Across the Bering Strait: assessing impacts of shipping in the Arctic

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[*]*Submitted as the final project requirement for GEOG 378: Emerging Issues in Climate Change Science, Spring 2024, Professor Karen Frey*

ABSTRACT

As sea ice in the Arctic rapidly declines with climate change, a new industry is emerging. Arctic shipping is advantageous to shipping over conventional shipping routes because it is shorter and faster, but there are environmental consequences as a result. This is a narrative review which synthesizes articles relating to impacts of Arctic shipping especially in the Bering Strait. There has been extensive research in modeling sea ice extent and the probability of shipping in across different climate change scenarios with different ships. The impacts related to Arctic shipping are split into categories of emissions impacts which include black carbon and aerosol impacts and impacts on wildlife which includes non-native species introduction, noise pollution, and risk of oil spills. Future initiatives for making Arctic shipping more environmentally friendly include quieter propellors, slow steaming, and alternative fuels. Policy recommendations are suggested to limit speeds and noise of ships in fragile animal habitats and to impose a tax on carbon emitting ships passing through the Arctic. Arctic shipping is an industry that has come to stay, but, with international cooperation, it can become regulated to allow the Arctic to remain as unaffected by anthropogenic disturbance as possible.

1. INTRODUCTION

1.1 The Arctic's Rapid Warming

"The Arctic has warmed nearly four times faster than the globe since 1979" (Rantanen et al., 2022). The Arctic is being affected by climate change more intensely than the rest of the world, and this has implications on the processes necessary for the Arctic to sustain itself. This warming can be partially attributed to the feedback loop exhibited when the sunlight melts ice which is typically very reflective of sunlight and that ice becomes water with a very low albedo. This water absorbs incoming heat from the sun and causes the environment to heat up even more creating a positive feedback loop. This feedback loop is part of the reason why sea ice melt in the Arctic is so rapid.

1.2 Sea Ice Decline

Arctic sea ice is declining at rapid rates and is at levels that have not been seen in thousands of years (Meier et al., 2014). The summer extent of sea ice has declined by over 30% over the last few decades and is one of the most rapidly changing aspects of Earth's climate system (Meier et al., 2014).

1.3 The Future of Arctic Sea Ice

Arctic sea ice is rapidly declining and that it is possible there will be ice free summers by 2076 under SSP 4.5 while the Arctic could be ice free by 2055 in the summer under SSP 8.5 (Wei et al., 2020). Figure 1 shows modeled shipping routes through the Arctic at RCP 2.6 compared to RCP 8.5 across 3 different time intervals. In RCP 8.5, the Arctic is freely navigable by open water vessels while under RCP 2.6 the Arctic would be nearly freely navigable by Polar Class 6 vessels and 68% of the Arctic would be navigable by open water vessels by 2075 to 2090 (Melia et al., 2016).

1.4 Impacts of Sea Ice Decline on Shipping

As Arctic sea ice melts, the region becomes much more accessible by ship. This accessibility is lucrative for shipping companies as they can ship their goods on more direct, faster routes through the Arctic as compared to going through the Suez Canal or other conventional shipping routes. Figure 1 illustrates the difference between shipping along conventional routes as compared to shipping through the Arctic. When ships pass through the Arctic, one area where they must pass through is the Bering Strait which is the home of many species of marine mammals. These marine mammals are affected by the disturbances such as noise pollution which come from shipping activity. Figure 2 shows the difference in shipping traffic through the Bering Strait between 2015 and 2019. There is far more traffic in 2019 than there was in 2015, and, as more sea ice melts, these shipping routes will only become more lucrative for shipping companies.

1.5 Impacts of Shipping on the Arctic

This increase in shipping has many impacts on wildlife as well as atmospheric and cryospheric effects. Some of the impacts on the atmosphere and cryosphere from Arctic shipping are an increase in black carbon concentrations on sea ice, varying effects of black carbon throughout the atmosphere depending on the altitude, and an increase in cloud generation from aerosol emissions. Arctic shipping impacts on wildlife include the introduction of non-native species through biofouling and ballast transfer, noise pollution, and the potential for oil spills. With many harmful impacts of Arctic shipping, there is space for future innovation to make the practice less environmentally harmful. Some proposed practices to limit the environmental effects of Arctic shipping are the encouragement of slow steaming for emissions reduction, electrification of ships along commonly used Arctic shipping routes, the use of alternative fuels such as Liquified Natural Gas, and the retro fitment of container ships with new propellors to reduce noise pollution. Figure 3 outlines the potential areas for future innovation in Arctic shipping.

1.6 Knowledge Gap

A previous review from 2024 was done assessing the environmental impacts of Arctic shipping throughout the entire Arctic. This is Qi et al. (2024) which separates the articles analyzed into 3 categories which are impact on water bodies, impact on air emissions, and impact on animal survival. Qi et al. (2024) does not analyze what future initiatives can be taken to make Arctic shipping less harmful for the environment. Another review assesses the economics of Arctic shipping and comes to the conclusion that there must be more analysis done on the environmental impacts of shipping in the Arctic and that a toll should be assessed to ships passing through the Arctic for the damage they are doing to the environment (Ng et al., 2018). The feasibility of shipping in the Arctic is assessed in another review which finds that there is extreme model variability in terms of shipping and sea ice levels in the Arctic, but most of the models find that shipping in the Arctic would be profitable (Lasserre, 2014). Figure 4 shows the steep increase that has occurred in publications that relate to the search term "Arctic Shipping" in Google Scholar by year. Figure 5 demonstrates how the literature is dominated by articles focusing on the melting of sea ice and modeling of Arctic shipping routes and does not focus on the effects that Arctic shipping has on the environment or future initiatives to make Arctic shipping less harmful. It is expected that as sea ice continues to melt and shipping becomes more feasible, the amount of literature concerning the topic will grow as well.

This narrative review will focus on the effects of shipping in the Arctic in general as well as going into depth on shipping through the Bering Strait. The Bering Strait is one of the most heavily trafficked areas in the Arctic by ships and marine life. This review will categorize papers into sections related to sea ice melt and Arctic shipping expansion, impacts from emissions, impacts on wildlife, and future initiatives which could lessen the impacts of shipping in the Arctic. Figure 6 outlines the structure of the paper which is divided into the four sections described above.

1.7 Methodology

Many of the sources that are selected for this review are selected from Qi et al. (2024) if they were relevant to this study. Papers that were selected were either concerned with sea ice melt, future initiatives of Arctic shipping, or the impacts that shipping has on the environment whether it is the physical environment or the impact that it has on wildlife. Figure 7 outlines the connections of keywords which have 2 or more occurrences and how they are connected to other keywords in the articles used in the analysis. The words fall into four categories related to the paper which are projections of sea ice loss and shipping route gain, pollution related to black carbon, environmental impacts of shipping, and exhaust emissions from ships not as closely related to black carbon.

