A Climate Change Vulnerability and Data Gap Assessment of Arctic Marine Species in the Tallurutiup Imanga National Marine Conservation Area

by

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Abstract

Arctic ecosystems are warming at twice the rate of oceans worldwide, resulting in a loss of sea ice and available habitat for many marine species. While new conservation policies are required to protect the increasingly vulnerable marine species in Northern Canada, the data gaps associated with Arctic marine ecosystems make it difficult to prioritize which species need to be protected, along with the best methods to do so. This project assessed the vulnerabilities of several cetaceans, pinnipeds, and fish present in the Tallurutiup Imanga National Marine Conservation Area to climate change under the RCP 8.5 emissions scenario to determine which species will be most at risk by 2055. A digital literature review was conducted to obtain life history information for each species, which was then used on two trait-based vulnerability assessment frameworks to determine the risks of climate change related impacts. Results showed that Arctic char, Arctic cod, and Atlantic walrus are most sensitive to climate change with vulnerability scores of 16/16 (Very High), while all other species were given a score of 12/16 (Very High). Cetaceans were found to be the most data rich taxon overall, followed by marine fish and then pinnipeds. The most pressing data gaps include outdated or nonexistent abundance measurements and a lack of natural mortality rates in marine mammals, making it difficult to assess the intensity of anthropogenic disturbances. The creation of more well-defined management groups, coupled with more frequent abundance and population age structure surveys would be beneficial to filling in these data gaps. For fish, a lack of knowledge about reproductive behavior, timing, and locations were the most pressing data gaps, which can be resolved through tracking seasonal movements and observation of suspected areas of importance.

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Chapter 1: Introduction

Section 1.1: Management Problem

As a result of anthropogenic climate change and other disturbances, 25 percent of marine species are currently at risk for extinction in the upcoming decades (Webb and Mindel, 2015). Temperature regimes, ocean acidity, weather patterns, and a myriad of other conditions are shifting away from their typical parameters faster than ecosystems can adjust to (Radchuk et al., 2019). These issues are magnified in Arctic ecosystems, where various geological feedback loops have resulted in the region warming twice as rapidly as anywhere else on Earth (Dai et al., 2019; National Snow and Ice Data Center, 2020). Climate change related ecosystem degradation in the Arctic is further compounded by an expected rise in potentially disruptive human activity as sea ice melts and more of the region becomes accessible to fisheries, shipping, and fossil fuel exploration (Burek et al., 2008; Crepin et al., 2017; Stroeve and Notz, 2018). Arctic marine species are becoming increasingly at risk from the combination of these disturbances, due to their inability to reproduce fast enough, or having specific habitat requirements that are being damaged as well (Moore and Huntington, 2008; Einum et al., 2008; Laidre et al., 2015).

To help mitigate the negative impacts of climate change, marine managers and government entities can employ spatial protection around key habitats for vulnerable species (McLeod et al., 2008). Marine protected areas are government designated and regulated ocean spaces with clearly defined borders and regulations (Laffoley et al., 2019). Created with predefined objectives on which and how much of a species or other natural resource to protect, MPAs vary in size, restricted activities, and the intensity of said restrictions (Fisheries and Oceans Canada, 2020). While MPAs exist in all three of the Oceans in Canadian territory, the Canadian Arctic is becoming an attractive option to create new ones, due to the benefit for Northern communities and an opportunity to establish protections before more human activities become established there (Gibbens, 2019). The Eastern Canadian Arctic bioregion in particular exhibits a high density of protected islands and MPAs (Parks Canada, 2019). Canada and other countries have shown commitment to future MPA development through the Aichi targets, a series of goals that include protecting at least 10 percent of coastal and marine areas (Convention on Biological Diversity, n.d). However, restricting other uses of ocean spaces often brings the creation of MPAs into conflict with other stakeholders that wish to use the same space for their own benefit. While minimizing damage to these environments would involve protecting all threatened marine habitats, compromises usually need to be made with other parties (Artis et al., 2020).

To help determine which species are in most need of protection and which can afford to lose additional habitats, vulnerability assessments can be conducted regarding various stressors (Reece et al., 2018). For the purposes of these assessments, vulnerability is defined as a combination of the exposure, sensitivity, and adaptive capability of habitats or species to current and future threats (Reece et al., 2018). All vulnerability assessments share the same goal of identifying future stressors and their intensities, but a variety of frameworks and required information exist to facilitate this (Morgan, 2011). One such method that has been gaining in popularity in recent years is known as trait-based vulnerability assessments. This framework type takes into account the life history strategies and characteristics of the species as a whole to determine how readily they can adapt to a rapidly changing climate and identify those that are too specialized or too slow in breeding to do so (Spencer et al., 2019).

Despite a pressing need for further protections to be placed in Arctic marine ecosystems, the difficulties associated with performing research in polar regions makes it difficult to research animals as effectively as in other parts of the world. The remote nature of the Arctic, current impassibility of sea ice, harsh weather, and the general elusiveness of many marine species in general makes it difficult to directly observe the life history requirements of animals in the region (Schlosser et al., 1997). This has resulted in the knowledge that Arctic marine wildlife is in decline, but the extent of which this is happening and intensity of vulnerability for each species is not completely known (Roff et al., 2021). Even in the relatively well-studied Eastern Canadian Arctic bioregion, data gaps exist for priority species (Niemi et al., 2019). As MPA design consists of balancing human stakeholder activity with habitat essential for various marine species, it is important to know which species can tolerate habitat loss or can thrive in multiple areas, and which require a minimum amount of undisturbed area or unique, irreplaceable physical features (Carr, n.d).

Section 1.2: Research Aims and Objectives

As stated before, a major issue associated with marine conservation in the Canadian Arctic is the lack of information regarding which species are most at risk, and how they are at risk. This project aims to address these issues through a multi-faceted, research-based approach to highlight where future Arctic conservation efforts should be prioritized. The first goal is to identify which species are most vulnerable to climate change relative to one another through trait-based vulnerability assessments. These assessments will be performed with the aid of pre-existing vulnerability assessment frameworks and extensive literature review on the life history requirements of each species. Along with this, the quality and amount of data found will be assessed for each species. If sufficient information is lacking for proper vulnerability assessments, the second goal is to analyze the gaps in data-poor species and identify what information needs to be found to support future assessments. From there, recommendations for future research will be discussed. As climate change is a global phenomenon that cannot be fully addressed through localized policy implementation, suggestions for directly addressing its impacts on these species are expected to be limited, with the focus remaining on the assessments and information gathering themselves.

Chapter 2: Methodology

Section 2.1: Study Area

Due to the extreme variability between both current and projected conditions of marine environments around the world, it is often unfeasible to perform species vulnerability assessments on a global scale (Patt et al., 2015). Instead, vulnerability assessments are typically limited to well defined geographic regions, such as archipelagos, marine protected areas, or other locations with defined boundaries (Wilson et al., 2020; Sousa et al., 2021). While risk assessments have been performed that consider the broader Arctic Ocean (Laidre et al., 2008), complications can arise when having to simultaneously consider the specific needs of multiple sub-populations of the same species. To avoid this and help guide future management decisions for Canadian waters, the Tallurutiup Imanga National Marine Conservation Area (TINMCA) was selected to be the study area for this project. This region was selected as a case study due to the wide variety of species expected to be impacted by climate change that inhabit the area (WWF, 2011). The area’s high profile and conservation interest compared to other Canadian Arctic marine spaces makes it a highly relevant space to consider when discussing marine protected areas in the Arctic and their future research needs.

At 44 300 km^2, the Tallurutiup Imanga National Marine Conservation Area encompasses the waters starting at the edge of Western Baffin Bay to the east and ending to the northwest of Somerset Island (Figure 1). Along with the main body of the Lancaster Sound, the TINMCA comprises a central system in the Lancaster sound and multiple offshoots of channels and bays. Along with the main system that runs between Devon Island and Baffin Island, the TINMCA extends north and south into the large number of channels and inlets that line the islands of Nunavut. The northern reaches of the area extend to the south of Ellesmere Island and adjacent to the Jones Sound, while the southern portions extend into mainland Baffin Island (Parks Canada, 2019).

While large sections of the Arctic Ocean are generally unproductive, the Lancaster Sound's main channel is known to be one of multiple primary production hotspots in Northern Canadian waters (Tremblay et al., 2018). This primary production is driven largely in part by the large seasonal polynya that forms between Northwestern Baffin Island and Southern Devon Island (IBA Canada, n.d). A common and important feature in marine Arctic ecosystems, polynyas are large patches of open ocean surrounded by thick landfast or sea ice (NSIDC, 2020). Within the Tallurutiup Imanga NMCA, its polynya typically forms from June until September, as a result of latent heat transfer and wind movement that keeps ice from forming over it (IBA Canada, n.d). Within the polynya, there is a high concentration of nutrient upwelling that supports mass planktonic growth (Jones and Coote, 1980; Tremblay et al., 2018). As a result of these unique conditions, the region is a large hotspot for Arctic marine biodiversity. The access to nutrient rich waters and sheltered ice structure provides feeding grounds for marine mammals, fish, seabirds, and polar bears. In addition to the diverse trophic web support, the ice obligate and ice associated marine mammals native to the Arctic are provided refuge from rising predation by orcas, a species that is steadily moving farther north into non-native waters (Higdon et al., 2012; Laidre et al., 2015; Lefort et al., 2020).

Along with the area's current value to biodiversity, the Lancaster Sound's presence will become increasingly more important as sea ice continues to retreat. By 2030, the Arctic is expected to be ice free during the summer, with the remaining patches confined to the Canadian Arctic Archipelago (AMAP, 2017). After that, this "Last Ice Area" will become the only region with consistent sea ice coverage suitable for the life history processes of many Arctic species, drawing the attention of conservation groups who highlight the need for its protection (WWF, n.d). As the Lancaster Sound is on the southern edge of the projected Last Ice area, it will become exposed to the ice-free waters and any disturbances that lie within them (AMAP, 2017).

In addition to the species rich waters and ice of the area, the Lancaster Sound Conservation area contains and is adjacent to multiple other national parks and sanctuaries (Table 1).

Table 1. A list of protected areas recognized through legislation in the Tallurutiup Imanga National Marine Conservation area, along with the species they aim to protect.

Protected Area	**Notable Conservation Features**
Nirjutiqavik National Wildlife Area	Thick-Billed Murre, Black-Legged Kittiwake, Polar Bears, Walrus, Beluga, Narwhal, Seal populations (Parks Canada, 2019).
Prince Leopold Migratory Bird Sanctuary	Thick-Billed Murres, Northern Fulmar, Black-Legged Kittiwake, Black Guillemot, Narwhal, Beluga, Bowhead, Walrus, Seal populations (Parks Canada, 2019).
Sirmilik National Park	Narwhal, Beluga, Polar Bear, Walrus, Ringed Seal (Parks Canada, 2021).
Bylot Island Migratory Bird Sanctuary	Thick-Billed Murres, Black-Legged Kittiwake, Polar Bear (Parks Canada, 2019).

While it is located outside of the Lancaster Sound's boundaries, Qausuittuq National Park is in close proximity to the TINMCA and should be noted for its species conservation services. Although it is primarily known for its populations of endangered Peary Caribou, the waters surrounding the islands are known to contain polar bears, walrus, beluga, narwhals, and seals. Along with wildlife, the presence of both Inuit and British artefacts makes the area valuable for archaeological research (Parks Canada, 2017). As it is relatively close to the productive waters within the Sound, it is likely there is marine mammal and seabird travel between the two areas, so it is worth mentioning in the context of this study (Parks Canada, 2017).

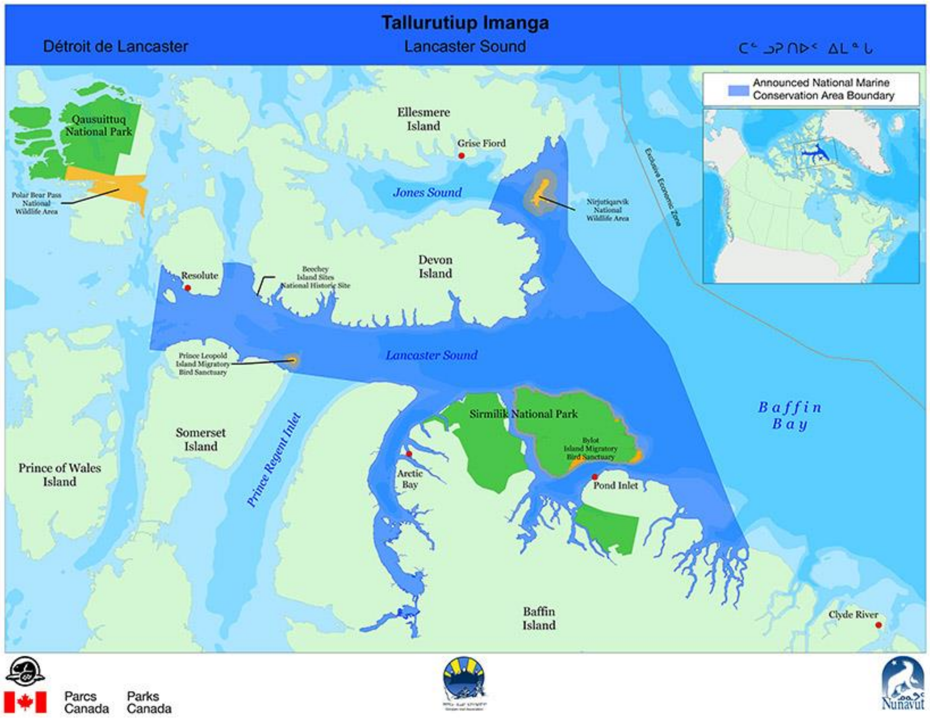


Figure 1. Map detailing the boundaries of the Tallurutiup Imanga National Marine Conservation Area, along with other national parks, wildlife sanctuaries, and communities in the region (Parks Canada, 2019).

Section 2.2: Species Selection

The species discussed and evaluated in this paper were selected to ensure that a wide variety of habitat needs, stakeholder values, and expected threats were represented. Therefore, 3 generalized functional groups of 3 species each were selected, each with varying physiologies and life history requirements (Table 2). A single species per category would not allow for intra-group comparison, and any extremes in a species vulnerability to a specific threat may not be representative of the whole functional group, which would bias results. Each species was also required to have a prominent presence within the Tallurutiup Imanga NMCA and have evidence that they use the area for various life history functions. Finally, each species has been noted as a priority for future conservation initiatives by reputable advocacy groups. While priorities may vary between different groups, each of the species mentioned in Table 2 were noted as a species of interest in the World Wildlife Fund's CanPAC report, a study published in 2021 highlighting various needs for future Arctic marine protection (Roff et al., 2021). This shows that each species selected has a preexisting conservation interest and will be more likely to be included in future management decisions. The species that were selected for this project are as follows:

Table 2. The 9 species to be discussed in this project categorized into 3 general functional groups.

Cetaceans	Pinnipeds	Marine Fish
Beluga (*Delphinapterus leucas*)	Ringed Seal (*Pusa hispida*)	Greenland Shark (*Somniosus Microcephalus*)
Narwhal (*Monodon monoceros*)	Bearded Seal (*Erignathus barbatus*)	Arctic Char (*Salvelinus alpinus*)
Bowhead Whale (*Balaena mysticetus*)	Atlantic Walrus (*Odobenus rosmarus*)	Arctic Cod (*Boreogadus saida*)

Section 2.3: Vulnerability Assessment

The vulnerability assessment portion of this project has been conducted using three different frameworks found via literature review. Cetaceans and pinnipeds share the same framework, while marine fish and sea birds follow their own separate approaches. Each vulnerability assessment was divided into two parts, sensitivity, and exposure. Sensitivity refers to the various life history traits of a species, such as diet or reproductive requirements, that may make them more vulnerable to climate change related decline. Exposure refers to the physical changes in the environment, such as in water temperature or salinity, that the species will be exposed to in a specified timeframe. To keep the timeframe appropriate for a marine management context and consistent with the frameworks' original publications, the timeframe is set to 2006-2056. This timeframe allows for enough future uncertainty that predicted vulnerability assessments are required but is close enough that preparatory management strategies could feasibility be implemented in the present day (Lettrich et al., 2019). On a species-by-species basis, sensitivity and exposure traits were scored into intensity bins, each graded from low (1) to very high (4) reflecting how strongly that trait impacts the species' chance for survival through climate change (Appendix A, Appendix B).

Section 2.3.1: Marine Mammals

The vulnerability framework used for cetaceans and pinnipeds was produced by Lettrich et al in 2019 for use by the National Oceanic and Atmospheric Association (NOAA), National Marine Fisheries Service (NMFS), and the United States Department of Commerce (USDOC) (Appendix A). Created with the intention for application to various ocean ecosystems, marine mammal sensitivity was defined with the following 11 criteria, each of which having the same 4 bins of intensity (low, moderate, high, very high):

Prey/Diet Specificity:

Species with a high variety in diet/prey preference are more likely to adapt to changing environmental conditions than those that specialized towards specific sources (Anouschka et al., 2012). Even if a species itself is tolerant of changing conditions, relying on prey that will decline from climate change may result in an area no longer being suitable to inhabit (Kortsch et al., 2015). Species with specialized diets will either need to follow their prey to new locations, adapt to consume other species, or starve and be extirpated from the area.

Habitat Specificity:

Species with a high dependency on specific habitat features are more likely to be disturbed through rapid environmental changes or anthropogenic disturbances to their environment than those that can live anywhere (Silber et al., 2017; Hashida et al., 2020). This is particularly evident in species with specific requirements for mating, birthing, or raising offspring, as a loss in suitable habitat would severely impede population stability and recovery.

Site Fidelity:

Site fidelity refers to the propensity of an individual or group of animals to either remain within the same area indefinitely, or to return to an area to carry out various life history functions (Greenwood, 1980). Species with high site fidelity, such as a preference for a specific bay or estuary, are more susceptible to disruptions than those with no fidelity. The degradation of an area important to a species' life history, such as a breeding or calving ground, may render that population unable to carry these processes out (Gonzalvo et al., 2013).

Lifetime Reproductive Potential:

Rather than a single criterion like the rest of the sensitivity traits, lifetime reproductive potential was determined using a matrix with two reproductive characteristics of female members of the species being considered. Due to lengthy pregnancies and calving periods in which they cannot mate again, female reproductive characteristics are the rate limiting factor, rendering male-specific details irrelevant (Gerlach et al., 2012).

The first Characteristic considers breeding interval, the average amount of time between calves born. Species with a shorter breeding interval are typically less susceptible to population decline, due to their numbers being replenished more frequently and a higher likelihood of adaptations to changing conditions occurring (Parry et al., 1981; Hoffman and Sgro, 2011).

The second characteristic, reproductive lifespan, was determined using one of two methods. If the females of the assessed species have been shown to experience reproductive senescence, the age associated decline of reproductive success and activity, then reproductive lifetime was determined by subtracting average female sexual maturity from the average age of senescence onset (Ward et al., 2009). Otherwise, the reproductive lifetime was determined by subtracting the average age of female sexual maturity with the average lifespan. A lack of literature regarding a species' females' reproductive senescence resulted in the assumption that it does not occur for the sake of simplicity.

Generation Length:

As largely K-selected species defined by lengthy offspring development and late sexual maturity, marine mammals are relatively slow breeders when compared to other taxa (Lockyer, 1981). Generation length refers to "…the average age of parents of the current cohort, reflecting the turnover rate of breeding individuals" (Pacifici et al., 2013). Species with longer generation lengths will have a lower population growth and adaptation rates, making them more susceptible to climate change and other disturbances (Silber et al., 2017).

Reproductive Plasticity:

Reproductive plasticity refers to the ease of which a species or population can alter their reproductive habits depending on their unique situations (Lettrich et al., 2019). Species with narrow timeframes for mating and calving, require specific habitat conditions, or significant preparatory behaviour are more likely to have their reproduction disturbed by climate change (Bronson, 2009).

Migration:

Migration refers to the consistent seasonal or annual large-scale movements of a population to reach an area more suited for various life history processes (breeding, feeding, etc.,) or to temporarily escape predictable but unsuitable environmental conditions (Dingle and Drake, 2007). Lettrich et al admits that this trait is the most difficult to assess regarding its effect on marine mammals exposed to climate change, but it is known that highly migratory species are more likely alter their distribution and adapt in response to climate change than species that remain in the same area year-round. (Lisovski et al., 2020).

