Marine Pollution Bulletin 135 (2018) 290–302

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic

Matthew K. Pine[a,b,*], David E. Hannay[c], Stephen J. Insley[a,b], William D. Halliday[a,b], Francis Juanes[a]

[a] Department of Biology, University of Victoria, Victoria, BC, Canada
[b] Wildlife Conservation Society Canada, Whitehorse, Yukon, Canada
[c] JASCO Applied Sciences, Victoria, BC, Canada

ARTICLE INFO

Keywords:
Underwater sound
Noise
Shipping
Marine mammal
Fish
Listening space
Masking

ABSTRACT

Vessel slowdown may be an alternative mitigation option in regions where re-routing shipping corridors to avoid important marine mammal habitat is not possible. We investigated the potential relief in masking in marine mammals and fish from a 10 knot speed reduction of container and cruise ships. The mitigation effect from slower vessels was not equal between ambient sound conditions, species or vessel-type. Under quiet ambient conditions, a speed reduction from 25 to 15 knots resulted in smaller listening space reductions by 16–23%, 10–18%, 1–2%, 5–8% and 8% respectively for belugas, bowheads, bearded seals, ringed seals, and fish, depending on vessel-type. However, under noisy conditions, those savings were between 9 and 19% more, depending on the species. This was due to the differences in species' hearing sensitivities and the low ambient sound levels measured in the study region. Vessel slowdown could be an effective mitigation strategy for reducing masking.

1. Introduction

The presence of sea ice has effectively preserved the western Canadian Arctic's natural underwater soundscape by making it inaccessible to most commercial shipping. Shipping through the Northwest Passage in the western Canadian Arctic has remained low, although shipping in the Arctic has recently increased (Eguíluz et al., 2016). Marine life in the western Canadian Arctic has therefore had little exposure to the anthropogenic noise pollution commonly reported at lower latitudes (Ahonen et al., 2017; Bazile Kinda et al., 2013; Insley et al., 2017; Roth et al., 2012)). However, the presence of sea ice has been declining (a trend that is expected to continue) and thus the region is becoming more accessible for shipping (Eguíluz et al., 2016; Miller and Ruiz, 2014; Ware et al., 2016). As a consequence, increased interactions with marine mammals and fish are expected (Laidre et al., 2015; Wilson et al., 2017).

Vessel transits through the Northwest Passage have increased from four per year in the 1980s to 20–30 between 2009 and 2013 (NWT, 2015). The vast majority (92%) of these transits occurred through the southern routes (11% of all vessel transits being passenger ships; 1% being container ships), with only 8% of the total traffic transiting north of Banks or Victoria Islands (NWT, 2015). Those numbers are likely to increase as the extent of summer sea-ice continues to decrease (Smith and Stephenson, 2013). Marine fauna in this region will therefore be exposed to increased vessel traffic noise (Moore et al., 2012). There is a growing concern that increased auditory masking from these exposures will lead to adverse ecological effects (Erbe et al., 2016; Slabbekoorn et al., 2010).

Marine mammals and fish use sound for critical life processes, such as communication, foraging, avoiding predators, reproduction, navigating and/or maintaining group cohesion. They are therefore more vulnerable to impacts caused by anthropogenic noise, such as injury, including hearing damage, stress, habitat avoidance, shifts in migration routes and behavioural changes (see reviews from Nowacek et al. (2007); Southall et al. (2007); and Weilgart (2007)). Auditory masking (the interference of a biologically-important signal by an invasive noise source that prevents the receiver from perceiving that signal (Erbe, 2008)) is arguably the most pervasive impact of vessel noise (Erbe et al., 2016). The western Canadian Arctic is important habitat for a number of marine mammal and fish species. Previous research has shown the distribution of marine mammals around the Beaufort Sea to vary and several known core-habitats have been identified (Citta et al., 2015; Harwood et al., 2017; Hauser et al., 2017). Bowhead whales (*Balaena mysticetus*) migrate from the North Pacific and along the