2. Arctic Shipping: Impacts and Initiatives

2.1. Sea Ice Melt and Shipping Projections

2.1.1. Arctic Sea Ice Projections

Arctic warming is apparent and it has been projected that there will be an ice free summer by 2050 (Min et al., 2022). Variability in sea ice forecasts as well as in as well in weather forecasts is immense (Gascard et al., 2017). For example, in 2007 (the second smallest sea ice year on record), the Northern Sea Route was blocked by a sheet of ice that was protruding from the main ice pack toward Russia (Melia et al., 2016). By mid-century, it is projected to be 10 days faster to travel from Europe to Asia via the Arctic compared to traditional routes outside of the Arctic (Melia et al., 2016).

2.1.2. Projected Increase in Arctic Shipping

Arctic shipping is increasing more quickly than model projections and will continue to increase as ice melts (Cao et al., 2022). Arctic shipping allows for ships to reduce the distance required for shipping by up to 30% (Meier et al., 2014). With the decrease in the distance required for ships to travel, there will be economic benefits to companies who ship their cargo through the Arctic (Min et al., 2022). A majority of models related to Arctic shipping find that it will be profitable for shipping companies to ship through the Arctic as opposed to their current routes (Lasserre, 2014). Even though it is a shorter route and less greenhouse gasses will be let off into the air, there will not be climate benefits of shipping in the Arctic because the impact of emissions in the Arctic will not offset the benefits of these shorter routes (Lindstad et al., 2016).

2.2. Emissions Impacts

2.2.1. Black Carbon Cryosphere Albedo Reduction

When oil is used as fuel in shipping, one of the byproducts of this is black carbon. Black carbon deposition causes a decrease in albedo on the ice which has a very high albedo. When the albedo of the ice is lowered, the ice begins melting faster which will make Arctic Shipping more lucrative. As demonstrated in figure 8, the addition of black carbon to the cryosphere by ships in the Arctic ignites a positive feedback loop. Papers used in this analysis find different conclusions on the effect of black carbon from Arctic shipping on the environment. By 2050, the increase in Arctic shipping will account for less than 1% of the black carbon deposition (Browse et al., 2013). Browse et al (2013) claims that the majority of the black carbon in the Arctic comes from emissions that travel northward rather than that which originates from shipping in the Arctic. In 2013, it was found that 4.3-9.8% of the black carbon around Resolute, Canada was found to be from shipping emissions (Aliabadi et al., 2015).

2.2.2. Aerosol Cooling for Cloud Generation

One of the byproducts of shipping with oil is the release of aerosols into the air which function as a vehicle for water droplets to attach to. With Arctic shipping continuing to rise through the end of the 21st century, the aerosol emissions from ships will help to prevent 1 degree Celsius of Arctic warming by 2099 (Stephenson et al., 2018). This aerosol generation from ships will lead to a negative feedback loop which will support ice generation with cooler temperatures (Stephenson et al., 2018).

2.2.3 Black Carbon Effects in the Atmosphere

While the emission of black carbon has a warming effect on the cryosphere, it has varying effects depending on where it is found in the atmosphere. Black carbon in the lowest layers of the atmosphere has strong warming effects, while when in the mid troposphere it has a slight warming effect, and in higher altitudes it has a cooling effect on the Arctic (Flanner, 2013). The cooling effect in the upper atmosphere is a result of absorption of sunlight at higher altitudes preventing that sunlight from making it to the surface of the Arctic (Flanner, 2013). In addition, this black carbon warming in the atmosphere encourages atmospheric stability meaning there will be less heat transfer from lower latitudes to upper latitude causing a cooling affect in the Arctic (Flanner, 2013).

2.3. Impacts on Wildlife

2.3.1. Non-Native Species Introduction

With shipping in the Arctic increasing, ships provide a way for organisms to move more quickly than they would be able to without the presence of Arctic shipping. From 1960 to 2015, 39% of the nonindigenous species that were introduced to the Arctic were introduced by vessels (Chan et al., 2019). There are multiple pathways for these nonindigenous species to enter the Arctic, but the main pathways these species enter nonnative territory is through the transfer of ballast water and from biofouling on ships (Chan et al., 2019).

2.3.2. Noise Pollution

Many Arctic marine mammals are dependent on a quiet environment that is not disturbed by anthropogenic activities for their survival. As shipping in the Arctic becomes more common, the noise pollution is likely to have an impact on these marine mammals. Sounds from ships underway from over 100 km away can be heard under quiet conditions (Halliday et al., 2017). In this study on shipping noise in relation to marine mammals in the western Canadian Arctic, it is recommended that ships reduce speed when marine mammals are spotted (Halliday et al., 2017). It is also recommended that marine mammal observers are on ships to help reduce the potential impact with marine species in the Arctic (Halliday et al., 2017).

2.3.3 Oil Spill Potential

As the traffic in the Arctic increases, the potential for oil spills also increases. Oil from spills would wrap the feathers of birds restricting their ability to fly as well as having detrimental impacts on fish (Qi et al., 2024). Oil spills have impacts throughout the food chain and could severely impact the Arctic ecosystem if one were to occur. There have been no large-scale oil spills recorded in the Arctic, but that does not mean there is not risk of oil spills in the Arctic in the future (Qi et al., 2024). An oil spill in the Arctic would be more challenging to clean up than one which occurred in an area that is free of ice because of the remoteness of the region as well as the fact that oil can be encased in the ice and absorbed by snow (Qi et al., 2024).

2.4 Future Initiatives

2.4.1. Slow Steaming

There are many ways in which shipping in the Arctic is harmful to the environment, but it is important to consider that there are ways shipping can be made less harmful for the environment. Slow steaming is a when cargo ships travel more slowly to conserve fuel. A regular speed for a ship is 23-25 knots while slow steaming is defined as 20-22 knots (Balcombe et al., 2019). Slow steaming reduced container ship emissions by 11% between 2008-2010 (Balcombe et al., 2019). In addition to the environmental benefits that slow steaming provides with reduced carbon emissions, slow steaming also provides benefits to shipping companies as they will be able to save money on fuel costs. These fuel costs can account for up to 50% of the total operating costs for these vessels (Balcombe et al., 2019). Figure 9 shows how average ships can reduce fuel consumption by 25% by reducing the speed only 1.5 meters per second.

2.4.2. Electrification

Another future initiative which would be beneficial for reducing the impact of Arctic shipping on the environment is the implementation of infrastructure to allow for shipping companies to convert their fleets to electric. Savard et al. (2020) proposed an electrified shipping corridor along the Northern Sea Route which where supply ships could provide large cargo ships with charged batteries while taking used dead batteries back to port to be charged for the next ships passing through. In the current state of the economy, electrification of ships passing through the Arctic will not be economically feasible as it will be cheaper and faster for shipping companies to continue to transport their goods with oil (Savard et al., 2020).

2.4.3 Liquified Natural Gas

The use of Liquified Natural Gas (LNG) as a more environmentally friendly means of fuel for ships serves as an alternative to oil with the ability to reduce greenhouse gas emissions by 20-30% (Balcombe et al., 2019). Balcombe et al. (2019) proposes LNG as a transition to electric shipping along the Northern Sea Route as it provides environmental benefits over oil, but those environmental benefits are not as advantageous as electric shipping.

