Impacts of Sea Ice Loss on Polar Bear Diet, Prey Availability, Foraging Behaviors, and Human-Bear Interactions in the Arctic

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This Master’s Project

**Impacts of Sea Ice Loss on Polar Bear Diet, Prey Availability, Foraging Behaviors, and Human-Bear Interactions in the Arctic**

By

**Jasmin Chen**

is submitted in partial fulfillment of the requirements for the degree of:

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in

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Submitted: 

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Date

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John Callaway 

Date
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<tr>
<td>CAD</td>
<td>Canadian Dollar</td>
</tr>
<tr>
<td>COSEWIC</td>
<td>Committee on the Status of Endangered Wildlife in Canada</td>
</tr>
<tr>
<td>DMTA</td>
<td>Dental Microwear Texture Analysis</td>
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<tr>
<td>DU</td>
<td>Designatable Units</td>
</tr>
<tr>
<td>ESA</td>
<td>United States Endangered Species Act</td>
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<td>FB</td>
<td>Foxe Basin</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<td>HB</td>
<td>Hudson Bay</td>
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<tr>
<td>HS</td>
<td>Hudson Strait</td>
</tr>
<tr>
<td>IQ</td>
<td>Inuit Quajimajatuqangit</td>
</tr>
<tr>
<td>ISM</td>
<td>Ingenious Stewardship Model</td>
</tr>
<tr>
<td>IUCN</td>
<td>International Union for the Conservation of Nature</td>
</tr>
<tr>
<td>LME</td>
<td>Large Marine Ecosystems</td>
</tr>
<tr>
<td>MMPA</td>
<td>Marine Mammal Protected Areas</td>
</tr>
<tr>
<td>NFB</td>
<td>Northern Foxe Basin</td>
</tr>
<tr>
<td>PBA</td>
<td>Polar Bear Alert Program</td>
</tr>
<tr>
<td>PBSG</td>
<td>Polar Bear Specialist Group</td>
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<tr>
<td>SARA</td>
<td>Canada's Species At Risk Act</td>
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<tr>
<td>SFB</td>
<td>Southern Foxe Basin</td>
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<tr>
<td>SHB</td>
<td>Southern Hudson Bay</td>
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<tr>
<td>SIA</td>
<td>Stable Isotope Analysis</td>
</tr>
<tr>
<td>TEK</td>
<td>Traditional Ecological Knowledge</td>
</tr>
<tr>
<td>USD</td>
<td>United States Dollar</td>
</tr>
<tr>
<td>WHB</td>
<td>Western Hudson Bay</td>
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Abstract

Anthropogenic-induced climate change has warmed the Arctic 2-3 times faster than the rest of the world, causing sea ice declines that introduce challenges for specialist species, such as polar bears, in adapting to rapid environmental changes. Comparative and quantitative analyses of three Hudson Bay polar bear subpopulations were used to determine the impacts of sea ice loss on polar bear diet, prey availability, foraging behaviors, and human-bear interactions in the Arctic. The study reveal that Hudson Bay polar bears experience the most severe impacts from sea ice declines, resulting in a 30% population decline. Due to their smaller body size, high energetic demands to support pregnancy, and dependency of their young, adult female polar bears with cubs are the most at risk of sea ice loss due to dietary restrictions. Longer ice-free periods force fasting bears to expend more energy foraging for suboptimal terrestrial resources, resulting in an energetic imbalance. Indigenous communities not only experience increasingly dangerous and frequent bear encounters in town, but also reduced socioeconomic gains from declining polar bear numbers. Declines in polar bear numbers have prompted the bears to be listed and managed under science-based regimes, reducing indigenous subsistence hunting activities and creating clashes of interests between scientific and indigenous communities. Integration and increased understanding of traditional ecological knowledge (TEK), habitat monitoring, and habitat protection is needed for future polar bear management to succeed. However, the foremost solution in halting polar bear extirpation is global aggressive, collaborative, and proactive greenhouse gas (GHG) emission reduction.
1. Introduction

Anthropogenic induced climate warming has caused the Arctic to warm 2-3 times faster than the rest of the world; the effects of atmospheric warming became prominent in the early 1980s through visible sea ice loss in the Arctic Circle (Derocher et al. 2004, Overland et al. 2019, Pagano, Anthony M. and Williams 2021). Sea ice is vital habitat for many Arctic wildlife species, such as polar bears (*Ursus maritimus*) and ringed seals (*Pusa hispida*), who use sea ice as resting, breeding, and foraging grounds (Florko et al. 2020). Arctic wildlife also evolved special adaptations that help them survive in this cold region. However, species with specific adaptations often face difficulty acclimating to a changing environment (Derocher et al. 2013, Johnson et al. 2019). Obligate carnivores like the polar bear have unique features that help them survive in the frigid environment, such as white fur to camouflage into the snowy terrain and a thick layer of blubber for insulation against the cold (Rinker et al. 2019). Polar bears are the largest land carnivore in the world, and their large body size and thermoregulation needs generate large energetic demands (Petherick et al. 2021). A polar bear gains almost all its energy by consuming high-fat and high-energy blubber from ringed seals and other marine mammal prey (Petherick et al. 2021, Pagano and Williams 2021). Morphological teeth and jaw adaptations that allow polar bears to consume soft foods restrict them from ingesting tougher and harder material (Petherick et al. 2021). The effects of atmospheric warming in the Arctic highlight the repercussions of sea ice loss to polar bears in the Canadian Arctic: loss of vital breeding grounds, foraging spots, resting areas, and denning sites, all of which affect polar bear populations, survivability, and productivity.

Polar bears are indicator or keystone species, meaning their presence aids in monitoring the environment’s health, conditions, and potential changes (Thiemann et al. 2008). If the polar bears are ailing, that means there has been some changes in the environment that caused the hardships for the bears. The breakup of sea ice primarily influences time available for polar bears to forage on their primary marine mammal prey, ringed seals (Regehr et al. 2007). Males and females of a species may exhibit differences that impact their survivability and resilience to change in the natural world. For polar bears, males and females exhibit different responses and adaptations to environmental change in the Arctic home (Thiemann et al. 2008). Different polar bear age groups also display responses and vulnerability following environmental stressors (Johnson et al. 2019). Decreased foraging opportunities create nutritional challenges for polar
bears enduring an increased fasting period during open water seasons that decrease body conditions, reproductive success, and survival (Galicia et al. 2016, Johnson et al. 2019, Florko et al. 2020, Jagielski et al. 2021, Pagano and Williams 2021).

Thirteen out of 19 polar bear subpopulations occur in the Canadian Arctic, and declines in polar bear productivity and population numbers has lead wildlife managers and conservationists to list the polar bear in various jurisdictions and areas across their range (Thiemann et al. 2008). The listings enabled polar bears to serve as the flagship species for the impacts of climate change and to lead the way in greenhouse gas (GHG) emission reduction efforts around the world. Greenhouse gas emissions is the primary cause for global warming, and sea ice loss in the Arctic is expected to continue, causing irreversible effects, and producing an unrecognizable Arctic in the future (Overland et al. 2019, Wunderling et al. 2020). The listing of the polar bears helps nudge countries around the world to begin reducing GHG emissions (Clark et al. 2008) to conserve the Arctic marine mammal. Global warming is caused by GHG emissions accumulated from around the earth, and large-scale collaborative action, effort, and enthusiasm is the only viable solution in delaying (and possible preventing) polar bear extirpation (localized extinction).

Despite the listing of polar bears serving as the role model for global GHG emission reduction, the listings receive backlash from local communities and indigenous populations who depend on polar bears as part of their livelihood (Wenzel 2011). Polar bears are utilized by indigenous communities for their cultural, economic, and traditional identities (Freeman and Wenzel 2006, Clark et al. 2008, Wenzel 2011). 86% of polar bear hunting occurs in Nunavut, a region in which 11 out of those 13 Canadian subpopulations occur (Peacock et al. 2011). Polar bears are hunted for their meat for food, fur for clothing, and parts for souvenir crafting that is then sold to tourists (Wenzel 2011). The shifting sea ice and declines in polar bear body condition and population numbers create challenges for indigenous hunters, and the listing of polar bears further restricts their traditional right to hunt them (Kakekaspan et al. 2013). Furthermore, starving polar bears that are unable to accumulate enough fat and energy to last through the summer fasting periods create problems as they enter human towns and settlements in search of food. Lured in by the scent of leftover food or garbage, their presence in towns produce human-polar bear interactions and conflicts that may result in injuries, loss of human and bear lives, and damaged property.
Numerous polar bear management plans and data are science-based, causing dissent within indigenous populations who collect their own data using traditional ecological knowledge (TEK) regarding polar bear population numbers, movement, behaviors, and distribution in their regions (Wenzel 2011, Laforest et al. 2018). Divides between the scientific and indigenous communities regarding the different types and sources of polar bear data produce complications when developing, implementing, and managing polar bear programs. Scientific communities often discredit TEK, and instead push science-based management as the applicable method of polar bear management. Cultural, linguistic, and technological differences may also hinder the ability of these two communities to cohesively collaborate (Clark et al. 2008). Finding common ground between ideas, information, and perspectives of all polar bear stakeholders, is vital for ensuring efficient polar bear management and conservation efforts.

The possibility of losing all the polar bears in the Arctic’s southern regions are impending; the southernmost polar bear subpopulations have already declined approximately 30% due to their southern latitudes (Laforest et al. 2018). Continued climate warming will increase the rate and extent of sea ice loss, and polar bears who already experience prolonged onshore fasting periods may find themselves stranded on land without adequate food resources. As climate warming worsens the conditions for the southern polar bear subpopulations, it is anticipated that the High Arctic (northern) subpopulations will encounter the same issues. Given the current rate of warming, southern polar bear subpopulations may be extirpated by this century, with the remaining bears found only in the High Arctic (Chervinski 2021). Studying polar bears’ ability to respond and adapt to environmental change is key in understanding their resilience and can not only assist in polar bear conservation and management efforts but educate polar bear lovers about the bears’ plight.

1.1 Background

1.1.1 Polar Bears

Polar bears are one of the most popular and well-known animals in the world, making them a fan favorite across animal lovers. They are not only the largest of the eight bear species, but also the largest land carnivore on Earth (Center for Biological Diversity 2022, The National Wildlife Federation 2022). These charismatic snow-white bears are native to the circumpolar Arctic and are evolutionarily adapted to living in the frigid and harsh environment. A polar
bear’s closest ancestor is the brown bear (*Ursus arctos*), from which it has been estimated to diverge 150,000 – 1,000,000 years ago (Moskowitz 2010, Petherick et al. 2021). Male polar bears can grow up to around eight to eleven feet in length and can weigh up between 1,300 and 1,700 pounds; female polar bears can measure 6-8 feet in length, and only weigh about half of a male polar bear at around 600 to 900 pounds. Most polar bears can live between 15 to 18 years in the wild, and some bears may live up 25 to 30 years (Center for Biological Diversity 2022).