Populations with multiple migration corridors are at less of a risk of travel interruption than those with only one (Moore, 2011).

Home Range:

Species with large suitable home ranges, up to entire ocean basins, will be less affected by habitat degradation in any particular area, due to their proven ability to inhabit various habitats across large distances (Beyer and Manica, 2020).

Stock Abundance:

The higher a species population is, the less likely that it will go extinct from climate change or anthropogenic impacts. Furthermore, every species and subpopulation has a limit on how far their numbers can decline, known as a “minimum viable population”. Once a population is reduced below this number, it faces a decline in reproductive success as a result of a failure in density dependent reproductive habits or a loss in genetic diversity which increases the chance of extirpation or extinction (Nunney and Campbell, 1993; Wang et al., 2019). For this framework, only stock abundance measurements from within the past 10 years will be considered (Lettrich et al., 2019).

Stock Abundance Trend:

Species already experiencing population loss from either natural or anthropogenic stressors have an increased likelihood of experiencing unsustainable loss from climate change (Lettrich et al., 2019). The causes of preexisting population loss and feasibility of their solutions can vary drastically between species and will be considered in the cumulative stressors sensitivity trait.

Cumulative Stressors:

The deleterious impacts from climate change do not exist in a vacuum, and species are often exposed to other threats as well. While some of these are natural, such as predation pressure, multiple non-climate cumulative stressors are often anthropogenic as well. Stressors including ship traffic, oil exploration, and fishery activity are expected to increase as waters warm and sea ice recedes, but this category only considers stressors currently affecting the populations being assessed (Morgunova, 2020; Mudryk et la., 2021). A stressor is considered significant enough to include if it either accounts for 10% or more of the population’s total annual mortality, or affects at least 50% of the total population, if it is a non-lethal impact.

(Lettrich et al., 2019.)

Section 2.3.2: Marine Fish

The sensitivity framework for marine fish and invertebrates was designed by Hare et al in 2016 (Appendix B). While its primary use is for the assessment of continental shelf species in the Northeast of the United States, the sensitivity traits are universal to fish and invertebrates across the globe, and the original assessment examined species that can be found in Arctic waters, such as Sand Lance and Atlantic Cod. The sensitivity traits used for this framework are split into the same 4 intensity intervals as marine mammals (low, moderate, high, very high) and are described below.

Habitat Specificity

Similar to marine mammals, species with fewer specific habitat requirements are less likely to be vulnerable to environmental decline than those with preferred conditions. Examples of specific habitat requirements in fish include sediment types, reefs, and proximity to continental shelves (Koslow et al., 2000; Holland et al., 2005; Brooker et al., 2013).

Prey Specificity

Marine fish is a more diverse and general functional group than cetaceans or pinnipeds, and therefore has a higher diversity of physiologies and foraging strategies (Ellis et al., 2009; Engelhard et al., 2013; Murphy et al., 2016). However, the logic is same as marine mammals for climate sensitivity. Species that can consume more types of prey will be less likely to be impacted than specialized species if the lower trophic chain is affected by climate change.

Adult Mobility

Species whose adult stages are highly mobile are more likely to be able to escape unfavorable environmental conditions and enter more favorable regions. Species with limited movement capabilities are more likely to be trapped in a specific area, even if environmental parameters become unsuitable for them (Coni et al., 2021).

Dispersal of Early Life Stages

Depending on the species' reproductive strategy and development of sub-adult stages, the amount of time that young can remain in the water column before recruitment into an area can vary (Wellington and Victor, 1989). Higher recruitment potential across larger areas is associated with a species' potential to colonize new areas and avoid extinction should their old habitat become unsuitable (Hilario et al., 2015; Bashevkin et al., 2020). Gametes within the water column, planktonic larvae, and live births from highly mobile species are all often acknowledged to have higher dispersal potentials than eggs and offspring restricted to the benthic environment (Seraphin and Holand, 2006; Riginos et al., 2011; Bashevkin et al., 2020). Dispersal potential is considered by the amount of time between egg laying and the absorption of the offspring's neonatal yolk sac (Hare et al., 2016).

Early Life History and Settlement Requirements

Fish species are often significantly different physiologically than their adult cohorts and may require different but specific environmental conditions to survive and develop into adulthood (Ramos et al., 2006). Examples of significant parameters include temperature, salinity, depth, and shelter from predators (Hannan et al., 1998; Feng et al., 2021) Species that require specific conditions during early life history stages are more likely to be disturbed from climate change, disrupting population growth, reproduction dynamics, and area recruitment (Levin, 1994; Ruesch et al., 2012; Cominassi et al., 2019).

Complexity in Reproductive Strategy

Species that require specific environmental conditions or significant preparatory behaviors prior to reproduction are more likely to be impacted by climate change than those that require few prerequisites for successful mating. Complexities include large migrations to specific locations, such as with salmonids, or density dependent mass spawning events that require large numbers of the species to participate at the same time (Haas et al., 2016; Erisman and Rowell, 2017).

Spawning Cycle

Those that can spawn throughout the year are at a lower risk of disruption to their reproductive success than those with mating opportunities lasting for a season or even just weeks long (Asch et al., 2019). Species with limited timeframes for mating are often dependent on specific environmental cues, such as temperature, migration to specific locations, or a large number of cohorts in the same area at the same time, all of which are vulnerable to climate change (Danilowicz, 1995, Lowerre-Barbieri et al., 2011 Erisman and Rowell 2017).

Sensitivity to Temperature

Depending on a given species' typical habitat preferences and distribution, the total range of temperatures that they can tolerate can vary (Wolfe et al., 2020). Common reactions to excessive heat exposure in fish species include physiological stress and a lowered immune system efficiency (Badr and Alfons, 2019; Alfonso et al., 2020). If no data for temperature tolerances are available, the original framework states that the species' distribution can also be used as a proxy. Using the map of defined ecoregions and provinces created by Spalding et al. (Appendix C) species that occur across more of these ecoregions are more likely to have a larger range of tolerable temperatures (Spalding et al., 2007).

Sensitivity to Ocean Acidity

While not as apparent as the impacts on corals and other calcareous animals (Taylor et al., 2015; Mollica et al., 2018), a rise in Carbon Dioxide driven ocean acidity can have a variety of deleterious effects on exposed fish populations. Common impacts of excessively low water pH include larval developmental disruptions (Stiasny et al., 2016; Rossi et al., 2018), damage to sensory organs (Simpson et al., 2011), and alterations to predator avoidance behaviours (Dixson et al., 2009). For this framework, a species is also considered sensitive if it relies on prey that is also sensitive to ocean acidification.

Population Growth Rate

Species that exhibit a high population growth rate will be more likely to recover from various disturbances and produce offspring with adaptations to changing environmental conditions than those with a slower growth rate (Beukof et al., 2019). It also allows for a higher sustainable catch amount if the species are a fishery species and can reproduce faster than they are being harvested (Fisheries and Oceans Canada, 2021). The vulnerability of a given species regarding its growth rate was determined through its intrinsic rate of growth, natural mortality rate, maximum age, age of sexual maturity, and a von Bertalanffy K value. Knowing any one of these variables was deemed enough to properly assign a sensitivity score.

Stock Size

Like growth rate, high fish species populations will allow for a greater amount of biomass lost through harvesting or other stressors before complications arise (Hilborn et al., 2020). Species with density dependent reproduction or other social activity will also benefit from high populations in an area and are more likely to adapt to changing conditions (Jorgensen and Fiksen, 2010; Eikeset et al., 2016).

Other Stressors

Similar to marine mammals, the marine fish framework takes into account stressors outside of climate change related impacts as well. Any other significant stressors will likely impact the species' ability to rebound from population decline and adapt to changing conditions (Gissi et al., 2021). However, unlike the marine mammal framework, there is no minimum percentage of the population that needs to be impacted before a stressor is considered significant enough to include. Therefore, any non-climate change related threat on a species' population in the Eastern Canadian Arctic will be included if it is found in literature produced within the last 10 years. Additionally, as the original framework considers a lack of known stressors to mean no stressors, data quality will still be considered high if there is no literature to suggest the presence of stressors for the fish species in question (Hare et al., 2016).

Section 2.3.3: Exposure

Coupled with sensitivity trait analysis, a second set of criteria was measured to determine overall vulnerability. The second category, exposure, refers to how much various environmental parameters have changed by 2055 under the RCP 8.5 emissions scenario. The RCP 8.5 trajectory is considered "business as usual," and is a result of no action being taken to limit greenhouse gas emissions. This is projected to result in a global temperature increase of 1.4° C to 2.6° C by the year 2065 (IPCC, 2014). Along with temperature, numerous other environmental parameters are expected to change, many of which can impact marine mammal and fish populations (Table 3, Table 4). Each exposure factor was also scored into 4 intensity bins (low, medium, high, very high) (Appendix D).

Table 3. Exposure factors for the marine mammal vulnerability framework (Lettrich et al., 2019).

Marine Mammal Exposure Factors
Sea Surface Temperature
Air Temperature
Precipitation
Salinity
Ocean Acidification
Sea Ice Cover
Dissolved oxygen
Ocean Circulation
Sea Level Rise

Table 4. Exposure factors for the marine fish vulnerability framework (Hare et al., 2016)

Marine Fish Exposure Factors
Mean Ocean Surface Temperature
Mean Ocean Surface Salinity
Mean Air Temperature
Mean Precipitation
Mean Ocean pH
Variability in Ocean Surface Temperature
Variability in Ocean Surface Salinity
Variability in Air Temperature
Variability in Precipitation
Variability in pH
Sea Level Rise
Ocean Currents

While the marine fish framework considers both a change in variability and a change in mean of exposure factors, the marine mammal framework only considers whichever is placed into a higher intensity bin (Hare et al., 2016; Lettrich et al., 2019). To determine the intensity of each exposure factor, predictive maps generated by the National Oceanic and Atmospheric Administration's climate change web portal were analyzed (Appendix E). These maps display the changes in mean and variability of each climate exposure factor by the year 2055 (NOAA, 2014).

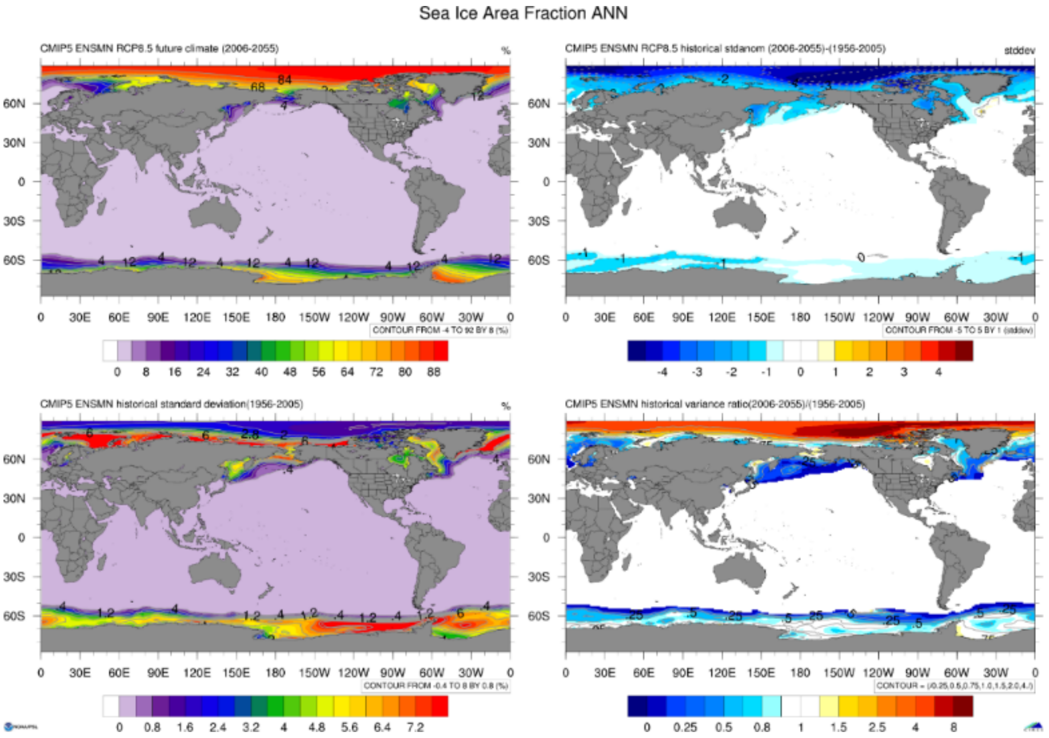


Figure 2. Sample output maps from the NOAA's climate change web portal detailing changes in sea ice coverage between two time periods, (1956-2005) and (2006-2055) (NOAA, 2014).

From the four maps generated by the climate change web portal, the top right is used to analyze the change in mean, while the bottom right is used to show the change in variability (Lettrich et al., 2019). The two maps on the left are not used for this project but were left in for completeness.

These exposure parameters were originally selected due to their potential to exacerbate the sensitivity traits for both marine mammals and marine fish as outlined above in their respective sensitivity analysis frameworks. Most of the threats produced from these changing parameters are a decline in habitat quality, decline in prey populations, and direct behavioral or physiological changes (Hare et al., 2016; Lettrich et al., 2019). If other threats tangentially related to climate change, such as vessel traffic or industrial pollution, exist for a specific species, it will be included in the species' respective *cumulative stressors* section (Hare et al., 2016; Lettrich et al., 2019).

Section 2.4: Literature Review

To perform the literature review, searches were conducted electronically through Google Scholar and Web of Knowledge via Dalhousie University's digital library platform. As predictions for future climate change impacts and species assessments evolve over time, preference will be given to the most recent published data available. However, standards for "recent" data will be less rigid for topics with less research performed on them, such as evasive marine species not frequently encountered or studied for information relevant to these vulnerability assessments. As grey literature from Government databases and reports, such as those from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or the Department of Fisheries and Oceans (DFO), often partitions species information according to management populations and their locations, these sources will be explicitly searched for and consulted from as well, without the aid of journal databases.

Key search terms varied between species sensitivity traits. However, each database inquiry included the phrases “Lancaster Sound”, “Eastern Canadian Arctic”, “Tallurutiup Imanga” or the name of the species’ management group living in the region, if such a group has been recognized. For example, as Bowhead whale management units are easily distinguished from one another and have their ranges clearly defined, search terms for this species included “Eastern Canada-West Greenland”, in reference to the population that is known to inhabit the study area. If search results did not contain literature discussing these areas, database inquiries were conducted again, excluding any location indicators to see if the desired information exists for the species regardless of study area.

During the literature review, a number from 1-3 was given to each of the species’ sensitivity factors to reflect data quality. A score of 1 will indicate that there was no published literature found discussing that sensitivity factor for the species in question. A score of 2 indicates that the information exists but is for the species as a whole or for populations not in this project’s study area. A score of 3 shows that reputable literature exists and makes explicit reference to species populations within the study area (Hare et al., 2016). To avoid excluding relevant information and to account for species that travel in and out of the Tallurutiup Imanga NMCA, any data that references populations within the Eastern Canadian Arctic will be given a data quality score of 3.

It should be noted that failing to find information on a given subject in the electronic databases does not necessarily mean that no information exists at all. Local and traditional ecological knowledge sources, such as fishers and Indigenous groups are often consulted during conservation planning, but often incompatible with westernized journals and empirical science (Noongwook et al., 2007; Alexander et al., 2019). This will be discussed further in the section *Limitations and Sources of Error.*

Chapter 3: Results

While not all the information required for complete individual vulnerability assessments was present in the reviewed literature, it was possible to create generalized results and minimum possible vulnerability assessment scores. The results are divided into functional groups, followed by individual species, and finally sensitivity traits intensity and data quality score. A summary of the results is provided in chapter 3.3.

Section 3.1: Literature Review Results

Section 3.1.1: Bowhead Whales (Eastern Canada/Western Greenland Population)

Prey/Diet Specificity

Due to the specialized baleen structure in its mouth, the bowhead whale's prey selection is more limited than what a species of its size would initially suggest. A survey of prey preference for bowhead whales in the Lancaster sound show a strong dependence on zooplankton, such as copepods, mysid shrimp, and krill (Pomerleau et al., 2012). Although the species is able to adjust its foraging strategy in response to the type of zooplankton available, its dependence on this functional group for most of its diet results in a sensitivity score of high (3) (Fortune et al., 2020). A data quality score of 3 was also given for this trait.

Habitat Specificity:

Generally, the species prefers to overwinter amongst the dense pack ice to avoid the worst of orca predation and to follow the highest densities of zooplankton (Ehrlich et al., 2020; Matthews et al., 2020). However, there was no literature found that suggests critical life stages, such as calving, are negatively impacted by the loss of sea ice. Therefore, the sensitivity for this trait is moderate (2), and its data quality score is 3.

Site Fidelity:

Bowhead whales in the Eastern Canadian Arctic display some seasonal site fidelity in accordance with sea ice formation. This population will consistently reside along the Lancaster Sound's coastlines during the summer and move Southward along Baffin Island to overwinter (Davis and Koski, 1980). As such, their sensitivity score for this trait is moderate (2). A data quality score of 3 has been given as well.

Lifetime Reproductive Potential

While their lifespans are not clearly defined, the species is known to frequently live to be 150 years old (Fisheries and Oceans Canada, 1999). Meanwhile, females will reach sexual maturity around 25 years of age (COSEWIC, 2021), placing their reproductive lifetime at least 125 years. Unlike belugas and narwhals, bowhead whales were found to be able to reproduce well towards the end of their lifespans, with no evidence of senescence found in females of advanced age (George et al., 2011). Reproduction interval is somewhat high with a female birthing a single calf once every 3 to 4 years (Koski et al., 1993). Despite their somewhat slow reproductive interval, their outlying lifespan relative to other cetaceans creates a large enough reproductive lifespan that the sensitivity can be graded as low (1). A data quality score of 3 was given to this trait.

Generation Length:

The generation length for bowhead whales is significantly long relative to other marine mammals at approximately 60 years and is one of the limiting factors for the species' population (Taylor et al., 2007; COSEWIC, 2012). This is far beyond the minimum requirement to meet the very high (4) sensitivity trait of 30 years, and so it has been assessed as such. Data quality was given a score of 3.

Reproductive Plasticity

Apart from the seasonal migrations that the species takes to the Foxe Basin and Cumberland sound, there do not seem to be any specific requirements that would lower the likelihood of successful reproduction in bowhead whales (Davis and Koski, 1980; Reeves et al., 1983). Nonetheless, the metabolic and time related requirements of migration to these areas is enough to give this trait a sensitivity score of high (3) (Insley et al., 2021). The data quality score for this trait is also 3.

Migration

As discussed for the population's site fidelity, the species seasonally migrates between the Lancaster Sound and Foxe Basin during the spring and summer, while migrating south along Baffin Island and into the Cumberland Sound during the fall and winter (Davis and Koski, 1980; Reeves et al., 1983). As their movement is seasonal, the sensitivity for migration is high (3), with a data quality score of 3 as well.

Home Range

Due to the population's tendency to travel throughout the Eastern Canadian Arctic and through the Atlantic Ocean to reach Greenland, their home range is large enough to be considered low sensitivity (1) (COSEWIC, 2012). The data quality for this trait was given a score of 3.

Stock Abundance

A survey of the East-Canada-West-Greenland Stock conducted in 2013 estimated the total abundance of this population to be approximately 6446 individuals (Doniol-Valcroze et al., 2020). While a relatively old estimate, it is still within the 10-year timeframe suggested for this sensitivity trait. This trait's sensitivity score is moderate (2) and data quality score is 3.

Stock Abundance Trend

As seen from Doniol et al., the stock abundance appears to be slowly but steadily recovering from the whaling activity that took place in the 20th century (2020). Sensitivity is low (1) and a data quality score of 3 was given for this trait.

Cumulative Stressors

Typical stressors for bowhead whales in the Eastern Canadian Arctic include:

(i) Killer Whale Predation (Matthews et al., 2020).
(ii) Pollution from oil exploration, ship effluent, and atmospheric emissions.
(iii) Noise Pollution from ships and resource exploration, which can scare them away from seasonal area use (Johnson et al., 1986; Erbe et al., 2019).
(iv) Fishing gear entanglement (Rolland et al., 2019).
(v) Collisions with ships and other Vessels (George et al, 1994).
(vi) Entrapment in ice, blocking off seasonal feeding grounds (George et al., 1985).