2.4.4 Quieter Propellors

Modifications to propellors are one of the ways that ships can reduce the noise created in transit. After voluntary guidelines for reducing noise pollution by retrofitting commercial ships were released by the International Maritime Organization, Maersk retrofitted five large container ships with new propellors which reduced the noise generated by 6 to 8 dB and also had reductions in fuel consumption (Duarte et al., 2021).

3. DISCUSSION

3.1. Summary of findings

3.1.1. Sea Ice Melting and Shipping Projections

Almost all of the papers concerning sea ice melt and the economic feasibility of Arctic shipping find that it is more lucrative for shipping companies to route their ships through the Arctic than it would be for them to continue on conventional routes. The variability in sea ice as well as weather forecasts is found to be immense, and that Arctic shipping may not be a reliable form of transit until more accurate models can be developed or enough sea ice melts that modelling is no longer as crucial.

3.1.2. Emissions Impacts

Papers analyzed in this review found varying effects of Arctic shipping emissions on the environment. Some papers found a positive feedback loop exhibited by the black carbon emitted by ships becoming deposited on ice while another found a negative feedback loop from black carbon in the upper atmosphere. A paper also found a negative feedback loop between the emissions of aerosols from ships with cloud formation (Stephenson et al., 2018).

3.1.3. Impacts on Wildlife

The impacts on wildlife found in the papers assessed in this analysis is focused on the ability of ships to introduce non-native species to new environments, the impacts of noise pollution from shipping, and the impacts of oil spills. Shipping through the Arctic and allowing ships to take on ballast will continue the spread of non-native species across the region. Noise pollution especially affects marine mammals and their ability to communicate when there are noise emitting ships that are passing through their habitats. Figure 10 outlines the habitats of the Gray, Beluga, and Bowhead whales which are dependent on a quiet environment for communication. When compared to Figure 2, shipping traffic is impacting that area more heavily in 2019 than in 2015 and is likely to become even more congested with ships as the sea ice extent in the Arctic continues to decline. Finally, the potential for an oil spill would be detrimental for the ecosystems of the Arctic as the oil would not only harm the organisms in the water, but the oil would get trapped in the ice and would be more challenging to clean up than if it were in a region without ice not only because it is less accessible by parties who would be cleaning it.

3.1.4. Future Initiatives

The future initiatives found in the papers analyzed in this review are the implementation of slow steaming, a possible electrification plan, the use of liquified natural gas instead of conventional fuel, and the modification of ships to use quieter propellors. The benefits of slow steaming are not exclusive to the Arctic as slow steaming would reduce the carbon dioxide emitted into the atmosphere, but carbon dioxide is a well-mixed gas that circulates throughout the atmosphere. Electrification of ships along the northern sea route would allow for reduced emissions, but it would not be economically feasible for shipping companies. The use of liquified natural gas would be beneficial as it would reduce greenhouse gas emissions from 20-30%, but it would not be as environmentally favorable as electric shipping. By retrofitting container ships with quieter propellors similar to what Maersk did in 2015, shipping companies will be able to save money because the propellors are more efficient and require less fuel and will be able to produce less noise while in transit (Duarte et al., 2021).

3.2. Knowledge gaps

As seen in figure 5, there are knowledge gap surrounding the impacts of Arctic shipping on marine life as well as future development to make Arctic shipping less environmentally harmful. There are only 3 papers in this study which analyze the impacts that Arctic shipping has on wildlife and 2 which focus on the future innovation of Arctic shipping. Arctic shipping is a force that is unlikely to be stopped because of how lucrative it is, so it is important to encourage practices which make Arctic shipping more sustainable. Unfortunately, if enough research has not been done to be knowledgeable on the impacts of Arctic shipping on marine life, for example, it will not be possible to implement policies and strategies to limit the impacts. First, research needs to be done to find the impacts of Arctic shipping then policy decisions can be made based on that research to limit the impacts of shipping.

3.3. Limitations

The limitation of this review is the articles used in the analysis. The articles almost exclusively come from Qi et al. (2024) so there is not a diverse set of papers coming from what has been published in recent years. Ideally, this review would use many more sources to get a better idea of all of the literature that exists on the topic, but due to time constraints when writing the review, this was not possible. Had more articles been analyzed, it is possible there would be different sections in the review and different impacts that would have been found throughout the articles analyzed.

3.4. Recommendations for Future Policy

Based on the findings in this paper, it is most important to develop policy which reduces carbon emissions and noise pollution from shipping in the Arctic. As suggested in Savard et al. (2020), electrification is an extremely effective way to reduce the amount of greenhouse gas emissions generated by Arctic shipping. Electrification of Arctic shipping along the proposed Northern Sea Route corridor is prohibitively expensive (Savard et al., 2020). One way this this could be combatted is with the use of a toll for ships that pass through the Arctic and emit carbon emissions. Ideally, this toll would be able to be put in place that would assess ships for carbon emissions they emit while passing through the Arctic. This funding could be used to support the electrification corridor on the Northern Sea Route suggested by Savard et al, (2020). If a tax was put on ships for carbon they released in transit, it would also encourage them to slow down and emit less greenhouse gasses by slow steaming. These practices would discourage environmentally harmful Arctic shipping and help to fund more sustainable methods of shipping within the Arctic and around the globe.

Another policy measure which could help marine life is the reduction of noise pollution in sensitive marine mammal habitats. A maximum speed or decibel rating could be implemented for ships that are passing through animal habitats which are sensitive to noise pollution. The reduction in speed would be beneficial for the wildlife because the shipping would be quieter and it would discourage companies from shipping in the Arctic because it would not be as quick as it once was. If ships are forced to slow down, shipping companies will lose money and be forced innovate in a way that will benefit areas outside of the Arctic. If a limit on the amount of noise pollution that was allowed to be emitted were to be put in place, shipping companies would be motivated to innovate their ships to be quieter at faster speeds.

3.5 Arctic Shipping not Recommended

The papers analyzed in this review come to varying conclusions on whether Arctic shipping can be justified over conventional shipping routes. One paper finds that by 2050, Arctic shipping will account for less than 1% of the black carbon found in the Artic because much of the black carbon comes from lower latitudes where it is generated and settles in the Arctic (Browse et al., 2013). Another article finds that 4.3% to 9.8% of the black carbon and 10% to 20% of the greenhouse gas emissions in two particular areas used for a case study are from shipping (Aliabadi et al., 2015). Many of the papers analyzed in this review find that Arctic shipping economically makes sense for shipping companies, but the environmental downsides outweigh the fuel and time savings of shipping through the Arctic.

