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Vessel traffic in the Canadian Arctic: Management solutions for minimizing impacts on whales in a changing northern region

Lauren H. McWhinnie[a,*], William D. Halliday[b,c], Stephen J. Insley[b,c], Casey Hilliard[d], Rosaline R. Canessa[a]

[a] Coastal and Oceans Resource Analysis Laboratory, Department of Geography, University of Victoria, Victoria, BC V8W 3R4, Canada
[b] Wildlife Conservation Society Canada, 189 Titanium Way, Whitehorse, Yukon Territory Y1A 0E9, Canada
[c] Department of Biology, University of Victoria, Victoria, BC V8P 5C2, Canada
[d] Institute for Big Data Analytics, Department of Computer Science, Dalhousie University, Halifax, B3H 4RS, Canada

ABSTRACT

Warming weather conditions in the Arctic are already resulting in changes in both sea ice extent and thickness. The resulting extended 'open water' season has many implications for vessel traffic and marine life. For example, an increase in vessel traffic due to ice-free waters will most likely lead to an increased risk of impact on cetaceans through increased noise pollution, strike risk for some cetacean species, and the possibility of exposure to chemical pollutants. The objective of this study was to pre-empt a predicted increase in vessels by investigating and exploring possible management scenarios, with the aim of mitigating negative impacts on locally important species such as bowhead and beluga whales. Utilizing insights gained from established vessel management schemes in more southerly regions, this paper evaluates the current suite of tools being implemented and their appropriateness for implementation in a more extreme Arctic environment.

1. Introduction

The Arctic Ocean and surrounding seas have had relatively modest levels of shipping in the past, primarily confined to the ice-free or reduced-ice summer season (Huntington, 2009). However, due to a warming climate, sea ice extent and volume is declining in all months of the year (Pongolini et al., 2017), and the continued reduction of ice cover based on predictive models has led many to anticipate a significant impact on shipping activities in the Arctic (Pizzolato et al., 2014). Loss of ice cover, coupled with growth in industrial development in the Arctic (Huntington et al., 2015), is making it an increasingly desirable and accessible destination (Allen, 2014), leading to greater integration with the global economy (Reeves et al., 2012) and a projected increase in vessel traffic (Reeves et al., 2014). The number of vessels which are heading to or from Arctic ports are increasing (Reeves et al., 2012). This includes vessels transiting navigationally constrained waters in both the Northwest Passage (Canadian Arctic) and the Northern Sea Route (Russian Arctic) while serving oil and gas exploration areas in the Beaufort and Chukchi Seas (Allen, 2014; Pongolini et al., 2017) and mining operations in Alaska (Huntington et al., 2015). In addition, cruise ships, military vessels, research boats, and support vessels for resource extraction, are all predicted to become more common in the region (Reeves et al., 2012) due to the longer ice-free season. The bulk of vessel traffic growth will likely occur in the ice-free months of summer and autumn; changes in freeze-up and break-up timing may extend these seasons (Huntington et al., 2015). This may also reduce the need for ice-breaker escorts during these months; however, winter traffic is still expected to require significant icebreaker capacity (Bourbonnais and Lasserre, 2015).

1.1. The side effects of increasing vessel activity

Until very recently the Arctic has functioned as an acoustic refuge from industrial noise (Diachok and Winokur, 1974), and is significantly quieter than non-Arctic areas due to the seasonal presence of sea ice and lack of shipping and industrial activity (Insley et al., 2017). Many studies have speculated that the introduction of anthropogenic noise to the Arctic soundscape, which will inevitably lead to masking and disturbance, could be one of the greatest long-term threats to marine mammals living within this region (Reeves et al., 2012). This is because sound is vital to the survival of marine mammals as they use it to detect and navigate their environment, locate predators and prey and communicate with one another (Huntington et al., 2015; McWhinnie et al., 2017). One of the primary concerns is that an increase in low frequency

* Corresponding author.
E-mail address: lmcwhin@uvic.ca (L.H. McWhinnie).

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chronic noise emitted from vessels may have wide ranging masking effects on cetaceans (McKenna et al., 2012; Erbe et al., 2016; Dunlop, 2016). Whales are also at risk of ship strikes, which is recognized by the International Whaling Commission as a global threat to numerous species of cetaceans because being struck by a vessel may result in significant injury or even mortality (Reimer et al., 2016). In addition, through increased vessel traffic cetaceans may face a greater risk of being exposed to vessel-generated oil spills or marine discharges such as oily water, wastewater, ballast water or garbage (Hoekstra et al., 2002, 2003; Huntington et al., 2015).

1.2. Arctic cetaceans

While climate change has caused dramatic shifts in northern sea ice regimes, the marine mammals that reside in Arctic waters have now attained a globally iconic status as they reflect the dangers of global warming (Meek et al., 2011). Arctic marine mammals are a particular conservation concern for multiple reasons, including their importance in subsistence culture and economy in northern hunting communities and their role within Arctic ecosystem functions (Reeves et al., 2012, 2014). Living resources such as whales have long been managed and utilized by indigenous communities, with ice cover previously being used to assist in the protection of some of these 'stock' species (Fernandez et al., 2016). Three species of cetacean are endemic in Arctic waters: bowheads (*Balaena mysticetus*), narwhals (*Monodon monoceros*), and belugas (*Delphinapterus leucas*) (Reeves et al., 2014), although only two of these species (belugas and bowheads) are found within our area of interest, the Beaufort Sea.

Belugas are the most numerous of Arctic whales: globally there are thought to be at least 150,000 belugas composed of at least 20 sub-populations (or 'stocks') (Reeves et al., 2014). Despite their overall numbers, some sub-polar populations, such as the St. Lawrence stock, are known to be in serious trouble. The St. Lawrence stock is currently listed as Threatened under Canada's Species at Risk Act (DFO, 2012) and Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC, 2014). Despite the application of protective measures, this population has shown no sign of recovery. This has mostly been attributed to the impact of anthropogenic activities within their environment and their exposure to environmental contaminants (Gervaise et al., 2012; Mosnier et al., 2015). One of the largest stocks spends its summer further north in the Beaufort Sea and is thought to comprise of almost 40,000 individuals (Reeves et al., 2014). Belugas are known to be sensitive to certain types of noise. For example, in Arctic regions they have been observed fleeing ice breakers and using alarm vocalization in response to distant ships (Cosens and Dueck, 1993; Reeves et al., 2014). They have, however, also been shown to become habituated to 'less-threatening' vessel noise and are found in busy waterways such as the St. Lawrence estuary.

Globally, the number of bowheads, comprised of four sub-populations, is thought to number over 18,000 animals (George et al., 2004), with some populations such as those in Bering-Chukchi-Beaufort Seas (the BCB population), having recovered to the point where they are now listed as a species of Least Concern by IUCN (IUCN, 1996). Two of the four sub-populations, the Okhotsk Sea and the Svalbard-Barents Sea populations, however, have not shown such recovery success and are red-listed as Endangered and Critically Endangered, respectively, by IUCN. All populations of bowheads are migratory to some degree although the extent of this movement varies regionally (Reeves et al., 2014). Studies have shown bowheads to be relatively sensitive to industrial activity, exhibiting avoidance responses to noise sources such as ships and seismic surveys at low received levels (Richardson et al., 1999; McDonald et al., 2012; Blackwell et al., 2013, 2015). Therefore, it is very likely that increased industrialized vessel traffic will increase the risk of harm to bowhead whales (Reeves et al., 2012). Alaskan subsistence hunters have already helped provide evidence of the bowheads susceptibility to ship strikes through the documentation of scars and wounds consistent with ship strikes on harvested individuals (George et al., 1994; Reeves et al., 2012). Indirect evidence that large vessels will also prove hazardous for bowheads can be derived from studies such as those conducted by Moore et al. (2004) on their close relatives, the North Atlantic Right Whale (*Eubalaena glacialis*). North Atlantic right whales are found in the heavily trafficked waters of eastern North America and their numbers have shown little recovery since their take by commercial whaling was prohibited in 1935 (Reeves et al., 2012; Kraus et al., 2016). This is in direct contrast to the BCB population of bowheads and Southern right whales (*Eubalaena australis*) (Bannister, 2001) that have seen their numbers increase steadily over the past few decades. Thus, there would appear to be sufficient evidence to raise concern over the future of BCB bowhead whale population, given the predicted increase in Arctic vessel traffic.

1.3. Implications for conservation and management of marine mammals

Marine mammal species in the Arctic, including beluga and bowheads, are top multi-level consumers within these ecosystems and have an integral role in sustaining high latitude ecosystems (Meek et al., 2011). As such, any increase in vessel traffic has implications, not only for conservation of these species, but also for the human indigenous communities that depend on these mammals for fundamental nutritional needs and their heritage and cultural identity (Meek et al., 2011; Reeves et al., 2012; Fernandez et al., 2016). Historically, marine mammal conservation initiatives have typically resulted in permanent or semi-permanent spatially-defined coastal regions under the implicit assumption that the target species would continue to aggregate within their known habitat distribution and utilize important areas within their range such as migratory corridors, calving ground or foraging sites (Reimer et al., 2016). However, any increase in underwater noise from the likes of vessel traffic could result in animals changing migration patterns or regional residency, becoming less predictable, and the abandonment of previously important areas (Findley and Vidal, 2002). In addition, as marine mammals also respond to environmental changes, migration patterns, or regional residency can become less predictable, thus conventional protection measures (e.g. spatially fixed regions such as marine reserves) may fail to provide sufficient protection (Reimer et al., 2016). In the Arctic, this could reduce the success rate of local subsistence hunters (Reeves et al., 2012) or force them to travel farther (Huntington et al., 2015). Another major criticism of marine reserves generally, and particularly several of those established for marine mammals, is that they represent "paper parks" that provide a false sense of conservation achievement (Hooker and Gerber, 2004).

Marine Protected Areas (MPAs) are a common generic term for different types of marine reserves that aim to protect and conserve associated flora and fauna within an area. MPAs and other marine planning tools can be used to mitigate a suite of threats via area based management schemes (Wright et al., 2011). Hoyt (2009) suggested that MPAs devised to protect marine mammals would require targeted management measures that would aim to address marine mammals and ecosystem threats either as part of the MPA itself or through existing laws and regulations. Therefore MPAs could potentially act as a legislative tool for countries to protect whales from the impacts of shipping. MPAs have been effectively used around the world to create sanctuaries from fishing (Côté et al., 2001), but their use for vessel management is not well documented. However, a placed-based tool for protecting whales from ships may be one of the few policy measures that a country can implement to physically protect whales from the presence and impacts of vessels within their habitats. Furthermore, when an area is designated as an MPA, it is set aside for some form of conservation, which can prove very restrictive for some activities within the area depending on the conservation needs and goals of that MPA. Therefore careful consideration must be given to the design, size, goals and management of MPAs, especially those in remote areas such as the Arctic where enforcement issues can arise (Nyman, 2016).

1.4. Regulation and management of vessels for marine mammals

In addition to the uncertainty related to the location of cetacean species, data on Arctic shipping has until recently been inadequate for environmental assessment purposes. Understanding of the general and dose-specific responses of Arctic whales to the new types and levels of disturbance associated with escalating vessel activity is also lacking (Reeves et al., 2014). It is also now recognized that further recovery and protection of cetacean species requires the implementation of conservation measures designed to mitigate the risks posed by various emerging stressors (Chion et al., 2017). While the risks posed from vessels have not been a great concern in the past, many now believe that precautionary measures should be proposed to protect these culturally-significant animals from threats that changing Arctic conditions may present (Allen, 2014).

Globally, regulation and management of vessel traffic utilizes relatively few measures to control the location, speed, and behavior of ships in order to reduce risks to safety and the environment (Huntington et al., 2015). We will discuss these limited measures extensively over the course of this paper. Many of these management measures have already proven successful in reducing vessel-strike risk to Atlantic right whales through altering the probability of vessel-whale co-occurrence or by reducing the lethality of strikes through vessel speed restrictions (Reimer et al., 2016). Many have suggested imposing shipping restrictions in advance of a boom in ship traffic may be easier than doing so after shipping has increased (Huntington, 2009).

