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National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2020/030

SCIENCE ADVICE FOR PATHWAYS OF EFFECTS FOR MARINE SHIPPING IN CANADA: BIOLOGICAL AND ECOLOGICAL EFFECTS

Cargo ship at anchor in the eastern Canadian Arctic. Photo credit: Cathryn Murray

Regional map of Canada (Credit: DFO)

Context:

Pathways of Effects (PoE) conceptual models describe the pathways (linkages) between human activities, associated stressors, and effects on the environment, and can be developed to be broad enough to be applicable in a range of environments and locations. A PoE model consists of a visual representation of the structure of the model, supported by evidence describing each pathway linkage based on available scientific literature and expert opinion. PoE models are useful scoping tools for a variety of types of environmental assessment, such as ecological risk assessment, environmental impact assessment, and cumulative effects assessment, as they describe the potential stressors and effects that could be included in such assessments.

PoE models for five sub-activities related to marine shipping were developed that build upon, and supersede, those developed in a previous process (DFO 2015). Each model described links from sub-activity to stressors to broad-scale effects and the provided tables of evidence describe the supporting evidence for effects to generic biological and ecological endpoint examples. Through these models and supporting evidence, Fisheries and Oceans (DFO) Science has provided a systematic review of the effects of shipping-associated activities on marine biological and ecological endpoints, in response to a request by Transport Canada. PoE models are part of a scoping phase of an assessment and do not include an evaluation of the magnitude of impact of these activities on specific endpoints; this would occur in a subsequent assessment step, such as risk assessment, and is not the goal of the current work.

This Science Advisory Report is from the November 19-21 2019 national peer review of Science Advice for Pathways of Effects for Marine Shipping. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Vessels involved in commercial marine shipping in Canada engage in the movement of goods or people by sea on the Arctic, Atlantic, and Pacific oceans. In response to a request by Transport Canada, DFO Science Branch developed a suite of Pathways of Effects (PoE) conceptual models for marine shipping in Canada.
- Pathways of Effects (PoE) conceptual models describe the pathways (linkages) between human activities, associated stressors, and their effects on endpoints. They have been developed to be broad enough to be adapted for application in a range of environments and locations. PoE conceptual models are supported by text describing each pathway linkage based on available scientific literature or expert opinion. Indigenous and local knowledge was not used in this current work.
- PoE models are useful tools for the scoping phase of a variety of environmental assessments, such as ecological risk assessment, environmental impact assessment, and cumulative effects assessment, as they clearly outline activities and stressors and clarify connections between human activities and potential effects on ecological endpoints. While some endpoints have been identified for illustrative purposes here, the assessor is responsible for comprehensively scoping the specific endpoints (e.g., valued components) and stressors to be included in the assessment.
- PoE models do not include any evaluation of the relative or absolute impact from these activities on specific endpoints; this would occur in a subsequent assessment step, such as risk assessment.
- This systematic review of the effects of shipping-associated activities on marine ecosystems describes PoE models for five sub-activities (anchoring and mooring, vessel at rest, grounding and sinking, movement underway, and discharge) and linked stressors. Tables of evidence (based on literature review and expert opinion) are provided to describe broad-scale effects to generic ecological endpoints.
- Each sub-activity was described by using one or more PoE models, to enhance manageability and understanding of the different PoE components. Despite this separation for practical purposes, there may be considerable inter-relationship and overlap, and it would be an oversimplification to consider each sub-activity model in isolation without acknowledging these connections among elements of the suite of models.
- Sub-activities and stressors were determined by assembling activity and stressor terms developed through DFO risk assessment processes and cross-referencing Transport Canada's initial national online engagement outcomes, undertaken at the outset of Transport Canada's Cumulative Effects of Marine Shipping initiative. Stressor effects were categorised at a broad scale (change in fitness, mortality, and change in habitat) to ensure consistency in structure and applicability across regions. Endpoint examples used were broad, generic ecological examples based on DFO Pacific Region's vulnerability assessment groupings.
- Stressors and their broad-scale effects are the focus of this advice, rather than the endpoint examples provided, which are not comprehensive, and were chosen to illustrate how stressors may interact with features of the marine environment but caution is advised when interpreting the outlined endpoints. In an assessment, users choose from many candidate endpoints, which can be specific to the region, or area of interest. The goal in developing these endpoints was that they adequately describe the effects of a stressor while remaining generic enough to be applicable across Canadian regions.

- Scientific evidence to confirm potential effects on endpoints was not found for a small number of effects described in the PoE models, with the time and resources available. An absence of evidence does not mean that there is no effect and regardless of the body of evidence available, any potential linkage that could be substantiated by literature or expert opinion was included in the PoE, in keeping with the precautionary approach.
- The scope of this work includes domestic and international marine shipping that occurs in the marine and coastal waters (including estuarine and intertidal environments) of the Arctic, Atlantic, and Pacific oceans of Canada. Each of these oceans comprise three bioregions related to biogeographic differences in ocean conditions and depth. Ice cover is only experienced in the Atlantic (seasonally) and the Arctic (both seasonally and year-round). Canada's large freshwater shipping industry is considered only to the extent that it interacts with the marine environment.
- Activities undertaken by vessels other than the movement of goods or people are not considered in this document, such as fishing, seismic surveying, dredging, port operations (e.g., when at-berth and while berthing). Non-commercial vessels (e.g., recreational vessels) are also not specifically included in these models. This work does not examine the effects of shipping activities and stressors on elements of human well-being, but is restricted to marine biota and habitats in coastal environments.
- Cumulative effects from multiple stressors, stressor interactions, and indirect effects (such as those associated with climate change) were not included in this work; however, these undoubtedly occur and are important considerations when using the PoE models in an assessment, or when implementing an ecosystem-based approach to management.
- The conditions, such as the baseline(s) against which change is measured has not been defined in the PoE models, but should be clearly specified and defined during an assessment phase.
- This work describes potential pathways of effects of marine shipping and synthesises evidence for effects based on current levels of understanding and regulations. As additional evidence is obtained over time, understanding of the effects and impacts will change, along with the environmental (e.g., climate), technological, and social (e.g., management measures, legislation, and regulations) factors that influence them. The shipping PoE models should be considered "evergreen" and should be reviewed and updated when our understanding of these factors changes.
- The PoE models for marine shipping were developed as a tool to examine effects on ecological endpoints, but the tool may be adapted for social, cultural, and economic endpoints.

