Vessel Traffic Trends in the Arctic and Overlap with Important Marine Mammal Areas

Report for Transport Canada

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26 January 2020

SUMMARY

As the Arctic becomes more ice-free, ship traffic and its associated underwater noise have been increasing. Arctic marine mammals appear to be sensitive to underwater noise, therefore an assessment of underwater noise in the Arctic and how it overlaps with marine mammal areas is needed. Here, we present the first step in this process by assessing trends in vessel traffic in the Arctic. We analyzed PAME's Arctic Ship Traffic Database (ASTD) to calculate distance traveled by different classes of ships within the Arctic, and then calculated the total distance traveled and area-corrected total distance traveled within different marine mammal areas in the month of September over three years, from 2016 to 2018.

Vessel traffic was highest around Iceland, along the Norwegian coast, and between the Norwegian coast and Svalbard, with vessels in many areas around Iceland and the Norwegian coast travelling more than 100,000 km within the 100 km^2 grid cells during the month of September. By comparison, shipping in the rest of the Arctic was sparse, but obvious routes were visible along the Northern Sea Route and the Northwest Passage, as well as between eastern Canada and west Greenland. After controlling for the total area within the different seas of the Arctic, the most traffic in September was in the Norwegian Sea, followed by the Bering Sea and North Atlantic around Iceland, then the Barents Sea and Baffin Bay-Davis Strait.

Based on the area-corrected total distance traveled, 50% of the top ten marine mammal areas with the most vessel traffic are in the Russian Arctic. These top ten areas are equally split between cetaceans and pinnipeds, but most notably, the top three areas are all for beluga whales and are all in the Russian Arctic in the Gulf of Anadyr, East Siberian Sea, and White Sea. The most common vessel class in marine mammal areas was bulk carriers, which have a relatively high source level, suggesting that these areas may receive relatively high amounts of underwater noise.

The marine mammal data used in this analysis were from Hauser et al. (2018). In that study, Hauser et al. assessed risks associated with vessel traffic to marine mammal populations, and came up with a list of marine mammal populations that were most at risk. An underlying component of that analysis was the amount of vessel traffic that each population was exposed to, and this metric was based on the overlap between each marine mammal area and either the Northern Sea Route or the Northwest Passage. In this report, we go a step beyond what was done in Hauser et al. (2018) by quantifying levels of traffic within each marine mammal area rather than just assessing overlap. Comparing the exposure values from Hauser et al. (2018) to the levels of vessel traffic in this report show large differences. For example, the population with the greatest level of vessel traffic in our study was assigned the lowest possible exposure value in Hauser et al.'s study. This demonstrates the importance of quantifying vessel traffic when assessing the exposure of marine mammals to vessel traffic.

The underlying marine mammal data provided a good representation of the distribution of each population in the month of September, and also included a metric of uncertainty related to each population. Notably, pinniped populations generally had more uncertainty than cetacean populations, and some geographic regions, such as the North American Arctic, had more

certainty than other regions. This marine mammal dataset is rare for the Arctic, and only represents a single month of the year. Further work is required to assess the distribution of all marine mammal populations in other months of the year, and this analysis is required before overlap with vessel traffic can be assessed in these other months.

The analysis presented in this report creates a good foundation for PAME's future work on underwater noise in the Arctic by quantifying vessel traffic in different Arctic seas and in different marine mammal areas in the month of September. PAME can use these results to frame their underwater noise modeling and to select certain marine mammal areas or regions of the Arctic to focus their efforts.

1. BACKGROUND

As summer sea ice retreats in the Arctic, new shipping routes are becoming available and more accessible (Stephenson et al. 2011, Pizzolato et al. 2014, Dawson et al. 2018). Furthermore, as the demand for natural resources continues to grow, new development opportunities may arise in the Arctic creating new stressors that if not properly managed could put ecosystems and cultures at risk (Reeves et al. 2014, PAME 2019). This increased ship traffic will likely lead to increased underwater noise (PAME 2019). Underwater noise is an important issue globally, and ship traffic is considered the most wide-spread contributor of anthropogenic underwater noise (Andrew et al. 2002, McDonald et al. 2006).

The Arctic is a special case for underwater noise because the Arctic has historically had lower levels of anthropogenic underwater noise and has lower ambient sound levels, which allows noise sources to be detected from further away (PAME 2019). Perhaps most importantly, Arctic marine animals appear to be especially sensitive to underwater noise (e.g., LGL 1986). Moreover, cultures and livelihoods of Arctic Indigenous Peoples depend on the continued health of living marine resources (Olsen et al. 2019, Dawson et al. 2020). Noise impacts affecting these species will be immediately felt in these communities (Olsen et al. 2019, Dawson et al. 2020).

Understanding current levels of underwater noise in the Arctic is an important first step in managing and mitigating underwater noise throughout the region (PAME 2019). Here, we examine ship traffic throughout the Arctic, and provide an initial assessment of how ship traffic overlaps with important marine mammal areas in the Arctic and highlight areas that may have higher levels of underwater noise. This report is a first step in PAME’s work plan on underwater noise, and will help identify priority areas for PAME to focus on in its continued work on underwater noise.

2. METHODS

2.1 Shipping Data

PAME’s Arctic Ship Traffic Database (ASTD) was used as the source for ship traffic data. The data provided consisted of point locations for individual ships, based on various sources of Automatic Identification System (AIS) data, between 2013 and 2018 throughout the Arctic and farther south. Data were grouped by month for each year. Each datum included a variable quantifying the distance to the next point for that individual vessel, which we used as our metric of distance traveled. Data were imported into ArcGIS (version 10.4.1), and then clipped into a reduced spatial extent which focused on latitudes of 60°N or greater that were directly influenced by the Arctic Ocean or adjacent seas. The only areas north of 60°N that were excluded were the Baltic Sea and parts of waters adjacent to the Bering Sea that were blocked by land from the Bering Sea (Cook Inlet and the Sea of Okhotsk) (Figure 1).

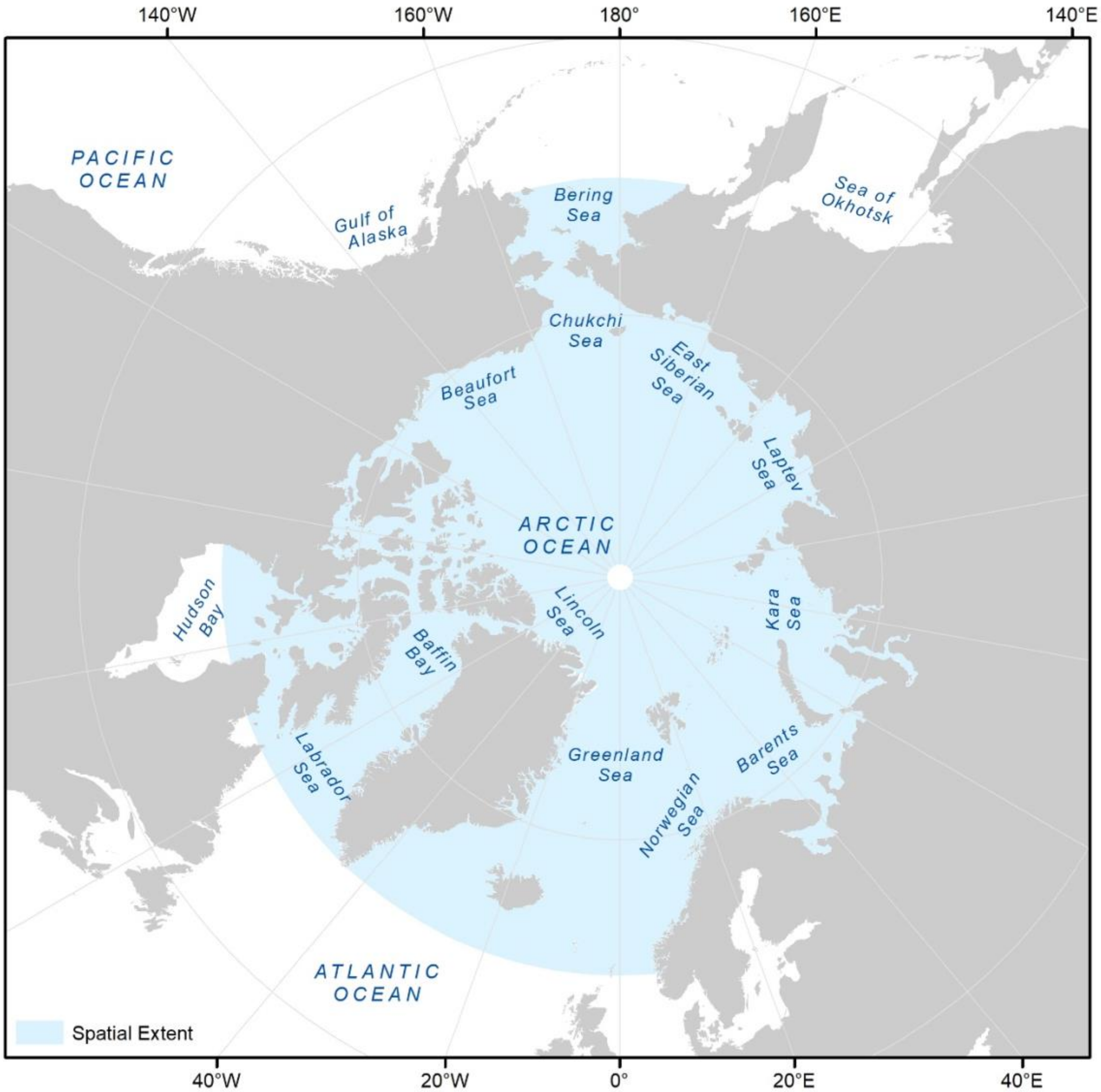

Figure 1. Map showing the spatial extent used for the vessel analysis within the Arctic.

Data were then split into the following ten ship class categories: 1) bulk carrier; 2) container ship; 3) cruise ship; 4) ferry; 5) fishing vessel; 6) government, research, or icebreaker ship; 7) military ship; 8) recreational boat; 9) tanker ship; and 10) tug boats and barges. See Appendix 1 Table 5 for a full list of the underlying ASTD categories and Lloyds 5 categories used to make up these ten categories. For each class of vessel, the total distance traveled was calculated in 10 x 10 km (100 km^2) cells within a month by summing the distance to next point variable for all data points for each vessel class within each 100 km^2 cell. We summarize vessel traffic trends in the different seas of the Arctic to quantify spatial variability across the Arctic. For this report, we focused on the month of September for the years 2016 to 2018, based on availability of consistent marine mammal data for that month.

