Risk of Ship Strike and Noise Pollution to Cetaceans in the Bering Strait

Thomas M. Kennedy

A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master’s of Marine Affairs

University of Washington
2020

Committee:
Dave Fluharty
Robert Pavia

Program Authorized to Offer Degree:
School of Marine and Environmental Affairs

University of Washington

Abstract

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Chair of the Supervisory Committee:
Dave Fluharty, Associate Professor
School of Marine and Environmental Affairs

As the Arctic sea ice extent decreases due to global climate change, new commercial shipping routes are opening through the Arctic. All of these routes connect the Arctic Ocean to the Pacific Ocean through the Bering Strait, a bottleneck region between Alaska and Russia. This same Strait is important habitat for cetaceans, including cetaceans migrating to northern feeding grounds, and cetaceans that remain in the Arctic region year-round. The overlap between shipping routes and cetacean habitat indicates an increased probability of a ship striking a cetacean and an increase in underwater noise pollution from the ships. A risk analysis was conducted for cetacean species, analyzing the risk posed by ship strike and ship noise as a function of exposure and vulnerability, with vulnerability being assessed as a combination of the resilience of the cetacean populations, and the potential threat posed by the ships. The analysis found the highest levels of risk to be among the humpback whale and North Pacific right whale populations in the Bering Strait region, although there remain high levels of uncertainty regarding both the rates of future ship traffic and the knowledge of the cetacean abundance and distribution in the region. The results were used to evaluate potential solutions to mitigate future ship strike rates and vessel noise in the region, including marine spatial planning, vessel actions, new technologies, and increased

monitoring capabilities. Given the remoteness of the Bering Strait region and the successes and failures of these solutions in other parts of the world, the most effective solution are likely a combination of several solutions, requiring cooperation to implement from the United States, Russia, and the international community.

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CHAPTER 1 INTRODUCTION

The Bering Sea is home to 29 marine mammal species, 18 of which are cetaceans (cetaceans being an infraorder of mammals consisting of whales, dolphins, and porpoises) (Greenwald and Callimanis, 2006). This list of species includes those that reside in the Arctic and subarctic year-round and those that make seasonal migrations. As these species are found in the United States Exclusive Economic Zone region, they are tracked in NOAA's marine mammal stock assessments, required by the Marine Mammal Protection Act, along with abundance and distribution studies produced cooperatively by the NOAA Marine Mammal Laboratory, federal, state, and local agencies, and private researchers, including aerial and boat visual surveys, passive acoustic monitoring, and indigenous traditional ecological knowledge (Muto et al., 2018, Clarke et al., 2019, Friday et al., 2016). The data are used to establish science-based policy recommendations by the US Marine Mammal Commission, an independent oversight agency responsible for reviewing policies and actions in order to minimize impacts to marine mammals.

The importance of understanding the abundance and distribution of cetaceans in the Arctic and subarctic becomes more and more apparent as environmental conditions change in the Arctic. In addition to impacts on the natural environment, the loss of sea ice is expected to lead to increased human activity in the Arctic which will increase environmental impacts. Oil and gas exploration, fisheries, tourism, and shipping are all expected to increase (Huntington, 2009). The reason for the shipping increase is the seasonal opening of new routes, shorter and potentially faster than conventional shipping lanes such as the Panama Canal or Suez Canal, specifically the Northern Sea Route (NSR) along Russia's northern coast and the Northwest Passage (NWP) connecting the Atlantic and Pacific north of Canada (Schøyen and Brathen, 2011). In addition, the Arctic is expected to become an important destination for cruise ship tourism, with the number of cruise ship itineraries doubling from 2005 to 2013 (Dawson et al. 2014). Any of these vessel movements through the Pacific side, whether entering or exiting the Arctic, require transiting through the Bering Strait.

Given the importance of the region as cetacean habitat, as ship traffic begins moving into areas that were previously only sparsely travelled, their proximity to cetaceans in these areas will also increase (Reeves et al., 2013). This is a potential problem for marine mammal protection because shipping brings several new risks into the Arctic marine ecosystem. Cetaceans have high site fidelity, often migrating to the same areas every year (Hauser et al., 2018). As ship traffic density increases, cetaceans are unlikely to quickly adapt, putting them at increased risk (Reeves et al., 2013, Hauser et al., 2018). When cetacean migratory patterns overlap with shipping routes, there is an increased risk of ship strikes (Vanderlaan et al., 2009). Ship strikes on cetaceans can cause serious injury or death, and can cause or contribute to population decline (Schoeman et al., 2020). Noise generated by vessels can travel long ranges with little attenuation (Hildebrand, 2009), and the noise increases stress levels, disrupts communication, and causes confusion in nearby cetaceans (Moore et al., 2012). Pollution, anywhere from an accidental discharge to a major marine casualty, can devastate Arctic ecosystems. While there have been several notable agreements amongst Arctic nations regarding regional cooperation-the 2011 Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic, the 2013 Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic, the 2015 Framework Plan for Cooperation on Prevention of Oil Pollution from Petroleum and Maritime Activities in the Marine Areas of the Arctic, and the 2017 Agreement on Enhancing International Arctic Scientific Cooperation- these areas still lack marine prevention and response infrastructure necessary to reduce environmental impacts (U.S. Coast Guard, 2019; PAME, 2009).

Transient whales are at particular risk from shipping because their migratory paths pass through the same bottlenecks as shipping routes (Hauser et al. 2018). Any whales trying to enter summer feeding grounds from warmer tropical or temperate waters have to pass through certain geographic bottlenecks. These are the same areas that ships entering or departing the Arctic must also utilize.

One of the worst bottlenecks identified by researchers is the Bering Strait, a body of water between Chukotskiy Peninsula (Russia) and Seward Peninsula of Alaska (USA) that connects the Bering Sea in the south to the Chukchi Sea in the north (Fletcher et al., 2016; Hauser et al., 2018; Reeves et al., 2013). Any shipping route originating or ending in the Pacific, whether utilizing the Northwest Passage or the

Northern Sea Route, requires use of the Bering Strait. The Bering Strait is also the only route for cetaceans migrating to or from their winter feeding habitat from the Bering Sea to the Arctic. The Bering Strait is only 82 km across at its narrowest point, making it a chokepoint for both vessels and cetaceans. Vessel traffic is also constrained by bathymetry. The Bering Strait is generally shallow, averaging 30-50 m in depth, and is currently not completely surveyed (Belkin, 2016).

Given these factors, this thesis is designed to assess the risk to cetaceans utilizing the Bering Strait from increased shipping given current knowledge. While increased ship traffic can pose risks to every species (Schoeman et al., 2020; Ivanova et al., 2019), the threat posed to cetaceans by ship strike and ship noise is well documented and might significantly hinder population recovery efforts. This thesis addresses two questions. First, what are the risks posed by increased shipping to cetaceans that rely on the same Bering Strait region for habitat and migratory routes? To answer this question, the thesis qualitatively analyzes the risk posed to specific species. While there is a large body of literature addressing the emerging risk to cetaceans overall, there is less research available into the specific risks to different species. While there is some overlap between risks among species, there are also some differences between species (Vanderlaan et al., 2009). Second, what solutions are proposed to minimize this risk? Here, the thesis evaluates the potential of multiple possible measures for protection or mitigation from ship strikes and vessel noise, taking into account the results from the first part of the study.

CHAPTER 2 BACKGROUND

CETACEANS, ARCTIC MARINE ECOSYSTEM, AND CHANGING CLIMATE

Warming temperatures associated with global climate change are causing a steady decrease in the overall extent of Arctic sea ice. Satellite data have been used by NOAA and the National Snow and Ice Data Center (NSIDC) at the University of Colorado to track sea ice extent since 1979. The years of 2015-2018 have had the four lowest extents on record (Osborne et al., 2018). In addition, the percentage of ice extent consisting of older, multiyear ice is decreasing, and the percentage of ice extent composed of younger, annual sea ice, which is thinner, more fragile, and melts quicker, is increasing (Osborne et al., 2018). The reason for this melting is ice is anthropogenic global climate change (IPCC, 2019). From 2014-2018, the years in which the lowest sea ice extents have been observed, the observed surface air temperature in the Arctic during the winter months was nearly 6° C warmer than the 1980-2010 average (IPCC 2019), causing sea ice to begin melting earlier in the winter, and begin freezing later in the autumn.

A nearly ice-free Arctic is defined by the IPCC as “when sea ice extent is less than 10^6 km^2 for at least five consecutive years” in September (2013). However, there is significant debate as to when, exactly, the Arctic will be nearly ice-free. Estimations of sea ice loss must take into account emissions scenarios. Higher emissions scenarios will lead to an ice-free September sooner, while decreased emissions scenarios could postpone or even prevent an ice-free September. The IPCC’s Fifth Assessment Report estimates an ice-free summer around 2050 for the RCP8.5 emission scenario, without providing predictions for lower emissions scenarios. While most research agrees that a nearly ice-free Arctic will eventually happen under current emissions scenarios, the complexity of the climate system and the challenges of long-term predictions leads to a prediction uncertainty of around two decades (Jahn et al., 2016) It should also be noted that neither of the models used by the IPCC, the Atmosphere-Ocean General Circulation Models (AOGCMs) and the Earth Systems Models (ESMs), show no evidence of irreversibility of Arctic sea ice loss (IPCC, 2013). In the Bering Strait, this is expected to lead to an average of 20 fewer days of sea ice per year over the next thirty years. The changes are far more dramatic in the northern East Siberian, Chukchi, and Beaufort Seas, which will see an estimated 60 day reduction in sea ice days (Wang et al., 2018).

A decrease in sea ice has important implications for the Arctic marine ecosystem. The sea ice is vital for the growth of epontic, or sea ice, algae and sub-ice phytoplankton, the main source of primary productivity in the Arctic ocean, which can provide over half of the biological productivity in Arctic marine ecosystems (Gosselin et al., 1997). Less overall sea ice and earlier ice melts, which shorten the time window for primary production, can decrease both the overall quantity of these algae which form the base of the Arctic food web. This in turn negatively impacts the Arctic zooplankton, which affects larger species further up the food web such as Arctic cod, baleen whales, and benthic organisms (Post et al., 2013). The combination of earlier sea ice melt and warmer ocean temperatures is altering the distribution of species within the Arctic, including a decrease in the abundance of copepods and benthic invertebrates, an influx of new fish species from the south, and increased predation competition amongst species in the Arctic (Huntington et al., 2020). These impacts are also felt on larger vertebrate species that rely on sea ice throughout their lifetimes. Arctic pinnipeds are dependent upon the sea ice for hauling out, whelping, and molting, and polar bears rely on sea ice for hunting, mating, and accessing denning areas, and there is evidence these species may be unable to adapt, or adapt quickly enough, to changing conditions (Laidre et al., 2008). Some cetacean species have been observed different migratory species moving farther north in the Chukchi Sea in recent years (Tsujii et al., 2016, Clarke et al., 2013).

PREDICTED CHANGES IN HUMAN ACTIVITY IN THE ARCTIC

There is still a high level of uncertainty regarding the level to which shipping will increase, and the rate at which this increase will occur. There is a severe lack of infrastructure to support increased Arctic shipping, including lack of deep draft ports, poor communications coverage, incomplete navigation charting, and lack of Search and Rescue and pollution response capabilities (U.S. Coast Guard, 2019). While the decrease in sea ice extent opens up new shipping routes, it also increases the risk to ships posed to unpredictable ice floes, increased poor weather, and greater wind speeds and wave heights (US Committee on Maritime Transport System, 2019). There is also the high cost of transit. Even with an ice-free Arctic, the cost of shipping through either the NSR or NWP remains extremely high (Hansen et al., 2016).