* Corresponding author at: Department of Biology, University of Victoria, Victoria, BC, Canada.
E-mail address: mattpine@uvic.ca (M.K. Pine).

https://doi.org/10.1016/j.marpolbul.2018.07.031
Received 24 June 2018; Received in revised form 9 July 2018; Accepted 10 July 2018

Canadian mainland coastline, forming summer core habitat areas in the western Canadian Arctic (Harwood et al., 2017). Beluga whales (*Delphinapterus leucas*) form several summer core habitat areas, including the Tuktoyaktuk Peninsula, Amundsen Gulf near Ulukhaktok and Viscount-Melville Sound (for males) (Hauser et al., 2014). While ringed and bearded seals (*Pusa hispida*, *Erignathus barbatus*, respectively) occur throughout the eastern Beaufort Sea region, ringed seals show high concentrations near the Hamlet of Ulukhaktok (Hartwig, 2009; Harwood et al., 2014). A range of fish species also occur, including the polar cod (*Arctogadus glacialis*) and Arctic cod (*Boreogadus saida*) (Hartwig, 2009). Audiograms of marine mammals and fish show that hearing ranges overlap with those of vessel noise, making these animals vulnerable to auditory masking. Vocalisations of these species often occur in the same frequency range as vessel noise (Stafford et al., 2017; Stanley et al., 2017), thereby making them impacted by masking. Vocalisations from bowhead whales vary in complexity and frequency range (Cummings and Holliday, 1987; Stafford et al., 2017; Tervo et al., 2011). Their songs (being reproductive advertisement calls) are complex and broadband, ranging between ~30 Hz and 5 kHz, while their vocalisations for group cohesion, socialising and navigating are simpler and below 500 Hz (Stafford et al., 2017). Beluga whale vocalisations are highly variable, with tonal sounds ranging between 400 Hz and 20 kHz and echolocation clicks ranging between 20 and 160 kHz (Stafford et al., 2017). Bearded seals also emit several different call types below 5 kHz, such as trills, moans, ascents and sweeps (Frouin-Mouy et al., 2016). Ringed seals produce yelps, barks and growls between 50 and 4 kHz (Mizuguchi et al., 2016), and arctic cod calls have been described as short (approximately 289 ms) grunts consisting of 6–12 pulses under 250 Hz (Riera et al., 2018). Vessel noise is very broadband (McKenna et al., 2012), ranging in frequencies below 10 Hz to over 60 kHz, depending on the type of vessel. Much of the noise from vessels is below 5 kHz (Simard et al., 2016) and so overlaps substantially with the primary vocalisations of the marine mammals and fish within the western Canadian Arctic. Since the source levels of large commercial vessels can be high (> 170 dB re 1 μPa @ 1 m (Veirs et al., 2016)), and because this noise can propagate over large distances, vessel noise can potentially mask vocalisations over large areas.

An effective method for assessing auditory masking in marine mammals and fish is to estimate the change in radius, due to increased anthropogenic masking noise levels, of the volume of ocean centred on a vocalising animal, within which communication with conspecifics is possible (Clark et al., 2009; Janik, 2000; Stanley et al., 2017). This volume of ocean is referred to as the animal's communication space. The sonar equation is used to quantify communication space, but its applicability depends on understanding the receiver's auditory filters and the call structure at its source. Detection thresholds and critical ratios, signal gains and call source levels across multiple spectra – all of which change between species and contexts (Erbe et al., 2016) – are also required inputs for the sonar equation (Clark et al., 2009). Unfortunately, these inputs are often unknown or are highly variable for many species, particularly for mysticete cetaceans (baleen whales). The calculation of communication space is therefore difficult as several assumptions or approximations are often required.