2.2 Marine Mammal Data

We obtained the marine mammal dataset created by Hauser et al. (2018), which they used for their recent analysis of shipping risks to Arctic marine mammals (Figure 2, Appendix 2 Table 6). This dataset specifically provides an estimate of the range of each population of six endemic Arctic mammal species in the month of September. The month of September was chosen by Hauser et al. (2018) because it represents the month with the most ship traffic for most of the Arctic. These September ranges were estimated based on published studies of these populations of marine mammals. Each population estimate also comes with a metric of uncertainty based on the quality of the underlying information used to delineate the range (Appendix 2 Table 6). The six marine mammals include three cetaceans (beluga whale (*Delphinapterus leucas*), narwhal (*Monodon monoceros*), and bowhead whale (*Balaena mysticetus*)) and three pinnipeds (bearded seal (*Erignathus barbatus*), ringed seal (*Pusa hispida*), and walrus (*Odobenus rosmarus*)), but do not include the polar bear (*Ursus maritimus*) due to the likelihood that underwater noise is not an important stressor for polar bears (Hauser et al. 2018, PAME 2019). Although many other species of marine mammal do also inhabit the Arctic during the ice-free season, particularly in areas close to the Atlantic and Pacific Oceans, we do not include them in this analysis for the same reasons that they were not included in PAME's review of underwater noise in the Arctic (PAME 2019). These reasons include limiting the scope of this study to animals that fully fall within the Arctic Council's focal area and maintaining comparability among datasets and analyses.

We examined total distance traveled for all vessel classes within each marine mammal area in the month of September for each year between 2016 and 2018. We also divided the total distance traveled by the total area of the marine mammal area to create a comparable metric per unit area, allowing for a fair comparison between different marine mammal areas. Finally, we assessed the relative contribution of different vessel classes to underwater noise levels based on their average source level (i.e. how loud in decibels a vessel is at a distance of 1 m). The source levels of different vessels are reviewed in Table 1. This assessment does not estimate underwater noise levels, but rather simply notes the source levels of different ships and describes the potential for underwater noise.

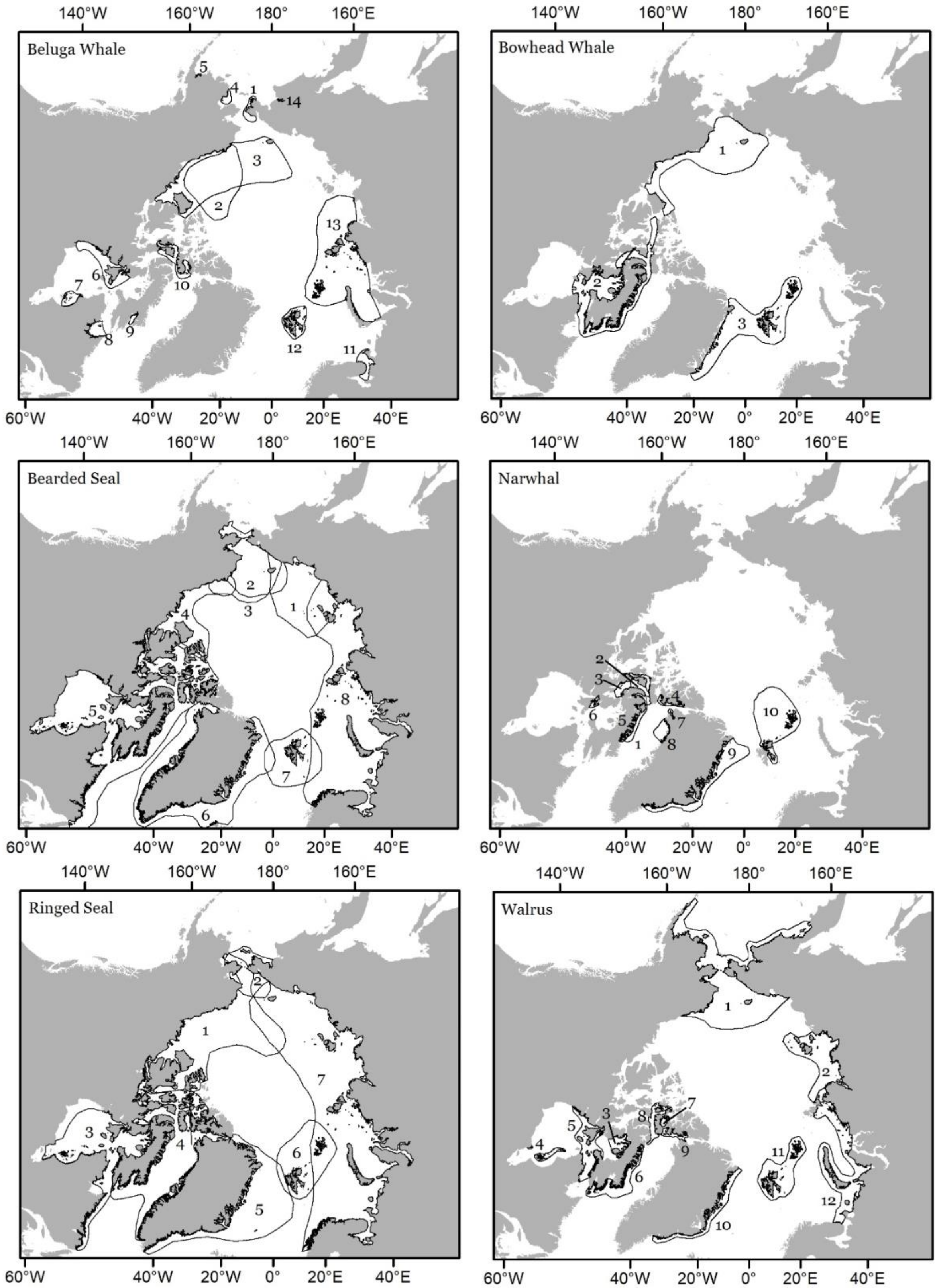

Figure 2. September ranges of Arctic marine mammal populations from Hauser et al. (2018). See Appendix 2 Table 6 for the names matching the numbered labels on each panel.

Table 1. Brief review of average source levels (dB re 1 μPa at 1 m; i.e. radiated noise levels) measured in two published studies, with the total sample size in parentheses beside the source level. NM = not measured.

<table>
<tr><th></th><th colspan="2">Source Level</th></tr>
<tr><th>Vessel Class</th><th>Veirs et al. (2016)</th><th>MacGillivray et al. (2019)</th></tr>
<tr><td>Bulk Carrier</td><td>173 (965)</td><td>188 (297)</td></tr>
<tr><td>Container Ship</td><td>178 (529)</td><td>191 (183)</td></tr>
<tr><td>Cruise Ship</td><td rowspan="2">166 (49)</td><td>184 (14)</td></tr>
<tr><td>Ferry</td><td>NM</td></tr>
<tr><td>Fishing Vessel</td><td>164 (65)</td><td>NM</td></tr>
<tr><td>Government, Research, or Icebreaker Ship</td><td>167 (14)</td><td>NM</td></tr>
<tr><td>Military Ship</td><td>161 (113)</td><td>NM</td></tr>
<tr><td>Recreational Boat</td><td>159 (41)</td><td>NM</td></tr>
<tr><td>Tanker Ship</td><td>174 (148)</td><td>188 (44)</td></tr>
<tr><td>Tug Boat or Barge</td><td>170 (337)</td><td>NM</td></tr>
</table>

3. RESULTS

Vessel traffic in September was highest around Iceland and along the Norwegian coast, was quite dense around Svalbard, but was otherwise sparse throughout the Arctic, with some obvious routes taken through the Bering Sea and Bering Strait, the Northern Sea Route, Baffin Bay, Hudson Strait, and the Northwest Passage (Figure 3). When examined quantitatively within different water bodies of the Arctic (Table 2), the Norwegian Sea had by far the highest levels of vessel traffic (2016-2018 average = 225 km/km$_2$). The next busiest areas were the North Atlantic, including around Iceland, and the Bering Sea (68 and 70 km/km$_2$, respectively), followed by the Barents Sea, Baffin Bay-Davis Strait, and the Chukchi Sea (27, 25, and 20 km/km$_2$, respectively) Trends were quite similar in all years from 2016 to 2018.

Vessel traffic in different marine mammals areas in September varied widely, with a minimum distance traveled by all vessel classes of 0 km, a maximum of nearly 2 billion km, and an average of just over 132 million km (Appendix 3 Table 7). When total distance traveled was corrected by the total size of the marine mammal area, this range was between a minimum of 0 km/km$_2$ and a maximum of 185 km/km2, with an average of 17 km/km$_2$. Note that none of the September ranges of any population of Arctic marine mammals overlapped with the high traffic areas around Iceland or the Norwegian coast. However, other non-Arctic marine mammals live in these areas and would be exposed to the high levels of vessel traffic.

The top ten marine mammal areas for each of the two metrics listed above are presented in Table 3 based on the average from 2016-2018 (for a full table with total distance values for all marine mammal areas and all vessel classes in each year, see Appendix 3, Table 7-10). 50% of the top ten marine mammal areas with the greatest total distance traveled are spread across the Russian Arctic (including the top three), and the remainder include the Bering-Chukchi Seas, Greenland, Svalbard, Canada, and Baffin Bay. Nine of the ten areas are for pinnipeds. When distance traveled was corrected by the total area, the list changed dramatically. 50% of the areas are still in the Russian Arctic, but the top ten areas are now equally split between cetaceans and pinnipeds. Perhaps most notably, the top three marine mammal areas with the greatest area-corrected distance traveled are for beluga whales (Figure 4).

In all years, bulk carriers were, on average, the greatest contributor to the total distance traveled within each marine mammal area, followed by tankers, and then government/research/ice breaker ships (See Appendix 3 Tables 8-10 for total distance traveled values for each vessel class in each marine mammal area). For the top ten areas with the greatest overall distance traveled, bulk carriers contributed the most to eight of the ten areas in all years between 2016 and 2018. The two areas with a different top contributor were for the bearded seal areas in Greenland and Svalbard, where fishing vessels were top in all years between 2016 and 2018, except for Greenland in 2016 (cruise ships) and Svalbard in 2018 (government ships). Similarly, bulk carriers were the top contributor for nine of the ten areas in all years between 2016 and 2018 based on the area-corrected distance traveled (Figure 4); the exception was for the beluga area in the Bering Sea where tug boats were the greatest contributor in all years from 2016-2018.