Male polar bears reach sexual maturity at 6-8 years old, and females reach that at 4-6 years old. Mating happens on sea ice from late March to June, but female polar bears can delay implantation until the fall season (Ramsay and Stirling 1988). Female polar bears den on land from August to March; litter sizes of two cubs (up to four cubs in rare cases) are most common and birth and nursing can take place as early as November to early January (Peacock et al. 2010, Smith and Aars 2015, Larson et al. 2020). Female polar bears dig dens in deep deposits of snow formed from buildup of ice flows converging (known as pressure ridges), closing it up after completion for insulation, protection from predators, and a buffer from outside disturbances (Derocher and Wiig 1999, Larson et al. 2020). During pregnancy, birth, and nursing, a female polar bear will stop eating and fast for up to eight months (Pagano and Williams 2021), losing as much as 43% of their total body weight (Larson et al. 2020). After two months in the den, the female polar bear will emerge with her cubs and return to the sea (Larson et al. 2020).

Polar bears currently occupy their entire historical range (Peacock et al. 2010), and span across five nations: The United States (Alaska), Russia, Greenland, Canada, and Norway; these nations are also known as the Range States (Elvin 2014). There is an estimate of approximately 20-25,000 polar bears in the Artic across these nations. Figure 1 shows the 19 subpopulations of polar bears in the Arctic: Southern Beaufort Sea, Northern Beaufort Sea, Viscount Melville Sound, M’Clintock Channel, Lancaster Sound, Gulf of Boothia, Foxe Basin, Norwegian Bay, Western Hudson Bay, Southern Hudson Bay, Baffin Bay, Kane Basin, Davis Strait, East Greenland, Arctic Basin, Barents Sea, Kara Sea, Laptev Sea, and Chukchi Sea; 13 of these subpopulations can be found in Canada (Thiemann et al. 2008). Figure 2 displays the size and trends of each of the 19 subpopulations. Understanding these trends assist polar bear managers and stakeholders in efficient conservation and management efforts.
Figure 1: The 19 polar bear subpopulations. Polar bears only occur in the Northern Hemisphere.
Source: [https://www.canadiangeographic.ca/article/truth-about-polar-bears](https://www.canadiangeographic.ca/article/truth-about-polar-bears)
The Arctic is a challenging environment for any species to reside in. Polar bears have numerous unique adaptations to a life in the Arctic. They have rounder bodies and ears to reduce surface area and thus heat loss, large furry paws with short sharp claws to help grip ice for traction as well as maintaining hold on prey, and webbing between toes to help with swimming (The National Wildlife Federation 2022, Center for Biological Diversity 2022). A polar bear’s white outer layer of fur reflects sunlight, helping them camouflage into their snowy environment and acting as a water repellent layer. A heavy undercoat along with a thick layer of blubber up to five inches thick assist the bear with insulation and thermoregulation (Center for Biological Diversity 2022, The National Wildlife Federation 2022). To survive the cold arctic and to generate enough energy to thermoregulate, a polar bear requires significant amounts of fat for insulation and energy to sustain its large body size.
As a large carnivore, a meat-eating lifestyle comes with a high metabolism (Pagano and Williams 2021). Therefore, polar bears have adapted to feeding on large quantities of high-energy, fat-rich marine mammal prey, mainly consisting of ringed seals (Pagano et al. 2018, Berta and Lanzetti 2020). Their diet also comprises of other marine mammal prey such as bearded seals (Erignathus barbatus), harp seals (Pagophilus groenlandicus), beluga whales (Delphinapterus leucas), and bowhead whales (B. mysticetus), which vary depending on the region and season (Peacock et al. 2010, Galicia et al. 2016, Pagano et al. 2018, Johnson et al. 2019, Florko et al. 2021). One special adaptation of feeding on fatty marine mammal prey is a unique skull and jaw morphology. Polar bears have slightly more elongated snouts compared to their sister bear species, adapted for hunting in the ice breathing holes utilized by their seal prey (Rinker et al. 2019, Petherick et al. 2021). As apex predators of the Artic, they have long and slender canines—longer than a grizzly bear’s (World Wildlife Fund 2022a)—to pierce and grasp prey and sharp modified molar teeth known as carnassials adapted to shearing into prey. A gap between a polar bear’s canines and carnassials to allow for deeper penetration and stronger grasps on prey (Rinker et al. 2019). A polar bear’s feeding strategy is known as the grip-and-tear strategy, where the bear will hold prey with its jaw and/or forelimbs and shake or tear off small chunks for ingestion (Berta and Lanzetti 2020). Another unique specialization is that polar bears have evolved to have smaller intestines to reduce the energetic demands of food digestion (Petherick et al. 2021, Pagano and Williams 2021), which allows them to easily digest soft material like blubber. Due to their large size and significant energy demands, polar bears do not actively expend energy to chase prey. Instead, to conserve energy, they are ambush hunters, sitting in wait at seal breathing holes in sea ice to ambush their prey when they come up to take a breath (Pagano et al. 2018, Pagano and Williams 2021). Although a polar bear’s main prey is the ringed seal, bears will also forage for a variety of marine mammals such as bearded seals, bowhead whale carcasses, and walruses (Odobenus rosmarus), depending on the region and subpopulation.

1.1.2 Significance of the Polar Bear

Polar bears are an indicator or sentinel species, meaning that they are used to gauge ecosystem and environmental health and changes (Thiemann et al. 2008, Moore and Huntington 2008, Bailey and Thompson 2009, Florko et al. 2020, Pagano and Williams 2021). Polar bear
body conditions and productivity are reflective of sea ice conditions; if polar bears are in poorer body condition, it is an indication that sea ice conditions are suboptimal. If sea ice is declining in extent and duration, it is likely that the environment and habitats are undergoing changes that affects the wildlife that depends on it. Polar bears are also keystone species; their presence—and absence—determines the food web dynamics in the ecosystem (Thiemann et al. 2008). Because sea ice dynamics trigger ecosystem changes, these changes affect polar bears and their ability to maintain healthy populations of prey species lower in the food web (Johnson et al. 2019).

Climate warming is causing declines in sea ice extent and duration, increasing primary productivity and ultimately the abundance of polar bears’ main prey, ringed seals (Johnson et al. 2019, Florko et al. 2021). If climate change were to extirpate polar bears, there will be no main predator to keep ringed seal numbers at a healthy level. Ringed seal populations will increase, and their food source, fish, will deplete. However, the increased abundance of ringed seals (and decreased sea ice extent) may cause other predators, such as killer whales (*Orcinus orca*), to take advantage of the booming prey, thus their increasing numbers, and potentially establishing and structuring a new food web regime (Moore and Huntington 2008, Peacock et al. 2010, Galicia et al. 2016, Florko et al. 2021). Therefore, polar bears are key in keeping food web regimes stable and help “monitor” the environment for changes.

Polar bears and humans have been interacting for millennia (Laforest et al. 2018). Indigenous communities (mainly Inuit) residing in the Arctic utilize polar bears for numerous reasons: meat for food; fur for clothing; parts for crafts and handiworks; hunting as a sense of identity; and money generated from polar bear viewing, tourism, and trophy and sport hunting (Freeman and Wenzel 2006, Clark et al. 2008, Kakekaspan et al. 2013, Elvin 2014, Larson et al. 2020). Polar bear hunting is a cultural and traditional right and an important aspect of indigenous livelihood (Wenzel 2011). For example, a young hunter’s first animal kill is significant, and a polar bear as a first kill is highly regarded by their community (Wenzel 2011). 86% of all polar bear harvest occurs in Nunavut, a territory that comprises most of the Canadian Arctic Archipelago (Peacock et al. 2011). Information regarding polar bear population numbers, movement, behaviors, and distribution in their regions are passed down through TEK and utilized by indigenous people for generations (Wenzel 2011, Laforest et al. 2018). Polar bear sport and trophy hunting are the most expensive of all sport hunts, bringing in significant income to the hunting guides, their families, and their communities; each polar bear hunt can net in
$19,300 per bear (Freeman and Wenzel 2006). Trophy and sport hunting not only generates revenue from non-locals who arrive in Canada to hunt polar bears, but they also provide jobs and income to Inuit locals and their families. Being hunting guides for trophy and sport hunting also allow the guides to provide fresh meat from polar bear kills to their community (Freeman and Wenzel 2006).

1.1.3 The Arctic and Climate Change

The Arctic is a polar region that is in the northernmost part of the world. This region, also called the Arctic Circle, surrounds the infamous North Pole, and sits at the latitude line of around 66°30’ N North of the equator (National Geographic 2022, Encyclopedia Britannica 2022). Polar bear territory is within the boundaries of the five Range States (Elvin 2014). The landscape and climate of the Arctic vary geographically and temporally, but snowy tundra, plains, ice sheets, permafrost, and glacial deposits dominate the landscape. Almost the entire Arctic is covered by frozen water: sea ice is frozen saltwater, and glaciers and icebergs are frozen freshwater (National Geographic 2022). In the winter months of January to March, Arctic temperatures can range between -30 to -20°F but can go as low as -65°F in North America. Winter months are often accompanied by storms, high winds, and precipitation in the form of snow. The summer months can range between 40°F in the northern regions, 60°F in the southernmost areas, and can have calm weather and continuous sunshine that persists throughout the entire day (Encyclopedia Britannica 2022). Rapid climate warming caused by GHG in the last five decades have increased air temperatures by 2-3°C throughout the entire Arctic region (Regehr et al. 2007). This warming occurs at almost twice the rate and intensity of the rest of the planet (Overland et al. 2019).

Increased temperatures melt glaciers and permafrost, releasing trapped gases into the atmosphere and further contributing to warming (Wassmann et al. 2011). Increased temperatures have a higher chance of converting snow to rain, promoting more terrestrial vegetation growth and primary productivity, which changes the marine ecosystem, its food web, and its productivity (Meier et al. 2014, Overland et al. 2019).

Arctic sea ice covers the expanse of the region. Many species of marine mammals use sea ice to survive. Bowhead whales use packed ice as a nursery and feeding ground, utilizing the ice floes as a barrier from predators. Ringed seals use sea ice as birthing lairs, nurseries, resting and molting areas, and as breathing holes in the cracks as they forage for food under the ice (Florko
et al. 2020). Polar bears use sea ice for traveling, mating, resting, and most importantly, hunting for marine mammal prey (Florko et al. 2020). In southern regions in the Arctic, such as the Hudson Bay (HB) in Canada, sea ice melts completely during summer months, whereas some northern regions retain sea ice all year round. Due to climate warming, Arctic sea ice extent has declined about 14% in the last 40 years. Sea ice thickness has declined approximately 40-60%, reaching levels that have not been seen in thousands of years (Meier et al. 2014, Overland et al. 2019). Arctic sea ice is one of the fastest changing elements of Earth’s cryosphere (frozen water parts of the Earth); predictions have been made that annual sea ice in the southern regions of the Arctic (e.g., Hudson Bay) may disappear completely by mid-century (Derocher et al. 2004, Wunderling et al. 2020). Additionally, decreased sea ice causes loss of critical habitat used by marine mammals while welcoming in seasonally migrant species that may expand their ranges into the Arctic, increasing competition and changing the trophic food web regime (Meier et al. 2014).

