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Canadian Science Advisory Secretariat
National Capital Region **Science Advisory Report 2014/059**

SHIPPING PATHWAYS OF EFFECTS: AN OVERVIEW

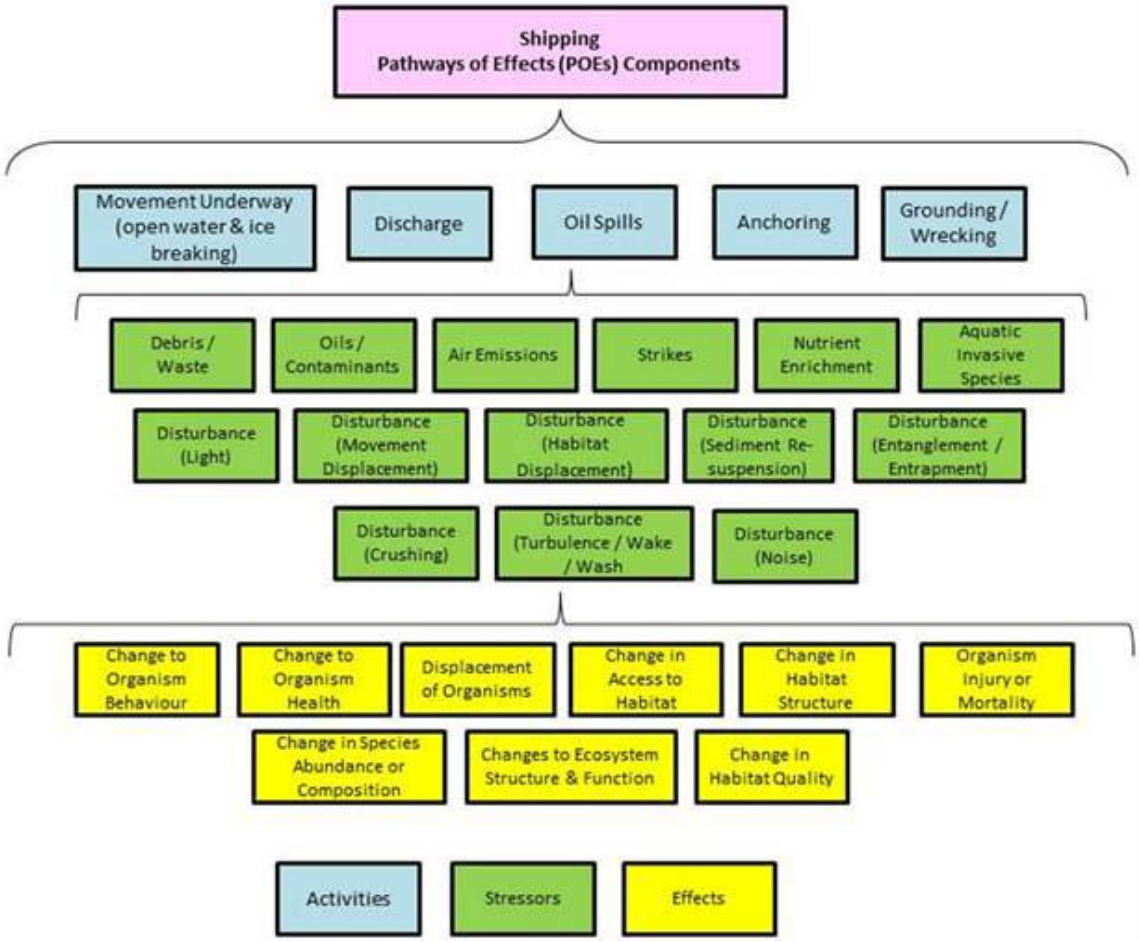

Figure 1. Shipping Pathways of Effects components: activities, stressors, and effects.

Context:

Canada is committed domestically and internationally to mitigating the potential impacts of human activities on the environment. Pathways of Effects (PoE) models are an important tool to illustrate the linkages between activities and their potential impacts on various aspects of the ecosystem. In addition, PoEs are essential to the development of threat and risk assessments.