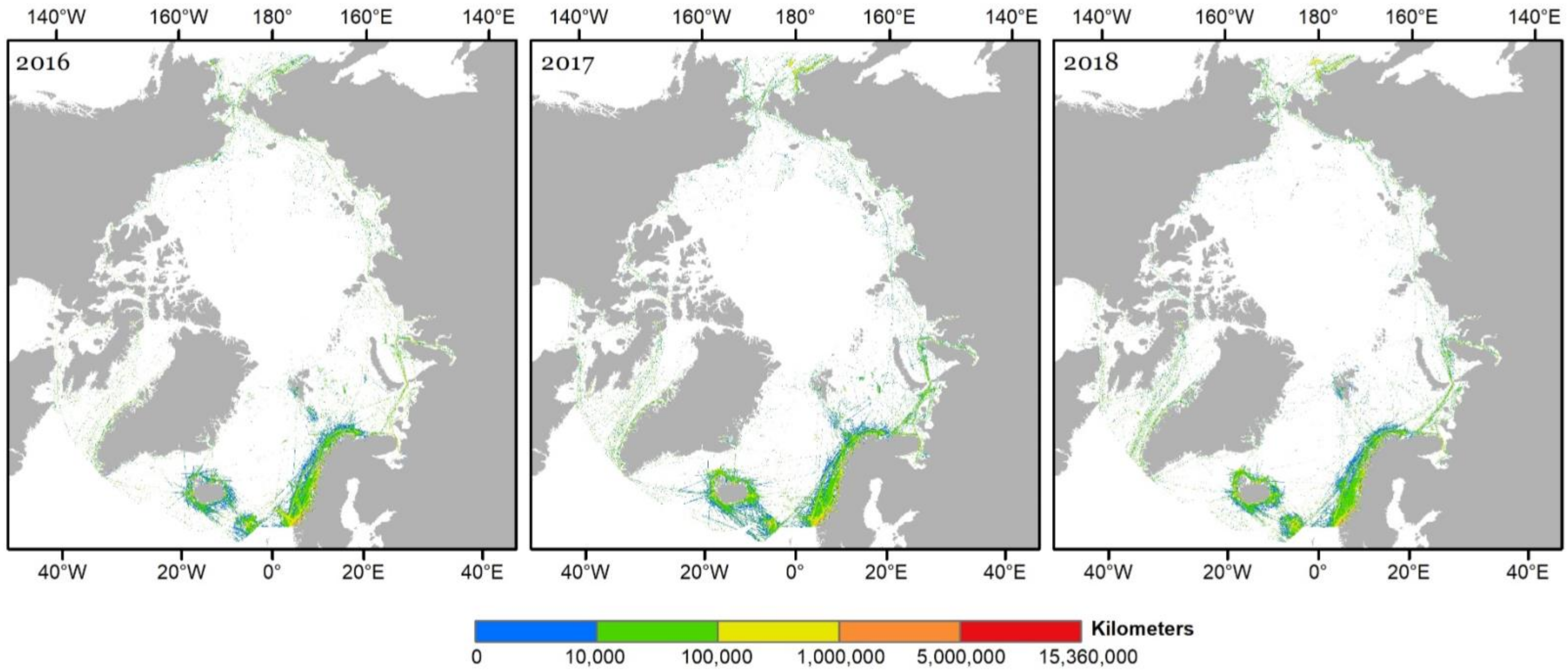

Figure 3. Vessel traffic throughout the Arctic in September of each year from 2016 to 2018. Data are displayed in 100 km2 cells, with the total distance traveled in each cell as the unit of measurement.

Table 2. The area-corrected total distance traveled (km/km2) by all vessel classes in different seas of the Arctic in 2016-2018. Area-corrected total distance traveled is measured by summing the total distance that all vessels travel within the region in the month of September, and then dividing it by the total area (km2) of the region.

Sea	**2016**	**2017**	**2018**	**2016-2018 Average**
Norwegian Sea	224.5	230.1	219.6	224.7
Bering Sea	46.4	83.4	80.9	70.2
North Atlantic	52.4	75.6	76.2	68.1
Barents Sea	28.2	27.6	24.8	26.9
Baffin Bay-Davis Strait	19.5	25.9	29.8	25.1
Chukchi Sea	27.1	18.4	15.6	20.4
Kara Sea	23.2	17.2	16.8	19.1
Greenland Sea	10.7	16.9	15.7	14.5
East Siberian Sea	15	13.9	12.1	13.7
Hudson Bay-Foxe Basin	12	12.8	13.6	12.8
Laptev Sea	13.9	11.8	10.6	12.1
Beaufort Sea	6.6	4.2	3	4.6
Canadian Arctic Archipelago	4.6	3.4	3.5	3.8
Arctic Ocean	1.1	0.1	0.1	0.4

Table 3. Top ten marine mammal areas with the most vessel traffic based on total distance travel (km) (left) and area-corrected total distance traveled (km/km^2) (right) within the month of September. Values are based on the average between 2016-2018. Total distance traveled is measured by summing the total distance that all vessels travel within the marine mammal area in the month of September, and area-corrected total distance traveled is calculated by dividing the total distance traveled by the total area (km^2) of the marine mammal area.

	Total Distance Traveled (km)		**Area-corrected Total Distance Traveled (km/km^2)**	
Rank	**Marine Mammal Area**	**Value**	**Marine Mammal Area**	**Value**
1	Ringed Seal – White-Barents-Kara-Siberian Seas	1,876,224,209	Beluga – White Sea	170
2	Bearded Seal – Barents-White-Kara-Laptev Seas	1,456,430,685	Beluga – Anadyr	70
3	Walrus – Novaya-Semlya-Barents Seas	317,632,405	Beluga – Siberian Sea	60
4	Bearded Seal – Greenland	277,185,530	Narwhal – Eclipse Sound	46
5	Beluga – Kara & Laptev	274,455,814	Walrus – Novaya-Semlya-Barents Seas	36
6	Ringed Seal – Baffin Bay	255,783,987	Ringed Seal – Bering Sea	29
7	Walrus – Bering-Chukchi	248,287,982	Bearded Seal – Barents-White-Kara-Laptev Seas	25
8	Bearded Seal – Canada	167,158,847	Beluga – Bering Sea	22
9	Bearded Seal – Svalbard	151,669,521	Walrus – SE Baffin	22
10	Walrus – Laptev	133,301,470	Walrus – Bering-Chukchi	21

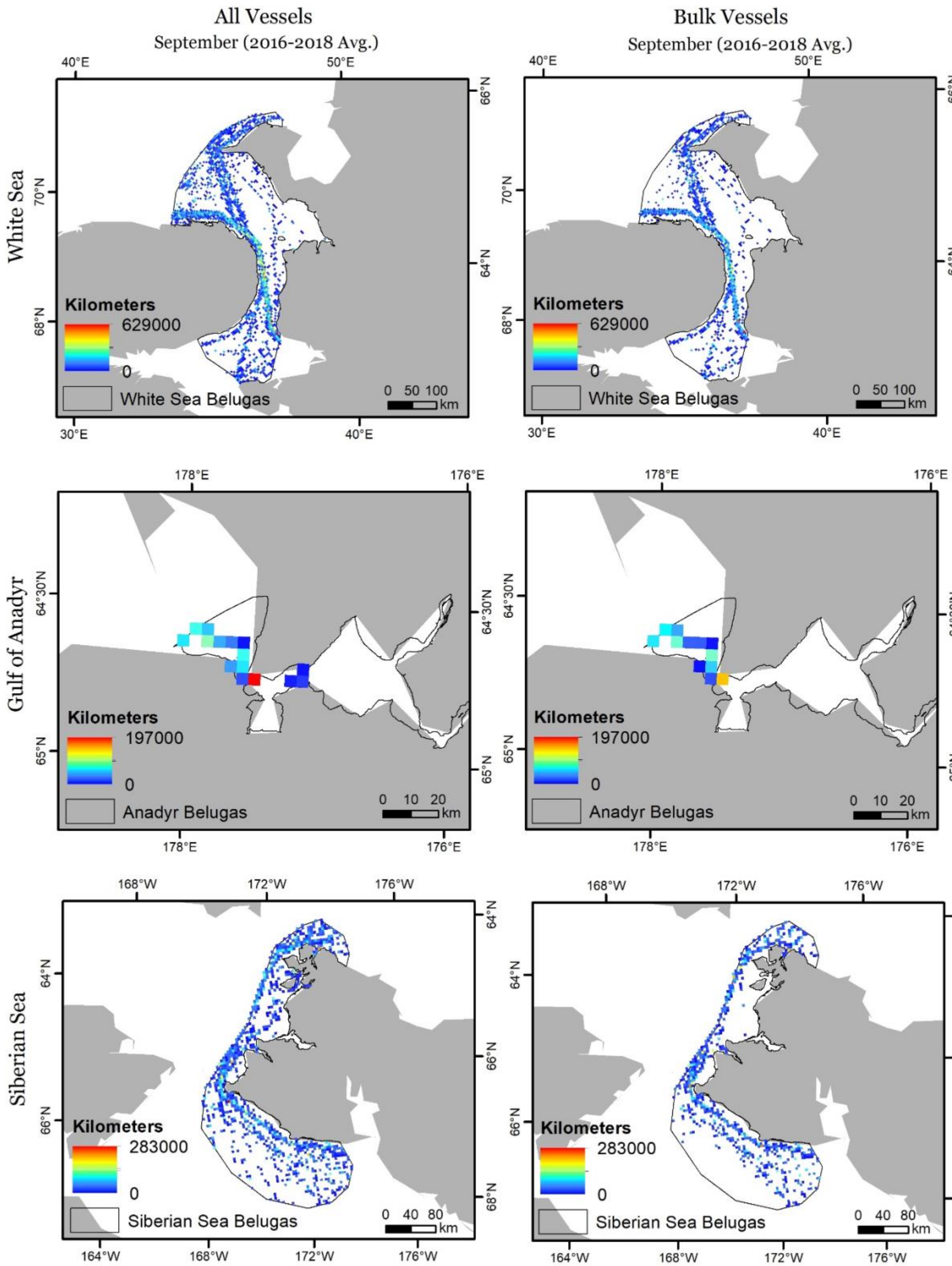

Figure 4. Total distance traveled within the September ranges of three beluga whale populations. Data are displayed cumulatively for all vessel classes (left) and just for bulk carriers (right) in 100 km2 cells as the average from 2016 to 2018.

Table 4. Top ten Arctic marine mammal populations for both cetaceans (left) and pinnipeds (right) based on the area-corrected total distance traveled (km/km2) in the month of September. Values are based on the average between 2016-2018. Area-corrected total distance traveled is measured by summing the total distance that all vessels travel within the marine mammal area in the month of September, and then dividing it by the total area (km_2) of the marine mammal area.

	Cetaceans		**Pinnipeds**	
Rank	**Marine Mammal Area**	**Value**	**Marine Mammal Area**	**Value**
1	Beluga – White Sea	170	Walrus – Novaya-Semlya-Barents Seas	36
2	Beluga – Gulf of Anadyr	70	Ringed Seal – Bering Sea	29
3	Beluga – Siberian Sea	60	Bearded Seal – Barents-White-Kara-Laptev Seas	26
4	Narwhal – Eclipse Sound	46	Walrus – SE. Baffin Island	22
5	Beluga – Bering Sea	22	Walrus – Bering-Chukchi Seas	21
6	Narwhal – Admiralty Inlet	19	Ringed Seal – White-Barents-Kara-Siberia Seas	20
7	Bowhead – E. Canada-W. Greenland	18	Walrus – N. Hudson Bay	20
8	Beluga - Svalbard	18	Ringed Seal – Baffin Bay	16
9	Narwhal – N. Hudson Bay	17	Walrus – Laptev Sea	15
10	Narwhal – Somerset Island	16	Bearded Seal – Greenland Sea	14

Focusing on the potential for underwater noise, bulk carriers, like other large merchant ships, have some of the highest source levels among all vessel classes (Table 1), ranking second or third highest according to Veirs et al. (2016) and MacGillivray et al. (2019). Tankers were also often among the top three contributors to vessel traffic, and also have a very similar source level to bulk carriers. Government vessels also often ranked high, but their source level is typically near the average for all source levels (Veirs et al. 2016). Fishing vessels were a top contributor in two bearded seal areas, but fishing vessels typically have among the lowest source levels of vessels carrying AIS beacons (Veirs et al. 2016), since they are typically a much smaller vessel. Therefore, these areas with a high number of fishing vessels may have lower overall underwater noise levels compared to other areas with similar distance traveled by a vessel with a higher source level. One beluga area in the Bering Sea had a high number of tug boats, and tug boats have a relatively high source level, although not as high as merchant vessels (Table 1).

