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Research Document 2012/154

Newfoundland and Labrador Region

Document de recherche 2012/154

Région de Terre-Neuve et Labrador

A draft framework to quantify and cumulate risks of impacts from large development projects for marine mammal populations: A case study using shipping associated with the Mary River Iron Mine project

Cadre provisoire visant à quantifier et cumuler les risques de répercussions des grands projets de développement sur les populations de mammifères marins : étude de cas prenant pour exemple le transport maritime lié associé au projet de mine de fer de la rivière Mary

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

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Correct citation for this publication:

Lawson, J.W. and Lesage, V. 2013. A draft framework to quantify and cumulate risks of impacts from large development projects for marine mammal populations: A case study using shipping associated with the Mary River Iron Mine project. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/154 iv + 22 p.

ABSTRACT

The abundance and distribution of marine mammal populations is influenced by a variety of factors, including ice structure and presence, resource availability, reproductive status, predator distribution, or more generally, mortality risks. While mortality incorporates natural and anthropogenic sources, for most managed populations the latter source has focussed on population losses due to hunting effort. Recently, anthropogenically-related, non-harvest removals are being considered for managed marine mammal populations, such as the role of climate change as a population-level factor that might reduce carrying capacity and/or increase mortality. More "proximal" negative consequences to marine mammal populations could arise from industrial activities and associated noise, vessel strikes, or introduction of new predators or other invasive species. There is currently no national approach as to how impacts of marine development projects should be evaluated by Fisheries and Oceans Canada (DFO) Science, which may lead to a perception of inconsistency and unfairness in the reviews. Given the recent increase in the number of large marine development projects requiring DFO reviews of potential impacts, there is a pressing need to develop a national approach to impact assessment, threshold setting, and monitoring standards, and to develop guidelines for the industry outlining the information needed for adequate impact assessment, and proposed methodologies for evaluating and mitigating impacts. Here, we outline a general framework to quantify and cumulate risks of impacts on marine mammal populations associated with marine development project, and which has been used to assess marine mammal risks from exposure to vessel noise or ship strikes associated with the Mary River Iron Mine project. We believe this framework could be extended to encompass other types of anthropogenic activities, and would benefit from further expert review to refine threshold values of impact and to determine if it is sufficiently precautionary.

RÉSUMÉ

L'abondance et la répartition des populations de mammifères marins sont influencés par divers facteurs, notamment la présence de glace et la structure de celle-ci, la disponibilité des ressources, l'état reproducteur, la répartition des prédateurs et, de manière plus générale, les risques de mortalité. Alors que la mortalité inclut les décès d'origine naturelle et anthropique, pour la plupart des populations gérées, la mortalité d'origine anthropique comprend essentiellement des pertes de population découlant de l'effort de chasse. Récemment, on se penche sur les prélèvements d'ordre anthropique, mais non liés à la pêche dans le cadre de la gestion des populations de mammifères marins. On étudie entre autres le rôle des changements climatiques en tant que facteur susceptible de réduire la capacité de support et/ou de hausser le taux de mortalité des populations. Des conséquences négatives plus « proximales » pour les populations de mammifères marins pourraient découler des activités industrielles et du bruit qu'elles entraînent, des collisions avec les navires ou de l'introduction de nouveaux prédateurs et d'autres espèces envahissantes. Il n'existe actuellement aucune approche nationale quant à la façon dont les répercussions des projets de développement maritime doivent être évaluées par le Secteur des Sciences de Pêches et Océans Canada (MPO). Cette situation pourrait donner lieu à la perception d'un manque de cohérence et de partialité dans les examens. Étant donné la hausse récente du nombre de grands projets de développement maritime nécessitant la réalisation d'examens des répercussions potentielles par le MPO, il presse d'élaborer une démarche nationale pour l'évaluation de ces conséquences et d’établir des seuils d’effets et des normes de surveillance. De plus, il est urgent de créer des lignes directrices pour l'industrie quant aux renseignements nécessaires à une évaluation adéquate des incidences de leurs projets et aux méthodes proposées pour l'évaluation et l'atténuation des répercussions. Nous présentons ici un cadre général visant à quantifier et à cumuler les risques de répercussions des projets de développement maritime sur les populations de mammifères marins. Ce cadre est utilisé pour évaluer les risques liés aux collisions de bateaux et à l'exposition au bruit des navires issus du projet de mine de fer de la rivière Mary. Nous croyons que le cadre pourrait être élargi de façon à englober les autres types d'activités anthropiques. Nous pensons également que la tenue d'un examen supplémentaire mené par des experts visant à revoir les valeurs des seuils liés aux répercussions et à déterminer si le cadre s'avère suffisamment préventif serait bénéfique à ce dernier.

INTRODUCTION

The abundance and distribution of marine mammal populations is influenced by a variety of factors, including ice structure and presence, resource availability, reproductive status, predator distribution, or more generally, mortality risks. While mortality incorporates natural and anthropogenic sources, for most managed populations the latter source has focussed on population losses due to hunting effort.

Recently, anthropogenically-related, non-harvest removals are being considered for managed marine mammal populations, such as the role of climate change as a population-level factor that might reduce carrying capacity and/or increase mortality. More "proximal" negative consequences to marine mammal populations could arise from human activities that cause displacement, severe injuries or death, including marine development projects (MDP) and associated noise, vessel strikes, or introduction of new predators or other invasive species.

The number of MDP requiring review of draft and final environmental assessments and formal Science Responses has increased dramatically, and this trend is expected to continue or be exacerbated in the future. There is also a need for the industry, and a desire by Federal and Provincial/Territorial governments to speed up the regulatory review process for MDP. However, there is currently no national approach as to how impacts should be evaluated by Fisheries and Oceans Canada (DFO) Science, which may lead to a perception of inconsistency and unfairness in the reviews. In this context, there is a pressing need to develop a national approach to impact assessment, threshold setting, and monitoring standards, and to develop a set of guidelines for the industry outlining the information needed for adequate impact assessment, and proposed methodologies for evaluating and mitigating impacts.

In this document, we outline a general framework to quantify and cumulate risks of impacts on marine mammal populations associated with MDP. This approach has been used to assess marine mammal risks from exposure to vessel noise or ship strikes associated with the Mary River Iron Mine project (DFO 2012b, c, d), which will involve unprecedented levels of marine shipping and icebreaking in the Arctic. This framework could be extended to encompass other types of anthropogenic activities, such as seismic exploration. We will seek further feedback on ways to improve the framework, to make the approach more widely applicable in terms of the sources of impact and context, and to ensure that it is sufficiently precautionary.

RATIONALE AND APPROACH

In terms of the potential effects of noise exposure and collisions with vessels, much research has been directed towards marine mammals in the last thirty years, although in the Arctic a large portion of the noise response studies have dealt with non-shipping sounds from seismic and construction activities (Mansfield 1983; Reeves 1992; Richardson 1997; DFO 2004; Weilgart 2007). Ship strike studies have been focussed largely in areas where endangered large whale populations are at risk from commercial shipping (see, for example Jensen and Silber 2003; Panigada et al. 2006; Douglas et al. 2008; Pace 2011).