This Science Advisory Report provides an overview of shipping PoEs (i.e. anchoring, grounding, movement underway, oils spills, and discharge) and their potential impacts on aquatic ecosystems. This advisory report is intended as a communication tool and provides general guidance to inform more detailed risk assessments related to shipping in Canadian waters.

This Science Advisory Report summarises the outcomes of the national peer review meeting held October 1-3, 2013 in Ottawa titled 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

- This science advisory report is intended to provide general advice on how shipping activities may potentially impact the marine and freshwater environment. The Pathways of Effects (PoE) models included in this report are general and simply illustrate linkages that may not be universally applicable. The potential impacts of shipping can be widespread or localised, and may be chronic or acute.
- The PoE components included in this report (i.e., movement underway, discharge, oil spills, anchoring, and grounding) are independent of time and space constraints, and do not address the frequency, likelihood of occurrence, nor magnitude of potential impact(s) on an ecosystem. In no way should this advice or the PoE components be interpreted as risk or threat assessments.
- A suite of stressors resulting from movement underway (i.e. water mixing, substrate disturbance, noise emissions, icebreaking, strikes, wake, and light emission) may lead to changes in habitat, community structure, and the health (fitness) and survival (mortality) of organisms.
- Operational and incidental or accidental discharges associated with shipping can result in the discharge of aquatic invasive species, debris, oils and other aquatic or atmospheric contaminants, and nutrients (e.g., via grey water, sewage). Such discharges can result in changes to habitat, community structure, the fitness, mortality, and/or function of aquatic organisms.
- Oil spills are one of the most damaging events in the aquatic environment, affecting multiple species and habitats. Spill recovery measures are often largely ineffective and long-term chronic ecosystem effects often result.
- Anchoring may create vertical obstructions in the water column and/or may result in substantial changes to the substrate composition and structure resulting from crushing and/or sediment re-suspension. Changes to the substrate as a result of anchoring may alter benthic habitats and may result in sub-lethal impacts or an increase in mortality of benthic organisms.
- Vessel grounding can affect the substrate, habitat, and benthic organisms. Groundings are more likely near shore when approaching ports but could also occur offshore (e.g., where shallow seamounts or ridges are located).
- The environmental effects of shipping are multifaceted, with potential consequences on all structures and components of the ecosystem. As such, PoE models can be strongly inter-related leading to linkages at various levels. However, given many of the linkages have limited documentation of varying quality and quantity, predicting the PoEs can be challenging. The PoE components included in this report were developed based on the current state of knowledge with many potential linkages remaining to be thoroughly quantified.

INTRODUCTION

This report provides advice on the potential impacts of shipping on Canadian aquatic ecosystems including oceans and large lakes and rivers (e.g., Great Lakes, Mackenzie River, Saint Lawrence River, etc.). The Pathways of Effects (PoE) components in this report are general and the linkages illustrated may not be universally applicable. It will be necessary to

consider more specific endpoints when conducting risk assessments for specific areas or situations.

In this report, 'shipping' is considered to include all vessels, regardless of type and size. 'Shipping activities' include the normal operations of vessels (i.e. movement underway, discharge, anchoring) as well as potential accidents (i.e. oil spills, grounding). The variability among potential impacts and different types and/or sizes of vessels is not included in this report.

The potential impacts of shipping included in this report are considered independently of time and space; they are intended to simply illustrate possible linkages among activities and impacts. Further, the PoEs in this report do not consider the frequency, likelihood, nor magnitude of the potential impacts on an ecosystem. Such estimates can only be determined through a thorough risk assessment. More area-based/regionally-specific assessments should consider any applicable regulations that may mitigate potential impacts.

ASSESSMENT

General PoEs for five shipping activities are presented below in the order they were discussed at the peer review meeting (i.e., movement underway, discharge, oil spills, anchoring, and grounding). The content of this advisory report is derived from the discussions at the peer review meeting, the expert opinion of participants who attended this advisory process, and a literature review.

