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Tourist vessel traffic in important whale areas in the western Canadian Arctic: Risks and possible management solutions

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ABSTRACT

Vessel traffic has been increasing rapidly in the Arctic, and within the Canadian Arctic, tourist vessels are the fastest growing maritime sector. Vessel traffic can cause a variety of impacts on whales, including ship strikes and acoustic disturbance. Here, the overlap between tourist vessels (e.g., pleasure craft/yachts and passenger vessels/cruise ships) and whale concentration areas is assessed within the Inuvialuit Settlement Region of the western Canadian Arctic. Different management measures which could be used to reduce impacts on whales are also assessed. Passenger vessels have had a relatively constant overlap with whale concentration areas through time, whereas pleasure craft have had a recent and rapid increase. Passenger vessels may have a greater impact on whales, compared to pleasure craft, since they are larger and travel faster. Excluding vessels from the two marine protected areas in the region would have no impact on whales within concentration areas, since vessels would likely just be displaced to adjacent areas with similar whale concentrations. Restricting vessels to the Canadian government's proposed low-impact corridor may reduce impact slightly, but creating a corridor completely outside of the known whale area could more significantly reduce the potential impact of vessels on whales in those areas. Restricting vessel speed within whale areas would also reduce the impact of passenger vessels, but would not likely reduce the impact of pleasure craft. Overall, a combination of management measures may be the best way to reduce impacts on whales in concentration areas.

1. Introduction

Vessel traffic can pose serious threats to whales. Vessels can directly strike whales [1], cause acoustic disturbance [2] or behavioural disturbance [3], increase stress levels [4], and can also pollute the waters where whales live [5]. Many populations of whales live in constant contact with vessels, and are therefore constantly at risk [6]. Other populations, such as those in remote areas, can be under reduced threat, but may have seasonal threats [7,8]. Although the overall contact with vessels is reduced for these populations, the overall risk may be greater since these whales are not as acclimated to vessels [e.g., [8,9]].

Three different management measures are typically used for decreasing the risks of vessels to whales [10]: 1) keeping vessels away from whales, either through ship routeing measures or exclusion zones; 2) restricting vessel speed, which reduces risks of ship strikes and can lower noise pollution; 3) using marine mammal observers or other forms of monitoring for whales near vessels, combined with altering vessel behaviour if whales are nearby (e.g., changing course, stopping engine). For example, adjusting the vessel corridor in the Roseway Basin of Canada to avoid the Right Whale Conservation Area was assessed to reduce the risk of ship strikes for North Atlantic right whales by 62% [11]. For another example, the Port of Vancouver (Canada) recently enacted an 11-knot slow-down in Haro Strait, reducing the amount of time when foraging by southern resident killer whales would be impacted by ~10% [12]. Management schemes that use multiple measures, such as an exclusion zone with a slow-down around it, may be more effective than any single management measure [10,13–15].

In the Arctic, vessel traffic volume has been steadily increasing over the past few decades, due to the greater access enabled by decreased sea ice in the summer, as well as improved technologies [16–20]. Additional vessel traffic will lead to further overlap between vessels and Arctic whales [8]. This issue is especially important because, due to the

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relative remoteness of the Arctic, many management tools available in non-Arctic regions will not be as effective [10]. For example, any management measure requiring enforcement will be less effective simply because there are fewer enforcement vessels in the Arctic with a much greater distance to patrol, although enforcement might be aided by ship tracking technology such as AIS (automatic identification system), on which some vessels are required to transmit. Moreover, whales are also a subsistence food source for Indigenous people in many Arctic communities, and these communities typically want vessels to stay out of important whale areas (e.g., [21]). The remoteness of the Arctic also means that the distribution and abundance of whales are not as well understood [22]. Even if mariners intend to avoid key whale areas, information on these whale areas may not be available to them. The harsh and unpredictable environmental conditions also demand flexibility in route planning, so avoiding whale areas may sometime be impossible even if those areas are known.

The Polar Code was recently implemented by the International Mariners Organization (IMO) in an attempt to make vessel traffic in the Arctic safer [23]. The Polar Code applies to all ships certified under SOLAS (International Convention for the Safety of Life at Sea) [24], which includes cargo vessels 500 gross tons or more, and all passenger vessels with greater than 12 passengers. The Polar Code does not apply to pleasure craft, fishing vessels, military vessels, and any other vessels not covered by SOLAS [25]. Most of the Polar Code is aimed at ensuring that vessels traveling in the Arctic meet certain standards and make appropriate voyage plans. However, Chapter 11 (Voyage Planning) of the Polar Code states that mariners should take into account current information and measures to be taken, relevant routeing systems, speed recommendations, and vessel traffic services relating to areas with higher densities of marine mammals, including seasonal migration areas. Mariners are to follow national and international laws and guidelines related to reducing impacts of vessels on marine mammals. However, as stated earlier, the particulars of where marine mammals congregate or migrate in the Arctic is not well understood, except for a few well studied populations [22], such as the Bering-Chukchi-Beaufort bowhead whales (*Balaena mysticetus*) [26,27] and Beaufort Sea beluga whales (*Delphinapterus leucas*) [28]. These two populations of whales make for a good case study of how vessel traffic interacts with key areas for these whales, given that these areas are known. Both of these whale populations have historically spent their winters in the Bering Sea and southern Chukchi Sea, and then migrate to the Beaufort Sea in the summer [26–28]. Much of their summer core use areas are in the eastern Beaufort Sea in the western Canadian Arctic (Fig. 1).

Vessel traffic has been increasing in the Canadian Arctic over the past three decades, and is three times higher now than it was in the 1980s [16,17,20]. The vessel types increasing the most are pleasure craft and passenger vessels [16,17,20]. Passenger vessels mostly comprise cruise ships and expedition-style tour vessels, and are defined under SOLAS as any vessel carrying 12 or more passengers [24]. Pleasure craft include the full spectrum of privately owned vessels used for pleasure, but most are private yachts that can range in size from very small to quite large. Both of these vessel classes are often destinational, and may spend time exploring and seeking out areas with more marine wildlife, although passenger vessels may spend more time transiting. These vessels may therefore cause greater disturbance to whales than other types of maritime traffic in the Arctic on the basis of proximity. Voluntary management measures, such as exclusion zones around whale areas, may not be effective for these vessels since they are actively seeking out marine mammals, and often have marine mammal observers on board who direct the ship towards marine mammals rather than away from marine mammals.