SHIPPING NOISE EXPOSURE

Commercial vessels cruising in open water emit relatively loud, low-frequency underwater noise especially in the 10 to 500 Hz (NRC 2003; Hildebrand 2009; McKenna et al. 2012). Propeller cavitation, the loud hiss created by the formation and collapse of bubbles in the water, has been identified as the primary source of noise from commercial ships (Ross 1976; Renilson 2009). However, noise output from cavitation remains less than the sounds caused by displacement of ice and engine noise by ice breakers (Thiele 1988; Thiele et al. 1990; Arctic Council 2009).

Exposure to ship-related noise or overlap of distribution with shipping route may or may not lead to mortality or other negative effects on marine mammal health, behaviour, and habitat use. Various factors affect the degree of reaction to noise and vessel traffic (Richardson et al. 1995), and effects can be categorized as follows:

1) the noise may be too weak to be heard, i.e., below ambient level, or below the hearing threshold at the specific frequencies where anthropogenic noise is emitted;
2) the noise may mask differing components of incoming communication calls or interfere with calls or environmental sounds useful to some vital functions such as foraging, navigation, or finding mates and reproduction;
3) the noise may be audible but not result in negative behavioural or physiological response;
4) the noise may be audible, and result in a negative response that can range from temporary alertness, to active avoidance of the area for short to prolonged period of time;
5) the noise can result in a progressive decrease in response as the animals habituate to it, or alternatively;
6) the noise can cause repeated and persistent disturbance or physiological stress if the animal remains in the area because of its importance for vital functions or because of a lack of alternate location to fulfil essential biological needs; and,
7) the noise, if it is very strong, can lead to temporary or permanent hearing damage.

The noise emitted by large commercial ships is unlikely to lead to hearing damage in marine mammals, at least following brief or infrequent exposures. However, ship noise overlaps with much of the sound frequency range used by many cetacean species, especially those which call at lower frequencies such as bowhead, right, blue, fin, and humpback whales (Watkins et al. 1987; Berchok et al. 2006; Mouy et al. 2009; Tervo et al. 2011; Hatch et al. 2012), and can cause signal masking (Erbe 1997; Weilgart 2007; Clark et al. 2009; Castellote et al. 2012). Masking occurs when increased levels of background noise reduce an animal's ability to detect relevant sounds (Clark et al. 2009), such as those used to detect prey, navigate, or communicate with conspecifics.

The absence of alternate habitat for potentially displaced marine mammals might result in temporary or persistent physiological (stress) and behavioural responses for a portion of the individuals exposed to these anthropogenic noise sources. Behavioural changes can include habitat abandonment, disruption of foraging activity, suppression or alteration of vocalization, and other effects, and lead to chronic stress and population-level impacts (Richardson et al. 1995; Nowacek et al. 2007; Weilgart 2007; Joint Working Group on Vessel Strikes and Acoustic Impacts 2012; Rolland et al. 2012). Until recently, it was not known if exposure to shipping noise could result in physiological responses that may lead to significant consequences for individuals or populations. Rolland et al. (2012) showed that reduced ship traffic in the Bay of Fundy following the terrorist events of 11 Sept. 2001, resulted in a 6 dB decrease (a halving of sound levels) in underwater noise, with a significant reduction at low frequencies. This noise reduction was associated with decreased levels of stress-related faecal hormone metabolites in local North Atlantic right whales (*Eubalaena glacialis*). This is evidence that exposure to low-frequency ship noise may be associated with chronic stress in whales, and has implications for all baleen whales in heavy ship traffic areas (Rolland et al. 2012).

Behavioural changes in response to the same signal source can range from subtle to vigorous and can vary dramatically among species and individuals, making it challenging to broadly characterize the impacts of shipping noise on marine mammal species (Ellison et al. 2012).

There are also currently no data available to assess with any degree of certainty the proportion of the exposed marine mammals for which effects of noise from shipping would lead to detrimental impacts on health, reproduction, or survival. One step towards estimating the significance of impacts is to determine the number of potential individual-exposures relative to total population size. Another is to determine whether specific segments of the population are likely to be impacted more than others (e.g., calving females).

For noise sources that are continuous, negative responses ranging from alertness, to minor to strong avoidance of the area ensonified is presumed to begin at received sound pressure levels (SPL) of 120 dB re 1 μPa rms for cetaceans. Levels eliciting similar reactions from pinnipeds are highly variable but encompass values for cetaceans (Southall et al. 2007), and thus, are assumed to be similar to those of cetaceans for the present exercise.

The number of individual-exposures per year can be estimated by multiplying the zone of influence (ZOI) around a ship track (i.e., with noise levels in excess of 120 dB re 1 μPa rms) by local marine mammal density estimates, and then correcting for marine mammal seasonal use of the area, and number of ship transits during period of overlap with each species. The ZOI around a ship corresponding to a SPL of 120 dB re 1 μPa is estimated ideally using sound propagation models developed specifically for the noise source being evaluated, or alternatively, a similar type of source and environment. Note that individual-exposures are not equivalent to the number of individuals exposed; it is assumed that the individual-exposure metric includes the likely repeated exposure of individuals to ships over a given period.

SHIP STRIKE

Similar to noise-related interactions, the number of individual whales or pinnipeds potentially struck by transiting vessels can be estimated. One theoretical and analytical basis for vessel-whale-strike-risk estimation is a mathematical area-interaction model (Tregenza et al. 2000; Tregenza 2001). The number of potential marine mammal encounters with a transiting ship can be estimated by multiplying the volume of water swept by a vessel at any one instant by the total transit length which contains these mammals, then by local density estimates and species body size, and then correcting for seasonal use of the area by the species, and the number of ship transits expected during periods of overlap between these mammals and the ships. The model uses the individual as a horizontal linear target at random orientation to the carrier's line of travel. This model assumes the following:

1) The vulnerable parts of the cetacean or pinniped can be represented as a line of the same length as the animal. The marine mammal as a horizontal linear target at random orientation to the vessel's line of travel will present an average "target size" of 0.64 times the mammal's length (N. Tregenza, pers. comm.);
2) The marine mammal's orientation relative to the direction of travel of vessel is random;
3) The marine mammal does not tend to move into or out of the vessel's path, actively or passively;
4) The vessel route has an overall density of marine mammals that is the same as some larger area from which a survey has produced a density estimate; and,
5) Vessels do not avoid marine mammals.

The model uses the marine mammal as a horizontal linear target at random orientation to the carrier's line of travel, and which would present an average "target size" of 0.64 $\times$ the mammal's length. From the length of the vessel transit a "collision area" can then be derived: $(W + 0.64L) \times D/1{,}000\ km^2$.