INTRODUCTION

Pathways of Effects (PoE) conceptual models are used to structure and describe the way that potential effects to the environment manifest from an activity through a suite of stressors, and are developed to be broad enough to be applicable in a range of environments and locations. PoE models are useful as scoping tools for environmental assessment, such as ecological risk assessment, environmental impact assessment, and cumulative effects assessment, as they describe the potential stressors and effects that could be included in such assessments but they do not include an assessment of relative or absolute impact, magnitude of change, or risk.

DFO Science was requested by Transport Canada to develop a suite of activity-based Pathways of Effects models for marine shipping. PoE model development involved the

identification and review of specific sub-activities associated with commercial shipping in Canadian marine waters, and the identification and description of broad-scale effects of resulting stressors on generic ecological endpoints in the marine ecosystem. The conceptual models developed include supporting evidence (based on scientific knowledge or expert opinion) for all PoE components (i.e., Activities, Stressors, Effects) and linkages (i.e., Activity→Stressor and Stressor→Effect), resulting in a suite of PoE models that represent the activities, stressors, and broad-scale effects of marine shipping within the scope outlined.

METHODS

Pathways of effects models

A PoE model consists of a visual representation of the conceptual model with accompanying text describing each pathway linkage and supported by available scientific literature where possible. The structure of the model, and the shape and colours of the components used were based on Government of Canada national guidelines (Government of Canada 2012), which outline four main levels of components for an activity-based PoE conceptual model: (i) activity and sub-activity of interest; (ii) stressor(s) associated with the sub-activity; (iii) effect(s) of the stressor on the marine environment and (iv) linkages to endpoints (Table 1; Figure). Linkages are the connections between components in a PoE model and are numbered to allow users to locate accompanying justification text.

Table 1: Definitions of Pathways of Effects components used in the study.

Component	Definition	Source
Activity / Sub-activity	"an action that may impose one or more stressors on the ecosystem being assessed"	O et al. 2015
Stressor	"any physical, chemical, or biological means that, at some given level of intensity, has the potential to change an ecosystem or one or more of its components"	O et al. 2015
Effects	"the broad range of potentially measureable changes that may be observed"	Boehlert and Gill 2010
Endpoint	"valued attribute of ecological entities"	EPA 1998
Impacts	"effects that, with some certainty, rise to the level of deleterious ecological significance"	Boehlert and Gill 2010

Activities and stressors were identified by assembling activity and stressor terms developed through DFO risk assessment processes (e.g., Clarke Murray et al. 2016). Stressor terms were cross-referenced for consistency and completeness with the outcomes of Transport Canada's engagement process.

Effects and impacts have been carefully defined (Table 1), and it is emphasised that the presence of a potential effect in the PoE model does not necessarily indicate a significant impact. To ensure consistency in structure and applicability across regions, three effect categories were used in each model to portray the broad-scale effects that stressors can have: change in fitness, mortality, and a change in habitat. Only direct effects were considered as indirect effects were beyond the scope of the current work.

Endpoint examples selected were based on broad-scale categories of endpoints used in DFO Pacific Region's vulnerability assessment groupings developed for oil spill planning and response (Hannah et al. 2017).

The approach used to develop PoE models was to include all potential effect pathways first through expert opinion, and then by systematically searching scientific literature for evidence of

measurable effect. If evidence to support the pathway was not available, the link was retained in the diagram and the lack of evidence noted in the evidence table.