The general PoEs for shipping activities are as follows:

1. Movement Underway

Pathway of Effects

Transiting ships create a wake and propeller wash as they move through the water column, emit a variety of sounds and intensities of light into the surrounding environment, and can interact with ice and organisms (if present).

State of Knowledge of Stressor-Effect Linkages

The wake and propeller wash of moving vessels can affect community composition and abundance, particularly of benthic organisms. Wake and propeller wash can also change the physical structure of shorelines and bottom habitats through sediment disturbance and/or erosion, which may potentially render them unsuitable for use by organisms. These stressors can also cause water mixing that may change the physical characteristics of the local environment (e.g., temperature, turbidity, nutrients).

Vessel strikes to aquatic organisms by direct collision with the hull and/or the propeller blades are known to cause injury and mortality, particularly large baleen whales. Strikes are most likely to occur where there are aggregations of species in time and space that are intersected by concentrated vessel traffic; the probability of a vessel strike being lethal increases with vessel speed.

Icebreaking by vessels can change the structure of the ice platform, may alter the behaviour of organisms, separate young from their mothers, and affect over-ice mobility of certain species (e.g., caribou, polar bears). Disturbance to ice habitat may also displace organisms or cause entrapments, injury, or mortality of ice-associated species. Impacts on pack ice can be temporary (i.e., opened channel refreezes behind the vessel); however impacts on landfast or multi-year ice tend to be chronic (persist) for the duration of the ice-cover season.

Shipping is the dominant source of manmade broadband noise in aquatic environments and the lower frequencies can radiate over large distances and depths. In higher traffic areas, this type of noise is considered by the scientific community as a continuous (chronic) sound and modifies the natural acoustic characteristics of benthic and pelagic habitats (i.e., soundscapes). A variety of organisms use naturally-produced sounds in their vital activities which can be compromised by vessel noise and may lead to effects on organism health and viability.

Artificial light from ships at night can be detected by organisms in and above the water column and could result in altered behaviour, disorientation, and/or the displacement of species from their habitats, particularly marine mammals and birds.

Knowledge Gaps

- The acute and chronic effects of noise on fish and invertebrates (including commercial species).
- The potential for organisms to become habituated (ignore) or adapt (alter behaviour) to vessel noise, and to what degree they can be habituated or adapt to a new source.
- The chronic and acute effects of vessel noise on sensitive ecosystem components.
- Characterization of noise from more modern ship designs; previous prediction models may be outdated.
- The potential ecological consequences of increased icebreaking in the Arctic, particularly on ice-associated fauna and the timing and/or extent of polynyas.
- The impacts related to repeated vessel presence through an area.
- The potential changes to organism health as a result of vertical mixing.

2. Discharge

Pathway of Effects

There are a variety of discharges associated with shipping, including operational discharges (e.g., ballast water, waste disposal, air emissions, sewage/grey water, cargo sweepings and bilge water) and incidental or accidental discharges (e.g., lost cargo, hull fouling, oil and other contaminants). Catastrophic oil spills are acute pollution incidents resulting in the accidental discharge of substantial amounts of oil that can be considered chronic in impact are considered in section (3) below.

State of Knowledge of Stressor-Effect Linkages

Discharges may impact aquatic ecosystems via the release of aquatic invasive species, debris, oils, aerial and aquatic contaminants, greenhouses gases, black carbon, and nutrients/introduction of biological material (e.g., via grey water, sewage).

Although regulations related to ballast water exchange have been shown to be an effective mitigation strategy, shipping is considered a key pathway for the introduction of aquatic invasive species through ballast water or hull fouling. Aquatic invasive species may alter ecosystem structure and function as a result of changes to species abundance and distribution through predation or competition for resources (e.g., food, habitat).