This study explores the potential impact of tourist vessel traffic (pleasure craft and passenger vessels) on whales in the western Canadian Arctic. The overlap between tourist vessel traffic and whale concentration areas in the Inuvialuit Settlement Region is examined, and three different management measures for reducing impacts of tourist vessels on whales are also explored. These measures include exclusion zones in marine protected areas, vessel routeing (i.e. corridors), and vessel slowdowns.

2. Methods

2.1. Study area

This study focuses on the Inuvialuit Settlement Region (ISR) in the western Canadian Arctic, which extends from the border between Yukon and Alaska in the west to the border between Northwest Territories and Nunavut in the east (Fig. 1). The western Canadian Arctic is the summer range for bowhead whales (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*). The Ecological Atlas of the Bering, Chukchi, and Beaufort Seas [29] was used to identify high concentration areas for bowhead and beluga whales, and spatial data for both species was obtained from this atlas. Female beluga whales with calves tend to congregate in the Mackenzie River Estuary [30,31], while subadults and males tend to spend time throughout the ISR [28,32]. The high concentration area at the Mackenzie River Estuary is used for this study, which covers an area of 33,556 km^2. The Tarium Niryutait Marine Protected Area (TNMPA), created in 2010 through a partnership with Fisheries and Oceans Canada and the Inuvialuit people, lies within the beluga congregation area in the Mackenzie River Estuary, was designated specifically for beluga whales, and covers an area of 1750 km^2. However, much of the beluga concentration area lies outside of the MPA, with only 5% protected by the TNMPA (Fig. 1). Bowhead whales use areas near the shelf break throughout the eastern Beaufort Sea and Amundsen Gulf, likely where upwelling creates large and rich foraging areas [27]. Three main foraging areas exist for bowhead whales throughout the ISR at Atkinson Point, Cape Bathurst, and Cape Parry [26,27,33], for a total area of 15,410 km^2. The bowhead foraging area at Cape Parry overlaps with a small corner of the Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA) (Fig. 1), which was created in 2016, and protects just 0.3% (43 km^2) of the total bowhead concentration area. The ANMPA is quite large (2361 km^2), but was not designated specifically for bowhead whales, but rather for Arctic char, cod, beluga whales, seals, polar bears, and sea birds.

2.2. Vessel traffic analyses

Multiple analyses were conducted on vessel traffic data, with the goal of describing trends in vessel traffic through time, overlaps with whale concentration areas, and vessel speed within whale concentration areas. The potential effectiveness of three management measures that could be used to reduce risk to whales was examined: marine protected areas, shipping corridors, and vessel slow downs. Two separate databases were used for these analyses. First, a database of vessel tracks through the Canadian Arctic from 1990 to 2015 was used, which has been fully described in previous publications [16,17,20], and henceforth referred to as the Canadian Coast Guard dataset. Briefly, this database was created using Canadian Coast Guard data for the NORDREG Zone, based on position reports from individual vessels transiting through the NORDREG Zone. These vessel points were then converted into tracks using a least cost path approach. The vessel track data were used for the analysis of vessel traffic through time and overlaps with whale concentration areas. The second dataset is a series of vessel tracks from satellite AIS data from ExactEarth (Cambridge, Ontario, Canada) from 2012 to 2017. Satellite AIS data were used to examine vessel speed.

First, trends in vessel traffic through time were examined using vessel tracks from the Canadian Coast Guard dataset from 1990 to 2015. The total distance traveled by all vessels within each vessel class during each year was calculated, and trends through time were analyzed using linear regression in R (package: stats; function: lm; [34]), with distance traveled as the dependent variable and year as the

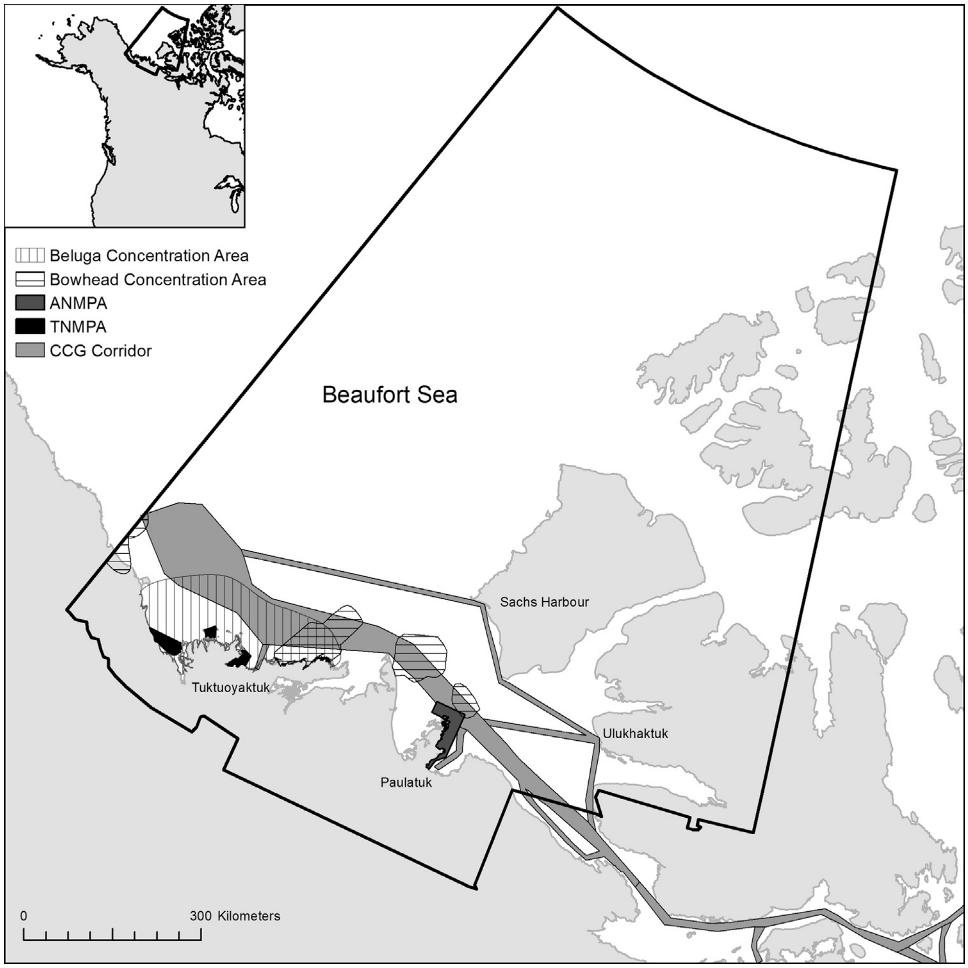

Fig. 1. Study area map, showing the Inuvialuit Settlement Region, the beluga whale and bowhead whale concentration areas, the current vessel corridor (CCG Corridor), and the Anguniaqvia Niqiqyuam Marine Protected Area (ANMPA) and the Tarium Niryutait Marine Protected Area (TNMPA).

independent variable. Two models were created for each vessel class, one with a linear term for year and the other with a quadratic term for year (using the 'poly' function), and models were compared using bias-corrected Akaike's information criteria (package: qpcR; function: AICc; [35]). These relationships were then compared to patterns of vessel traffic in the entire Canadian Arctic, calculated using the same dataset [20].