1.5. Arctic vessel management

Mobile and stationary Arctic resources, for example marine mammals and mineral deposits, may straddle various political and geographic boundaries at regional and international scales (Fernandez et al., 2016). For example, the *trans*-boundary nature of the bowhead and beluga populations in the Beaufort Sea makes it important that communication and strategic planning are pursued on an international basis (Reeves et al., 2012). Currently, each Arctic country and indigenous community may have sovereign legally binding statutes separately in their own jurisdictions. However, the Arctic region as a whole is lacking a coherent and binding policy with regard to shipping (the Arctic Council has non-legally binding policy) (Fernandez et al., 2016). One mechanism aims to bridge all Arctic jurisdictions is the International Maritime Organization's (IMO's) Polar Code, which is a mandatory code of conduct which aims to harmonize and upgrade vessel operating standards within international Arctic waters (Reeves et al., 2014; IMO, 2017). However, many still feel that the existing Arctic governance structure is insufficient and too fragmented to handle an increase in human activities and while sectoral agreements like the Polar Code are important, they cannot address the need for integrated governance (Fernandez et al., 2016). International management instruments may prove to be an alternative and good mechanisms for implementing or at least preserving conservation options until such a multi-functional agreement is developed. For example, IMO has designated 13 large areas as Particularly Sensitive Sea Areas (PSSAs), although none have been designated in the Arctic as yet (Reeves et al., 2014). Designation of any PSSA will still require it to be linked to jurisdictional policies and regulations alongside any measures taken by industries in order to prevent pollution and impacts from ships (Reeves et al., 2014). Therefore the capacity of the Arctic to adapt to change and associated development will likely depend on cooperation between the various stakeholders that may or may not be formally linked by a current governance institution (Fernandez et al., 2016).

In this paper, we examine current mechanisms being employed to manage vessels and mitigate the risks that they pose to cetaceans in non-Arctic waters. Since there are few examples of vessel management within the Arctic, we draw on conservation measures to address shipping effects outside the Arctic, which may have application potential in the North. Furthermore, application of these measures to the Arctic would seem like a logical and important first step toward ensuring minimal impacts arise from any increase in vessel traffic in the North (Huntington, 2009). Through the application of a lessons learned approach, we evaluate each tool or mechanism identified during a review of MPAs currently utilizing vessel management schemes in terms of suitability for use in the Arctic. We then explore the utility of these management scenarios using automatic identification system (AIS) data for vessels and GIS analysis for a study site containing recently designated MPAs in the eastern Beaufort Sea and Amundsen Gulf. This work highlights several issues related to vessel management within an Arctic context in an anticipatory and proactive manner. In the final section of this paper, we provide recommendations for future management consideration that aim to both safeguard local populations of Arctic cetaceans and ensure that any future increase of vessel traffic and associated socio-economic development is managed responsibly.

2. Materials and methods

2.1. Review of non-Arctic vessel management schemes within MPAs

We began by utilizing the extensive review of MPAs published in *Marine Protected Areas for Whales, Dolphins, and Porpoises: A world handbook for cetacean habitat conservation and planning* by Hoyt (2011). Hoyt (2011) reviews and compiles a list of 1076 MPAs that have been designated globally which have in some manner an affiliation with one or more species of cetacean. We were only interested in MPAs that have both an established management plan in place and plans which referenced and attempted to address issues related to vessels within that MPA. Of the 1076 “cetacean MPAs' that Hoyt reviewed, only 78 of these were found to meet the criteria laid out for this study. We then reviewed these MPAs in further detail and collected information related to the management tools proposed, developed, and employed along with the status of their implementation. It became apparent at this stage of the exercise that while many management plans listed vessels as a potential threat and proposed several strategies for mitigating risk to marine mammals (when it was acknowledged that there was a specific risk to that species), very few have actually employed active management tools/mechanisms. This reduced the total number of MPAs reviewed in this study to 33.

From the 33 MPAs identified as having ‘active’ vessel management schemes, we identified a total of 14 management tools/initiatives (with some variations such as voluntary/mandatory and permanent/seasonal), many of which appeared in the management schemes of multiple MPAs. In addition, several tools were often employed within a single MPA to manage vessels. For this reason, as well as the scale and detailed nature of this assessment, we decided to classify the tools identified into four distinct groups: *Spatial*, *Vessel*, *Monitoring*, and *Outreach*. Details about each of the tools within these groups, including information related to their application, examples of MPAs that currently employ them, evidence of successful elements of their deployment, and some of the challenges encountered so far, can be found in Tables 1–4.

At this stage of the analysis, we combined our experience as well as knowledge gained from published literature to evaluate each tool identified and then assessed the potential suitability of each tool under deployment in Arctic conditions. We compiled a list of possible challenges and opportunities for each tool and then discussed at length which tools, given the evidence gathered, should be most readily considered in the context of managing vessels in the Arctic (Tables 1–4).

2.2. Case study: Amundsen Gulf, Canadian Arctic

We use this case study to examine how the different vessel management measures described in Tables 1–4 would work in an Arctic scenario. The case study area that we selected was the eastern Beaufort

Table 1
Spatial management tools for vessels in use within MPA management schemes.

Tool	Evidence: Successful Components	Evidence: Issues that have arisen	Challenges that may arise in the Arctic	Opportunities that could present in the Arctic
Mandatory Exclusion Zone: No vessels allowed within designated area. **Examples of Implementation:** Al Hoceima National Park; Gulf of Trieste Miramare MPA; Great Australian Bight Marine National Park	* Only management tool that offers complete vessel protection through removal of all risk. **Robson Bight:** As part of the Critical Habitat for Northern Resident Killer Whales it ensures that this exclusion zone is legally binding. It's also enforced via boat patrols in peak season (BC Parks, 2017).	* Slow, difficult and costly to implement and ensure compliance. * Highly restrictive often leading to stakeholder opposition. **Saguenay–St Lawrence Marine Park:** Entire estuary is important beluga habitat, so increased risk in condensed areas, and noise pollution everywhere persists (Gervaise et al., 2012).	* Insufficient policy/legislation for Arctic MM to mandate such a management tool? * Issues could arise with monitoring/ compliance/ enforcement. *Local peoples may require access to the area, therefore a blanket ban on vessel traffic is unfeasible. * Navigational safety issues could also preclude a blanket ban due to changes in ice regime requiring vessels to access an area.	* Ice cover in many regions precludes vessels entering many areas for at least part of the year. * Mandatory zones are potentially easier to police, if vessels are seen in area that is off limits then there are no grey areas about the means by which it was transiting. * No vessel, no risk of impact.
Restricted Access/Permitting System: Designated area has a carrying capacity for a certain number of vessels each year. Only certain vessels with the appropriate permits are allowed in. **Examples of Implementation:** Prince Edward Islands MPA; Northeast Sakhalin Whale Wildlife Refuge;	* Limits the number of vessels to what is deemed an acceptable amount for a given area. * Often implemented on a seasonal /temporary basis. **Glacier Bay**: no more than 25 vessels per day are permitted within the bay from 1 June to 31 August each year. Violations of the permitting system can lead to evictions and citations (McKenna et al., 2017).	* Complex and costly to implement and enforce. * Often unclear who will be responsible for developing, financing, implementing and maintaining such a scheme **Marine Mammal Sanctuary of Silver and Navidad Banks**: The licensing system could be open to corruption, given that the permits are issued to whale watching companies. Proving the violations is also inherently difficult and costly if taken to court will the fees be enough to cover such costs? [a]	* Most vessels in the Arctic are transiting and need to be in the areas as a means of passing through, therefore restricted access is unlikely to be a feasible option. * Seasonal restrictions are also unfeasible as MMs and shipping co-occur within the ice-free season, they cannot transit at an alternative time of year (at the moment), essentially creating a temporal bottleneck. * Current permitting schemes exist in the Arctic and are acknowledged as being quite complex, another permit could add to this problem and result in poor acknowledgement and ultimately compliance. * Impractical to restrict 100% of local vessels primarily due to the need to hunt	* Implementing a permitting system could allow data collection on vessels transiting areas with poor AIS coverage. This could be used to keep track of vessel time and movement. * Daily quotas on permits would potentially allow for better management of vessels in specific bottlenecked areas during ice free months. * Permits could act as a means of staggering traffic along sections of busy routes. * As other permit schemes already exist there is an existing legal framework that can potentially be adapted/built upon. * Potential job opportunities, local training and further qualifications.
Voluntary Exclusion Zone /Area to be Avoided: Recommended that vessels avoid a designated area. **Examples of Implementation:** The Gully MPA; Doubtful Sound Marine Mammal Sanctuary	* Potentially the quickest and least costly spatial tool to implement. **Roseway Basin**: IMO adopted a voluntary ATBA, within 5 months, 71% of vessels complied with ATBA and reduced risk to right whales by 82% (Vanderlaan and Taggart, 2009).	* Compliance not guaranteed * Incentive schemes to increase compliance may be costly and it is often unclear who should bear the financial burden of such initiatives **Roseway Basin:** 29% of vessels ignored ATBA (Vanderlaan and Taggart, 2009).	* Possibly difficult to identify an alternative route due to ice cover and navigational safety issues. * What incentives could be offered in the Arctic? Other examples have used reduced berthing fees, but this would not be applicable here. * Pilotage schemes could help, however this would be costly and difficult to implement in remote regions as discussed further in Table 2	* Compliance could be aided by the inclusion of ATBA within pre-existing documents such as the Polar Code and other charts used by vessels when planning journeys in the Arctic. * Insurance providers could mandate that vessels must comply with the coastguard shipping route (which would take into account the ATBA). * The natural dynamism of voluntary measures means that they are widely more accepted and adaptable.
Vessel Re-routing /Transit Separation Scheme): Vessel routes are restricted within a designated area. **Examples of Implementation:** Las Perlas Archipelago; Channel Islands National Marine Sanctuary	* Removes vessels from section of route that has shown to pose a high risk of vessel/marine mammal overlap **Grand Manan Basin**: Amended TSS that avoids right whale conservation area reduced risk of vessel strike by 62%; unknown compliance (Vanderlaan et al., 2008).	* In many instances re-routing is not an option due to navigational safety issues (Silber et al., 2012) **Grand Manan Basin:** voluntary measures, so compliance is not 100% (Vanderlaan et al., 2008).	* Difficult to identify an alternative route due to ice cover and navigational safety issues. * No current examples of IMO changing routes in the Arctic. * Route changes need to be 'championed' and evidence provided to initiate any move, can this be provided for a particular species in the Arctic. * The process to implement lane re-routes are lengthy and potentially quite costly	* Current shipping corridor was designated with no conservation knowledge or objectives, therefore, the rationale to move them in light of new evidence would not be as likely to meet opposition on those grounds. * Movement of lanes where possible, would likely be marginal due to physical restrictions and therefore this would potentially make compliance more likely.

MM – Marine Mammals.
[a] Not from citable literature.

Table 2
Vessel based tools in use within MPA management schemes.

Tool	Evidence: Successful Components	Evidence: Issues that have arisen	Challenges that may arise in the Arctic	Opportunities that could present in the Arctic
Pilotage: Pilots are required on vessels when navigating certain areas, or when entering or leaving a Port **Examples of Implementation:** Saguenay-St. Lawrence Marine Park	* Education of local pilots increases likelihood of voluntary management measures being observed. **Saguenay-St. Lawrence Marine Park:** 72% of piloted vessels complied with speed restriction compared to 13% prior to slow down (Parrott et al., 2016)	* Pilotage schemes are expensive and difficult in terms of logistics. **Globally:** Pilots are becoming difficult to recruit and can be costly (Bruno and Lützhöft, 2009)	* Arctic vessel costs are already high, additional pilotage may make them financially unviable. * Unlikely that pilots could only be placed on ships for part of a journey due to the remoteness of anchorage locations * Logistical difficulties placing pilots on vessels, could be more easily implemented on cruise ships than other commercial vessels * Lack of pilots operating in northern regions that are trained to navigate Arctic waters	* Having trained Arctic pilots on vessels could ensure better vessel compliance with spatial and vessel management tools * Could increase local jobs if local people were trained as pilots.
Code of Conduct: Vessel must abide by a given Code of Conduct, including min distances from MM **Examples of Implementation:** Moray Firth SAC; Cardigan Bay SAC; Marine Mammal Sanctuary of Sliver and Navidad Banks; Pelagos Sanctuary	* Setting out clear guidelines for vessels makes it more likely that they will comply with regulations as they know what is expected of them. * Codes of Conduct can be used to inform vessel journey planning **Cardigan Bay:** Produce and distribute a code of conduct http://www.cbmwcwildlife/code-of-conduct/	* Long, complex codes of conduct may not be followed or well learned by vessels, or only those parts that relate to mariner safety **Moray Firth:** Inconsistences in key recommendation across voluntary codes of conduct. Statutory codes may not be well received by stakeholders and costly to enforce (Inman et al., 2016).	* Polar Code doesn't explicitly state the various issues that relate to MM and vessels * An additional Code could prove confusing but additions to the existing code would need to come through IMO. * Compliance would also be difficult to monitor and because there is little safety risk for mariners from MM, compliance with suggested actions could be low. * Difficulty could arise when it comes to its distribution amongst smaller craft and local vessels- important as the number of recreational boats is increasing.	* As the Polar Code is published, it could be easier to add additional sections related to MM than creating an additional document, saving money and time. * Training could be ensured on all vessels if insurance companies mandated that it was a compulsory part of obtaining their coverage.
Reporting: Vessel must report its position and course along a given route, often coupled with MM locations being reported to vessels. **Examples of Implementation:** Pelagos Sanctuary for Mediterranean Marine Mammals; Eastern USA Seasonal Management Areas for Atlantic Right Whales	* Mandatory positions will allow boats to be made aware of whales in close proximity to them **Roseway Basin:** East coast Canada Vessel Traffic Services Zone Regulations. Mandatory reporting when entering and departing the area (Vanderlaan et al., 2008)	* Improper use, location errors from the use of GPS along with noncompliance. * Replication of some information if AIS is also being collected. **Globally:** mapping (GPS precision) and measurement errors (GPS error) introduce further distance travelled errors (Palmer, 2008)	* Vessel reporting requires good communication between vessels and land based authorities, this is not always possible in remote Arctic areas, * No current network in place to record and report whale locations, and place them in relation to vessels. * Real time vessel reporting and MM detections could be costly and unobtainable due to environmental conditions and physical limitations as well as financially unsupported.	* Local indigenous communities have local knowledge of MM and vessels locations that would aid the formation of a sightings network. * Sighting information can be combined with ship reporting to ensure accuracy. * This would require the efforts of local communities and may provide some jobs * Reporting could be enabled through the use of land based receiver networks or satellites in more remote areas that are also used to capture AIS data
Speed Reduction: Vessel must slow to a defined speed **Examples of Implementation:** Las Perlas Archipelago Special Coastal Mgmt Zone; Sha Chau and Lung Kwu Chau Marine Park; St. Lawrence-Saguenay Marine Park	* Speed reductions have been proven to significantly reduce cetacean mortality events through ship strikes. * Reducing speed can reduce cavitation and therefore the amount of noise emitted into the environment. **Eastern USA SMAs:** seasonal speed reduction effectively reduced whale mortality to zero whales within the SMA (Silber et al., 2014).	* If speed restrictions are only voluntary, compliance not guaranteed, therefore, unlikely to reduce the risk that vessels pose to whales * Sometimes due to navigational safety, slowing down is not an option for vessels traveling in hazardous waters **Eastern USA SMAs:** compliance was originally below 5% but did increase through time. (Silber et al., 2014).	* Vessels transiting Arctic waters are often going quite slow due to navigational hazards, therefore further speed reductions could be unfeasible and additionally not result in a notable change in risk. * Speed reductions have proven to reduce the risk of vessel strikes but the results are less conclusive when it comes to reducing noise	* Due to hazards, Arctic vessels are naturally not traveling as fast as they would be in open ocean, this means that the strike risk they pose is already reduced. * Small changes are more palatable; if vessels have to reduce speed to comply with management it would likely only be by a small amount and may result in a higher uptake if the measure was voluntary.