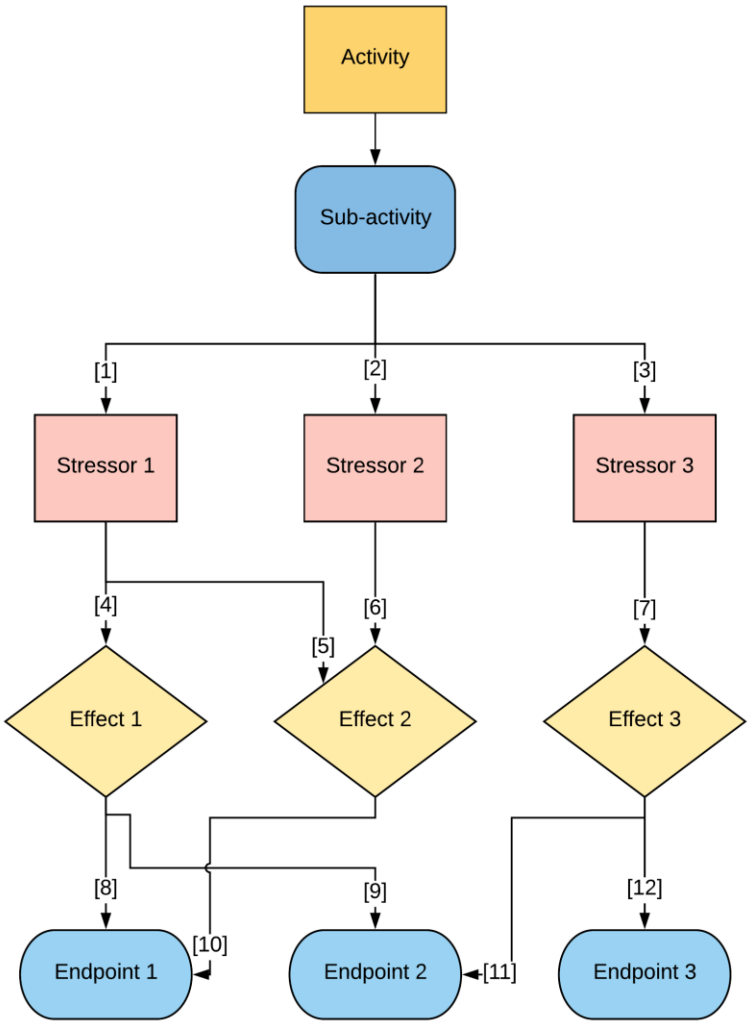

Figure 1: Structure of an example generic Pathway of Effects (PoE) model diagram. Arrows indicate the linkages between components, numbering links to supporting text.

ASSESSMENT

Pathways of Effects models for marine shipping

The five sub-activities described in the PoE models (presented in Figure 2) are all part of marine shipping and together effectively represent one overarching shipping PoE model. However, they have been separated into the following distinct individual sub-activity PoE models to enhance manageability and understanding of the different components: Anchoring and Mooring (Figure 2a), Vessel at Rest (Figure 2b), Grounding and Sinking (Figure 2c), Movement Underway (Figure 2d), and Discharge (Figure 2e). Despite this separation for practical purposes, there may be considerable inter-relationship and overlap, and it would be an oversimplification to consider each sub-activity model in isolation without acknowledging these connections among elements of the suite of models.