The distance traveled by all pleasure craft and passenger vessels was examined within 10 × 10 km grid cells within the ISR using the vessel tracks from the Canadian Coast Guard dataset from 1990 to 2015. Values for distance traveled within whale concentration areas were extracted, and distance traveled within each whale area and within the entire ISR were compared through time. Polygons were also created around all vessel tracks for both pleasure craft and passenger vessels within the ISR for four time periods (1990–2000, 2001–2005, 2006–2010, 2011–2015) in order to delineate the overall area impacted by each vessel type within each period. The amount of overlap between the vessel use polygons and whale concentration areas was examined.

Vessel speed was calculated using satellite AIS data from 2012 to 2017. Satellite AIS data were converted into individual vessel tracks, and vessel speed was calculated as the distance between the locations of consecutive AIS messages divided by the time between the two messages. The speed of pleasure craft and passenger vessels was examined within the entire ISR, and within the beluga whale and bowhead whale high concentration areas. Analysis of variance in R (package: stats; function: aov) was used to examine differences in speed between pleasure craft and passenger vessels and between the entire ISR, the beluga area, and the bowhead area.

2.3. Effectiveness of marine protected areas and vessel corridors

The amount of overlap between MPAs and whale concentration areas was examined to assess the effectiveness of excluding vessels from MPAs towards the goal of reducing impacts on whales, irrespective of other considerations such as hydrography or sea ice concentration.

To examine the effectiveness of the vessel corridor, three questions were examined: 1) How much does the current vessel corridor [36] overlap with whale concentration areas? 2) Is there a better placement for the corridor that would reduce overlap with whale concentration areas? 3) If pleasure craft and passenger vessels followed the corridor (either current or new placement), how much would it reduce their overlap with whale concentration areas? Pleasure craft and passenger vessels may be less inclined to follow a corridor, since they are often seeking out wildlife or interesting locations. However, for this analysis, we assume that there is some requirement for these vessels to follow the corridor. To answer these questions, overlap between the current corridor and whale concentration areas was examined. Different positions for the corridor were then assessed that might reduce overlap with whale areas. Finally, overlap between vessel use areas (described previously) and the corridors was examined.

2.4. Effectiveness of vessel slowdowns

Based on distances traveled between AIS messages and vessel speed over that distance, the time spent by each vessel within bowhead and beluga areas was examined. Three hypothetical vessel slowdowns were then applied: 15 knots (used in Saguenay-St. Lawrence Marine Park for beluga whales; [37]); 11 knots (used in Haro Strait for Port of Vancouver slowdown for underwater noise and southern resident killer whales; [12]); and 10 knots (used by Government of Canada in 2017 St. Lawrence Channel slowdown for north Atlantic right whales; [38]). The number of vessels of each class that would be impacted by each slowdown scenario were assessed. For any vessel speed greater than the slowdown speed, the slowdown speed was applied to that distance segment for the vessel and the time taken to travel that segment was calculated. The difference between the time spent in each area without a slowdown versus each slowdown scenario was analyzed for each vessel type in each area using analysis of variance in R (package: stats; function: aov). AIS data is not fully representative of all vessels traveling through the ISR, based on the Canadian Coast Guard dataset that was used. For example, in 2015, according to AIS, there were four pleasure craft and one passenger vessel in the ISR, yet according to the Canadian Coast Guard dataset, there were 13 pleasure craft and two passenger vessels. This trend was consistent between 2012 and 2015, the years of overlap between the two databases (Table 1). However, despite this difference between the databases, it was assumed that the speeds traveled by vessels monitored by AIS were similar to vessels not monitored by AIS.

3. Results

3.1. Vessel traffic

Three classes of vessel traveled through the ISR in most years between 1990 and 2015: government vessels/ice breakers, passenger vessels, and tugs/barges (Fig. 2), with government vessels/ice breakers and tugs/barges traveling the farthest per year. Pleasure craft were occasionally present between 1990 and 2007 (present 7 of 18 years), but then showed a strong increasing trend between 2008 and 2015, when they were present every year (Fig. 2). All other vessel classes (bulk carriers, fishing vessels, general cargo, oil and gas exploration, tanker ship) were present for five years or less between 1990 and 2015. Distance traveled by government vessels/ice breakers increased in a linear fashion between 1990 and 2015 at a rate of 952 ± 208 km/year (± SE) (R^2 = 0.47) (all results from statistical tests presented in Table 2; all results presented here are statistically significant at $\alpha = 0.05$). Tugs/barges did not increase in a linear fashion ($R^2 = 0.56$), but rather increased their distance traveled by 1850 ± 222 km/year between 1990 and 2010, then dropping drastically in 2011, with no significant change in distance traveled between 2011 and 2015. The average distance traveled per year by tugs in 2011–2015 (26,560 ± 5228 km/year) was significantly lower than between 2006 and 2010 (43,750 ± 30,100 km/year) (Student's T test: $t = 2.8$, $p = 0.03$, mean difference = 17,191 km). Distance traveled by passenger vessels did not change significantly between 1990 and 2015, with an average distance traveled of 3269 ± 214 km/year. Distance traveled by pleasure craft did not change in a linear fashion (R^2 = 0.74), but rather stayed consistently low between 1990 and 2007 (average distance traveled = 977 ± 225 km/year), and increased drastically between 2008 and 2015 at a rate of 1544 ± 467 km/year.

Table 1
Comparison of vessel data from AIS versus the Canadian Coast Guard (CCG) dataset. Values are presented as the total number of unique vessels in the Inuvialuit Settlement Region per year.