MM – Marine Mammals.

Table 3
Monitoring tools for vessels in use within MPA management schemes.

Tool	Evidence: Successful Components	Evidence: Issues that have arisen	Challenges that may arise in the Arctic	Opportunities that could present in the Arctic
Acoustic: **Passive acoustic monitoring** - ambient noise and MM presence. Also used to calculate vessel source levels and track MMs. Real time acoustic monitoring can send notifications to vessels alerting them of MMs. **Examples of Implementation:** Gerry E. Studds Stellwagen Bank National Marine Sanctuary; Grays Reef National Marine Sanctuary	* Passive, relatively inexpensive system allows non-intrusive continuous data collection **Cardigan Bay**: Allows detection in bad weather conditions when visual observations not possible (Simon et al., 2010).	* Generates a lot of data, which is quite costly to store and process. There can also be issues with analysis not being undertaken in real time. Maintenance of the system can be costly and time consuming. **Glacier Bay:** Low acoustic detection rates could be due to the location of hydrophone (McKenna et al., 2017).	* Due to physical limitations in the Arctic, it could be difficult to get real time acoustic data analysis established using hydrophones because of seafloor topography/ice cover. The distance from shore for a cable array could be considerable, therefore, as with all types of Arctic installation, could prove costly. * Deployment and retrieval of devices can also prove difficult due to seasonal presence of sea ice.	* Vocal MM species are highly suitable for acoustic surveillance. Currently lack of shipping/anthropogenic background noise (regardless of high levels of natural background noise from moving ice) allows for good detection rates and recordings. * Hydrophone deployment would allow year round monitoring (potentially remotely) for long term fluctuations in sound/noise levels to be obtained. Current measurements would allow for a baseline to be established against future changes, something that is lacking in many other datasets.
Visual: **MM Observation:** land or vessel observers that report location of cetaceans to vessels. **Examples of Implementation:** Gulf of Farallones National Marine Sanctuary; Cordell Bank National Marine Sanctuary	* Allows no intrusive data collection and actively alerts vessels to the presence of MM. **Pelagos Sanctuary**: REPCET system for real-time knowledge transfer of marine mammal sightings. Ship operators are trained to look for cetaceans, adjust their behavior on the vessel, and report sightings through the REPCET system (David et al., 2011).	* Requires a significant amount of personnel resources. Can only take place during the day. **Pelagos Sanctuary:** Relies on vessels in the area to report sightings, and other vessels to respond to sightings. Voluntary system, so some may not participate. Sea state/weather will limit the effectiveness of this system. (David et al., 2011).	* Extreme Arctic weather conditions mean that it could be impossible to collect visual observation data year round. * The distance from vessels to shore could be considerable making visual detection probability poor. * Visual detections would also require paid personnel, therefore proving costly. * MMs are only at the surface for short periods of time and occur in an unpredictable manner making visual detection challenging, even on days with good visibility.	* Visual observers could provide a source of work to individuals living in remote communities. * Visual observers on ships provide the best chance of reducing strike risk.
Spatial: **AIS:** used to record and monitor vessel movement within an area **Examples of Implementation** Agoa (Sanctuary of the French Antilles); The Gully; Stellwagen Bank	* Provides continuous coverage of vessel movement within area. **Stellwagen Bank**: monitored vessels traveling through Stellwagen Bank to assess their contribution to noise levels (NOAA, 2017a).	* System produces vast quantities of data and requires expert training to process and analyse. **Agoa (Santuary of the French Antilles):** Slight lag from the time of data collection to presentation. There are inherent issues with AIS data that can lead to inaccuracies, also it does not allow for the capture of non AIS vessels. [a]	* Land-based AIS stations are not currently established in most places in the Arctic. Satellite AIS would need to be used or land based installations put in place, both of which are costly. * Could be issues with data resolution in remote areas, an issue that is improving with increased numbers of satellites and time. Data storage and processing can be costly but could lead towards real time management in areas where land based systems are in place.	* Additional data related to vessels can be gathered even in remote regions (in the case of satellite AIS). Providing a way to inform vessel reporting and monitor compliance management measures in areas where other observation techniques are not possible. * Some satellite AIS providers can also use AIS to provide real-time notifications to ships/land based receivers.

MM – Marine Mammals.
[a] Not from citable literature.

Table 4
Outreach tools for vessels in use within MPA management schemes.

Tool	Evidence: Successful Components	Evidence: Issues that have arisen	Challenges that may arise in the Arctic	Opportunities that could present in the Arctic
Ship: Training /information provided to pilots or captains related to MM and related impacts of vessels and how to avoid or mitigate these impacts. **Examples of Implementation**: Gerry E. Studds Stellwagen Bank National Marine Sanctuary	* Production of materials that are distributed at no costs to mariners. **Turneffe Atoll:** Produced a document related to responsible travel within the MPA. Most of the management is targeted at fisheries specifically however, for vessels they aim to increase awareness by engaging boat captains. http://www.responsibletraveldocs/Turneffe%20Atoll%20Full%20Report.pdf	* Training is voluntary so not always adhered to and only excluded unregulated boats within the boundaries of the reserve. **Marine Mammal Sanctuary of Silver and Navidad Banks:** Outside the MPA permit site unregulated marine mammal tourist boats are in operation. In response to instances of harassment in areas outside the MPA, the government have issued a guide to good practices for the conservation of MM and a training program. Adherence to these guidelines is not mandatory.	* Vessels already receive training related to Arctic navigation, therefore additional training may not be deemed as important. * Due to remoteness, any training provided would be delivered to vessels before leaving non-Arctic ports and therefore may be forgotten by the time they enter Arctic waters. * Vessels may be preoccupied by navigational challenges and less inclined to observe MM training examples. * It is also difficult to monitor the success of such schemes. * Many vessels will be foreign and crews may not have an appreciation or strong attachment to the environment or the need to protect it through self-education. * Due to data limitations, it is difficult to provide vessels with accurate distribution maps for all MM species throughout the full extent of their range.	* Documents such as the Polar Code could make such ship education schemes mandatory for all personnel navigating Arctic waters. * Length of time of Arctic vessel voyages gives extra time for ship personnel to read material if it is provided onboard ships, which would reduce costs.
Industry/Stakeholders: Information provided across industry related to vessels and MM. Information distributed all stakeholders involved. **Examples of Implementation:** West Coast USA Sanctuaries	**West Coast USA Sanctuaries:** Listserv sends reminders out to shipping industry with reminders of seasonal whale presence. Also have shipping industry meetings about strike risk (NOAA, 2017b).	*Voluntary so industry would need to be on board.	* Industry/stakeholder representatives are rarely based in the Arctic themselves and in addition many shipping businesses are multinational. * How this should be approached and who would lead and cover such an expense is unclear, as is how to monitor feedback of this outreach and relate it to actual changes in vessel behavior.	* At the moment there are less industries and stakeholders in the Arctic than would normally have to be included in other coastal areas.
General Public: Information delivered to the general public through outreach and engagement activities/events informing them about MM and vessels. **Examples of Implementation:** Robson Bight / Michael Bigg Ecological Reserve; Hawaiian Islands Humpback Whale National Marine Sanctuary.	* Dedicated personnel for outreach and engagement work. **West Coast U.S.A. MPAs**: good information readily available on NOAA websites, and also have public outreach programs for children and courses for adults. E.g: "See a spout, watch out!" campaign: https://www.greateratlantic.fisheries.noaa.gov/protected/mmp/viewing/spout/index.html	* Lack of promotional material or ineffective material need to be assessed/altered. **Shoal Islands Marine Park:** Upon reassessment 2 recommendations were made; More signage provided at additional access points to the marine park and that research relevant to management by volunteers, educational institutions and government agencies be encouraged/supported. http://www.conservation.wa.gov.au/media/22523/4.3.13%20shoalwater%20islands%20marine%20park%20management%202007-2017%20periodic%20assessment%20report.pdf	* Remote communities are often spread out over considerable distances making them costly to target. * The public often have little to do with the shipping industry, however, are responsible for smaller watercraft, and therefore there is still a value in spreading awareness. * Arctic communities have to use vessels for local travel and subsistence so this is an activity that will not be modifiable, especially if it results in increased costs. * Difficult to assess effectiveness.	* Indigenous communities are often involved with managing local areas and MPA therefore making them aware of vessel related issues has an important conservational value. * Many communities also have a vested interest in maintaining marine mammal stocks due to them being a subsistence food source in several areas.

MM – Marine Mammals.

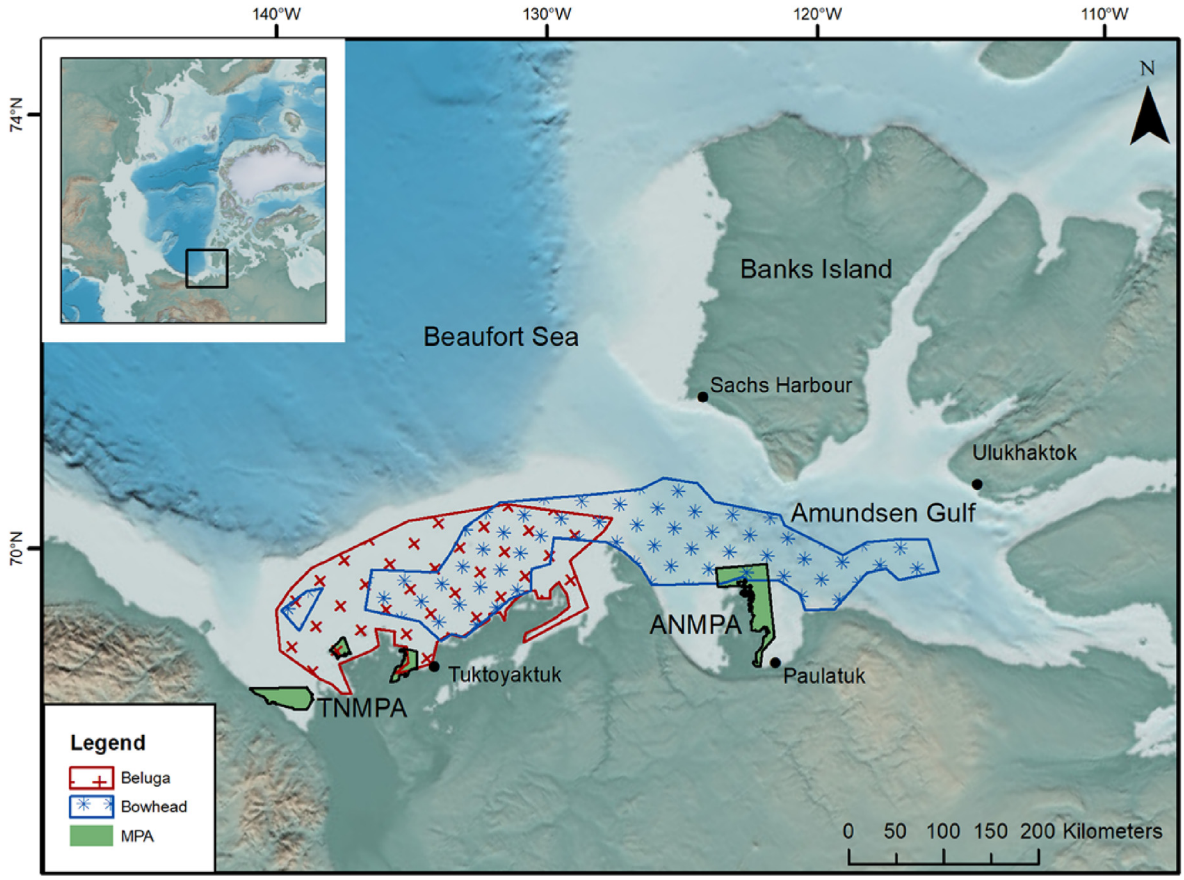

Fig. 1. The eastern Beaufort Sea and Amundsen Gulf study area showing important areas for cetaceans (bowhead and beluga whales) and the Tarium Niryutait MPA (TNMPA) and Anguniaqvia Niqiqyuam MPA (ANMPA). Areas for cetaceans are representations of the 50% utility distributions calculated by Citta et al. (2015) (bowhead whales) and Hauser et al., 2014 (beluga whales). Base map provided by NOAA Environmental Satellite Data and Information Service.