Most of the vegetation in the Arctic consists of low shrubs, mosses, lichens, and flowering plants. Arctic vegetation grows in compact clumps as shelter from the atmospheric conditions that constantly buffer them. Growing season is short but intense in the Arctic, and flowering vegetation reproduce asexually during periods where the snow and frost still covers the ground (Encyclopedia Britannica 2022). Lichen and mosses cling to ice deposits, and shrubs are found wedged between rocks in the Arctic deserts. Summertime bears a larger abundance of vegetation, ranging from small shrubs to large thickets of birch trees in plains and tundra. Arctic vegetation provides a grazing food source to resident grazers and seasonally migrant species. Majority of Arctic vegetation provides no food options for man, aside from a few berry species like black crowberry and cloudberry; these are utilized by indigenous communities and explorers. Although shrubs and bushes are not consumed by aboriginal peoples, woody material are often used as fuel for fires or to craft material such as arrow shafts (Encyclopedia Britannica 2022). Climate warming over the past three decades has increased shrub cover and vegetation growth in the Arctic tundra (Walker et al. 2006, Post et al. 2009). Warm temperatures promote warmer soil temperatures and greater soil microbial activity, allowing for shrubs to expand and take over other types of vegetation, reducing overall plant diversity in the short term (Post et al. 2009).
Arctic wildlife is surprisingly abundant, but in individual animals rather than in species diversity. Popular terrestrial animals include the Arctic fox, Arctic hare, Arctic wolf, snowy owls, and migratory caribou. Hibernation is not possible in the Arctic because there are no regions that are not seasonally free of ice and frost. As a result, all warm-blooded terrestrial and migratory mammals must stay active during the winter. Because of the frigid climate, cold-blooded reptiles and amphibians are not found in the Arctic. There are only a few species of freshwater fish in the Arctic: whitefish, lake trout, speckled trout, two species of stickleback, and Arctic char (Encyclopedia Britannica 2022). Large marine mammals, both resident and migrant, are abundant in the Arctic. Cetaceans such as the bowhead, beluga, narwhal (*Monodon monoceros*), and migratory killer whales are often distributed across the Arctic, along with pinnipeds like ringed, harbor, fur, and harp seals, and walrus. All seabird species, like the common eider (*Somateria mollissima*) (Jagielski et al. 2021), Arctic tern, and the common glaucous-winged gull, that visit the Arctic are migratory. There can be an abundance of these migratory seabird colonies found along the shores or on islands, where they take advantage of the short and intense growing season that provides an abundance of grazing vegetation and invertebrates (e.g., mosquitoes, flies) to feed on during nesting and breeding seasons (Encyclopedia Britannica 2022). A variety of species across the different habitats and terrains create an ecosystem that is self-sustaining. However, a warming climate has contributed to significant habitat alteration and loss. The consequences of habitat degradation are amplified for highly specialized or adapted species (i.e., the polar bear). Habitat declines and loss can affect the availability and abundance of resources, timing of life history events, reproductive and foraging success, and introduce new mechanisms that inflict disease and inter-species competition for ice-dependent species (Laidre et al. 2008). On the contrary, habitat loss for one species may be beneficial to other species in which ice acts as barriers. Cetaceans like bowhead and killer whales may benefit from sea ice loss as it opens accessibility to new feeding grounds (Laidre et al. 2008).

The Arctic contains large quantities of valuable resources such as oil, natural gas, petroleum, gemstones, minerals (copper and nickel ore), and rare earth metals (used in technological components like magnets and batteries) (National Geographic 2022) This makes the Arctic an attractive region for expansion and extraction operations. Resource extraction companies work with indigenous communities to drill and export barrels upon barrels of oil and natural gas each year (National Geographic 2022). Natural gas and oil are abundant in the Arctic,
creating potential to begin resource development and demand in extracting them (Gautier et al. 2009). The Arctic has become more accessible due to declines in sea ice extent and cover, capturing the attention of oil and gas companies wanting to expand into and extract from the Arctic (Harsem et al. 2011). Technological advances also create fresh opportunities for Arctic exploration and development (Gautier et al. 2009). Nearly a quarter of the world’s undiscovered oil and natural gas deposits are in the Arctic, and demands from world powerhouses (i.e., China, India) increases the pressure to extract from the Arctic (Harsem et al. 2011).

1.1.4 Polar Bear Listings and Community Responses

Excessive hunting as led to a drastic decline in polar bear populations, which prompted the creation and signing of the 1973 International Agreement on the Conservation of Polar Bears (hereafter, the Agreement) (Peacock et al. 2010) by the five nations (hereafter, Range States) with polar bears in their jurisdiction. The Agreement set an annual sustainable harvest quota for participating regions that reduced and limited the number of polar bears that can be hunted and allowed for polar bear populations in the Canadian Arctic to regrow. Declines in polar bear body condition, reproductive success, survival rates, and population size and abundance led to the polar bear being listed as follows: “Vulnerable” in Norway, Greenland, and the International Union for the Conservation of Nature (IUCN) in 2008; “Threatened” under the United States Endangered Species Act (ESA) in 2008; “Special Concern” in Canada in 2011; and “Uncertain” in Russia (Derocher et al. 2013, Miller et al. 2013, Elvin 2014, World Wildlife Fund 2022b). The ESA listing of the polar bears as “threatened” highlighted the impacts of climate change and Arctic warming on polar bears and serve as a nudge to encourage the U.S. government to begin aggressive GHG emission reductions to conserve the polar bears and their habitats (Clark et al. 2008, U.S. Fish and Wildlife Service 2016). Canada’s Species At Risk Act (SARA) established the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2002, listing polar bears as “Special Concern” in 2011 due to the reduction in sea ice coverage, duration, and feeding opportunities that result from Arctic warming (Government of Canada 2011, Department of Environment 2022a). The SARA offers protection and recovery for threatened, endangered, and extirpated wildlife species and their habitat, while the COSEWIC focuses on analyzing and addressing risks for wildlife species extinction using science and TEK (Department of Environment 2022a, Department of Environment 2022b). The management of polar bears in
Canada is carried out by the federal government, four provinces, three territories, and land claim settlement wildlife management boards (Government of Canada 2011).

The decisions to list and manage polar bears in multiple nations induced dissatisfaction in the local communities that rely on polar bears, primarily quota reductions and limits, and bans on the sales of polar bear crafts and goods (Government of Canada 2011, Kakekaspan et al. 2013). The listings reduced harvest quotas for the Inuit in attempts to prevent population decline, sparking outrage in these communities as these quota reductions violate traditional and treaty rights (Kakekaspan et al. 2013). Harvest quota reductions also reduced the economic benefits (jobs, income, food) acquired from polar bear subsistence harvesting, and created rifts and decreased trust between local and scientific communities (Freeman and Wenzel 2006, Clark et al. 2008). These topics will be covered in depth later in this paper.

1.2 Research Questions

Given the vulnerability of the polar bear from climate induced sea ice loss, and their significance to indigenous communities, I will be answering the following question: How does anthropogenic-induced sea ice loss impact polar bear diet, prey availability, foraging behaviors, and human-polar bear interactions in the Arctic? The following sub-questions will provide and answer details that shed light onto the consequences of Arctic sea ice loss: Which region will experience the most severe impacts of declining sea ice? This question will provide insight on which region should receive the most effort and attention in monitoring and studying sea ice loss and its effects on the ecosystem. Which polar bear age/sex group is the most and least at risk? This question aims to reveal the various morphological and behavioral characteristics of male and female polar bears, and how these qualities impact their vulnerability and resilience to ecosystem change. What are the short and long-term impacts of dietary change? By analyzing the immediate and long-term impacts of sea ice loss and dietary change, our understandings will highlight the importance, consequences, and future predictions of sea ice loss to the polar bears and the local communities that interact with them. How can these changes affect people that have a relationship with the polar bears (i.e., indigenous communities and their economy)? Revealing the negative impacts of sea ice loss on polar bears educates us on how communities that depend on these large marine carnivores navigate dissent and distrust between their
communities and polar bear managers, and how they must create new methods to adapt to increasing human-polar bear interactions.

2. Methods

I conducted a comparative and quantitative analysis of literature pertaining to areas and subpopulations that are experiencing the most severe impacts from declining sea ice. Studies of various regions across the Canadian Arctic will help me to identify which regions require the most attention, mitigation actions, research, and/or monitoring. By analyzing different regions’ sea ice movement and dynamics (e.g., sea ice and open water duration, sea ice retreat, sea ice reformation), it will help me identify which areas of the Arctic are most susceptible to climate change-induced sea ice loss. A comparison of the decline in sea ice per region per decade in relation to temperature increases will also aid in revealing which areas are the most vulnerable to climate change and sea ice loss.

A comparative and quantitative analysis was also used to reveal which polar bear age/sex groups are most at risk of sea ice declines and diet changes. Because foraging behavior vary spatially and temporally between the age and sex of polar bears, comparing different subpopulations’ behaviors and their ability to adapt to potential changes in prey availability and foraging behavior will bring into light which populations are the most vulnerable to sea ice loss and alterations in primary prey. This analysis will be also used to determine the immediate and long-term impacts of dietary change, and how these changes impact people who have relationships with the polar bears. As previously stated, different populations, age, and sex groups vary in their behavior and diet in relation to sea ice, and through the analysis of which groups are most at risk, I can determine the future consequences of dietary shifts. These consequences can include changes in distribution, foraging behavior, and increased human-bear conflicts.

A comparative and quantitative analysis was also used to analyze the various inputs and opinions of indigenous Inuit communities regarding polar bears and their management. Most of the input regarding polar bears and their management come from interviews conducted in Arctic communities by the authors of various literature to document their knowledge on polar bears in
their regions. Recommendations were made based on what improvements the Inuit would like to see going forward for polar bear management.

The literature I used in this paper primarily included peer-reviewed literature and government websites (e.g., U.S. Fish and Wildlife Service, National Marine Fisheries Service, Canada.ca) spanning topics regarding polar bear population dynamics, reproductive behavior, diet analysis, human-bear interactions, climate change impacts, and management and policy recommendations. This paper primarily focused on the Canadian Arctic, with brief mentions of the other Arctic Range States/regions (e.g., Alaska) as supporting evidence.