4. CONCLUSIONS

Arctic sea ice is declining at a rapid rate and that opens new shipping routes for goods being transported through the Arctic. Shipping companies can reduce the number of miles needed to travel to ship goods between Asia and Europe by over 30% when comparing to the route through the Suez Canal. Shipping in the Arctic has become much more common with the reduction of ice cover in the summer and will only get more popular with ice free summers in the Arctic plausible by the end of the century.

Impacts from shipping in the Arctic range from the emissions from the ships such as black carbon and aerosols to the noise pollution and oil spill risk brought onto the marine life which lives in the Arctic. Black carbon emissions on ice cause a positive feedback loop demonstrated in figure 8 while higher atmosphere black carbon exhibits a cooling effect. Aerosol emissions from ships create a negative feedback loop as they encourage cloud generation upon emission. Gray, Beluga, and Bowhead whales are dependent on the Bering Strait for their livelihoods, but this is shipping corridor that will become busier as sea ice in the Arctic melts and shipping through the Arctic becomes more lucrative. Shipping in these habitats affects the animals because they are dependent on quiet environments for communication, but large cargo ships emit noise pollution which affects the livelihoods of Arctic marine mammals.

Despite the impacts on marine life and the Arctic environment, there are initiatives for the future which can make Arctic shipping less environmentally harmful. These include but are not limited to the use of alternative fuels such as liquified natural gas and batteries for greenhouse gas reduction efforts, the implementation of slow steaming which reduces the fuel used and emissions produced from shipping, and the retro fitment of ships to be quieter and more efficient for the sake of the environment.

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FIGURES

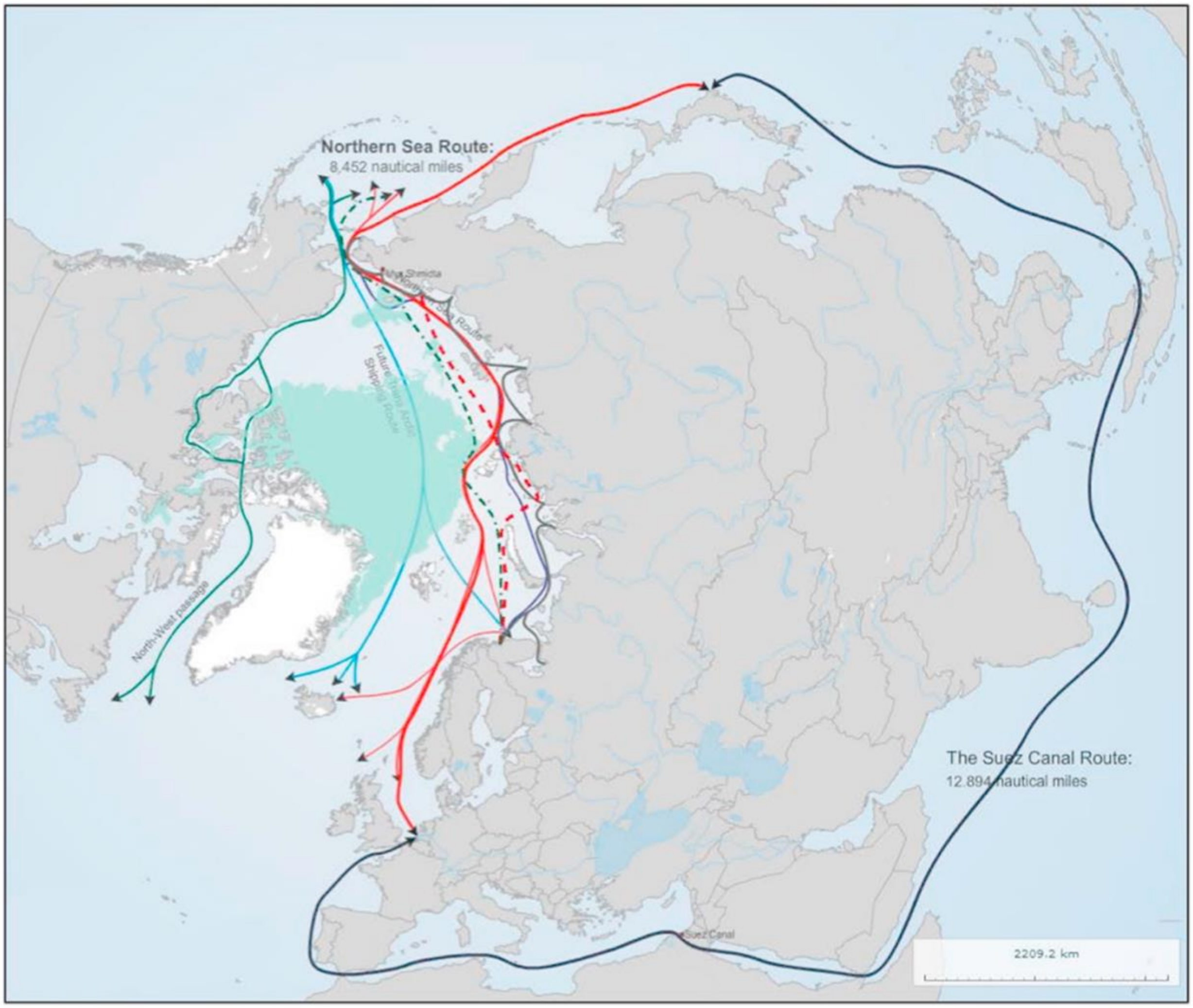

Figure 1. Representation of Northern Sea Route through the Arctic compared to the Suez Canal Route. Figure courtesy of arcticportal.org.