Given that cetaceans and pinnipeds have different relative risks to vessels and underwater noise (Hauser et al. 2018, PAME 2019), we re-assessed the top ten marine mammal populations separately for each group based on the area-corrected total distance traveled (Table 4). The top ten cetacean populations were more evenly distributed throughout the Arctic, with three in the Russian Arctic, five in eastern Canadian Arctic-west Greenland, one in Bering Sea, and one in Svalbard. Five populations were for belugas, four for narwhal, and one for bowhead. The top ten pinniped populations were also widely distributed, with four in the Russian Arctic, three in the eastern Canadian Arctic-west Greenland, two in the Bering-Chukchi, and one in the Greenland Sea. Five of the pinniped populations were for walrus, three were for ringed seals, and two were for bearded seals.

4. DISCUSSION

4.1 Vessel Risk in Marine Mammal Areas

September ranges for Arctic marine mammal populations along the Northern Sea Route (i.e. the Russian Arctic) and the Pacific entrance to the Northern Sea Route and Northwest Passage were exposed to the most vessel traffic per unit area, especially for four populations of beluga whale (Table 2). Only two marine mammal populations in the top ten list for area-corrected distance traveled were outside of the Russian Arctic and Pacific Arctic: narwhal in Eclipse Sound and walrus in southeast Baffin Island, both of which are exposed to vessel traffic from a mining operation on northern Baffin Island. For 90% of these top ten areas, bulk carriers are the largest contributor to vessel traffic, and these bulk carriers also have a relatively high source level, which means that these marine mammal areas will likely have relatively high levels of underwater noise compared to other marine mammal areas in the Arctic. However, detailed modeling work is required to effectively examine underwater noise levels in the different marine mammal areas.

The areas of the Arctic with the most vessel traffic (by multiple orders of magnitude) and likely the most underwater noise are around Iceland, along the Norwegian coast, and to a lesser extent, around Svalbard. Although we did not quantify these levels precisely for this report, Iceland and the Norwegian coast also see vessel traffic in all months of the year, whereas the shipping season for the majority of the Arctic is between July and October. However, the Arctic marine species that were the focus of this study do not overlap with either Iceland or the Norwegian coast for their September ranges, and to the best of our knowledge, would have little or no overlap in other months of the year. But other species of marine mammals, including killer whales, humpback whales, and harbour seals, do inhabit these areas (IUCN 2020) and would be exposed to these high levels of ship traffic and underwater noise.

When examining cetaceans and pinnipeds separately (Table 4), a few points become clear. First, beluga and narwhal populations are exposed to more vessel traffic than bowhead populations. This is due in part to the fact that there are only three bowhead populations but 14 beluga populations and ten narwhal populations. The bowhead populations cover a much larger area, which therefore reduces the area-corrected values. This, however, does not negate the fact that beluga and narwhal do inhabit some relatively busy areas for shipping. The cetaceans are also affected more by traffic through the Northwest Passage and coming up from the North Atlantic than the pinnipeds are. Within the pinnipeds, walrus have the highest number of populations with a high overlap with vessels. A key difference between the pinnipeds and cetaceans is that many of the cetacean populations are better studied than the pinniped populations, so we have more certainty in estimates of their September range. This is especially true for the five of the top ten cetacean populations that are within eastern Canada-west Greenland, versus five of the top ten pinniped populations that are in the Russian Arctic.

Hauser et al. (2018) provided a useful first step in this analysis, which assessed the relative risk of these same populations of marine mammals to ship traffic. However, the analysis by Hauser et al. (2018) did not quantify ship traffic in these areas, but rather simply examined the extent to which the marine mammal areas overlapped with either the Northwest Passage or Northern Sea Route. Here, we have gone a step further and quantified how much vessel traffic was in each marine mammal area. For the sake of comparison, we include the exposure score from Hauser et al. (2018) in Table 4 (Appendix 3) to show how the results differ between this analysis and the Hauser et al. (2018) analysis. The population with the highest area-corrected distance traveled has the lowest possible score from the Hauser et al. (2018) exposure score (value = 1), which demonstrates that a detailed vessel analysis such as the one presented in this report is required to estimate exposure to vessel traffic.

4.2 Comparison of Metrics

The area-corrected total distance traveled is a metric that is more indicative of traffic density, which should align more closely with the number of vessels that individual animals might be exposed to. Correcting by area also removes any bias associated with certain important areas being larger than others, which is the case for the majority of the ringed seal and bearded seal areas (Figure 2), which also have higher uncertainty because seals are generally wide-spread and understudied. Only three areas were consistently in the top ten list for both variables: walrus areas in the Bering-Chukchi Seas and Novaya-Semlya-Barents Seas, and the bearded seal area in

Barents-White-Kara-Laptev Seas. These differences reinforce that the metrics used must be carefully selected, and for this analysis that focuses on overlaps with marine mammals, a variable representing traffic density is most appropriate.

Another metric that we measured, but did not fully assess in this report, was total number of unique vessels within the area (see data for each vessel class in each marine mammal area in Appendix 3 Tables 11 to 13). This tracked closely with total distance traveled, where larger areas with more vessel traffic had more unique vessels traveling within them. Again, this metric on its own is not the most useful when examining impact on marine life because the same vessel could make multiple trips, or some vessels could travel much farther than others.

4.3 Concerns with Datasets

The Arctic Ship Traffic Database provides an extensive dataset of ship traffic across the entire Arctic. However, we did find a few issues that limited our ability to assess other metrics, which we highlight here. First, the database contains erroneous data points, such as points on land. We were able to remove these points by clipping out land, but there may have been other erroneous points over water that we did not detect. Second, the dataset was provided as a point layer, but having points connected into ship tracks would have allowed for a more accurate analysis of distance traveled and also an analysis of ship density. Although we could have converted the point data into ship tracks, we did not have sufficient time for this task given the short timeframe of this contract.

The marine mammal data that we used have several limitations. First, the underlying data quality varies greatly between populations. Hauser et al. (2018) created a very useful dataset, but there is quite a bit of uncertainty underlying many of the populations (see Appendix 2 Table 4). Beyond this specific dataset, it would have been extremely useful to compare vessel traffic with marine mammal areas in other months, but this would require someone to either replicate Hauser et al.'s (2018) process for different months of the year, or find other comparable datasets for all marine mammal populations in the Arctic, which do not appear to exist at this time.

The best possible analysis examining the overlap between vessel traffic and marine mammals would use vessel density and marine mammal density data. The underlying vessel data already exist, and simply need to be processed appropriately, as suggested above. The marine mammal data, however, may not currently exist for all of the marine mammal populations. Marine mammal density can only be estimated using different survey methods, such as aerial surveys, which are costly and time-consuming. Other metrics, such as identifying hotspots or core use areas (Hauser et al. 2014, Citta et al. 2015, Yurkowski et al. 2019), can be conducted using aerial surveys or telemetry, which are similarly costly and time consuming. These data certainly exist for some populations, including most of the Arctic cetacean populations in the North American Arctic. However, comparable analyses need to be performed for different datasets, and data need to be made available before a comparative analysis can be undertaken.

4.4 Next Steps

This report highlights some seas of the Arctic and marine mammal areas that are exposed to more traffic than others in the month of September. The next step is to assess levels and variability of vessel traffic throughout the year to identify if these patterns presented for the month of September shift in other months. If high quality marine mammal data can be found for other months of the year, then the same assessment provided in this report should be carried out for all of those months as well.

Beyond this specific analysis of trends in Arctic shipping data, the next step for PAME's underwater noise project should be to select the best spatial and temporal extent for focused underwater noise mapping. This could focus on a pan-Arctic assessment, or could instead be based on the analysis presented in this report, focusing on a subset of seas in the Arctic or on specific September marine mammal areas with high ship traffic. My recommendation is to focus on the top three seas of the Arctic with the most ship traffic that also overlap with multiple marine mammal areas: Bering Sea, Barents Sea, and Baffin Bay-Davis Strait.

4.5 Conclusion

In conclusion, a subset of marine mammal populations in the Arctic are exposed to more ship traffic than others, and within most of these areas, the majority of traffic is from bulk carriers. This suggests that underwater noise levels might be higher in these regions of high ship traffic, but more work is needed to assess underwater noise levels.

5. ACKNOWLEDGEMENTS

We are grateful to PAME for providing the ASTD, Donna Hauser for sharing the marine mammal data, and Nicole Le Baron for assisting with analyses and preparing figures. Thanks to Francis Juanes and Rosaline Canessa at the University of Victoria for the use of lab space and computers.

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7. APPENDIX 1. VESSEL CATEGORIES

Table 5. Vessel categories used in this analysis, and how they are defined based on two categories from the ASTD (astd_cat or lloyds5_cat).

Our Category	ASTD Category or Lloyds Category 5
Bulk Carrier	**In astd_cat**: Bulk carriers, General cargo ships, Refrigerated cargo ships, or Ro-Ro cargo ships
Container Ship	**In astd_cat**: Container ships
Cruise Ship	**In astd_cat**: Cruise ships
Ferry	**In astd_cat**: Passenger ships
Fishing Vessel	**In astd_cat**: Fishing vessel
Government, Research, or Icebreaker Ship	**In lloyds5_cat**: Research Survey Vessel, Icebreaker, Icebreaker/Research, Patrol Vessel, Search & Rescue Vessel
Military Ship	**In lloyds5_cat**: Mooring Vessel, Naval Auxiliary, Research Vessel, Naval Auxiliary, Diving Vessel, Naval Auxiliary, Aircraft Carrier, Command Vessel, Destroyer, Frigate, Helicopter Carrier, Patrol Vessel, Naval, Weapons Trials Vessel, Logistics Vessel (Naval Ro-Ro Cargo), Infantry Landing Craft, Tank Landing Craft
Recreational Boat	**In lloyds5_cat**: Sailing Vessel, Yacht, Yacht (Sailing), Sail Training Ship
Tanker Ship	**In astd_cat**: Oil product tankers, Gas tankers, Crude oil tankers, or Chemical tankers
Tug Boat or Barge	**In astd_cat**: Offshore supply ships, Other service offshore vessels **In lloyds5_cat**: Tug, Articulated Pusher Tug, Pusher Tug, Bucket Ladder Dredger, Cutter Suction Dredger, Grab Dredger, Backhoe Dredger, Bucket Wheel Suction Dredger, Suction Dredger, Dredger (unspecified), Grab Hopper Dredger, Suction Hopper Dredger, Trailing Suction Hopper Dredger, Hopper/Dredger (unspecified), Work/Repair Vessel, Mining Vessel, Towing/Pushing, Inland Waterways, Covered Bulk Cargo Barge, non propelled, Bulk Cement Barge, non propelled, General Cargo Barge, non propelled, Trans Shipment Barge, non propelled, Hopper Barge, non propelled, LPG Tank Barge, non propelled, Products Tank Barge, non propelled, Crude Oil Tank Barge, non propelled

8. APPENDIX 2. ARCTIC MARINE MAMMAL POPULATIONS

Table 6. Arctic marine mammal populations used in this analysis. Uncertainty values (1 = low, 3 = high) are written in parenthesis beside each population, and are from Table S1 in Hauser et al. (2018).