Nevertheless, shipping is likely to continue to increase in the Arctic. A scenario analysis conducted by Lloyd’s Registrar identified multiple drivers expected to increase worldwide shipping demand by 2030, including rising population, an increasingly globalized economy, and industrial growth in the Global South (Lloyd’s, 2013). The Arctic opens up new opportunities for natural resource exploration in a world that continues to depend on fossil fuels (US Committee on Maritime Transport System, 2019). Because Russia, China, and the United States and NATO allies are all Arctic or Arctic-interested nations, there is increased military and naval presence during any ice-free season (Scopelliti and Perez, 2016, U.S. Coast Guard, 2019, U.S. Department of Defense, 2019). The climate processes that lead to a summer ice-free Arctic have already been set in motion, even if it will take time for the associated impacts to fully occur.

A comprehensive ten-year study conducted by the US Committee on Maritime Transport System (2019), using AIS data from the Maritime Exchange of Alaska over a ten-year period from 2008-2018, identified an increase in total Arctic vessel transits, from 120 in 2008 to 276 in 2018, and an increase in navigation season days in the Bering Strait, from 142-206. The same study, using four scenarios, projected a vessel increase of anywhere from 29 (reduced activity scenario) to 281 (accelerated, but unlikely scenario) vessels in the Arctic by 2030. So while any rapid changes in the Arctic shipping rate are unlikely, it is almost certain that there will be a continuous increase over the next several decades, no matter what climate scenario occurs.

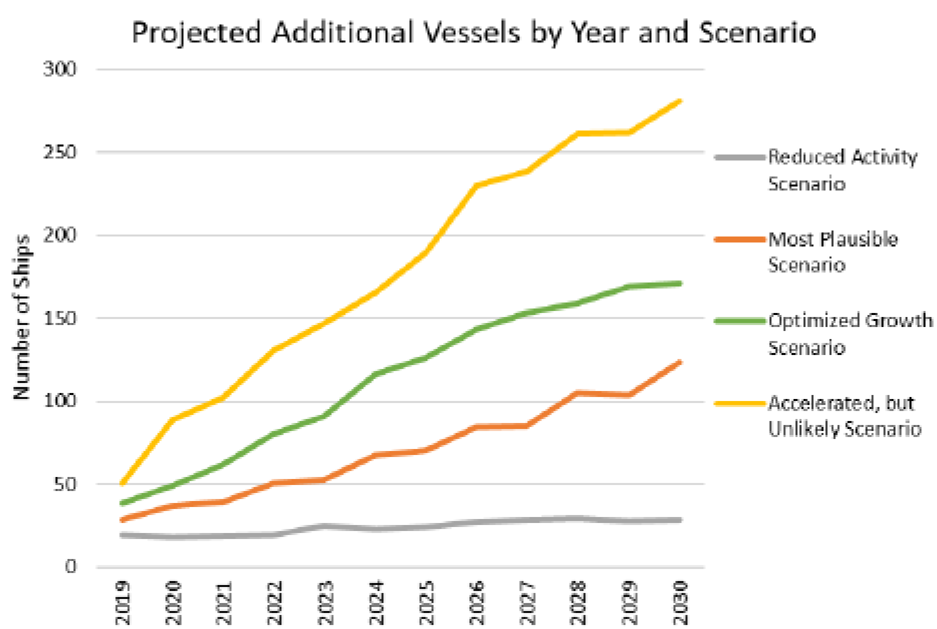

Figure 1-Projected additional vessels in the Bering under different conditions (US Committee on Maritime Transport System, 2019).

The most common types of vessels currently utilizing the Bering Strait are general cargo, bulk, and tankers. The Bering Strait shipping landscape also includes container ships, government vessels (including research vessels, military vessels, and icebreakers), passenger vessels, pleasure craft, and fishing vessels (Fletcher et al., 2016). There are more bulk carriers, tugs, and government vessels in US waters, and more cargo and fishing vessels in Russian waters (Fletcher et al., 2016). The greatest rate of increase is among government vessels, pleasure craft, and tankers (Pizzolato et al., 2013). There large numbers of fishing vessels in the southern Bering Sea, but few farther north (Fletcher et al., 2016). On the U.S. side of the Bering, the greatest vessel densities occur around Nome, AK, an important resupply port (U.S. Committee on Maritime Transport System, 2019). There is also a relatively high density of traffic of vessels transiting to and from the Red Dog Mine north of Kotzebue, AK (Fletcher et al., 2016). On both the U.S. and Russian sides, the traffic in the region is currently dominated by vessels servicing local ports (Fletcher et al., 2016). Between 2015 and 2017, vessels flagged from 37 different nations transited through the Bering Strait (U.S. Committee on Maritime Transport System, 2019).

CHAPTER 3 METHODS

SCOPE OF THE RESEARCH

The first part of this analysis is an examination of the potential risk posed to different species of cetaceans. Because this is a very broad category of risk, the analysis focuses on specific risks to specific species in a specific geographic region.

The analysis focuses on the Bering Strait region. For this analysis, the Bering Strait's geographic boundaries are defined by the two-way routes and precautionary areas submitted jointly by the United States and Russia and approved by the IMO (International Maritime Organization, 2017a). The southern boundary is Precautionary Area "A", a circle with a 4.0 mile radius centered at 58°45.00' N, 167°27.81' W. The northern boundary is Precautionary Area "C", a circle with a 4.0 mile radius centered at 66°30.00' N, 168°25.00' W. These routes were established primarily for the purposes of safe navigation, with environmental protection, specifically oil spill prevention, as a secondary priority. The use of these routes and precautionary areas is voluntary;

however, a study of early traffic patterns found that larger vessels transiting through the region, such as bulk carriers and tankers, generally adhered to the IMO routes, altering course primarily for ports of call or lightering, while smaller vessels engaged in local commerce, such as tugs or fishing vessels, were less likely to utilize the routes (Fletcher et al., 2020). For the purposes of this research, it is assumed that ships navigating the Bering Strait utilize these routes whenever possible. In addition, this geographic area covers the narrowest point of the Bering Strait, which means it is the area with most potential congestion for cetaceans and ship traffic.

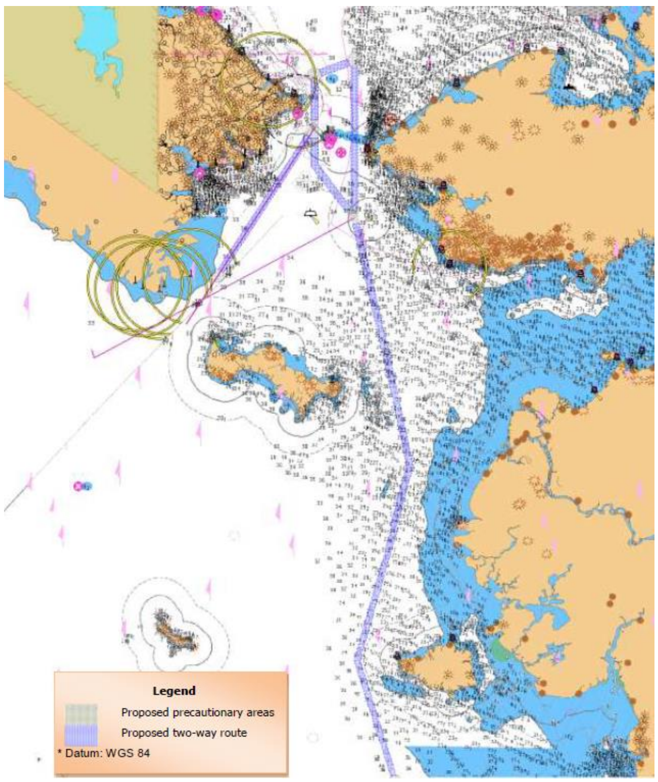

Figure 2-Study area. The purple lines represent the approved two-way routes (International Maritime Organization, 2017a)

Given these geographic constraints, the risk analysis is limited to those cetacean species and populations that have been observed in the defined geographic area. For this research, the analysis included two of the three Arctic resident cetaceans-the beluga (*Delphinapterus leucas*) and the bowhead whale (*Balaena mysticetus*)-and four seasonal Arctic residents-the humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), common minke whale (*Balaenoptera acutorostrata*), and

North Pacific right whale (*Eubalaena japonica*) (Muto et al., 2018). A third Arctic resident species, the narwhal (*Monodon monoceros*), has insufficient abundance and distribution data to be evaluated (Muto et al., 2018). The four seasonal resident species were selected due to the relative risk posed by increased shipping to large, baleen cetaceans (Fletcher et al., 2016).

For the marine mammals, the risk is analyzed at the population level, as opposed to the individual or community level. By looking solely at the population level, the analysis takes into account potential risks to populations, or species as a whole, that are threatened or endangered, or may become threatened or endangered, and would likely be of greater importance to marine mammal protection mangers and policymakers (Thomas et al., 2016). According to the Endangered Species Act of 1973 (16 USC 35 § 1532), an endangered species is defined as any species in danger of extinction throughout all or a significant portion of its range, and a threatened species is a species likely to become endangered in the foreseeable future. The ESA allows U.S. federal agencies to identify species as endangered or threatened (16 USC 35 § 1533) and use its authority to conserve said species (16 USC 35 § 1536).

As mentioned previously, there are multiple risks posed from increased shipping. The different risks can be divided into two categories: **normal risk**, or incidents that occur when the vessel is operating as intended, such as a ship strike or noise pollution, and **accidental risk**, incidents that occur when something goes wrong, such as a pollution incident or fishing gear entanglement. For this research, only risks from the first category, normal risk, are analyzed. This allows the analysis to focus on specific risks posed to cetaceans even when vessels are operating normally, and to evaluate potential solutions accordingly. This ensured that the potential solutions evaluated were focused solely on mitigating the risk of ship strike and ship noise. This research does not include risks posed by stationary installations such oil/gas exploration or dredging operations.

Changes in shipping activity can fluctuate from year to year-while the number of vessels in the U.S. Arctic from 2008-2018 has increased, the single year with the highest number of vessels was 2015 (US Committee on Maritime Transport System, 2019). However, the overall trend of decreasing sea ice, and the corresponding shipping increases, are expected to continue over the next decade, regardless of emissions scenarios. In addition, cetaceans are complex organisms, and their responses to environmental and anthropogenic changes are not instantaneous. Cetacean population dynamics are still affected by multiple factors, most notably recovery from whaling (Brower et al., 2018). These factors make it difficult to estimate risk to cetaceans at the community or population level in the near-term. Therefore, this analysis focuses on the long term (10+ years) risks in the Bering Strait associated with increased ship traffic. Performing analysis at this time scale is the most effective for understanding long-term changes in the Bering Strait and the resulting risks, it also increases the associated uncertainty, as any predictions (sea ice extent, ship traffic, marine mammal abundance and distribution) are less certain further into the future.