An alternative approach is to consider masking from the perspective of the listener. Increased masking noise, such as due to a passing vessel, will reduce the volume of ocean within which the listener can detect biologically-important sounds (Barber et al., 2010; Matthews et al., 2016). This volume is referred to as the listening space, and differs from communication space in that it is not focussed on the vocalising animal but rather an animal that is listening for any biologically-important signal. Marine mammals and fish listen for changes in background sounds to detect approaching predators/danger, to find prey and to locate mates for breeding (Au and Hastings, 2008; Bradbury and Vehrencamp, 2000; Clark, 1990). For example, mysticetes, including bowhead whales, sing to attract mates (Payne and McVay, 1971; Tervo et al., 2011), odontocete cetaceans vocalise to maintain group cohesion, socialise, find prey and to solicit aid when in danger (Castellote et al., 2014), and fish vocalise during spawning (Slabbekoorn et al., 2010). Changes to the size of the listening space, due to a passing vessel can be calculated without knowledge of several of the parameters required to calculate communication space. The relative amount of listening space reduction requires knowledge of the frequency-dependent propagation loss of the call, the change in masking noise levels and the species' audiogram (Barber et al., 2010; Matthews et al., 2016). Thus, this method can serve as a potentially efficient technique that can either replace (when species-specific data are unknown) or supplement generalised communication space assessments (Matthews et al., 2016).

The issue of masking has been widely discussed and recognised, with the International Maritime Organisation (IMO) adopting guidelines to reduce underwater noise from commercial ships (IMO, 2014) and the marine industry trialling mitigation strategies to reduce noise effects on sensitive marine life (Chion et al., 2017; Constantine et al., 2015; POAL, 2015; POV, 2017). Management of marine shipping has been discussed in an Arctic context by the Arctic Council (Arctic Council, 2015), with modification of vessel operations through areas of high marine mammal densities and vessel slowdowns being suggested as possible measures to mitigate vessel noise effects (Arctic Council, 2015; Chion et al., 2017; Huntington et al., 2015). Vessel slowdown is becoming increasingly attractive in areas where re-routing shipping corridors is not possible, particularly as it can also reduce the risk of ship strike (Chion et al., 2017; Constantine et al., 2015). Furthermore, slowing vessels reduces emitted noise levels and consequently decreases masking for marine mammals and fish (Putland et al., 2017). These management strategies will become more important over the next 30 years as the number of vessels, particularly container vessels and cruise ships, transiting the Northwest Passage increases. It is important to understand the effectiveness of slowing vessels for reducing masking. We investigated the potential relief in masking from a 10 knot speed reduction (from their normal operating speed of 25 knots) for container and cruise ships (given their expected increases in the Northwest Passage in future years), under varying ambient sound conditions. The potential benefit of vessel slowdown within the western Canadian Arctic is demonstrated and quantified by assessing the percentage change in listening space of marine mammals and fish.

2. Methods and materials

2.1. Study areas

Noise levels produced by container and cruise ships were predicted for an unmitigated (baseline) speed of 25 knots and a mitigated speed of 15 knots (15 knots was selected as being more realistic than 10 knots, and is not being considered for legislation). The ships were simulated passing through four sub-areas of the western Canadian Arctic (together referred to as the study region) via the Northwest Passage (Fig. 1). The sub-areas (referred to as the Mainland, Ulukhuktok (Ulu), Prince of Wales Strait (PWS), and Viscount-Melville Sound (VMS)) were selected based on current knowledge of core-use areas for bowhead whales and beluga whales and known aggregation areas for bearded and ringed seals (Citta et al., 2015; Harwood et al., 2017; Hauser et al., 2014). Fish species were assumed to occur at all sites, although no information on their distributions was found. The use of multiple sub-sites, with differing bathymetries, sound speed profiles and seafloor compositions, helped demonstrate differences in masking effects due to these parameters. Currently, container and cruise ships make up very few vessel transits through the Amundsen Gulf (NWT, 2015), with no vessels travelling through the PWS or VMS sites (those two sites were selected to investigate a future marine traffic route, and to provide region-wide estimates of masking impact in marine mammals and fish).