With the number of vessel transits per year and the density of whales at risk, the annual number of marine mammal encounters that could result in a ship strike, along a vessel's path in the modelled area would equal $(W + 0.64L) \times D/1{,}000 \times Y \times T \times P$, where

W = hull width (or damaging width in case of ice-breaking) of the vessel, in metres

L = animal's length, in metres

D = distance travelled by the vessel within the population survey area, in kilometres

Y = yearly number of transits

T = percentage of time the animal is near surface

P = population density – mean number of marine mammals per square kilometre in a survey area which ideally includes the vessel transit route

ASSESSING CUMULATIVE RISKS OF IMPACTS

Environmental Impact Assessments often do not attempt to quantify impact levels using potential exposures, but instead employ a posteriori verification to determine whether a given threshold for population decline is exceeded during the life of a project. Not only are these thresholds set arbitrarily in most cases, but for almost all species the threshold decline values are so small that it is difficult to determine whether they have been exceeded or not, even using the best study designs (see review in Taylor et al. 2007). As a result, project effects on marine mammal populations are not easily detected and if such changes are detected, it may be when project activities have resulted in dramatic population declines. Such a strategy for impact assessment is not in keeping with the precautionary approach.

The proposed approach to assessing significance of impacts is based, like the majority of previous assessments, on a combination of impacts likelihood and severity if they were to occur. However, in contrast with previous assessments, quantitative criteria are used here to determine the significance of impacts. These criteria are largely based on those put forward by Wood et al. (2012) in their assessment of the PG&E offshore 3D seismic survey project, as well as using some of the standards developed for assessing impacts of marine seismic research conducted by the U.S. Geological Survey or funded by the National Science Foundation (2011).

The likelihood of impacts depends on the biological context for the species of concern and the intensity of effects in terms of scale, magnitude, and persistence. The biological context includes several aspects, such as population size, seasonal densities or total number of individuals present in the affected region, conservation status, habitat use for critical functions, and known susceptibility of the species or population segment to the stressor. The overall significance of impacts is examined after mitigation measures that have a demonstrated effect on reducing the number of individual exposures and/or impacts have been implemented.

Severity of effects is rated according to four intensity components: the geographical extent of effects, their magnitude, duration, and frequency (Table 1). Severity also depends on whether exposure results in injuries, mortality, or in behavioural changes (categories that are equivalent to NMFS' statutory threshold Level A and Level B harassment, respectively; e.g., NMFS 2004). Ship strikes would be considered as Level A harassment while exposure to shipping noise, assuming it would not cause injuries such as permanent hearing damage, would enter the second category. The number of individual marine mammal exposures to ship strikes and noise levels that are susceptible to induce behavioural changes are calculated using the methodology presented in the previous section, and are used to define the magnitude of impacts.

Marine development projects that include components with prolonged or repeated activities, such as shipping, will likely produce multiple exposures for each individual marine mammal in the area. While the use of summation of individual-exposures certainly overvalues the number of individuals affected by anthropogenic activities, this measure can provide insights into the severity of impacts and is also precautionary. However, quantities against which number of individual exposures need to be compared should differ depending on whether injury/mortality (ship strike) or behavioural changes (noise exposure) are expected. Impacts could be examined relative to the residual allowable harm in the case of ship strikes, and relative to population size or regional population size in the case of broader-scale noise-related effects.

The residual allowable harm (AH_{res}) represents the allowable harm for a stock or population once harvest mortality has been incorporated into management measures. In fact, total allowable harm (AH_{total}) is supposed to include all human-induced mortality, and accounts for population size, uncertainty associated with density estimates, and a population's conservation status (Wade 1998). AH_{total} can be estimated either using a method referred to as the Potential Biological Removal (PBR; Wade 1998) for stocks where there are insufficient data to make a full assessment (Hammill and Stenson 2007), or using population modelling results for stocks that are considered more "data-rich". The PBR method produces a threshold abundance value; if human-induced removals are below this accepted threshold, then the population is likely to increase towards, or to maintain itself at or above, its Maximum Net Productivity Level (MNPL). I.e., the population size at which the combined size and growth rate of the population produces the largest number of animals per year (largest productivity). PBR is estimated as:

$$PBR = 0.5 \times R_{max} \times N_{min} \times F_r$$

N_{min} is the 20^{th} percentile of the log-normal distribution of the estimated population size, equivalent to the lower 60% confidence limit. R_{max} is the maximum rate of increase for the population. When unknown for a particular population, R_{max} is set at a default value of 0.04 for cetaceans, and 0.12 for pinnipeds. It is halved ($0.5 \times R_{max}$) to simulate the effect of logistic density-dependent growth. F_r is a recovery factor with values set to reduce the base PBR value to improve the probability of recovery. Depending on a population's status, F_r is set at 0.1 for a critically-low population status, 0.5 for a depleted status (<MNPL), and 1.0 for a healthy status (Wade and Angliss 1997).

In the case of noise-related impacts, the number of individual exposures can be compared to a total, or if there are concerns for site fidelity and desertion of a specific area, to a minimum local population size (see below).

The criteria used by Wood et al. (2012) to rate overall significance of impacts for stressors that might cause mortality or injuries are largely inspired from the U.S. *Marine Mammal Protection Act* (MMPA) and its numerical threshold for the magnitude of mortality relative to PBR. Accordingly, it is concluded that stressors causing mortality less than 10% of AH_{res} for a marine mammal stock should be considered "not of concern". Magnitude of potential effects should increase from low to moderate to high as a percentage of stock AH_{res} likely affected by the activity increases from 10-50%, 50-100%, to more than 100% of AH_{res}.

While a number of individual marine mammal exposures below the residual AH is an easily-calculated risk for a population suffering from ship strikes, the definition of magnitude for noise effects is not as straightforward and predominantly subjective in most studies. In this process, the conservation status, and proportion of the total (or local) population likely exposed to noise magnitudes liable to cause behavioural changes are examined in combination with temporal and spatial extent of the exposure to determine overall severity of effects (Tables 1 and 2). Severity is then examined in combination with the likelihood of effects to determine their overall significance for an exposed population (Table 4).

Determining the likelihood of effects, i.e., whether the potential effects are plausible or just speculative, is a chiefly subjective step as it is based largely on professional judgment. Wood and co-authors (2012) define a "high likelihood effect" as those that could arise from reasonable or demonstrated mechanisms, and for which mechanisms have a greater than 50% chance of occurring. Effects with “medium likelihood” are described as possible or probable, those with “low likelihood” are described as unlikely and those with very low likelihood are described as very unlikely (Table 3).

Table 1. Descriptors for quantifying temporal and spatial extent of effects (adapted from Wood et al. 2012).

Geographical Extent		
	Extra-regional	Effects likely extend outside regional boundaries, but within Canadian waters
	Regional	Effects likely extend outside of project boundary to regional setting
	Local	Effects likely to be limited within project boundary
Magnitude (Mortality/Injury/Level 'A' Harassment)		
	High	>100% of stock population AH_{res} affected
	Moderate	50−100% of stock population AH_{res} affected
	Low	10−50% of stock population AH_{res} affected
	Negligible	<10% of stock population AH_{res} affected
Magnitude (Disturbance/Level 'B' Harassment)		
	High	>25% of regional non-listed species minimum population/>2.5% of SARA- or COSEWIC-listed regional minimum population
	Moderate	15−25% of regional non-listed species minimum population/1.5−2.5% of SARA- or COSEWIC-listed regional minimum population
	Low	5−15% of regional non-listed species minimum population/1 SARA- or COSEWIC-listed species, and <1.25% of SARA- or COSEWIC-listed regional minimum population
	Negligible	<5% of regional non-listed minimum population/<1% SARA- or COSEWIC-listed animals
Duration		
	Long-term	Refers to more permanent effects that may last for more than 3 months (a season) to years, and from which the affected animals or resource never revert back to a “normal” condition
	Moderate-term	Refers to a temporary effect that lasts 1 to 3 months, and affected animals or resource may revert back to a “normal” condition
	Short-term	Refers to a temporary effect that lasts from days to 1 month, and affected animals or resource revert back to a “normal” condition
Frequency		
	Continuous	Effects continuous
	Intermittent	Effects intermittent, but repeated
	Isolated	Effects confined to one or two periods

Table 2. Severity rating matrix methodology (adapted from Wood et al. 2012).