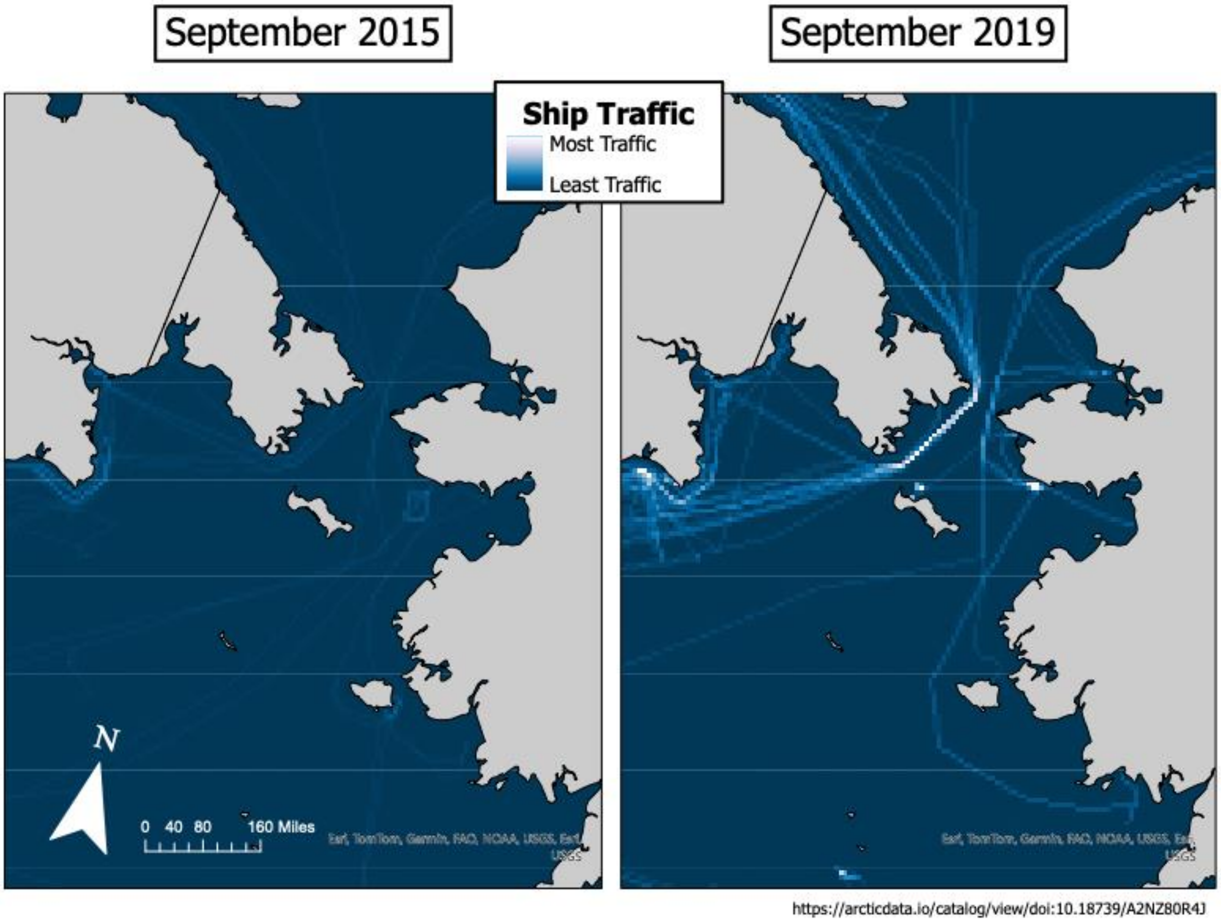

Figure 2. Representation of automatic identification system (AIS) signals received in September of 2015 compared to September of 2019.

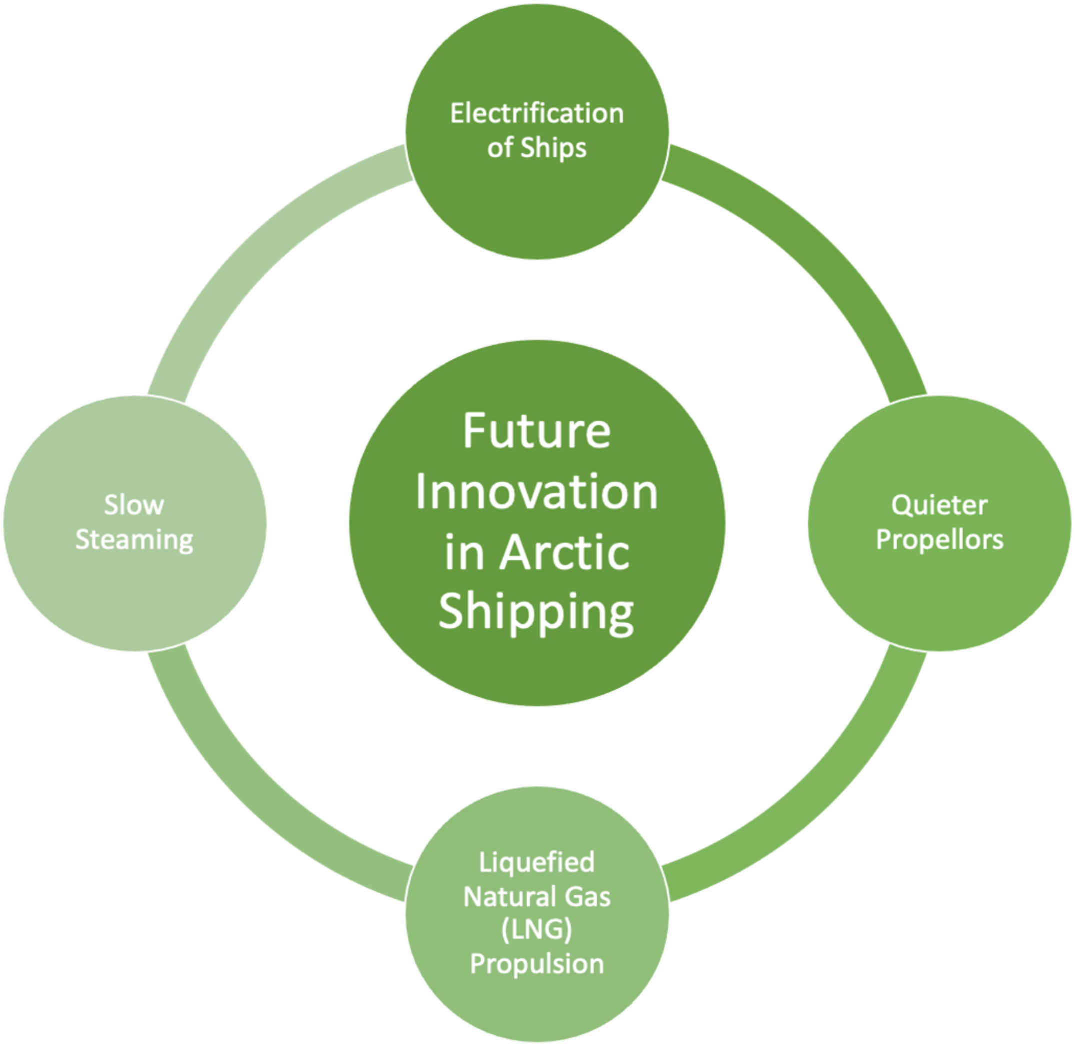

Figure 3. Outlines fields which studies have identified as potential for making Arctic shipping less environmentally harmful.