3. Results

3.1 The Hudson Bay and its At-Risk Polar Bear Subpopulations

The area that experiences the most severe consequences of sea ice loss is the Hudson Bay (HB) in the northeastern Canadian Arctic (Gormezano and Rockwell 2013). Due to the HB’s lower latitude, the region experiences the first and most severe effects of climate warming. The HB region houses the three southernmost polar bear populations: Southern Hudson Bay (SHB), Western Hudson Bay (WHB), and Foxe Basin (FB) polar bears (Peacock et al. 2010, Johnson et al. 2019). The WHB and SHB experience completely sea-ice free summers for up to five months (Gormezano and Rockwell 2013), reducing time available for polar bears to forage on marine mammal prey. The FB still retains some sea ice in the summer due to the higher latitude (Galicia et al. 2016), allowing for polar bears there to be less affected by sea ice loss, have a longer foraging period, and be less at risk of population declines (Galicia et al. 2016).

Increasing Arctic temperatures causes spring sea ice in HB to break up earlier and increases the duration of open water period of summer months (Pagano et al. 2018, Johnson et al. 2019, Pagano and Williams 2021). Pagano and Williams (2021) discovered that sea ice is breaking up roughly 3-9 days earlier and reforming 3-9 days later each decade, and Thiemann et al. (2008) found that warming temperatures has caused sea ice to break up three weeks earlier than nearly half a century ago. The average sea ice loss estimates for the Arctic are approximately 10-14% each decade, including loss of thickness, extent, and duration (Table 1). Sea ice thickness and volume has declined by 60% since the 1980s (Overland et al. 2019). Continual sea ice declines gradually reduce habitat connectivity, and the quality and quantity of
stable foraging, resting, and traveling areas for marine mammals like polar bears and ringed seals. The steady loss of sea ice, coupled with increasing atmospheric temperatures amplified in the HB, means that future ice-free summers in the southern latitudes of the Arctic are not only imminent, but currently occurring. It also causes sea ice reformation to occur increasingly later each decade (currently reforming early November to early December) (Peacock et al. 2010). Studies have shown that polar bears usually come onto land after half of the sea ice has already melted, which is around 20-30 days (Johnson et al. 2019) after breakup begins. In the WHB, sea ice melts completely in the summer, forcing the entire subpopulation of polar bears onto land, requiring the bears to fast on stored fat accumulated from spring foraging on ice or alter their diets (Thiemann et al. 2008). However, in recent times, ice refreeze happens two weeks later than previously documented, resulting in less foraging time on ice and forcing bears to endure a longer fasting period (Peacock et al. 2010, Johnson et al. 2019).

Table 1: Recorded sea ice loss data for the Arctic. An average of 10-14% loss of sea ice per decade has caused declines in sea ice extent, thickness, and habitat connectivity.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Findings</th>
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<tbody>
<tr>
<td>Derocher et al. 2004</td>
<td>- Multiyear sea ice: 9% loss per decade</td>
</tr>
<tr>
<td></td>
<td>- Total sea ice: 14% loss since 1978</td>
</tr>
<tr>
<td>Post et al. 2009</td>
<td>45,000 km² loss per year</td>
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<tr>
<td>Wassmann et al. 2011</td>
<td>- 10% loss per decade</td>
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<td></td>
<td>- Ice free summers in this century</td>
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<tr>
<td>Elvin et al. 2014</td>
<td>10-12% loss per decade</td>
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<tr>
<td>Meineker et al. 2014</td>
<td>- Summer sea ice: 30% loss past few decades</td>
</tr>
<tr>
<td></td>
<td>- 40% decline in overall thickness</td>
</tr>
<tr>
<td>Pagano et al. 2018</td>
<td>14% loss per decade</td>
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<tr>
<td>Overland et al. 2019</td>
<td>- Summer sea ice: 75% volume loss since 1979</td>
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<tr>
<td></td>
<td>- Multiyear sea ice: 60% loss since 1980s</td>
</tr>
<tr>
<td>Wunderling et al. 2020</td>
<td>- Summer sea ice: 10% loss per decade</td>
</tr>
<tr>
<td></td>
<td>- Ice free summers in this century</td>
</tr>
<tr>
<td>Pagano and Williams 2021</td>
<td>- September sea ice: 13.3% loss per decade</td>
</tr>
<tr>
<td></td>
<td>- Winter sea ice: 3.4% loss since 2000</td>
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The primary reason why the WHB subpopulation is the most at risk from sea ice decline is because of their low diet diversity and choice of prey compared to the more northern FB polar bears. The early retreat of spring ice, and loss of summer ice, primarily impacts WHB polar bears by decreasing accessibility and abundance of ringed seal prey and forcing the entire WHB subpopulation onto land (Whiteman et al. 2017). This decreases the time available for WHB polar bears to hunt seal prey and store enough fat for summer fasting. Because the WHB subpopulation does not have as many prey choices as FB, WHB polar bears are restricted to fewer marine mammal prey options, forcing them to increase reliance on suboptimal terrestrial resources, such as vegetation or seabird eggs (Jagielski et al. 2021). Ringed seal productivity decreases with sea ice loss, making it more energy-intensive for polar bears (e.g., swimming across broken ice floes) to forage for less abundant seals and in open waters (Florko et al. 2020). In a study conducted by Gormezano and Rockwell (2013), polar bears in WHB attempted to utilize new and flexible foraging strategies to survive: prey switching, changing between prey species as a response to quality or availability; omnivory, consuming both plant and animal material; and food mixing, eating material from different species at once that offers various nutritional input. However, the bears that utilized these new foraging tactics were inefficient in maintaining positive energetic balances, likely due to their lack of foraging experiences and consumption of suboptimal energy sources that are unable to sustain their high metabolisms (Gormezano and Rockwell 2013, Pagano and Williams 2021). Increased dependency on terrestrial resources, combined with increased energy expenditure in locomotion to find and consume low energy foods, can cause WHB polar bears to lose up to almost 20% of their muscle mass (Whiteman et al. 2017, Polar Bears International 2022). Walking bears expend approximately 13 times more energy than a stationary bear sitting near a breathing hole waiting to ambush seals as they come up for air, and swimming bears use approximately 4.3 times the energy cost of walking bears (Pagano and Williams 2021). This ultimately results in declines in body condition, health, reproductive success, and population numbers (Galicia et al. 2016, Johnson et al. 2019, Florko et al. 2020, Jagielski et al. 2021, Pagano and Williams 2021). Their high dependency on one main prey type (i.e., marine mammals), and increased utilization of inefficient terrestrial resources makes them the most at risk from sea ice changes. As a result, the WHB polar bear population has declined approximately 22% since 1987 (Thiemann et al. 2008).
Out of the three HB subpopulations, the FB subpopulation is the least at risk from sea ice declines. Foxe Basin is split into three further polar bear subpopulations: the Northern Foxe Basin (NFB), Southern Foxe Basin (SFB), and the Hudson Strait (HS) (Galicia et al. 2016). The FB polar bears have the greatest diet diversity out of the three subpopulations in HB; they have access to bowhead whales, beluga whales, walrus, harp seals, and bearded seals (Peacock et al. 2010, Galicia et al. 2016), some of which are migratory (e.g., bowhead whales), adding another available prey source to the mix of marine mammals. Increased bowhead whale carcasses in FB polar bear diets provide an important additional—or alternative—food and energy resource for HB polar bears (Pagano and Williams 2021). Bowhead whale populations have been increasing in FB because of decreased commercial whaling and a more sustainable harvesting regime by indigenous communities (Peacock et al. 2010). Recent studies have shown that FB sea ice cover has been reduced from 9 to 7 months out of the year, and these lighter sea ice conditions enable bowhead whales to use FB as nursery and feeding grounds, increase productivity and population numbers (Galicia et al. 2016, Moore and Reeves 2018). Lighter sea ice conditions also allow for killer whales to expand their range into FB, increasing predation and carcasses of bowhead whales (Galicia et al. 2016). These carcasses provide an additional food source to FB polar bears, increasing their prey diversity and increase foraging opportunities in the short run (Peacock et al. 2010, Galicia et al. 2016). The FB polar bears are not as dependent on mainly ringed seals like WHB and SHB subpopulations and have greater diversity and abundance in prey, making them the most stable and least at risk from sea ice loss.

The overall HB region and its polar bear subpopulations are the most at risk because the three subpopulations frequently overlap population and foraging boundaries and mate with each other. This interbreeding dilutes the local adaptations, reducing differentiation between the three subpopulations and resulting in low genetic diversity (Thiemann et al. 2008). This also creates a homogenous genetic cluster unique to the HB subpopulations (Thiemann et al. 2008). Although the three subpopulations have distinct demographics and behavior, their low genetic diversity decreases their chance to adapt to shifts in diet, prey availability, and other environmental factors (Peacock et al. 2010). The three HB subpopulations have similar diet compositions and prey availability (Thiemann et al. 2008) due to their overlap, meaning that declines in sea ice and primary marine mammal prey, coupled with shorter spring foraging and increased open water periods, puts these polar bears in grave danger of extirpation. However, despite having similar
diet compositions and prey availability, male and female polar bears have various characteristics and morphological adaptations that allow them to exhibit different responses to sea ice loss and diet changes.

3.2 Adult vs. Subadult, Male vs. Female

Adult female polar bears, subadult (juvenile) polar bears, and females with cubs are the most at risk of climate change and sea ice loss. Because female and subadult polar bears have a smaller body size compared to males, they are more restricted in the types of prey that they can hunt and must rely more on smaller prey such as ringed seals and harbor seals (Thiemann et al. 2008). Female polar bears require more energy to support reproduction (Florko et al. 2021), and they spend the spring months on sea ice foraging for ringed seals. An adult female polar bear requires 1 adult ringed seal, 3 subadult seals, or 19 seal pups every 10-12 days to maintain their energetic balance or break even (Pagano et al. 2018). They fast on their stored body fat to insulate, give birth, and nurse their cubs while denning from August to March (Smith and Aars 2015). Female polar bears have high metabolisms to support pregnancy and lactation (Derocher et al. 1993), and the dependency of cubs increases the amount of time and energy mother bears spend to feed their cubs. Therefore, female polar bears are more likely to feed on terrestrial food, such as carcasses of larger prey (Florko et al. 2020), as a supplement to ringed seal prey to support the growth of their cubs (Derocher et al. 1993).

Female polar bears in the HB have switched from denning on sea ice to denning on land in the last few decades. This can be the result of the bears being stranded on land as sea ice break up severs the connection between sea ice and on-ice denning areas (Meier et al. 2014). Increasing Arctic temperatures can dry out the vegetation in terrestrial denning areas, increasing the risk of fires that may destroy den sites and rendering them useless for multiple years; this can further reduce the number of suitable denning sites for female polar bears to use (Derocher et al. 2004). When females and their cubs emerge from their dens two months after birth, they must avoid infanticidal adult males that forage on free-floating ice floes, restricting their foraging areas to land-fast ice where ringed seals are abundant (Johnson et al. 2019, Florko et al. 2021). As polar bears aggregate along the shores during ice-free periods waiting for ice to reform, female polar bears with cubs are more likely to travel more inland, away from the adult males that linger along the coast. This increases energy expenditure, decreases the likelihood of finding
marine prey, and broadens their diet (although they terrestrial they are consuming are suboptimal) (Gormezano and Rockwell 2013, Johnson et al. 2019). Overall, female and subadults’ dependency on ringed seals indicates a less diverse diet composition, making them more at risk of dietary shifts.