Magnitude	Extent	Temporal duration/frequency	Severity rating
High	Regional	Any	High
Moderate	Regional	Any except short-term/isolated	
High	Local	Any	
Any	Extra-Regional	Any	
Moderate	Regional	Short-term/isolated	Medium
Moderate	Local	Any	
Low	Regional	Any	
Low	Local	Any except short-term/isolated	
Low	Local	Short-term/intermittent or isolated	Low
Negligible	Any	Any	Negligible

Table 3. Likelihood rating matrix methodology (adapted from Wood et al. 2012).

Likelihood	Definition
High	Effects that could arise from reasonable or demonstrated mechanisms and that these mechanisms have a >50% chance of occurrence
Medium	Effects are possible or probable
Low	Effects are unlikely
Very Low	Effects are very unlikely

Table 4. Impact rating matrix methodology (adapted from Wood et al. 2012).

Severity Rating	Likelihood of Occurrence	Impact Rating
High	High or Medium	High
High	Low	Moderate
Medium	High or Medium	Moderate
Low	High	Moderate
High	Very Low	Low
Low	Medium	Low
Low	Low	Low
Medium	Low or Very Low	Low
Low	Very Low	Negligible
Negligible	Any	Negligible

Other aspects of the assessment of overall significance of impacts requires that we account for effects that occur during a sensitive or critical part of the year, within potentially important habitat, and whether the life history strategies of the population is sufficient to adjust to short- or long-term change in the quality of their habitat. Acknowledgement of the uncertainty in estimating the various parameters involved in this assessment, e.g., predicted animal densities and behavioural response, is also of importance.

CASE STUDY USING MARY RIVER MINE PROJECT

A number of threats have been identified that could negatively impact the marine environment as a result of shipping year-round through Hudson Bay, Foxe Basin, and Hudson Strait for the Mary River and other large-scale marine development projects (e.g., Megannety 2011; Reeves et al. 2011; Stewart et al. 2011).

Using the Mary River Mine project as an example, we outline a process to assess shipping-related anthropogenic impacts on marine mammal populations. We do so by describing the biological characteristics of relevant marine mammal populations, then provide quantified assessments for noise exposure and collision risks, and an overall assessment of shipping-related risk for these populations.

SPECIES-SPECIFIC BIOLOGICAL CHARACTERISTICS AFFECTING IMPACTS

Current distribution data available for bowhead whales (Figure 1 in Ferguson et al. 2010), Northern Hudson Bay narwhal (Richard 1991; Westdal et al. 2010), and beluga whales (e.g., Finley et al. 1982; Luque and Ferguson 2010) indicate that shipping routes for large-scale mining developments such as Mary River, Hopes Advance, and Raglan mines in the Arctic largely overlap or will overlap with areas of core use for these species, especially during winter when open water areas and ice leads provide the only habitat available. Also, there is a relatively high abundance of ringed seals and walrus along this particular shipping route (DFO 2012d).

Susceptibility to noise

In the only well-documented case of beluga and narwhal reaction to icebreakers in a relatively noise-pristine area (Finley et al. 1990), beluga whales exhibited strong overt reactions to an approaching icebreaker still 35 to 50 km away, displacement distances of up to 80 km, and return times to the disturbed area of nearly two days. Reactions and return times were less for narwhal than beluga, as the former exhibited no visible panic reaction to the approaching ship but rather a “freeze” response and returned to the disturbed area within 1 to 2 days. These strong reactions of narwhals and belugas at long ranges are unique in the literature of vessel noise responses by marine mammals, possibly due to the whales being trapped in open water along the ice-edge as the ships approached, their lack of previous experience with ships, and good sound propagation conditions.

Similarly, bowhead whales exhibited avoidance responses to a drill site with high levels of associated icebreaker activity at ranges up to 25 km (Brewer et al. 1993), as well as a drilling operation with relatively little associated icebreaking. These whales may have responded to several features of these sites, such as the icebreaker or drilling noise or the ice characteristics, so further icebreaker studies are warranted (see Richardson et al. 1995).

Mine proponents have concluded that underwater shipping and construction sounds loud enough to elicit disturbance to pinnipeds could propagate many kilometres from the sources. While this would not impact walrus and seals hauled out, these are places where these animals aggregate in water before and after hauling out and may be impacted by such anthropogenic underwater sound levels – not to mention the visual impacts that might arise from the nearby passage of such large vessels since walrus are known to react negatively to unusual things on their visual horizons (R. Stewart, pers. comm.).

Recently, there is evidence that exposure to low-frequency ship noise may be associated with chronic stress in whales, and this will have implications for all baleen whales, and possibly other species of marine mammals, in heavy ship traffic areas (Rolland et al. 2012), such as bowhead whales in Hudson Strait when large ore carriers or other large vessels operate year-round.

Susceptibility to ship strike

The true number of marine mammals that suffer ship strikes is likely higher than reported in the literature since most ship strikes go undocumented (e.g., Allison et al. 1991; Kraus et al. 2005; Williams et al. 2011), or it is not possible to ascertain whether a marine mammal was struck by a ship antemortem in some cases. This ship strike underestimation is attributed largely to the fact that most whales are negatively buoyant and sink rather than wash ashore or float (Allison et al. 1991); this is particularly true for mid- and small-size odontocetes, and cetaceans that sink in at least 850 m of water (Allison et al. 1991). The proportion of struck whales that strand has been estimated to range from <5% to 17% of true mortality, suggesting ship strikes could be at least 10 times higher than the number reported (Williams et al. 2011).

There is currently little data to evaluate the susceptibility of bowhead whales to ship strikes. Vessel strike and fishing gear trauma have been documented in bowhead, but at a much lower rate than in right whales (Reeves et al. 2011) likely due to the lower amount of vessel traffic and fishing activities in the Arctic, the low capacity to detect whales or collisions from ships or icebreakers, or as a result of prevailing light and weather conditions. However, like the North Atlantic right whale, the bowhead whale has certain characteristics (e.g., relatively slow swimming speed, group size, a mid-water, or surface feeding strategy, and positive buoyancy due to high body fat content), that probably make it as vulnerable to ship strikes as right whales. For example, right whales appear to exhibit a small degree of escape response to avoid a ship strike, perhaps only in the closing seconds (Kite-Powell et al. 2007). Silber (unpubl. rep.) suggested that bowhead whales could be expected to exhibit similar behaviour. They appear to concentrate a considerable proportion of their diving activity at shallow depths (Pomerleau et al.