Shipping debris can impact the fitness and mortality of organisms if it is ingested (particularly plastics), by crushing (bottom habitats or species), or by causing entanglements of species such as marine mammals, sea turtles, or birds. In some cases, debris may create new habitat and be colonized by species (e.g., invertebrates).

Contaminants can be released into the aquatic environment from shipping (e.g., chronic leaks) and can have varying impacts on the fitness of organisms or can cause mortality depending on the level of toxicity. Air emissions are another potential source of contaminants and may alter air quality from local to wide geographic distances, and can form black carbon deposits which can accelerate localized ice melting.

Shipping discharges can also include nutrients which may reduce water quality, may create algal blooms, and may potentially impact the health of organisms. In some cases, nutrient discharges can result in an increase in local productivity.

Knowledge Gaps

- Quantification of oil leakage and other unintentional discharges from vessels.
- Quantification of the relationship between the number of aquatic invasive species released into a new environment and the probability of population establishment.

3. Oil Spills

Pathway of Effects

Oil may be released into the environment through accidental or incidental discharges as covered above in (2) or it may enter the environment in a catastrophic event as a result of a shipping accident (e.g., collision, grounding). This section addresses the potential impacts of a catastrophic oil spill.

State of Knowledge of Stressor-Effect Linkages

Oil spills are possibly one of the most damaging events that can occur in the aquatic environment, and will likely impact any species or habitat interacting with the spill. Oil spills have the potential for long-term chronic negative impacts to the ecosystem depending on the volume and extent of the spill.

Oil spills can substantially impact organism fitness if individuals are exposed internally through ingestion or respiration. Similarly, organism health is impacted through external exposure such as oiling of feathers or fur, and smothering. Both internal and external exposure routes can ultimately result in mortality and changes to ecosystem structure and function.

Oil spills can also impact habitats through smothering and changes to the sediment composition as a result of increased hydrocarbons and other chemicals, which can render the habitat toxic or unusable to organisms.

Knowledge Gaps

- The dynamics of oil in ice-covered conditions; particularly in quantities that would be considered a ‘spill’.
- The fate and behaviour of different oils in water and sediment under various conditions.
- Monitoring and establishment of baseline levels in order to determine pre-spill status of aquatic ecosystems.
- The chronic impacts of oil on various organisms.
- The potential effects of dispersants and other clean-up responses.

4. Anchoring

Pathway of Effects

A vessel at anchor may create vertical obstructions in the water column or changes to the substrate through physical abrasion or sediment re-suspension. Anchored vessels may also increase the emission of noise and light in the area where they are located (see previous section on discharge) or introduce aquatic invasive species into the environment.

State of Knowledge of Stressor-Effect Linkages

Vertical obstructions as a result of the anchor chain are particularly a concern for marine mammals and large fish (e.g., sharks). Many ships anchored in the same coastal area (e.g., while awaiting a berth at port) can create a "forest" of such obstructions. These vertical obstructions may result in injuries through collisions, altered behavior, and potentially displacement. Anchors and chains may also act as a vector for aquatic invasive species by providing habitat for these organisms.

If a ship at anchor is not secure, wind and wave action may cause the ship to move, dragging the anchor and/or anchor chain along the bottom. This activity may cause injury or mortality to organisms in the path of the anchor, particularly static organisms (e.g., vegetation, corals, sponges). The substrate itself can also be altered by a moving anchor and/or anchor chain which may destroy benthic habitat or render it unsuitable for use by benthic organisms. In addition, sediments may be suspended in the water column which can reduce organism health through smothering. A loss of habitat generally leads to reduced abundance and often to declines in species abundance and/or composition.

Knowledge Gaps

- In general, the potential impacts of anchoring are less studied than other aspects of shipping.
- Quantification of the effects of anchoring depending on size and length of anchors and chains, spacing between anchored vessels, and the repetition rate and interval between multiple anchorings).
- Further understanding of anchoring/anchor chains as a vector for aquatic invasive species.
- The effects of anchoring on benthic fauna and flora, and the means to mitigate these impacts.