3.2.1 Adult Females with Cubs
3.2.1.1 Mother Polar Bears

Adult female polar bears with cubs are the most vulnerable from sea ice changes and prey availability because the body condition of the mother influences the body size and survival of her cubs (Robbins et al. 2012). Female polar bears, and their reproductive success, are highly dependent on fat accumulated from consuming ringed seals (Elvin 2014), and the lack of ringed seals and decreased foraging opportunities lowers the chance for pregnant polar bears to increase their body condition in time for denning, birth, and nursing (Pagano and Williams 2021). Molnár et al. (2010) stated that reproductive success is dictated by body condition, and body condition is correlated with cub litter mass, which is also a dictating factor for cub survival. Female polar bears in better body condition (i.e., fatter) give birth and lactate earlier and produce more milk or higher quality milk than females in poorer condition (i.e., leaner), resulting in cubs that are larger in size and better nourished (Robbins et al. 2012). Female polar bears can lose up to 43% of their body weight while fasting (Larson et al. 2020) and mothers in poorer body condition have reduced or limited milk production, increasing chances of cub mortality (Molnár et al. 2010). If temperatures in the HB increase by 1°C, female polar bears can lose an additional 22 kilograms each fasting period (Dawson et al. 2010).

Long interbirth intervals, or the period of time between successful births, can reduce fitness and reproductive capability and success as the female bears age (Robbins et al. 2012). It may take an older female polar bear longer to reaccumulate fat stores to prepare for and restart the reproductive process (i.e., finding a mate, rebuilding dens) upon losing her cubs to predation or natural causes. The delays in restarting the reproductive process may impact the success of future maternal efforts and the fitness capability of the female bear (Robbins et al. 2012). Females that produce a limited amount of milk may try to focus their resources towards the healthiest or largest cub in the litter (usually two, but up to four), increasing competition within the litter and decreasing the survival of the other littermates (Robbins et al. 2012). Severely food stressed mother bears may also stop producing milk altogether, causing dire implications for
lactation and cub survival (Molnár et al. 2010). If temperature increases another 2°C, female HB polar bears may stop producing cubs altogether within the next two decades (Dawson et al. 2010).

3.2.1.2 Cubs

Robbins et al. (2012) found that smaller polar bear cubs (less than 6 kg) in WHB had under 20% survival rate in their first year, whereas larger cubs (more than 22 kg) had up to 80% chance of survival. Larger cubs are less at risk of infanticidal adult males because they are better at keeping up with their mother during foraging trips after emerging from their dens than smaller cubs (Robbins et al. 2012). Being able to keep up with their mother on sea ice is crucial because sea ice is constantly changing, prompting polar bears to swim or walk longer distances search of prey (Molnár et al. 2010). Cubs that are smaller in size may not be able to compete for resources with cubs that are larger and healthier, resulting in decreased cub survival.

3.2.1.3 Impacts of Terrestrial Denning

Adult female polar bears are at risk from sea ice changes because of increased chances of human interactions while denning on land. Increased terrestrial denning also puts pregnant female bears closer to human activity such as resource extraction or production facilities (Larson et al. 2020), which increases the chances for female polar bears to come in contact with pollutants, toxins, diseases. Den sites may also be contaminated from runoff or other anthropogenic wastes, and toxins can be transferred to their cubs during nursing (Elvin 2014), further contributing to cub mortality. Because adult female polar bears have an increased reliance on ringed seals, it increases their risk of bioaccumulating toxins from industrial waste through ringed seal consumption. Ringed seal habitats receive an inflow of runoff through currents in their habitat and foraging grounds, and these bioaccumulated pollutants may be passed on to cubs and impact their survival, health, and fitness (Elvin 2014).

3.2.2 Adult Females Without Cubs

Adult female polar bears without cubs are less at risk of sea ice changes and diet restrictions than adult females with cubs, but more at risk than adult male polar bears (Johnson et al. 2019). Adult female polar bears who have not yet mated, or are just out of the breeding age, do not have the energetic pressure of raising young cubs, giving them greater freedom to take advantage of more resources as they do not have to worry about avoiding infanticidal adult males (Johnson et al. 2019). However, because adult female polar bears are smaller in size compared to
adult males, they are still restricted to smaller prey such as ringed seals (Florko et al. 2021). As lighter sea ice conditions persist, and the use of suboptimal terrestrial resources (e.g., carcasses) increases (Peacock et al. 2010, Pagano and Williams 2021). This puts adult female polar bears more at risk of sea ice declines and starvation as ringed seal foraging opportunities decrease, leading to declines in adult female body condition, reproductive success, cub health and survival rate (once they breed successfully), and ultimately, overall population number (Peacock et al. 2010, Pagano and Williams 2021).

3.2.3 Subadults/Juvenile Polar Bears

Subadult polar bears are at risk from sea ice loss and available prey options because younger bears might not have as much foraging experience as older adult males (Johnson et al. 2019). Additionally, their smaller body size does not enable them to forage on larger prey such as bearded seals or walrus like adult male bears can (Peacock et al. 2010). Additionally, larger adult males tend to steal food from the subadults. To avoid conflict with adult male bears, younger bears avoid adult males, increasing their reliance on such as ringed seals which adult males do not have a need to compete for (Thiemann et al. 2008, Johnson et al. 2019). Avoiding adult male polar bears also increases subadult polar bears’ reliance on terrestrial resources and scavenging on carcasses that provide less nutritional and energetic value. In fact, subadult polar bears are the group that scavenges the most out of all age/sex groups (Galicia et al. 2016). Galicia et al. (2016) revealed that subadult polar bears consumed more bowhead whale carcasses than adult polar bears, presumably because carcasses are not actively guarded by aggressive larger bears given their low nutritional value and large energetic costs to process (chew) the carcass. Their study also showed that carcass utilization by smaller and younger bears results from being less experienced or less efficient in catching prey unlike larger adult males (Molnár et al. 2010). Bowhead whale carcasses serve as an important energy source during ice free periods (Galicia et al. 2016) in a young bear’s growth.

3.2.4 Adult Males

Adult male polar bears are the least at risk from sea ice loss and prey diversity. Adult male polar bears have a larger body size compared to adult females and subadults (Figure 3), enabling them to hunt larger bodied prey, such as bearded seals and walrus, and decreases their
specialization and reliance on ringed seals (Galicia et al. 2016, Florko et al. 2020). A larger body size means larger skulls and jaws, enabling adult male polar bears to better alter their diet to incorporate harder and tougher terrestrial material (e.g., carcasses, flesh) that smaller bears find difficult processing (Petherick et al. 2021); harder material require more energy to process and digest, and a larger body size equates to a larger bite force and more energy to aid in chewing and digestion.

Figure 3: Polar bear size comparisons. Adult male polar bears are nearly twice the size and weight twice the amount of adult female polar bears. Source: BBC Earth

3.2.5 Dietary Differences Between Males vs Females, Subadult vs Adult

Ringed seals made up the largest percentage of a polar bear’s diet for females across all age/sex groups, while harbor seals and bearded seals made up the largest portion of an adult male’s diet (Johnson et al. 2019). While adult females and subadults are more reliant on ringed seals due to their smaller body size, adult males can be more generalist foragers, which enables them forage for and adapt to a larger variety of prey (Johnson et al. 2019). A stable isotope analysis (SIA) of the three HB subpopulations revealed nitrogen isotope values were different across all age/sex classes except for subadult females and subadult males, indicating that these two age/sex groups had similar diet compositions. Adult male polar bears had the highest carbon
and nitrogen isotope values in comparison to all other age/sex classes, indicating that there was a notable difference in prey choice in their diets compared to subadults and adult females (Johnson et al. 2019). As male polar bears get older and larger, they shift their diet from being ringed seal dominated to include more bearded seals (Thiemann et al. 2008). These distinctions help visualize the similarities in diet for male and female subadult polar bears, before larger adult males shift their dependence and diet away from primarily ringed seals to larger prey better suited for their growth and energetic demands.

There was a direct link between carbon isotope values and sea ice dynamics, and results from the SIA indicate that a large isotopic niche size correlates with a broader prey diversity (Johnson et al. 2019). Carbon isotope values were significantly higher in adult male polar bears compared to all other age/sex classes, and the high consumption of bearded seals aligns with the fact that bearded seals make up a large percentage of a male polar bear’s diet (Thiemann et al. 2008). Nitrogen is generated during a polar bear’s fast, and the high nitrogen value in adult male polar bears indicate that they produce this higher nitrogen value during fasting to maintain health and fitness (Johnson et al. 2019). Adult male polar bears do not have to worry about growth and reproduction as much as females, so they can allocate their energy towards maintaining a healthy body condition and optimal locomotion (Pagano et al. 2018).

Subadults, solitary females, and females with cubs had the most isotopic niche overlap, indicating that they shared similar prey (i.e., ringed seals) and hunting grounds (land-fast ice along the coast) (Johnson et al. 2019). In contrast, bearded seals, which are larger than ringed seals, use broken ice floes further from the shore and are primary foraging areas for adult male polar bears (Johnson et al. 2019). The low overlap between adult males, adult females, and subadults means that the three age/sex groups had different foraging areas and diet compositions (Johnson et al. 2019). Derocher et al. (1993) noted that terrestrial feeding was most common in subadults and females, which explains how these two age/sex groups have overlapping isotopic niches. The similarities in diet and foraging area for subadults and adult females indicate that they are more specialists than adult males.

Because male polar bears exhibit a more generalist foraging strategy and broader diet diversity than adult females and subadults, we can conclude that changes in sea ice extent will have larger consequences for solitary adult females, adult females with cubs, and subadult polar
bears (Table 2) (Johnson et al. 2019). Pregnant or nursing female polar bears are highly
dependent on smaller marine mammal prey and must forage more to intake more nutrients to
support reproduction and lactation (Johnson et al. 2019). Their narrower diversity can cause long
term declines in overall reproductive rate and population demographics if energetic demands are
not met. Although the HB region has a wide diversity of locally and seasonally available prey,
the restriction of smaller adult females from utilizing larger bodied prey highlights the fact that
the diets in adult male polar bears were more diverse than subadults and adult female polar bears
due to their ability to consume larger bodied prey and process tougher material. Within the three
subpopulations of the HB, subadults and adult females are the most at risk of prey availability
and dietary changes (Thiemann et al. 2008).

Table 2: Summary of impacts and issues for the polar bear age/sex groups.