FRAMEWORK FOR RISK ANALYSIS

When discussing climate change, risk is often discussed as a combination of three factors: sensitivity, or susceptibility to harmful effects of an incident, adaptive capacity, or the capacity to change in response to the changing climate, and exposure, or probability of an incident occurring (Jurgilevich, 2017). In this case, this means sensitivity is the susceptibility of cetaceans to ship strike and ship noise, and exposure is the likelihood of an incident occurring, with an incident being defined as either a ship strike on a cetacean, or a cetacean being within the vicinity of a ship in which the ship’s noise negatively affects the cetacean. This framework has been used when analyzing the possible risk posed from climate change to species (Hauser et al., 2018; Reeves et al., 2013). In these analyses, multiple aspects or criteria of sensitivity are often used to provide a complete picture of the total sensitivity.

Hauser et al. (2018) evaluated risk to Arctic marine mammals by ranking species and populations in sensitivity, exposure, and uncertainty. In this analysis, sensitivity describes the potential impact posed by both human activity such as ship strike and noise pollution, and population health as indicated by population size and trends. Uncertainty for sensitivity was estimated using the number of studies specific to a given species and the general consensus between the studies. Exposure was calculated quantitatively using the percentage of overlap between the population habitat range and the NWP and NSR. Uncertainty in exposure was calculated using the number of years of observation and the number of methods used to identify a population's range.

Reeves et al. (2013) conducted a qualitative survey of potential risks to cetaceans throughout the entire Arctic. In this analysis, the Arctic range of cetacean species are compared to maps of shipping routes and hydrocarbon development to identify overlap. This analysis does not utilize variables or provide scores for separate categories. Instead, the risk is discussed as a combination of the overlap of habitat with human activity and the sensitivity of the species.

Risk analysis in natural disasters is often analyzed using the risk triangle (See Figure 3), where risk is a combination of exposure, vulnerability, and hazard, where hazard refers to the potential damage caused by an incident (Crichton, 1999). In these analyses, the combination of hazard and vulnerability can be analyzed as a similar component to sensitivity.

Figure 3-Elements of the risk triangle (Crichton, 1999)

For this analysis, exposure and sensitivity are evaluated, where sensitivity is defined as a combination of two factors: resilience and threat. Resilience is the natural strength of the population, particularly the population's adaptive capacity when exposed to new elements. This criterion captures the vulnerability and adaptive capacity of the species. Threat is the severity of the population impact caused by ship strike or ship noise to a population, and functions similar to hazard in natural disaster risk analysis. This is a division of the sensitivity variables used by Hauser et al. (2018), with resilience being the measurement of the sea ice-loss sensitivity, abundance, and population trends, and threat being a measurement of the vessel disturbance, collision, and acoustic impact variables. Exposure remains the probability of an incident occurring. For this analysis, this will include the vessel frequency criterion from Hauser et al. (2018).

To assess vulnerability, it is important to have an understanding of the resilience of the cetacean population. In the framework developed by Moore and Reeves (2018) (See Figure 3), marine mammal population resilience can be measured as a combination of population size, population range, behavioral plasticity, and health. Larger populations are able to overcome or recover from changes better than smaller populations. Populations that are highly migratory are better able to adapt to changing conditions than populations with a narrow, defined habitat. Species with higher behavioral plasticity are more likely to quickly adapt to changing conditions, as opposed to species that continue with unchanged behaviors even as conditions change. Finally, a species that has overall better health will be better able to adapt to change than a species with poor health (Moore and Reeves, 2018).

Figure 4-Framework for assessing intrinsic resilience of cetaceans (Moore and Reeves, 2018)

Threat, on the other hand, is a function of how damaging an incident, or multiple incidents, can be to a cetacean population. For this study, that means estimating the threat posed to cetaceans from increased ship traffic. In other words, how bad is a ship strike, or, how bad is increased noise? This threat is be different depending on the population or species being assessed. For example, the threat of ship strikes could be greater for cetaceans that are larger or slower moving, behaviors that make cetaceans difficult to avoid, or historical susceptibility to fatal ship strikes (Hauser et al., 2018; Vanderlaan and Taggart, 2007). This separation is necessary in order to assess all the possible components of risk that could impact a population. For example, a population with a high resilience could also have especially vulnerability to ship strikes. Similarly, a population that has a higher tolerance to increased ship traffic may have low resilience, where even a small increase in risk could cause lasting damage.

The other factor is exposure-what is the likelihood of the incident occurring? An incident might be particularly impactful if it does happen, but if the incident is unlikely to occur, then overall risk is less. In order for increased ship traffic to pose a threat to Arctic cetacean populations, the ships and cetaceans must be in the same place at the same time. Exposure to shipping risk is based on factors such as how many vessels are operating, when and where are they operating, and what types of vessels are operating (Fletcher et al., 2016).

Finally, the analysis must account for uncertainty. There is a lot of uncertainty in predicting future scenarios 10+ years out. The cetacean species and populations identified are all highly migratory. This makes them both difficult to study and difficult to analyze from a protection perspective. Even the information available from NOAA, compiled from multiple surveys, is an estimation at best. Because of the difficulty in studying cetaceans, there is still a large a great deal to be learned about the specific impacts of ship strikes or ship noise. Historic ship strike data are incomplete, as many cetaceans killed by ship strike sink in the ocean, and many non-fatal strikes are only detected when the cetacean body is found from another means (i.e., stranding, subsistence hunting), or when the cetacean's injuries are observable during a visual survey (Conn and Silber, 2013). While it is obvious shipping will be increasing in the next decades, it is difficult to predict exactly how much or to what to degree. There is also, as described in Figure 1, a high amount of uncertainty as to what degree shipping will increase. Shipping uncertainty is likely to affect exposure in particular, as the number of vessels in the Bering Strait region directly correlates to an increased probability of an incident. So, the risk analysis will also need to include a recognition of how much uncertainty there is in the underlying assumptions.

METHODS FOR RISK ANALYSIS

In order to measure risk, each species is evaluated qualitatively with respect to each of the three criteria mentioned above: resilience, threat, and exposure. Each species is scored on a scale of one to three in each category, with one being the lowest score, and three being the highest score. A combined score from these criteria is used to form a qualitative risk assessment.

For resilience, the scoring is based on the previously discussed framework in Figure 3. Literature review of NOAA stock assessments (Muto et al., 2018) and supplementary research is reviewed for selected species and is used to identify population size, population trends, and potential biological removal (PBR), defined by the Marine Mammal Protection Act, 16 USC 1361-1407, as “the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population”, which is a factor of the population size, the reproductive potential, and the recovery factor. The stock assessments and literature review will also be used to assess anticipated natural or ecological impacts of Arctic climate change, the population responses to these changes. While the analysis relies heavily on stock assessments produced by NOAA, the analysis includes cetacean populations from both the United States and Russian sides of the Bering, as both the stock assessments and supporting literature include the entire Bering Strait region. A score of 1 indicates a PBR greater than 10, or a PBR greater than 5 with an increasing population trend, including the impacts of climate change and sea ice loss. 2 indicates a PBR between 5 and 10 with a declining population, or a PBR between 1 and 5 with an increasing population. 3 indicates a PBR less than 1.

For threat, literature review is used to judge severity of ship strikes and ship noise on the specific species. This includes historic data on ship strikes for each species, in both the Bering Strait and in other regions of the world, and historic data on impacts of ship noise. It will also include literature on specific behaviors or life cycle occurrences which could make them more susceptible to either ship strike or ship noise. A score of 1 indicates minimal potential threat from both ship strike and ship noise. 2 indicates potential threat from either ship strike or ship noise, or possible threat both ship strike and ship noise with a high level of uncertainty. 3 indicates potential threat from both ship strike and ship noise, or significant sensitivity to either ship strike or ship noise. Significant sensitivity, for the purposes of this analysis, is defined as a degree of sensitivity such that environmental policymakers concerned with cetacean protection should prioritize mitigating this particular threat above others.

For exposure, the score will reflect the likelihood of a particular incident occurring in the vicinity of the cetacean. Previous risk analyses have measured exposure by looking at the overlap between habitat and shipping routes (Hauser et al., 2018; Reeves et al., 2013). Since this thesis analyzes risk only within a small geographic region, overlap alone is not a sufficient measurement for exposure. So, this analysis also includes the size of a population and the number of vessels to estimate exposure. Overlap is estimated qualitatively using the range of the species habitat-a smaller range leads to a greater likelihood of exposure-and site fidelity of the species, if known-a species with high site fidelity is more likely remain in an area with increased ship traffic. The size of the population has previously been included in resilience; in this instance, it is included to indicate that a high number of individuals means a higher likelihood of a vessel encountering an individual or group. A score of 1 indicates one or zero categories (overlap, population size, vessel traffic) that lead to a higher probability of exposure, or population so low that there is minimal probability, regardless of exposure factors, that the population will be exposed to ship traffic. A score of 2 indicates two categories that lead to a higher probability of exposure. A score of 3 indicates all three categories that lead to a higher probability of exposure, or a population so high that there is high probability, regardless of exposure factors, that the population will be exposed to ship traffic. The probability criteria are estimates dependent on future shipping projections, which are subject to uncertainty. Therefore, two different exposure scores will be assigned, for lower and higher growth rates of shipping traffic.

CHAPTER 4 RESULTS OF RISK ANALYSIS

BOWHEAD WHALE

Although there are four internationally recognized bowhead whale stocks, only one inhabits Pacific waters. The Bering-Beaufort-Chukchi stock is faring well compared to other stocks, with an estimated abundance of over 16,000 individuals, the population has more than tripled since 1978, and the PBR is 161 (Muto et al., 2018). There is evidence bowheads may be negatively impacted by climate change, as they are ice associated, using ice edges and leads to transit and access otherwise impenetrable areas (Muto et al., 2018). They receive a resilience score of 1. They are listed as “Least Concern” by the IUCN Red List (Reilly et al., 2008a).

As a year-round Arctic resident species, there are few historic data available regarding bowhead interactions with shipping. However, some surveys have shown a low frequency of ship strike occurrence even in recent years. In one survey of 521 bowhead whales harvested by Alaskan natives over two decades, less than 2% of carcasses showed evidence of ship strike injury (George et al., 2017). This figure could change as shipping increases throughout the bowhead habitat. Bowhead whales feed via skimming, a foraging strategy that keeps them at the surface for long periods of time (Pivorunas, 1979), which could make them more vulnerable to ship strike while feeding. Bowhead whales show sensitivity to acoustic disturbance. They are one of two cetacean species that produce complex songs and vocalizations (Stafford, 2018) which could be disrupted by increased ship noise. There is evidence that bowheads may alter calling behavior in response to increased acoustic disturbance (Blackwell et al., 2015). Due to their high latitude range, bowhead whales may also be naïve to shipping, and unable to adapt quickly to rapid increases in ship density (Reeves et al., 2013). They receive a threat score of 3.

The increased shipping density correspond highly with bowhead habitat, including fall and spring migrations between the Bering Sea and the Beaufort and Chukchi Seas through the Bering Strait (Muto et al., 2018). Bowhead whales have a high site fidelity, returning annually to the same feeding grounds (Laidre et al., 2015). This greatly increases the likelihood bowheads will be in close proximity with increased ship traffic. They receive exposure scores of 2, for lower growth rate scenario, and 3, for higher growth rate scenario.