However, the extent of non-lethal stressors and the deaths from lethal ones are not known. Additionally, annual mortality rate has not been determined for this population, so sensitivity cannot be determined. A data quality score of 1 has been given as well.

Section 3.1.2: Beluga (Eastern High Arctic Population)

Prey/Diet Specificity

While the preferred prey of belugas in the Eastern Arctic appears to be Arctic cod, they have also been observed readily feeding on amphipod crustaceans and squid (Matley et al., 2015). Combined with the ability to feed on Arctic char, Greenland halibut, and polychaete worms as seen in other populations, Eastern Canadian Arctic belugas are prey generalists (Marcoux et al., 2012). Nonetheless, their strong preference for Arctic cod as the majority of their caloric intake means that they have a high (3) sensitivity for this trait. A data quality score of 3 was given as well.

Habitat Specificity

Belugas are classified as an ice-associated species, meaning that while they prefer to remain in the vicinity of the edges of sea ice formations, none of their life history functions are impossible without it (Moore and Huntington, 2008). A recent survey of the Eastern High Arctic Population showed that as sea ice receded and gaps opened in the sheets, the population was able to expand its typical range and move further away from the coastlines to which they are usually confined (Heide-Jorgensen et al., 2010). A lack of sea ice may be a benefit to beluga populations in the future, but due to their habit of remaining along the fringes of ice formations, sensitivity for this trait has been scored as moderate (2). A data quality score of 3 has been assigned as well.

Site Fidelity

Belugas within the Eastern Canadian Arctic display a high degree of site fidelity towards their summer sites, down to a micro-geographical scale. For example, the same matriarchal lineage of belugas will consistently return to the same estuary on Southern Ellesmere Island to wean their young, suggesting that site selection is a learned behavior (Brown Gladden et al., 1997). Sensitivity for beluga site fidelity is very high (4), and data quality has been given a score of 3.

Lifetime Reproductive Potential

While typical beluga lifespans are anywhere from 30 to 60 years old, the Eastern High Arctic population has been noted to have a lifespan of just 15 years (Lair et al., 2015; Fisheries and Oceans Canada, 2017). No explanation for this discrepancy was given, but was obtained from Fisheries and Oceans Canada, a reliable source for grey literature. While belugas do exhibit reproductive senescence, it begins to show around 30 years of age, making it irrelevant for this population (Ellis et al., 2018). Meanwhile, females sexually mature at 10 to 11 years old and will typically have one calf every 3 to 4 years (Matthews and Ferguson, 2015; Ferguson et al., 2020). While other populations would have a sensitivity score of low (1) for this trait, the High Arctic’s lower total lifespan makes the sensitivity very high (4). Data quality has been given a score of 3.

Generation Length

The generation length of belugas in the Eastern Canadian Arctic was found to be around 15 years, a typical length for marine mammals, which gives the population a sensitivity score of moderate (2) (Stewart et al., 2006). Data quality has been given a score of 3.

Reproductive Plasticity

The only factor that potentially affects this population of beluga’s reproductive plasticity is the seasonal migration that individuals must take to reach breeding and calving grounds (Koski et al., 2002). As such, this trait has a sensitivity score of high (3), and a data quality score of 3.

Migration

The belugas from this population that remain in Canadian waters exhibit seasonal movements throughout the Eastern Canadian Arctic. The typical pattern involves individuals overwintering in the North Water Polynya in the Baffin Bay, while returning to the Lancaster Sound and surrounding islands and estuaries to raise their calves (Koski et al., 2002). As a result of their seasonal migrations, the sensitivity for this population is high (3). Data quality has been given a score of 3.

Home Range

Assuming that the belugas in the Eastern Canadian Arctic and Western Greenland are part of the same management group, then the population's home range is large, with individuals able to cross the open North Atlantic Ocean if they wish (COSEWIC, 2020). As a result, the species' sensitivity is low (1), and has a data quality score of 3.

Stock Abundance

As of 2020, the population of the Eastern High Arctic beluga population is approximately 10 000 individuals (COSEWIC, 2020). While there is some confusion over whether this population should be split into Canadian and Greenlandic populations, this estimate is accepted by COSEWIC for conservation purposes in Canadian waters. As such, the sensitivity for stock abundance is low, with a data quality score of 3.

Stock Abundance Trend

While the population's decline from overharvesting has stopped and is now at a sustainable level, there is uncertainty over whether it is remaining stable or slowly recovering (COSEWIC, 2020). No sensitivity assessment can be made for this trait, and a data quality score of 1 has been assigned.

Cumulative Stressors

According to the stressor calculator created for the 2020 COSEWIC assessment of Belugas in the Eastern High Arctic, the main stressors currently affecting at least 50% of the population are:

(i) Noise Pollution from ships and other machinery has been known to interfere with prey detection, communication, and seasonal area use. Is thought to affect 71% to 100% of the population (Lesage et al., 2013; NMRWB, 2020; COSEWIC, 2020; COSEWIC, 2021).

(ii) Chemical Pollution from atmospheric emissions, coastal runoff, and ship effluent is thought to impact 71% to 100% of the population, but the exact effects are unknown (Gong et al., 2018; Vard Marine, 2018; COSEWIC, 2020; COSEWIC 2021).

Sensitivity for this trait is moderate (2), with a data quality score of 3.

Section 3.1.3: Narwhal (Eastern Canadian High Arctic Population)

Prey/Diet Specificity

Similar to belugas, Narwhals in the Eastern Canadian Arctic exhibit a strong preference for Arctic cod as their main prey item but will hunt amphipods and squid as well (Matley et al., 2015). As most of their diet consists of one species, although they can switch to another if needed, the narwhal's sensitivity for prey specificity is high (3). A data quality score of 3 was given as well.

Habitat Specificity

Little is known about the specific habitat requirements of the species, and how critical each component is, but trends regarding their preferences have been noted. During the winter, most of the Canadian populations will reside in the Baffin Bay amongst the heavy pack ice (Heide-Jorgensen et al., 2003). Apart from ice conditions, Eastern Canadian Arctic Narwhals prefer travelling along continental shelves with depths of around 1000 meters, presumably to avoid being trapped by ice formations closer to shore (Dietz et al., 2000). Finally, congregations are known to occur near upwelling areas, but the reason for this is not known (Barber, 1989). As there is no indication of any of the species' life events being impossible to complete without the presence of the previously mentioned habitat features, the sensitivity for this trait is moderate (2). A data quality score of 3 has been given as well.

Site Fidelity

Narwhals in the Eastern Canadian Arctic and Western Greenland display high seasonal site fidelity that varies with the population being observed. While their usual wintering grounds are known to be within the general Baffin Bay, individuals will return to specific portions of coastline along Somerset Island. As a result, sensitivity for site fidelity is very high (4), and data quality has been given a score of 3 (Heidi-Jorgensen et al., 2003).

Lifetime Reproductive Potential

The average lifespan of Narwhals in the Canadian Arctic is thought to be around 50 years, with females become sexually mature at 5 years old (Hay, 1984). Meanwhile females are thought to birth a calf every 2 to 3 years, and senescence was found to occur when they are in their mid 40's (Kingsley, 1988; Ellis et al., 2018). This combination of reproductive traits gives the species a sensitivity score of low (1), and a data quality score of 3.

Generation Length

There are fewer observations on narwhal population dynamics and age structure than with belugas and bowhead whales, so the species' generation length has not been confirmed. However, estimates place the generation length at 21.9 years for populations living in the Canadian Arctic which has been accepted by the IUCN as reliable data (Taylor et al., 2007; Lowry et al., 2017). This is somewhat high when compared to other marine mammals, and so the narwhal's sensitivity is high (3). A data quality score of 3 has been assigned as well.

Reproductive Plasticity

As narwhal populations in the Eastern Canadian Arctic exhibit migratory behavior to reach mating and calving grounds, along with a preparatory feeding period in the winter, the sensitivity for reproductive plasticity is high (3) (Hay, 1984; Heide-Jorgensen et al., 2003). Data quality has been given a score of 3 as well.

Migration

As there are multiple and distinct narwhal populations residing in the Eastern Canadian Arctic, there are multiple seasonal areas and migration routes (Jorgensen et al., 2003). That being said, many of the whales will overwinter in the middle of Baffin Bay, travel back into Canadian Waters through the Lancaster Sound during the spring, and reside in their preferred bays within the Eastern Canadian Arctic during the summer (Heide-Jorgensen et al., 2003). As all of these are seasonal, the sensitivity is high (3), and the data quality score is 3 as well.

Home Range

Canadian narwhals will readily travel between the coastlines within the Eastern Canadian Arctic, the middle of Baffin Bay, and the coasts of Western Greenland (Heide-Jorgensen et al., 2003). While there are annual timings associated with each location, the total area an individual is able to travel means that sensitivity is low (1). Data quality has been given a score of 3 for this trait.

Stock Abundance

Obtained from aerial surveys in 2013, the total abundance of narwhals that reside in the Eastern Canadian Arctic is approximately 142 000 (Doniol-Valcroze et al., 2020). While somewhat dated, this survey has still taken place within the 10-year timeframe required by this framework. Although the surveyors admit that the numbers are not completely accurate due to the possibility of double counting some narwhals and missing submerged individuals, the confidence intervals still place this populations sensitivity into the low (1) score. Data quality has been given a score of 3.

Stock Abundance Trend

As the most recent abundance survey was conducted in 2013, while the estimates from before that were obtained in the early 2000's (Higdon and Ferguson, 2017). As such, no population trend in the last 10 years can be determined. A data quality score of 1 was given for this trait.

Cumulative Stressors

Typical stressors for High Arctic Narwhal populations are similar to the other cetaceans discussed

(i) Noise pollution from ships and mining activity, disrupting feeding, and calving activity (COSEWIC, 2004; Jones, 2021).
(ii) Predation from killer whales (COSEWIC, 2004; Ferguson et al., 2012).
(iii) Alteration of ice formation patterns and timings from ice breaking ships, leading to the possibility of individuals becoming trapped during seasonal migrations (Heide-Jorgensen et al., 2002; COSEWIC, 2004; Laidre et al., 2011).
(iv) Pollution from ship effluent, ballast, and atmospheric emissions (COSEWIC, 2004; Gong et al., 2018; Vard Marine, 2018).

As total annual mortality rate and the extent of these stressors are not known, sensitivity cannot be determined. Data quality has been given a score of 1.

Section 3.1.4: Atlantic Walrus (High Arctic Population)

Prey/Diet Specificity

Atlantic Walrus in the Eastern Canadian Arctic are specialized for foraging along the benthos, where they will consume mostly a single species of clam, *Mya truncata.* Supplementary prey species include other bivalves, polychaetes, and snails (Fisher and Stewart, 1997). In rare but not unique cases, Atlantic walrus have been observed actively hunting ringed seals, bearded seals, and thick-billed murres with a moderate level of success (Mansfield, 1958; Mallory et al., 2004). For this reason, they have been given a sensitivity score of high (3), and a data quality score of 3.

Habitat Specificity

Similar to the other pinnipeds, the semi-aquatic nature of the Atlantic Walrus means that its amount of suitable habitat is limited. While adults can mate underwater, they require large patches of pack ice or low land to raise their calves (Fisheries and Oceans Canada, 2018). Furthermore, preferred haul out sites are above waters with depths no more than 100 meters, to ensure successful foraging along the benthos (Fisheries and Oceans Canada, 2018). As Climate change is expected to reduce sea ice cover and swallow low-lying land through sea level rise, the species' sensitivity for habitat specificity is very high (4) (Kovacs et al., 2015). A data quality score of 3 has been given for this trait.

Site Fidelity

Female individuals displayed a high amount of seasonal site fidelity to pack ice and landmasses to act as haul out sites where they can return to raise their calves through multiple years (Fisheries and Oceans Canada, 2002). Males will also display some fidelity towards feeding and mating grounds after pack ice recedes in the spring months, but not to the extent that females and their calves display (Freitas et al., 2009). Sensitivity for this trait is very high (4), and data quality has been given a score of 2.

Lifetime Reproductive Potential

Female Atlantic walruses are thought to become sexually mature at 6 to 7 years, birth one calf every 3 to 4 years, and live until they are 35 to 40 years of age (Mansfield, 1958; Garlich-Miller, 1994; COSEWIC, 2006). Contrary to the reproductive natures of the other pinnipeds explored in this project, it is suggested that female walruses experience senescence as they age and is thought to occur in most females around 24 years of age (COSEWIC, 2006; Ellis et al., 2018). As a result of this relatively early onset of senescence, the sensitivity for lifetime reproductive potential in female Atlantic Walruses is high (3), and has a data quality score of 3 as well.

Generation Length

Atlantic Walrus generation length was calculated to be around 21 years, giving the trait a high sensitivity score (3) (Pianka, 2011). As there was no source population named for this calculation, the data quality score is 2.

Reproductive Plasticity

As female walruses require the space-limited habitat offered by pack ice or shorelines to properly raise their calves, along with the need to seasonally migrate back to the same calving areas as previous years, the sensitivity for their reproductive plasticity is very high (4) (Fisheries and Oceans Canada, 2002; 2018). Data quality has been given a score of 3.

Migration

Walruses in the high Arctic population display seasonal migration patterns that coincide with the formation of sea ice in the Lancaster Sound. The majority appear to travel westward out of the Lancaster Sound and into the wider Canadian Archipelago region during July and August (Stewart, 2008; COSEWIC, 2017). Meanwhile, some will move Eastward out of the Sound and into the Baffin Bay once sea ice forms in the Fall and Winter (Stewart et al., 2002; COSEWIC, 2017). Due to these seasonal movements, the sensitivity for this trait in Atlantic Walrus is high (3), and data quality has been given a score of 3.

Home Range

Despite the frequent movements as outlined in migrations, a large portion of the population prefers to remain within the coastal waters within the Lancaster Sound and wider Archipelago (Stewart et al., 2002, 2008). As such, its sensitivity is high (3), with a data quality score of 3.

Stock Abundance

No population surveys that were taken in the last 10 years were found during the literature review. A data quality score of 1 has been given.

Stock Abundance Trend

As no total population has been determined within the last 10 years, no trend can be determined. A data quality score of 1 has been given.

Cumulative Stressors

The most common non-climate change related stressors currently affecting the High Arctic walrus population are:

(i) Noise pollution from fishing boats, aircraft, freighters, and other vessels that are gaining new pathways into the ice, causing individuals to abandon their seasonal haul out areas and heading to less suitable areas (COSEWIC, 2017).

(ii) Predation from polar bears (Kiliaan and Stirling, 1978).

(iii) Subsistence and traditional harvesting from local hunters (Fisheries and Oceans Canada, 2018).

However, the extent of non-lethal threats is not known, and there is no annual mortality rate to which the lethal disturbances can be compared. As such, no sensitivity score for this trait can be defined, and a data quality score of 1 has been given.

Section 3.1.5: Ringed Seal (No Population Defined)

Prey/Diet Specificity

Across the species' entire distribution, the Ringed seal's usual diet is relatively diverse. A typical individual's diet in the central and Southern reaches of its distribution consists of capelin, Arctic cod, sand lance, sculpin, and a multitude of crustaceans (McLaren, 1958; Gjertz and Lydersen, 1986; Smith, 1987; Labansen, et al., 2007; Yurokowski et al., 2016) However, recent observations on prey selection between latitudes show that diversity decreases the further North the seal travels. Instead of the myriad of prey species mentioned earlier, Ringed Seals residing within the Lancaster Sound and Northern portions of the East Canadian rely almost exclusively on Arctic cod (Yurkowski et al., 2016). As will be seen in this review, the Arctic cod is potentially prone to climate change related disturbances. However, as the species is able to adapt to a variety of prey types if need be, a sensitivity score of high (3) has been given for this trait. A data quality score of 3 has been assigned to this trait.

Habitat Specificity

Ringed seals are heavily reliant on sea ice forming under the right conditions and in the right location for successful reproduction and raising their pups (COSEWIC, 2019). Along with being sufficiently large enough to hold their pups while they grow through the whelping season, ideal ice habitat includes snow drifts of 50 cm or more to hide their young from predators and shelter them from the elements (Hezel et al., 2012). The lack of proper sea ice coverage and sufficiently deep snow drifts have been associated with a significant decline in reproductive success in lower latitudes (Hezel et al., 2012). As sea ice is often temporary in nature and its formation patterns are highly vulnerable to climate change, the sensitivity for habitat specificity has been assigned a score of very high (4), and a data quality score of 3.

Site Fidelity

Both sexes of the species display extreme site fidelity during breeding season. Dominant males will attempt to keep their sea ice patches safe from competitors each year, while females will return to the same areas of sea ice formation to raise their young (McLaren, 1958; Smith and Hammill, 1981). Sensitivity has been given a score of very high (4) and a data quality score of 3.

Lifetime Reproductive Potential

Female ringed seals typically begin producing offspring at 7 years old and will on average live until they are 20, giving them a reproductive lifetime of approximately 13 years (McLaren, 1958). Meanwhile, females will typically give birth to a single pup every 1 to 2 years (Smith, 1973). No evidence of reproductive senescence was found in the literature review. This combination of reproductive traits gives them a low vulnerability score (1) and a data quality score of 3.

Generation Length

There was no clear consensus found between the works consulted for generation length in ringed seals, but the average generation length is between 11 and 13 years (Palo et al., 2001; Coeswic, 2019). This range of ages places the sensitivity for generation length into the moderate bin (2). The data quality score was 2, as none of the literature found referenced populations within the Eastern Canadian Arctic.

Reproductive Plasticity

As the species requires the limited and temporary habitat offered by sea ice patches to successfully birth and raise a pup, the sensitivity score has been given a score of high (3) (COSEWIC, 2019). The data quality has been given a score of 3.

Migration

Ringed seals display a seasonal migration that is timed with sea ice formation, but there are no migration routes or destination shared by a majority of the population (Yurkowski et al., 2016). A sensitivity score of high (3) and a data quality score of 3 were assigned.

Home Range

Individuals within the Lancaster Sound region prefer coastal waters and pack ice but can cross the Atlantic Ocean basin to reach Greenland if desired (Yurkowski et al., 2016). A sensitivity score of moderate (2) and a data quality score of 3 have been given for this trait.

Stock Abundance

Complete abundance assessments have never been performed on ringed seal populations due to the logistical limitations associated with surveying large populations over large distances that are either on impassible sea ice or underwater (Green et al., 1995). Furthermore, governmental attention to the species' conservation is somewhat recent, resulting in less attention being given to the species than other Arctic marine mammals (CBC, 2021). Estimates place the total population at 1.15 million individuals as of 2020, but this includes seals residing in Greenland, Russia, and Alaska. Therefore, sensitivity cannot be assessed for this trait, and a data quality score of 1 was assigned.

Stock Abundance Trend

While there do not appear to be any extreme fluctuations in ringed seal populations, there is no available data regarding trends (Fisheries and Oceans Canada, 2019). Like the stock abundance trait, the large population and lack of division of the species into management units makes it difficult to monitor overall species health. No sensitivity score can be created, and a data quality score of 1 has been given.

Cumulative Stressors

Stressors that are known to impact at least 50% of the Canadian ringed seal population include:

(i) Pollution from atmospheric emissions, ship effluent, and solid waste (Gong et al., 2018; Vard Marine, 2018; COSEWIC, 2019; Oceans North, 2021).
(ii) Noise pollution from mineral exploration and ship traffic (COSEWIC, 2019; Cook et al., 2020).
(iii) An increase in viral and parasitic spread, causing a variety of deleterious effects (Onderka, 1989; Nielsen et al., 2001; COSEWIC, 2019).
(iv) Pupping issues stemming from habitat loss and general stress associated with ice breaking ship activity (Wilson et al., 2017; COSEWIC, 2019).

However, the COSEWIC threat calculator does not differentiate between seals in the Northwest Territories, where many of its citations are created, and seals in the Eastern Canadian Arctic or lower Canada. As seals in the Western Canadian Arctic are unlikely to enter the Eastern Canadian Arctic or interact with individuals native to these areas under normal circumstances, no sensitivity score can be provided (Harwood et al., 2012; Yurkowski et al., 2016). A data quality score of 1 has been given to this trait.