	Pleasure craft		Passenger vessels	
	AIS	CCG	AIS	CCG
2012	2	14	2	2
2013	7	18	3	4
2014	5	11	1	2
2015	4	13	1	2

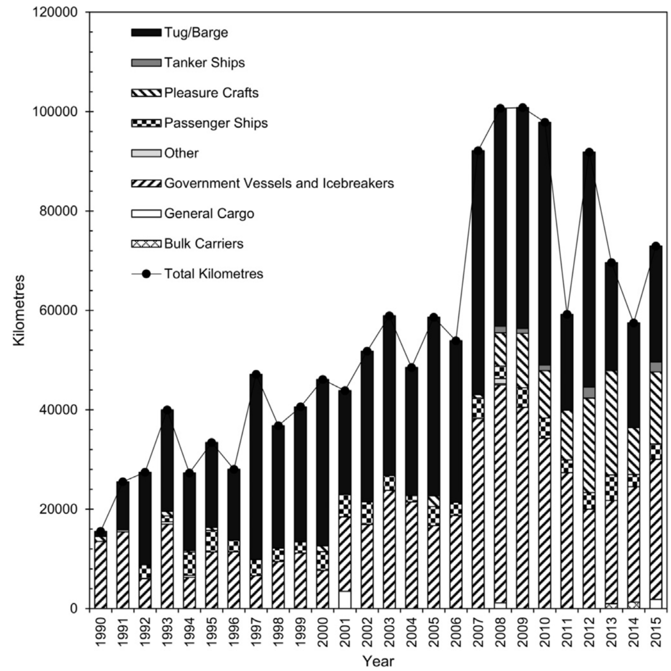

Fig. 2. Trends in distance traveled within the Inuvialuit Settlement Region by different vessel classes between 1990 and 2015.

Table 2
Detailed statistical results for trends in distance traveled by different vessel classes through the Inuvialuit Settlement Region between 1990 and 2015. N.S. = not statistically significant.

Vessel class	Slope ± SE (km/year)	df	t	p
Government Vessels/Ice Breakers	952 ± 208	24	4.6	< 0.0001
Tugs/Barges (1990–2010)	1850 ± 222	19	8.3	< 0.0001
Tugs/Barges (2011–2015)	N.S.	4	0.4	0.69
Passenger Vessels	N.S.	22	0.6	0.57
Pleasure Craft (1990–2007)	N.S.	5	1.1	0.32
Pleasure Craft (2008–2015)	1544 ± 467	8	3.3	0.01

Pleasure craft traveled < 5000 km in the beluga area in both 1990–2000 and 2001–2005, but then quickly increased to near 19,000 km in 2006–2010 and more than 45,000 km in 2011–2015 (Figs. 3 and 4). In the bowhead area, pleasure craft traveled less than 10,000 km in both 1990–2000 and 2001–2005, but then quickly increased to more than 25,000 in 2006–2010 and nearly 70,000 km in 2011–2015 (Figs. 3 and 4). Passenger vessels traveled similar amounts in both the beluga and bowhead areas, with peak distance traveled in 2001–2005 with just over 20,000 km in the bowhead area and almost 18,000 km in the beluga area (Figs. 3 and 5). Trends for both vessel types roughly match their total distances traveled within the ISR, although pleasure craft show a clear trend of spending more time in the bowhead area than beluga area, especially in more recent years.

Vessel use polygons had low levels of overlap (8–38%) for pleasure craft within both whale areas between 1990 and 2005, followed by large increases in overlap within both whale areas from 2006 to 2015, with the highest levels found in the bowhead area (88% overlap in 2011–2015), and slightly lower levels of overlap in the beluga area (71% overlap in 2011–2015) (Fig. 3). Between 1990 and 2015, passenger vessels showed greater levels of overlap with both whale areas compared to passenger vessels, with a minimum overlap of 32% (bowhead area, 2001–2005), and all other levels staying above 52% in

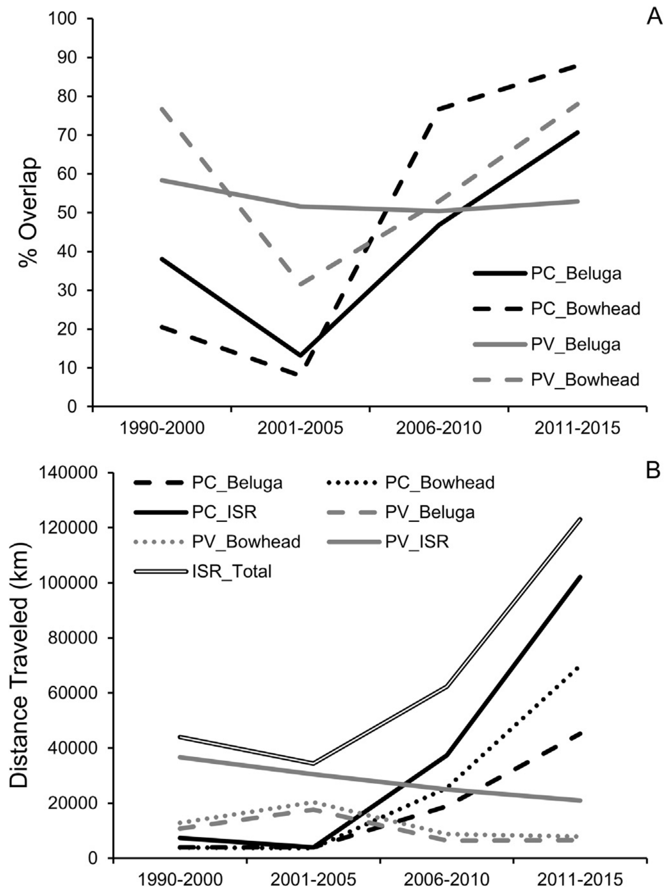

Fig. 3. Overlap between vessel traffic and beluga and bowhead high concentration areas through time (A), and changes in distance traveled within beluga and bowhead areas through time (B). PC = pleasure craft, PV = passenger vessel, ISR = Inuvialuit Settlement Region.

both whale areas. Peak overlap for passenger vessels with the beluga area occurred in 1990–2000 (58%), and in 2011–2015 for the bowhead area (78%).