HUMPBACK WHALE

There are currently two recognized stocks of humpback whales in the Pacific northern hemisphere-the Western North Pacific stock and the Central North Pacific stock. The Western North Pacific stock typically feeds in the Bering Sea, Gulf of Alaska, and the Aleutian Islands, but has been observed up through the Bering Strait. This stock is currently recovering from whaling, however there is still only an estimated population of 865, with a PBR of 3 (Muto et al., 2018). The Central North Pacific, is much larger, with an estimated population of 7,891 and a PBR of 83 (Muto et al., 2018). Under a proposed change to the humpback whale listing in the Endangered Species Act (ESA), 18 FR 62259, the humpback whale will be listed in the ESA as 14 DPSs, including the Western North Pacific stock, which will be listed as Endangered. Humpback whales may thrive, at least initially, with the changing climate, as melting sea ice increases their range and increased pelagic biological productivity increases the forage fish on which they feed (Moore and Huntington, 2008). They receive a resilience score of 3. The humpback whale species is currently listed by the IUCN as a species of “Least Concern” (Reilly et al., 2008b).

Humpback whales are well known for being the other cetacean species with complex vocalizations and songs (Stafford, 2018). A review of noise impacts on marine mammals showed humpback whales changed their calls in the vicinity of acoustic disturbance, and were susceptible to hearing damage (Weilgart, 2007). Another study showed that, in addition to ceased singing, humpbacks in the vicinity of acoustic disturbance showed decreases in dive time, travel speed, and breaching (Erbe, 2019). They have been observed switching from vocal communication to surface-generated communications such as breaching and pectoral slapping, methods with lower information content, in the presence of high background noise (Dunlop et al., 2010). Humpback whales may also be particularly susceptible to ship strikes. In one survey of ship strikes in the Gulf of Alaska, 86% were of humpback whales (Neilson, 2012). The study also showed that some of the collisions occurred when vessels were drifting or at anchor, indicating that humpbacks may be unaware of vessels or even approaching them. There is evidence humpbacks may be more vulnerable to smaller, faster moving vessels such as pleasure craft and whale watching vessels, and less vulnerable to the large vessels most likely to transit the Bering Sea (Douglas et al., 2008). They receive a threat score of 3.

Currently the Bering Strait is the very northern point of the humpback range. However, as sea ice melts, humpbacks are expected to begin moving farther north (Muto et al., 2018). There is also the possibility that the Central North Pacific stock may move farther north as well, increasing the probability of interactions with transiting vessels (Muto et al., 2018). Both stocks of humpback whales have long migratory routes, meaning they are more likely to be transiting during the fall and spring seasons than in the Bering Strait, although there will still be overlap during the summer (Reilly et al., 2008). They receive exposure scores of 1, for lower growth rate scenario, and 2, for higher growth rate scenario.

RIGHT WHALE

The North Pacific right whale population was decimated by historical whaling, and there are currently only approximately 300 individuals left (Cooke and Clapham, 2018), and only 30 individuals left in the Eastern stock, which is the only stock that occurs in US waters (Muto et al., 2018). Due to the low numbers, there are not enough data available to estimate population trends. The PBR is 0.05, or one individual removed every twenty years (Muto et el., 2018). They receive a resilience score of 3. The species is listed by the IUCN as “Endangered”, and the eastern North Pacific stock is listed separately as “Critically Endangered” (Cooke and Clapham, 2018), so they also receive a score of 1 for their global status.

Due to the extremely low numbers, there are few data available regarding human impacts on North Pacific right whales (Muto et al., 2018). Estimations of the threats posed by ship strikes and ship noise can be estimated by looking at the impacts on the North Atlantic right whale (*Eubalaena glacialis*). The two were recognized as the same species until differentiated via mtDNA phylogenetic analysis (Rosenbaum et al., 2000) and were recognized by the International Whaling Commission (IWC) as separate stocks in 2004; however, they are still similar enough that studies of the North Atlantic right whale are the best estimate for impacts of ship strikes on the North Pacific right whale (Cooke and Clapham, 2018).

North Atlantic right whales have faced significant threats from shipping, possibly even more so than other species. A comparison of historical ship strike data found that, per capita, North Atlantic right whales are the most susceptible species in the world, over two orders of magnitude greater than the next closest species (Vanderlaan and Taggart, 2007). Right whales feed via skimming, a foraging strategy that keeps them at the surface for long periods of time (Pivorunas, 1979), which could make them more vulnerable to ship strike while feeding. Observational studies have shown North Atlantic right whales can be unresponsive to oncoming vessels, sometimes even turning towards them, indicating the ship noise is not sufficient to alert individuals to the danger (Terhune and Verbloom, 1999). North Atlantic right whales are also adversely affected by ship noise. One study found decreased stress hormone metabolites in right whales following a period of decreased ship noise (Rolland et al., 2012). However, another study found that North Atlantic right whales were the only species to experience low levels of masking in response to ambient noise (Cholewiak et al., 2018). They receive a threat score of 3.

Given the low numbers of North Pacific right whales, the probability of an individual being in the vicinity of a ship is quite low, even in a higher growth rate scenario for increased vessel traffic. Although the species range extends into the study area, the critical habitat established by NOAA for this population is in the Gulf of Alaska and the Bering Sea in the vicinity of the Aleutian Islands, far south of the study area (50 CFR 226). North Pacific right whales have been detected via passive acoustic monitoring in the northern Bering Sea, which is within the study area, indicating that North Pacific right whales may, like other species, be migrating farther north (Wright et al., 2018). This northern migration could increase the probability of an encounter. Given the low PBR, even a single incident could have a profound impact on the population’s survival. They receive an exposure score of 1 for both scenarios.

FIN WHALE

Fin whales in the Pacific are currently recognized as a single stock. Some stock separations have been suggested, but there is currently a lack of sufficient data showing genetic or geographic distinction (Mizroch et al., 1984). The current estimated population of fin whales is 2,554, with a PBR of 5.1 (Muto et al., 2018). Like other populations, the fin whale Pacific stock is recovering from the impacts of whaling, with an increasing population trend. Multiple surveys have observed fin whales moving farther north as sea ice melts, indicating an increase in possible habitat (Clarke et al., 2013; Brower et al., 2018). There have also been reports of increased duration of fin whale calls (Tsujii et al., 2016). They receive a resilience score of 2. They are listed as “Vulnerable” by the IUCN Red List (Cooke, 2018a).

Like other species, fin whales are vulnerable to ship strikes and ship noise. There currently are few data available specifically focused on the impacts on fin whales. In records of historical ship strike data from 1885-2002, fin whales were the species that were struck the most (Laist et al., 2001; Jensen and Silber, 2003). A survey of ship strike data in Puget Sound showed fin whales were more likely to die from ship strikes than other species, even though all recorded species were observed foraging within shipping lanes (Douglas et al., 2008). However, given the species population numbers, the per capita number of strikes is lower than for other species (Vanderlaan and Taggart, 2007). There are no specific papers referencing ship noise impacts on fin whales in the North Pacific. An analysis of the impacts of increased noise pollution on fin whales in the Mediterranean found behavioral changes in the presence of seismic air guns and ship traffic; however, the impact of ship noise was less than the impact of the seismic air guns (Castellote et al., 2012). They receive a threat score of 2.

With both an increase in fin whales moving north of the Bering Strait, and an increase in shipping, it is likely that the probability of fin whales in the vicinity of ships will increase. Fin whales have a large range and long migratory routes, meaning they are more likely to be transiting during the fall and spring seasons than in the Bering Strait (Cooke, 2018a). They receive exposure scores of 1, for lower growth rate scenario, and 2, for higher growth rate scenario.

MINKE WHALE

Minke whale stock structure is currently debated. The IWC recognizes three stocks: one in Japan/East Asia, one in the Western Pacific, and one comprising the remainder of the Pacific. Within the US, the remainder stock is divided into a stock off the coast of the western continental US, which is more residential than other populations, and a stock in Alaska, which is more migratory than other populations (Muto et al., 2018). The Alaska stock is common in the Bering, Beaufort, and Chukchi seas. Due to lack of data, there are currently no population estimates from NOAA for the Alaska minke stock, and no corresponding PBR or population trends (Muto et al., 2018). One study estimated the population to be 389; however, this estimate has not been corrected for missed or submerged animals (Friday et al., 2013). Minke whales are more difficult to study than other cetacean species in part because they can be difficult to approach and hard to observe when at the surface (Bartha et al., 2011). They receive a resilience score of 2. They are listed as a species of “Least Concern” by the IUCN (Cooke, 2018b).

While minke whales, like other baleen species, are at risk from ship strike and ship noise, there is no evidence that they are more susceptible to either risk than any other species. Minke whales have the lowest per capita ship strike rate of any baleen species worldwide (Vanderlaan and Taggart, 2007). It has been suggested that due to the relatively small size of the minke whale, that ship strikes may be unreported because they are often fatal before the whale can be sighted or strand itself on shore (Douglas et al., 2008). Minke whales exhibited masking in response to ambient noise. In the study, as opposed to other species, minke whales exhibited more masking in response to fishing or whale watching vessels, as opposed to large-ton vessels (Cholewiak et al., 2018). In the Bering Strait, this could indicate that minkes may be less impacted by the ships most commonly transiting. Minke whales did exhibit higher levels of stress than other baleen species in response to naval SONAR (Sivle et al., 2015). They receive a threat score of 2.

Minke whales have a wide range, but are less migratory than other species in this analysis (Muto et al., 2018), meaning that any they may be more likely to encounter a transiting vessel. Given their relatively inconspicuous behavior near the surface, they may also be difficult for ships to notice and evade. While the Alaska stock is relatively understudied, high levels of small-scale site fidelity have been observed in populations in the eastern Pacific and the north Atlantic (Dorsey et al., 1990). They receive exposure scores of 2, for lower growth rate scenario, and 3, for higher growth rate scenario.

BELUGA WHALE

The beluga whale is the only odontocete, or toothed whale, included in this analysis. It is included because, as an Arctic resident species, it could be disproportionally impacted by any changes in the Arctic marine ecosystem, including an increase in ship traffic. NOAA Marine Mammal Assessments in Alaska track five stocks, three of which are within the study area: the Beaufort Sea stock, the Eastern Chukchi Sea stock, and the East Bering Sea stock. The Beaufort stock is estimated at 32,453, the East Chukchi stock is estimated at 12,194, and the East Bering stock is estimated at 5,173 (Muto et al., 2018). Due to the large numbers of individuals and the amount of time since the assessments were conducted, there are not estimates of PBR. However, the population numbers are high enough that scientists believe they can absorb significant mortality events. All stocks within the study area are estimated to be stable or increasing (Muto et al., 2018). Belugas are an ice associated species, but the impacts of sea ice loss are predicted to be minimal, especially given the belugas wide range and behavioral flexibility (Laidre et al., 2008). Belugas have a much smaller migratory range than other species, which puts them at greater risk for changes in a particular area (Muto et al., 2018). In this case, that could be problematic for the East Bering stock, as their habitat is directly within the study area bottleneck. They receive a resilience score of 1. They are listed as a species of “Least Concern” by the IUCN (Lowry et al., 2017).

Belugas, as a species, are smaller, faster, and deeper divers than the other species discussed in this analysis. This means they are less likely to be threatened by ship strikes from large vessels (Norman et al., 2015). Belugas are also more likely to choose habitat closer to moderate to heavy ice (Moore et al. 2000). While this could put them at greater risk for icebreakers and any following vessels, this likely decreases their risk posed by the majority of vessels that may try to avoid dangerous sea ice areas. Belugas, like all cetaceans, are susceptible to ship noise. Noise in Cook Inlet, one of the noisiest regions in Alaska, affecting a different stock of belugas, has been responsible for masking beluga communications and causing belugas to move away from the noises

(Carter and Nielson, 2011). Belugas have somewhat of an advantage over other species because they hear and communicate best at frequencies of 45-80 kHz (Norman et al., 2015), while most shipping noise is in lower frequencies of 10-500 Hz (Hildebrand, 2009). Belugas in other parts of the world have also habituated to louder noise levels in busy ports such as Anchorage, Alaska and the St. Lawrence River in Quebec (Reeves et al., 2013). They receive a threat score of 1.