Species	Population	
Beluga (*Delphinapterus leucas*)	1. E. Siberian and W. Chukchi Seas (3) 2. E. Chukchi Sea (1) 3. E. Beaufort Sea (1) 4. E. Bering Sea (2) 5. Bristol Bay (2) 6. W. Hudson Bay (2) 7. E. Hudson Bay (1)	8. Ungava Bay (3) 9. Cumberland Sound (2) 10. E. High Arctic-Baffin Bay (1) 11. White Sea (3) 12. Svalbard (3) 13. Kara and Laptev Seas (3) 14. Gulf of Anadyr (2)
Narwhal (*Monodon monoceros*)	1. Eclipse Sound (1) 2. Admiralty Inlet (1) 3. Somerset Island (1) 4. Jones Sound/Smith Sound (3) 5. E. Baffin Island Fjords (3)	6. N. Hudson Bay (2) 7. Inglefield Bredning (3) 8. Melville Bay (2) 9. E. Greenland (3) 10. Svalbard (3)
Bowhead (*Balaena mysticetus*)	1. Bering-Chukchi-Beaufort Seas (1) 2. E. Canada-W. Greenland (1)	3. Svalbard-Barents Sea (2)
Ringed Seal (*Pusa hispida*)	1. Beaufort and Chukchi Seas (2) 2. Bering Sea (2) 3. Hudson Bay and James Bay (2) 4. Baffin Bay (2)	5. Greenland Sea/Spitsbergen (2) 6. Svalbard (1) 7. White, Kara, Laptev, and E. Siberian Seas (3)
Bearded Seal (*Erignathus barbatus*)	1. E. Siberian Sea (3) 2. Bering Sea (1) 3. Chukchi Sea (1) 4. Beaufort Sea (1)	5. Canadian waters (3) 6. Greenland (3) 7. Svalbard (2) 8. Barents, White, Kara, and Laptev Seas (3)
Walrus (*Odobenus rosmarus*)	1. Bering-Chukchi Seas (1) 2. Laptev Sea (3) 3. N. and Central Foxe Basin (2) 4. S. and E. Hudson Bay (2) 5. N. Hudson Bay (2) 6. SE Baffin Island (2)	7. W. Jones Sound (2) 8. Penny Strait/Lancaster Sound (2) 9. Baffin Bay summer (2) 10. E. Greenland (2) 11. Svalbard/Franz Josef Land (1) 12. Novaya-Semlya-Barents-Pechora-White Seas (2)

9. APPENDIX 3. VESSEL TRAFFIC DATA FOR EACH VESSEL CLASS WITH ALL SEPTEMBER MARINE MAMMAL AREAS

Table 7. Vessel traffic data for all vessel classes combined for the years 2016-2018, as well as the average of all three years. Two variables are presented for each year: the total distance traveled (km) of all vessel classes, and the area-corrected total distance traveled (km/km2). Rows are ordered from largest to smallest based on the average area-corrected total distance traveled. Exposure score (1 = low, 3 = high) is the value calculated by Hauser et al. (2018) for each population.

		Total Distance Traveled (km)				**Area-corrected Total Distance Traveled (km/km2)**				**Exposure Score**
Species	**Population**	**2016**	**2017**	**2018**	**Average**	**2016**	**2017**	**2018**	**Ave**	
Beluga	White Sea	64,079,926	80,690,056	77,169,208	73,979,730	147.2	185.3	177.2	169.9	1
Beluga	Anadyr	771,474	417,062	830,341	672,959	80.3	43.4	86.4	70.1	1.32
Beluga	Siberian Sea	17,794,351	15,158,081	12,059,873	15,004,102	70.8	60.3	48	59.7	2.84
Narwhal	Eclipse Sound	24,451,434	32,329,924	40,433,546	32,404,968	34.7	45.8	57.3	45.9	3
Walrus	Novaya Semlya Barents	341,076,185	305,367,378	306,453,653	317,632,405	38.6	34.6	34.7	36	2.22
Ringed	Bering Sea	84,613,449	65,680,096	66,382,112	72,225,219	33.8	26.2	26.5	28.8	2.28
Bearded	B-W-K-L Seas	1,524,608,079	1,469,655,617	1,375,028,359	1,456,430,685	26.7	25.7	24.1	25.5	2.13
Beluga	Bering Sea	3,271,974	715,811	4,415,123	2,800,969	26.1	5.7	35.2	22.3	1
Walrus	SE Baffin Island	21,934,430	30,044,669	26,645,572	26,208,223	18.3	25.1	22.2	21.9	2.84
Walrus	Bering-Chukchi	231,105,891	271,814,594	241,943,461	248,287,982	20	23.5	20.9	21.4	1.9
Ringed	White, Barents, Kara, Siberia	1,931,583,430	1,900,110,373	1,796,978,824	1,876,224,209	20.5	20.1	19	19.9	1.96
Walrus	N Hudson Bay	18,900,655	24,680,316	28,168,621	23,916,531	15.6	20.4	23.2	19.7	1
Narwhal	Admiralty Inlet	10,892,579	10,159,915	18,507,467	13,186,653	15.3	14.3	26	18.5	3
Bowhead	ECWG	83,405,959	93,984,606	107,401,278	94,930,614	15.4	17.4	19.9	17.6	1.9
Beluga	Svalbard	56,205,122	54,073,976	69,944,292	60,074,464	16.3	15.7	20.3	17.5	1
Narwhal	N Hudson Bay	1,000,484	1,177,945	2,012,493	1,396,974	11.8	13.9	23.7	16.5	1

Narwhal	Somerset Island	16,814,368	18,749,663	22,597,094	19,387,042	13.7	15.3	18.5	15.9	2.68
Ringed	Baffin Bay	200,303,910	260,563,654	306,484,399	255,783,987	12.2	15.9	18.7	15.6	2.36
Walrus	Laptev	151,778,911	137,830,435	110,295,064	133,301,470	16.9	15.4	12.3	14.9	3
Bearded	Greenland	189,406,184	329,024,835	313,125,573	277,185,530	9.4	16.4	15.6	13.8	1.29
Beluga	W Hudson Bay	8,928,605	14,560,334	16,161,625	13,216,855	9	14.6	16.2	13.3	1
Beluga	High Arctic-Baffin Bay	13,923,867	14,529,278	22,734,842	17,062,662	9.6	10	15.7	11.8	2.88
Bearded	Bering Sea	108,580,357	81,918,422	68,389,112	86,295,964	14.4	10.9	9.1	11.4	2.32
Bearded	Chukchi Sea	100,429,956	80,447,665	55,612,860	78,830,160	9.5	7.5	14.5	10.5	3
Walrus	Foxe Basin	7,322,851	5,433,599	2,821,434	5,192,628	12.4	10	6.9	9.8	2.43
Walrus	Penny Strait Lancaster Sound	11,574,292	9,142,925	17,672,425	12,796,547	13.4	10	5.2	9.5	1
Bearded	Svalbard	179,183,436	151,205,321	124,619,808	151,669,521	10.7	9	7.4	9	1
Ringed	Hudson Bay, James Bay	40,595,156	46,346,485	49,285,436	45,409,026	7.9	9	9.6	8.8	1.01
Bearded	Canada	144,593,113	182,819,797	174,063,631	167,158,847	7.3	9.2	8.7	8.4	1.6
Beluga	Cumberland Sound	949,948	350,308	483,773	594,676	6.7	7.5	10.2	8.1	1.59
Narwhal	E Baffin Island	952,096	1,078,326	1,461,957	1,164,126	9	7.7	7	7.9	1
Walrus	Svalbard	116,166,492	99,130,675	90,594,674	101,963,947	12.1	4.5	6.1	7.6	1
Bearded	Siberian Sea	134,036,704	121,927,432	106,861,563	120,941,900	7.8	7.1	6.2	7	2.07
Beluga	Kara & Laptev	309,881,361	260,448,004	253,038,075	274,455,814	9.1	7	4.6	6.9	2.55
Bowhead	BCB	104,734,943	80,975,277	52,738,281	79,482,834	7.6	6.4	6.2	6.7	2.22
Beluga	Ungava Bay	967,166	1,252,644	2,188,758	1,469,523	4.3	5.5	9.7	6.5	1
Narwhal	Inglefield Bredning	847,678	520,340	1,282,049	883,355	5.3	3.3	8.1	5.6	1
Bearded	Beaufort Sea	47,878,540	30,990,691	18,600,403	32,489,878	6.2	5.3	4.3	5.3	1
Bowhead	Svalbard	150,283,106	127,442,333	104,311,381	127,345,607	6	4.8	5.2	5.3	1
Walrus	E Greenland	18,953,649	15,366,369	16,564,241	16,961,420	6.9	4.4	2.7	4.7	2.98
Narwhal	E Greenland	33,475,244	31,003,771	27,943,502	30,807,506	4.8	4.4	4	4.4	1
Ringed	Bering-Chukchi	119,547,134	95,441,238	71,221,320	95,403,231	4.6	3.7	2.8	3.7	2.01
Beluga	Beaufort Sea	68,739,991	55,938,135	32,818,013	52,498,713	3.8	2.5	2.8	3	1.18

Narwhal	Melville Bay	4,022,488	2,655,566	2,942,372	3,206,808	3.2	2.6	2.4	2.7	1
Ringed	Svalbard	134,880,450	108,423,153	102,338,307	115,213,970	3.4	2.8	1.6	2.6	1.92
Beluga	Chukchi Sea	27,195,123	21,071,109	14,217,155	20,827,796	2.4	2.5	1.9	2.3	1
Ringed	East Greenland	67,542,875	70,106,219	53,527,927	63,725,674	2	1.6	1.1	1.5	1.62
Narwhal	Jones Sound-Smith Sound	511,723	146,116	1,328,700	662,180	0.8	0	3.4	1.4	1
Walrus	Baffin Bay	675,107	219,814	2,322,758	1,072,560	0.9	0.3	3.1	1.4	1
Walrus	W Jones Sound	216,886	0	913,137	376,675	1	0.3	2.6	1.3	1
Narwhal	Svalbard	15,134,585	21,967,954	22,599,362	19,900,634	0.3	0.4	0.4	0.4	1