a. Anchoring and Mooring

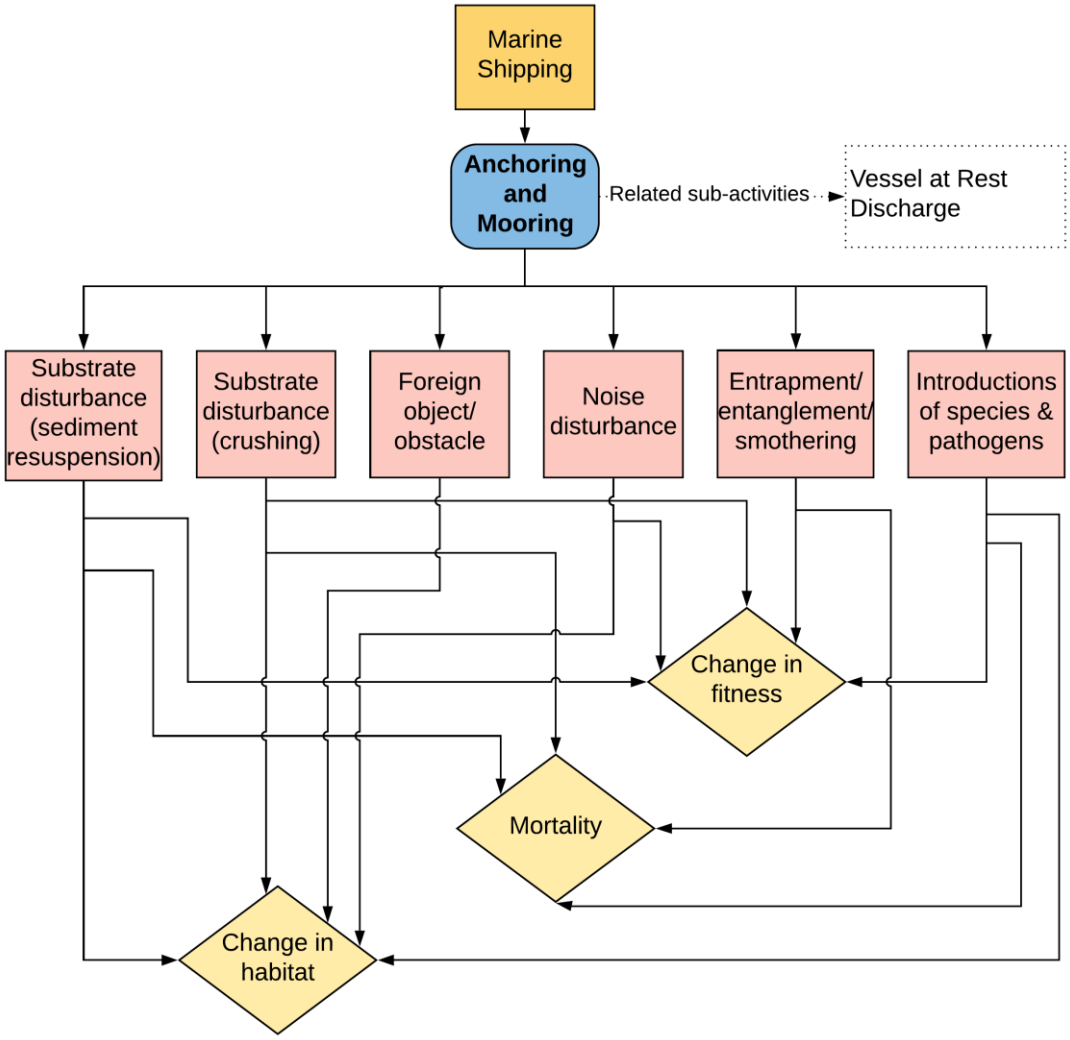

Figure 2: Pathways of effects model diagrams for shipping sub-activities: a) Anchoring and Mooring; b) Vessel at Rest, c) Grounding and Sinking, d) Movement Underway, and e) Discharge. Diagrams include references to related sub-activities to identify which are linked (dashed box). For simplification, these diagrams are presented without numbered linkages on each line, which would represent supporting justification text in a full PoE model.

b. Vessel at Rest

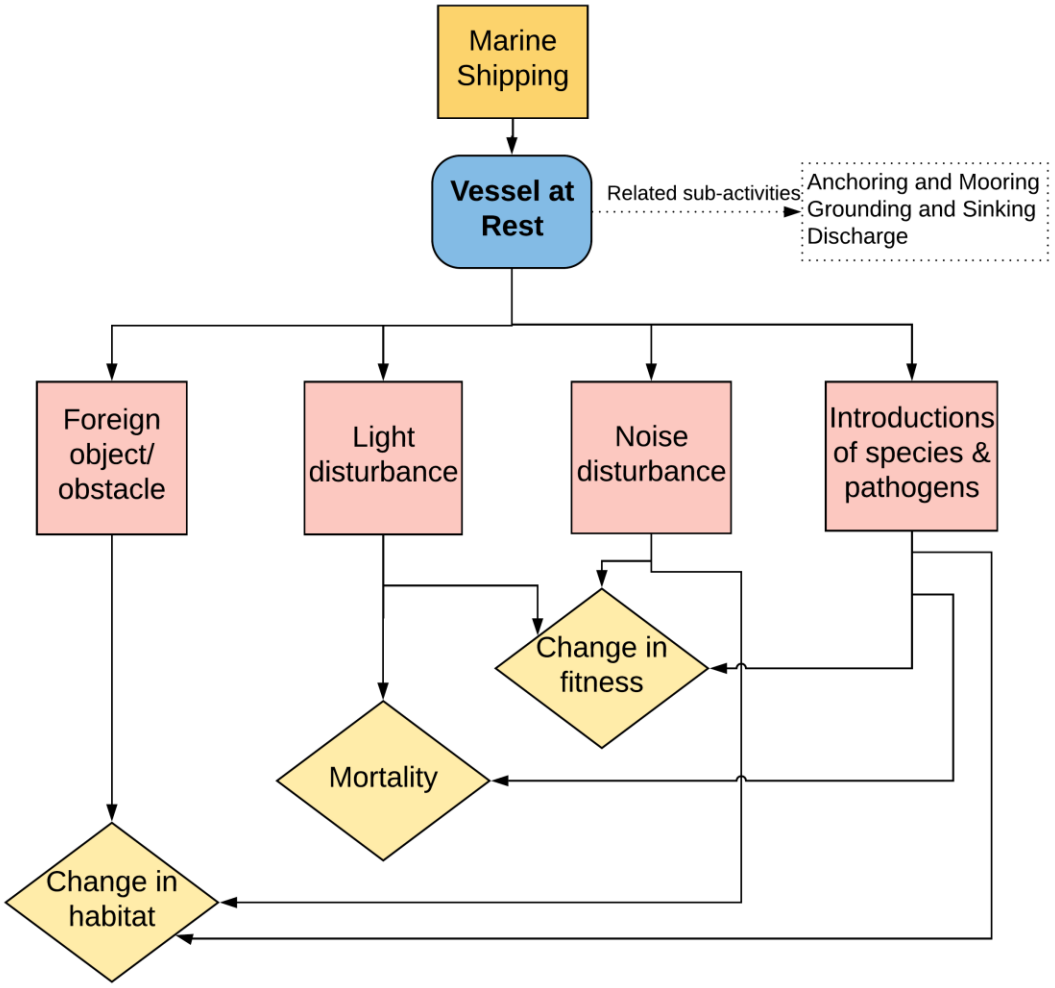

Figure 2: Continued.