Given the large population numbers and relatively small migratory paths, it seems likely belugas will be in the vicinity of ships given any noticeable increase in vessel traffic. This is especially true given that belugas display high small-scale site fidelity to seasonal habitats (Heide-Jørgensen et al., 2003). They receive an exposure of 3 for both scenarios.

SUMMARY OF RESULTS

Species	Resilience	Threat	Exposure	Total
Bowhead	1	3	2	6
Humpback	3	3	1	7
Right	3	3	1	7
Fin	2	2	1	5
Minke	2	1	2	5
Beluga	1	1	3	5

Table 1-Scoring for Lower Rate of Shipping Growth Scenario

Species	Resilience	Threat	Exposure	Total
Bowhead	1	3	3	7
Humpback	3	3	2	8
Right	3	3	1	7
Fin	2	2	2	6
Minke	2	1	3	6
Beluga	1	1	3	5

Table 2-Scoring for Higher Rate of Shipping Growth Scenario

CHAPTER 5 DISCUSSION

IMPLICATIONS OF THE ANALYSIS

Based on this analysis, the greatest risk of ship strike and ship noise exists for the North Pacific right whale and the humpback whale. For the North Pacific right whale, the small number of individuals in the population means any incident, even a non-fatal incident, will have serious repercussions on the long-term survival of the species. For the humpback whale, the species as a whole will most likely be resilient to increased ship traffic. However, given the uncertainty of the species stock separation, combined with the species recovery from commercial whaling and their higher vulnerability to both ship strike and ship noise, means that ship traffic will likely have negative impacts to one or more of the distinct stocks.

Lowest risk exists for the and beluga whale. Belugas would have the lowest score were it not for the exposure scores. This indicates that while ship strike and ship noise pose less of a risk to belugas, the probability of an incident, given the belugas smaller range and larger population, is much higher.

The differences in the resilience and threat to different species and/or populations highlights the need pay attention to species-specific needs when developing protection and management plans, potentially even creating species- or population-specific plans. Many of the papers utilized in this analysis described threats of shipping to cetaceans as a whole, but do not highlight the specific threats that need to be addressed. Management plans that fail to include species-specific data, such as site fidelity or reproductive potential, may not be sufficient to protect all cetaceans from emerging threats (Ferrera, 2017).

The exposure scores increase in the higher growth scenario for all species except the right whale and the beluga whale. For these two species, the populations are small enough and large enough, respectively, that regardless of the rate of shipping growth, the likelihood of an incident remains the same.

This analysis attempts to identify major threats to particular species and populations. A lower risk score does not mean species are not still at risk; rather, the goal of this analysis is to aid in prioritizing species and threats for protective purposes.

EFFECTIVENESS AND LIMITATIONS OF ANALYSIS

The greatest limitation with this analysis is the amount of inherent uncertainty. As discussed previously, there is a large amount of uncertainty inherent with both the cetacean data and the shipping scenarios.

While this analysis attempts to incorporate all of the important elements for assessing marine mammal protection, as it is qualitative analysis, it is ultimately subjective. A method for quantitatively estimating the increased probability using historic ship strike data (Jensen and Silber, 2003) and the predicted vessel increases (US Committee on Maritime Transport System, 2019) used by Vanderlaan and Taggart (2007) was considered; however, there are not enough historic ship strike data available for the bowhead whales and beluga whales.

This subjectivity makes it challenging to use the overall scores as a ranking measure. While this method allowed the analysis to account for a large amount of data and high levels of uncertainty; however, it does make it challenging to display significant differences between the species. For example, the North Pacific right whale received the highest risk scores possible in resilience and IUCN status. However, the three-point and one-point scales do not necessarily convey the threat posed to the species given their extremely low numbers, and the severity of even a single incident. The greatest benefit of the analysis comes from recognizing the specific risks, and degrees of risk, faced by specific species. The analysis also highlights the differences between certain species, which need to be understood in order to develop effective management and protection plans.

The scope of this research is limited to risk from ship strike and ship noise. Some species that have a lesser risk to these effects may have a greater vulnerability to other anthropogenic changes in the Arctic, such as increased seismic exploration, fishing, or pollution (Huntington, 2009). Some species may also experience stress from natural climate change impacts. For example, some species may be vulnerable to increased predation threats as killer whales move north (Norman et al., 2015). These other risks must be considered when discussing possible conservation or protection plans.

CHAPTER 6 FUTURE PROTECTION MEASURES

Given the challenges facing cetaceans in the Bering Strait, the second part of the thesis addresses the question of what should be done to protect cetaceans. There have been multiple solutions to managing cetacean protection and shipping that have seen various degrees of success in other parts of the world.

CURRENT MANAGEMENT REGIMES

The main entity for Arctic international cooperation is the Arctic Council, an intergovernmental forum comprising the eight Arctic nations of the United States, Canada, Russia, Norway, Denmark, Sweden, Finland, and Iceland. The Arctic Council plays an important role in facilitating international cooperation and information sharing, as well as in identifying gaps in both science and management. An assessment by the Arctic Council finds that only the vast majority of the protected areas created by member states are terrestrial; only 4% of the Arctic marine region is protected, and there are no protected areas within the Bering Strait region, even though the region is identified as an Environmentally and Biologically Sensitive Area by the Convention on Biological Diversity (CAFF and PAME, 2017).

The other international entity with involvement in Arctic shipping is the IMO. As mentioned previously, the IMO has established a Polar Code regulating standards for vessels operating in Polar regions. The Polar Code is predominantly concerned with human safety and pollution prevention, and makes minimal mention of mitigating the normal risk to the environment inherent with shipping, with the only exception being guidance on voyage planning (International Maritime Organization, 2017b).

The final international entity to consider is the IWC., While originally established as an entity to regulate whaling, the IWC is now the main international entity for the protection of cetaceans. Each of these entities will likely play a role in the establishment of protection measures. These international entities provide a forum for the negotiation and implementation of international agreements and treaties. Because these entities are composed of independent nations, the international bodies, and the associated agreements they produce, have only as much power as given by the member states (Young, 2017). This is evidenced by Japan's decision to resume commercial whaling after it withdrew from the IWC, despite the IWC's whaling moratorium (Graves, 2018). This is important because it means any international measures identified for cetacean protection in the Bering Strait are dependent on continued support from individual member nations.

The Bering Strait region exists entirely within the Exclusive Economic Zones (EEZs) of the United States and Russia (Berkman et al., 2016). This means any whale protection actions require cooperation between the two nations. The region is also still subject to transit passage, Part III, Section 2 of the United Nations Convention for the Law of the Sea (UNCLOS), meaning that vessels from other nations may transit the region, so long as they adhere to the requirements for transit passage. Any vessels utilizing transit passage would still be required to adhere to US or Russian laws established for cetacean protection, as UNCLOS also requires countries, in Part V, Articles 64 and 65, to cooperate in the protection of marine mammal stocks occurring in multiple EEZs, as long as the laws or regulations do not discriminate among foreign ships or impair the right of transit passage (Huntington et al., 2015). Russia is a signatory to UNCLOS, and the United States, while not a signatory, recognizes UNCLOS as normal international law (Berkman et al., 2016). The United States is also a signatory to the 1979 Convention on Conservation of Migratory Species of Wild Animals, which requires cooperation of all states to conserve migratory species. Russia is not a signatory to this treaty (Berkman et al., 2016). Unfortunately, the United States and Russia have been identified as the two nations most ambivalent towards the Arctic Council (US Department of Defense, 2019). There is precedent for environmental cooperation between the two countries in the region, such as the 1973 Agreement on the Conservation of Polar Bears (Young, 2017). In addition, shipping regulations that impact the industry outside of the Arctic, such as technology improvements or safety requirements, will require input from Canada, as vessels using the Bering Strait to reach the Northwest Passage will be passing through Canadian internal waters (U.S. Department of Defense, 2019).

Any solutions developed will need to be integrated into both environmental protection plans and climate adaptation plans. This means that both cetacean protection needs will have to be balanced with other environmental considerations, and that plans will need to explicitly consider the impacts on cetaceans (Alter et al., 2009). Any solutions will also require cooperation on behalf of both the US and Russia. While the two nations have previously expressed a desire for cooperation in the governance of the region, cetacean protection will likely require something more formal, such as a bilateral agreement. An agreement of this type has been successfully to used to guide the US and Canada in managing the St. Lawrence seaway, a highly trafficked area that is also home to a population of belugas (Berkman et al., 2016).

MARINE SPATIAL PLANNING MEASURES

One potential solution is to create a Marine Protected Area (MPA) in the region. MPAs are highly utilized as marine conservation tools, limiting the activities within a spatial area, or enforcing certain restrictions within the area. MPAs have had varying levels of success throughout the world. MPAs are not generally ideal for migratory species or species with a wide distribution, in this case, the cetaceans, because they don't remain within the MPA (Agardy et al., 2011). Even if an MPA were established, it would still need to be resolved which restrictions would need to be applied within the area, as it would not be feasible to completely ban shipping from the only Pacific-Arctic entrance. Any MPA would also need to be transboundary, requiring commitment from both the US and Russia to establish and maintain.

Seasonal Management Areas (SMAs) are areas where restrictions are in effect at times corresponding with high levels of cetacean activity (Conn and Silber, 2013). SMAs have been effective in other regions of the world. In the Bering Strait, SMA may be effective for Arctic resident species, the bowhead and the beluga. They may be less effective for migratory species, as the timing of the melting sea ice, which opens up the region for the shipping, corresponds directly to the times of year when migratory cetaceans are moving into and out of the Arctic.

Areas to be Avoided (ATBAs) are a type of routing measure that designate areas where either navigation is especially hazardous, or it is exceptionally important to avoid casualties (Huntington et al., 2019). The IMO-approved routes utilize ATBAs, and several more have been recommended by the U.S. Coast Guard. ATBAs can be a highly effective tool for marine protection, particularly when vessels are forced to leave established traffic lanes (Vanderlaan et al., 2009). For the Bering Strait region, establishing additional ATBAs would require increased scientific understanding of the specific regions of high concentration of the species within the Strait that they are meant to protect. For cetaceans, this would require increased scientific understanding of migratory routes and small-scale critical habitat areas. Traditional ecological knowledge could play an important role in identifying these areas (Huntington et al., 2019). It would be important to also identify how these areas are potentially changing as migratory species move farther north.

In conjunction with ATBAs, it might also be possible to use marine spatial planning to identify critical areas within the Bering Strait and redesign shipping routes to minimize the probability of ship strike. One study in the Channel Islands showed the effectiveness of using specific data on habitat and migratory routes to redesign optimal shipping routes (Redfern et al., 2013). Rerouting seems an unlikely solution for the Bering Strait. First, because it will require significant investment in research and monitoring to identify which specific areas would need to be avoided. Any type of marine spatial planning requires knowledge of the probability of ship strike within certain areas (Vanderlaan et al., 2009). Second, the Bering Strait, as a shipping bottleneck, presents fewer and fewer options for routing as the bottleneck narrows. This means there is less likelihood it would be possible to identify new routes safe for both navigation and cetacean protection. Even if new routes could not be designed, ABTAs could still be used to identify specific critical habitat to be avoided. The study also noted, when looking at species-specific protection planning, the optimum routes for one species often conflicted with the optimum routes for another (Redfern et al., 2013). It seems likely this would also be the case for the Bering Strait. A more likely solution would be to use the routes approved by the IMO, and after a set period of time, use any historic data collected on ship strikes to revise routes.