Sea and Amundsen Gulf of the western Canadian Arctic (henceforth referred to as "the study area"; Fig. 1), which we chose based on our familiarity with this site, because it is an important area for both beluga and bowhead whales, and because it already has two MPAs established (Tarium Niryutait MPA (TNMPA) and Anguniaqvia Niqiqyuam MPA (ANMPA)). Another key reason for selecting this area is due to its proximity to the western entrance of the Northwest Passage, anticipated to be a crucial area for managing ship traffic in the future as the route becomes more ice-free and utilized as a passage for traffic traveling between the Atlantic and Pacific Oceans.

The TNMPA, located near the community of Tuktoyaktuk, was designated in 2010 specifically for beluga whales. The area protects important foraging and congregation areas, especially for mothers and calves (see beluga whale core use area on Fig. 1). The ANMPA, located at Darnley Bay near the community of Paulatuk, was designated in 2016 for a wide range of species, including Arctic char, cod, sea birds, beluga whales, ringed and bearded seals, and polar bears. The ANMPA also overlaps with important core use areas for bowhead whales (see bowhead whale core use area on Fig. 1). The TNMPA currently has a management plan that includes a small section on shipping (p. 25):

> "Bathymetry of the seafloor limits shipping activities to corridors that run through Zone 1(a) areas, so avoidance of these areas is not possible. With regard to shipping activity in Zone 1(a) areas, the BSBMP states: "All shipping activities (including dredging) should be confined to designated shipping routes and areas. Passage through or close to Zone 1a outside of designated routes, even if it's the shortest route, should be avoided from break-up to 15 August" (FJMC, 2001, p. 14)".

The ANMPA does not yet have a management plan, but it will likely also include a statement about designated routes, as the community of Paulatuk relies on shipping for much of their supplies.

During our review of MPAs (outlined in section 2.1.), we found two 'Spatial' tools, *voluntary avoidance* and *slow down areas*, which provisionally look to have a relatively high suitability for Arctic application, and we examined these tools using geospatial analysis within our study area. We used satellite AIS data on vessel traffic moving within the eastern Beaufort Sea and Amundsen Gulf between 2012 and 2016, which was provided by exactEarth Ltd. through the Marine Environmental Observation Prediction and Response Network National Centre of Excellence (MEOPAR NCE) sponsored NEMES (Noise Exposure to the Marine Environment from Ships) project. For each year between 2012 and 2016, we examined vessel tracks throughout the study area. We then traced a polygon around the outside of the majority of the vessel tracks to delineate the areas generally used by vessels (Fig. 2), which we refer to as the vessel use area. We excluded tracks from the Canadian Coast Guard Ship, CCGS Amundsen, that were northwest of Sachs Harbour because these tracks were related to research activities and do not represent normal shipping activity (i.e. community supply vessels, typical ice-breaking activity, and tourist vessels) within the region. We compared vessel use areas between years, and use 2016 as a representative year because it encompasses vessel use areas from all other years. This vessel data was then used to consider several shipping impacts including vessel strike and acoustic disturbance that may be experienced by cetaceans that regularly utilize the study area during the corresponding time period.

The boundary of the TNMPA currently delineates an area of approximately 1751 km^2, and the ANMPA an area of 2361 km^2. It is well known that vessel noise, due to its acoustic properties, is able to travel considerable distances and although a vessel may be operating outside

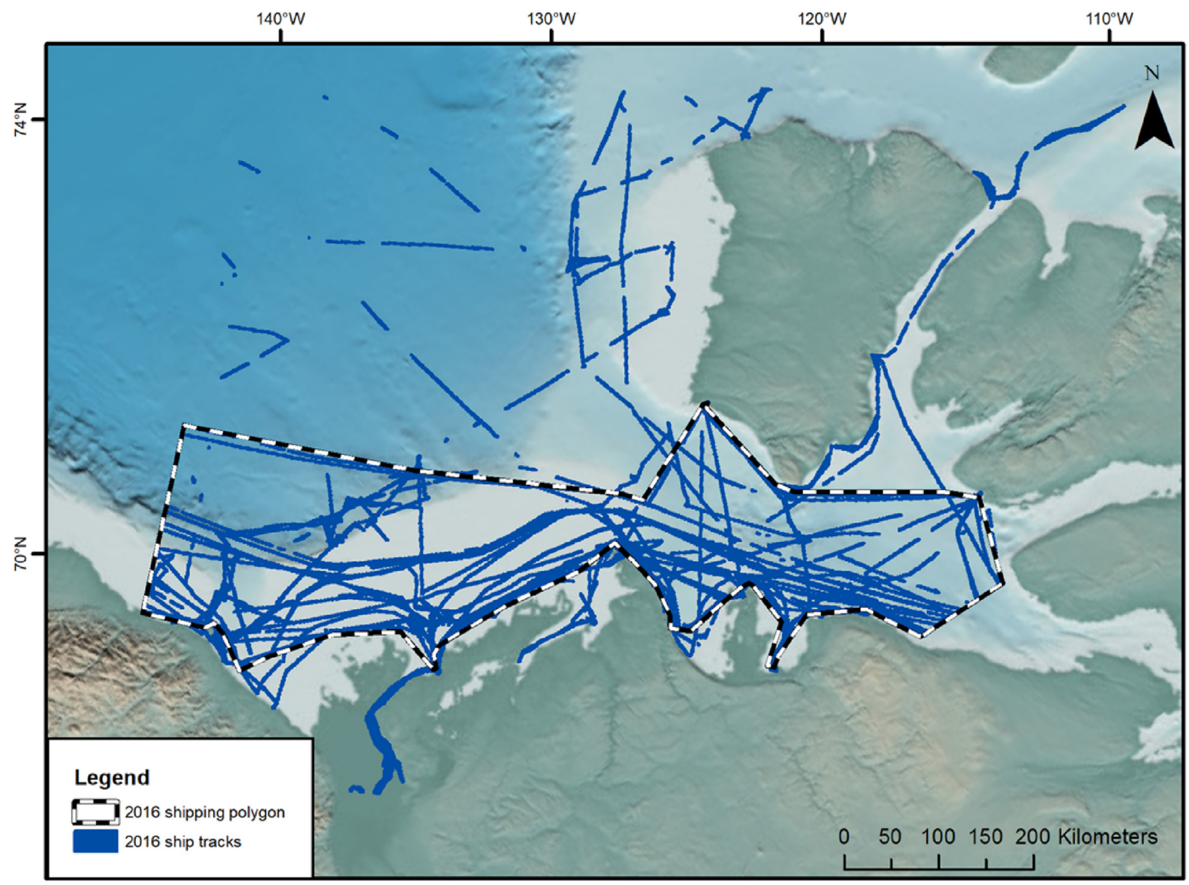

Fig. 2. Vessel tracks within the eastern Beaufort Sea and Amundsen Gulf in 2016 and the derived Vessel Use Area (VUA) for vessels during 2012–2016. Base map provided by NOAA Environmental Satellite Data and Information Service.

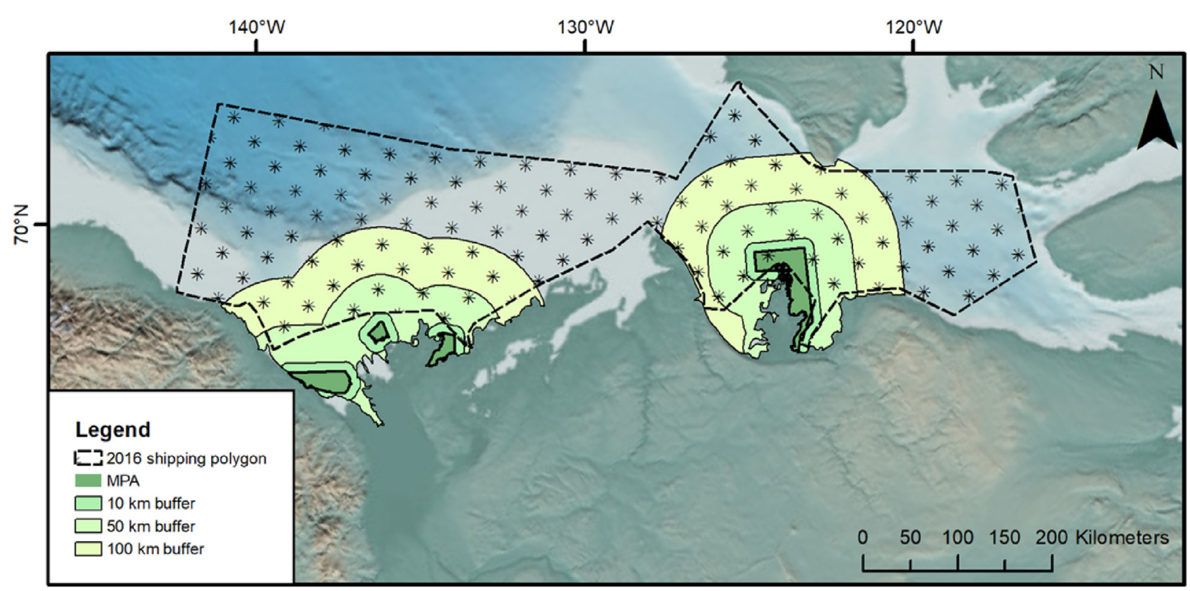

Fig. 3. Tarium Niryutait MPA (TNMPA) and Anguniaqvia Niqiqyuam MPA (ANMPA) designations and additional 10, 50 and 100 km management zones in relation to the 2012–2016 VUA. Base map provided by NOAA Environmental Satellite Data and Information Service.

the boundaries of the MPA, noise emitted from the vessel will likely be present within the MPA itself (Halliday et al., 2017). For example, vessels traveling through quiet Arctic waters near these MPAs have been heard from over 130 km away (Halliday et al., 2017). Therefore, in order for a management tool to effectively mitigate noise within the MPA boundaries, it may be necessary to extend the area for any management tools beyond current boundaries in order to meet the management goals set for a designated area. There have already been several management tools developed in both terrestrial and marine planning (Lynch and Corbett, 1990; Silva and Williams, 2001; Day, 2002) that utilize 'buffer zones' around designated areas in order to meet goals that have been set in order to deal with pervasive threats. In this exercise, we explored three different sizes of buffer zones: 10, 50 and 100 km (see Fig. 3). The 10 km buffer zone was added based on noise reduction recommendations for the Gully MPA on the east coast of Canada with the aim of protecting marine mammals from the effects of noise from a variety of sources (Agardy et al., 2011). A 50 km zone provides sufficient distance from noise sources, such as most ships, that the received levels would no longer be likely to cause behavioural disturbances for marine mammals (based on NOAA criteria; Southall et al., 2009) although they may still be audible (Halliday et al., 2017). A 100 km zone is large enough to remove most (if not all) influence of vessel noise on an area (Hoyt, 2011). Buffer zones, along with most other vessel management measures, at present would only need to be seasonal given that vessels currently only travel in this region between July and October when it is ice-free. However, the ice-free season has been extending in recent history and vessel traffic is utilizing this is prolonged period of open water (Pizzolato et al., 2014). Any seasonal measure implemented would therefore have to be adaptive in order to account for variation in duration of the ice-free season.