5. Grounding

Pathway of Effects

Vessel grounding occurs when the hull makes contact with the bottom, which usually creates a substrate disturbance and/or the release of materials (including aquatic invasive species) from the vessel into the environment.

State of Knowledge of Stressor-Effect Linkages

Grounding most commonly results in substrate alteration (e.g., crushing or gouging of the bottom), damage or displacement of biota, and/or sediment re-suspension. However, in some cases, sunken vessels can provide additional or new habitat. Singly and in aggregate the combination of these effects can lead to changes in species abundance and/or composition.

Accidental discharges (e.g., fuel, oil, ballast, contaminants) or cargo spills as a result of grounding have the potential to impact the environment (see previous section on discharge).

Knowledge Gaps

- Impacts of the release of cargo and contaminants from sunken or grounded vessels.

Sources of Uncertainty

Information on the environmental effects of shipping is multifaceted, with potential consequences on virtually all structures and components of the ecosystem. As such, PoE models for shipping activities can be strongly inter-related. Although this report is focused on the potential linkages between shipping and the aquatic environment, there may also be impacts to components of terrestrial ecosystems.

Many of the linkages have limited documentation with which to predict potential effects. Consequently, the PoE models were developed based on the current state of knowledge with many potential linkages still requiring thorough documentation. Regardless of the body of evidence available, any potential linkage that could be substantiated by literature or expert opinion was included in the PoE overviews.

Although not considered in this report, there are undoubtedly cumulative effects resulting from multiple pressures that should be considered when implementing an ecosystem-approach to management.

Specific gaps in knowledge for each PoE component are identified in the previous sections.

CONCLUSIONS

This science advisory report provides general advice on how shipping activities may potentially impact the marine and freshwater environment. The potential impacts of shipping can be widespread or localised, and may be chronic or acute. The environmental effects of shipping are multifaceted, with potential consequences on all structures and components of the ecosystem. As such, PoE models can be strongly inter-related leading to linkages at various levels. However, given many of the linkages have documentation of varying quality and quantity, predicting the PoEs can be challenging. The PoE components included in this report were developed based on the current state of knowledge with many potential linkages remaining to be thoroughly quantified.

The PoE components included in this report (i.e., movement underway, discharge, oil spills, anchoring, and grounding) were considered independent of time and space constraints, and do not address the frequency, likelihood of occurrence, nor magnitude of potential impact(s) on an ecosystem. In no way should this advice be interpreted as a risk or threat assessment.

OTHER CONSIDERATIONS

There are domestic and international regulations that could provide guidance when conducting shipping risk assessments or when considering mitigation measures for potential impacts. In general, regulations will differ according to the size of the vessel, with larger vessels often subject to more stringent regulations than smaller ones.

There are other anthropogenic activities other than those associated with shipping that may impact various aspects of an ecosystem. It is acknowledged that the combination of all of

these activities, along with potential confounding effects from natural drivers, may result in cumulative effects on an ecosystem.

It is noted that there may be impacts associated with rescue and spill response activities (e.g., salvaging, deployment of skimmers and booms, etc.) that have not been covered in this report but that may have environmental impacts.

Although fishing gears may be deployed when a vessel is operating, the potential impacts of fishing gears on an ecosystem are not included in this report. Two science advisory processes were previously conducted to discuss the potential impacts of fishing gears on ecosystem components.

The titles of these meetings were:

(i) Impacts of trawl gears and scallop dredges on benthic habitats, populations, and communities (2006) and

(ii) Potential impacts of fishing gears (excluding mobile bottom-contacting gears) on marine habitats and communities (2010).

Similarly, a science advisory process to review the scientific information on the potential impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals was conducted in 2004.

SOURCES OF INFORMATION

This Science Advisory Report is from the national peer review process on Science Advice for Pathways of Effects for Marine Shipping held October 1-3, 2013 in Ottawa. The Proceedings from this meeting is available on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule.

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