Section 3.1.6: Bearded Seal (No Population Specified)

Prey/Diet Specificity

While Arctic cod and sculpins formed the bulk of bearded seal diets in the Eastern Canadian Arctic, a variety of invertebrates, such as shrimp, whelks, polychaete worms, and squid were found as well

(Finley and Evans, 1983). The species is a generalist when it comes to prey selection, which means that its sensitivity score for this trait is low (1). A data quality score of 3 has been given for this trait.

Habitat Specificity

Although the exact preferences of bearded seals towards sea ice formations are not known, it is accepted that the species is ice-obligate and requires large patches to raise their pups and gain access to foraging areas (Boye et al., 2020). Due to the ephemeral nature and vulnerability of sea ice to climate change, the sensitivity for this trait is very high (4). Data quality has been given a score of 3.

Site Fidelity

There was no literature discussing site fidelity regarding bearded seals in the Eastern Canadian Arctic. However, surveys in Northern Alaska have shown that male individuals display a high degree of site fidelity towards specific harbors during mating season and throughout their lifetimes (Van Prarijs and Clark, 2006). As such, sensitivity for this trait is high (3), but the data quality score is 2.

Lifetime Reproductive Potential

The average lifespan of bearded seals in the Eastern Canadian Arctic is around 25 years**,** while females become sexually mature at 6 years old (McLaren, 1958). The reproductive interval for the species is thought to be 1 pup per female every two years (McLaren, 1958). No literature suggesting reproductive senescence was found during the literature review. This combination of reproduction factors gives the species a sensitivity score of low (1). The data quality score is 3.

Generation Length

Generation length for bearded seals in any location was not found during the literature review. Therefore, no sensitivity score can be assigned, and a data quality score of 1 was given.

Reproductive Plasticity

While their habitat preferences are not as clearly defined as those of the ringed seals, it is known that bearded seals still require the presence of sea ice for a successful whelping season (Boye et al., 2020). Therefore, the sensitivity score for this trait is high (3). A data quality score of 3 was also given.

Migration

Exact migration patterns of bearded seals in the Canadian Arctic are not known, but the typical habit for populations in the Eastern Canadian Arctic is to travel with the sea ice formation in the Baffin Bay. During November to June, individuals will venture onto the sea ice within the middle of the Bay and remain on their preferred mating grounds. When sea ice recedes during the summer, seals will follow the receding ice back into Eastern Canada or Western Greenland and long the coastlines (Boye et al., 2020). Due to the seasonal nature of these migrations, sensitivity is high (3). Data quality has been given a score of 3 as well.

Home Range

As stated in the migration section, Eastern Arctic bearded seals are known to travel to Greenland as sea ice forms in Baffin Bay. However, this is reliant upon the presence of seasonal sea ice, and they will typically remain along coastlines otherwise (Stephenson and Hartwig, 2010; Boye et al., 2020). Sensitivity for this trait is low (1), and data quality has a score of 3.

Stock Abundance

Accurate bearded seal population estimates were not found for the same reasons regarding ringed seals (Green et al., 1995; Fisheries and Oceans Canada, 2019). A data quality score of 1 has been assigned for this trait.

Stock Abundance Trend

Due to the relative lack of attention given to the species and a difficulty of monitoring their large, undefined populations, there are no known population trends known for the bearded seal (Fisheries and Oceans Canada, 2019). A data quality score of 1 has been given for this trait.

Cumulative Stressors

Due to their seemingly high abundance and difficulty in monitoring their populations, there is less information on cumulative stressors for bearded seals, especially for those outside of Alaskan waters. However, known threats include the following:

(i) Predation from polar bears (Smith, 1980; Cameron et al., 2010).
(ii) Harvesting from Northern communities and hunters (Cameron et al., 2010; Gryba et al., 2021).
(iii) Oil and effluent pollution (Cameron et al., 2010; Gong et al., 2018; Vard Marine, 2018).
(iv) Noise Pollution, which can disrupt their mating vocalizations and scare them away from areas of seasonal importance (Cameron et al., 2010; Wilson et al., 2017).

Section 3.1.7: Greenland Shark (No Population Specified)

Habitat Specificity

As seen from baited remote underwater video (BRUV), the species does not appear to have any specific habitat requirements and is readily found within the multitude of channels in the Tallurutiup Imanga NMCA, along with the main channel of the Lancaster Sound (Devine et al., 2018). The tracking studies of Lancaster Sound sharks conducted via mark report satellite tags show that the species will readily travel across open ocean during annual migrations as well (Hussey et al., 2018). A sensitivity score of low (1) and a data quality score of 3 have been assigned.

Prey Specificity

Stomach content analysis of Greenland sharks in Greenland and Norway have shown that the species is a generalist, with the ability to adapt its diet based on its location. While Arctic cod makes up a large portion of its caloric intake, seals, skates, squids, and crustaceans are known prey items as well (Nielsen et al., 2014, 2019). Along with active predation, the species is a known scavenger, feeding from the carcasses of large marine mammals (Lelerc et al., 2011). Due to the wide variety of potential prey items and an ease of adapting its feeding preferences, the sensitivity for Greenland shark prey specificity is low (1). Data quality has been given a score of 2.

Adult Mobility

While relatively slow swimmers, Greenland sharks are highly mobile species with annual migrations of over 1000 km, taking them through the Atlantic Ocean basin and to the coasts of Greenland (Campana et al., 2015). As these long-distance migrations are a normal occurrence for the species in the Canadian Arctic, sensitivity for this trait is low (1). The data quality was given a score of 3.

Dispersal of Early Life Stages

Along with species with lengthy planktonic phases, Hare et al states that live bearing members of *Elasmobranchii* (sharks, skates, and rays) are considered to have high dispersal potential, presumably as dispersal occurs while the animal is developing in the mobile mother instead of being confined to the benthos or reliant upon ocean currents (2016). As female Greenland sharks can give live birth to 10 pups at once, their dispersal potential is high (Carter and Soma, 2020). Gestation period, another important factor in dispersal potential, is unknown (Whitmee and Orme, 2012; Carter and Soma, 2020). Nonetheless, the intensity level for dispersal potential is low (1). Data quality was assigned a score of 3.

Early Life History and Settlement Requirements

As the Greenland shark is an elasmobranch and its young do not have any known restrictive environmental requirements, the sensitivity for this trait is low (1) (Carter and Soma, 2020). Data quality has been given a score of 3.

Complexity in Reproductive Strategy

Mating behavior in Greenland Sharks has not been observed in any marine space as of 2021. Furthermore, multiple surveys comprising over 300 individual sharks in the Eastern Canadian Arctic have shown a lack of adult females, suggesting that reproduction may not occur in the Talliurutiup Imanga NMCA (Skomal and Benz, 2004; Fisk et al., 2002, 2012; Leclerc et al., 2012; Hussey et al., 2015, 2018; Devine et al., 2018, as noted in Edwards et al., 2019). Recent tagging surveys show an annual migration of males to the West coast of Greenland, where adult females are known to inhabit, but whether this is for mating or other purposes is unknown. A data quality score of 1 has been assigned to reproductive strategy.

Sensitivity to Temperature

There is little literature discussing the thermal tolerances of Greenland sharks, and so the bioregion map method discussed in the original framework was used instead (Spalding et al., 2007; Hare et al., 2016). As individual sharks residing in the Eastern Canadian Arctic tend to remain in the same bioregion as outlined in Spalding et al., sensitivity to temperature has been given a score of high (3) (Spalding et al., 2007; Devine et al., 2018; Hussey et al., 2018). Data quality has been given a score of 3.

Sensitivity to Ocean Acidification

An assessment on various arctic marine species and their reactions to ocean acidification say there is currently no concern for the species, as ocean acidification is not expected to significantly alter the availability of the species' typical prey items (Arctic Monitoring and Assessment Programme, 2011). As such, the sensitivity is low (1), with a data quality score of 3.

Spawning Cycle

There was no literature discussing the frequency or timings of Greenland shark reproduction found during the review. No sensitivity score can be assigned, and a data quality score of 1 has been given.

Stock Size

There is no information regarding the stock size of Greenland sharks within the Tallurutiup Imanga NMCA or wider Canadian Arctic. Occasional bycatch records and studies using tracking tags or underwater cameras can help determine the presence of the species in a particular area, but the otherwise limited data are not enough for create a population estimate (Cosandey-Gordin et al., 2014; Devine et al., 2018; Hussey et al., 2018). A data quality score of 1 has been assigned with no sensitivity score available.

Population Growth Rate

The intrinsic rate of increase, a von Bertalanffy K value, and natural mortality rate could not be found for Greenland sharks. As the species is thought to become sexually mature at 134 years at the earliest and live for over 500 years, the sensitivity for population growth rate is thought to be very high (4) (Nielsen et al., 2016). A data quality score of 2 has been given.

Cumulative Stressors

Due to the species' elusive nature, it is difficult to determine which stressors are having a significant impact on its population, if any at all. There are some concerns over unsustainable bycatch, but the effects of this on the species' total abundance is not known (Cosandey-Godin et al., 2014). This framework considers a lack of evidence of cumulative stressors to mean no stressors, so intensity has been assigned a low score (1), and data quality has been scored as 3.

Section 3.1.8: Arctic Cod (No Population Specified)

Habitat Specificity

As a purely pelagic species, juvenile and adult Arctic cod have no specific benthic or biological habitat requirements (Richard and Crawford, 2009). Sensitivity for this trait is low (1). Data quality for this trait has a score of 3.

Prey Specificity

Due to its relatively low position in the trophic chain, prey selection for the Arctic cod is relatively narrow and restricted by size. While adults can switch between amphipods, copepods, and crustacean larvae, juveniles are almost completely restricted to copepods and planktonic organisms of an equally small size (Matley et al., 2013). The sensitivity for this species' prey selection is high (4), with a data quality score of 3.

Adult Mobility

Adult Arctic cod are highly mobile and do not exhibit any site dependence apart from general areas for the spawning season (Kessel et al., 2017). As such, the sensitivity for this trait is low (1), and a data quality score of 3 has been given.

Dispersal of Early Life Stages

As eggs will often take 3.5 months to hatch, and another 22 days to absorb their yolk sacks, the sensitivity for dispersal ability is low (1) (Rass, 1968; Aronovich et al., 1975). A data quality score of 2 has been given to this trait.

Early Life History and Settlement Requirements

The early life stages of larval Arctic cod and eggs are known to be strongly dependent on the presence of widespread sea ice (Huserbraten et al., 2019). As discussed in prey specificity, Arctic cod larvae are almost entirely dependent on sufficient copepod populations. Due to these requirements of vulnerable ice formations, the sensitivity for this trait is very high (4). Data quality has been given a score of 2.

Complexity in Reproductive Strategy

There are multiple requirements for a successful spawning period, giving this trait a sensitivity of high (3).

(i) Spawning and subsequent egg laying is highly associated with dense sea ice coverage above the breeding population (Ponomarenko, 1968).
(ii) Large aggregations of the species in one location at the same time is required to maximize the amount of offspring produced (Ponomarenko, 1968).
(iii) Long distance migration to spawning grounds towards which populations display fidelity is required before spawning can begin (Ponomarenko, 1968).

Data quality for these requirements has a score of 2.

Spawning Cycle

While spawning has not been observed in the Eastern Canadian Arctic, populations in Alaskan and Russian waters spawn from December to late March (Rass, 1968). As the species will consistently spawn within a seasonal timeframe, the sensitivity for this trait is high (3). Data quality was given a score of 2.

Sensitivity to Temperature

As the typical temperature range of Arctic cod is between 0° C and 4° C, the sensitivity of Arctic Cod to temperature changes is very high (4) (Fisheries and Oceans Canada, 2016). Data quality has been given a score of 2.

Sensitivity to Ocean Acidity

While the full extent of the impacts is not completely understood, a rise in ocean acidity to levels predicted to occur in the Arctic in the near future was found to impact the speed and overall efficiency of Arctic cod swimming performance (Kunz et al., 2018). As this is expected to cause a decline in predator evasion and competition for food, the sensitivity for ocean acidity has been graded as very high (4) (Kunz et al., 2018). Data quality has been given a score of 2.

Population Growth Rate

The intrinsic rate of increase, von Bertalanffy K, and natural mortality rate could not be found for Arctic cod. As the species usually sexually matures around 2 to 3 years of age and has a lifespan of 4 to 5 years, the sensitivity for growth rate is low (1) (Loewen et al., 2010). Data quality has been given a score of 3.

Stock Size

As the species is not a valuable commercial fish in this region, there are no stock size assessments from which to form a sensitivity score. A data quality score of 1 has been assigned for this trait.

Other Stressors

The only notable, non-climate change induced stressors currently known for Arctic cod in the Eastern Canadian Arctic are noise pollution and bycatch in the shrimp fishery. While not immediately lethal or physically damaging to nearby cod, noise pollution from shipping has been shown to disrupt cod behavior and alter their home range as they try to escape the noise. In turn, this may disrupt the open water feeding season upon which cod and their predators rely (Ivanova et al., 2019). Meanwhile, Arctic cod are a common bycatch species in the shrimp fisheries in Baffin Bay. However, as this accounts for less than 0.1% of the total stock in the region, it is not considered a priority issue (Walkusz et al., 2020). As there were two found stressors to Arctic cod in the Eastern Canadian Arctic, the sensitivity for this trait is moderate (2). Data quality has been given a score of 3.

Section 3.1.9: Arctic Char (No Population Specified)

Habitat Specificity

As a primarily anadromous species, the Arctic char is suited for both freshwater and saltwater environments (Chavarie et al., 2010). Since it is a pelagic species, there are no specific benthic features or biological habitats, such as sea grass beds, to which it is restricted (Harris et al., 2020). Sensitivity for this trait is low (1), and the data quality score is 3.

Prey Specificity

Arctic char in the Eastern Canadian Arctic commonly consume a wide variety of prey species across multiple functional groups in both freshwater and saltwater environments. This selection includes algae, freshwater plants, polychaetes, shrimp, and other freshwater fish (Isinguzo, 2009). Due to the generality of the species' diet, the sensitivity for this trait is low (1). A data quality score of 3 has been given.

Adult Mobility

While there is a degree of site fidelity and mass congregations at particular estuaries and rivers for overwintering, it has also been found that seasonal habitat selection can change if easier migration routes become available (Moore et al., 2017). While some populations are landlocked in lakes and cannot escape unsuitable environmental conditions, the anadromous populations have a sensitivity score of moderate (2). Data quality has been given a score of 3.

Dispersal of Early Life Stages

As Arctic char eggs are laid in benthic freshwater habitats and within freshwater systems, the dispersal potential of the species' young is very low (Loewen et al., 2010). Sensitivity is very high (4), and a data quality score of 3 has been given.

Early Life History and Settlement Requirements

There are a number of known environmental requirements for juvenile Arctic char survival, placing the sensitivity for this trait in the very high (4) intensity bin, with a data quality score of 2.

(i) Juvenile Arctic char that migrate from freshwater rivers into the ocean are likely to do so due to a lack of prey required to gain mass and develop into adults. Juveniles that are obstructed from entering the ocean by a barrier are likely to starve. However, the juveniles that are anadromous and enter the ocean have a higher mortality rate than landlocked individuals (Jensen et al., 2018).

(ii) If prey availability in the river is insufficient, juveniles will not be large enough to survive in the ocean and subsequently die from overexertion (Jensen et al., 2018).

(iii) Juveniles are less resistant to rising temperatures than adults, and rising temperatures associated with climate change can impact development (Wang et al., 2021).

Complexity in Reproductive Strategy

Due to the high number of requirements for successful spawning to occur in Arctic Char populations, the sensitivity for this trait is very high (4). A data quality score of 2 has been given for this trait.

(i) Warm waters, such as those above 8°C, will disrupt and eventually inhibit ovulation in female individuals (Gillet, 1991).

(ii) Individuals often display high site fidelity toward the river where they hatched and will attempt to return there to spawn. Obstructions along the inland migration path, such as dams, may result in a severe decline of individuals arriving at the spawning area (Tallman et al., 1996; Gyselman, 2011).

(iii) Successful spawning requires access to freshwater rivers with oxygenated gravel beds to lay eggs in. Freshwater systems are easily disrupted by nearby sources of pollution, sedimentation, or other anthropogenic disturbances (Evans et al., 2005; Minnow Environmental, 2021)

(iv) Successful spawning requires mass migration of adults up river into suitable spawning grounds (Beddow et al., 1998).

Spawning Cycle

There is little literature discussing specific spawning times for anadromous Arctic char in the Eastern Canadian Arctic. However, reproduction is thought to take place from September to October, suggesting that there are multiple spawning events in a limited, annual timeframe (Fisheries and Oceans Canada, 2014). As such, the sensitivity for this trait is high (3), and data quality has been given a score of 2.

Sensitivity to Temperature

During their seasonal migrations between the ocean and freshwater systems, Arctic Char in the Eastern Canadian Arctic regularly encounter temperatures ranging from 0° to 21° C (Gilbert et al., 2016, 2020). However, the upper range of these temperatures will cause respiratory distress in adults and juveniles that exert themselves during migration (Gilbert et al., 2020). This range of regular temperature exposure results in a low sensitivity score (1) for thermal tolerance in Arctic Char. A data quality score of 3 has been assigned.

Sensitivity to Ocean Acidity

Outside of extreme instances of localized, acute pollution, there do not seem to be any significant impacts of acidification on Arctic char survival (Hesthagen et al., 1995). As the species will readily switch between a variety of prey items, there is likely no significant threat from ocean acidification to food availability either. Although more research is required on the effects of ocean acidification on finfish, the current literature suggests a low sensitivity (1) (Hare et al., 2016). A data quality score of 3 has been given for this trait.

Population Growth Rate

The intrinsic growth rate, natural mortality, maximum age, and a von Bertalanffy K value were not found for Arctic char in the Eastern Canadian Arctic. The only relevant parameter for growth rate assessment found for species in the region was age of maturation, which was estimated to be 10 to 13 years of age (Loewen et al., 2010). As a result, the sensitivity for population growth rate has been rated as high (3). Data quality has been given a score of 3.

Stock Size

There are no estimates or proxies available for total Arctic char abundance in the Eastern Canadian Arctic. As individuals are divided into populations based on their natal rivers, a population count of all rivers in a region would be difficult (Zhu et al., 2021). A data quality score of 1 has been given for this trait.

Other Stressors

While secondary sources cite a 2006 COSEWIC assessment stating the Arctic Char in the Eastern Canadian Arctic are vulnerable to unspecified disturbances, this document was not found during the literature review or a specified search through the committee's database. The only found stressors to Arctic Char in the Eastern Canadian Arctic were those associated with the Mary River Iron mine on Baffin Island. Initial fears over this project included destruction of spawning habitat, excessive pollution, and disturbance of juvenile char (George, 2011). Recent environmental assessments have shown that pollution and direct impacts to char eggs are not significant (Kamermans, 2021). While not to the extent that the stocks are at risk of extinction, about a third of the rivers assessed on Baffin Island had a reduction in char passage due to culvert placement and other physical obstructions (Kamermans, 2021). Due to the low number of known stressors on this population, sensitivity is low (1). Data quality has a score of 3.

Section 3.2: Exposure

With the exception of dissolved oxygen and precipitation, the predicted changes for each mean exposure factor were found to be very high (4) (NOAA, 2014). Conversely, apart from ocean surface temperature, the predicted changes for each variability exposure factor, along with the changes to ocean currents, were found to be low (1) (NOAA, 2014). Finally, the exposure to complications from sea level rise varied between species, due to their varying habitat requirements. While most of the species in this paper were given a low exposure score (1), both beluga and Arctic char were given a score of high (3), due to their near-shore and estuarine habitat requirements (Brown Gladden et al., 1997; Evans et al., 2005).

Table 5. Exposure intensities for environmental parameters under climate change in the TINMCA (Appendix D, Appendix E).