<table>
<thead>
<tr>
<th>Age/Sex Group</th>
<th>Impacts/Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Female with Cubs</td>
<td>- smaller body size → restricted to smaller prey</td>
</tr>
<tr>
<td></td>
<td>- high energy demands for pregnancy and lactation</td>
</tr>
<tr>
<td></td>
<td>- increased terrestrial denning</td>
</tr>
<tr>
<td></td>
<td>- more SPECIALIZED</td>
</tr>
<tr>
<td>Adult Female (Solitary)</td>
<td>- smaller body size → restricted to smaller prey</td>
</tr>
<tr>
<td></td>
<td>- no energetic pressure of raising cubs</td>
</tr>
<tr>
<td>Adult Male</td>
<td>- larger body size → can hunt larger prey</td>
</tr>
<tr>
<td></td>
<td>- more prey choice and diversity</td>
</tr>
<tr>
<td></td>
<td>- can better process and use terrestrial resources</td>
</tr>
<tr>
<td></td>
<td>- more GENERALIST</td>
</tr>
<tr>
<td>Subadult/Juvenile Male and Female</td>
<td>- smaller body size</td>
</tr>
<tr>
<td></td>
<td>- inexperience with foraging</td>
</tr>
<tr>
<td></td>
<td>- rely on terrestrial resources and scavenging</td>
</tr>
</tbody>
</table>

3.3 Short and Long-Term Impacts of Dietary Change

The cutoff and distinction of the short and long-term years are not concrete; they often
blur together, and overlap based on the rate and severity of sea ice loss. Therefore, it may be hard
to distinguish specific time frames. In the case of polar bears and their diet change pressures,
short-term impacts can be referred to as taking place within 1-5 years, whereas long-term impacts may span out across multiple decades. The short-term impacts may be noticeable shortly after occurring, such as increased foraging opportunities for polar bears from sea ice declines washing out ringed seal pups. The long-term impacts may take numerous years to notice and are not as distinct, such as hybridization of polar bears and grizzly bears (*Ursus arctos horribilis*).

3.3.1 Short-Term Impacts: Increased Foraging Opportunities and Prey Availability

In the short run, polar bears may experience increased foraging opportunities from the effects of warming Arctic temperatures, such as decreased sea ice, melting events, and increased precipitation as rain instead of snow. These events in early spring, which is during ringed seal pupping and nursing season, can cause ringed seal subnivean (areas under layers of snow but above the ground) birthing lairs to thin out, melt, collapse, or wash out seal pups, leaving them vulnerable to predation by polar bears (Ferguson et al. 2005, Post et al. 2009, Reimer et al. 2019). This increased availability of exposed ringed seals and their pups provides optimal foraging opportunities for polar bears to stock up on their fat reserves for summer fasting and ice-free periods. Although warming Arctic temperatures increase polar bears foraging opportunities and productivity in the short run (Florko et al. 2021), prolonged open water periods and extensive sea ice melting will eventually cause negative consequences to polar bear foraging in the long run.

3.3.2 Long-Term Impacts: Increased Scavenging and Consumption of Suboptimal Resources

In the long run, polar bears will be forced onto land earlier and for longer durations, pressuring them to utilize more terrestrial foraging tactics and consume more terrestrial material (Stempniewicz 2017, Jagielski et al. 2021). Ice that is too thin or sparse (like in WHB) are unable to support ringed seals, reducing the seals’ productivity, abundance, and accessibility for foraging polar bears (Ferguson et al. 2005). Complete ice melt in the summer and decreased overall sea ice extent in the WHB further limits marine mammal prey for polar bears. Scavenging of terrestrial and marine mammal carcasses (e.g., bowhead whales) from commercial and subsistence hunting has increased as the duration spent on land increased. Carcasses make up about 26% of a polar bear’s diet (Peacock et al. 2010) as polar bears use them to sustain their fast. Bowhead whale carcasses have been documented to wash up more on shore, presumably from killer whale hunts (Galicia et al. 2016). Although these carcasses offer a supplement to their preferred ringed seal prey, this can ultimately cause polar bears to shift more towards a
scavenger foraging style (Galicia et al. 2016). Because polar bears are adapted to feeding on soft blubbery material from marine prey, their morphology makes them inefficient predators of harder or bonier material such as tougher animal carcasses. Additionally, open water periods also attract predators like killer whales that cross into polar bear range; this can potentially cause a shift in the ecological dynamic with the introduction of a new apex predator (Galicia et al. 2016) and increasing competition of marine prey for polar bears (Peacock et al. 2010). As sea ice continues to deteriorate, we can see an increased number of carcasses available, prompting polar bears to turn to scavenging as one of their main foraging methods.

As the duration of spring sea ice decreases, and summer open water months increase, WHB polar bears experience restricted prey availability, reduced foraging opportunities, and are forced to expend significantly larger amounts of energy walking or swimming in search of prey on quickly fragmenting sea ice. A single adult ringed seal can sustain an adult female polar bear for about 12 days (Pagano and Williams 2021). Spring (March-May) is peak foraging season for polar bears; ringed seals are weaning their pups on sea ice, and their abundance determines whether polar bears accumulate enough body fat for summer fasting (Peacock et al. 2010, Johnson et al. 2019). The bears must also endure a longer fast on shore for up to two months longer (Peacock et al. 2010, Whiteman et al. 2017), meaning they are without high-energy foods for a longer duration, increasing risks of starvation (Figure 4). An alternative is that they must change their foraging habits and diet to continuously meet their energetic needs.
Alternative foraging methods cause the polar bear to exert large amounts of energy. Additionally, the terrestrial resources they come upon do not provide the same amount of energy and fatty material that their large body sizes and high metabolisms demand as marine mammals (Pagano and Williams 2021), and these active terrestrial foraging tactics cause a polar bear to be in an energetic imbalance (expend more energy than foraging on sea ice) (Galicia et al. 2016). Marine mammal prey is rare to come by, if any at all, whilst polar bears are on land, and the use of terrestrial resources forces the bears to utilize alternative foraging tactics and food resources not normally used during on-ice periods. Terrestrial material consumed includes grass, seabird eggs, and carcasses (Stempniewicz 2017, Jagielski et al. 2021, Pagano and Williams 2021), and may be accessed using foraging tactics such as climbing cliffs, actively chasing prey, and grazing on vegetation (Jagielski et al. 2021). The importance of consuming ringed seals is highlighted in a study done by Pagano and Williams (2021), where they discover that to match the energy gained from a single adult ringed seal, a polar bear would need to consume 1.5 caribou, 37 Arctic char, 74 snow geese, or 3 million crowberries. In addition to the low energetic value, terrestrial material also requires more energy to digest. Polar bear’s small intestines have evolved to
specialize in digesting fatty material, meaning that their specialized adaptations make it more difficult to chew and digest non-fatty material (Petherick et al. 2021), resulting in more energy expenditure and less energy gains.

Two notable new foraging behaviors were of polar bears using visual cues to forage for seabird eggs and climbing cliffs to graze on grass. Jagielski et al. (2021) studied the polar bears’ ability to use visual cues in seabird egg foraging on Mitivik Island in NHB, an island used as a breeding area for migratory common eiders and serves as a pit stop for HB polar bears to cross in spring and early summer to reach the Foxe Basin ice floes. The overlap of the eider breeding season and polar bear crossings presents opportunities for the bears to forage on eider eggs (Jagielski et al. 2021) to sustain their fast. Stempniewcz (2017) observed polar bears grazing on scurvy grass (*Cochlearia groenlandica*) in Spitsbergen, Svalbard (Norway). Utilizing visual cues, such as flushing an eider hen from a nest, allowed the polar bears to consume more eggs, but because this foraging method is not normally used to hunt seals, this method is noted to be inconsistent and not universally adapted within the studied polar bears (Jagielski et al. 2021). Grass/vegetation grazing is another foraging method not normally utilized by polar bears, but because polar bears on land do not have access to ringed seal prey, they may not be getting adequate nutrients (i.e., vitamins, energy). Vitamin C is normally found in prey seals, but the lack of seals while on land indicate that fasting or starving polar bears may be suffering from a vitamin C deficiency, prompting the bears to turn to grazing on scurvy grass to replenish their vitamin C and caloric intake temporarily (Figure 5) (Stempniewcz 2017). Jagielski and colleagues’ study also found that polar bears did not concentrate their search on areas of the breeding colony where more nests are clumped together to maximize foraging time and energy (Jagielski et al. 2021). This can be because polar bears do not have experience foraging in high prey density environments; their marine prey are encountered at low densities and frequencies (Jagielski et al. 2021).
Dental microwear texture analyses (DMTA) of polar bear teeth found that polar bears’ teeth and jaws are not adapted to eating vegetation or harder material like seabird eggs (Petherick et al. 2021). As specialized carnivores, they have carnassial teeth for shearing flesh instead of flat molars for grinding (Berta and Lanzetti 2020). This morphological adaptation does not allow for them to mechanically process harder foods (Petherick et al. 2021). Because of rapidly declining sea ice and accompanying seal prey loss, polar bears are shifting to harder and tougher terrestrial material (i.e., seabird eggs and scurvy grass) which require more energy to chew and digest and are unable to replace the energy and nutritional deficits that result from the loss of seals (Petherick et al. 2021). Furthermore, vegetation grazing is unsustainable in the long run as the polar bears’ large energy expenditure in foraging overtake such little energy consumption (Stempniewicz 2017). The energy tradeoff between processing and digesting grass, and energy expenditure gained from vegetation consumption will not be enough to sustain a polar bear’s fast. Seabird eggs may also not be sustainable in the long run; the energy expended for foraging and
egg consumption exceeds the amount of energy gained. Additionally, overconsmption of eggs can eventually lead to seabird population declines (Jagielski et al. 2021).

Improper morphological adaptations, the lack of experience, and inefficiency in new foraging behaviors combined with low nutritional and energetic gains from terrestrial material continues to push the polar bears’ boundaries and their ability to survive in a warming Arctic (Stempniewicz 2017, Jagielski et al. 2021). However, as polar bears continue to come onto land and stay for longer durations, they may be able to one day pick up these new foraging techniques and improve their ability to find food, but declines in body condition, health, reproductive success, and population size are expected to continue as they increase reliance on suboptimal material in attempts to replace the loss of their seal prey (Jagielski et al. 2021).

3.3.3 Long-Term Impacts: Increased Fasting Periods and its Consequences on Polar Bear Body Condition and Health

Polar bears who are fasting do not eat, but as the fasting period increases in the long-run, polar bears are likely to turn to alternate food sources to sustain their extended fast (Derocher et al. 1993). They travel longer distances and expend more energy in search of food resources. Polar bears who are fasting are already in a state of deterioration as they deplete their stored fat. Female polar bears require a significant amount of stored fat for reproduction, but male polar bears have leaner tissue (i.e., muscle) content, and an adaptive fast can burn muscle (Petherick et al. 2021), meaning they cannot fast as long as female polar bears (Molnár et al. 2010). Adaptive fasts prioritize stored fat and reduces muscle loss by burning tissues from other areas (ex: skeletal muscle) to create sugar to sustain the nervous system (Whiteman et al. 2017) and by recycling the body’s byproducts to make new nutrients. However, even adaptive fasts cannot mitigate protein and muscle loss during extended fasting periods, and WHB polar bears can lose up to 18% of their muscle mass, contributing to declines in body condition and decreases their chance of successfully hunting prey to meet their energetic demands (Whiteman et al. 2017, Petherick et al. 2021). A two month increase of fasting periods may also cause female polar bears to stop reproduction, and these implications along with the negative consequences for adult male polar bears put WHB polar bears more at risk of decline than any other region of the Arctic (Peacock et al. 2010). The connection between longer fasting periods, the switch to more
terrestrial foraging, and increased energy expenditure are the main culprits for declines in polar bear populations regardless of age and sex.