2011), where the drag and propeller suction effects from passing ships could make them vulnerable to collisions (Silber et al. 2010).

While most ship strike reports pertain to baleen whales, records of odontocete cetaceans such as beluga (a single animal in Cook Inlet, AK; Neilson et al. 2012), pilot (*Globicephala* spp.), killer (*Orcinus orca*), and various species of beaked whales, do appear in ship strike databases as well (Silber unpubl. rep.; DFO 2012d) – although in many cases the exact cause of death was undetermined or it was not known if these smaller whales were struck antemortem. Smaller cetaceans may be less vulnerable to collisions with large vessels than larger whales such as bowheads, given that their greater overall manoeuvrability relative to large whales, echolocation capabilities, and social behaviour (groups of individuals travelling together) may enhance vessel detection and escape – assuming such escape is not constrained by local conditions. However, there are several reports of collisions between small odontocetes and smaller vessels (e.g., van Waerebeek et al. 2007), indicating evasive actions are not always successful for these smaller cetaceans.

Pinnipeds facing shipping traffic in open water are expected to respond similarly to odontocetes and avoid collisions in most cases, given their manoeuvrability. However, their auditory discrimination and thus, their capacity to accurately detect and evade approaching vessels might be less than odontocetes. Ice-breaking represents a serious threat for pinniped species using pack-ice to give birth, such as ringed, grey, hooded or harp seals, as at least the pups can be crushed with little opportunity to escape (DFO, unpubl. data).

IMPACTS CAUSED BY EXPOSURE TO SHIPPING NOISE

Many of the marine mammals that would be exposed to the rising levels of Arctic shipping are currently industrially-naïve populations. Therefore, reactions from beluga and narwhal from Hudson Strait, Foxe Basin, and Hudson Bay might be expected to be similar to those documented in the high Arctic. Tempo of vessel passage could also be a particular concern for Arctic marine mammals considering that the time elapsed between two ore carriers transits associated with the Mary River Project will be less than two days, and thus shorter than the time documented for beluga to return to normal activity in the high Arctic. And the high rate of shipping could result in significant structural and temporal changes in sea ice cover.

The ZOI for cetaceans around an ice-breaking ore carrier corresponding to a SPL of 120 dB re 1 μPa is unknown, but for the Mary River Project was estimated to be 8 km based on an icebreaker study conducted elsewhere. This is likely an underestimate as it is based on underwater noise levels (20−1000 Hz) from an icebreaker (*Robert Lemeur*) that was not in ice-breaking mode; the ZOI was nearly doubled when breaking ice (Richardson et al. 1995, Figure 6.12). This is confirmed by the proponent's own evaluation where larger radii are assumed for most species. The total ZOI of an ore carrier transiting through Hudson Strait was then obtained as the product between the length of Hudson Strait (1,000 km) and ZOI, i.e., 8 km x 1,000 km = 8,000 km^2. Again, the total ZOI is an underestimate as it doesn't take into account transits through Foxe Basin or to the eastern mouth of Hudson Strait where bowhead whale concentrations are observed during winter (M.-P. Heide-Jorgensen, pers. comm.).

The number of individual whales potentially affected by the shipping component of the Mary River Project was estimated by multiplying the ZOI around the ship track by local cetacean density estimates, while correcting for seasonal use and number of ship transits during the period of overlap between these mammals and the ships (see Table 5). The latter was estimated to be approximately seven months per year, i.e., between November and May, inclusively, based on sightings data, peak hunting period, and satellite telemetry, for narwhal (for a review, see Richard 1991; 120213-08MN053-final EIS-App.8A-2; Westdal et al. 2010), beluga whales (Hammill and Lesage 2009; Luque and Ferguson 2010; Bailleul et al. 2012), and bowhead whales (Ferguson et al. 2010). Given that all species except narwhal occur throughout the year in Hudson Strait, although in smaller numbers during summer, and that cape-size ore carriers will transit Hudson Strait twelve months a year, the period used for calculating interactions with shipping activity each year is considered minimal, and operational impact risks are likely underestimated.

Density estimates necessary to calculate the number of exposed individuals were obtained specifically from Hudson Strait marine mammal aerial surveys and thus, represent composites of several populations in cases (e.g., beluga) where they are known to share the same wintering area (Hudson Strait). Also, density estimates ignore the gregarious nature of many of the marine mammal species being considered, and the overlap of the proposed shipping route with areas of core use rather than of “average” use. Gregariousness increases the risk that if one animal is impacted, many will be. The use of an average density rather than above-average densities in the calculation, also likely negatively biases the estimate of exposed individuals.

Estimates of the number of individual whales potentially affected by the shipping component of the Mary River well exceed population size in the case of narwhal and Ungava Bay and Eastern Hudson Bay beluga, while they represent 14 to 130% of the bowhead whale population, and 33 to 75% of the western Hudson Bay beluga population (Table 6). Marine mammal survey design was inadequate to determine densities for ringed seal and walrus and thus, estimates of potentially harassed individuals need to be interpreted with caution. These calculations do not take into account individuals potentially exposed in other seasons, or in other areas during winter. Note also that for beluga and pinnipeds, numbers are uncorrected for whales missed during surveys, adding more negative bias.

Odontocetes have a reduced hearing sensitivity at low frequencies compared to mysticetes (Ketten 1994; Southall et al. 2007). However, avoidance reactions of beluga to an icebreaker more than 35 km away (Finley et al. 1990) indicate that an 8 km ZOI for odontocetes remains conservative as a threshold to estimate the number of individuals aware of the presence of an ore carrier, and the number of those potentially harassed by shipping noise. Given that the proposed shipping route overlaps with areas of core use, rather than “average” areas for cetacean species, it is also expected that above-average marine mammal densities will be encountered in areas of overlap with shipping. Therefore, the use of average densities of mammals to assess exposure to noise and collision risks further negatively biasing impact estimates.

It is difficult to predict the proportion of animals for which exposure to shipping noise will result in negative responses of sufficient magnitude to cause detrimental effects on reproduction, survival, and eventually, in a reduced availability to hunters. However, with the current level of hunting exploitation for some of the beluga populations exposed to shipping, noise-related impacts on reproduction or survival of even a few individuals could lead to negative impacts on population recovery (see above), and may jeopardize management objectives.

Considering that four of the six species likely affected by shipping in the Arctic have special conservation status under COSEWIC, and that more than 2.5% of the total population is likely to be exposed to potential disturbance, severity of impact would be considered high using the above-proposed criteria, regardless of the extent (regional or local), duration, or frequency of effects (Tables 1 and 2). The percentage of the populations potentially affected would be even higher if we were to use the U.S. approach as they considered regional minimum population rather than total population size to assess the proportion of the population potentially disturbed by the Mary River Project. Given the existing literature on reaction of beluga, narwhal, and bowhead whale to icebreakers or other industrial activity, the likelihood of effects is considered possible or probable, resulting in an overall impact rating of the Mary River Projects as “High” for marine mammals (Table 4).