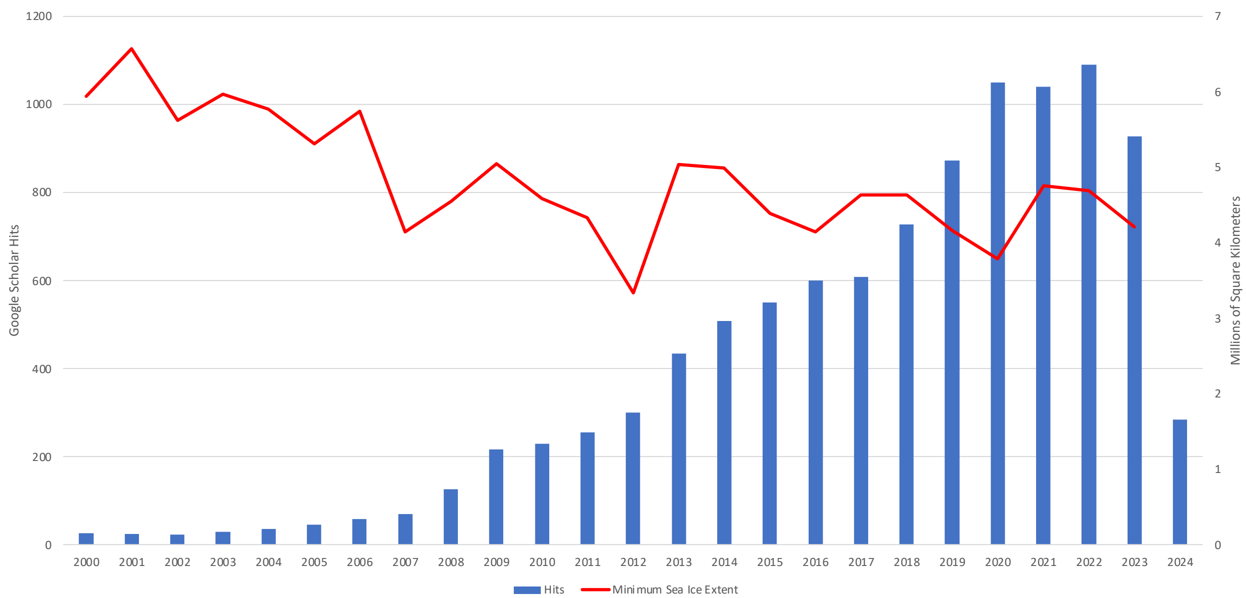

Figure 4. Google Scholar hits when searching for "Arctic Shipping" by year on bar plot (blue) while the minimum sea ice extent in the Arctic in millions of square kilometers on line plot (red). Credit: Sea Ice Index, National Snow and Ice Data Center.

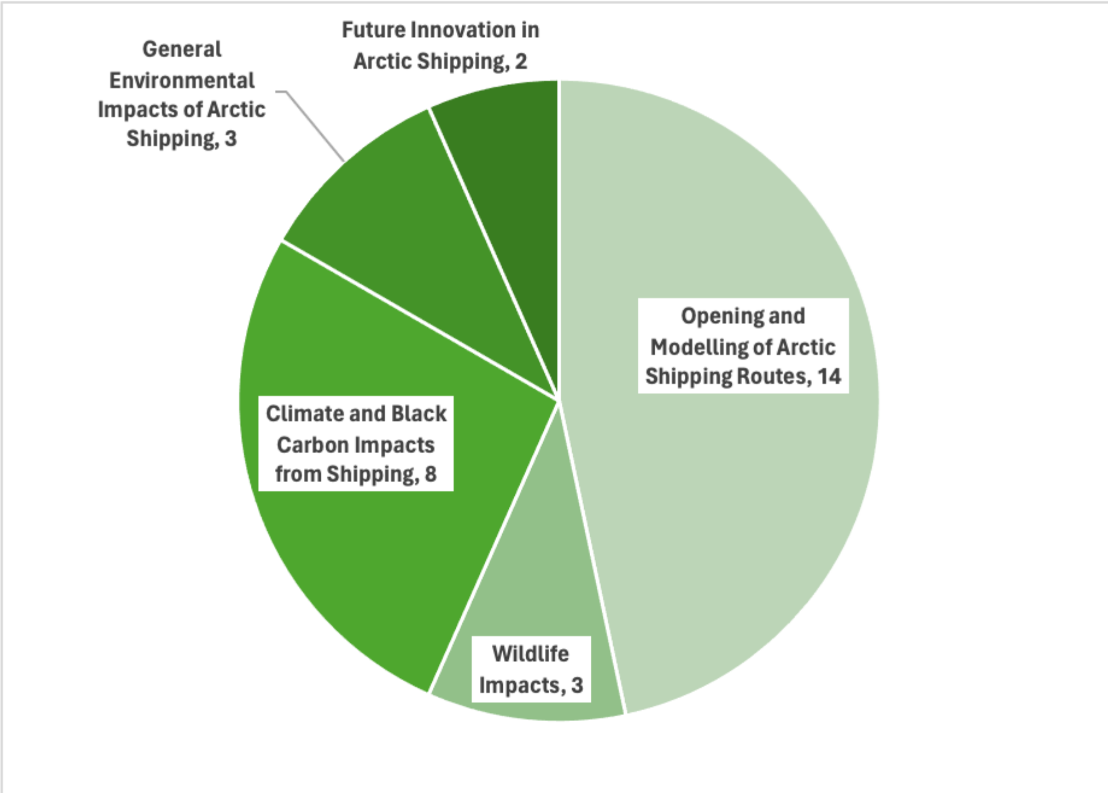

Figure 5. Distribution of articles used in review into categories. The number represents the number of articles in the category.