Although adult males are the least at risk from sea ice changes and dietary changes (Galicia et al. 2016, Florko et al. 2020), they are more at risk from fasting than solitary adult females (Molnár et al. 2010). Fasting is directly related to energy expenditure and is one of the main factors for polar bear demise. Fasting periods of up to eight months significantly increase the necessity of locomotion in search of food to prolong a fast (Larson et al. 2020). If these conditions continue to occur, it is expected that 3-6% of adult male polar bears in WHB will die from starvation following a 120-day fasting period, and up to 28-48% will die after a 180-day fasting period (Molnár et al. 2010, Derocher et al. 2013).

3.3.4 Short and Long-Term Impacts: Increased Human-Bear Interactions in Local Communities

In the short run, sea ice loss and dietary change in polar bears may increase human-bear interactions for subpopulations that occur in or overlap with human territories (like WHB polar bears and the town of Churchill in Manitoba, Canada). Polar bears on land during ice-free periods are likely fasting, and increased time on land increases chances of starvation and nutritional deficit (Derocher et al. 1993, Johnson et al. 2019). As polar bears travel northward within their ranges to anticipate sea ice freeze up, they may come across human territories and/or aboriginal communities such as Inuit in Nunavut or resource extraction areas; this increases the number of human-bear interactions in these communities (Moore and Huntington 2008, Peacock et al. 2010). Increased human-bear interactions are also a long-term impact because an increased fasting period may cause more starving bears, attracted by the smell of food or garbage, to encroach into human territory to look for additional sources of food to stave off starvation (Petherick et al. 2021). Polar bears are large and aggressive carnivores that can endanger human lives and damage property when foraging, and defense of life and property in aboriginal communities can involve the killing of problem polar bears (Derocher et al. 2013). However, Inuit communities have attributed increasing polar bear sightings in their towns as increasing polar bear populations, demanding to raise harvest quotas to cull problem bears. (Stirling et al. 1999, Laforest et al. 2018). Increasing number of problems bears in town can decrease the tolerance that townsfolk have for the bears, resulting in more polar bears being killed (Clark et al. 2008). There is a set quota of bears that local hunters are allowed to kill each year for subsistence
activities (as part of polar bear conservation and management plans), but necessary and sometimes unavoidable defense polar bear kills may surpass the subsistence harvesting limits allowed (Clark et al. 2008); this can cause disputes with polar bear stakeholders and managers.

The timeframe distinguishing short and long-term impacts for increased human-bear interactions are not concrete and often blur together because the short-term effects can result in the long-term effects. In this case of human-bear interactions in local communities, the short-term increased frequency of bear visits may lead to the rising long-term motivation of locals wanting to deter or kill hungry bears in defense of their life and properties. Although starving bears only started visiting local communities recently, increased nutritional stress may force more bears to come into town looking for food. This will create pressure for the local peoples to take action to develop better measures to defend their lives and properties as polar bear presence increases in town (Miller et al. 2013).

3.3.5 Long-Term Impacts: Increased Exposure to Disease and Sickness

In the long run, female polar bears that den on land will become more exposed to anthropogenic activity, especially in areas of intense activity such as resource extraction and production that lead to reproductive failure and cub mortality (Laforest et al. 2018, Larson et al. 2020). Increased human-bear interactions may lead to female den abandonments (Larson et al. 2020). Den abandonments happened if the stressors happened in high intensity and near the dens, such as low flying aircraft. Early den abandonments can cause reproductive failures because female polar bears have already exerted a considerable amount of energy creating their dens, rendering them even more energetically and nutritionally stressed. Cubs that emerge too early are exposed to the harsh conditions of the environment, subjecting them to hypothermia and increased risk of attack and predation by larger adult bears (Larson et al. 2020). Increased human-bear interactions can also produce human and food-habituated polar bears that have decreased vigilance and wariness to human presence (Larson et al. 2020). As polar bears encroach into local communities and resource extraction and exploration sites, they can ingest human foods and garbage, increasing the risk of carrying and transferring diseases and parasites back to members of their population, their cubs, or other wildlife (Patyk et al. 2015). Because specialist foragers are less resistant to diseases and stress than generalist foragers, polar bears...
may not be able to fight off foreign sicknesses and/or parasites (Moore and Reeves 2018), adding another factor that can put their populations at risk of decline.

3.3.6 Long-Term Impacts: Increased Polar Bear Aggression and Cannibalism

In the long run, increased fasting periods and nutritional stress may cause increased aggression and cannibalism in polar bears. Large adult male polar bears are known be more aggressive and steal kills from smaller subadult polar bears (Galicia et al. 2016), and in times of decreased availability and abundance of prey, the smaller bears might be more incentivized to defend their kills from thieves. This can elevate intraspecies competition in a period where optimal food resources are less accessible. Increased fasting periods and nutritionally stressed polar bears have led to cases of cannibalism where adult male polar bears chase family units or unearth dens to predate on cubs (Derocher and Wiig 1999, Wilder et al. 2017). These acts of cannibalism can be seen not only as a way for starving polar bears to acquire nutrients and energy but may also be a way for adult polar bears to reduce competition for resources in an already food-scarce environment (Derocher and Wiig 1999).

3.3.7 Long-Term Impacts: Hybridization of Polar Bears and Grizzly Bears

In the long run, sea ice loss and diet change will cause the hybridization of polar bears and grizzly bears as ice-free periods and increasing temperatures convert the southern latitudes of the Arctic into more temperate environments. Grizzly bears are a subspecies of the brown bear and the polar bear’s closest relative. During ice-free periods, WHB polar bears are forced onto land and towards more southern regions into the temperate range of the grizzly bear. The overlap of the polar bear and grizzly bear can be attributed to a breakdown of species barriers or ranges, likely due to increasing northern temperatures of the grizzlies’ range and of the polar bears’ southern range (Pongracz et al. 2017). Male grizzly bears are more likely to expand their ranges and travel further than females, and as the southern limits of polar bears’ ranges are warming, the two species often meet at the edges of their ranges and mating events occur. This overlap of ranges may allow the two species to mate and produce hybrid offspring known as grolar bears or pizzlies (Mallet 2008, Pongracz et al. 2017). Hybrids (Figure 6) can have a blend of brown and white fur, a slightly humped back, and batches of brown fur on its face (characteristics of grizzly bears). Pongracz et al. (2017) discovered that these hybrids are already beginning to occur; eight hybrids (four first generation hybrids and four backcross hybrids) found by hunters were traced
back to a single female polar bear who mated with two grizzly bears. The presence of hybrids may foreshadow the increased likelihood of these mating events occurring in the long run as warming temperatures push these two species boundaries closer together.

*Figure 6: Polar bear-grizzly hybrid, known as pizzly bears or grolar bears, at Osnabrück Zoo in Germany. Source: [https://en.wikipedia.org/wiki/Grizzly%E2%80%93polar_bear_hybrid](https://en.wikipedia.org/wiki/Grizzly%E2%80%93polar_bear_hybrid)*

Diet changes are the main challenge for polar bears in a warming Arctic, but their hybrid offspring may be able to survive a changing environment with inherited traits from both parent species. While polar bears are specialist foragers of specific prey, grizzly bears are generalist foragers that eat anything, making grizzlies better at utilizing a variety of food resources. The mating of these two closely related species may allow for their hybrid offspring to better adapt diet changes and food resource availabilities. These hybrids may also better adapt to their respective parents’ natural habitats and be able to forage for and eat a wider variety of food sources with characteristics from their parents (Turner 2021). The morphological features of a pizzly’s skull, teeth, and/or jaw may allow the hybrids to better adapted to a wider variety of food, potentially giving them an advantage in consuming an even wider diversity of resources than their parent species (Turner 2021, Petherick et al. 2021).

Despite hybridization giving pizzlies an advantage in better utilizing changing environments and habitats, pizzlies may outcompete polar bears due to their wider foraging tactics and dietary composition (Turner 2021). Polar bear populations are declining by 10-12% per decade (Elvin 2014), with their specialization being the main factor of their demise (Petherick et al. 2021). The expansion of grizzly bears into polar bear ranges puts additional
pressure on the Arctic species, increasing competition and often resulting in grizzly bears outcompeting polar bears for alternate/terrestrial food resources (Turner 2021). The loss of polar bears and increase of hybrids can cause a loss of biodiversity. Unfortunately, pizzlies seem to be here to stay (and increase in presence) and may be a sad compromise that can potentially allow the polar bears’ hybrid offspring to survive in the future extended ice-free periods in the Arctic that their polar bear parents are increasingly struggling in unless polar bears eventually manage to alter their foraging tactics to reduce competition with grizzlies as the Arctic increasingly warms (Turner 2021, Tseng 2021). But because there are so few documented polar bear-grizzly hybrids, there is still a great deal of uncertainty about the survivability, adaptability, and resilience of the hybrids in a rapidly changing environment. However, the fact that there have been hybrids documented may serve as a prediction that more hybrids are likely to occur into the near future as climate warming changes the boundaries of both polar bears and grizzlies.

3.3.8 The Largest Implications of Sea Ice Declines

The most important consequence of sea ice declines and dietary changes for polar bears is increased scavenging and the consumption of suboptimal terrestrial resources. The main culprit of declining polar bear health and body condition is the increased energy used in foraging: traveling longer distances across their range and habitat; using more energy-intensive traveling methods (walking and swimming rather than a sit-and-wait ambush method); and using more energy to process harder or tougher food material (Pagano et al. 2018, Florko et al. 2020, Petherick et al. 2021). These foraging behaviors expend more energy than acquired upon ingesting terrestrial material that are inadequate in replacing the energy and nutrition gained from fatty marine mammal prey. Sea ice dynamics are the main driver behind the productivity, behaviors, habitat characteristics, distributions, and foraging ecologies of polar bears and other ice-obligate species (Figure 7) (Moore and Huntington 2008, Berta and Lanzetti 2020). Sea ice increases promote productivity for ice-dependent species like polar bears and their ringed seal prey, but as sea ice declines, ringed seal productivity, numbers, and stable ice hunting platforms also decline. This reduces the opportunity and time for polar bears to efficiently store enough fat and energy to last through an extended onshore fasting period (Whiteman et al. 2017). The effects on these marine carnivores are profound and will continue to alter polar bear diet, foraging behaviors, energy usage, health, and body condition as climate warming intensifies.
Furthermore, sea ice declines will also impact indigenous communities that have relationships with polar bears, and present opportunities for human commercial activities expansions.