c. Grounding and Sinking

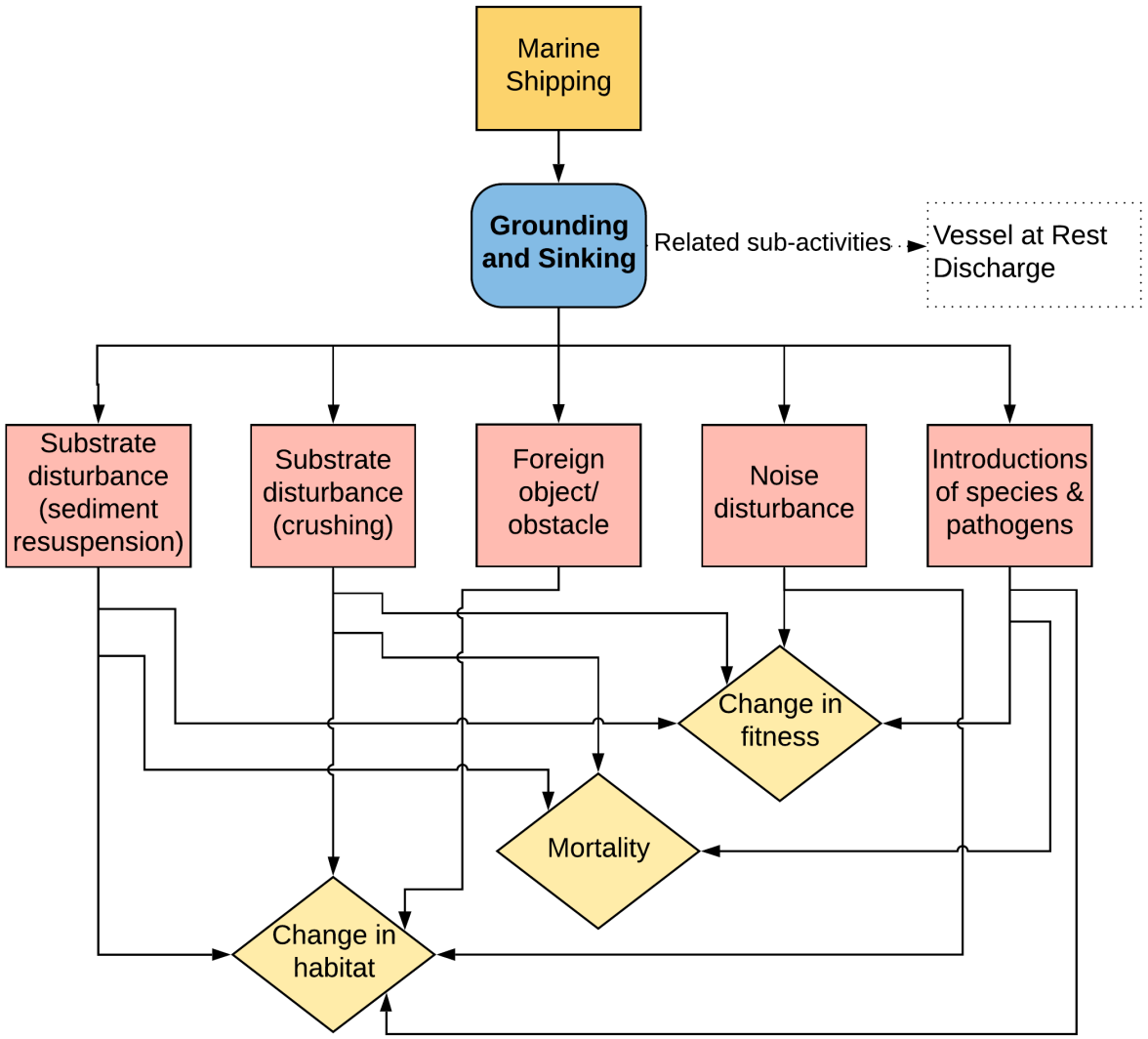

Figure 2: Continued.