IMPACTS CAUSED BY SHIP STRIKE

A more direct source of negative interaction between marine mammals and large-scale shipping would be the mortality or severe injury resulting from ship strikes. In the case of the Mary River Project, beluga, narwhal, and bowhead whales, as well as ringed seals in birthing lairs or basking on ice, and bearded seals are the species most likely to be exposed to potential ship strikes, although walruses might be encountered too. Small odontocetes such as narwhal and beluga are expected to be less vulnerable to ship strikes than bowhead whales, although the baseline data for ship strikes on small- and medium-sized whales is less clear (see above).

Table 5. Estimated number of individuals exposed to shipping noise levels ≥120 dB re 1 µPa on the Mary River Project shipping route.

Species	Source[d]	Density estimate (n per km^{-2})	Corrected density (n per km^{-2})	N exposed per transit	N exposed per period (7 mo × 17 transits/mo)
Northern Hudson Bay narwhal	Final EIS (Vol. 8)	0.006−0.008	0.019−0.025[a]	152−200	18,088−23,800
EC-WG bowhead	Koski et al. 2006 Final EIS (Vol. 8)	0.002−0.02	0.002−0.02	16−160	1,940−19,040
Beluga	Finley et al. 1982	0.047	N	376	44,744
	Final EIS (Vol. 8)	0.02−0.03	N	160−240	19,040−28,560
Ringed seals	Final EIS (Vol. 8)	0.002−0.003	N	16−24	1,904−2,856[c]
Bearded seals	Final EIS (Vol. 8)	0.006-0.007	N	48−56	5,712−6,664[c]
Walruses	Final EIS (Vol. 8)	0.001−0.002	N	8−16	952−1,904[c]

[a] Using a 0.31 correction factor for perception and availability biases (Westdal 2008).
[b] Using a 0.18 correction factor for perception and availability biases (Koski et al. 2006).
[c] This assumes that SPLs potentially eliciting reactions in pinnipeds are similar to those documented in cetaceans.
[d] Density estimates extracted from the final EIS are from Hudson Strait during April and June, i.e., surveys corresponding most closely to the period of use of these wintering grounds for cetaceans.

Table 6. Estimates of total (AH_{total}) and residual allowable harm (AH_{res}) for harvested cetaceans in the Mary River Project area.

Species	Estimate	Fully-corrected	CV	95% CI	COSEWIC Status	N_{min}	Recovery Factor	AH_{total}	Annual Harvest	AH_{res}	Source
Northern Hudson Bay narwhal	12,485	yes	0.26	7,515−20,743	Special Concern	10,040	1.0	157[a]	~100[b]	~57	DFO 2012a
EC-WG bowhead	6,344	no		3,119−12,906	Special Concern	3,119	0.1	6	6	0	IWC 2008
	14,400	yes	0.61	4,810−43,105		8,991	0.1	18	6	12	Dueck 2008
Western Hudson Bay beluga	63,122	yes	0.20		Special Concern	53,563	1.0	908	~550-650[c]	~360−460	Richard 2008; DFO, unpubl. data; Doniol-Valcroze et al. 2012
Eastern Hudson Bay beluga	3,030	yes		1,256−6,535	Endangered	-	-	50[d]	> 50	0	Doniol-Valcroze et al. 2012
Ungava Bay beluga	32	yes		0−94	Endangered	12	0.1	0	0	0	Doniol-Valcroze and Hammill 2012

[a] Total allowable landed catch is presented which is the AH_{total} corrected for hunt losses (1.28; Richard 2008).
[b] Updated survey estimates have yet to be considered by co-managers in Nunavut and Nunavik. If subsistence harvest levels increase it would reduce the AH_{res}.
[c] Including a harvest of 300−400 individuals in Nunavut, approximately 200 in Nunavik, and a 30% struck and loss value.
[d] To achieve a 50% probability of increase in stock abundance, as determined from Bayesian modelling of population trajectory.

The ship strike modelling suggests that Project-related shipping traffic could encounter and possibly collide with up to five bowhead whale, 49 narwhal, and 14 beluga (Table 7). A comparison of these numbers to the AH_{res} indicate that the threshold set for maintaining conservation objectives may be exceeded without taking noise impacts into account for each cetacean population except western Hudson Bay beluga and Northern Hudson Bay narwhal, making severity of impacts medium or high in magnitude. As discussed above, values for beluga and narwhal most probably represent a worst-case scenario as it is likely that individual whales will be able to move out of the path of these relatively slow-moving vessels, unless they are constrained by ice or bathymetry. However, and as pointed out for noise-related impacts, these calculations are for winter and Hudson Strait exclusively and so, ignore risks in other areas and seasons.

Table 7. Ship strike model assumptions and strike estimates for bowhead, narwhal, and beluga whales within the Mary River shipping route through Hudson Strait.

Species	Body Length (m)	Fraction of Time at Surface (%)	Population Density (n/km^2)	Modelled N at Risk of Ship Strike/Year
Northern Hudson Bay narwhal	4.25	25	0.019	49
EC-WG Bowhead whales	15.00	20	0.002	5
Beluga	3.75	23	0.006	14

Potential impacts on pinniped populations are difficult to assess given the lack of information on population size. In the absence of abundance data, a precautionary approach was adopted in assessing impacts of the Mary River Project on pinnipeds; effects were deemed significant, and we recommended that every effort be made to reduce them to a minimum.

Again, using the methodology proposed here for assessing magnitude of impacts related to mortality/severe injury, the Project was rated as potentially causing high magnitude effects on marine mammal populations based on risks of ship strikes alone.

Given the assumptions used in the ship strike model, and the generalized nature of the model itself, there are a number of sources of error in the produced estimates. We have reduced the magnitude of strike estimates by using the lowest estimate of mammal density in the study area, a body length size which is not the maximum for the species, and only surface interval time rather than the additional time the mammal might be at a position within a few metres of the surface (and hence shallower than an ore carrier's keel). We have also assumed ships encounter whales as single individuals rather than groups (or that the loss of an adult does not affect the survival of a dependent offspring or relative). Variations in the local densities of the species have probably the largest impact on the magnitude of the ship strike risk estimate. For example, ore carriers crossing migratory pathways, feeding aggregations or other areas of core use would have a higher risk of striking an animal. If individuals have an avoidance reaction to approaching carriers, and are able to move away without being constrained by ice or bathymetry, then ore carrier passage would entail lower risks. The whales' flukes and caudal peduncles may present a lower risk of mortality if struck than the body, making the "risk length" shorter than assumed in this exercise. On the other hand, the time interval during which the animals are just below surface will also be a source of risk as the animal will not be visible to facilitate avoidance manoeuvres by the vessel. And finally, in open water the displacement of an animal by the water flow around the large bow (pressure wave) may reduce the injury risk in this part of the vessel. However, there is a whale strike modelling study which used towed ship and whale models to detail laminar flow around large vessels; its authors concluded that in some cases, whales beside or below the stern of the large vessel could be drawn towards the stern and propellers by a low-pressure water flow effect (Silber et al. 2010).