3.2. Vessel speed

Passenger vessels traveled faster than pleasure craft (passenger vessel mean = 12.3 ± 0.01 knots (mean ± S.E.), maximum = 17.2 knots; pleasure craft mean = 7.4 ± 0.02 knots, maximum = 22.1 knots; mean difference = 4.8 knots, $F_{1,91828} = 39{,}733.4$, $p < 0.0001$). Vessels also traveled slightly faster in the bowhead concentration area than in either the beluga concentration area (mean difference = 0.13 knots, $F_{2,91828} = 15.3$, $p < 0.0001$) or in the entire ISR (mean difference = 0.18 knots, $F_{2,91828} = 15.3$, $p < 0.0001$); however, this difference in speed between locations is quite minimal, and is more a function of the large sample size than a meaningful difference in vessel speed. The interaction between location and vessel type was significant ($F_{2,91828} = 104.4$, $p < 0.0001$) but, similarly to speed, any differences between locations for a vessel type were minor.

3.3. Effectiveness of marine protected areas and vessel corridors

The TNMPA overlaps with 5% of the beluga concentration area, and the ANMPA only overlaps with 0.3% of the bowhead concentration areas. Given that the MPAs only overlap with a small proportion of whale areas, an exclusion zone for vessels within MPAs would only have a small impact on the whale concentration areas. Moreover, an exclusion zone within the MPAs would simply displace vessels into the adjacent whale areas, so this management measure would be ineffective at reducing the impact of vessels on whales in these core use areas.

The corridor proposed by the Canadian government overlaps with 13,894 km^2 of the beluga high concentration (41% of the total area), and overlaps with 8440 km^2 of the bowhead high concentration area (55% of the total area). Given that pleasure craft overlapped with between 13% and 71% of the beluga area and with between 8% and 88% of the bowhead area (Fig. 3), staying within the corridor would have only been beneficial between 2006 and 2015 (the years during which overlap with whale areas was greater than the overlap between the corridor and the whale areas). Passenger vessels overlapped with between 50% and 58% of the beluga area and with between 32% and 78% of the bowhead area (Fig. 3), so most of the time, it would be beneficial for passenger vessels to stay within the corridor.

The new corridor designed in this study that goes around whale areas follows the same general direction as the current corridor, but travels north of all whale areas (Fig. 6), while leaving all secondary corridors (i.e. community supply routes) intact. This new corridor avoids all important whale areas. Vessels traveling across the ISR using the original corridor, without any course deviations, would travel roughly 850 km, whereas vessels traveling the new corridor would travel 910 km. For a passenger vessel traveling at their average speed of 12.3 knots, they could traverse the original corridor in 37 h, and the new corridor in 40 h. For pleasure craft traveling at their average speed of 7.4 knots, they could traverse the original corridor in 62 h and the new corridor in 66 h. This new corridor would not add much time to the trip of these vessel classes, and would greatly reduce the risks to whales.

3.4. Effectiveness of vessel slowdowns

A hypothetical vessel slow-down would impact passenger vessels, but not pleasure craft ($F_{1,184} = 51.1$, $p < 0.0001$), and this impact varied by the magnitude of the slowdown ($F_{2,184} = 14.2$, $p < 0.0001$) and the location of the slowdown ($F_{2,184} = 4.6$, $p = 0.01$). In a 15-knot slow-down, an average of 0.07 ± 0.02 h would be added to travel time for passenger vessels, and pleasure craft would not be affected. In an 11-knot slow-down, passenger vessels would take an additional 3.8 ± 1.2 h, and pleasure craft would take an additional 0.07 ± 0.04 h. In a 10-knot slow-down, passenger vessels would take an additional 6.1 ± 1.8 h, and pleasure craft would take an additional 0.2 ± 0.09 h. Passenger vessels traveling through the beluga area would take longer than when traveling through the bowhead area ($p < 0.02$); pleasure craft were unaffected by the location of the slowdown ($p = 1.00$). Vessels would have to slow down over roughly 400 km of the corridor if traveling along the center of the current CCG corridor. For all passenger vessels monitored by AIS that traveled through this region between 2012 and 2017, six vessels would be affected over a total of 3247 km for a 15-knot slow-down, and six vessels over 9771 km for both an 11-knot and 10-knot slow-down. For pleasure craft monitored by AIS, only one vessel would be affected over a total of 3 km for a 15-knot slow-down, five vessels over 1058 km by an 11-knot slow-down, and seven vessels over 1695 km by a 10-knot slow-down.

4. Discussion

4.1. Vessel traffic patterns

Trends in vessel traffic within the ISR are quite different from the trends throughout the rest of the Canadian Arctic. Throughout the rest of the Canadian Arctic, general cargo, bulk carriers, government vessels/icebreakers, tug/barge, and tanker ships have made up most of the vessel traffic since the 1990s [20], yet in the ISR, government vessels/ice breakers and tugs/barges have made up the majority of vessel traffic during the same time period. There are also numerous fishing vessels in the eastern Canadian Arctic which are not present in the ISR. Passenger vessels have seen a larger increase in the rest of the Canadian Arctic

