery	Reproductive capacity	Fish species with very low reproductive capacity, such as very long lived and infrequent reproducers.
Recovery	Endemism or Isolation	Fish endemic / with isolated populations in the region.
Recovery	Close association with sediments	Fish that forage in the sediment, or who closely associate with sediment for shelter or camouflage.

A4. MARINE INVERTEBRATES

Criterion type	Criterion name	Guidance for this group
Exposure	Concentration (aggregation) and/or site fidelity	Concentrations or aggregations linked to a physical area or habitat (e.g. mussel beds), and/or mobile sub-groups that return to or do not leave particular areas.
Exposure	Mobility	This criterion would be fulfilled by sessile and low mobility groups such as barnacles and mussels.
Exposure	Sea surface interacting	Intertidal and surface feeding marine invertebrates; pelagic groups that undergo vertical migrations; some cephalopods (i.e. jumping squid).
Exposure	Sediment interacting	Marine invertebrates that live within the sediment (e.g., clams) or spend a large proportion of time in contact with it for shelter/camouflage or forage within it.
Sensitivity	Loss of insulation	Not relevant for marine invertebrates.
Sensitivity	Reduction of feeding/ photosynthesis	Particularly relevant for filter feeding marine invertebrates.
Sensitivity	Impairment due to toxicity	Marine invertebrates identified in the literature as experiencing severe toxic impacts.
Recovery	Population status	Identifying marine invertebrates with reduced population levels will be challenging given their under-representation in listings such as SARA. However, reduced population levels demonstrated in the literature or by experts can be used for guidance.
Recovery	Reproductive capacity	Marine invertebrates generally have high reproductive

Criterion type	Criterion name	Guidance for this group
		potential relative to all other species groups, as they are mostly r-strategists. This criterion would be fulfilled by sub-groups with very low reproductive capacity, such as very long lived and infrequent reproducers.
Recovery	Endemism or Isolation	Marine invertebrates that are endemic to the region or with isolated populations .
Recovery	Close association with sediments	Marine invertebrates that live within the sediment or that spend a large proportion of time in contact with it for shelter/camouflage or forage within it (e.g., clams).

A5. MARINE ALGAE/PLANTS

Criterion type	Criterion name	Guidance for this group
Exposure	Concentration (aggregation) and/or site fidelity	For example, canopy forming kelp and seagrasses concentrations.
Exposure	Mobility	Members of this group are not mobile.
Exposure	Sea surface interacting	Such as phytoplankton; intertidal species; those that can extend from the seabed to the surface.
Exposure	Sediment interacting	Species rooted in sediments (e.g. eelgrass).
Sensitivity	Loss of insulation	Not relevant for marine plants.
Sensitivity	Reduction of feeding/ photosynthesis	Marine algae/plants with frond types that can retain oil (tufted or rough) will be more likely to experience reduced photosynthesis.
Sensitivity	Impairment due to toxicity	Marine algae/plants identified in the literature as experiencing severe toxic impacts.
Recovery	Population status	Where there is limited representation in lists such as SARA, other resources such as the literature and experts can be used to determine population levels.
Recovery	Low reproductive potential	This criterion would be fulfilled by sub-groups with very low reproductive capacity, such as very long lived and infrequent reproducers.
Recovery	Geographic range	Marine plants endemic to the region or with isolated populations.
Recovery	Close association with sediments	Species that live in/amongst sediment (e.g. eelgrass).

APPENDIX B: EXAMPLE TEMPLATE FOR ACCOMPANYING SCORING TABLES

Group	Sub-groups			Species example	Areas/sites to be mapped	Depth component				Seasonal abundance (1= no information, 2=rare, 3=common, 4=abundant, 5=highly abundant) (after NOAA ESI)											
						Surface	Water Column	Benthic	Intertidal	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Marine mammals	Pinnipeds	Other Pinnipeds	Discrete	Species example 1	Haul outs																

…cont.

Vulnerability Criteria										
Proposed Exposure Criteria				Proposed Sensitivity Criteria			Proposed Recovery Criteria			
Concentration (aggregation) and/or site fidelity	Sessile/low mobility	Sediment interacting	Sea surface interacting	Loss of insulation	Reduction of feeding/photosynthesis	Impairment due to toxicity	Population status	Reproductive capacity	Endemism or Isolation	Close association with sediments

APPENDIX C: GLOSSARY OF TERMS

Term	Definition
Anadromous	Fish that migrate up rivers from the sea to breed in freshwater.
Catadromous	Fish that migrate down rivers to the sea to spawn.
Cumulative impacts	Cumulative impacts are changes to the environment that are caused by an action in combination with other past, present and future human actions.
Demersal	Organisms, usually fish, that live and feed on or near the ocean floor.
Diadromous	Fish that spend some portion of their life cycle partially in freshwater and partially in salt water.
Discrete Mammals	Organisms that are gregarious and live in distinct groups.
Dispersed Mammals	Organisms with a continuous or randomly distributed population.
Estuarine	Organisms that live in an estuary and are capable of surviving a wide range of salinities.
Forage fish	Small pelagic fish which are preyed upon by larger predators for food.
Intertidal	The shoreline area that exists between the low and the high tides, also known as the littoral zone. Organisms that live in the intertidal zone are adapted to harsh extremes in temperature, salinity, desiccation, wave action and solar radiation.
Mean high water springs (MHWS)	Average height of the high waters of spring tides (also termed called spring high water).
Off Shelf	Fish that live off the continental shelf in deeper waters. Also termed ‘offshore’ fish.
On Shelf	Fish that live in the zone between the shoreline and the edge of the continental shelf. Also termed ‘inshore’ fish.
Pelagics	Organisms that live in the water column (not near the bottom or the shore) of coasts and open oceans.
Perigean spring tide	A tide that occurs only a few times a year when the Moon's perigee (its closest point to Earth during its orbit) coincides with a spring tide.
Secondary impacts	Trophic or food web impacts.
Sediment epifauna	Organisms which live on the surface of the ocean floor.
Sediment in-fauna	Organisms which live in the sediments of the ocean floor.
Semi-demersal	Fish traditionally defined as demersal, and with a body shape adapted to living close to the bottom, but often observed in mid-waters.
Sensitivity	Sensitivity is a nested factor of vulnerability (Vulnerability being 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).
Sessile	Organisms that are permanently attached or fixed to the ocean floor.
Subtidal benthic	Organisms that live on the seafloor in a zone that is permanently immersed by tidal water.
Vulnerability	Vulnerability is the degree to which a system is susceptible to, and unable to cope with, injury, damage, or harm (De Lange et al. 2010).