A factor lowering ship strike risk for these large vessels would be ship speed. Vanderlaan and Taggart (2007) analysed worldwide records of vessels striking large whales to examine the influence of vessel speed. The probability of a lethal injury (P_{lethal}) to a large whale when struck by a vessel at speeds from 8.6 to 15 knots was 0.21 to 0.79. Above 15 knots, P_{lethal} asymptotically approached 1.0 indicating an almost certainty of whale death following a ship strike. The probability of a lethal injury dropped below 0.5 at 11.8 knots, although this proportion becomes highly variable at lower ship speeds. If these relationships hold true for Arctic whales and the Mary River Project ore carriers, then a ship strike during the open-water season will likely be fatal. It is anticipated that during the open-water period (August to December) ore carrying vessels will travel at a higher average speed, while during the ice-covered period (January to August) vessel speed will likely be reduced. During the winter the vessels will be moving more slowly, so it is anticipated that a ship strike will be less probable, and a whale struck by an ore carrier would be less likely to be killed or seriously harmed. This assumes that movements of these whales are not constrained when in ice.

As well, the ship strike model does not address the potential influence of social, aggregative behaviour for species such as beluga and narwhal. For these two species, in particular, if they form large groups, an "average" density would underestimate the possible vulnerability of "clumped" whales to ship strike. Unless the risk of ship strike was lower in groups due to improved detection of the vessels by the whales, or easier detection and avoidance of the whale groups by the vessels.

DISCUSSION

The proposed impact assessment framework can help quantify risks of impacts of marine development projects (MDP) on marine mammal populations and the activities relying on stock sustainability, including aboriginal harvest. This approach has the benefit of alleviating some of the constraints from more quantitative approaches, although it does rely on a minimum amount of hard data, especially for marine mammal densities, distribution, and minimum regional or total population size. In our case study, the scarcity of data on pinnipeds has impaired our capacity to assess impacts for the case study, and a precautionary approach was adopted.

One remarkable finding from using the proposed approach is that the number of individual-exposures for noise-related effects will likely be high for any MDP that involves regular transits by large vessels through areas populated by marine mammals. In the context of any other large-scale upcoming mining development in the Arctic, it is unlikely that conclusions as to the scope of marine mammal exposures to shipping noise will be much different from those for the Mary River Project using the proposed impact criteria. These were developed by Wood et al. (2012) to assess oil and gas development effects, and specifically seismic surveys, which are generally more localized and short-term than chronic shipping over basin-wide scales. There might be a need to examine more closely the degree of similarity in expected effects on marine mammals from seismic activities versus shipping and to revise the proposed criteria accordingly. The Marine Strategy Framework Directive (Tasker et al. 2010) of the European Union (EU) specifies indicators to assess the health of marine habitats with respect to low frequency, continuous sound, such as from shipping, and these threshold levels (e.g., 100 dB re 1 μPa rms) would likely be lower than those cited in Wood et al. In other words, the area where noise levels from ships would exceed thresholds potentially causing behavioural changes would be even larger than for the Mary River Project using the EU criteria and thus, would result in higher numbers of individual-exposures. Other countries, including Canada, ascribe qualitative guidelines for anthropogenic sound levels in critical habitats of acoustically sensitive species, but do not yet specify thresholds or limits of acceptable change.

An important advantage, the proposed framework also allows calculation of cumulative effects of MDPs. For instance, consequences from additional transits as a result of expansion of an existing MDP or new projects can be assessed quantitatively, as they can be expressed as a percentage increase in individual-exposures or risks of shipping-related impacts.

As formulated, the ship strike model is unable to account for evasive movements by marine mammals or the role of vessel speed when estimating collision risks. One approach to account for vessel speed would be to model the range of speeds in the study area, and create risks categories that would be applied as multiplicative factors in the model. For instance, if vessel speed is greater than 15 knots, where the ship strike literature suggests that the risk to a marine mammal of severe injury or mortality is high (Vanderlaan and Taggart 2007), the multiplier would be 1.0. If vessels speeds are less than 10 knots, and the risk of severe injury and mortality is reduced by 30%, then the multiplier could be 0.70. Similar “risk multipliers” could be derived for different marine mammal species depending on their measured or perceived ability to avoid being struck by a vessel. Finally, the model could have risk multiplier factors for contexts where ship strike risks are augmented or reduced by ice conditions or bathymetry.

Given the assumptions used in the ship strike model, and the generalized nature of the model itself, there are a number of sources of error in the ship strike estimates. The process employed in this paper minimizes the estimated risk by selectively biasing the errors in the most favourable (fewer strikes) direction. For instance, DFO:

1) used the lowest estimate of whale density in the study area (although higher densities due to aggregations may be equally valid, since in this case using an average density value increases estimate error);
2) used a body length size which is not the maximum for the species, although for bowhead at least, a large number of whales in west Hudson Strait are thought to be mature females;
3) used only surface interval time rather than the additional time a whale might be in a position within 20 metres of the surface (e.g., within strike distance of the large cargo vessels); and,
4) assumed ships encounter marine mammals as single individuals rather than groups (or that the loss of an adult does not affect the survival of a dependent offspring or relative).

Variations in the local densities of the marine mammal species of interest have probably the largest impact on the magnitude of the ship strike risk estimate. For example, ore carriers crossing migratory pathways or feeding aggregations would have a higher risk of striking an animal.

Further, if whales have an avoidance reaction to approaching carriers – and are able to move away without being constrained by ice or bathymetry, then ore carrier passage would entail lower risks of ship strike. The whales’ flukes and caudal peduncles may present a lower risk of mortality if struck than the body, making the “risk length” shorter than assumed in this exercise, although a tail-strike could still inflict a lethal swimming disability. Relatively smaller pinnipeds such as bearded and ringed seals may present very small strike targets.

On the other hand, the time interval during which whales are just below surface will be an additional source of risk as the marine mammal will not be visible to facilitate avoidance manoeuvres by the vessel.

Finally, given the slow speed of the ore carrier in the winter period, it is possible that the risk of ship strike during this period will be less, and the injuries to bowhead, narwhal, and beluga whales will be less severe. However, even if the occurrence of ship-struck animals was restricted to the open-water period, the minimum number of modelled strikes would still not be zero for any species in the study area.

We conclude there are currently no effectual (or well-described) mitigation measures proposed currently for any Arctic shipping operation to monitor interactions or avoid/reduce potential impacts of shipping on marine mammals (for some recommendations to address this, see below). Therefore, a portion of several already-vulnerable populations would have an uncertain degree of risk of ship strike, and would be exposed to noise with potential consequences to their health, behaviour, and habitat use. Both of these sources of risk, if realized, could impact population trajectories, and should be considered during estimation of annual harvest allocations. In this paper we investigate ways of characterising and partitioning these two sources of non-harvest mortality (ship strikes and displacement by ship noise). While the number of potential ship strikes are easily interpreted relative to residual allowable harm, there is a need to determine a mechanism to estimate potential realized loss of animals as a result of noise-related impacts so that they are taken into account in non-harvest mortality.