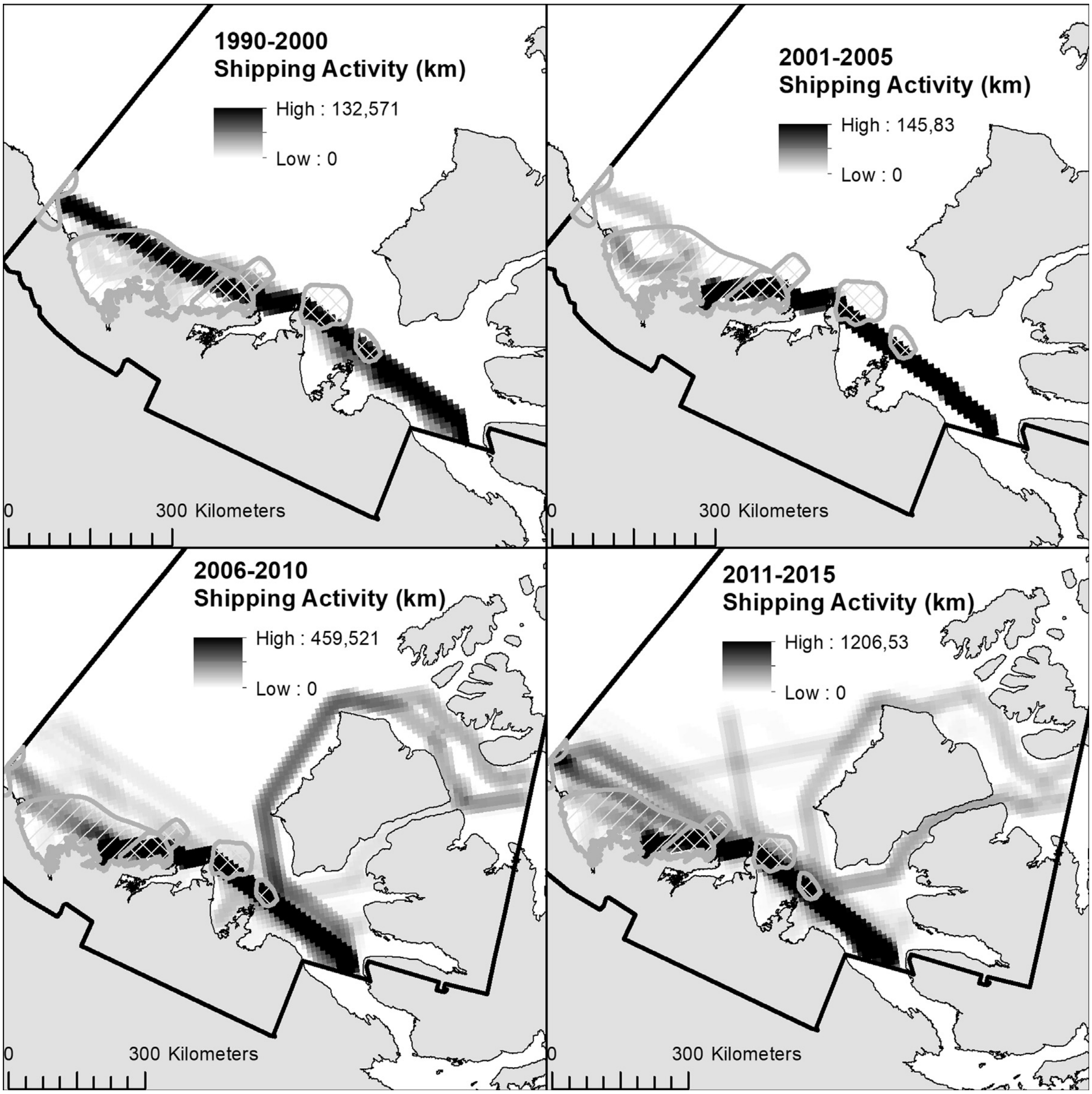

Fig. 4. Shipping activity by pleasure craft in the Inuvialuit Settlement Region, and overlap with whale concentration areas, during four time periods: 1990–2000, 2001–2005, 2006–2010, and 2011–2015. Shipping activity measured as distance traveled within 10 × 10 km grid cells within the time period. The beluga and bowhead concentration areas are delineated in gray hatched and cross-hatched polygons, respectively.

[20] compared to the ISR. A large driver of these differences are due to geography, tourism demand, and national policy instruments. Like other developed nations, Canada requires foreign flagged vessels to pay a significant duty tax should they operate solely in Canadian waters. Since all of the expedition cruise ships (passenger vessels) currently operating in Arctic Canada are foreign flagged, they tend to establish itineraries that either begin or end in another country in order to avoid this tax. The distance needed to travel is long and the tourism features available between Alaska and Arctic Canada tend not to be as popular as the natural features and cultural heritage available along shorter routes between Greenland and Nunavut [39,40]. Furthermore various mining projects are in various stages of development across Nunavut right now that do not exist in the ISR. There is also a larger coastal population within Nunavut that is serviced by a variety of vessels, whereas there are fewer coastal communities within the ISR, typically serviced by a single tug coming out of Inuvik. One trend that remains consistent between the rest of the Canadian Arctic and the ISR is that pleasure craft traffic has been increasing rapidly in recent years [20].

Both types of tourist vessels (pleasure craft and passenger vessels) traveled quite a bit through concentration areas for both species of whales. The extent of passenger vessels' voyages has remained relatively consistent since 1990, but generally overlap with more than 50% of the whale concentration areas. Pleasure craft had minimal overlap with whale areas between 1990 and 2005, but then had a rapidly increasing overlap, where they previously overlapped with less than 40% of whale areas, but now overlap with more than 60% of whale areas. However, pleasure craft may pose lower risks to whales than passenger vessels, which are generally much larger and travel much faster, and may have a greater likelihood of striking whales. Passenger vessels are also more likely to cause increased noise pollution compared to pleasure craft due to their increased size and speed. The increased presence of pleasure craft, however, may still cause significant impact to whales by interrupting important foraging and migrating events. Both classes of tourist vessels likely actively seek out marine mammals and other marine wildlife, so represent greater potential for disturbance to whales than other vessel classes.