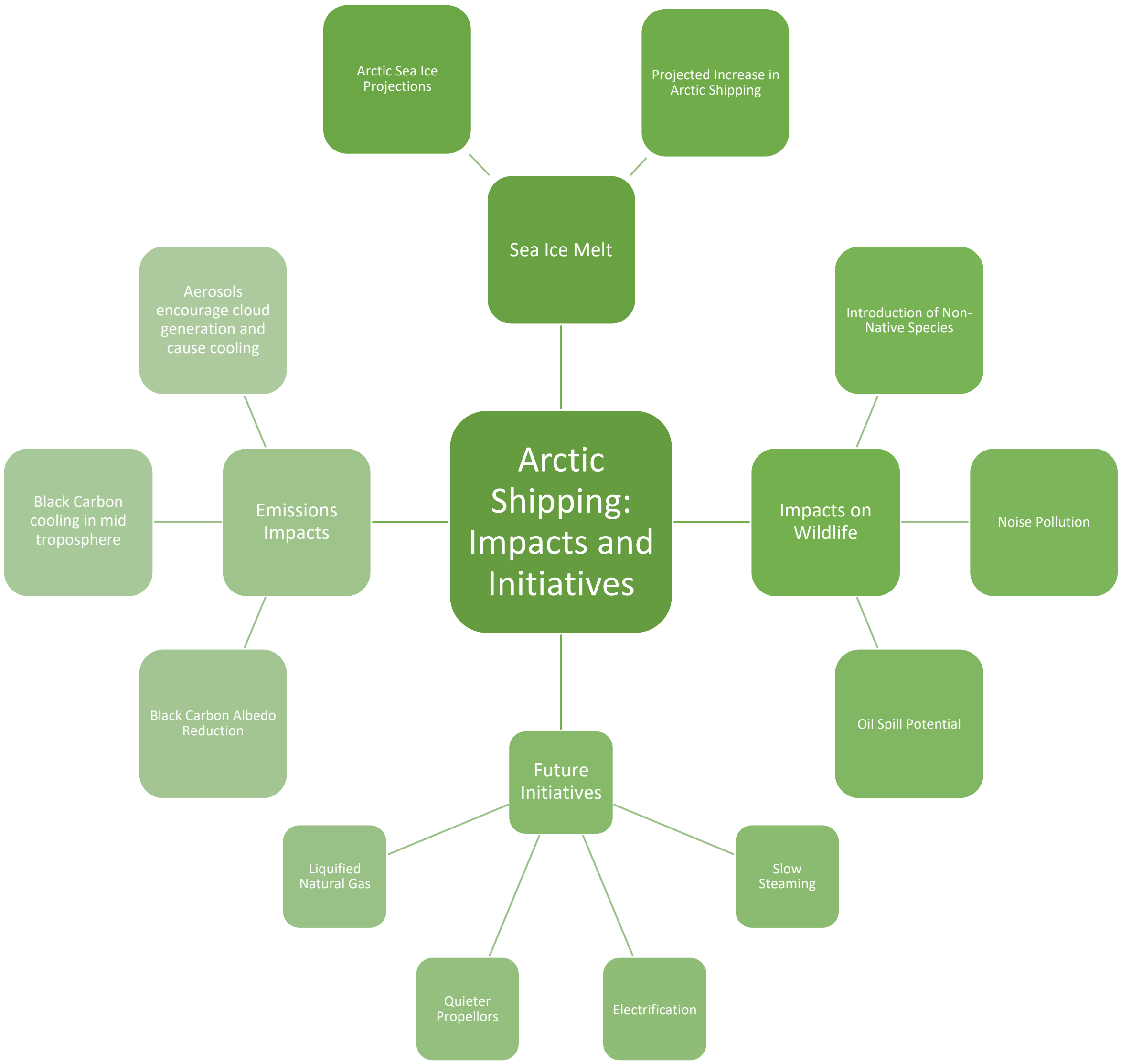

Figure 6. Overview of the structure of the review starting with Arctic sea ice melt and shipping route development (top), followed by emissions impacts and impacts on wildlife (left and right), and future initiatives in Arctic shipping (bottom).

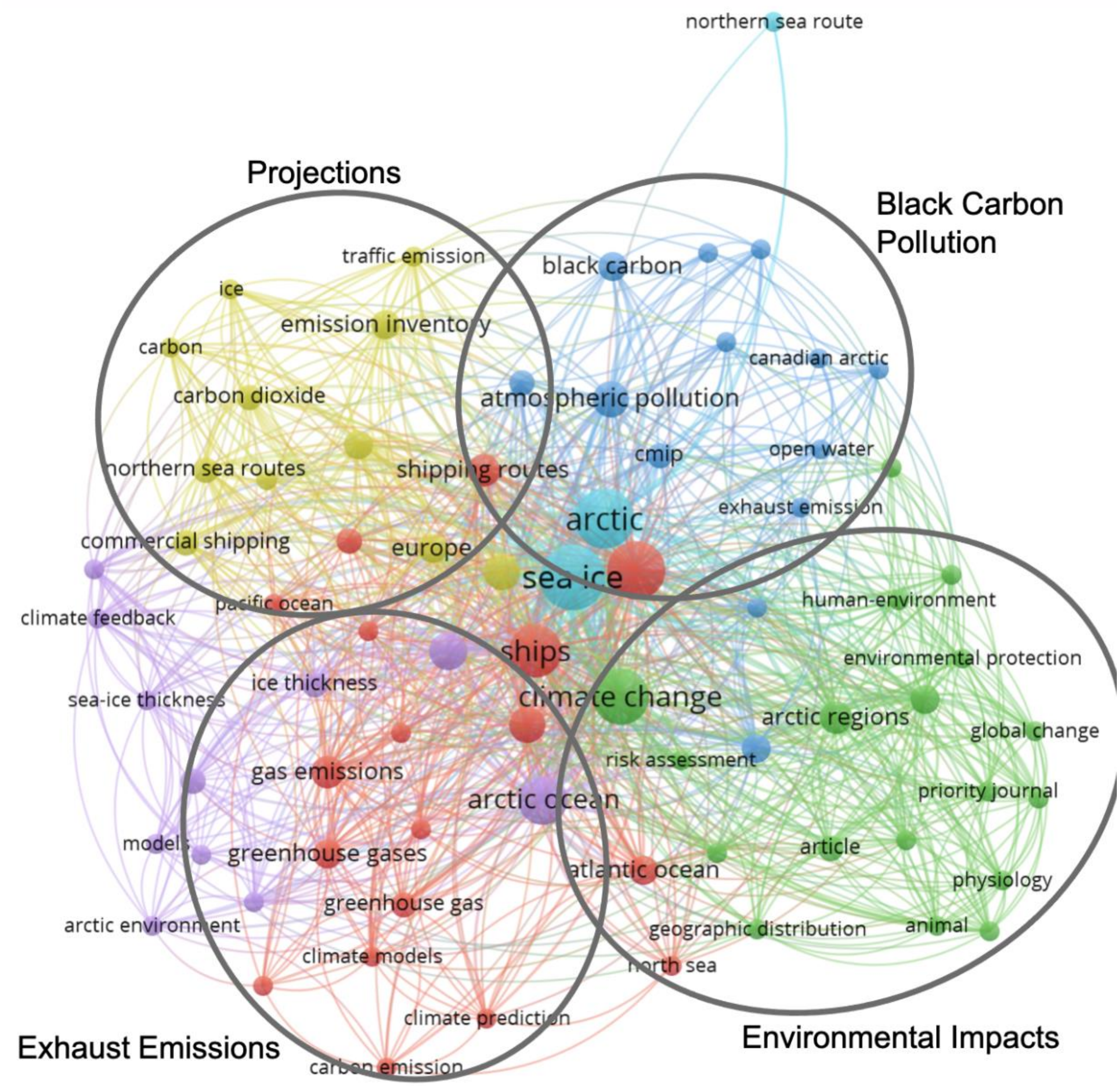

Figure 7. Overview of keywords with more than 1 occurrence across papers analyzed in this review. Circles represent categories which fit the clusters of words.

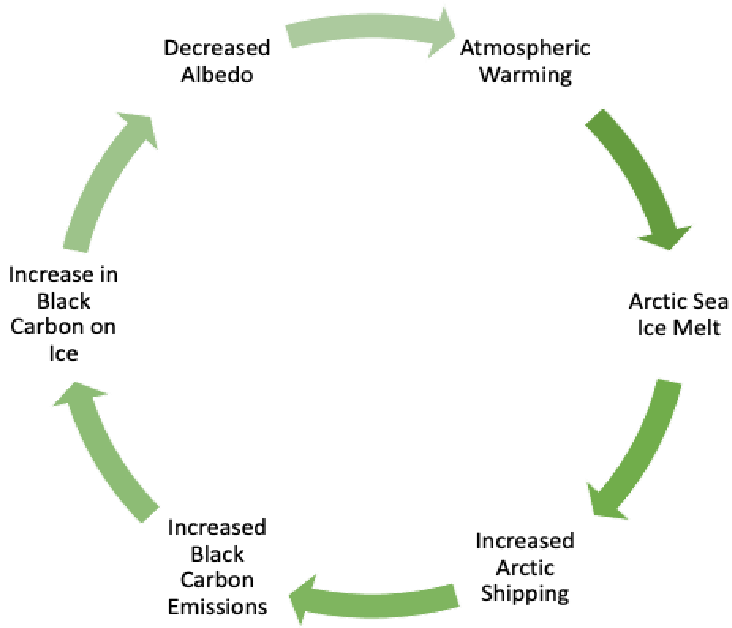

Figure 8. The positive feedback loop exhibited by black carbon emissions from Arctic shipping and the deposition of that black carbon in the cryosphere.