d. Movement underway

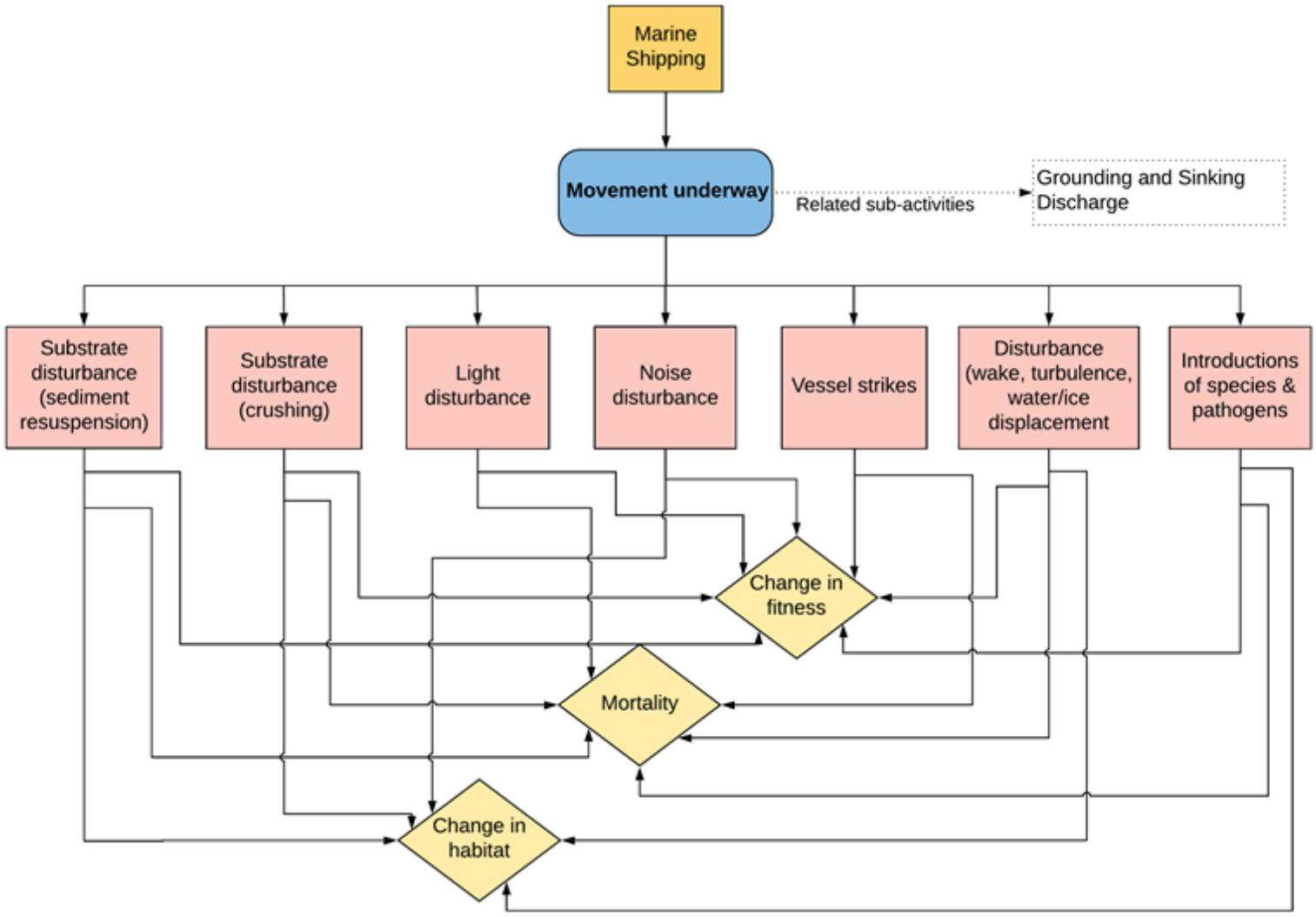

Figure 2: Continued.

e. Discharge

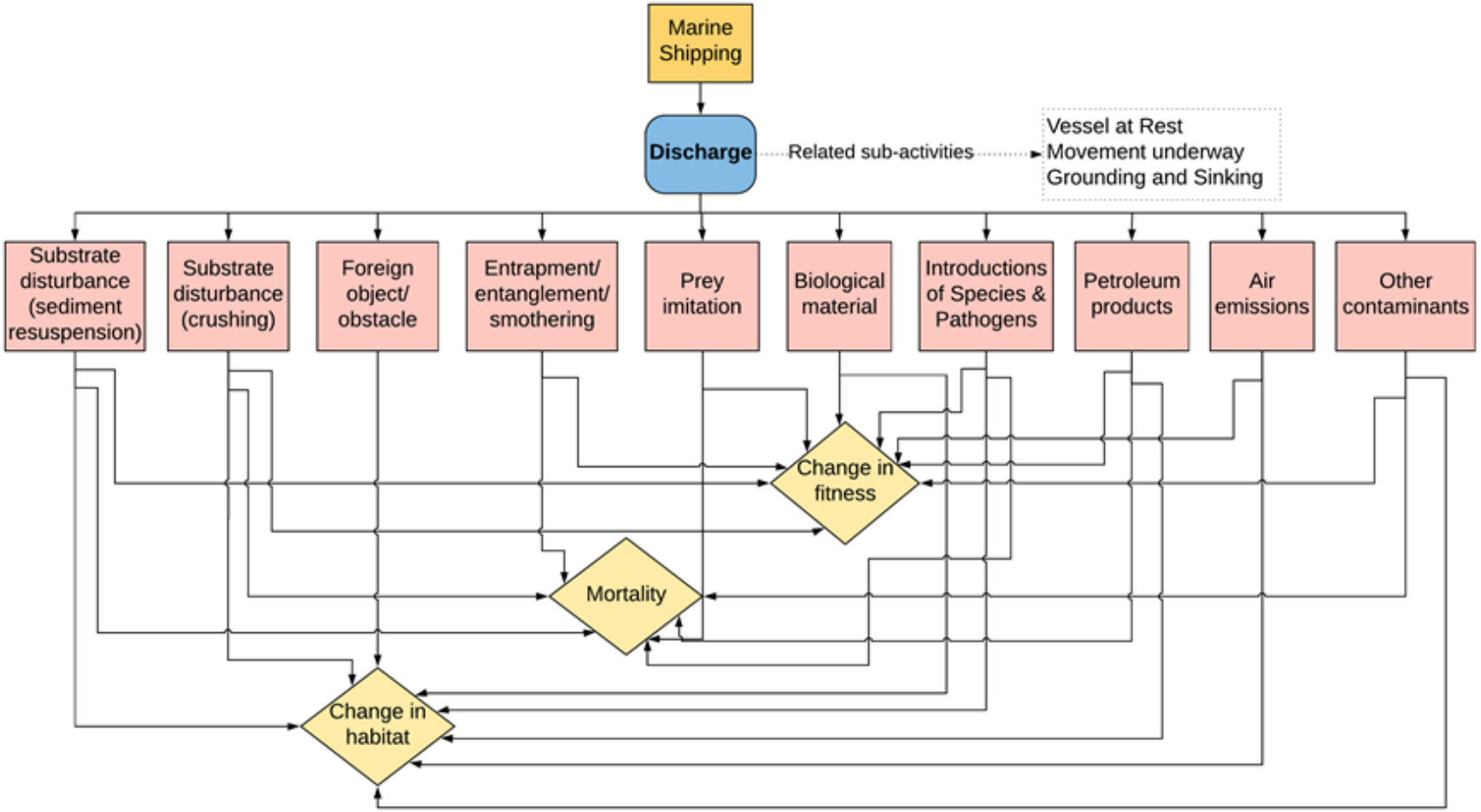

Figure 2: Continued.

The sub-activities, stressors, and broad-scale effects captured in each of the PoE models are summarized in Table 2.

Table 2: Overview of the sub-activities and their linked components (stressors and effects) in the shipping PoE models (effects: F=change in fitness, M=mortality, H=change in habitat).