Table 8. Total distance traveled (km) for different classes of vessel in September 2016 for each marine mammal area. Table is ordered alphabetically by species and population.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	7,476,585	0	1,592,716	2,406,053	0	10,187,731	0	0	1,866,443	24,349,012
Bearded	Bering Sea	31,263,749	1,904,076	5,486,501	1,111,274	0	23,441,750	0	0	10,356,224	35,016,783
Bearded	B-W-K-L Seas	561,979,636	0	16,851,348	99,354,538	192,762,125	165,050,657	0	0	315,009,902	173,599,874
Bearded	Canada	65,261,955	0	23,715,541	2,920,373	0	20,777,556	0	0	26,213,320	5,704,368
Bearded	Chukchi Sea	29,691,853	1,451,161	4,570,380	1,227,182	0	24,502,520	0	0	8,224,878	30,761,982
Bearded	Greenland	28,182,912	27,087,182	39,185,289	23,632,967	28,609,738	24,472,875	0	0	15,050,262	3,184,960
Bearded	Siberian Sea	59,443,132	879,539	1,885,941	0	0	30,869,372	0	0	30,690,177	10,268,542
Bearded	Svalbard	22,530,789	0	16,774,786	12,129,244	76,317,511	37,131,059	0	0	7,803,943	6,496,105
Beluga	Anadyr	602,122	42,334	50,260	0	0	35,259	0	0	41,498	0
Beluga	Beaufort Sea	7,426,228	0	2,432,807	2,368,284	0	26,189,839	0	0	2,003,720	28,319,113
Beluga	Bering Sea	303,120	0	0	0	0	36,340	0	0	0	2,932,513
Beluga	Chukchi Sea	2,900,186	0	656,159	377,937	0	15,326,102	0	0	373,166	7,561,574
Beluga	Cumberland Sound	319,321	0	630,628	0	0	0	0	0	0	0
Beluga	High Arctic-Baffin Bay	3,054,831	0	3,994,484	1,174,503	0	4,193,856	0	0	1,506,192	0
Beluga	Kara & Laptev	131,221,253	0	5,488,542	0	0	65,654,755	0	0	79,913,001	27,603,810
Beluga	Siberian Sea	9,576,173	914,728	1,790,632	803,920	0	910,909	0	0	2,677,308	1,120,681
Beluga	Svalbard	10,741,382	0	13,174,610	9,142,655	2,173,460	14,774,425	0	0	1,338,759	4,859,831
Beluga	Ungava Bay	556,916	0	410,249	0	0	0	0	0	0	0
Beluga	W Hudson Bay	4,286,366	0	0	0	0	1,944,359	0	0	2,606,297	91,583
Beluga	White Sea	42,295,954	0	208,558	319,074	0	2,072,230	0	0	16,473,232	2,710,876
Bowhead	BCB	28,420,135	1,531,469	5,159,181	2,242,640	0	27,214,724	0	0	7,944,430	32,222,366
Bowhead	ECWG	34,095,865	0	15,782,229	1,004,055	0	15,590,728	0	0	16,711,985	221,097
Bowhead	Svalbard	15,209,933	0	22,475,180	15,198,683	52,447,825	35,524,479	0	0	4,161,647	5,265,359
Narwhal	Admiralty Inlet	3,164,176	0	2,915,554	317,141	0	3,635,949	0	0	859,759	0

Narwhal	E Baffin Island	81,635	0	870,460	0	0	0	0	0	0	0
Narwhal	E Greenland	0	889,320	14,276,867	8,695,373	0	7,433,939	0	0	2,179,745	0
Narwhal	Eclipse Sound	15,093,701	0	4,853,321	0	0	2,912,845	0	0	1,300,579	290,988
Narwhal	Inglefield Bredning	0	170,479	172,520	86,092	0	233,496	0	0	185,090	0
Narwhal	Jones Sound-Smith Sound	239,944	0	271,779	0	0	0	0	0	0	0
Narwhal	Melville Bay	405,877	1,020,226	734,982	450,947	0	553,360	0	0	857,095	0
Narwhal	N Hudson Bay	200,158	0	0	0	0	244,625	0	0	555,702	0
Narwhal	Somerset Island	3,694,808	0	3,436,827	473,044	0	6,469,574	0	0	2,740,114	0
Narwhal	Svalbard	760,596	0	3,913,675	0	3,005,071	6,783,946	0	0	527,060	144,237
Ringed	Hudson Bay, James Bay	18,490,522	0	2,426,146	0	0	6,202,708	0	0	13,475,780	0
Ringed	Baffin Bay	72,644,140	24,140,683	33,953,895	14,984,528	2,115,776	26,069,286	0	0	22,768,359	3,627,242
Ringed	Bering Sea	31,244,540	1,963,885	5,138,205	1,130,072	0	12,595,453	0	0	9,048,715	23,492,579
Ringed	Bering-Chukchi	23,042,596	297,353	4,764,361	3,379,228	0	32,390,424	0	0	9,144,578	46,528,595
Ringed	East Greenland	5,459,270	1,508,881	20,475,701	11,396,939	5,318,775	20,101,456	0	0	2,887,988	393,864
Ringed	Svalbard	13,237,436	0	15,446,710	9,560,797	56,607,430	29,052,584	0	0	4,850,365	6,125,128
Ringed	White, Barents, Kara, Siberia	754,828,386	1,463,016	21,248,299	210,927,558	208,191,493	194,468,685	0	0	349,167,369	191,288,623
Walrus	Baffin Bay	189,024	0	399,167	86,916	0	0	0	0	0	0
Walrus	Bering-Chukchi	99,111,487	4,026,584	10,257,380	2,401,411	0	32,778,671	0	0	26,195,130	56,335,229
Walrus	E Greenland	0	576,762	9,641,087	5,017,769	0	1,617,660	0	0	2,100,370	0
Walrus	Foxe Basin	1,950,367	0	403,998	0	0	2,345,551	0	0	2,622,935	0
Walrus	Laptev	64,377,607	0	1,392,280	400,606	0	30,211,583	0	0	47,533,393	7,863,442

Walrus	N Hudson Bay	8,226,587	0	526,098	0	0	2,398,128	0	0	7,749,841	0
Walrus	Novaya Semlya Barents	162,897,371	0	2,941,437	0	0	28,988,473	0	0	105,987,548	40,261,356
Walrus	Penny Strait Lancaster Sound	2,931,681	0	3,257,380	881,309	0	3,660,489	0	0	843,432	0
Walrus	SE Baffin Island	9,391,872	0	8,725,484	0	0	1,582,344	0	0	2,230,227	4,502
Walrus	Svalbard	11,620,695	0	14,978,163	9,222,864	48,807,138	22,585,162	0	0	4,098,641	4,853,829
Walrus	W Jones Sound	0	0	0	216,886	0	0	0	0	0	0

Table 9. Total distance traveled (km) for different classes of vessel in September 2017 for each marine mammal area. Table is ordered alphabetically by species and population.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	5,901,474	0	2,227,347	0	0	9,555,441	0	0	1,923,482	11,382,947
Bearded	Bering Sea	31,531,654	1,858,045	1,290,001	1,427,592	81,588	16,392,679	0	0	5,907,258	23,429,604
Bearded	B-W-K-L Seas	503,391,355	0	19,303,813	104,624,458	146,091,471	181,400,712	14,438	377,529	282,990,692	231,461,150
Bearded	Canada	93,602,934	0	20,499,860	0	4,168,032	30,829,513	0	3,075,454	25,275,429	5,368,575
Bearded	Chukchi Sea	28,416,246	1,671,957	1,203,005	1,198,975		21,694,267	0	0	4,800,018	21,463,196
Bearded	Greenland	48,154,553	27,626,139	52,323,558	18,643,044	147,206,516	18,417,174	0	958,772	12,064,822	3,630,256
Bearded	Siberian Sea	62,070,226	1,130,009	0	2,221,128	0	20,879,903	0	0	25,248,444	10,377,722
Bearded	Svalbard	16,097,200	0	15,432,419	13,074,813	57,335,219	34,401,428	0	1,117,754	4,671,952	9,074,535
Beluga	Anadyr	171,741	100,194	55,797	59,217	0	0	0	0	30,114	0
Beluga	Beaufort Sea	6,241,417		2,117,346	187,396	0	30,889,919	0	0	1,769,205	14,732,852
Beluga	Bering Sea	107,407	0	0	0	0	161,904	0	0	0	446,499
Beluga	Chukchi Sea	2,117,336		257,578	0	0	15,577,593	0	0	971,881	2,146,721
Beluga	Cumberland Sound	175,178	0	175,130	0	0	0	0	0	0	0
Beluga	High Arctic-Baffin Bay	2,947,396	0	3,354,898	0	0	6,697,003	0	79,234	938,074	512,673
Beluga	Kara & Laptev	92,586,473	0	9,715,771	8,691,769	1,025,417	49,165,945	0	0	65,983,431	33,279,198
Beluga	Siberian Sea	10,640,109	838,009	152,741	444,266	0	347,154	0	0	1,746,078	989,725
Beluga	Svalbard	8,333,747	0	12,353,949	10,987,180	6,840,785	9,444,277	0	797,484	1,067,255	4,249,298
Beluga	Ungava Bay	316,802	0	607,707	0	0	328,135	0	0	0	0
Beluga	W Hudson Bay	7,234,591	0	0	0	0	2,596,317	0	0	4,460,544	268,882
Beluga	White Sea	49,507,406	0	530,486	537,603	50,139	2,444,911	0	0	16,546,942	11,072,570
Bowhead	BCB	28,063,283	1,668,568	2,038,696	1,265,509	0	25,239,725	0	0	4,052,477	18,647,018
Bowhead	ECWG	44,413,994	0	11,825,554	0	3,408,207	16,675,273	0	1,402,818	14,450,655	1,808,107

Bowhead	Svalbard	12,913,538	0	20,654,970	16,657,036	37,071,216	28,517,828	0	890,702	4,581,494	6,155,549
Narwhal	Admiralty Inlet	3,087,052	0	1,247,517	0	0	3,637,593	0	168,272	1,453,735	565,745
Narwhal	E Baffin Island	58,344	0	921,178	0	0	0	0	98,803	0	0
Narwhal	E Greenland	0	156,507	14,198,977	7,238,212	50,409	7,343,521	0	0	1,776,651	239,493
Narwhal	Eclipse Sound	22,340,559	0	3,867,203	0	0	2,664,854	0	952,659	1,877,435	627,214
Narwhal	Inglefield Bredning	0	355,805	108,069	0	0	0	0	0	56,465	0
Narwhal	Jones Sound-Smith Sound	146,116	0	0	0	0	0	0	0	0	0
Narwhal	Melville Bay	827,284	380,960	514,534	0	0		0	0	932,788	0
Narwhal	N Hudson Bay	319,629	0	0	0	0	453,751	0	0	404,565	0
Narwhal	Somerset Island	3,727,956	0	3,812,826	0	0	8,831,576	0	0	1,827,114	550,192
Narwhal	Svalbard	3,375,013	0	5,222,581	1,965,822	4,176,453	3,561,835	0	0	1,136,626	2,529,624
Ringed	Hudson Bay, James Bay	20,357,968	0	2,969,534	0	0	8,726,061	0	0	13,057,416	1,235,506
Ringed	Baffin Bay	122,176,685	24,645,358	38,954,063	8,606,114	18,293,445	23,778,237	0	3,481,521	15,134,537	5,493,694
Ringed	Bering Sea	29,637,761	2,102,311	1,647,010	875,894	352,616	6,825,887	0	0	7,131,371	17,107,244
Ringed	Bering-Chukchi	19,998,478	581,549	4,404,755	171,886	81,588	37,006,786	0	0	8,056,443	25,139,753
Ringed	East Greenland	1,980,982	877,112	20,030,507	10,818,823	8,563,884	22,629,973	0	0	4,250,333	954,605
Ringed	Svalbard	12,397,615	0	15,690,468	12,706,047	35,701,174	18,818,809	0	822,295	4,565,505	7,721,239
Ringed	White, Barents, Kara, Siberia	699,356,945	3,369,959	21,647,068	215,140,719	181,565,778	204,464,854	14,438	934,026	315,341,358	258,275,229
Walrus	Baffin Bay	219,814	0	0	0	0	0	0	0	0	0
Walrus	Bering-Chukchi	96,391,872	5,449,515	3,364,926	2,549,877	80,002,341	25,062,264	0	0	23,471,414	35,522,385