Using the vessel use area previously derived from the AIS vessel track data logged between 2012 and 2016, we also assessed the number of vessels likely to be impacted by any associated management within the extended areas for each of the buffer sizes (see Table 6).

2.3. Application of management measures

We explored the effect of voluntary avoidance measures on vessels in each MPA and in the three buffers around each MPA, specifically examining how many vessels would be affected in each year between 2012 and 2016. We also examined the impact on maximum vessel speed for a voluntary slow down application in each of the buffer areas derived for the study area MPAs. We specifically focused on the number of vessels that would be affected by 15, 10, and 5 knot speed restrictions, if they were traveling their maximum speed, using data from each year between 2012 and 2016.

Finally, we examined vessel routes for two vessels during 2016, the Kelly Ovayuak and the Crystal Serenity, and one vessel during 2013, the Nordic Orion, to explore, in further detail, the implication of applying a vessel slowdown management scheme within the different buffer areas around each of the MPAs. Crystal Serenity is a tourist cruise ship (length > 100 m), Kelly Ovayuak is a tug boat (length < 50 m), and the Nordic Orion is a bulk carrier (length > 200 m), therefore it was expected that each vessel would exhibit different transit behavior and undertake different routes through the study area. Tug boats, like Kelly Ovayuak, represent typical current traffic in the region because these boats act as community supply vessels, and have been active in the region for many years. Tourist vessels, like Crystal Serenity, are becoming more common in this area, with Crystal Serenity being the first tourist vessel to transit the Northwest Passage. Freighters, like Nordic Orion, are relatively uncommon in the region, but are expected to increase in the future as the Northwest Passage becomes a more viable route connecting the Pacific to the Atlantic. Nordic Orion was also the first bulk carrier to fully transit the Northwest Passage.

Table 6
Vessel speeds and the amount of change given the implementation of a speed restriction in different buffer zones.

MPA	Buffer Size (km)	Year	Total no. of vessels	No. of vessels with max speed > 15knots	No. of vessels with max speed > 10knots	No. of vessels with max speed > 5knots	% Vessels effected by 10knot speed restriction
TNMPA	0	2012	0	0	0	0	NA
		2013	0	0	0	0	NA
		2014	0	0	0	0	NA
		2015	0	0	0	0	NA
		2016	0	0	0	0	NA
	10	2012	4	0	2	4	50
		2013	6	0	3	6	50
		2014	7	0	4	7	57.1
		2015	5	0	5	5	100
		2016	6	0	6	6	100
	50	2012	11	4	9	11	81.8
		2013	15	5	12	15	80
		2014	9	3	9	9	100
		2015	10	6	10	10	100
		2016	13	5	10	13	76.9
	100	2012	17	7	15	16	88.2
		2013	21	12	20	21	95.2
		2014	13	9	13	13	100
		2015	19	12	19	19	100
		2015	17	10	15	17	88.2
ANMPA …	0	2012	8	4	7	8	87.5
		2013	11	4	9	11	81.8
		2014	8	3	6	8	75
		2015	10	5	9	10	90
		2016	8	2	6	8	75
	10	2012	11	4	10	11	90.9
		2013	14	6	11	14	78.6
		2014	9	4	8	9	88.9
		2015	11	6	10	11	90.9
		2016	12	4	9	12	75
	50	2012	15	4	14	15	93.3
		2013	17	9	15	17	88.2
		2014	13	9	13	13	100
		2015	18	10	18	18	100
		2016	17	9	9	17	94.1
	100	2012	15	5	13	15	86.7
		2013	17	12	16	17	94.1
		2014	14	10	13	14	92.9
		2015	18	14	17	18	94.4
		2016	17	13	16	17	94.1

Using three different types of vessels in this manner allowed us to consider the implications that these management tools would have for different types of vessels. For each vessel, we calculated the distance each vessel travelled within each MPA and in each of its associated buffer areas. We used both the maximum speed recorded and mean speed travelled in the study region, which we calculated using the AIS data (Crystal Serenity: max speed = 21.8 knots, mean speed = 11.2 knots; Kelly Ovayuak: max speed = 11.8 knots, mean speed = 6.9 knots; Nordic Orion: max speed = 20.6 knots, mean speed = 12.1 knots; estimated via satellite AIS data) and the total distance travelled to calculate the minimum total time spent traveling (based on max speed) and the likely time spent traveling (based on mean speed). From this information, we calculated approximate values for the extra time that would be incurred given the observance of a slowdown within the buffered areas and in the MPAs, and also the impact of an exclusion zone within MPAs for vessels that travelled through either of these areas.

3. Results

We identified 14 vessel management tools during the MPA review, which we separated into four different groups: Spatial, Vessel, Monitoring, and Outreach. All bar the four spatial tools could prevail beyond the MPAs themselves, especially those associated with outreach. We evaluated each group of tools, including evidence of success or failure, and the efficacy of using each tool in the Arctic (see Tables 1–4).

3.1. Spatial tools

Four of the tools which we identified were predominantly spatial in nature (Table 1): mandatory exclusion zones, restricted access/permitting systems, voluntary exclusion zones/area to be avoided, and vessel re-routing/transit separation schemes. Note that both areas to be avoided and transit separation schemes are typically designated by the IMO once they have support from a member country. Both of these tools have been used in non-Arctic MPAs with some success (Table 1). What became apparent from looking at several case studies was that many of these tools were only implemented following the establishment of protection for recognized endangered species or populations, proof of ecological uniqueness/significance, or due to recognized impacts from vessels. Therefore, for any of them to be readily applied within the Arctic, one of these factors would likely need to act as a driver also in this region as well. If such evidence does not exist, this may suggest that the likelihood of a spatial tool being successfully applied is decreased. Spatially delineating areas could also prove challenging in the Arctic due to the rapidly changing environment and ice formations, and adaptability could be a necessity if a spatially explicit tool is to be introduced.

Many additional points were discussed among the authors in relation to Arctic deployment of these tools, such as lack of deep water harbours and vessel bearing capacities of many areas not being well established. These and many more important points were not included in this table; only the challenges and opportunities perceived to be key to Arctic vessel management in general can be found in columns three and four of Table 1 below. We also noted that, in our experience, any voluntary management tools usually found greater uptake if they utilized local people and engaged with those involved from the start of the process. This may prove more difficult for all Arctic tools due to the remoteness. We also all agreed that voluntary measures would likely prove to be important for the successful more immediate implementation of any tool given that enforcement or monitoring would also be difficult at such latitudes.

3.2. Vessel tools

A total of four tools were identified as being predominantly 'vessel-based', although most also had strong spatial components (see Table 2). Speed reduction as a tool sparked recent discussions as to its effectiveness for reducing vessel noise (McWhinnie et al., 2017), however, it is widely accepted to be a viable tool for reducing ship strike risk in certain cetacean species (Vanderlaan and Taggart, 2007; Lagueux et al., 2011). Therefore in addition to the points highlighted in this table, discussions around this and many other tools emphasized that it will also be important to consider the nature of the primary vessel threat as well as the target species.

The authors also recognized that in the case of adopting a code of conduct in the Arctic, this would in no way be comparable to the Polar Code. This said, having an established 'universal' Arctic code such as this IMO document that for safety reasons ensures all Arctic mariners are familiar with it, could present a unique opportunity not present in non-Arctic waters. Inclusion of a 'code of conduct' for vessels when in the presence of marine mammals within existing frameworks (e.g. Polar Code) may enable wider dissemination. The Polar Code currently tells vessels to avoid marine mammal congregation areas, but does not tell vessels where these are or how to avoid them. This information is a crucial next step.

3.3. Monitoring tools

The three tools that we classified as monitoring tools (Table 3) are arguably not management tools at all but rather a means of measuring the success of a management measure being deployed. However, given that many of these schemes utilize a suite of tools and that monitoring is implicit in gauging their success, the addition of a management tool group within this analysis was deemed necessary.

3.4. Outreach tools

Many of the examples of management schemes that were explored utilized more than one outreach tool working in conjunction with the other spatial and/or vessel tools. The three broad categories into which we have grouped these tools into (Table 4) reflect the target recipients rather than the tools themselves. Often, outreach schemes in the examples included more than one of these groups in their strategies.

3.5. Case study: application of management tools

After compiling the data gathered from the MPA review within Tables 1–4, we evaluated the viability of each tool for use in the Arctic. We identified two tools, voluntary exclusion zones and voluntary speed reduction zones, as the tools that could most readily be deployed in the immediate future. We explored the use of these two different management tools spatially within the study area.

We used vessel track data from 2012 to 2016 to derive a vessel use area (Fig. 2). The area predominantly used by vessels over all five years is delineated within Fig. 2, while the vessel tracks shown are from a representative year of vessels transiting the area in 2016. A total of 67 unique vessels travelled within the study area between 2012 and 2016 (some of these vessels travelled within the study area over multiple years). Of these vessels, 18% were government/research vessels (including coast guard ice breakers), 18% were tug boats, 15% were passenger vessels, 13.5% were recreational vessels, 10.5% were container ships, 6% were naval vessels, 4.5% were tankers, and the remaining two vessels were a dredger and a fishing vessel.

The three buffers applied (10, 50 and 100 km) around each MPA, were specifically delineated with the goal of reducing the levels of associated vessel noise within the MPAs (See section 2.2 for further details). With the application of each of the different buffers, the areas covered by the MPA increase to between 4486 and 34,340 km^2 for the

Table 5
Area within each MPA and buffer zones around the MPAs that overlaps with the 2012–2016 VUA, and percent of the 2012–2016 VUA that overlaps with MPAs and buffers. Total area of the 2012–2016 VUA is 136,860.96 km^2.

MPA	Buffer Size (km)	Area of vessel use area covered (km^2)	% Area of vessel use area covered
TNMPA	0	0	0
	10	168	0.1
	50	6894	5.0
	100	22,901	16.7
ANMPA	0	1275	0.9
	10	3268	2.4
	50	13,414	9.8
	100	30,269	22.1

TNMPA and between 4720 and 36,655 km^2 for the ANMPA (Fig. 3). It was observed that the application of a 100 km buffer around the ANMPA site provides complete coverage between Cape Parry and Banks Island, and around TNMPA blocks travel in/out of the Mackenzie River delta, therefore an exclusion zone throughout the entire 100 km buffer would stop vessel traffic within the region, which is not reasonable. We therefore only assess exclusion zones within the MPA, and slowdowns in the buffer zones around the MPAs.

We calculated the area of overlap between the vessel use area and each of the buffer sizes around each MPA (Table 5). With the application of the smallest buffer (10 km) to both of the MPAs, this would equate to less than 3% of the total vessel use area being subject to a management measure. In contrast the addition of the largest (100 km) buffer to both MPAs would result in almost 40% of the vessel use area being subjected to a vessel management scheme.

We calculated the average speed of vessels transiting through each of the buffer zones for each year between 2012 and 2016 (Table 6). What is notable is that regardless of the year, more than half of all vessels transiting through the MPAs and their buffer zones within this study area were traveling at more than 10 knots. In general, the average vessel speed was greater for vessels that were further from the MPAs. The percentage of vessels traveling faster than 10 knots over the 5 years of data was lower in the 10 km buffer (71.4% for TNMPA and 84.9% for ANMPA) than in the 100 km buffer (92.3% for TNMPA and 92.4% for ANMPA).

On average, 44% of vessels within 10 km of TNMPA were traveling at over 15 knots as were 59% of vessels within 10 km of ANMPA. In comparison, 41 and 44% of vessels within the 50 km boundaries were traveling faster than 15 knots, which dropped further still to 39% of vessels within the 100 km buffer for both MPAs (Table 6).

In all instances, regardless of buffer size, more than half of vessels in the vessel use area would likely be affected in some way should a 10 knot slowdown be imposed. Interestingly, the number of vessels potentially affected did not change significantly when the buffer size was increased from 50 to 100 km.

3.6. Case study: vessel transits and spatial management

The three different vessels considered in this analysis, the Crystal Serenity, the Kelly Ovayuak, and the Nordic Orion, conducted very different transits through the study area (Fig. 4). The Crystal Serenity followed a relatively direct route through the study area, traversing 1153.2 km. It did not come into contact with the TNMPA, nor the buffer areas out to 100 km from it, and therefore would not be affected by any management measures for this MPA. The Crystal Serenity similarly did not pass through the ANMPA, but did pass through both its 50 and 100 km buffers. In the absence of any vessel management schemes, the Crystal Serenity could complete its journey in 28.6 h if it travelled at maximum speed (21.8 knots) throughout the journey, and could complete its journey in 55.6 h if traveling at mean speed (11.2 knots). By complying with a slow-down to 10 knots in the 100 km buffer, the Crystal Serenity would add an additional 14 h to its journey, if it was otherwise traveling at max speed, and an additional 2.3 h to its journey if traveling at mean speed. A 10 knot speed restriction in the 50 km buffer would add 5 h to Crystal Serenity's journey, if traveling at max speed, and 0.8 h if traveling at mean speed.