Any of the above actions are also unlikely to be effective at mitigating the risk posed by ship noise, as the noise produced by vessels can travel large areas (Hildebrand, 2009). While this might not be an issue in other areas, the Bering Strait is narrow enough that any actions to mitigate noise pollution will likely need to be implemented throughout the entire region.

VESSEL ACTIONS

Individual vessels can play a role in ship strike avoidance by utilizing active whale avoidance, or intentional action by the vessel to avoid cetaceans if possible.

Encouraging individual action to avoid cetaceans would be an easy part of the solution, one that private industry working in conjunction with the US and Russia could encourage. While active whale avoidance has been shown to decrease strike risk, there are several aspects of leaving whale avoidance to the individual vessels that are challenging. Active whale avoidance puts the burden on the vessel to detect the whale, which is often difficult when the whales are underwater or at night (Sèbe et al., 2019). Detection must be accomplished with enough time to take avoidance action. The mariners are often forced to choose between the risk to the whale and other risks, such as risk to safe navigation (Gende, 2019). This could be a problem in challenging maritime areas such as the Bering Strait. Several proposed solutions for these issues include cetacean specific training for lookouts, standardizing whale protocol for any vessels operating within the region, and sharing of real-time cetacean data between vessels (Gende et al., 2019).

Reduced speed has been shown to be effective in reducing the risk posed by ships. Speed restriction in the critical habitat of the North Atlantic right whale is estimated to have reduced fatal strike incidents as much as 90% (Conn and Silber, 2013). Speed restrictions are also a measure that reduces underwater noise (MacGillivray et al., 2019). The biggest challenge other regions have faced in implementing speed restrictions is that they are often voluntary. Voluntary speed restrictions in other areas have shown varying levels of success (Huntington et al., 2015). Vessels travelling at reduced speeds take longer to transit, which is both costly to the shipping companies and potentially dangerous in a region with unpredictable weather and a lack of support infrastructure, such as the Arctic. Regarding noise pollution, not all vessels actually make less noise at lower speed, and for propulsion systems that are not properly maintained, can be louder at slower speeds (Lubofsky, 2016). While slower speeds may decrease the overall intensity of noise, since it takes the vessel longer to transit, it can increase the duration of the noise (Merchant, 2019).

The most promising solution to noise mitigation would be to require the use of propulsion technology with lower levels of underwater noise. These technologies exist today, and are often used by scientists studying marine mammals as a way to get closer to animals without disruption. Due to the increased costs of incorporating these technologies into new ship, they are not widely used by the commercial shipping industry (Lubofsky, 2016). This technology could be required, either by the IMO through revisions in the Polar Code, or jointly by the US and Russia. Individual countries could also provide economic incentives to commercial shipping companies to reduce noise pollution, through a combination of voluntary speed restrictions and lower-noise technology (Merchant, 2019). This solution would likely be more economically efficient, and thus more attractive to shipping companies. It seems a less practical solution for the Bering Strait region, as it would be up to individual nations to implement these incentives, and thus would not mitigate the impacts of vessels flagged to nations that do offer the incentives.

MONITORING SYSTEMS

An aggressive monitoring program could be implemented in order to watch for cetaceans. A monitoring program could be a single monitoring program, such as biological models, remote sensing, vessel reporting, scientific monitoring stations, etc., or a combination of multiple programs (Welsh, 2018). Either way, the goal of a monitoring program would be to detect cetaceans and notify any vessels of their locations. Given the remote nature of the region, this would likely involve partnerships between both governments, researchers, indigenous communities, and private industry.

Once the monitoring program is in place, there would also need to be an effective method of transmitting information to any vessels in the area. The most effective option would be the establishment of a Vessel Traffic Service (VTS) covering the region (Berkman et al., 2016). A VTS is defined by the IMO as “a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment” with “the capability to interact with the traffic and to respond to traffic situations” (International Maritime Organization, 1997). In addition to the benefits of a full-time VTS in an increasingly high capacity shipping route, a VTS would have the capability to gather and disseminate information on any cetaceans to all vessels within the area. A similar model was used in Canada, using Transport Canada’s operations center to distribute information on North Atlantic right whales within shipping lanes (Welsh, 2018). In order to implement such a system, a full-time VTS would need to be established in the region with the necessary communications equipment, command and control capabilities, and personnel. This would be an extremely expensive undertaking for a very remote region. In order to be effective, both the US and Russia would need to establish a VTS. And per the IMO, a VTS can only be established within a nation's territorial seas (International Maritime Organization, 1997), meaning that for any cetaceans spotted outside the territorial seas, a VTS would, at best, act in advisory capacity. The increased shipping through the Bering will require long-term investment in Arctic infrastructure (U.S. Coast Guard, 2019), and a VTS could be a necessary part of that infrastructure development. Even if there is not a full service VTS, it might be possible to establish a communications center to support environmental protection, including cetacean avoidance.

Even if a communications center is not established, it might be possible to pass information via AIS. Automatic Identification System (AIS) allows other vessels and shoreside facilities to view a vessel's name, unique identification, position, course and speed, and other important info, and is required on ships over 300 GT, and is often used voluntarily on smaller vessels (Huntington et al., 2015). AIS would be a much cheaper than a fully staffed VTS, and is already required on the majority of the vessels in the Bering Strait. In its current version, AIS is inadequate as a notification tool for cetacean strike avoidance (McGillivary et al., 2009). It might be possible to update the AIS retransmit system and to increase bandwidth within the Bering Strait region. This would require a similar infrastructure investment as previously discussed options (McGillivary et al., 2009).

DYNAMIC OCEAN MANAGEMENT

The ideal regional plan will likely include a combination of the solutions discussed above. One framework that could be utilized to bring these solutions together while alleviating the challenges is through dynamic ocean management. Many current marine protection plans are modeled after terrestrial protection plans, and are therefore static. Dynamic ocean management is a which real time data is used to guide spatial distribution of management and modified in real-time in response to changing conditions

(Lewison et al., 2015). While there are multiple models of dynamic ocean management, each of them involves taking data input and creating a final data product output.

Dynamic management is a seven-step process (See Figure 4). In this process, data are collected from multiple sources (biological models, remote sensing, AIS traffic, monitoring programs, etc.) and integrated and delivered to users, with users being anyone from mariners to shipping companies to shoreside decision-makers to scientific advisers. These data then allow users to make decisions in real time on how to modify regulations to balance multiple priorities, in this case cetacean protection and economic gain (Maxwell et al., 2015). Dynamic ocean management does not replace traditional management tools; rather, it creates a framework by which traditional methods can be implemented and modified in response to changing conditions.

This may look different depending on the circumstances and the data. In the case of cetacean protection, it begins with using systems of monitoring as described above to create a real time picture of cetacean activity and distribution. This information can then be used to make decisions depending on the current state of cetacean activity. It may involve implementing or lifting speed restrictions at a certain time, or implementing an ATBA given the presence of a large number of cetaceans.

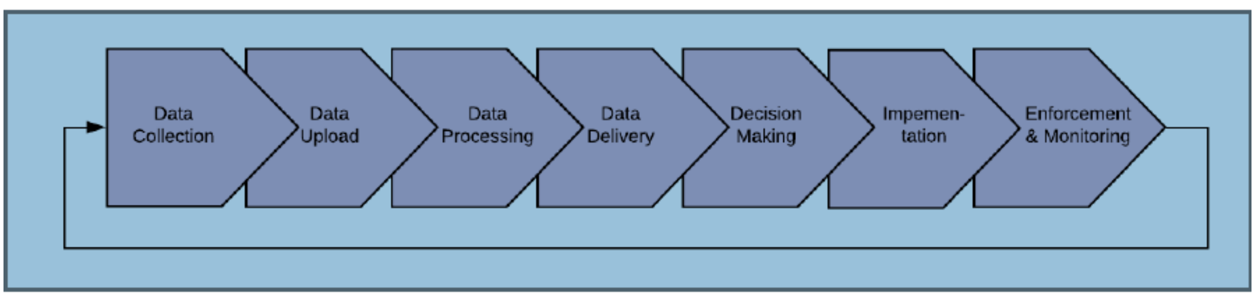

Figure 5-Seven steps of dynamic ocean management (Welsh, 2018)

Dynamic ocean management has been applied in several situations, including cetacean protection. The app WHALE Alert has been used in the Stellwagen Bank National Marine Sanctuary to provide real time data on North Atlantic right whales (Lewison et al., 2015). A similar program, Whale Watch, has been developed in for whale conservation off the coast of California (Hoag, 2014).

The biggest challenge to implementing dynamic ocean management in the Bering Strait is the lack of infrastructure within the region. More research is needed into specific cetacean feeding areas and migratory routes, and how these are changing with climate change.

CHAPTER 7 CONCLUSION

FURTHER RESEARCH

Any solutions would require some enforcement mechanism in order to be effective (Berkman et al., 2016). With respect to the United Nations Convention on the Law of the Sea, the United States and Russia would be able to enforce any regulations within their territorial seas. It would be much more difficult to enforce any regulations in the rest of the Bering Sea, where the IMO has the authority to establish regulations, but not the capacity to enforce (Huntington et al., 2015). Even the current shipping routes established by the IMO are voluntary. Legal enforcement would also require even more infrastructure investment in the region (U.S. Coast Guard, 2019). Any proposed solution will also likely require consideration of cost-effectiveness (Sèbe et al., 2019).

Many of the proposed solutions would have to account for increased military activity in the region. Naval vessels typically attempt to maintain a low presence when transiting; until recently, the US Navy did not broadcast its ship information on AIS, and still only broadcast in highly trafficked areas (Miller et al., 2019). Military vessels may not be subject to the same restrictions as commercial vessels (Conn and Silber, 2013). Any increased military presence in the Arctic, from any nation, will likely prioritize national security concerns over environmental protection (Scopelliti and Perez, 2016). This will need to be taken into account by environmental managers, and will likely require increased cooperation by the US and Russia, nations with a long history of hostility, to mitigate any impacts on protected species. It should be noted that there have been submarine operations in the Arctic for many years (Hilde, 2013).

One area of further exploration is the risk posed by different types of vessels. Vessels of all types are increasing in the Bering Strait region (Fletcher et al., 2016). Historically, all types of vessels have been involved in ship strikes, with the highest rates amongst military vessels, container ships, cargo ships, whale watching vessels, and cruise ships (Jensen and Silber, 2003). These data could be skewed because larger vessels may not even realize when a strike has occurred, while military vessels have strict reporting requirements for any incidents (Jensen and Silber, 2003). Different types of vessels may also have different sound signatures.

One area that has not been discussed in this analysis, but that should be considered, is the effects of shipping on the ecosystems upon which cetaceans are dependent. Arctic cod, an important Arctic marine keystone species and a primary prey source for belugas, view ship noise as threat, and increased shipping has been found to alter their behavior and distribution (Ivanova et al., 2019). Artificial light from ships has altered the behavior of zooplankton, which could impact the prey sources for mysticetes (Berge, 2020). Any impacts lower on the food web could have additional reverberating impacts on cetaceans.