Walrus	E Greenland	0	213,461	6,885,655	3,398,747	38,630	2,756,884	0	0	1,659,647	413,344
Walrus	Foxe Basin	1,152,376	0	445,214	0	0	1,058,579	0	0	2,777,431	0
Walrus	Laptev	52,393,044	0	2,739,330	1,813,086	759,715	23,604,820	0	0	52,417,160	4,103,280
Walrus	N Hudson Bay	11,898,047	0	866,601	0	0	4,907,014	0	0	6,428,417	580,237
Walrus	Novaya Semlya Barents	113,443,147	0	7,554,219	6,266,222	3,220,954	33,912,525	0	0	76,291,235	64,679,076
Walrus	Penny Strait Lancaster Sound	1,828,682	0	2,484,354	0	0	3,978,395	0	143,818	445,381	262,294
Walrus	SE Baffin Island	15,880,766	0	5,966,116	0	3,542,101	2,116,068	0	875,316	1,664,302	0
Walrus	Svalbard	11,050,487	0	14,407,882	12,355,435	34,709,586	15,897,171	0	757,537	3,690,089	6,262,488
Walrus	W Jones Sound	0	0	0	0	0	0	0	0	0	0

Table 10. Total distance traveled (km) for different classes of vessel in September 2018 for each marine mammal area. Table is ordered alphabetically by species and population.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	1,902,693	0	0	0	0	4,235,497	0	0	2,626,792	9,835,421
Bearded	Bering Sea	20,670,902	930,188	1,445,002	0	39,394	14,380,352	0	0	8,237,310	22,685,964
Bearded	B-W-K-L Seas	465,901,172	4,079,540	6,513,712	93,131,718	177,717,793	134,507,769	0	433,311	332,917,222	159,826,124
Bearded	Canada	109,389,160	0	18,522,580	3,257,322	5,060,911	0	0	0	31,915,729	5,917,930
Bearded	Chukchi Sea	16,665,091	777,209	997,566	0	0	14,369,630	0	0	6,812,667	15,990,697
Bearded	Greenland	61,586,744	20,067,350	46,897,960	23,024,457	125,256,153	13,021,684	0	323,254	18,699,751	4,248,220
Bearded	Siberian Sea	48,872,635	1,710,981	283,429	0	0	31,924,637	0	0	20,301,728	3,768,152
Bearded	Svalbard	15,724,297	0	20,658,879	15,582,663	20,476,937	30,831,798	0	2,805,719	11,257,389	7,282,126
Beluga	Anadyr	690,035	0	0	0	0	0	0	0	140,306	0
Beluga	Beaufort Sea	2,195,724	0	117,943	0	0	17,448,515	0	0	3,757,733	9,298,098
Beluga	Bering Sea	1,367,850	0	0	0	0	0	0	0	285,179	2,762,095
Beluga	Chukchi Sea	589,065	0	0	0	0	10,858,284	0	0	2,040,451	729,355
Beluga	Cumberland Sound	149,075	0	107,256	0	0	227,442	0	0	0	0
Beluga	High Arctic-Baffin Bay	5,808,168	0	6,966,401	927,673	0	7,902,999	0		676,953	452,649
Beluga	Kara & Laptev	80,244,956	1,961,163	0	0	28,395	67,654,952	0	0	71,297,137	31,851,472
Beluga	Siberian Sea	6,072,250	253,563	1,027,330	0	0	1,632,956	0	0	2,333,253	740,521
Beluga	Svalbard	7,948,565	0	15,857,458	13,160,519	4,222,918	17,274,436	0	2,135,005	3,783,935	5,561,457
Beluga	Ungava Bay	954,876	0	371,606	0	341,837	291,921	0	0	228,519	0
Beluga	W Hudson Bay	9,218,671	0	0	0	0	1,191,564	0	0	5,340,636	410,755
Beluga	White Sea	47,986,523	0	184,298	848,150	3,515,493	3,482,057	0	0	17,845,033	3,307,654
Bowhead	BCB	14,572,092	785,415	819,419	0	0	17,652,328	0	0	6,993,495	11,915,533
Bowhead	ECWG	56,607,258	0	11,701,997	2,152,998	631,542	16,413,219	0	0	17,005,169	2,889,094

Bowhead	Svalbard	0	0	25,802,053	17,829,582	14,038,964	30,086,690	0	2,361,504	8,391,438	5,801,149
Narwhal	Admiralty Inlet	5,515,186	0	5,002,609	432,485	0	5,661,260	0	0	1,247,272	648,654
Narwhal	E Baffin Island	70,955	0	801,250	185,078	0	23,769	0	0	380,905	0
Narwhal	E Greenland	788,996	146,305	12,832,607	5,942,208	0	6,007,175	0	0	2,226,210	0
Narwhal	Eclipse Sound	27,588,495	0	3,633,862	1,769,098	527,530	2,790,321	0	0	2,795,774	1,328,465
Narwhal	Inglefield Bredning	566,056	0	715,993	0	0	0	0	0	0	0
Narwhal	Jones Sound-Smith Sound	75,156	0	922,053	200,456	0	131,035	0	0	0	0
Narwhal	Melville Bay	789,355	0	2,022,037	0	42,844	0	0	0	88,135	0
Narwhal	N Hudson Bay	719,105	0	0	0	0	1,019,929	0	0	273,459	0
Narwhal	Somerset Island	6,121,079	0	4,256,096	0	0	10,163,823	0	0	1,572,290	483,806
Narwhal	Svalbard	1,206,763	0	5,350,862	1,097,368	481,537	12,584,564	0	0	469,176	1,409,092
Ringed	Hudson Bay, James Bay	27,865,199	0	2,095,235	0	667,017	2,471,859	0	0	16,087,555	98,571
Ringed	Baffin Bay	145,599,526	17,662,749	40,431,193	19,143,918	21,469,530	30,901,191	0	323,254	22,936,256	8,016,780
Ringed	Bering Sea	22,358,175	845,465	2,780,895	0	39,394	8,634,347	0	0	8,994,103	22,729,733
Ringed	Bering-Chukchi	14,901,310	290,108	478,811	0	39,394	23,051,298	0	0	9,641,741	22,818,657
Ringed	East Greenland	4,549,776	1,074,840	19,118,817	8,699,894	409,830	13,759,443	0	0	5,915,326	0
Ringed	Svalbard	10,665,362	0	19,426,709	14,015,048	13,098,432	30,328,748	0	2,286,713	6,770,936	5,746,359
Ringed	White, Barents, Kara, Siberia	652,839,222	7,257,581	10,242,778	198,498,294	212,157,558	172,540,520	0	1,639,634	368,856,710	172,946,528
Walrus	Baffin Bay	282,785	0	1,418,789	360,016	0	261,168	0	0	0	0
Walrus	Bering-Chukchi	78,627,569	1,609,416	4,874,663	0	61,089,092	27,352,780	0	0	27,187,977	41,201,964

Walrus	E Greenland	567,060	170,712	6,817,493	3,448,450	0	3,422,559	0	0	2,137,966	0
Walrus	Foxe Basin	1,160,526	0	0	0	0	294,331	0	0	1,366,577	0
Walrus	Laptev	44,615,747	1,312,279	0	0	0	14,692,300	0	0	40,322,849	9,351,889
Walrus	N Hudson Bay	16,731,875	0	919,513	0	0	1,290,042	0	0	9,151,056	76,134
Walrus	Novaya Semlya Barents	109,236,267	799,401	173,561	0	5,938,153	46,978,908	0	0	89,348,658	53,978,705
Walrus	Penny Strait Lancaster Sound	5,445,867	0	5,071,405	1,158,027	0	4,895,137	0	0	595,178	506,811
Walrus	SE Baffin Island	12,301,369	0	2,768,413	242,655	927,333	4,047,910	0	0	4,434,283	1,923,608
Walrus	Svalbard	9,080,631	0	18,685,523	13,784,625	9,330,027	25,775,710	0	2,107,722	6,304,654	5,525,783
Walrus	W Jones Sound	386,818	0	94,853	0	0	431,466	0	0		0

Table 11. Total number of unique vessels in September 2016 in each Arctic marine mammal area.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	4	0	1	1	2	5	0	0	1	15
Bearded	Bering Sea	37	1	3	1	0	12	0	0	10	25
Bearded	B-W-K-L Seas	264	0	8	53	279	54	0	0	111	20
Bearded	Canada	32	0	7	1	0	7	0	0	9	3
Bearded	Chukchi Sea	37	1	3	1	0	10	0	0	8	26
Bearded	Greenland	36	8	26	4	126	16	0	0	5	1
Bearded	Siberian Sea	34	1	2	0	0	14	0	0	19	5
Bearded	Svalbard	19	0	8	6	142	20	0	0	4	5
Beluga	Anadyr	4	1	1	0	3	1	0	0	1	0
Beluga	Beaufort Sea	4	0	3	1	2	14	0	0	3	17
Beluga	Bering Sea	1	0	0	0	1	1	0	0	0	8
Beluga	Chukchi Sea	4	0	1	1	2	5	0	0	1	9
Beluga	Cumberland Sound	1	0	3	0	0	0	0	0	0	0
Beluga	High Arctic-Baffin Bay	5	0	6	1	0	5	0	0	2	0
Beluga	Kara & Laptev	73	0	3	0	10	20	0	0	35	19
Beluga	Siberian Sea	24	1	3	1	3	3	0	0	5	3
Beluga	Svalbard	15	0	7	6	67	14	0	0	2	4
Beluga	Ungava Bay	5	0	2	0	4	0	0	0	0	0
Beluga	W Hudson Bay	3	0	0	0	0	1	0	0	3	1
Beluga	White Sea	68	0	2	1	36	5	0	0	28	8
Bowhead	BCB	28	1	3	1	0	14	0	0	8	21