The Kelly Ovayuak took a more complexroute through the study area, traversing a total of 1601.6 km, this included multiple changes in direction and stops at multiple destinations while passing through the ANMPA, and through all buffers for both MPAs. In the absence of any vessel management schemes, the Kelly Ovayuak could complete its voyage in 73.3 h if traveling at maximum speed (11.8 knots) throughout its journey, or complete its journey in 125.3 h if traveling at mean speed (6.9 knots). Although avoiding the ANMPA entirely would substantially alter the route of this voyage (see Fig. 4), simply skirting the edge of the ANMPA would not add additional distance to the route of the Kelly Ovayuak (see following paragraph). A 10 knot slowdown in the MPA would add 0.4 h onto Kelly Ovayuak's journey if traveling at max speed. While a 10 knot slowdown in the 10, 50, or 100 km buffers would add 9.9, 20.0, or 33.2 h, respectively, onto the Kelly Ovayuak's journey if traveling at max speed. Notably, given that the Kelly Ovayuak's mean speed is slower than 10 knot, the speed required for the slowdown, this vessel would likely be unaffected by a 10 knot slowdown if traveling at mean speed.

A more complex vessel management scheme might be necessary in this region for a variety of reasons. We also examined a management scenario with a voluntary exclusion zone within the ANMPA. Under this scenario, Kelly Ovayuak would change its route to follow the outside edge of the ANMPA and then gradually join its previous route, which essentially does not affect the total distance travelled, and would not affect its time spent traveling if no other speed restrictions were in place. If we then applied a 10 knot speed restriction within the 10, 50, or 100 km buffers, the Kelly Ovayuak's journey would take an additional 10.4, 11.9, or 33.2 h, respectively, presuming she travels at max speed in all areas without a speed restriction.

The Nordic Orion's route essentially followed the mainland coastline, traversing a total of 901.6 km within our study area. Nordic Orion travelled through the 100 km buffer for the TNMPA, and the 10, 50, and 100 km buffers for the ANMPA, but never travelled through either MPA. In the absence of any speed restrictions, this voyage would take 23.6 h if traveling at max speed (20.6 knots) or 40.2 h if traveling at mean speed (12.1 knots). If a 10 knot slowdown was applied to the 10, 50, or 100 km buffers around both MPAs, the Nordic Orion's journey would take an additional 0.6, 3.8, or 8.8 h if traveling at max speed, and an additional 0.2, 1.1, or 2.6 h if traveling at mean speed.

4. Discussion

4.1. Reviewing a lessons learned approach

While appraising the management plans for the MPAs identified during the review, it was noted that there was a dearth of targeted management with respect to vessels and cetaceans outlined within the plans themselves. This was noted despite the risks posed to marine mammals from vessels frequently being acknowledged within the broader literature related to the MPA. For example, within management goals and objectives it was often noted that vessels pose a range of significant threats in and around the MPA ranging from acoustic disturbance to fatal strikes. It is important to note that a relatively small number of MPAs provided examples where management schemes for vessels had been developed and implemented despite the large number of MPAs reviewed. Interestingly, the number of tools identified across the MPAs that were reviewed was again relatively small, with similar tools such as speed restrictions, being utilized in multiple examples. The tools documented were not usually employed alone but rather used in conjunction with a suite of other management mechanisms in order to

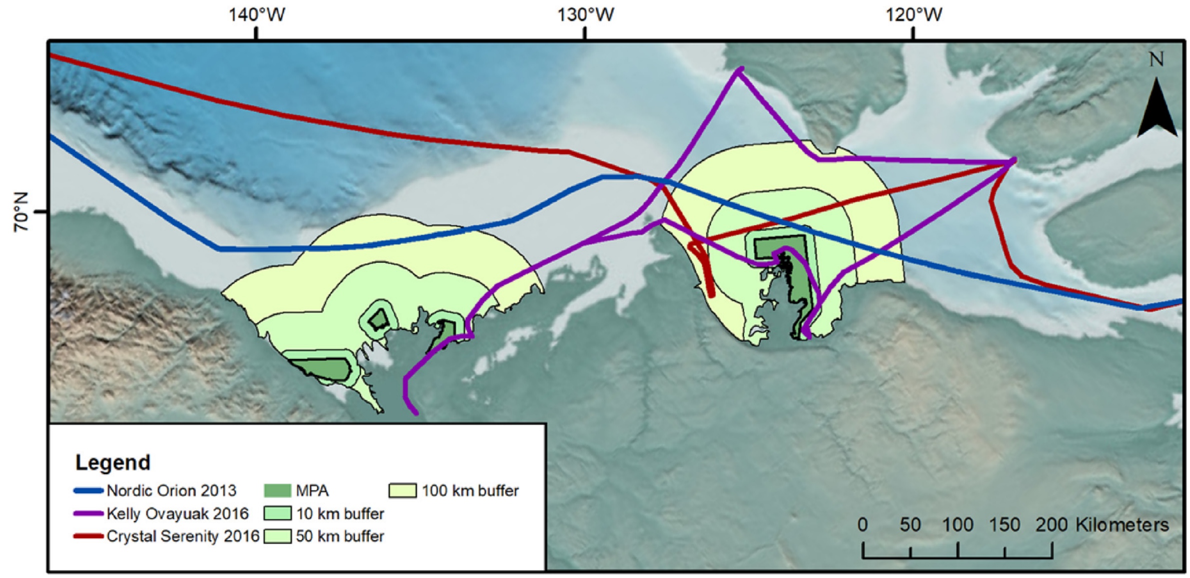

Fig. 4. Vessel transits by the Crystal Serenity (upper), the Kelly Ovayuak (middle) and the Nordic Orion (lower) showing their passage through proposed management zones. Base map provided by NOAA Environmental Satellite Data and Information Service.

attempt to achieve the desired outcomes and goals of the management plan.

It is also important to acknowledge that in using the review of MPAs published by Hoyt in 2012, that this study precluded more recently designated MPAs. Given their relative newness, it was deemed unlikely that any recently designated areas would have already developed or have implemented management plans. Therefore, while this review was not exhaustive, it was comprehensive, given that we were only aiming to review tools that have already been initiated. Although the variety of vessel management tools identified was not extensive, we decided to divide them into four types of tools based on their primary traits: Spatial, Vessel, Monitoring, and Outreach. In some instances a tool was deemed to potentially span two of these categories (i.e. spatial and vessel), it was asserted that each tool predominantly belonged in one of the four categories. One of the main recommendations of this paper is that multiple tools should be selected from across the four categories, therefore, classifying the tools in this manner should not lead to the omission of important components from any final management scheme devised. In almost every example of MPA management plans that we assessed, more than one tool was implemented, moreover, very often certain tools appeared to always be employed in conjunction with one another. For example, spatial tools such as a slow-down were often paired with a vessel tool such as pilotage.

Additional vessel management tools that did not appear within MPAs were not considered within this review. For example, Particularly Sensitive Sea Areas (PSSAs) were considered for additional review at the beginning of this study, however, none as of yet have been designated on the basis of protecting cetaceans from the threats of vessels in an area. Therefore, while the authors acknowledge their potential as a vessel management tool, they were not considered within this review. Within the schema set out here, a PSSA is essentially just an alternative designation for an area to be avoided (either mandatory or voluntary), and therefore could overlap and be integrated with the other spatial tools that we identified in our review.

Where possible, we sought evidence of the application of the tools within MPAs, however, official documentation assessing or monitoring vessel management schemes were very often found to be lacking online. In some cases, we had to use evidence gained from expert knowledge and personal opinions when evaluating the success of a management strategy. For example, if a tool listed was related to establishing a knowledge exchange program, and we could not find any evidence or materials from such a program after thorough online searches, then we were unable to examine any supporting evidence of success and had to rely on our own judgment and opinions. Effort was made to render such searches complete, not limited to online reports and documentation material, but also evidence of events/workshops/training programs that may have been held to disseminate information to local groups. Thus, we acknowledge that there may be additional information or evidence that is not openly accessible online, and therefore not taken under consideration during this review. In some instances, through reading the material, the review process highlighted areas where aspects of a strategy could be further improved upon or elements that appeared logical and very successful. Often these weren't or haven't been highlighted within publications as yet, but are known to be already acknowledged within the application of other management schemes; for example, the importance of stakeholder engagement (Newton and Elliott, 2016).

Through reviewing several studies that have begun to address and highlight management in Arctic environments, it became apparent that ice cover and remoteness are the two predominant factors that will affect the application of all the tools identified in some manner. However, these factors affect measures considered in greatly differing degrees. For example, pilotage is always a costly exercise, yet in the Arctic, the logistical feat of getting a pilot onboard and the duration over which they are required to stay on a ship could increase this fee substantially. When assessing each of the tools identified through an Arctic lens, we have had to draw upon our own expert knowledge as well as published resources in the absence of actual evidence in some instances. However, some evidence was found to exist, for example, texts outlining the already high complexity of permitting schemes in the Arctic. When possible the finding of such studies were drawn upon.

As well as the application of the tools themselves, other important points came to light from reviewing the management schemes employed within other MPAs. In many cases, it appeared that despite initial success and considerable efforts, many MPAs only received initial and limited funding to establish the MPA, and post designation, this funding was not always maintained. This seemed to be very common globally, and perhaps contributes to the growing concern that many MPAs are simply designated as paper parks (Pieraccini et al., 2017). The vast majority of MPAs we reviewed did not appear to have developed any significant management schemes to address the concerns outlined. In addition, while many of these MPAs listed cetacean species as key within their conservation efforts, few have produced targeted management plans that include action plans for these species. While we acknowledge that many forms of vessel traffic require higher levels of management from organizations such as IMO and national transportation management agencies, the governance of MPAs can be used to exert and force regulations on many domestic types of vessel and act as a driver of change at higher management levels. At the very least, MPAs can be used to elicit changes in vessel behavior through initiating voluntary management measures, incentive schemes, and outreach programs.

4.2. To slow down or avoid, that is the question

The two spatial tools that we selected for further exploration, *voluntary slow down* and *voluntary avoidance areas*, are amongst the most routinely employed mechanisms employed within MPAs, according to our review. Given the differences between the two management tools under consideration, it was very important to evaluate the geospatial application of these buffers. Referring to Fig. 3, it was notable that the application of the 100 km buffer as an avoidance area will be impractical around ANMPA because it completely encompasses the area between the mainland at Cape Parry and the southern tip of Banks Island, which also happens to be the only passage for most vessels currently transiting the region. A 100 km buffer may, however, be more feasible at TNMPA, if aimed at vessel traffic that is traveling through the region rather than community supply vessels, which must pass very close to the TNMPA when traveling between Inuvik and Tuktoyaktuk. While such a large avoidance area at ANMPA would not be suitable for vessel avoidance schemes, it would still be an option for deploying a slowdown. In fact, this large buffer would likely be the most effective in the case of reducing noise via a slowdown scheme given what is known about the propagation of underwater noise, especially in the Arctic, where vessels are audible when more than 100 km away (Halliday et al., 2017).

When exploring the implications of imposing management, the sample case studies focused on the implementation of a vessel slowdown option are important. There are inherent issues, however, with inferring speed data from AIS due to inaccuracies in GPS positions and observation time stamps, particularly at extreme latitudes such as in the Arctic. Therefore, the values generated in this exercise should only be used as indicative of the likely types of delays that would be experienced by vessels on different types of transits.

The vessels that are most likely to travel through the MPAs and the surrounding buffers are small community supply vessels that tend to hug the coastline, like the Kelly Ovayuak (Fig. 4). These vessels already travel much slower than vessels that travel farther from shore, and therefore will not be greatly affected by slowdown restrictions. For example, slowing down to 10 knots within the ANMPA would only add an additional 4 h onto a journey that was already 73.3 h long for the Kelly Ovayuak if it is traveling at max speed, and travel time would be unaffected by this slowdown if the Kelly Ovayuak was traveling at mean speed. This is particularly significant if such slow-down measures are going to be introduced on a voluntary basis, since it is more likely that vessels will comply if voyage times of vessels are not substantially increased. Although an exclusion zone within the ANMPA would not affect the distance travelled by the Kelly Ovayuak, it would force the vessel to travel farther from shore where it is more likely to be affected by strong winds coming from the west. For this reason, an exclusion zone might be impractical for small vessels, even though it would have little impact on travel times under ideal conditions. While the presence of any vessel will pose a potential risk of impact to a marine mammal, the presence of small relatively slow boats such as the Kelly Ovayuak, will arguably represent a lesser threat than large, fast moving ships. Therefore, for the moment, it is perhaps more practical to target management initiatives at those vessels that will likely have the greatest impact on marine mammals within the MPAs.