Exposure Factor	Exposure Intensity Bin
Mean Ocean Surface Temperature	**Very High (4)**
Mean Ocean Surface Salinity	**Very High (4)**
Mean Air Temperature	**Very High (4)**
Mean Precipitation	**Moderate (2)**

Mean Ocean pH	**Very High (4)**
Mean Sea Ice Cover	**Very High (4)**
Mean Dissolved Oxygen	**Low (1)**
Variability in Ocean Surface Temperature	**Very High (4)**
Variability in Ocean Surface Salinity	**Low (1)**
Variability in Precipitation	**Low (1)**
Variability in Air Temperature	**Low (1)**
Variability in pH	**Low (1)**
Sea Level Rise	**High (3) (Beluga, Arctic Char) (Kopp et al., 2014)** **Low (1) (Remaining Species)**
Ocean Currents	**Low (1)**

Section 3.3: Summary of Results:

Table 6. Summary of the vulnerability assessments for cetaceans and pinnipeds. An X denotes the lack of information required to properly assign a sensitivity score.

	Bowhead	**Beluga**	**Narwhal**	**Ringed Seal**	**Bearded Seal**	**Walrus**
Prey Specificity	**High (3)**	**High (3)**	**High (3)**	**High (3)**	**Low (1)**	**High (3)**
Habitat Specificity	**Moderate (2)**	**Moderate (2)**	**Moderate (2)**	**Very High (4)**	**Very High (4)**	**Very High (4)**
Site Fidelity	**Moderate (2)**	**Very High (4)**	**Very High (4)**	**Very High (4)**	**High (3)**	**Very High (4)**
Lifetime Reproductive Potential	**Low (1)**	**Very High (4)**	**Low (1)**	**Low (1)**	**Low (1)**	**High (3)**
Generation Length	**Very High (4)**	**Moderate (2)**	**High (3)**	**Moderate (2)**	**X**	**High (3)**
Reproductive Plasticity	**High (3)**	**High (3)**	**High (3)**	**High (3)**	**High (3)**	**Very High (4)**
Migration	**High (3)**	**High (3)**	**High (3)**	**High (3)**	**High (3)**	**High (3)**

Home Range	**Low (1)**	**Low (1)**	**Low (1)**	**Moderate (2)**	**Low (1)**	**High (3)**
Stock Abundance	**Moderate (2)**	**Low (1)**	**Low (1)**	**X**	**X**	**X**
Stock Trend	**Low (1)**	**X**	**X**	**X**	**X**	**X**
Cumulative Stressors	**X**	**Moderate (2)**	**X**	**X**	**X**	**X**
Average Data Quality	**2.81**	**2.81**	**2.63**	**2.27**	**2.18**	**2.27**
Overall Climate Change Vulnerability	**Very High (12)**	**Very High (12)**	**Very High (12)**	**Very High (12)**	**Very High (12)**	**Very High (16)**

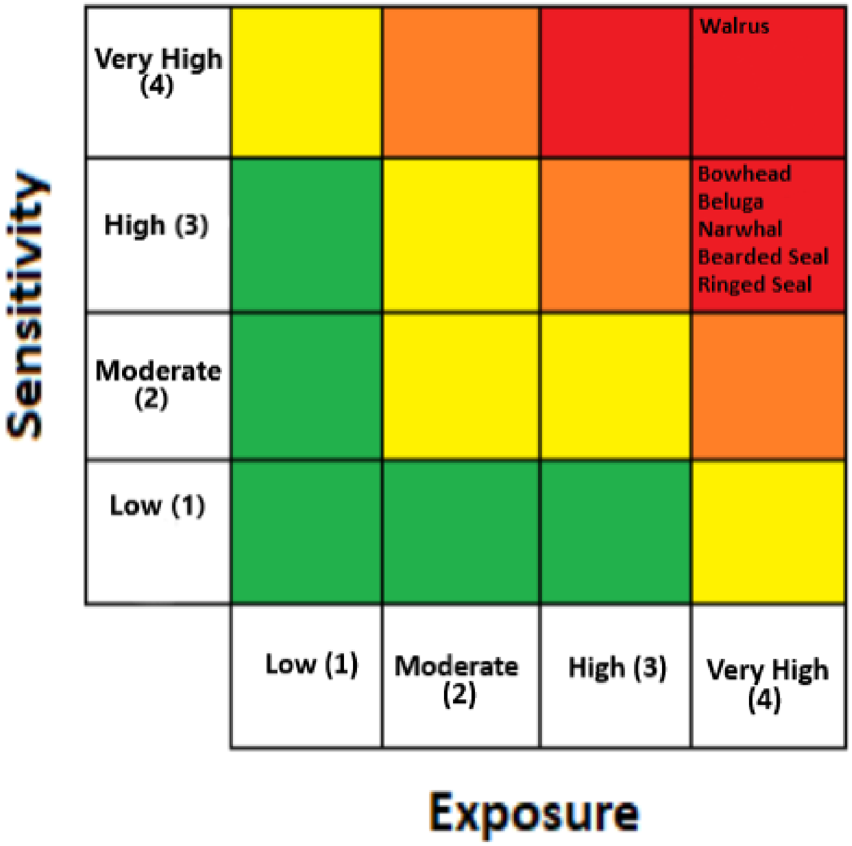
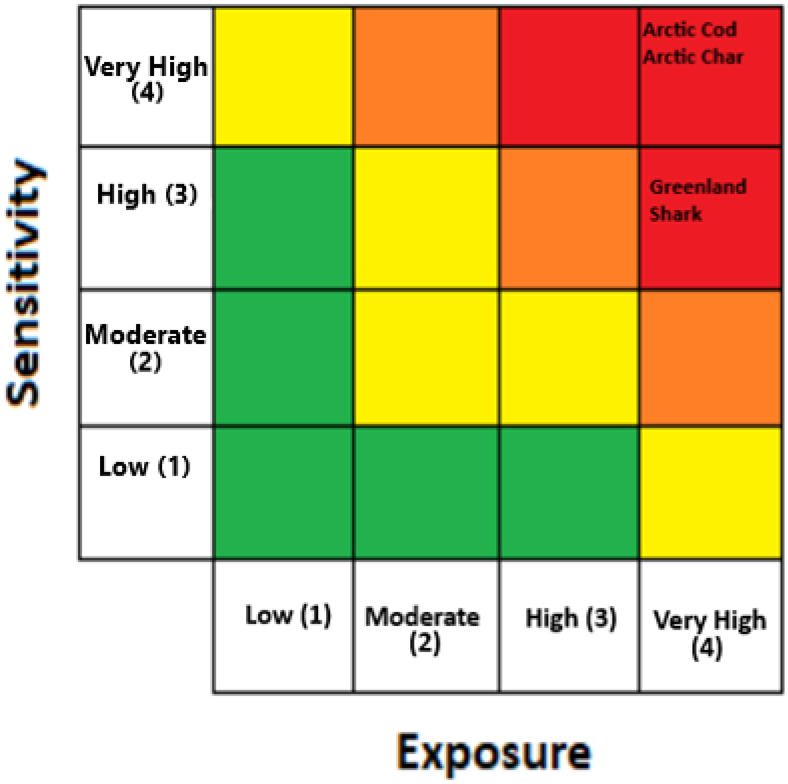


Figure 3. Climate change vulnerability index for cetaceans and pinnipeds. Framework from Lettrich et al., 2019.

Table 7. Summary of the vulnerability assessment for marine fish. An X denotes that sufficient information was not available to assign a proper sensitivity score for that trait.

	Greenland shark	**Arctic Cod**	**Arctic Char**
Habitat Specificity	**Low (1)**	**Low (1)**	**Low (1)**
Prey Specificity	**Low (1)**	**Very High (4)**	**Low (1)**
Adult Mobility	**Low (1)**	**Low (1)**	**Moderate (2)**
Dispersal of Early Life Stages	**Low (1)**	**Low (1)**	**Very High (4)**
Reproductive Complexity	**X**	**Very High (4)**	**High (3)**
Early Life Requirements	**Low (1)**	**High (3)**	**Very High (4)**
Spawning Cycle	**X**	**High (3)**	**High (3)**
Sensitivity to Temperature	**High (3)**	**Very High (4)**	**Low (1)**
Sensitivity to Ocean Acidity	**Low (1)**	**Very High (4)**	**Low (1)**
Population Growth Rate	**Very High (4)**	**Low (1)**	**High (3)**
Stock Size	**X**	**X**	**X**
Other Stressors	**Low (1)**	**Moderate (2)**	**Low (1)**
Average Data Quality	**2.33**	**2.33**	**2.58**
Overall Climate Change Vulnerability	**High (3)**	**Very High (4)**	**Very High (4)**



Sensitivity

Very High (4)	🟨	🟧	🟥	🟥 Arctic Cod Arctic Char
High (3)	🟩	🟨	🟧	🟥 Greenland Shark
Moderate (2)	🟩	🟨	🟨	🟧
Low (1)	🟩	🟩	🟩	🟨
	Low (1)	Moderate (2)	High (3)	Very High (4)

Exposure

Figure 4. Climate change vulnerability matrix for marine fish. Template from Lettrich et al., 2019.

Chapter 4: Discussion

Section 4.1: Interpretation of Results

Section 4.1.1: Marine Mammals

Both vulnerability and data quality scores for marine mammals were similar to the expectations for results prior to the literature review and assessment. As largely K-selected species that emphasize heavy time and energy investment in a small number of offspring, marine population recovery is often heavily limited by their slow reproduction (Punt et al., 2018). As a result, the death of even one calf, pup, or breeding age female can severely hamper conservation initiatives (Booth et al., 2020). However, despite being given similar vulnerability scores, pinnipeds are all essentially guaranteed to suffer abundance losses, while the success of cetaceans will heavily depend on how well human activity can be managed.

The most common vulnerability across all of the pinnipeds was their high reliance on sea ice to raise their young, coupled with a high fidelity towards certain specific ice patches (Mansfield 1958; Smith, 1973; Van Parijs and Clark, 2006; Wilson et al., 2017). While walruses do not need whelping dens and will often haul out on land structures in addition to sea ice, the moderate degree of sea level rise is likely to reduce the amount of available space above water (Kopp et al., 2014; Kovacs et al., 2015). As a loss of sea ice, and in the case of ringed seals a loss of snow cover, is correlated with a significant decline in reproductive success, the heavy loss of both in the TINMCA will likely disrupt the species' replacement rates (Ferguson, 2017). This could result in Inuit harvests, along with polar bear predation, becoming unsustainable in areas no longer suitable for breeding (Pagano and Williams, 2021; Neustaeter, 2021). As pinnipeds in latitudes lower than the Lancaster sound are already experiencing discrepancy in offspring survival during warming events, this further loss of snow and ice may result in these areas becoming completely unsuitable for reproduction altogether (Chambellant, 2010).

Despite their tendencies to remain within the vicinity of sea ice edges, none of the cetaceans were mentioned in literature that discussed a decline in reproductive success without it. As their calves do not require constant surface access and will instead follow their mothers to wean, sea ice is not necessary to hold them above the water and dens are not necessary to avoid predation and the elements. Outside of natural causes and anthropogenic stressors, a non-negligible source of mortality in Arctic marine mammals is entrapment in sea ice (Huntington et al., 2017). As Arctic marine mammals must time their migrations with the formation of sea ice to enter uncovered wintering grounds, it is possible for individuals to become trapped if they do not move soon enough, or if the ice forms earlier than usual

(Kovacs et al., 2011). In significant entrapment events, hundreds of individual whales have been known to die, severely disrupting their population dynamics and sustainable harvest metrics (Fisheries and Oceans Canada, 2018). Lengthier ice-free periods, along with less ice coverage in general may result in fewer entrapment caused mortalities, which would be beneficial to these cetacean species (Ferguson et al., 2010). Along with a reduction in ice entrapments, the loss of sea ice and an increase in ocean temperature has been shown to be beneficial to the growth of *C.glacialis*, the zooplankton most favored by bowheads, potentially increasing available foraging areas for the species in the future (Pomerleau et al., 2012; Feng et al., 2016).

While the literature review results do not suggest any overwhelming sources of anthropogenic mortality for these species, there is some concern over the rising presence of seasonal shipping traffic in the Eastern entrance to the Lancaster sound, increasing the risk of vessel impacts and noise pollution (Halliday et al., 2022). In particular, the Mary River Mine on Baffin Island accounted for almost all the shipping traffic in 2019, with most of the vessels being 105-foot-long bulk carriers (Jones, 2021). A significant amount of this traffic occurs near migration routes and seasonal grounds for both narwhals and belugas, placing them at risk specifically (Halliday et al., 2022). Bowhead whales, Atlantic walrus, and the two seal species did not exhibit a significant presence in the area during the study's timeframe, so concerns over them are currently not as high (Halliday et al., 2022).

While the legislation for the TINMCA does not state any limitations on vessel speed or other traffic regulations, the precedent for new regulations may still exist. As the legislation for the marine conservation area affirms the general right of Inuit communities to participate in managing responsible shipping practices, there is precedent for shipping restrictions to be applied if Inuit groups or the federal government decides that there is an unacceptable risk for marine mammals in the conservation area (Qikiqtani Inuit Association and Government of Canada, 2020). While not created to protect Arctic species, it was found that reducing vessel speed of ships longer than 65 feet to 10 knots or less reduced the strike related mortality of right whales by 90% while they were seasonally active in shipping areas (Conn and Silber, 2013). This same speed has also been shown to reduce noise pollution by an appropriate amount for resident killer whales, a species that utilizes echolocation and other vocalizations in a similar fashion to belugas and narwhals (Whitlow et al., 1989; Koblitz et al., 2016; Joy et al., 2019; Vergara et al., 2021; Ames et al., 2021). It should be reiterated however, that there was no information regarding specific Mary River Mine vessel related mortalities or an estimate on how many narwhals the noise pollution affects, so they cannot be accurately assessed with the vulnerability frameworks utilized in this paper (COSEWIC, 2004). If other stressors remain negligible in the Arctic, seals and walruses may eventually require more specialized area protection plans than cetaceans in order to preserve the last remaining locations suitable for breeding. If whales are permitted to continue to replenish their populations, then their vulnerability may not be as severe as what the framework results suggest, but it would be prudent to monitor any new areas that become suitable for cetacean inhabitation regardless.

Assuming that anthropogenic activity can remain limited in the Eastern Canadian Arctic, perhaps the largest variable relevant to marine mammal populations is the level of killer whale presence in the region. Historically, killer whales were prevented from entering the wider Canadian Arctic and its polynyas due to the sea ice that blocked their passage (Matthews et al., 2019). However, shorter ice-covered seasons and less ice coverage in general has resulted in a higher number of killer whales being able to travel further into Arctic waters in the recent decades (Lefort et al., 2020). As killer whales will readily feed on each of the marine mammals discussed in this paper and are the only regular predators of belugas, narwhals, and bowheads apart from human harvesting, an increase in their presence may eventually contribute to a large portion of non-natural mortalities of multiple Arctic species (Higdon et al., 2011; Lefort et al., 2020). Unlike purely anthropocentric impacts, there were no obvious or feasible policy implementations to address the spread of Orcas in the Arctic found in the literature review.

While a growth in Arctic Orca population and subsequent increase in apex predation pressure is a negative influence on many of the native marine mammal populations in the region, their presence may yield some unexpected benefits for other at-risk species. A 2015 study of the Foxe Basin showed that Orcas have begun to regularly feed on Bowhead Whales in the region. While this is undoubtedly a stressor on local Bowhead populations, it was found that the remains of predated carcasses would drift to the coastline and allow Polar Bears to scavenge from them (Galacia et al., 2016). Although there has been a trophic shift that has removed Polar Bears from apex predator status, this may be a positive change. Along with most other locations in the Arctic, the Foxe Basin has been steadily losing sea ice from climate change (Hayden et al., 2020) This not only results in a reduction of critical habitat for various seal species, as seen earlier in this project, but deprives Polar Bears of their travel routes and hunting grounds, denying them access to their traditional prey (Hamilton et al., 2014). This sudden influx of consistent carcass availability may allow for the subsidization of Polar Bears that can no longer hunt as efficiently as in the past (Galacia et al., 2016). Due to this mix of positive and negative interactions, it is difficult to determine if the rising presence of this species in Arctic ecosystems should be seen as a positive or negative outcome. Combined with the Orca's immense influence in conservation and the public consciousness as a charismatic species, any control options, especially those that involve directly culling, may be met with backlash from various parties (Roberge, 2014). Nonetheless, many Inuit hunters in Canada express negative opinions towards the species for competing with them for whales and seals, while communities in Greenland already hunt Orcas when able to (Westdal et al., 2013; CBC News, 2014). If the presence of Orcas in the Eastern Canadian Arctic is eventually determined to be mostly negative, then it may be beneficial to promote selective harvesting of the species to reduce predation pressure on native Arctic marine mammals.

Section 4.1.2: Marine Fish

In contrast to the shared vulnerabilities seen across the marine mammals, the three fish species greatly varied regarding which sensitivity traits scored the highest. As the species exhibit significantly different life history requirements and are only distantly related to one another taxonomically, this was to be expected.

Out of the three fish species, the Greenland shark appears to be the least vulnerable to climate change related impacts. The species' non-specific habitat and dietary requirements, along with a seemingly uncomplicated reproductive strategy, means that there is little to be disrupted by climate change, and that individuals can likely acclimate to new conditions (Devine et al., 2018; Julius et al., 2019; Carter and Soma, 2020). However, its exceedingly long maturation time of at least 134 years is excessively high, even when compared to other slow developing species like the bowhead whale (Nielsen et al., 2016). As such, each death of an adult at prime breeding age will take a substantial amount of time to replace. While their populations are currently thought to be stable, their elusiveness makes it difficult to confirm this, raising uncertainties over the true impacts of anthropogenic mortalities, such as bycatch (Cosandey-Godin et al., 2014).

While the Arctic char was assigned the same vulnerability score as the Arctic cod, it is difficult to determine if this score is accurate. Although the sensitivity and exposure scores are applicable enough for adult, anadromous Arctic char, the juvenile and lake dwelling char are constantly exposed to freshwater habitats that are likely too small to be accounted for by the climate maps generated by the NOAA's climate change portal (NOAA, 2014). Despite not being reflected in the exposure maps, these freshwater systems are expected to increase in temperature and acidity at a faster rate than marine environments (Scanes et al., 2020). Along with temperature increases, salinity may also become a limiting factor as sea levels rise and salt water enters freshwater systems (White Jr and Kaplan, 2017). While adults can survive in marine conditions, it is only a seasonal adaptation, with their ability of osmoregulation significantly declining in the winter months (Finstad and Nilssen, 1989). Furthermore, juveniles and lake-locked individuals are also less tolerant of high salinity content than their adult, anadromous counterparts (Nilssen, 1989; Dempson, 1993; Staurnes et al., 2011). As the original framework focuses primarily on purely marine species, salinity tolerance was not included as a sensitivity trait (Hare et al., 2016). While mitigation methods exist for saltwater intrusion in freshwater systems, there require infrastructure that would likely be too difficult to implement in remote Arctic islands (White Jr. and Kaplan, 2017). Continued monitoring of char bearing rivers prone to salinity buildup is likely the only available option for the foreseeable future.

Perhaps the most notably vulnerable species of the three is the Arctic cod, due to the higher confidence in how the species will be affected in the Eastern Canadian Arctic. Due to the lesser amount of sea ice coverage predicted to occur by 2055, the opportune timeframe for mass spawning events may be shortened, and habitat with sea ice coverage sufficient to help larvae develop reduced (Huserbraten et al., 2019). Furthermore, the increase in shipping traffic and subsequent noise pollution is known to scare cod away from foraging grounds and other mass congregations, further reducing their fitness (Ivanova et al., 2019). As a result of this habitat loss, Arctic cod abundance is expected to decline by 50% by the year 2100 (Florko et al., 2021). While no literature regarding restricting vessel speeds to reduce noise pollution for fish was found, the previously discussed restrictions intended to protect marine mammals may be beneficial for Arctic cod as well.

Arctic cod in the Eastern Canadian Arctic should be monitored extensively due to their importance in the regional food web. Out of the 8 other species discussed in this paper, 5 were found to rely on predictably accessible Arctic cod stocks for a non-negligible portion of their diet, with the exceptions being bowhead whales, Arctic char, and Atlantic walrus (Finley and Evans, 1983; Nielsen et al., 2014; Matley et al., 2015). As cod are expected to be replaced by temperate fish species, such as sand lance, this may disrupt the feeding behavior of higher trophic species, especially if the new species do not follow similar seasonal distribution patterns that cod predators have adapted to (Welch et al., 1993; Florko et al., 2021). If the new species are unsuitable for consumption by marine mammals, then this loss of ice cod stocks may offset the benefits for the predator species discussed previously. However, similar to their response to a loss of sea ice, bowhead whales may benefit from a decline in Arctic cod abundance, or at the very least be unaffected. As Arctic cod also heavily rely upon *C. glacialis* and other closely related copepods, they may be a direct competitor with bowhead whales for prey access, meaning that their decline in abundance would allow bowheads more feeding opportunities (Pomerleau et al., 2012; Matley et al. 2013).