Sub- activity	Stressors	Effects		
		F	M	H
Anchoring and Mooring Related sub-activities: *Vessel at Rest* *Discharge*	Substrate disturbance (sediment re-suspension)	✓	✓	✓
	Substrate disturbance (crushing)	✓	✓	✓
	Foreign object / obstacle			✓
	Noise disturbance	✓		✓
	Entrapment/ Entanglement/ Smothering	✓	✓	
	Introductions of species & pathogens	✓	✓	✓
Vessel at rest Related sub-activities: *Anchoring & Mooring* *Grounding & Sinking* *Discharge*	Foreign object / obstacle			✓
	Light disturbance	✓	✓	
	Noise disturbance	✓		✓
	Introductions of species & pathogens	✓	✓	✓
Grounding and Sinking Related sub-activities: *Vessel at Rest* *Discharge*	Substrate disturbance (sediment re-suspension)	✓	✓	✓
	Substrate disturbance (crushing)	✓	✓	✓
	Foreign object / obstacle			✓
	Noise disturbance	✓		✓
	Introductions of species & pathogens	✓	✓	✓
Movement underway Related sub-activities: *Grounding & Sinking* *Discharge*	Substrate disturbance (sediment re-suspension)	✓	✓	✓
	Substrate disturbance (crushing)	✓	✓	✓
	Light disturbance	✓	✓	
	Noise disturbance	✓		✓
	Vessel strikes	✓	✓	
	Disturbance (wake, turbulence, water/ice displacement)	✓	✓	✓
	Introductions of species & pathogens	✓	✓	✓
Discharge Related sub-activities: *Vessel at Rest* *Movement underway* *Grounding & Sinking*	Substrate disturbance (sediment re-suspension)	✓	✓	✓
	Substrate disturbance (crushing)	✓	✓	✓
	Foreign object / obstacle			✓
	Entrapment/ Entanglement/ Smothering	✓	✓	
	Prey imitation	✓	✓	
	Biological material	✓		✓
	Introductions of species & pathogens	✓	✓	✓
	Petroleum products	✓	✓	✓
	Air emissions	✓		✓
	Other contaminants	✓	✓	✓

Sources of Uncertainty

- Knowledge gaps are identified within each PoE model description and are also captured in evidence tables, where the available knowledge (or lack of knowledge), for a specific linkage is described.
- The effects of an accidental cargo or fuel spill can be highly variable depending on the type of cargo, fuel, its volume, and the local ecosystem affected. The 'other contaminants' stressor in the Discharge PoE model described here incorporates a range of cargo and fuels with different effects and impacts on ecological endpoints, and should be considered in more detail during an assessment.
- Scientific evidence to confirm potential effects on endpoints was not found for a small number of effects described in the PoE models, with the time and resources available. An absence of evidence does not mean that there is no effect and regardless of the body of evidence available, any potential linkage that could be substantiated by literature or expert opinion was included in the PoE, in keeping with the precautionary approach.
- It is acknowledged that some stressors associated with shipping (e.g., air emissions) cause indirect climate effects; however, the complex and varied effects of global climate change were not included in this work.
- Definitions of environmental baselines (e.g. historical [based on a temporal reference point] or ecological [based on a 'pristine' or 'altered' system]), along with associated 'shifting baselines', create uncertainty for both the PoE model and its application in assessments; for example comparing anchoring effects in well-used anchorage areas with a long history of use compared to more recent, and lesser-used areas. When applying the PoE models in a specific context, clearly defining the baseline conditions against which to measure change is important.
- Cumulative effects from multiple stressors, stressor interactions, and indirect effects (such as those associated with climate change) were not included in this work; however, these undoubtedly occur and may be important considerations in an assessment, or when implementing an ecosystem-based approach to management.
- The supporting evidence provided herein does not include indigenous, traditional or local knowledge, as this was not within the scope of the request for this work. These knowledge sources will provide important evidence and/or understanding of conditions, including environmental baseline(s) for subsequent assessments.
- This work describes potential pathways of effects of marine shipping and synthesises evidence for effects based on current levels of understanding and regulations. As additional evidence is obtained over time, understanding of the effects and impacts will change, along with the environmental (e.g., climate), technological, and social (e.g., management measures, legislation, and regulations) factors that influence them. The shipping PoE models should be considered "evergreen" and should be reviewed and updated when our understanding of these factors changes.

CONCLUSIONS AND ADVICE

Pathways of Effects (PoE) models allow the user to clearly articulate and define the system of interest in a structured way utilising graphical display with corresponding scientific evidence (Canada 2012). The suite of PoE models developed for marine shipping in this work identify known PoE components and pathway linkages that describe how the stressors associated with five sub-activities can result in broad-scale effects to generic endpoints. The presence of each PoE component was supported by scientific evidence and/or expert opinion with areas of uncertainty identified. PoE models are the first step in the scoping phase of an assessment, and are primarily used to ensure that all activities and stressors have been identified and described, and that all effect pathways are captured. Once assessment-specific endpoints (which may consist of single or multiple valued components) are identified, the user can identify the types of stressors and effects that may be applicable to that specific endpoint. The creation of PoE models has been recommended as a first step in risk assessment (O et al. 2015) and are used explicitly in cumulative effects assessments (Murray et al. 2019). Caution is advised when applying these shipping PoEs during an assessment since indirect effects and cumulative effects (interactions) were not included.