4.2. Management options

Three different vessel management tools were examined in this

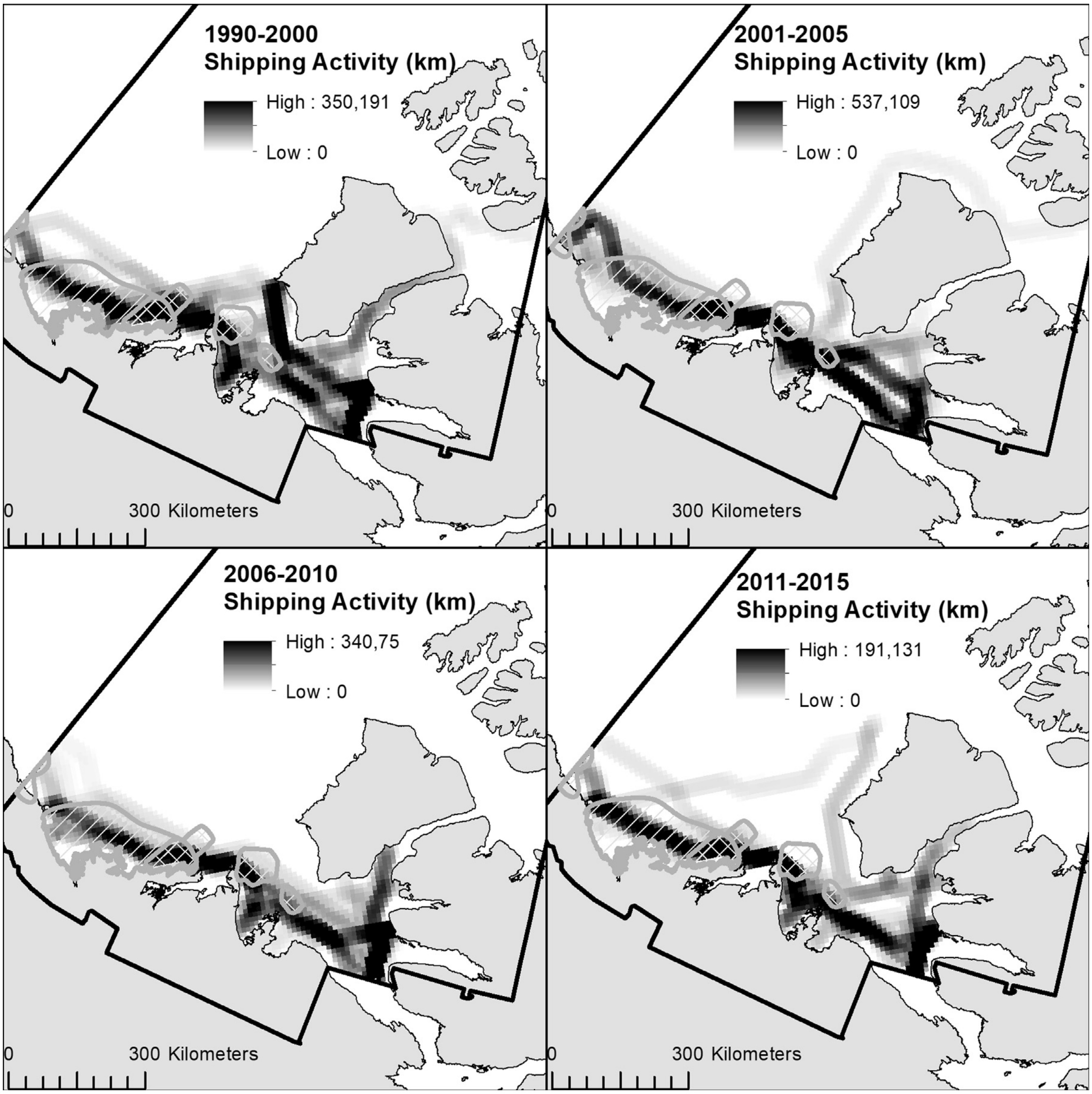

Fig. 5. Shipping activity by passenger vessels in the Inuvialuit Settlement Region, and overlap with whale concentration areas, during four time periods: 1990–2000, 2001–2005, 2006–2010, and 2011–2015. Shipping activity measured as distance traveled within 10 × 10 km grid cells within the time period. The beluga and bowhead concentration areas are delineated in gray hatched and cross-hatched polygons, respectively.

study for both classes of tourist vessel: exclusion zones in MPAs, vessel corridors, and speed restrictions. Exclusion zones within MPAs would likely be ineffective at protecting whales in whale concentration areas because MPAs only overlapped with 0.3% and 5% of the areas; if vessels were excluded from MPAs, they would likely travel through the waters adjacent to the MPAs, which are also whale concentration areas. Exclusion zones in MPAs would therefore not be expected to change the impacts of vessel traffic on whales in concentration areas. An exclusion zone around the entire whale concentration area could be very effective, and could be considered an area to be avoided by mariners, such as the areas recently designated by IMO near Nunavik Island, St. Lawrence Island, and King Island in the Bering Sea [41]. But these exclusion zones would need to be mandatory and enforced to keep tourism vessels out.

The current shipping corridor currently overlaps with 41% and 55% of whale concentration areas, and the total concentration of both pleasure craft and passenger vessels currently overlap with 50–90% of whale concentration areas. Restricting these vessels to the proposed corridor could reduce overlap with whale concentration areas, but these vessels would still have some impact on whale areas. A new corridor was drawn in this study just north of the whale concentration areas (Fig. 6), and vessels traveling this corridor would fully avoid these whale areas. The current proposed corridors are based on locations where at least 70% of vessels traveled [36]; however, tourist vessels spend much less time within these corridors [42], so other vessel classes, such as bulk carriers, tankers, and government vessels, make up the majority of vessels using these corridors. While traditional shipping vessels, such as tankers and container ships, may be likely to follow a corridor, tourist vessels are often traveling to targeted destinations or looking for interesting marine wildlife, and may be far less likely to travel using a corridor that is designed for transiting through a region, especially if it is not mandatory. However, the analysis presented here assumes that vessels are required to use the corridor when possible, so compliance should be relatively high. The current corridor also does not fully account for ecologically sensitive areas, such as the whale concentration areas that were examined in this study. The corridor does avoid marine protected areas that currently exist in the eastern Canadian Arctic, but not in the western Canadian Arctic [36]. This will no longer be the case once the Tallurutiup Imanga National Marine Conservation Area in Lancaster Sound officially comes into force, considering its location at the eastern entrance to the Northwest Passage.