Section 4.2: Data Gaps and Suggestions for Future Research

Due to the wide variety of species considered, along with their specific life history requirements and vulnerabilities to future climate change, there is no one plan that would efficiently address all their needs at the same time. Filling in the data gaps outlined below requires multiple separate observation programs, research projects, and management plans. In general, a greater interest in Arctic marine ecosystem conservation, followed by an increase in funding and logistical support for research from governing bodies is required.

Section 4.2.1: Marine Mammals

As with the vulnerability scores, the data quality scores were mostly in line with expectations prior to the literature review. This research attention and knowledge bases likely come from each of the species' charismatic nature to the public, their presence in traditional Indigenous knowledge, and the international cooperation involved in helping their stocks recover from historical overharvesting (Moore and Hauser, 2021; McGowan et al., 2020; Nelms et al., 2021). As shown in the literature review results, the most seen data gaps were regarding the species' population abundances and trends, along with cumulative stressors.

In the cases of the three cetaceans and the Atlantic Walrus, evaluating their population abundances and trends has been done before, albeit sporadically, and have produced results usable for conservation initiatives (Innes and Stewart, 2000; Richard et al., 2009; Stewart et al., 2013; Doniol-Valcroze et al., 2019). Their predictable seasonal movements, relatively limited numbers, and designation into separate management units, such as the Bering-Chukchi-Beaufort and Eastern Canada-West Greenland designations of bowhead whales, have made it possible to survey species health in different areas across the Canadian Arctic (COSEWIC, 2012). These previous studies have only been excluded from the vulnerability assessment as Lettrich et al.'s framework only allows for abundance surveys that have been conducted in the past 10 years (Lettrich et al., 2019). As the previous methods of aerial and drone-based surveys have been proven to produce results usable in conservation planning, there is little to change in this regard (Richard et al., 2009). However, these surveys may need to be conducted on a more frequent basis if potential sources of anthropogenic disturbances increase in the upcoming decades in the Eastern Canadian Arctic.

As stated before, population abundance measurements are more difficult to perform on ringed and bearded seals due to high population numbers, individuals being obscured underwater or in snow dens, and a lack of discrete management unit designations (Green et al., 1995). As such, a lack of proper observation strategies may result in climate change related population declines going unnoticed. To remedy the general confusion associated with surveying large, undefined populations, it may be prudent to divide the species into observable management groups. While there is likely no hard barrier separating ringed seal populations throughout Canada, there are several tendencies that vary between individuals at differing latitudes that may help to create separate management groups. As referenced in the results section, the dietary habit of the ringed seal varies with Southern individuals eating a mixture of prey items, while Northern seals rely almost exclusively on Arctic cod (Yurkowski et al., 2016). Furthermore, the annual timing of whelping seasons occurs at least two months earlier in lower latitudes than in the Eastern Canadian Arctic, changing the time period at which the species is at its most vulnerable to disturbances such as vessel traffic and ice breaking (Smith, 1973, 1975; Niemi et al., 2013; Wilson et al., 2017). Finally, the migration routes of seals living in Hudson Bay, Baffin Bay, and the Western Canadian Arctic all take their respective individuals to separate locations, reducing the chances of seals from each location interacting and breeding with one another (Martinez-Bakker et al., 2013; Yurkowski et al., 2016). A split between populations living in Eastern Canada and Western Greenland may also be beneficial, as there are doubts over how many individuals travel between the two coastlines (Ogloff et al., 2021). All these life history variations between locations may eventually result in different threats and conservation requirements as well, meaning that a single management group and protection strategy would not be effective. There was no literature found to suggest similar variabilities in bearded seals, but as these two species have been appearing in new conservation priorities in recent years, future studies may reveal more characteristics to help differentiate between populations.

As for detecting seal dens during whelping seasons, there is no method that has been shown to detect enough seals over a large enough area to form a population estimate. Dogs have been traditionally used to locate dens through smell, but this is limited due to the large distances that they must travel over ice patches, along with the stress both animals would be exposed to when forced to interact with one another (Kingsley et al., 1990). While it would not be effective over extreme ranges, the use of aerial drones may help to observe seals during whelping season and when they are on sea ice (Kingsley et al., 1990). Drones equipped with infrared cameras have been successfully used to observe polar bear dens beneath snow and can detect heat signatures from 180 meters in altitude, potentially high enough to avoid disturbing individuals during critical life history processes (Kingsley et al., 1990; Ryabov, 2020). To avoid the worst of shipping impacts in terms of ice-habitat destruction and noise pollution, aerial surveys using infrared camera equipped drones could be performed at the start of whelping season, that taking place in March to May (Smith and Stirling, 1975). As this takes place just weeks before the sea ice begins to break up, surveying at this time would allow for the early location of areas with high den density and subsequent planning of shipping routes around them (Smith and Stirling, 1997; Copland et al., 2021).

While there appears to be a lack of urgency from the government literature regarding anthropogenic threats towards marine mammals in the study area, the lack of actual mortality rates makes Lettrich et al.'s framework inapplicable for cumulative stressors. However, even if each death from a cumulative stressor were able to be tracked, it would still not be enough to determine if it would be significant enough to include in the vulnerability assessment. As Lettrich et al's framework only considers a lethal stressor if it accounts for 10% or more of a population's annual mortality rate, the natural death rate must be known as well (Lettrich et al., 2019). Natural mortality rate, referred to by the variable M, is often difficult to measure directly, due to the high effort required to track the large number of individual deaths needed to make an assessment (Dureuil and Froese, 2021). These difficulties are likely further compounded by the remote and inaccessible nature of Arctic marine species. The only species whose population referenced in this paper that has a natural mortality rate that was found during the literature review is the Atlantic walrus, with an annual natural death rate of 2% of the population per year (Witting et al., 2017). It is expected that the rest of the marine mammals discussed in this paper will have similarly low mortality rates, due to their long lifespans and slow reproduction (Fay et al., 2006; Witting et al., 2019).

Although it is a generalized approach, Dureuil and Froese have shown that it is possible to calculate an approximate natural mortality rate through population-age related proxies. This method is summarized with the following equation:

$$\boldsymbol{M = -(\log_e(P))/t_{max}}$$

In this formula, M is the natural mortality rate, t_{max} is the mean age of the longest living 10% of the population, and e is Euler's constant. P is the proportion of the population that survives to the average maximum age for the species (Dureuil and Froese, 2021). While this method has been shown to work for marine mammals, it is still difficult to calculate a mortality rate for the species mentioned in this paper due to age-population structures being absent from the literature. As with abundance estimates, more recent and frequent population surveys are required to gain a greater understanding on these aging, growth, and death dynamics.

For individual marine mammal species, the most pressing data gap is found in the High Arctic beluga populations. While it was enough to provide a sensitivity score, there was no explanation provided in the literature for why the average life expectancy for this population is 15 years, less than half of what is typical in other populations in Canada (COSEWIC, 2004). If this measurement is accurate, it means that females on average would have just 1 offspring before death (COSEWIC, 2004). This could potentially result in the replacement rate of the population becoming insufficient should cumulative stressors increase in the future. The literature does not suggest that this population is exposed to any chronic disturbances that would lower their lifespans that other belugas would not experience as well. On the contrary, belugas at higher latitudes were often found to be older and larger when compared to their Southern counterparts, but there were not enough samples taken in the Baffin Bay to confirm if this trend remains true for the management group (Luque and Ferguson, 2010). Human harvesting, one of the other stressors of note in COSEWIC documents, does not appear to preferentially target specific age brackets, with the average age of killed individuals in other regions being almost 10 years higher than the High Arctic population’s average lifespan regardless (Harwood et al., 2002). Similar to ringed and bearded seals, belugas in this region may benefit from being split into 2 separate management groups, as there is uncertainty over how many belugas migrate to Greenland to overwinter (COSEWIC, 2004). As harvesting occurs more often in Greenland and is considered a more pressing stressor than hunting in Canada, identifying a distinct Canadian population may help to determine the full impacts of human hunting, and more accurately reflect the lifespan of individuals that do not cross Baffin Bay (COSEWIC, 2004).

Section 4.2.2: Marine Fish

The lack of information regarding some of the sensitivity traits was also in line with prior expectations. As fisheries, both commercial and traditional, are important proxies of information for marine fish, their relatively small presences within the TINMCA limits what data can be obtained for both commercial and bycatch species (Drew, 2005; Moriarty et al., 2020). As opposed to marine mammals, the three fish species in this project do not spend large periods of time at or near the surface, making it less likely that they will be observed by researchers or members of the public.

As stated previously, the most pressing issue for Greenland sharks found in this literature review is uncertainty over their reproductive and early life habits. The framework adapted from Hare et al. automatically assigns a sensitivity score of low to these traits for the species. This is due to the Greenland shark being an elasmobranch, a taxon that either lays eggs more durable than that of a typical fish, or exhibits ovoviviparity, allowing their young to develop while shielded from the elements and predators (Kruger et al., 2020). However, as stated earlier, their long maturation time, coupled with the general uncertainty over the presence of females and newborn individuals in the Canadian Arctic makes it unknown whether their reproduction is being disturbed (Edwards et al., 2019). As juveniles have been observed in the Scott Inlet, a series of channels within Baffin Island, it is possible that this area and nearby channels could be nursery grounds for offspring to grow before entering the wider Canadian Arctic (Hussey et al., 2015). To further confirm these areas as nursery grounds and to estimate potential population densities, the use of baited remote underwater video (BRUV) cameras should be utilized. Previous Greenland shark surveys have shown that this equipment is effective in identifying individual sharks, along with their sex and general age (Devine et al., 2018). At the same time, using this equipment can help measure the population density in an area, helping to find locations with high abundances that may need to be preserved (Devine et al., 2018). What remains to be seen from these observations is whether females travel to these channels to birth their young, or if the young migrate on their own after being born. Regardless, another data gap to address is the uncertainty over migration routes taken to reach these nursery areas. As the closest adult females are known to occur within the waters of Western Greenland, it is likely that either the mother or offspring would need to cross the Baffin Bay to reach these nursery grounds in Canada, placing them at risk of becoming bycatch in the Greenland halibut and Northern shrimp fisheries that operate in the same area (Bryk et al., 2018; Fisheries and Oceans Canada, 2018, 2020; Nielsen et al., 2020). Once the locations of any nursery grounds in the Canadian Arctic are confirmed, along with when offspring reside there to develop, it may be beneficial to prohibit fishery activity in these areas until pups are able to travel into the wider marine ecosystem.

As it had the highest average data quality score out of the three fish species discussed in this paper, there are few significant data gaps missing from Arctic char vulnerability in the Eastern Canadian Arctic. Properly assessing the total population of Arctic char in the region is likely impossible, due to the large number of rivers that host spawning char each year (Sebastien-Moore et al., 2013; Bilous and Dunmall, 2020). Instead, the current *ad hoc* approach of evaluating rivers near industrial development or used for fishing activity may be sufficient.

Like the Greenland Shark, the most pressing data gaps in Arctic cod apart from stock size is the uncertainty surrounding the timing and locations for their mass spawning events. While the general concept surrounding their reliance on seasonal sea ice formation and mass migrations to reach spawning grounds is known through stocks in other countries, little is known regarding these factors for cod in the Canadian Arctic (Kessel et al., 2017). As the majority of the TINMCA experiences fewer months with complete sea ice coverage than the Bering Sea, an area where data on cod spawning behavior exists, this could result in Eastern Canadian Arctic cod having drastically different timings and movement behaviors than other stocks, ultimately influencing when the recommended seasonal vessel speed restrictions suggested in section 4.1 should be practiced (NSIDC, 2021). As tracking seasonal movements of Arctic forage fish is a new concept and there are no major fisheries in the area that could help locate them, the only realistic method to learn more about cod spawning in the Eastern Canadian Arctic is to continue performing telemetry analysis on cod in the region (Ponomorenko, 1968; Kessel et al., 2017).

Despite the relative lack of information found for marine fish regarding some of their sensitivity traits, it is likely that the literature able to supplement these gaps can be found elsewhere, outside of the electronic databases consulted for this project. In particular, it is likely that details on stock dynamics for the Arctic cod and Arctic char exist in Russian databases, as these species are prominent in the country's fisheries (Honneland, 2004; Zhuraleva and Trotcenko, 2020). Additionally, as the Greenland shark is also found in Russia within the Barents Sea and is a regular bycatch item, there may be observations or local knowledge detailing the species' more elusive seasonal behavior (Rusyaev and Orlov, 2013). However, much of the fishery data dates to the mid-20th century during the cold war, resulting in withheld information that may now be fragmented or incomplete (Popov and Zeller, 2018). Finally, the information may be presented in Russian or Cyrillic script, excluding it from English search engines, such as Novanet, and making it difficult to understand for researchers that are not literate in Slavic languages (D. Chiasson, personal communication, May, 2021). Even if any relevant information is able to be recovered and translated, it would only be given a data quality score of 2, as it would be regarding fish populations outside of the Tallurutiup Imanga NMCA and Eastern Canadian Arctic as a whole.

Section 4.3: Summary of Recommendations

In summary, each of the species exhibit potentially high vulnerabilities to climate change, but the degree of how vulnerable they truly are is highly dependent on how human activities continue to develop in the Canadian Arctic. The most notable recommendations for addressing data gaps and species vulnerabilities as seen in this paper are:

- Cetaceans have the potential to suffer high abundance losses in the upcoming decades, but only if direct, anthropogenic mortalities become commonplace. Frequent population abundance and age structure surveys should be conducted on a regular basis to establish natural mortality rates and assess the true effects of human activity on marine mammal populations and their death frequencies. A direct assessment of the impacts of human disturbances on marine mammals is not possible without a greater understanding of each group's population dynamics.

- Further observations are required on the age-population structure of belugas in the Eastern High Arctic/Baffin Bay population to reassess their abnormally low average lifespan of 15 years. Dividing the population into 2 sub-groups, Eastern Canadian Arctic and Western Greenland, may help to determine if the high harvesting rates in Europe are having a disproportionate impact on the entire population's lifespan calculation.

- Further studies of killer whales in the Arctic should be conducted to further understand their effects on the ecosystem. The promotion of selectively hunting orcas may be a method to limit the species' impact if they are found to be a net-negative influence.

- Pinnipeds are essentially guaranteed to suffer high abundance loss, due to the projected decline in sea ice available during their sensitive whelping seasons. To make surveys on ringed seals more feasible, the entire population should be broken up into subgroups, consisting of Western Canadian Arctic, Eastern Canadian Arctic, Hudson Bay, and Western Greenland management groups, with further divisions created if needed.

- Infrared camera equipped drone assisted surveys should be performed at the start of ringed seal whelping season, March to May, to find high densities of whelping dens and allow for the planning of shipping around them.

- The Greenland shark's lengthy maturation time means that females and offspring are potentially vulnerable to unnatural deaths. Nursery grounds and migratory paths to these areas should be surveyed for using satellite tagging and remote cameras in suspected locations. Discovered nursery grounds should be protected with seasonal fishery closures while females travel to give birth and offspring develop.

- Arctic char spawning rivers should continue to be monitored on an *ad hoc* basis, with additional attention being given to locations at risk of salinization.

- Arctic cod stocks should be heavily monitored due to their expected heavy decline in abundance and status as a staple prey item in the Arctic food web. Annual large-scale movements should be monitored to determine when and where spawning begins. Vessel speed restrictions during these timeframes may help to keep critical spawning behavior from being disturbed.

- Outreach and cooperation efforts should be conducted with Russian and Northern European fisheries to search for data that may help to fill in the remaining data gaps

Section 4.4: Additional Species for Consideration

The species examined in this project has been limited to vertebrate macrofauna and megafauna that are often seen as charismatic species and specifically acknowledged during conservation planning. While this selection provides a general overview of the vulnerabilities and future needs of many species at the top of the trophic chain and at the forefront of public perception, it fails to provide a holistic view of the wider Arctic ecosystem. While including every species known to occur in the Eastern Canadian Arctic or even just the Tallurutiup Imanga NMCA in this vulnerability assessment is far beyond the scope of this paper, it is possible that critical species interactions are being missed by failing to provide enough variety in the vulnerability assessment.

The inclusion of rare but ecologically invaluable invertebrates such as corals, sponges, and sea pens would have provided additional insight due to their habitat formation and community supporting capabilities (Cathalot et al., 2015; van den Beld et al., 2017). Additionally, their unique conservation threats, such as the destruction of the benthos, slow growth time, and vulnerability to environmental heavy metal poisoning would have created a notable contrast in the cumulative threats section (Freiwald et al., 2004; Sabdono, 2009; Brooker et al., 2017). Furthermore, as each of the species assessed in this project are surface dwelling, pelagic, or semi-pelagic, the inclusion of benthic species would help to diversify the environments included in this study. As corals are being found at increasingly higher latitudes, including in the Baffin Bay, as more surveys are being conducted it is worth searching for undiscovered communities in the TINMCA before excessive shipping or mining activity grows further (Pierrejean et al., 2020).

Crustaceans, such as the Northern shrimp (*Pandalus borealis*), could be studied using the marine fish framework as well, and should be assessed due to their important link in the Arctic trophic web (Kortsch et al., 2015). Currently, the relative lack of fishery activity within the Eastern Canadian Arctic, along with a relative lack of focus in conservation initiatives result in a loss of proxies for information on these species (Fisheries and Oceans Canada, 2018; Roff et al., 2021). As the shrimp fishery is only limited by the presence of inaccessible sea ice during the winter months, climate change may allow for constant exploitation of these stocks to an unknown effect (Fisheries and Oceans Canada, 2018).

While considered a marine mammal by conservation groups, it is difficult to determine if the marine mammal framework used in this paper would apply for polar bears, another high-profile Arctic species expected to suffer climate change related population declines (Peacock et al., 2011). Being the only water-obligate ursid and confined to the Arctic, Lettrich et al made no mention of their framework's application to the species, as their original work is intended for global application and not specialized for polar species. Many of the sensitivity traits, such as slow reproduction and obligation to specific ice habitat conditions are seen in polar bear populations, making at least some of them appropriate for climate sensitivity analysis (Rode et al., 2018). However, other traits, such as the polar bear's partially land-based migrations, makes it difficult to compare to the fully aquatic movements of pinnipeds and cetaceans (Cherry et al., 2013). Furthermore, many of the exposure traits, such as water acidity, oxygen content, or salinity are included due to their potential effects on fish and invertebrates, species that are commonly present in the diets of marine mammals (Lettrich et al., 2019). As polar bears are apex predators and feed primarily on pinnipeds and carrion, both of which are not known to be directly impacted by the above environmental parameters, it is difficult to determine if these exposure factors would be applicable to the species to the same extent as those discussed in this paper (Gormezano and Rockwell, 2013).

The final functional group that should be considered in future assessments are the seabirds that inhabit the sea ice and remote islands in the Eastern Canadian Arctic and Archipelago. Species in this group that are thought to be vulnerable to climate change and have already received at-risk classifications include the ivory gull (*Pagophila eburnea*), thick-billed murre (*Uria lomvia*), and little auk (*Alle alle*). Like the vulnerabilities seen in pinnipeds and cetaceans, each of the mentioned sea bird species display extreme site fidelity during breeding and chick rearing, in the form of philopatry towards the breeding colony of their birth (Steiner and Gaston, 2005; Mallory et al., 2012; Keslinka et al., 2019). As each breeding colony often hosts tens of thousands of individuals, often accounting for as much as 20% of a species' Canadian population, disruption to these areas, whether from sea level rise or human disturbance, can severely impact a significant portion of their reproductive potential (Iverson et al., 2014; Government of Canada, 2019). However, producing exact climate change vulnerability estimates for seabirds in the Canadian Arctic is more difficult than for marine mammals or fish, due to a lack of pre-existing, suitable frameworks. Trait-based climate change vulnerability assessments for birds do exist, but most are inapplicable as many of the sensitivity and exposure traits focus on foliage habitat requirements or deforestation rate, factors that are irrelevant for sea birds and Arctic species (Foden et al., 2013).