FINAL THOUGHTS

Climate-change associated sea ice loss is expected to continue, and commercial interests, including shipping, will take advantage of new opportunities in the region. The Bering Strait region is no different from any other region of the world, in that, if left unregulated, the short-term economic opportunities will likely overwhelm environmental concerns. Multiple species of cetaceans have only started the long process of recovery after decades of commercial whaling, and are facing new stressors such as climate change and pollution. The analysis conducted here shows that different species within the Bering Strait all face a different level of risk. There are multiple potential solutions to these challenges. Each solution has significant limitations, and it is likely that a combination of the solutions described in this thesis will be necessary in order to solve the problem. Given these facts, it is essential that scientists, policymakers, environmental advocates, Bering Strait communities, and the commercial shipping industry should cooperate to preemptively increase scientific research into a developing region, and utilize the data to develop dynamic solutions that balance environmental protection with emerging economic interests.

REFERENCES

Agardy, T., di Sciara, G. N., and Christie, P. (2011). Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Marine Policy* 35, 226–232. doi:10.1016/j.marpol.2010.10.006.

Alter, E. S., Simmonds, M. P., and Brandon, J. R. (2010). Forecasting the consequences of climate-driven shifts in human behavior on cetaceans. *Marine Policy* 34, 943–954. doi:10.1016/j.marpol.2010.01.026.

Bartha, G. (2011). Population Size and Site Fidelity of North Atlantic Minke Whales (Balaenoptera acutorostrata) off the Atlantic Coast of Nova Scotia, Canada. *Aquatic Mammals* 37, 454–463. doi:10.1578/AM.37.4.2011.454.

Belkin, I. (2016). Comparative assessment of the West Bering Sea and East Bering Sea large marine ecosystems. *Environmental Development* 17, 145-156. doi:10.1016/j.envdev.2015.11.006

Berge, J., Geoffroy, M., Daase, M., Cottier, F., Priou, P., Cohen, J. H., et al. (2020). Artificial light during the polar night disrupts Arctic fish and zooplankton behavior down to 200 m depth. *Communications Biology* 3, 102. doi:10.1038/s42003-020-0807-6.

Berkman, P. A., Vylegzhanin, A. N., and Young, O. R. (2016). Governing the Bering Strait Region: Current Status, Emerging Issues and Future Options. *Ocean Development and International Law* 47, 186–217. doi:10.1080/00908320.2016.1159091.

Blackwell, S. B., Nations, C. S., McDonald, T. L., Thode, A. M., Mathias, D., Kim, K. H., et al. (2015). Effects of air gun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. *PLoS ONE* 10, e0125720. doi:10.1371/journal.pone.0125720.

Brower, A. A., Clarke, J. T., and Ferguson, M. C. (2018). Increased sightings of subarctic cetaceans in the eastern Chukchi Sea, 2008–2016: population recovery, response to climate change, or increased survey effort? *Polar Biology* 41, 1033–1039. doi:10.1007/s00300-018-2257-x.

CAFF. (2013). Arctic biodiversity assessment: status and trends in Arctic biodiversity. Arctic Council, 669 pp.

CAFF and PAME. (2017). Arctic Protected Areas Indicator Report. Arctic Council, 19 pp.

Carter, B. T. G., and Nielsen, E. A. (2011). Exploring ecological changes in Cook Inlet beluga whale habitat though traditional and local ecological knowledge of contributing factors for population decline. *Marine Policy* 35, 299–308. doi:10.1016/j.marpol.2010.10.009.

Castellote, M., Clark, C. W., and Lammers, M. O. (2012). Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and air gun noise. *Biological Conservation* 147, 115–122. doi:10.1016/j.biocon.2011.12.021.

Cholewiak, D., Clark, C., Ponirakis, D., Frankel, A., Hatch, L., Risch, D., et al. (2018). Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. *Endangered Species Research* 36, 59–75. doi:10.3354/esr00875.

Clarke, J., Stafford, K., Moore, S., Rone, B., Aerts, L., and Crance, J. (2013). Subarctic Cetaceans in the Southern Chukchi Sea: Evidence of Recovery or Response to a Changing Ecosystem. *Oceanography* 26, 136–149. doi:10.5670/oceanog.2013.81.

Conn, P. B., and Silber, G. K. (2013). Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. *Ecosphere* 4, art43. doi:10.1890/ES13-00004.1.

Crichton, D. (1999). The risk triangle, in Ingleton, J. (ed.) Natural Disaster Management. Tudor Rose, London, pp. 102-103.

Critical Habitat for the North Pacific Right Whale. (2020). 50 CFR § 226.215

Dawson, J., Johnston, M. E., and Stewart, E. J. (2014). Governance of Arctic expedition cruise ships in a time of rapid environmental and economic change. *Ocean and Coastal Management* 89, 88–99. doi:10.1016/j.ocecoaman.2013.12.005.

Dorsey, E. M., Stern, S. J., Hoelzel, A. R., and Jacobsen, J. (1990). Minke whales (Balaenoptera acutorostrata) from the west coast of North America: individual recognition and small-scale site fidelity. *Report of International Whaling Commission*, 12.

Douglas, A. B., Calambokidis, J., Raverty, S., Jeffries, S. J., Lambourn, D. M., and Norman, S. A. (2008). Incidence of ship strikes of large whales in Washington State. *Journal of the Marine Biological Association of the United Kingdom*88,

1121–1132. doi:10.1017/S0025315408000295.
Dunlop, R. A., Cato, D. H., and Noad, M. J. (2010). Your attention please: increasing ambient noise levels elicits a change in communication behaviour in humpback whales (*Megaptera novaeangliae*). *Proceedings of the Royal Society B: Biological Sciences* 277, 2521–2529. doi:10.1098/rspb.2009.2319.
Endangered Species Act. (1973). 16 USC 35 § 1531-1544.
Endangered and Threatened Species: Identification of 14 distinct population segments of the humpback whale (*Megaptera novaeangliae*) and revision of species-wide listing. (2016). 81 FR 62259. 50 CFR 223 and 224, pp. 62259-62320.
Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L. E., and Embling, C. B. (2019). The effects of ship noise on marine mammals-a review. *Frontiers in Marine Science* 6, 606. doi:10.3389/fmars.2019.00606.
Ferrara, G. A. (2017). Assessing the Vulnerability of Marine Mammal Subsistence Species in the Bering Sea to Climate Change. Master’s Thesis, University of Washington, Seattle, WA, 35 pp.
Fletcher, S., Higman, B., Chartier, A., and Robertson, T. (2020). Adherence to Bering Strait Vessel Routing Measures. Nuka Research and Planning Group, LLC, 36 pp.
Fletcher, S., Robertson, T., Higman, B., James, M., Sughroue, A., DeCola, P., Mom, C. (2016). Bering Sea vessel traffic risk analysis. Nuka Research and Planning Group, LLC, 88 pp.
Fobar, R. (2018). Japan will resume commercial whaling. *National Geographic*. https://www.nationalgeographic.com/animals/2018/12/japan-considers-leaving-international-whaling-commission/
Friday, N. A., Zerbini, A. N., Waite, J. M., Moore, S. E., and Clapham, P. J. (2013). Cetacean distribution and abundance in relation to oceanographic domains on the eastern Bering Sea shelf, June and July of 2002, 2008, and 2010. *Deep Sea Research Part II: Topical Studies in Oceanography* 94, 244–256. doi:10.1016/j.dsr2.2013.03.011.
Gende, S. M., Vose, L., Baken, J., Gabriele, C. M., Preston, R., and Hendrix, A. N. (2019). Active whale avoidance by large ships: components and constraints of a

complementary approach to reducing ship strike risk.? *Frontiers in Marine Science* 6, 592. doi:10.3389/fmars.2019.00592.

George, J. C., Sheffield, G., Reed, D. J., Tudor, B., Stimmelmayr, R., Person, B. T., et al. (2017). Frequency of Injuries from Line Entanglements, Killer Whales, and Ship Strikes on Bering-Chukchi-Beaufort Seas Bowhead Whales. *Arctic* 70, 37. doi:10.14430/arctic4631.

Gosselin, M., Levasseur, M., Wheeler, P. A., Horner, R. A., and Booth, B. C. (1997). New measurements of phytoplankton and ice algal production in the Arctic Ocean. *Deep Sea Research Part II, Topical Studies in Oceanography, 44(8):* 1623-1625, 1627-1644.

Greenwald, N., and Callimanis, S. (2006). The Bering Sea: a biodiversity assessment of vertebrate species. Center for Biological Diversity, 63 pp.

Hansen, Ø. C. (2016). *Arctic Shipping: Commercial Opportunities and Challenges*. CBS Maritime, Copenhagen, 92 pp.

Hauser, D. D. W., Laidre, K. L., and Stern, H. L. (2018). Vulnerability of Arctic marine mammals to vessel traffic in the increasingly ice-free Northwest Passage and Northern Sea Route. *Proceedings of the National Academy of Sciences* 115, 7617–7622. doi:10.1073/pnas.1803543115.

Heide-Jørgensen, M. P., Richard, P., Dietz, R., Laidre, K. L., Orr, J., and Schmidt, H. C. (2003). An estimate of the fraction of belugas (Delphinapterus leucas) in the Canadian high Arctic that winter in West Greenland. *Polar Biology* 26, 318–326. doi:10.1007/s00300-003-0488-x.

Hilde, P. S. (2013). The “new” Arctic: the military dimension. *Journal of Military and Strategic Studies, 15*(2), 130-153.

Hildebrand, J. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395, 5–20. doi:10.3354/meps08353.

Hoag, H. (2014). This technology could save endangered blue whales from colliding with cargo ships. *Takepart magazine*. http://www.takepart.com/article/2014/07/22/technology-predicts-where-endangered-blue-whale-will-travel-keep-them-safe-ships

Huntington, H. P. (2009). A preliminary assessment of threats to arctic marine mammals and their conservation in the coming decades. *Marine Policy* 33, 77–82. doi:10.1016/j.marpol.2008.04.003.

Huntington, H. P., Bobbe, S., Hartsig, A., Knight, E. J., Knizhnikov, A., Moiseev, A., et al. (2019). The role of areas to be avoided in the governance of shipping in the greater Bering Strait region. *Marine Policy* 110, 103564. doi:10.1016/j.marpol.2019.103564.

Huntington, H. P., Daniel, R., Hartsig, A., Harun, K., Heiman, M., Meehan, R., et al. (2015). Vessels, risks, and rules: Planning for safe shipping in Bering Strait. *Marine Policy* 51, 119–127. doi:10.1016/j.marpol.2014.07.027.

Huntington, H. P., Danielson, S. L., Wiese, F. K., Baker, M., Boveng, P., Citta, J. J., et al. (2020). Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. *Nature Climate Change* 10, 342–348. doi:10.1038/s41558-020-0695-2.

International Maritime Organization. (1997). Guidelines for Vessel Traffic Services. Resolution A.857(20). IMO, London, 23 pp.

International Maritime Organization. (2017). Polar Code. MEPC 68/21/Add 1.IMO, London, 55 pp.

International Maritime Organization. (2017). Routing measures and mandatory ship reporting systems: establishment of two-way routes and precautionary areas in the Bering Sea and Bering Strait. NCSR 5/3/7. IMO, London, 17 pp.