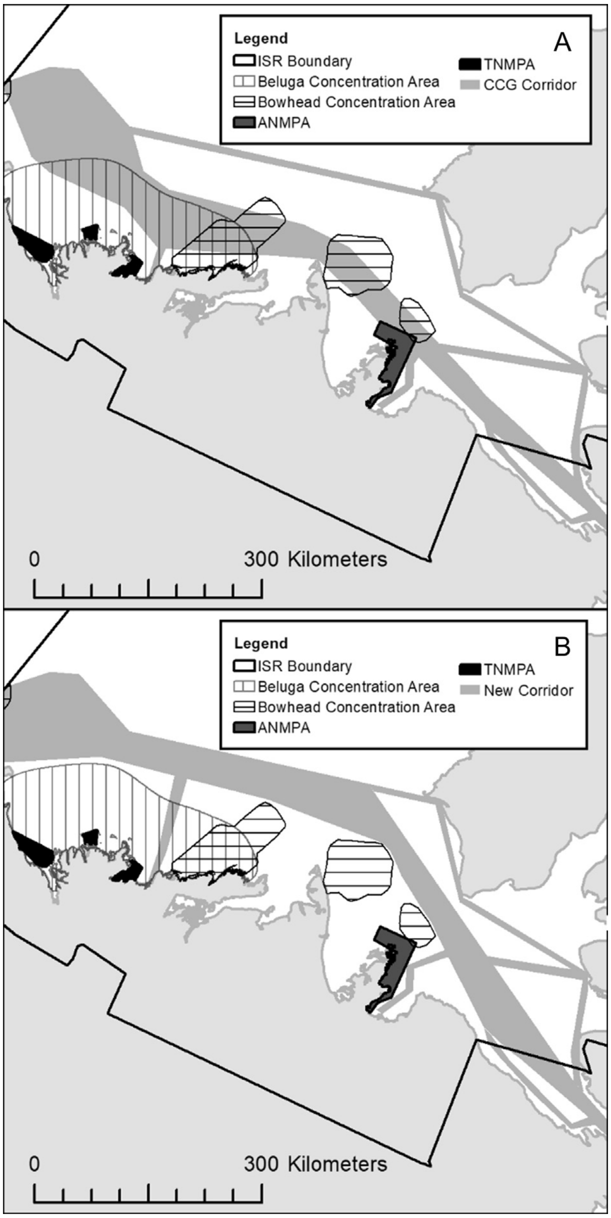

Fig. 6. Comparison of the original Canadian Coast Guard (CCG) corridor (A) and the new corridor that avoids whale concentration areas (B).

While the new corridor that we drew in the ISR avoids the whale areas, it does not consider other issues, such as patterns in hydrography and sea ice, or the safety requirements of specific vessels; all of which would need to be fully reflected in any reprioritization of the current corridors [36]. Small pleasure craft or small passenger vessels may be restricted to traveling close to shore because they cannot handle the rough waters farther from shore. In this case, small vessels might be unable to travel in either corridor in the ISR. Clearly more work is needed on this corridor, and it must balance the needs of vessels with the safety of marine wildlife and the needs of local communities. If the current corridor or the new corridor presented in this study are ineffective for these vessels, then perhaps a different corridor following the shoreline would be more effective. This shoreline corridor would need to travel through whale areas, but would at least still restrict these vessels to a smaller percentage of the whale areas.

A vessel slow-down would effectively slow passenger vessels, but would have little impact on pleasure craft. This result suggests that a slowdown would have correspondingly little effect on whales with respect to pleasure craft. Passenger vessels were found to be traveling much more quickly, so a slow-down may help to lower the risks to whales caused by these vessels. Both classes of vessel may already slow-down when they see whales to have a better view of the whales; however, if these vessels are slowing down, the slow-down did not affect the results shown in this study.

Enforcement for all three of these management measures could be achieved relatively easily using AIS data or vessel reporting requirements, as long as all vessels were required to carry AIS or report locations frequently. This region does not have any land-based AIS stations that we are aware of, so managers would need to rely on satellite AIS or develop a network of AIS ground stations.

Other management measures that were not examined in this study include: limiting the number of vessels in an area [13], codes of conduct or industry best standards, using marine mammal observers, or developing a system that monitors the positions of vessels and whales simultaneously [10]. An example of industry best standards includes the guidelines developed by the Association of Arctic Expedition Cruise Operators, which are mandatory for all members of this organization [43]. These measures and more may be very useful in reducing the impacts of tourism vessels on whales.

4.3. Whale concentration areas

The whale concentration areas that were used for this study were taken from the Ecological Atlas of the Bering, Chukchi, and Beaufort Seas [29]. The beluga area that was used was created from multiple data sources, including science (aerial surveys and satellite telemetry) and traditional knowledge [30,31]. The bowhead areas were only based on satellite telemetry [26,27,33]. In order to be as robust as possible, these whale areas should both be delineated based on a variety of evidence, including science and traditional knowledge. Traditional knowledge related to vessel traffic and whales (and other marine wildlife) has now been collected in all six communities within the ISR [21], and should be added to these assessments. These whale areas also represent the summer distribution of both species, which typically shifts through the season (e.g., [28]), so a more thorough analysis of impacts should match the distribution of these whales with a concurrent distribution of vessels. This analysis is significantly more data intensive, but is necessary to assess actual impacts. This analysis would also need to consider the effects of climate change, which possibly include a shifting distribution of whales through time, changing patterns of sea ice concentration, and also changes in vessel traffic patterns.

5. Conclusions

Vessel management tools within the ISR are currently limited to within the two established MPAs or rules which generally apply to all of Canada (federal regulations), the globe (IMO regulations), or to the entire Arctic (i.e. Polar Code). The TNMPA, which overlaps with the beluga concentration area, restricts vessels movements within the MPA, and only allows vessels that are traveling to communities. While the Polar Code states that mariners should respect national and international rules related to areas with high densities of marine mammals, information on where these areas exist is not readily available to mariners traveling through the ISR, and further, while the Code applies to passenger vessels, it does not apply to pleasure craft. Moreover, the two whale areas in the ISR also happen to be very close to two common destinations for tourists: Herschel Island and the Smoking Hills. Herschel Island is just west of the beluga area, and all vessels traveling to the island from the east pass directly through the beluga area. The Smoking Hills are on the west side of Franklin Bay, directly south of the bowhead area near Cape Bathurst, so vessels following the coastline to see the smoking hills will pass directly through this area. Given the proximity of marine mammal areas to tourist destinations, it is very unlikely that management interventions could fully exclude tourist vessels from these marine mammal areas.

Aside from completely excluding vessels from an area, two other management tools are commonly used to reduce impacts: vessel corridors and speed restrictions [10]. Transport Canada, Canadian Coast Guard, and Canadian Hydrographic Service have proposed a corridor throughout the entire Canadian Arctic [36], which was examined in this study. While a corridor would not stop vessels from visiting sites such as the Smoking Hills or Herschel Island, it might reduce the impact for all other vessels traveling through the ISR. For vessels traveling outside of the corridor, a speed restriction of 10 knots might be an effective management measure within whale concentration areas for reducing impacts on whales. Slowdowns are typically used in the context of marine mammals for two reasons: to reduce the likelihood of ship strikes [38] and to reduce acoustic disturbance [12]. While slowdowns are effective for both of these reasons, they also add travel time to vessels, which often leads to conflict with the shipping industry. Tourist traffic, however, may be less concerned with longer travel time compared with other types of destinational vessels. Increased time in a region may also cause a longer disturbance to wildlife. If, for example, the presence of a vessel increases stress or disturbs the behaviour of wildlife independently of speed, then a greater time spent in an area will increase the overall disturbance. Managers must therefore balance decreasing direct risks of ship strikes and acoustic disturbance versus the increased disturbance caused by the presence of vessels. These actual risks should be quantified, which is itself a challenging task.

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