Section 4.5: Limitations and Sources of Error

Due in part to the scale of this project, number of species examined, and general uncertainty associated with both vulnerability assessments and Arctic ecosystems, it is inevitable that there will be some potential inaccuracies regarding the results. As such, there are a number of potential sources of error that should be acknowledged to maintain transparency and recognize the limitations still associated with vulnerability assessments in the Canadian Arctic.

The first limitation to mention is the uncertainty over the actual intensity of climate change that will be experienced in the upcoming decades. The exposure maps used for this project's vulnerability assessments were created using data from the RCP8.5 scenario, modelled by the Intergovernmental Panel for Climate Change. Included in a list of seven total scenarios, RCP8.5 is considered the worst case or "business as usual" trajectory, with a temperature increase ranging from 1.4°C to 2.6°C by 2065 (IPCC, 2014). As there are six other potential, less intense trajectories made possible depending on how much effort is given to curb global greenhouse gas emission, the future change in climate parameters is less certain than what this paper would imply. While this would not change the sensitivity traits based on each species' life histories, total vulnerability scores would likely be lower if exposure scores turn out to be less intense as well. However, adhering to the precautionary principle and preparing for a worst case climate change scenario regardless of which emissions projection occurs may be prudent.

To maintain simplicity and keep the results relevant to potential management decisions within the Tallurutiup Imanga National Marine Conservation Area, certain aspects of the vulnerability assessment frameworks had to be modified. Most notably is the alteration of how exposure for each species was determined. While the original framework considers the changing conditions across the population in question's entire range, this paper only considered how conditions would change within the confines of the TINMCA (Lettrich et al., 2019). This is not likely to impact the results of species such as the Arctic cod or Arctic char, as their known annual movements keep them in the study area, or relatively close to the border if they leave. However, for highly migratory animals with ranges well outside of the study area, such as bowhead whales and belugas, their exposure scores may be different if their whole range were to be considered (Lettrich et al. 2019). Additionally, as this study was conducted under the assumption that the Tallurutiup Imanga NMCA will host a higher relative density of Arctic species in the future due to its presence in the Last Ice Area, the results may be inaccurate if species distributions do not change or they migrate to a different area instead (Lettrich et al., 2019).

While this study is only meant to be a general assessment of climate vulnerability and data quality for Arctic Marine species, there is an aspect missing from each framework that may reduce the certainty associated with these results. In the original frameworks, and therefore in this project as well, each exposure factor was weighted equally among the species assessed. For example, while Arctic cod are heavily reliant upon the presence of sea ice to reproduce and Greenland sharks are not, both species are given the same very high exposure score regarding future ice loss. As a result, some species' exposure scores may have been artificially inflated by including parameters not relevant to them specifically. The habitat or prey specificity may help to somewhat rectify this, but the scores do not differentiate between what kind of habitat or prey a species is partial towards. In the original concept for the marine mammal vulnerability framework, the authors acknowledge this lack of weighting and its presence in other assessments but wished to minimize complexity instead (Lettrich et al., 2019).

The final limitation to this project is not specific to this project or vulnerability assessments in general. Rather, it is a systemic issue that is prevalent in environmental study literature reviews in areas with historical Indigenous community inhabitation. As literature reviews are often conducted using virtual databases consisting of peer reviewed literature, other sources of knowledge that do not conform to the empirical standards of western science can often be excluded (Alexander et al., 2019). This is especially notable in topics concerning the Canadian Arctic, where the traditional knowledge of Inuit and other Indigenous groups about the region and its wildlife have been built for thousands of years (Pearce et al., 2015). As it is unknown how much of this traditional knowledge has not been converted into or mentioned in virtually published data, it is difficult to say if this literature review and risk analysis have been completely comprehensive. While some of the scoring bins utilized by the vulnerability assessment frameworks discussed in this paper require precise numerical data, such as calving intervals or population counts, conservation planning is often conducted with traditional Indigenous knowledge (Alexander et al., 2019). As an example relevant to Arctic species, while the population trend of bowhead whales is not completely certain, observations from Inuit hunters throughout the decades have acknowledge that it has been recovering (Noongwook et al., 2007). As a result, actual conservation research and planning may have fewer quantitative requirements than the vulnerability frameworks used for this paper would suggest. Although having proper representation of traditional knowledge in published literature is important for creating a proper viewpoint of this issue, the mechanisms of how to accomplish this are beyond the scope and field of this paper and are best left to studies that cooperate with or comprise Indigenous groups directly.

Chapter 5: Conclusion

Although climate change is an observed phenomenon with drastic consequences in the future if left unmitigated, it is still difficult to accurately scope how drastic they will be. As such, it can often be difficult to determine if currently implemented measures will be sufficient to protective the planet's vulnerable marine environments. The different requirements, life history strategies, and threats each species exhibits further complicates the situation, forcing conservationists to predict what species are going to be more vulnerable in the future, and if any need to be prioritized over others. While not without its limitations, trait-based vulnerability assessments stemming from thorough literature review can help to mitigate these uncertainties, and shine light on where further research needs to be done.

As has been shown in this project, many Arctic species are sensitive to a loss of breeding habitat and human interference, but data gaps remain that prevent a complete assessment of their overall vulnerability. A greater focus on monitoring Arctic species in general would be beneficial to eliminating these gaps, but a focus on population dynamics, along with breeding behaviors and well-defined management group designations would be the most effective in determining the best strategies for future conservation initiatives.

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Appendix A. Sensitivity Trait Scoring Criteria for Marine Mammals

The scoring criteria for each of the 11 sensitivity traits used in the marine mammal vulnerability assessment framework (Lettrich et al., 2019).

Table A.1. Prey specificity scoring criteria

Score	Score Requirements
Low (1)	Generalist; feeds on a wide range of prey types and sizes.
Moderate (2)	Generalist; feeds on a limited number of prey types or sizes, but a wide variety of species within those types.
High (3)	Specialist; exhibits strong preference for one prey type for the majority of its caloric intake, but is capable of switching prey types.
Very High (4)	Specialist; reliant on one prey type, often a single genus or family, for the majority of its caloric intake, and is unable to switch to other prey types.

Table A.2. Habitat specificity scoring criteria

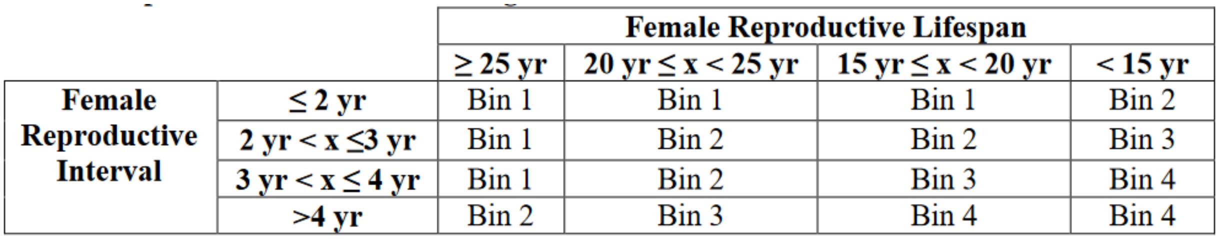
Score	Score Requirements
Low (1)	Stock exclusively utilizes physical features resilient to climate conditions.
Moderate (2)	Stock utilizes a variety of features but is not reliant on physical features vulnerable to climate conditions and/or biogenic habitat for specific life stages.
High (3)	Stock relies on biogenic habitat or physical features vulnerable to climate conditions for one life stage or event.

Very High (4)	Stock relies on biogenic habitat or physical features vulnerable to climate conditions for multiple life stages or events, or for any one particularly critical life stage or event.

Table A.3. Site fidelity scoring criteria

Score	**Score Requirements**
Low (1)	Individuals display no site fidelity.
Moderate (2)	Individuals display a low degree of site fidelity (i.e., archipelagos or coastlines of a general region).
High (3)	Individuals display a high degree of site fidelity (i.e., specific islands or bays) for either foraging or breeding.
Very High (4)	Individuals display a high degree of site fidelity (i.e., specific islands or bays) for both foraging and breeding.

Table A.4. Reproductive lifespan scoring criteria



		Female Reproductive Lifespan			
		≥ 25 yr	**20 yr ≤ x < 25 yr**	**15 yr ≤ x < 20 yr**	**< 15 yr**
Female Reproductive Interval	**≤ 2 yr**	Bin 1	Bin 1	Bin 1	Bin 2
	2 yr < x ≤3 yr	Bin 1	Bin 2	Bin 2	Bin 3
	3 yr < x ≤ 4 yr	Bin 1	Bin 2	Bin 3	Bin 4
	>4 yr	Bin 2	Bin 3	Bin 4	Bin 4

Table A.5. Generation length scoring criteria

Score	**Score Requirements**
Low (1)	x < 10 years
Moderate (2)	10 years ≤ x < 20 years

High (3)	20 years ≤ x <30 years
Very High (4)	≥ 30 years

Table A.6. Reproductive plasticity scoring criteria

Score	**Score Requirements**
Low (1)	Reproduction of the stock is described by all of the following: a) Pupping/calving season is 4 months or longer; b) Mating and pupping/calving do not require ephemeral or space-limited habitat; c) Less than half of the stock mates or gives birth in the same location; and d) A seasonal-specific behavior or physical trait entailing significant metabolic or time preparation is not required for successful mating, birth, or nursing.
Moderate (2)	Reproduction of the stock is described by all of the following: a) Pupping/calving season is greater than 1 month but less than 4 months; and b) More than half of the stock mates or gives birth in the same location.
High (3)	Reproduction of the stock is described by only one of the following: a) Pupping/calving season is 1 month or less; b) Mating or pupping/calving requires ephemeral or space-limited habitat; c) Entire stock mates or gives birth in the same location; or d) A seasonal-specific behavior or physical trait entailing significant metabolic or time

	preparation is required for successful mating, birth, or nursing
Very High (4)	Reproduction of the stock is described by more than one of the following: a) Pupping/calving season is 1 month or less; b) Mating or pupping/calving requires ephemeral or space-limited habitat; c) Entire stock mates or gives birth in the same location; or d) A seasonal-specific behavior or physical trait entailing significant metabolic or time preparation is required for successful mating, birth, or nursing.

Table A.7. Migration scoring criteria

Score	**Score Requirements**
Low (1)	Annual migration; multiple migratory pathways.
Moderate (2)	Annual migration; single migratory pathway.
High (3)	Seasonal migration.
Very High (4)	No migration; local movement only.

Table A.8. Home range scoring criteria

Score	**Score Requirements**
Low (1)	Individuals' home ranges are broad (e.g., include much of an ocean basin).
Moderate (2)	Individuals' home ranges are moderate to large (e.g., spend the majority of time along coasts, within continental shelf waters, or along the continental slope, but may utilize deeper waters).

High (3)	Individuals typically remain in bays or archipelagos and seldom travel farther but could if needed.
Very High (4)	Individuals' home ranges are relatively small (e.g., confined to bays or archipelagos) and are limited from traveling farther by a combination of geographic features, physical capabilities, and behaviors.

Table A.9. Stock abundance scoring criteria

Score	**Score Requirements**
Low (1)	Stock comprises > 10,000 individuals.
Moderate (2)	Stock comprises 1,001-10,000 individuals.
High (3)	Stock comprises 101-1,000 individuals.
Very High (4)	Stock comprises < 100 individuals.

Table A.10. Stock abundance trend scoring criteria

Score	**Score Requirements**
Low (1)	Increasing abundance trend over past 10-year period.
Moderate (2)	Stable abundance trend over past 10-year period.
High (3)	Declining abundance trend over past 10-year period.
Very High (4)	Rapidly declining abundance trend over past 10-year period.

Table A.11. Cumulative stressors scoring criteria

Score	**Score Requirements**
Low (1)	Stock currently experiences 1 or fewer additional stressors.
Moderate (2)	Bin 2 (Moderate): Stock currently experiences 2 or 3 additional stressors.
High (3)	Stock currently experiences 4 or 5 additional stressors.
Very High (4)	Stock currently experiences greater than 5 additional stressors or has one additional stressor that accounts for more than half of annual mortality.

Table A.12. Overall vulnerability scoring criteria

Score	**Score Requirements**
Low (1)	3 or more attribute or factor mean scores ≥ 3.5.
Moderate (2)	2 or more attribute or factor mean scores ≥ 2.5, but does not meet threshold for “High” or “Very High.”
High (3)	2 or more attribute or factor mean scores ≥ 3.0, but does not meet threshold for “Very High.”
Very High (4)	3 or more attribute or factor mean scores ≥ 3.5.

Appendix B. Sensitivity Trait Scoring Criteria In Marine Fish

The scoring criteria used for each of the 12 sensitivity traits used in the marine fish vulnerability assessment framework (Hare et al., 2016).

Table B.1. Habitat specificity scoring criteria

Score	**Score Requirements**
Low (1)	The stock is a habitat generalist and/or utilizes very common physical habitats.
Moderate (2)	The stock strongly prefers a particular habitat.
High (3)	The stock is a specialist on an abundant biological habitat.
Very High (4)	The stock is a specialist on a restricted biological habitat.

Table B.2. Prey specificity scoring criteria

Score	**Score Requirements**
Low (1)	The stock eats a large variety of prey.
Moderate (2)	The stock eats a limited number of prey types (3 or fewer types).
High (3)	The stock is partial to a single prey type.
Very High (4)	The stock is a specialist.

Table B.3. Sensitivity to ocean acidification scoring criteria

Score	**Score Requirements**
Low (1)	Stock not reliant on sensitive taxa.
Moderate (2)	Stock is somewhat reliant on sensitive taxa for food or habitat but can switch to alternatives.
High (3)	Stock is reliant on sensitive taxa for food or habitat and cannot switch to alternatives.

Very High (4)	Stock is a sensitive taxon.

Table B.4. Complexity in reproductive strategy scoring criteria

Score	**Score Requirements**
Low (1)	The stock contains no more than one characteristic that suggest complexity in reproductive strategy.
Moderate (2)	The stock has two characteristics that suggest complexity in reproductive strategy
High (3)	The stock has three characteristics that suggest complexity in reproductive strategy.
Very High (4)	The stock has four or more characteristics that suggest complexity in reproductive strategy.

Table B.5. Sensitivity to temperature scoring criteria

Score	**Score Requirements**
Low (1)	Species occurs in a wide range of temperatures (>15 °C) or is found across 3 or more provinces.
Moderate (2)	Species occurs in a moderately wide range of temperatures (10-15 °C), or is found across 2 provinces
High (3)	Species occurs in a moderately narrow range of temperatures (5-10 °C), or is found within one province but has a variable depth distribution.
Very High (4)	Species occurs in a narrow range of temperatures (<5 °C), or is found within one province and has a limited depth

	distribution (i.e., depth range is <100 m).

Table B.6. Larval and early life history stages requirements scoring critieria

Score	**Score Requirements**
Low (1)	Stock has general requirements for the larval stage that are relatively resilient to environmental change. Elasmobranchs should be ranked as “Low.”
Moderate (2)	Stock requirements are not well understood, and recruitment is relatively constant, suggesting limited environmental influence.
High (3)	Stock requirements are not well understood, but recruitment is highly variable and appears to have a strong dependence on environmental conditions.
Very High (4)	Stock has specific known biological and physical requirements for larval survival.

Table B.7. Stock size scoring criteria

Score	**Score Requirements**
Low (1)	B/BMSY ≥ 1.5 (or proxy)
Moderate (2)	B/BMSY ≥ 0.8 but < 1.5 (or proxy)
High (3)	B/BMSY ≥ 0.5 but < 0.8 (or proxy)
Very High (4)	B/BMSY < 0.5 (or any stock below <10,000 individuals)

Table B.8. Cumulative stressors scoring criteria

Score	**Score Requirements**

Low (1)	Stock is experiencing no more than one known stressor.
Moderate (2)	Stock is experiencing no more than two known stressors.
High (3)	Stock is experiencing no more than three known stressors.
Very High (4)	Stock is experiencing four or more known stressors.

Table B.9. Growth rate scoring critieria

Parameter	**Low**	**Moderate**	**High**	**Very High**
Intrinsic Rate of Increase (r)	>0.50	0.16-0.50	0.05-0.15	<0.05
von Bertalanffy K	>0.25	0.16-0.25	0.11-0.15	<=0.10
Age at Maturity	<2 years	2-3 years	4-5 years	>5 years
Maximum Age	<10 years	11-15 years	15-25 years	>25 years
Natural Mortality (M)	>0.50	0.31-0.50	0.21-0.30	<0.2

Table B.10. Dispersal of early life stages scoring criteria

Score	**Score Requirements**
Low (1)	Duration of planktonic eggs and larvae greater than 8 weeks and/or larvae are dispersed >100 km from spawning locations.
Moderate (2)	Duration of planktonic eggs and larvae less than 8 but greater than 2 weeks and/or larvae are dispersed 10-100 km from spawning locations.
High (3)	Duration of planktonic eggs and larvae less than 2 weeks and/or larvae typically found over the same location as parents.

Very High (4)	Benthic eggs and larvae or little to no planktonic early life stages.

Table B.11. Adult mobility scoring criteria

Score	**Score Requirements**
Low (1)	The stock is highly mobile and non-site dependent.
Moderate (2)	The stock has site-dependent adults capable of moving from one site to another if necessary.
High (3)	The stock has site-dependent adults that are restricted in their movement by environmental or behavioral barriers.
Very High (4)	The stock has sessile adults.

Table B.1. Spawning cycle scoring criteria

Score	**Score Requirements**
Low (1)	Consistent throughout the year.
Moderate (2)	Several spawning events throughout the year.
High (3)	Several spawning events per year within a confined time frame.
Very High (4)	One spawning event per year.

Table B.13. Overall vulnerability scoring critieria

Score	**Score Requirements**
Low (1)	3 or more attribute or factor mean scores ≥ 3.5.
Moderate (2)	2 or more attribute or factor mean scores ≥ 2.5 but does not meet threshold for “High” or “Very High.”

High (3)	2 or more attribute or factor mean scores ≥ 3.0 but does not meet threshold for “Very High.”
Very High (4)	3 or more attribute or factor mean scores ≥ 3.5.

Appendix C. Marine Ecoregion Map

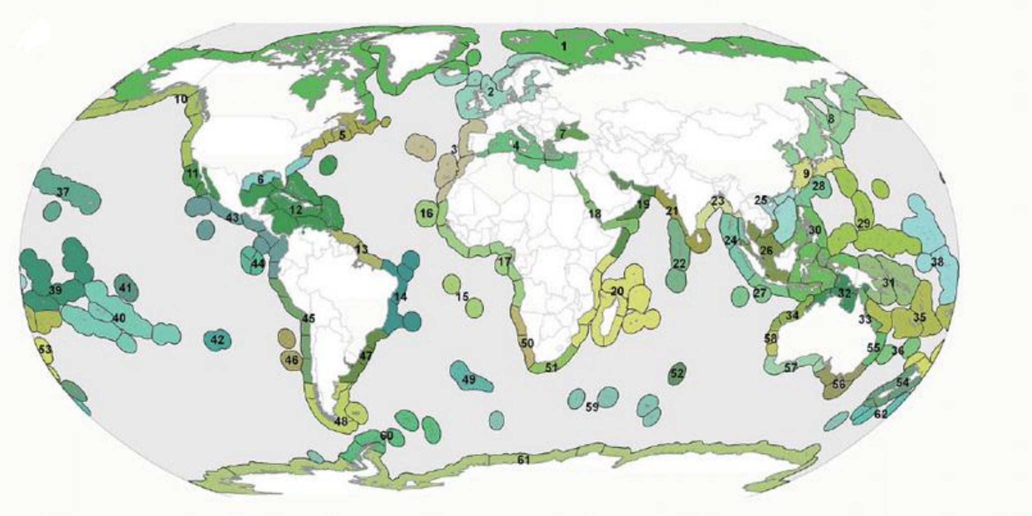


Figure C.1. Marine ecoregion map used to determine temperature tolerance in marine fish (Spalding et al., 2007).

Appendix D. Exposure Scoring Criteria

The scoring criteria for the exposure variables used in both the marine mammal and marine fish vulnerability assessment frameworks (Hare et al., 2016; Lettrich et al., 2019).