IPCC. (2013). Climate change 2013: the physical science basis. Contributions of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 1535 pp.

IPCC. (2019). Technical summary. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. In press, 69 pp.. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_TS_FINAL.pdf

Ivanova, S. V., Kessel, S. T., Espinoza, M., McLean, M. F., O'Neill, C., Landry, J., et al. (2020). Shipping alters the movement and behavior of Arctic cod (*Boreogadus saida*), a keystone fish in Arctic marine ecosystems. *Ecological Applications* 30. doi:10.1002/eap.2050.

Jahn, A., Kay, J. E., Holland, M. M., and Hall, D. M. (2016). How predictable is the timing of a summer ice-free Arctic? *Geophysical Research Letters, 43*: 9113-9120.

Jensen, A. S., Silber, G. K., Calambokidis, J., Campbell, C., Cordaro, J., Deiter, R., et al. Large Whale Ship Strike Database. 39.

Jurgilevich, A., Räsänen, A., Groundstroem, F., and Juhola, S. (2017). A systematic review of dynamics in climate risk and vulnerability assessments. *Environmental Research Letters* 12, 013002. doi:10.1088/1748-9326/aa5508.

Laidre, K. L., Stern, H., Kovacs, K. M., Lowry, L., Moore, S. E., Regehr, E. V., et al. (2015). Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century: Arctic Marine Mammal Conservation. *Conservation Biology* 29, 724–737. doi:10.1111/cobi.12474.

Laist, D. W., Knowlton, A. R., Mead, J. G., Collet, A. S., and Podesta, M. (2001). Collisions between ships and whales. *Marine Mammal Science* 17, 35–75. doi:10.1111/j.1748-7692.2001.tb00980.x.

Lewison, R., Hobday, A. J., Maxwell, S., Hazen, E., Hartog, J. R., Dunn, D. C., et al. (2015). Dynamic ocean management: identifying the critical ingredients of dynamic approaches to ocean resource management. *BioScience* 65, 486–498. doi:10.1093/biosci/biv018.

Lloyd’s Register. (2013). Global Marine Trends 2030. Farnborough: London. 75 pp.

MacGillivray, A. O., Li, Z., Hannay, D. E., Trounce, K. B., and Robinson, O. M. (2019). Slowing deep-sea commercial vessels reduces underwater radiated noise. *The Journal of the Acoustical Society of America* 146, 340–351. doi:10.1121/1.5116140.

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., et al. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Marine Policy* 58, 42–50. doi:10.1016/j.marpol.2015.03.014.

McDonald, M. A., and Fox, C. G. (1999). Passive acoustic methods applied to fin whale population density estimation. *The Journal of the Acoustical Society of America* 105, 2643–2651. doi:10.1121/1.426880.

McGillivary, P. A., Schwehr, K. D., and Fall, K. (2009). Enhancing AIS to improve whale-ship collision avoidance and maritime security. IEEE Oceans, 462.

Merchant, N. D. (2019). Underwater noise abatement: Economic factors and policy options. *Environmental Science and Policy* 92, 116–123. doi:10.1016/j.envsci.2018.11.014.

Miller, T. C., Rose, M., and Faturechi, R. (2019). Fight the ship: death and valor on a warship doomed by its own Navy. *ProPublica*.

Mizroch, S. A., Rice, D. W., and Breiwick, J. M. (1984). The fin whale, Balaenoptera physalus. *Marine Fisheries Review*, 6.

Moore, S. E., DeMaster, D. P., and Dayton, P. K. (2000). Cetacean habitat selection in the Alaskan Arctic during summer and autumn. Arctic 53, 432–447. doi:10.14430/arctic873.

Moore, S. E., and Huntington, H. P. (2008). Arctic marine mammals and climate change: impacts and resilience. *Ecological Applications* 18, S157–S165. doi:10.1890/06-0571.1.

Moore, S. E., and Reeves, R. R. (2018). Tracking arctic marine mammal resilience in an era of rapid ecosystem alteration. *PLoS Biology* 16, e2006708. doi:10.1371/journal.pbio.2006708.

Moore, S. E., Stafford, K. M., Melling, H., Berchok, C., Wiig, Ø., Kovacs, K. M., et al. (2012). Comparing marine mammal acoustic habitats in Atlantic and Pacific sectors of the High Arctic: year-long records from Fram Strait and the Chukchi Plateau. *Polar Biology* 35, 475–480. doi:10.1007/s00300-011-1086-y.

Mullen, K. A., Peterson, M. L., and Todd, S. K. (2013). Has designating and protecting critical habitat had an impact on endangered North Atlantic right whale ship strike mortality? *Marine Policy* 42, 293–304. doi:10.1016/j.marpol.2013.03.021.

Muto, M. M., Helker, V. T., Angliss, R. P., Boveng, P. L., Breiwick, J. M., Cameron, M. F., et al. (2018). Alaska Marine Mammal Stock Assessments, 2018. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-393, 390 pp.

Neilson, J. L., Gabriele, C. M., Jensen, A. S., Jackson, K., and Straley, J. M. (2012). Summary of reported whale-vessel collisions in Alaskan waters. *Journal of*

Marine Biology 2012, 1–18. doi:10.1155/2012/106282.

Osborne, E., Richter-Menge, J., and Jeffries, M. (2018). Arctic Report Card 2018. https://www.arctic.noaa.gov/Report-Card.

Norman, S. A., Hobbs, R. C., Goertz, C. E. C., Burek-Huntington, K. A., Shelden, K. E. W., Smith, W. A., et al. (2016). Potential natural and anthropogenic impediments to the conservation and recovery of Cook Inlet beluga whales, Delphinapterus leucas. *Marine Fisheries Review* 77, 89–105. doi:10.7755/MFR.77.2.5.

PAME. (2009) Arctic Marine Shipping Assessment. Arctic Council, 187 pp.

Pivorunas, A. (1979). The feeding mechanisms of baleen whales. *American Scientist* 67, 432-440.

Pizzolato, L., Howell, S. E. L., Dawson, J., Copland, L., Derksen, C., and Johnston, M. E. (2013). Climate Change Adaptation Assessment for Transportation in Arctic Waters (CATAW) Scoping Study: Summary Report. Transport Canada, Ottawa, Ontario, 17 pp.

Post, E., Bhatt, U. S., Bitz, C. M., Brodie, J. F., Fulton, T. L., Hebblewhite, M., et al. (2013). Ecological consequences of sea-ice decline. *Science* 341, 519–524. doi:10.1126/science.1235225.

Redfern, J. V., Mckenna, M. F., Moore, T. J., Calambokidis, J., Deangelis, M. L., Becker, E. A., et al. (2013). Assessing the risk of ships striking large whales in marine spatial planning: assessing ship-strike risk. *Conservation Biology* 27, 292–302. doi:10.1111/cobi.12029.

Reeves, R. R., Ewins, P. J., Agbayani, S., Heide-Jørgensen, M. P., Kovacs, K. M., Lydersen, C., et al. (2013). Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. *Marine Policy* 44, 375–389. doi:10.1016/j.marpol.2013.10.005.

Rolland, R. M., Parks, S. E., Hunt, K. E., Castellote, M., Corkeron, P. J., Nowacek, D. P., et al. (2012). Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B: Biological Sciences* 279, 2363–2368. doi:10.1098/rspb.2011.2429.

Rosenbaum, H. C., Brownell, R. L., Brown, M. W., Schaeff, C., Portway, V., White, B. N., et al. (2000). World-wide genetic differentiation of *Eubalaena* : questioning the number of right whale species. *Molecular Ecology* 9, 1793–1802. doi:10.1046/j.1365-294x.2000.01066.x.

Schoeman, R. P., Patterson-Abrolat, C., and Plön, S. (2020). A global review of vessel collisions with marine animals. *Frontiers in Marine Science* 7, 292. doi:10.3389/fmars.2020.00292.

Schøyen, H., and Bråthen, S. (2011). The Northern Sea Route versus the Suez Canal: cases from bulk shipping. *Journal of Transport Geography* 19, 977–983. doi:10.1016/j.jtrangeo.2011.03.003.

Sèbe, M., Kontovas, C., A., and Pendleton, L. (2019). A decision-making framework to reduce the risk of collisions between ships and whales. *Marine Policy* 109, 103697. doi:10.1016/j.marpol.2019.103697.

Sivle, L. D., Kvadsheim, P. H., Curé, C., Isojunno, S., Wensveen, P. J., Lam, F.-P. A., et al. (2015). Severity of expert-identified behavioral responses of humpback whale, minke whale, and northern bottlenose whale to Naval Sonar. *Aquatic Mammals* 41, 469–502. doi:10.1578/AM.41.4.2015.469.

Terhune, J. M., and Verboom, W. C. (1999). Right whales and ship noises. *Marine Mammal Science* 15, 256–258. doi:10.1111/j.1748-7692.1999.tb00799.x.

Thomas, P. O., Reeves, R. R., and Brownell, R. L. (2016). Status of the world's baleen whales. *Marine Mammal Science* 32, 682–734. doi:10.1111/mms.12281.

Tsujii, K., Otsuki, M., Akamatsu, T., Matsuo, I., Amakasu, K., Kitamura, M., et al. (2016). The migration of fin whales into the southern Chukchi Sea as monitored with passive acoustics. *ICES Journal of Marine Science* 73, 2085–2092. doi:10.1093/icesjms/fsv271.

U.S. Committee on Maritime Transport System (2019). A Ten-Year Projection of Maritime Activity in the U.S. Arctic Region, 2020–2030. Washington, DC, 153 p.

U.S. Coast Guard (2019). Arctic Strategic Outlook. U.S. Department of Homeland Security, Washington, DC, 48 pp.

U.S. Department of Defense (2019). Department of Defense Arctic Strategy. Office of the Undersecretary of Defense for Policy, Washington, DC, 18 pp.

Vanderlaan, A., Corbett, J., Green, S., Callahan, J., Wang, C., Kenney, R., et al. (2009). Probability and mitigation of vessel encounters with North Atlantic right whales.

Endangered Species Research 6, 273–285. doi:10.3354/esr00176.

Vanderlaan, A. S. M., and Taggart, C. T. (2007). Vessel collisions with whales: the probability of lethal injury based on vessel speed. *Marine Mammal Science* 23, 144–156. doi:10.1111/j.1748-7692.2006.00098.x.

Wang, M., Yang, Q., Overland, J. E., and Stabeno, P. (2018). Sea-ice cover timing in the Pacific Arctic: the present and projections to mid-century by selected CMIP5 models. *Deep Sea Research Part II* 152, 22-34. doi: 10.1016/j.dsr2.2017.11.017

Weilgart, L. S. (2007). A brief review of the known effects of noise on marine mammals. *International Journal of Comparative Psychology*, 20, 159-168.

Welsh, H. (2018). Managing Canada's endangered: an analysis of Canada's efforts to mitigate shipping impacts on North Atlantic right whales. Master's Thesis, Dalhousie University, Halifax, NS, 94 pp.

Wright, D. L., Berchok, C. L., Crance, J. L., and Clapham, P. J. (2019). Acoustic detection of the critically endangered North Pacific right whale in the northern Bering Sea. *Marine Mammal Science* 35, 311–326. doi:10.1111/mms.12521.Young, O. R. (2016). The shifting landscape of Arctic politics: implications for international cooperation. *The Polar Journal* 6, 209–223. doi:10.1080/2154896X.2016.1253823.