Larger vessels that tend to travel farther from shore and at greater speeds are the likely to be the most impacted by slowdown areas. If cargo vessels like the Nordic Orion are traveling at 20 knots, a slowdown in the 100 km buffer around both MPAs could add nearly 9 h onto their journey through the region. However, given that cargo vessels and tankers transiting the Northwest Passage are predicted to show the greatest increase in vessel traffic in the future, management strategies that specifically impact these vessels should be considered a high priority. Reducing their overall impact on the fragile Arctic ecosystem by reducing ship strikes and decreasing noise pollution is imperative, and a large slowdown area will help meet that goal.

Therefore, to summarize, in many Arctic areas such as the area explored in this study, avoidance areas, depending on size, are often infeasible due to geographical limitations and navigational hazards, but speed restrictions on vessels are likely to be a more suitable candidate for wide spread application. Speed restrictions have already been widely acknowledged as having the ability to greatly reduce the level of risk associated with marine mammal and vessel impacts (Huntington et al., 2015).

Speed reductions, despite some evidence supporting associated increased fuel efficiency, may still result in an economic cost due to longer voyage times. However, exploring scenarios such as the ones in this study using different vessel types and sizes of management areas may help limit extra time incurred and therefore minimize such costs. Vessels in Arctic waters will also need to ensure that they maintain sufficient speed to maneuver, particularly around floating hazards such as ice, so any areas sporting speed restrictions will have to take safety into account. Additionally, adoption of speed restrictions may have the additional benefit of reducing noise levels within the wider water basin as well as in constrained areas, where this may have the greatest impact.

4.3. Recommendations for the immediate future and beyond

From the review, it was deemed that voluntary management options would likely have the more immediate potential to be enacted within the Arctic. Proactive management in the form of voluntary schemes could facilitate future mandatory measures being put in place through the provision of evidence of success or highlighting difficulties. Compliance with both voluntary and mandatory measures can be determined through several factors including the knowledge of regulations and the severity of consequences for non-compliance that is related to the costs and benefits of compliance (Reimer et al., 2016). Incentive schemes that include elements such as reduced berthing fees have been employed in other areas, however, in the Arctic setting, new Arctic-centric incentives would perhaps need to be developed. Another proven means of increasing compliance has been the use of pilotage schemes, with ‘pilot buy in’ the adoption of voluntary measures has been found to be significant. However, as noted in Table 2, placing pilots on boats is expensive and while extending compulsory pilotage to encompass the entire Exclusive Economic Zone (EEZ) in the Arctic is another option, it is likely that many operators and managers may judge such extensions to be overly burdensome (Reeves et al., 2012). A compromise would be additional operator training or selective extensions to existing piloted sections of routes to cover specific areas within core marine mammal habitat areas or MPAs. This would likely be a more feasible option given the scale and complexity of navigation through Arctic waters.

The two recently designated MPAs within our study area are actively developing management plans, and one of the issues within this area is the impact of increasing vessel activities in the future. Therefore, voluntary measures implemented now could be written into these management plans as they develop and are revised when the plans themselves are re-evaluated. If additional monitoring tools can also be concurrently established, this will provide useful information not only for assessing the effectiveness of the management tools but of the MPA's management plan in relation to its specific goals. Such monitoring tools could include satellite or land-based AIS, which would allow for tracking of vessels within the region, and help monitor compliance of any management schemes. Passive acoustic monitoring could be used to track changes in underwater noise levels after management schemes are enacted, and can also be used to monitor marine mammal presence and potential overlap between marine mammals and vessels.

Looking to the future, the goal for many management schemes, not only in the Arctic, is to move to near real-time management measures in conjunction with real-time feedback. The development of real-time tools would likely utilize existing technology such as passive acoustic monitoring and AIS to relay information between vessels, managers, and observation networks. For example, in the Portifino Marine Protected Area they are using a permanent autonomous real-time passive acoustic monitoring system to improve the conservation of bottlenose dolphin (*Tursiops* truncates), through tracking in real-time the simultaneous presence of dolphins and motorboats within the reserve. The data gathered is used to prevent collisions and reduce noise pollution through relaying warning messages to boaters (Casale et al., 2016). This sort of increased information flow has already been predicted to mitigate vessel strike risk, and is more adaptable than current spatially fixed measures (Reimer et al., 2016). This would be based on the assumption that vessels could adequately and relatively quickly respond to changes in marine mammal distribution, which may not be feasible if ice conditions are poor. Bringing near real-time conservation and management information to vessel captains and pilots will also ultimately be dependent on the cooperation of the fleet. Vessel owners and operators will have to be receptive to an emerging technology and be prepared to take on the financial burden of carrying such equipment, or else measures to defray this cost be introduced.

Addressing vessel management in the wider area out with these MPAs was not the focus of this exercise, however it is important to acknowledge the future need to consider more broad scale Arctic management schemes, for example, Marine Spatial Planning (MSP) frameworks or Integrated Coastal Zone Management (ICZM). There are still many ecologically important areas in the Arctic that do not have conservation designations such as MPA attributed to them, and as such may currently lack the means by which to leverage management actions. Investigating the ability of large scale management schemes to address the threat of vessel related impacts in important yet unprotected habitat areas, could also be a prudent first step in seeking to attain conservation designations for such sites. Furthermore, marine mammals are mobile species, many undertake seasonal migrations and very often populations are transboundary in nature. Therefore, the potential role of international or bi-national institutions in initiating management protocols that will harmonise the protection of shared resources should also be explored.

Lastly, resource managers and academics have long noted the importance of local participation in the success of any governance related action (Meek et al., 2011). This will likely be especially pertinent in remote Arctic regions, both at a community level and amongst vessel operators. Some tools in particular could be naturally suited and benefit the inclusion of local community knowledge, for example, pilotage schemes could incorporate the training and deployment of local pilots on vessels. The importance of developing a substantial outreach scheme, that may in fact encompass all three of the outreach tools should also not be overlooked. Reimer et al. (2016) highlighted the belief that mariners who are more knowledgeable, or are aware of the conservation status and issues faced by species of marine mammal, will probably be more likely to engage with such issues and may be more receptive to new management measures, technologies and programs to minimize their impacts.

5. Conclusions

In order to develop effective vessel management plans for an Arctic area or Arctic MPA, the findings of this study would support the need to employ more than one management tool. From the four 'toolkits' identified (Spatial, Vessel, Monitoring, and Outreach), at least one tool should be adopted from each and in conjunction with each other used to establish a comprehensive management scheme that regulates the movement of vessel in the water, places personnel on board that are aware of issues related to marine mammals, and also uses observations to inform future management decisions. Some management strategies may be unfeasible for immediate application, but should still be considered for future implementation. Due to an immediate need to start addressing vessel traffic, over what is still at the moment a relatively short summer season, the implementation of voluntary measures and the adoption of monitoring and outreach schemes that 'piggy back' on already established projects should be prioritized in the near future. Any voluntary schemes implemented now, if well monitored, can potentially provide evidence in support of developing more long-term, permanent, and enforced management solutions if necessary.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2018.03.042.

References

Agardy, T., di Sciara, G.N., Christie, P., 2011. Mind the gap: addressing the shortcomings of marine protected areas through large scale marine planning. Mar. Policy 35 (2), 226–232. http://dx.doi.org/10.1016/j.marpol.2010.10.006.

Allen, A.S., 2014. The development of ships' routeing measures in the Bering Strait: lessons learned from the North Atlantic right whale to protect local whale populations. Mar. Policy 50, 215–226. http://dx.doi.org/10.1016/j.marpol.2014.05.019.

Bannister, J., 2001. Status of southern right whales (Eubalaena australis) off Australia. J. Cetacean Res. Manag. 2, 103–110.

Blackwell, S.B., Nations, C.S., McDonald, T.L., Greene, C.R., Thode, A.M., Guerra, M., Macrander, A.M., 2013. Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea. Mar. Mamm Sci. 29, 342–365.

Blackwell, S.B., Nations, C.S., McDonald, T.L., Thode, A.M., Mathias, D., Kim, K.H., Greene, C.R., Macrander, A.M., 2015. Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. PLoS One 10 (6), e0125720. http://dx.doi.org/10.1371/journal.pone.0125720.

Bourbonnais, P., Lasserre, F., 2015. Winter shipping in the Canadian Arctic: toward year-round traffic? Polar Geogr. 38 (1), 70–88. http://dx.doi.org/10.1080/1088937X.2015.1006298.

Bruno, K., Lützhöft, M., 2009. Shore-based Pilotage: pilot or autopilot? Pilotage as a control problem. J. Navig 62, 427–437. http://dx.doi.org/10.1017/50373463309005335.

Casale, A., Brunoldi, M., Grosso, D., Alessi, J., Cappanera, V., Taiuti, M., 2016. ARION System for coastal dolphin conservation: a tool for real-time dolphin passive acoustic monitoring in the Portifino Marine Protected Area. Proc. Meet. Acoust. 27, 070009. https://doi10.1121/2.0000283.

Chion, C., Lagrois, D., Dupras, J., Turgeon, S., McQuinn, I.H., Michaud, R., Ménard, N., Parrott, L., 2017. Underwater acoustic impacts of shipping management measures: results from a social-ecological model of boat and whale movements in the St. Lawrence River Estuary (Canada). Ecol. Model. 354, 72–87. http://dx.doi.org/10.1016/j.ecolmodel.2017.03.014.

Citta, J.J., Quakenbush, L.T., Okkonen, S.R., Druckenmiller, M.L., Maslowski, W., Clement-Kinney, J., George, J.C., Brower, H., Small, R.J., Ashijan, C.J., Harwood, L.A., Heide-Jørgensen, M.P., 2015. Ecological characteristics of core-use areas by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006-2012. Prog. Oceanogr. 136, 201–222. http://dx.doi.org/10.1016/j.pocean.2014.08.012.

Cosens, S.E., Dueck, L.P., 1993. Icebreaker noise in Lancaster Sound, N.W.T., Canada: implications for marine mammal behaviour. Mar. Mamm Sci. 9 (3), 285–300. http://dx.doi.org/10.1111/j.1748-7692.1993.tb00456.x.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada), 2014. COSEWIC Assessment and Status Report on the Beluga Whale Delphinapterus leucas, St. Lawrence Estuary Population, in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa xii + 64 pp.

Côté, I.M., Mosqueira, I., Reynolds, J.D., 2001. Effects of marine reserve characteristics on the protection of fish populations: a meta-analysis. J. Fish Biol. 59 (sA), 178–189. http://dx.doi.org/10.1111/j.1095-8649.2001.tb01385.x.