Table D.1. All Exposure Factors (excluding currents and sea level rise) scoring criteria

Score	**Score Requirements (Change in Mean)**	**Score Requirements (Change in Variability)**
Low (1)	|x| < 0.5 std dev	<1.15
Moderate (2)	0.5 std dev ≤ |x| < 1.5 std dev	1.15 ≤ x <1.54
High (3)	1.5 std dev ≤ |x| < 2.0 std dev	1.54 ≤ x < 1.78
Very High (4)	|x| ≥ 2.0 std dev	≥ 1.78

Table D.2. Current exposure scoring criteria

Score	**Score Requirements**
Low (1)	Stock distribution overlaps almost exclusively with large boundary currents or tidal currents
Moderate (2)	Majority of stock distribution overlaps with large boundary currents or tidal currents. Stock may also interact with mesoscale features such as fronts or eddies.
High (3)	Majority of stock distribution overlaps with currents that are expected to have a high magnitude of change such as estuarine circulation, nearshore density currents, and/or wind driven currents. Stock may also interact with mesoscale features such as fronts or eddies.
Very High (4)	Stock distribution overlaps almost exclusively with currents that are expected to have a high

	magnitude of change such as estuarine circulation, nearshore density currents, and/or wind driven currents.

Table D.3. Sea level rise exposure scoring criteria

Score	**Score Requirements**
Low (1)	Stock is found generally in deeper water beyond the continental shelf.
Moderate (2)	Stock is generally coastal or found in continental shelf waters.
High (3)	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and the change in regional sea level within their range is expected to increase less than 7 mm yr-1 by 2050.
Very High (4)	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and regional sea level within their range is expected to increase greater than or equal to 7 mm yr-1 by 2050.

Appendix E. Climate Change Exposure Maps

The climate change exposure maps generated by the NOAA climate change web portal detailing the change in each parameter, excluding sea level rise and currents, by 2055 under the RCP 8.5 scenario (NOAA, 2014).

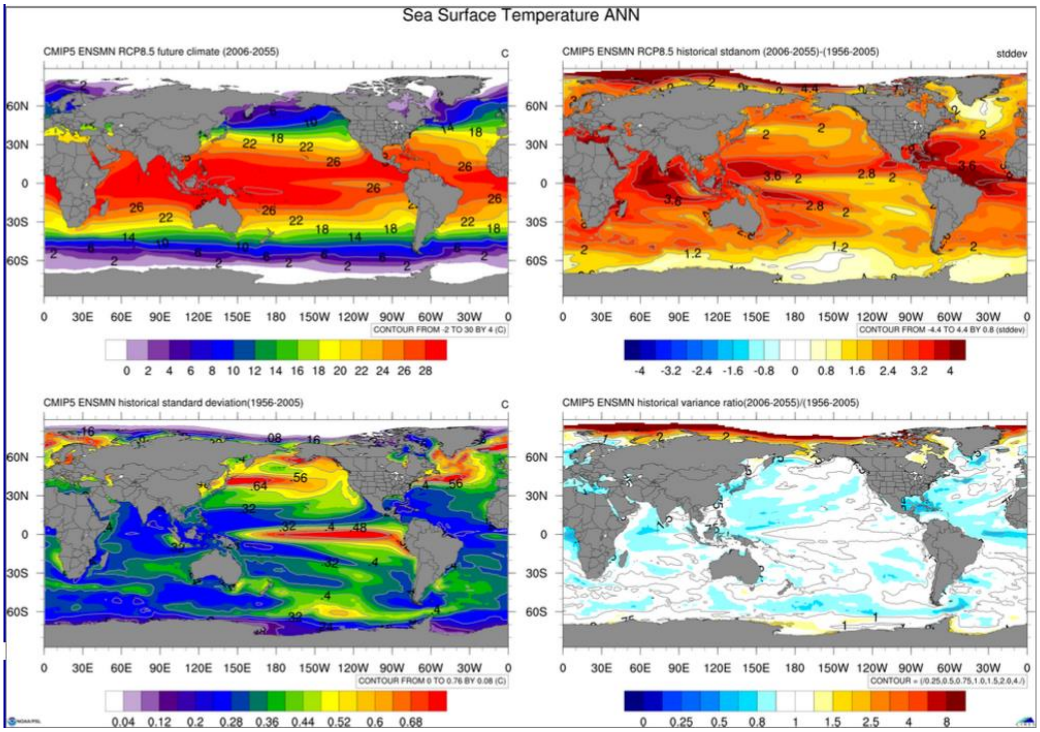


Figure E.1. Climate change exposure map for sea surface temperature by the year 2055.

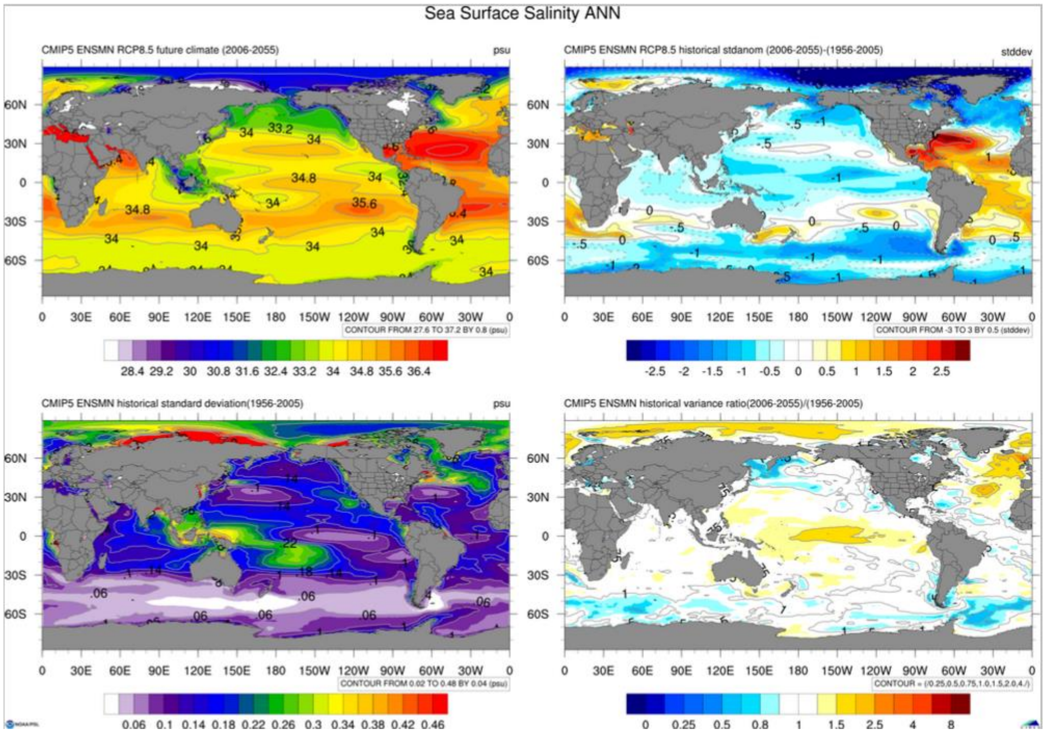


Figure E.2. Climate change exposure map for sea surface salinity by the year 2055.

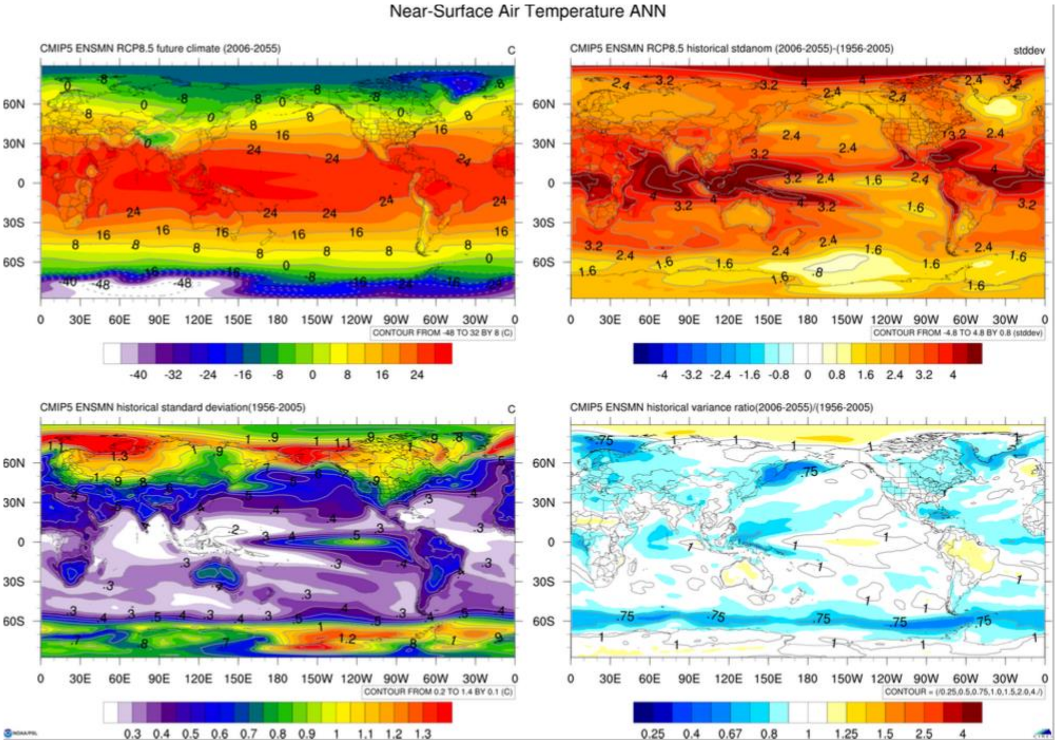


Figure E.3. Climate change exposure map for air temperature by the year 2055.

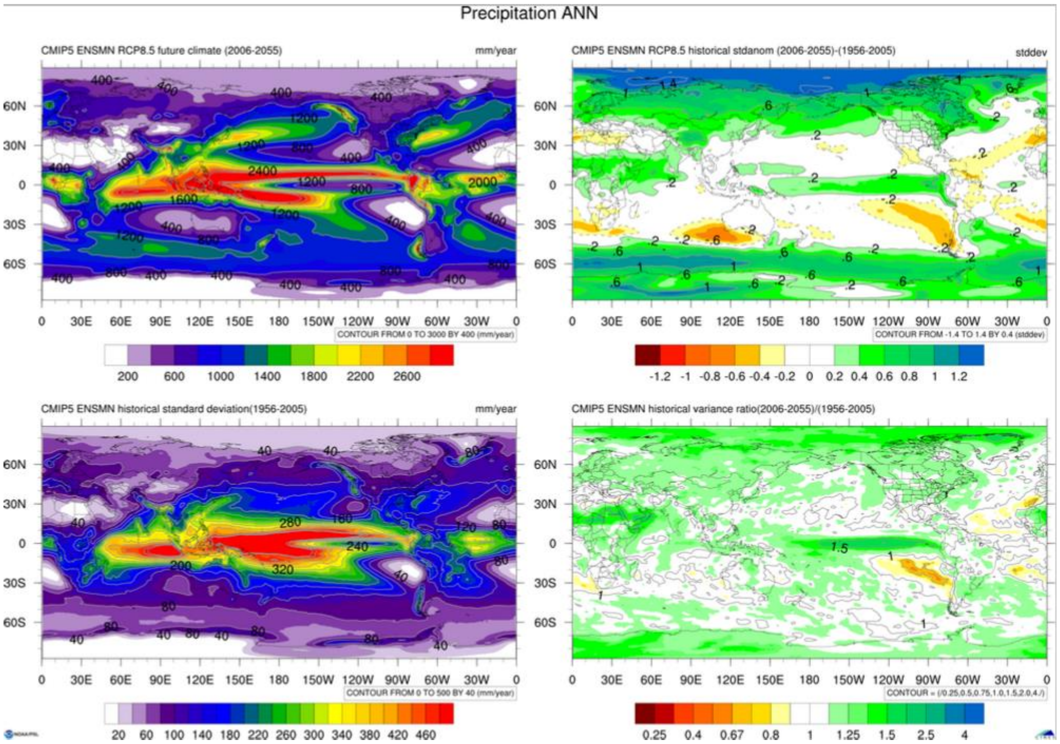


Figure E.4. Climate change exposure map for precipitation by the year 2055.

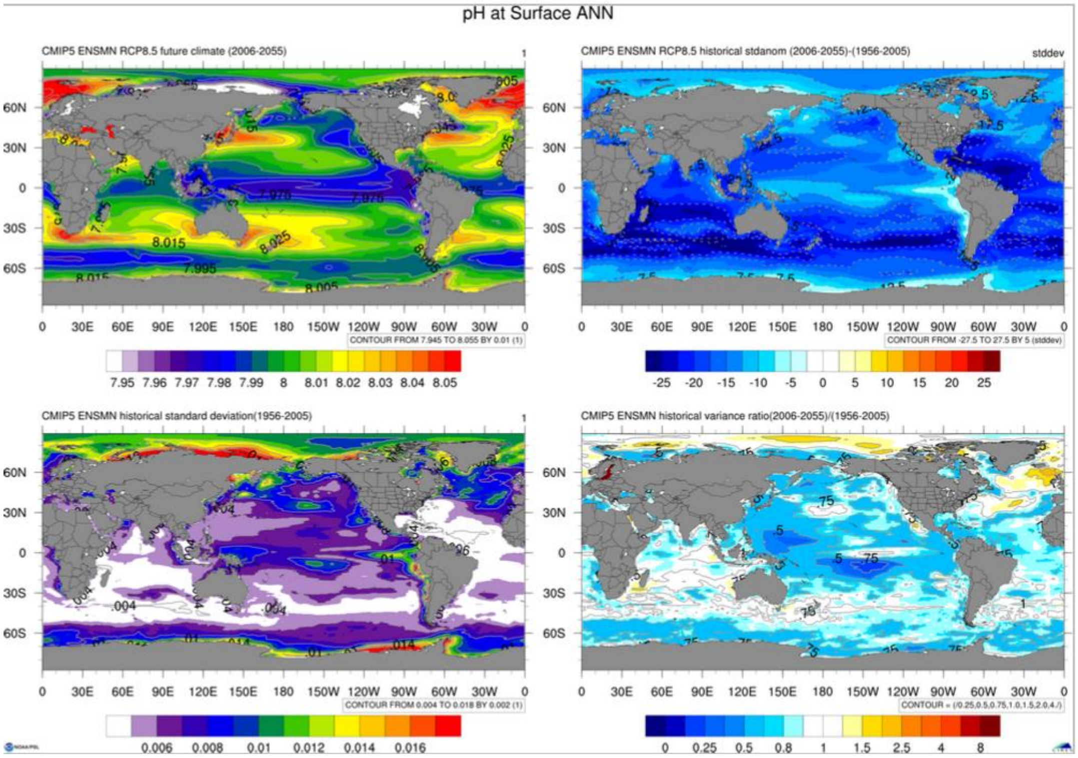


Figure E.5. Climate change exposure map for pH by the year 2055.

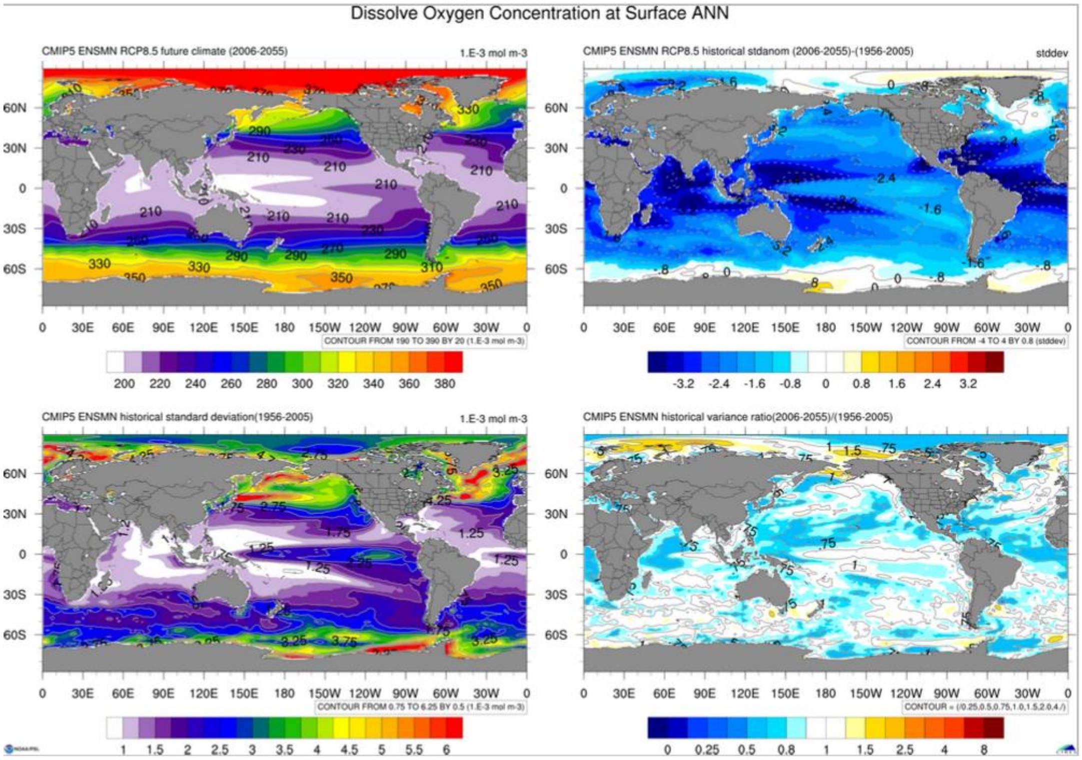


Figure E.6. Climate change exposure map for dissolved oxygen concentration by the year 2055.

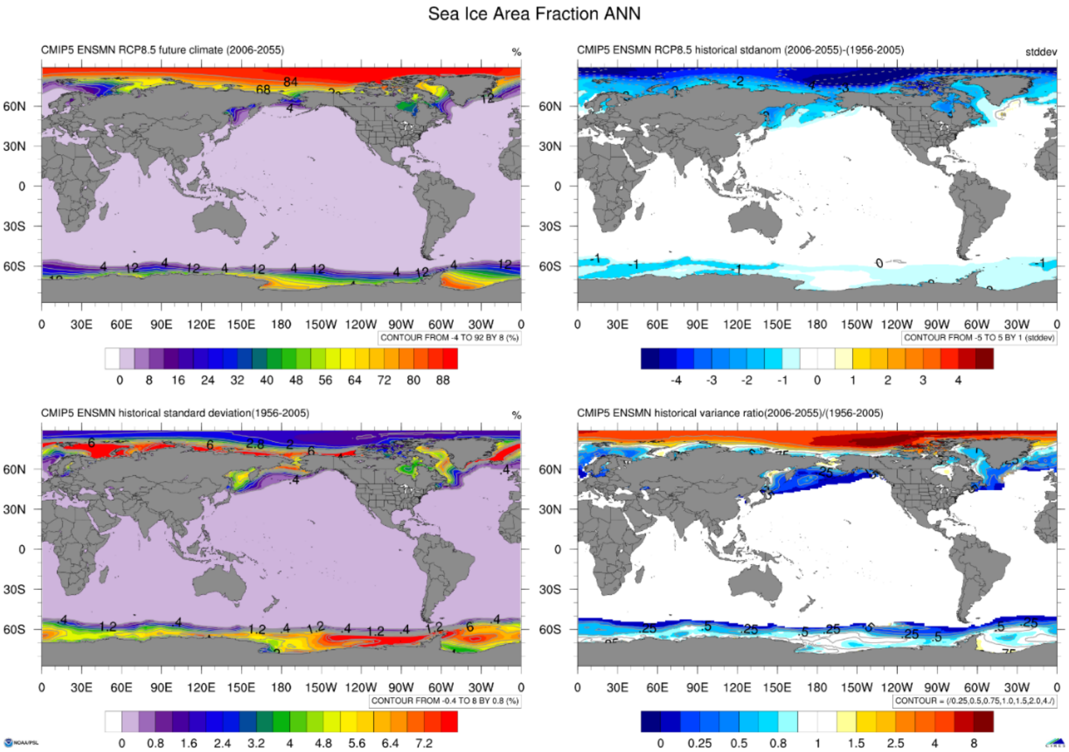


Figure E.7. Climate change exposure map for sea ice coverage by the year 2055.