- The conditions, such as the baseline(s) against which change is measured, have not been defined in the PoE models but should be clearly specified and defined during an assessment phase.
- Cumulative effects from multiple stressors, stressor interactions and indirect effects (such as those associated with climate change), were not included in this work; however, these undoubtedly occur and are important considerations when using PoE models in an assessment, or when implementing an ecosystem-approach to management
- Stressors and their broad-scale effects are the focus of this advice, rather than the endpoint examples provided, which are not comprehensive, and were chosen to illustrate how stressors may interact with features of the marine environment, and caution is advised when interpreting the outlined endpoints. In an assessment, users choose from many candidate endpoints, which can be specific to the region, or area of interest. The goal in developing these endpoints was that they adequately describe the effects of a stressor while remaining generic enough to be applicable across Canadian regions.
- The PoE models developed could be used in a variety of processes and assessments, including environmental impact assessment, cumulative effects assessment, risk assessment, and in a number of management contexts (e.g., Species at Risk, Marine Spatial Planning, and Ecosystem-Based Management).
- This work describes potential pathways of effects of marine shipping and synthesises evidence for effects based on current levels of understanding and regulations. As additional evidence is obtained over time, understanding of the effects and impacts will change, along with the environmental (e.g., climate), technological, and social (e.g., management measures, legislation, and regulations) factors that influence them. The shipping PoE models should be considered “evergreen” and should be reviewed and updated when our understanding of these factors changes.

OTHER CONSIDERATIONS

- To get a full understanding of the effects of the shipping industry in a specific area, other related activities, such as port activities and construction of infrastructure may be included.
- Even though social, cultural, and economic endpoints are beyond the scope of this work, this PoE model could be expanded to capture these types of endpoints.
- The representation of air emissions as a single stressor within the PoE model for the discharge sub-activity may limit the scope for capturing the diverse ways air emissions can manifest and affect marine ecosystems. In particular, in an assessment it is important to consider the indirect effects of air emissions and their contribution to larger processes such as climate change and ocean acidification. Similarly, contaminants (other than petroleum products) are represented by a single stressor despite the complexities of contaminant types (e.g., polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals, etc.) and their specific effects.
- The logical next step would be to adapt the PoE models to a regional or local scale for use in assessments. This would include the identification of specific endpoints, and selection of appropriate sub-activities and stressors, and incorporating indigenous and local knowledge in the process.
- PoE models are only one part of the scoping phase of an assessment; the other main aspect is the identification and selection of endpoints of ecological, social, or cultural importance (e.g., Valued Components - VCs), which may be selected and screened using criteria appropriate to that value.
- Stressors identified in the PoE models can be tabulated against VCs to determine where interactions occur in order to help determine what should be included in an assessment.
- PoE models are intended to be used as part of the scoping phase of assessments, such as Transport Canada's Cumulative Effects Assessment of Marine Shipping Initiative. In the context of an assessment, PoE models are one component of the scoping phase. An assessment following the scoping phase can then evaluate the impact of the activity and its stressors on specific components of interest. As an example of the above, at the time of writing, a national cumulative effects assessment framework for marine shipping is under development under Transport Canada's aforementioned initiative. This framework broadly outlines the phases and steps, including the additional scoping steps identified above, and can be followed to undertake these assessments.
- An assessment phase would aim to assess the impact of the stressors on VCs, singly and/or in combination and can be qualitative, semi-quantitative, or fully quantitative. Stressors can be evaluated for characteristics such as intensity, frequency and spatial scale and can be ranked, estimated, or modelled for the region of interest. The consequences to the VECs are evaluated using variables such as degree of effect on fitness, scale of mortality events, duration of effect, and level of impact (individual, population, species). Indirect effects could be brought into the assessment phase in order to fully consider the effects of an activity on the valued components of interest.

LIST OF MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Burton	Sara	Transport Canada
Clarke	Keith	DFO, Science, Newfoundland and Labrador
Doucette	Paula	Transport Canada
Galbraith	Lindsay	Council of the Haida Nation
Hannah	Lucie	DFO, Science, Pacific
Herbert	James	Gitxaala Nation
Herborg	Matthias	DFO, Science, Pacific
Houston	Kim	DFO, Science, Pacific
Klaver	March	DFO, Science, Pacific
Lawson	Jack	DFO, Science, Newfoundland and Labrador
Lemieux	Jeffrey	DFO, Science
Locke	Andrea	DFO, Science, Pacific
Mortimor	James	DFO, Science, Pacific
Murray	Cathryn	DFO, Science, Pacific
Nelson	Jocelyn	DFO, Science, Pacific
O	Miriam	DFO, Science, Pacific
Paslawski	Darcy	Vancouver Fraser Port Authority
Paul	Maya	North Coast-Skeena First Nations Stewardship Society/ MaPP/ESI NC Cumulative Effects Program
Paulic	Joclyn	DFO, Science, Central and Arctic Region
Rear	Scott	Canadian Coast Guard
Reid	Dan	Transport Canada
Salter	Natasha	DFO, Science, Pacific
Scherr	Jason	Prince Rupert Port Authority
Taft	Spencer	Tsleil-Waututh Nation
Templeman	Nadine	DFO Science, National Capital Region
Trounce	Krista	Vancouver Fraser Port Authority
Vagle	Svein	DFO, Science, Pacific

SOURCES OF INFORMATION

This Science Advisory Report is from the November 19-21 2019 national peer review of Science Advice for Pathways of Effects for Marine Shipping. 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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Centre for Science Advice
National Capital Region
Fisheries and Oceans Canada
200 Kent St
Ottawa ON K1A 0E6
Telephone: (613) 990-0194
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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