David, L., Alleaume, S., Guinet, C., 2011. Evaluation of the potential of collision between fin whales and maritime traffic in the north western Mediterranean Sea in summer and mitigation solutions. J. Mar. Anim Ecol. 4 (1), 7–28.
Day, J.C., 2002. Zoning- lessons from the great Barrier Reef Marine park. Oceans Coast. Manag. 45 (2–3), 139–156. http://dx.doi.org/10.1016/S0964-5691(02)00052-2.
DFO, (Department of Fisheries and Oceans), 2012. Recovery Strategy for the Beluga Whale (Delphinapterus leucas) St. Lawrence Estuary Population on Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa 88pp + Xpp.
Diachok, O.I., Winokur, R.S., 1974. Spatial variability of underwater ambient noise at the Arctic ice-water boundary. J. Acoust. Soc. Am. 55, 750–753. http://dx.doi.org/10.1121/1.1914594.
Dunlop, R.A., 2016. The effect of vessel noise on humpback whale, Megaptera novaeangliae, communication behavior. Anim. Behav. 111, 13–21. http://dx.doi.org/10.1016/j.anbehav.2015.10.002.
Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K., Dooling, R., 2016. Communication masking in marine mammals: a review and research strategy. Mar. Pollut. Bull. 103, 15–38. http://dx.doi.org/10.1016/j.marpolbul.2015.12.007.
Fernandez, L., Kaiser, B., Moore, S., Vestergaard, N., 2016. Introduction to special issue: arctic marine resource governance. Mar. Policy 72, 237–239. http://dx.doi.org/10.1016/j.marpol.2016.04.035.
Findley, L.T., Vidal, O., 2002. Gray whale (Eschrichtus robustus) at calving sites in the Gulf of California, Mexico. J. Cetacean Res. Manag. 4 (1), 27–40.
Fisheries Joint Management Committee, 2001. Beaufort Sea Beluga Management Plan. FJMC, Inuvic 28p.
George, J.C., Philo, L.M., Hazard, K., Withrow, D., Carroll, G.M., Suydam, R., 1994. Frequency of killer whale (Orcinus orca) attacks and ship collisions based on scarring on bowhead whales (Balaena mysticetus) of the Bering-Chukchi-Beaufort Seas stock. Arctic 47 (3), 247–255.
George, J.C., Zeh, J., Suydam, R., Clark, C., 2004. Abundance and population trend (1978-2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. Mar. Mamm Sci. 20, 755–773. http://dx.doi.org/10.1111/j.1748-7692.2004.tb01191.x.
Gervaise, C., Simard, Y., Roy, N., Kinda, B., Menard, N., 2012. Shipping noise in whale habitat: characteristics, sources, budget, and impact on Belugas in Saguenay-St Lawrence Marine Park hub. J. Acoust. Soc. Am. 132 (1), 76–89. http://dx.doi.org/10.1121/1.4728190.
Halliday, W.D., Insley, S.J., Hilliard, R.C., de Jong, T., Pine, M.K., 2017. Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. Mar. Pollut. Bull. 123 (1-2), 73–82. http://dx.doi.org/10.1016/j.marpolbul.2017.09.027. (in press).
Hauser, D.D.W., Laidre, K.L., Suydam, R.S., Richard, P.R., 2014. Population-specific home ranges and migration timing of Pacific Arctic beluga whales (Delphinapterus leucas). Polar Biol. 37, 1171–1183. http://dx.doi.org/10.1007/s00300-014-1510-1.
Hoekstra, P.F., O'Hara, T.M., Pallant, S.J., Solomon, K.R., Muir, D.C.G., 2002. Bioaccumulation of organochloride contaminants in bowhead whales (Balaena mysticetus) from Barrow, Alaska. Arch Environ. Contam. Toxicol. 42, 497–507.
Hoekstra, P.F., O'Hara, T.M., Fisk, A.T., Borgå, K., Solomon, K.R., Muir, D.C.G., 2003. Trophic transfer of persistent organochlorine contaminants (OCs) within an Arctic marine food web from the southern Beaufort-Chukchi Seas. Mar. Pollut. 124 (3), 509–522.
Hooker, S.K., Gerber, L.R., 2004. Marine reserves as a tool for ecosystem-based management: the potential importance of megafauna. BioScience 54 (1), 27–39. http://dx.doi.org/10.1641/0006-3568(2004)054[0027:MRAATF]2.0.CO;2.
Hoyt, E., 2009. Marine Protected Areas. Encyclopedia of Marine Mammals, second ed. pp. 696–705.
Hoyt, E., 2011. Marine Protected Areas for Whales, Dolphins and Porpoise: a World Handbook for Cetacean Habitat Conservation and Planning. 2nd Edition revised. Earthscan, London and New York 477 pp.. ISBN: 978-1-84407-762-5 and 978-1-84407-763-2.
Huntington, H.P., 2009. A preliminary assessment of threats to arctic marine mammals and their conservation in the coming decades. Mar. Policy 33, 77–82. http://dx.doi.org/10.1016/j.marpol.2008.04.003.
Huntington, H.P., Daniel, R., Hartsig, A., Harun, K., Heiman, M., Meehan, R., Noongwook, G., Pearson, L., Prior-Parks, M., Robards, M., Stetson, G., 2015. Vessels, risks and rules: planning for safe shipping in Bering Strait. Mar. Policy 51, 119–127. http://dx.doi.org/10.1016/j.marpol.2014.07.027.
IMO, International Maritime Organisation, 2017. The Polar Code. url. https://edocs.imoFinal Documents/English/MEPC 68-21-ADD.1(E).doc.
Inman, A., Brocker, E., Dolman, S., McCann, R., Wilson, M., 2016. The use of marine wildlife-watching codes and their role in managing activities within marine protected areas in Scotland. Ocean Coast. Manag. 132, 132–142. http://dx.doi.org/10.1016/j.ocecoaman.2016.08.005.
Insley, S.J., Halliday, W.D., de Jong, T., 2017. Seasonal patterns in ocean ambient noise near Sachs Harbour, Northwest Territories. Arctic 70, 239–248. http://dx.doi.org/10.14430/arctic4662.
IUCN, Cetacean Specialist Group, 1996. Balaena Mysticetus (Bering-chukchi-Beaufort Sea Subpopulation). http://dx.doi.org/10.2305/IUCN.UK.1996.RLTS.T2468A9442786.en. The IUCN Red List of Threatened Species 1996: e.T2468A9442786, Downloaded on 21 September 2017.
Kraus, S.D., Kenney, R.D., Mayo, C.A., McLellan, W.A., Moore, M.J., Nowacek, D.P., 2016. Recent scientific publications Cast doubt on North Atlantic right whale future. Front. I Mar. Sci. http://dx.doi.org/10.3389/fmars.2016.00137.
Lagueux, K.M., Zani, M.A., Knowlton, A.R., Kraus, S.D., 2011. Response by vessel operators to protection measures for right whales Eubalaena glacialis in the southeast US calving ground. Endanger. Species Res. 14, 69–77. http://dx.doi.org/10.3354/esr00335.
Lynch, J.A., Corbett, E.S., 1990. Evaluation of best management practices for controlling non-point pollution from agricultural operations. J. Am. Water Resour. Assoc. 26 (1), 41–52. http://dx.doi.org/10.1111/j.1752-1688.1990.tb01349.x.
McDonald, T., Richardson, W., Greene, C.J., Blackwell, S.B., Nations, C.S., Nielson, R.M., Steever, B., 2012. Detecting changes in the distribution of calling bowhead whales exposed to fluctuating anthropogenic sounds. J. Cetacean Res. Manag. 12 (1), 91–106.
McKenna, M.F., Ross, D., Wiggins, S.M., Hildebrand, J.A., 2012. Underwater radiated noise from modern commercial ships. J. Acoust. Soc. Am. 131 (1), 92–103. https://doi10.1121/1.3664100.
McKenna, M.F., Gabriele, C., Kipple, B., 2017. Effects of marine vessel management on the underwater acoustic environment of Glacier Bay National Park, AK. Ocean Coast. Manag. 139, 102–112. http://dx.doi.org/10.1016/j.ocecoaman.2017.01.015.
McWhinnie, L., Smallshaw, L., Serra-Sogas, N., O'Hara, P., Canessa, R., 2017. The grand challenges in researching marine noise pollution from vessels: a horizon scan for 2017. Front. Mar. Sci. http://dx.doi.org/10.3389/fmars.2017.00031.
Meek, C.L., Lovecraft, A.L., Varjopuro, R., Dowsley, M., Dale, A.T., 2011. Adaptive governance and the human dimensions of marine mammal management: implications for policy in a changing north. Mar. Policy 35, 466–476. http://dx.doi.org/10.1016/j.marpol.2010.10.021.
Moore, M.J., Knowlton, A.R., Kraus, S.D., McLellan, W.A., Bonde, R.K., 2004. Morphometry, gross morphology and available histopathology in North Atlantic right whale (Eubalaena glacialis) mortalities (1970-2002). J. Cetacean Res. Manag. 6, 199–214.
Mosnier, A., Doniol-Valcroze, T., Gosselin, J.F., Lesage, V., Measures, L.N., Hammill, M.O., 2015. Insights into process of population decline using an integrated population model: the case of the St. Lawrence Estuary beluga (Delphinapterus leucas). Ecol. Model. 314, 15–31. http://dx.doi.org/10.1016/j.ecolmodel.2015.07.006.
Newton, A., Elliott, M., 2016. A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory process. Front. Mar. Sci. http://dx.doi.org/10.3389/fmars.2016.00230.
NOAA, 2017a. Passive Acoustic Monitoring. URL. https://stellwagen.noaa.gov/science/passive_acoustics_noise.html, Accessed date: 28 August 2017.
NOAA, 2017b. Reducing Ship Strike Risk to Whales. URL. https://sanctuaries.noaa.gov/protect/shipstrike/shipping_outreach.html, Accessed date: 28 August 2017.
Nyman, E., 2016. *Protecting the Poles: Marine Living Resource Conservation Approaches in the Arctic and Antarctic.* Ocean and Coastal Management. Article in Presshttp://dx.doi.org/10.1016/j.ocecoaman.2016.11.006.
Palmer, M., 2008. Calculation of distance travelled by fishing vessels using GPS positioned data: a theoretical evaluation of the sources of error. Fish. Res. 89 (1), 57–64. http://dx.doi.org/10.1016/j.fishres.2007.09.001.
Parks, B.C., 2017. Robson Bight Ecological Reserve. URL. http://www.env.gov.bc.ca/bcparks/eco_reserve/robsonb_er.html, Accessed date: 28 August 2017.
Parrott, L., Chion, C., Turgeon, S., Ménard, N., Cantin, G., Michaud, R., 2016. Slow down and save the whales. Solutions 6 (6), 40–47.
Pieraccini, M., Coppa, S., De Luca, A.G., 2017. Beyond marine paper parks? Regulation theory to assess and address environmental non-compliance. Aquat Conserv Mar. Freshw. Ecosyst. 27, 177–196. http://dx.doi.org/10.1002/aqc.2632.
Pizzolato, L., Howell, S.E.L., Derksen, C., Dawson, J., Copland, L., 2014. Changing sea ice conditions and marine transportation activity in Canadian Arctic waters between 1990 and 2012. Climact Change 123 (2). http://dx.doi.org/10.1007/s10584-013-1038-3.
Pongolini, L., Pälsson, J., Folkunger, J., Larsson, J., Bouyssou, A., Hildebrand, L., Bellefontaine, N., 2017. Assessing and Mitigating the Environmental Impacts of Shipping in the Arctic. Project Report. http://commons.wmu.se/arctic_shipping/1.
Reeves, R., Rosa, C., George, J.C., Sheffield, G., Moore, M., 2012. Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. Mar. Policy 36, 454–462. http://dx.doi.org/10.1016/j.marpol.2011.08.005.
Reeves, R.R., Ewins, P.J., Agbayani, S., Heide-Jørgensen, M.P., Kovacs, K.M., Lydersen, C., Suydam, R., Elliott, W., Polet, G., van Dijk, Y., Blijleven, R., 2014. Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. Mar. Policy 44, 375–389. http://dx.doi.org/10.1016/j.marpol.2013.10.005.
Reimer, J., Gravel, C., Brown, M.W., Taggart, C.T., 2016. Mitigating vessel strikes: the problem of peripatetic whales and the peripatetic fleet. Mar. Policy 68, 91–99. http://dx.doi.org/10.1016/j.marpol.2016.02.017.
Richardson, W.J., Miller, G.W., Greene, C.R., 1999. Displacement of migrating bowhead whales by sound from seismic surveys in shallow waters of the Beaufort Sea. J. Acoust. Soc. Am. 106, 2281. http://dx.doi.org/10.1121/1.427801.
Silber, G.K., Vanderlaan, A.S.M., Arceredillo, A.T., Johnson, L., Taggart, C.T., Brown, M.W., Bettridge, S., Sagarminga, R., 2012. The role of the international maritime organization in reducing vessel threats to whales: process, opinions, actions and effectiveness. Mar. Policy 36 (6), 1221–1233. http://dx.doi.org/10.1016/j.marpol.2012.03.008.
Silber, G.K., Adams, J.D., Fonnesbeck, C.J., 2014. Compliance with vessel speed restrictions to protect North Atlantic right whales. PeerJ 2, e399. http://dx.doi.org/10.7717/peerj.399.
Silva, L., Williams, D.D., 2001. Buffer zones versus whole catchment approaches to studying land use impacts on river water quality. Water Res. 35 (14), 3462–3472. http://dx.doi.org/10.1016/S0043-1354(01)00062-8.
Simon, M., Nuuttila, H., Reyes-Zamuollo, M.M., Ugarte, F., Verfub, U., Evans, P.G.H., 2010. Passive acoustic monitoring of bottlenose dolphin and harbor porpoise in Cardigan Bay, Wales, with implications for habitat use and partitioning. J. Mar. Biol. Assoc. U. K. 90 (8), 1539–1545. http://dx.doi.org/10.1017/S0025315409991226.
Southall, B., Bowles, A., Ellison, W., Finneran, J., Gentry, R., Greene, C., Kastak Jr., D.,

Kette, D., Miller, J., Nachtigall, P., Richardson, J.W., Thomas, J.A., Tyack, P., 2009. Marine mammal noise exposure criteria: initial scientific recommendations. J. Acoust. Soc. Am. 125, 2517. http://dx.doi.org/10.1121/1.4783461.

Vanderlaan, A.S.M., Taggart, C.T., 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Mar. Mamm. Sci. 23 (1), 144–156.

Vanderlaan, A.S.M., Taggart, C.T., 2009. Efficiency of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. Conserv. Biol. 23 (6), 1467–1474. http://dx.doi.org/10.1111/j.1523-1739.2009.01329.x.

Vanderlaan, A.S.M., Taggart, C.T., Serdynska, A.R., Kenney, R.D., Brown, M.W., 2008. Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endanger. Species Res. 4, 283–297. http://dx.doi.org/10.3354/esr00083.

Wright, A.J., Deak, T., Parsons, E.C.M., 2011. Size matters: management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. Mar. Pollut. Bull. 63, 5–9. http://dx.doi.org/10.1016/j.marpolbul.2009.11.024.