Bowhead	ECWG	31	0	7	1	0	6	0	0	8	2
Bowhead	Svalbard	16	0	12	7	132	21	0	0	6	4
Narwhal	Admiralty Inlet	5	0	6	1	0	5	0	0	2	0
Narwhal	E Baffin Island	2	0	5	0	0	0	0	0	0	0
Narwhal	E Greenland	1	2	7	3	0	7	0	0	1	0
Narwhal	Eclipse Sound	24	0	6	0	2	5	0	0	3	2
Narwhal	Inglefield Bredning	0	1	1	1	3	1	0	0	1	0
Narwhal	Jones Sound-Smith Sound	1	0	1	0	0	0	0	0	0	0
Narwhal	Melville Bay	1	2	2	1	9	1	0	0	1	0
Narwhal	N Hudson Bay	1	0	0	0	0	1	0	0	2	0
Narwhal	Somerset Island	5	0	6	1	0	5	0	0	3	0
Narwhal	Svalbard	2	0	7	0	53	11	0	0	3	2
Ringed	Hudson Bay, James Bay	10	0	1	0	0	4	0	0	7	0
Ringed	Baffin Bay	30	5	12	2	48	12	0	0	7	1
Ringed	Bering Sea	40	2	3	1	0	9	0	0	10	23
Ringed	Bering-Chukchi	37	1	6	1	0	11	0	0	10	27
Ringed	East Greenland	17	4	12	4	46	12	0	0	2	2
Ringed	Svalbard	15	0	9	6	125	19	0	0	5	5
Ringed	White, Barents, Kara, Siberia	340	3	10	82	310	60	0	0	120	103
Walrus	Baffin Bay	1	0	1	1	0	0	0	0	0	0

Walrus	Bering-Chukchi	74	2	4	1	0	15	0	0	24	30
Walrus	E Greenland	0	2	7	3	0	4	0	0	1	0
Walrus	Foxe Basin	4	0	1	0	0	3	0	0	4	0
Walrus	Laptev	47	0	2	1	5	13	0	0	28	6
Walrus	N Hudson Bay	8	0	1	0	3	1	0	0	7	0
Walrus	Novaya Semlya Barents	113	0	4	0	52	18	0	0	45	28
Walrus	Penny Strait Lancaster Sound	5	0	6	2	0	5	0	0	2	0
Walrus	SE Baffin Island	21	0	6	0	12	2	0	0	3	1
Walrus	Svalbard	15	0	9	6	115	18	0	0	5	4
Walrus	W Jones Sound	0	0	0	1	0	0	0	0	0	0

Table 12.Total number of unique vessels in September 2017 in each Arctic marine mammal area.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	3	0	1	0	0	6	0	0	2	8
Bearded	Bering Sea	34	1	2	1	6	8	0	0	8	19
Bearded	B-W-K-L Seas	253	1	7	51	272	53	1	1	112	110
Bearded	Canada	45	0	10	0	14	10	0	2	9	8
Bearded	Chukchi Sea	34	1	1	1	5	8	0	0	6	16
Bearded	Greenland	48	5	32	7	114	15	0	1	8	7
Bearded	Siberian Sea	42	1	0	1	0	8	0	0	19	4
Bearded	Svalbard	13	0	6	5	118	16	0	1	3	8
Beluga	Anadyr	3	1	1	1	0	0	0	0	1	0
Beluga	Beaufort Sea	5	0	1	1	0	9	0	0	2	10
Beluga	Bering Sea	1	0	0	0	0	2	0	0	0	2
Beluga	Chukchi Sea	4		1	0	0	6	0	0	1	4
Beluga	Cumberland Sound	1	0	1	0	0	0	0	0	0	0
Beluga	High Arctic-Baffin Bay	5	0	4	0	0	7	0	1	2	1
Beluga	Kara & Laptev	57	1	3	2	12	17	0	0	29	30
Beluga	Siberian Sea	25	1	1	1	0	3	0	0	4	2
Beluga	Svalbard	8	0	6	5	67	10	0	1	2	4
Beluga	Ungava Bay	3	0	3	0	0	2	0	0	0	0
Beluga	W Hudson Bay	5	0	0	0	0	2	0	0	4	1
Beluga	White Sea	67	0	2	1	25	5	0	0	24	13
Bowhead	BCB	27	1	1	1	0	7	0	0	7	12

Bowhead	ECWG	41	0	10	0	9	9	0	2	8	5
Bowhead	Svalbard	13	0	11	8	99	14	0	1	8	4
Narwhal	Admiralty Inlet	5	0	3	0	0	7	0	1	2	1
Narwhal	E Baffin Island	1	0	5	0	0	0	0	1	0	0
Narwhal	E Greenland	0	1	7	3	3	6	0	0	2	1
Narwhal	Eclipse Sound	31	0	5	0	0	6	0	2	3	4
Narwhal	Inglefield Bredning	0	1	1	0	0	0	0	0	1	0
Narwhal	Jones Sound-Smith Sound	1	0	0	0	0	0	0	0	0	0
Narwhal	Melville Bay	2	1	1	0	0	0	0	0	1	0
Narwhal	N Hudson Bay	1	0	0	0	0	2	0	0	2	0
Narwhal	Somerset Island	5	0	5	0	0	7	0	0	3	1
Narwhal	Svalbard	5	0	5	2	13	8	0	0	5	1
Ringed	Hudson Bay, James Bay	13	0	6	0	6	4	0	0	7	2
Ringed	Baffin Bay	45	5	14	3	16	13	0	2	8	9
Ringed	Bering Sea	37	2	2	1	29	7	0	0	9	19
Ringed	Bering-Chukchi	35	1	2	1	6	14	0	0	10	19
Ringed	East Greenland	9	1	15	4	59	12	0	0	6	5
Ringed	Svalbard	13	1	7	6	96	15	0	1	7	5
Ringed	White, Barents, Kara, Siberia	329	5	8	84	310	59	1	1	119	121
Walrus	Baffin Bay	1	0	0	0	0	0	0	0	0	0

Walrus	Bering-Chukchi	79	2	2	1	88	12	0	0	22	24
Walrus	E Greenland	0	1	7	3	4	6	0	0	2	1
Walrus	Foxe Basin	1	0	2	0	0	3	0	0	3	0
Walrus	Laptev	43	0	1	1	8	12	0	0	34	6
Walrus	N Hudson Bay	9	0	1	0	0	4	0	0	7	2
Walrus	Novaya Semlya Barents	98	0	3	2	3	18	0	0	39	40
Walrus	Penny Strait Lancaster Sound	4	0	4	0	0	6	0	1	2	1
Walrus	SE Baffin Island	32	0	8	0	10	3	0	2	5	0
Walrus	Svalbard	13	0	7	6	93	14	0	1	5	4
Walrus	W Jones Sound	0	0	0	0	0	0	0	0	0	0

Table 13. Total number of unique vessels in September 2018 in each Arctic marine mammal area.

Species	Population	Bulk	Cont	Cruise	Ferry	Fish	Gov	Mil	Rec	Tank	Tug
Bearded	Beaufort Sea	4	1	1	0	1	4	0	0	4	9
Bearded	Bering Sea	26	3	1	0	3	9	0	0	9	27
Bearded	B-W-K-L Seas	253	5	8	50	272	16	0	2	141	113
Bearded	Canada	52	1	7	1	15	4	0	0	17	9
Bearded	Chukchi Sea	25	1	1	0	0	9	0	0	8	19
Bearded	Greenland	51	5	25	7	115	5	0	3	9	8
Bearded	Siberian Sea	29	4	1	0	11	12	0	0	21	6
Bearded	Svalbard	20	3	11	5	114	13	0	4	10	14
Beluga	Anadyr	5	0	0	0	3	0	0	0	3	0
Beluga	Beaufort Sea	6	1	2	0	2	6	0	0	5	9
Beluga	Bering Sea	2	0	0	0	2	0	0	0	1	8
Beluga	Chukchi Sea	3	1	2	0	2	4	0	0	2	9
Beluga	Cumberland Sound	1	0	1	0	1	1	0	0	0	0
Beluga	High Arctic-Baffin Bay	7	0	6	1	1	4	0	0	2	2
Beluga	Kara & Laptev	51	5	0	1	6	23	0	0	35	33
Beluga	Siberian Sea	14	1	2	0	2	4	0	0	5	2
Beluga	Svalbard	11	0	9	5	69	11	0	2	5	2
Beluga	Ungava Bay	6	0	2	0	3	1	0	0	1	0
Beluga	W Hudson Bay	7	0	0	0	0	1	0	0	7	1
Beluga	White Sea	75	0	2	2	35	6	0	0	21	8
Bowhead	BCB	21	4	2	0	6	9	0	0	8	12

Bowhead	ECWG	48	0	7	1	12	1	0	0	13	6
Bowhead	Svalbard	22	3	11	6	99	14	0	4	9	7
Narwhal	Admiralty Inlet	6	0	6	1	0	4	0	0	2	1
Narwhal	E Baffin Island	2	0	2	1	0	1	0	0	2	0
Narwhal	E Greenland	5	2	7	2	0	4	0	0	2	0
Narwhal	Eclipse Sound	38	0	5	1	4	5	0	0	4	4
Narwhal	Inglefield Bredning	1	0	4	0	0	0	0	0	0	0
Narwhal	Jones Sound-Smith Sound	2	0	3	1	1	1	0	0	0	0
Narwhal	Melville Bay	2	0	4	0	5	0	0	0	1	0
Narwhal	N Hudson Bay	2	0	0	0	0	1	0	0	1	0
Narwhal	Somerset Island	6	0	5	0	0	4	0	0	2	2
Narwhal	Svalbard	8	0	5	1	64	10	0	0	3	3
Ringed	Hudson Bay, James Bay	13	0	2	0	7	2	0	0	9	2
Ringed	Baffin Bay	51	5	11	4	43	8	0	1	14	10
Ringed	Bering Sea	28	1	2	0	14	8	0	0	10	25
Ringed	Bering-Chukchi	28	2	5	1	4	11	0	0	13	26
Ringed	East Greenland	23	7	16	3	48	1	0	0	7	7
Ringed	Svalbard	20	2	9	5	68	15	0	2	8	4
Ringed	White, Barents, Kara, Siberia	331	11	10	83	309	23	0	4	154	127
Walrus	Baffin Bay	2	0	5	1	1	1	0	0	0	0

Walrus	Bering-Chukchi	60	3	2	0	82	13	0	0	27	31
Walrus	E Greenland	1	1	6	2	1	4	0	0	2	0
Walrus	Foxe Basin	2	0	0	0	0	1	0	0	2	0
Walrus	Laptev	40	1	0	0	1	14	0	0	31	6
Walrus	N Hudson Bay	11	0	1	0	0	1	0	0	8	1
Walrus	Novaya Semlya Barents	88	3	1	1	1	23	0	0	54	42
Walrus	Penny Strait Lancaster Sound	6	0	6	1	0	3	0	0	2	3
Walrus	SE Baffin Island	26	0	4	1	1	6	0	0	3	3
Walrus	Svalbard	14	0	9	5	95	14	0	2	7	4
Walrus	W Jones Sound	1	0	2	0	0	1	0	0	0	0