We have outlined a framework to quantify and cumulate the risks to marine mammals from exposure to vessel noise or ship strikes, and have illustrated how this approach was used in the context of the Mary River Project impact assessment. The model we have used to assess impacts of shipping noise could be made more robust, and it could be extended to encompass other types of anthropogenic noise sources, including pulsed or non-pulsed sources. With further development, such as through incorporation of variance in model inputs, we feel this review framework could be more widely applicable in terms of the sources of impact (for example, impacts of tourism-related disturbance) and context (for example, better applicability to pinnipeds) (Fig. 1). One of the goals of this exercise was to highlight the requirement to incorporate non-hunt sources of injury and mortality into management practices in a quantified and comparable way. New, large-scale marine projects in the north and elsewhere in Canada have to be assessed in the context of their potential additions to the overall anthropogenic impacts on marine mammal populations, and how such impacts should be incorporated into precautionary population management by DFO.

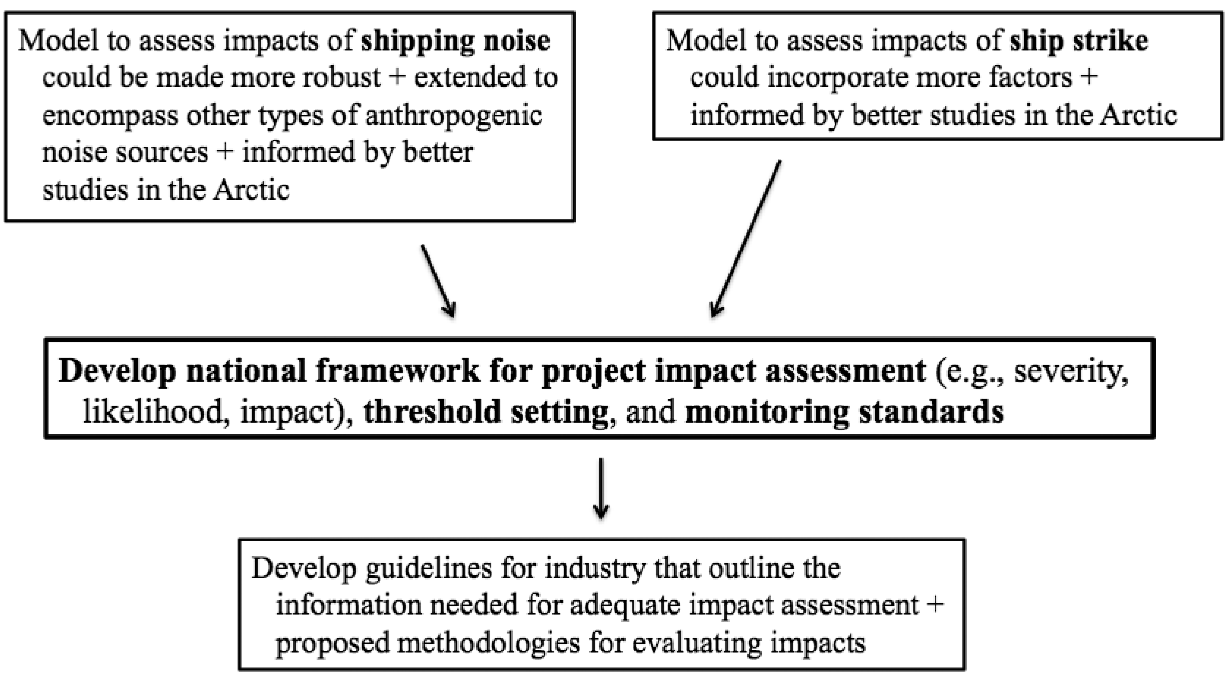

Figure 1. Schematic illustrating how the proposed framework could be extended to encompass other types of anthropogenic activities, and undergo further expert examination to refine the framework and its threshold values, and develop guidelines for industry.

RECOMMENDATIONS FOR SHIPPING IMPACT MITIGATION

Considering that whales can exhibit strong negative reactions to ships and icebreakers typically while vessels are still several, or even tens of kilometres, distant (e.g., Finley et al. 1990; Pirotta et al. 2012), such reactions will go undetected and undocumented with most current surveillance programmes. This, combined with the limited capacity to manoeuvre large ice-breaking ore carriers, ice breakers or cargo vessels over short distances to avoid marine mammal aggregations or whales in leads (Weinrich et al. 2010)[1], suggests it is highly unlikely that any proposed surveillance monitoring will achieve its goals of providing information on negative interaction and facilitating a means to avoid such interactions. For all these reasons, we conclude there are currently no effectual (or well-described) processes proposed currently for any Arctic shipping operation to monitor interactions or avoid/reduce potential impacts of shipping on marine mammals.

Commercial shipping operations should undertake the following mitigation measures aimed at reducing the potential for interaction with marine mammals in the Arctic:

- give careful consideration to reducing shipping rates during winter months when interactions with marine mammals may be the most problematic, such as in the eastern Arctic;
- give careful consideration to alternate shipping routes to avoid areas that are identified as having higher marine mammal concentrations;
- reduce vessel speed as a mitigation measure, which might lower collision risks in open water (Vanderlaan and Taggart 2007; Silber et al. 2010) and to some extent reduce vessel noise output – although this may be ineffective in reducing or eliminating the risk for whales in polynya or dense pack ice;
- project proponents should be required to submit clearly-defined monitoring and mitigation plans that will collect baseline information necessary to later determine if there have been project-related changes in marine mammal behaviour or residence;
- ensure that data produced by surveillance monitoring programmes are analysed rigorously by experienced analysts to maximize their effectiveness in providing baseline information and for detecting potential effects of shipping activities on marine mammals. Data from any long-term monitoring program should be treated with the same rigor;
- more environmental data are needed to assess the impact of ship tracks through pack ice and resulting implications for marine mammals. As pack ice is dynamic in its movements, ship tracks may affect a broad area. The higher frequency of occurrence, timing and location of ice breaking along ship tracks such as will occur during the Mary River Project mean that project-related ice breakage differs from natural (undisturbed) ice dynamic processes. As a result, there will be biological implications including changes to the epontic (sub-ice) community that have not been evaluated;
- DFO could develop “minimum information” standards for project proponents based on existing guidelines from Habitat that are updated with the assistance of Science. Official guidelines to industrial proponents could be developed from these syntheses; and,
- Impact assessment methodology must be more comprehensive by being extended to cumulative effects as there is a critical need to address those in a more formal and systematic way.

[1] For most commercial ships, turning radii and distances over which speed can be reduced are large; reducing the effectiveness of dedicated observers, especially when an animal is sighted at close range (e.g., <450 m).

Table 8. Proposed approaches, ranging from relatively simple (but less effective) to comprehensive (more effective, but more complicated and costly to enact), as means to monitor and mitigate potential impacts of ore shipping on marine mammals during the Mary River Project.

Monitoring Approach	Complexity to Enact	Cost to Enact
Trained Marine Mammal Observers (MMOs) aboard ore carriers, with expert analysis of data	Low	Low
Acoustic recorders within, near, and far from ore carrier route, with expert analysis of data	Moderate	Moderate
On-going replicate aerial survey coverage of the ore carrier route, with expert analysis of data	High	High
Autonomous Underwater Vehicles (AUVs) flown ahead of ore carriers early in shipping programme, with expert analysis of data	High	High

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