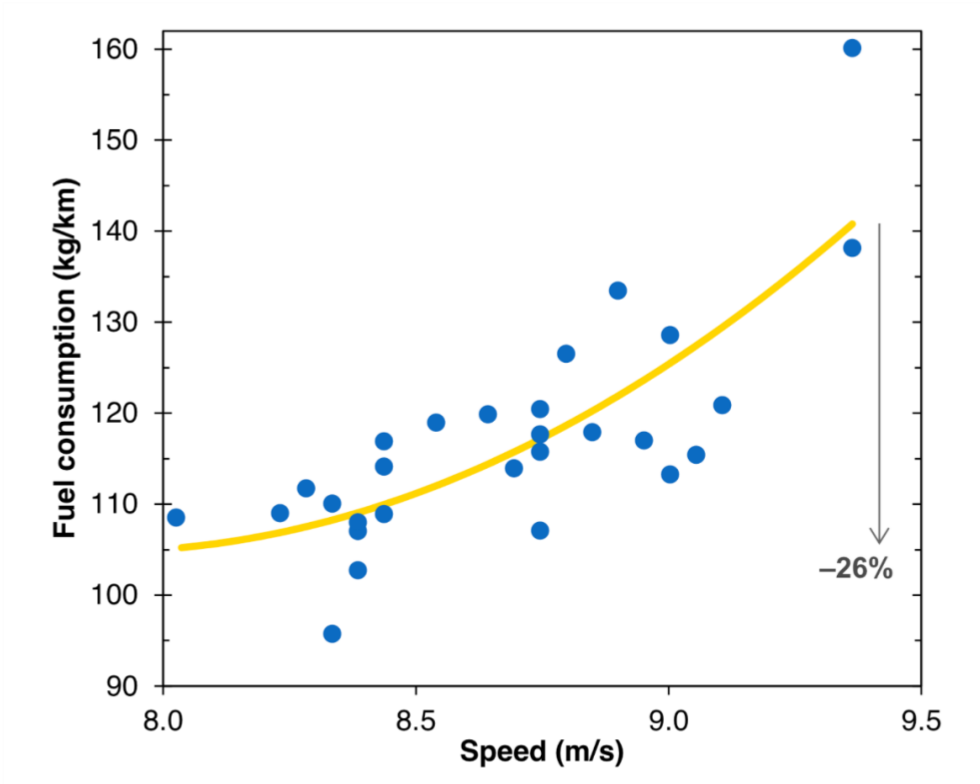

Figure 9. Outlines the reduced fuel consumption benefit of slow steaming. Reprinted from "How to decarbonize international shipping: options for fuels, technologies and policies," by Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., & Staffell, I., 2019, Energy conversion and management, 182, p. 23.

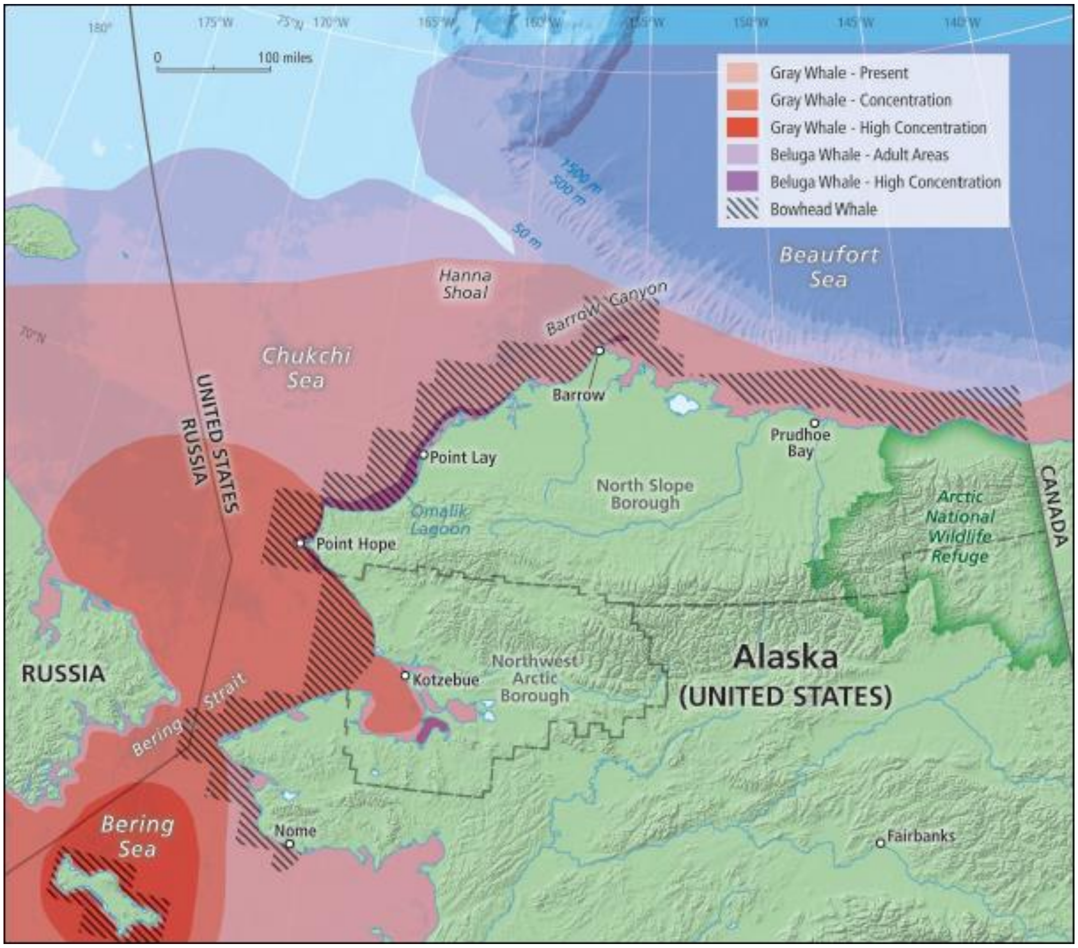

Figure 10. The habitats of whales surrounding the Bering Strait which are dependent on quiet environments for their survival. Reprinted from *Responding to oil spills in the US Arctic marine environment* (p. 53), by National Research Council, Transportation Research Board, Marine Board, Division on Earth, Life Studies, Polar Research Board, ... & Committee on Responding to Oil Spills in the US Arctic Marine Environment, 2014, National Academies Press.