The productivity of Arctic wildlife is largely dependent on the characteristics of sea ice (Figure 7). Sufficient sea ice cover decreases the chance of seasonally migrant species intruding into polar bear ranges and creating competition for food resources. Arctic wildlife and their lifestyles are highly adapted to the environment, and long-term sea ice declines ultimately decrease the productivity of ice-obligate and ice-associated species by reducing suitable habitat necessary for breeding, resting, and other life history events. Decreased ice cover and more open water allows for seasonally migrant species to expand their territories and migration routes into polar bear foraging areas, creating competition for food (Moore and Huntington 2008). Therefore, changes in sea ice dynamics creates a cascading effect that eventually impacts polar bears at the top of the Arctic food chain.

Figure 7: Conceptual model of sea ice dynamic impacts on ice-obligate, ice-associated, and seasonally migrant species. Sea ice declines may negatively impact ice-dependent species but may also benefit seasonally migrant species; this can cause food web regime shifts.
3.4 Impacts on Human Civilizations, Indigenous Communities, and their Economies

3.4.1 Increased Industrial Activities, Decreased Human Subsistence Activities

Sea ice declines increase the presence of industrial activities and reduces human subsistence activities (Figure 7). Reduced sea ice coverage increases the chance of human expansion into the Arctic, which can reduce wildlife habitats, alter distributions, and changes feeding ecology for Arctic wildlife (Berta and Lanzetti 2020). Less sea ice also allows easier access and navigation for boats and ships, increasing the chance for the establishment of industrial activities (i.e., shipping, exploration, resource extraction) that can harm polar bear denning and other life history events (Peacock et al. 2011, Larson et al. 2020). Declining sea ice decreases polar bear productivity, lowering the quantity and quality of bears harvested and creating hardship for local communities whose economies depend on natural resources and wildlife (Freeman and Wenzel 2006, Derocher et al. 2013). Indigenous peoples depend on polar bears for their meat, furs, and parts, and polar bears in poor body condition may not provide good quality goods able to be consumed by the community (meat) or sold to visitors (crafts and handiwork). Declining polar bear conditions and population numbers also prompts polar bear managers to reduce indigenous hunting quotas, further reducing the number of subsistence hunts (Kakekaspan et al. 2013). Nonetheless, the impacts of climate change and sea ice loss on polar bears, indigenous subsistence hunting activities, and chances of further human commercial activities are profound, and continual warming will create an Arctic that may be unrecognizable in the coming future.

3.4.2 Decreased Indigenous Hunting Success and Restricted Livelihood Gains

Sea ice declines and polar bear population declines put pressure on indigenous communities because these communities utilize polar bears subsistence harvesting not only for food and sustenance, but also to foster their livelihoods. Polar bears provide a sense of culture, identity, and economic incentives (Freeman and Wenzel 2006, Clark et al. 2008, Lokken et al. 2019). Changes in sea ice and increasingly unpredictable weather forces indigenous hunters to alter their hunting patterns and strategies (e.g., timing and location of hunts). Previously accessible locations such as solid and thick sea ice, as well as trails leading hunting sites, are no longer as accessible as they used to be, decreasing the chances of a successful and efficient subsistence hunt (Ford and Smit 2004, Pearce et al. 2015). Unstable ice conditions can cause the ice floes utilized by hunters to crack and detach from land-based ice sheets, stranding them...
offshore. Additionally, the hunters would have to travel and hunt in unfavorable conditions, putting them at risk of not only the harsh elements of the Arctic, but also reduced hunting success from further travels (Ford et al. 2008). The WHB polar bears continue to be harvested by indigenous communities for subsistence, despite their population declining the fastest out of the three HB subpopulations due to climate warming (Peacock et al. 2010). Because meat from hunted polar bears is distributed throughout the community as a food source, decreased abundance of polar bears and hunting success would mean less food for the community (Wenzel 2011).

Traditional ecological knowledge is used by indigenous peoples to document polar bear movement, population numbers, behaviors, and distribution in their regions which aids in subsistence hunts (Laforest et al. 2018). It also includes hunting knowledge, such as how to navigate on ice and other dangerous situations and following the migration of animals. Inuit TEK is often passed down through the generations and is constantly being updated as new experiences or information comes (Pearce et al. 2015). The rapid rate of sea ice declines may cause indigenous hunters to learn how to navigate new hazardous environments or terrains (thin or unstable ice) or find new routes to hunting grounds that were destroyed by sea ice breakup. Reductions in polar bear number and abundance (especially during summer) may lead to hunters changing hunting times to different months or seasons, spending more money to invest in new technology (vehicles like boats or all-terrain vehicles) that allow them better access to polar bears, learning new hunting grounds, and learning new bear behaviors (Pearce et al. 2015). These new adaptions may cause subsistence hunts to be inefficient, more time consuming, and yield less harvest.

3.4.3 Restricted Socioeconomic Gains: Subsistence, Trophy, and Sport Hunting

Declines in sea ice and polar bear populations prompt polar bear managers to implement restrictions on the economic utilization of polar bears by indigenous communities. The HB polar bear subpopulations have been harvested for thousands of years. Overharvesting caused the implementation of harvest quotas to prevent further population declines (Peacock et al. 2010, Derocher et al. 2013). Because the main source of polar bear population declines (before climate change became prominent) was from subsistence hunting, quotas were reduced or adjusted to promote population sustainability, restricting economic gain from polar bear parts for local
communities (Kakekaspan et al. 2013). Now that climate change and sea ice loss are the main causes of polar bear habitat fragmentation and population and body condition declines (Serreze et al. 2007), the economic benefit for local communities have been further restricted after boycotts and bans of polar bear parts and crafts trade (Clark et al. 2008, Derocher et al. 2013, Larson et al. 2020). A single large polar bear provides several hundred kilograms of meat for the community, and the skin and furs are essential “currency” between traders and Inuit hunters (Wenzel 2011). Therefore, reduced harvest quotas, declining polar bear body conditions, boycotts, and bans of the polar bear parts and crafts trade reduce the monetary gain that are essential for purchasing tools (firearms, ammunition, vehicles) to make future hunts more efficient and diverse (Wenzel 2011, Pearce et al. 2015).

Because 86% of polar bear harvesting occurs in Canada, restricting the utilization of polar bears threatens Inuit culture and socioeconomics (Freeman and Wenzel 2006). Polar bear sport hunting is the most expensive of all sport hunts, and although there have been boycotts of polar bear trophy and sport hunting, Inuit sport and trophy hunting guides earn roughly $1,500,000 CAD per year (approximately $1,164,783.30 USD; total price for 150-200 hunting guides) (Freeman and Wenzel 2006, Wenzel 2011). Inuit women who make clothes, crafts, and souvenirs from hunting polar bears also generate revenue for the region (about 2% of overall Inuit income) (Wenzel 2011). “Tags” (permissions to hunt a polar bear) are sold by local hunters to non-locals that allow outsiders to hunt polar bears, with each tag costing approximately $20,000 USD (Elvin 2014). Hunting guides and outfitters (businesses that employ hunting guides) can earn roughly $19,300 per trophy hunter and nearly $310,000 for just 20 clients (Freeman and Wenzel 2006). The money generated from trophy and sport hunting is used to purchase hunting equipment (e.g., snowmobiles, all-terrain vehicles, rifles, ammunition, fuel) that would make future hunts more efficient or successful (Wenzel 2011).

3.4.4 Decreased Revenue from Tourism

The polar bear viewing industry may be negatively impacted as WHB polar bear body conditions and health continue to deteriorate. Polar bear viewing and tourism is a large industry in Churchill, Manitoba, generating approximately $7.2 million CAD a year (ÉcoRessources Consultants 2011, Elvin 2014). During ice free seasons in WHB, polar bears, often in poor condition from loss of foraging opportunities and increased fasting periods, gather around the
shores of Churchill, Manitoba waiting for sea ice to refreeze (Regehr et al. 2007, Dawson et al. 2010, Schmidt and Clark 2018). Tourism operators have taken advantage of this “waiting period” where polar bears are abundant and visible, bringing in 6,000-10,000 visitors each year to see the aggregation of polar bears (Dawson et al. 2010, Schmidt and Clark 2018). There is uncertainty regarding how tourists will respond to unhealthy polar bears. As sea ice conditions (and body condition and health) for WHB polar bears continue to worsen over time (Regehr et al. 2007), people may be discouraged to spend money to view unhealthy bears, lowering the numbers of visitors, and thus revenue for local communities and governments (Dawson et al. 2010). On the contrary, the declining health of WHB polar bears may create a craze where more tourists travel to the Arctic to partake in “last chance tourism” before the polar bears are extirpated from the region, thus generating high revenue (Dawson et al. 2010). Although sea ice declines may benefit polar bear viewing companies in the short run as it lengthens the polar bear waiting period and viewing season, long term sea ice declines will continue to decrease polar bear health and body conditions, disincentivizing tourists from visiting (Dawson et al. 2010). However, the increased traveling and its associated carbon costs and emissions may in fact speed up extirpation of the very polar bears individuals come to see, but this topic is beyond the focus of my research and will not be evaluated in detail.

Reduced economic profit from polar bear viewing may reduce the income of Churchill and indigenous communities. Out of the $7.2 million CAD revenue, 35% ($2.2 million CAD) of the profit goes to Manitoba province and the companies that run the polar bear viewing tours. Approximately 10% of the $2.2 million CAD makes up the income of Churchill residents. Average Inuit income is less than $20,000 CAD per year, and 2% of that comes from the sales of souvenirs and crafts (Wenzel 2011, ÉcoRessources Consultants 2011). With the uncertainty of how tourists will respond to viewing unhealthy polar bears in the coming future, it is unknown how much of an impact decreased tourism will impact Churchill and Manitoba. However, because indigenous communities have a more direct and intimate relationship with polar bears, it is predicted that decreased polar bear tourism and visitors to their communities will decrease economic profits and create hardships in their livelihoods. The 2% of income barely contributes to an economy where a liter of milk costs approximately $5.25 (Wenzel 2011). Therefore, although reduced polar bear viewing and tourism in the future may reduce profit for Churchill and indigenous communities, it is predicted that indigenous communities will be more impacted.
3.4.5 Increased Human-Bear Interactions in Human Settlements

Polar bear dietary and foraging changes increase the likelihood of starving bears entering human settlements, causing human-bear interactions, conflicts, and injuries (Clark et al. 2008, Peacock et al. 2011). Nutritionally stressed polar bears are likely in poor body condition and are attracted to human settlements in search of leftover food and human garbage to satiate their hunger (Derocher et al. 2013, Schmidt and Clark 2018). Starving bears are also motivated to obtain food however and whenever they can, even risking encountering humans in towns as a result (Wilder et al. 2017). Adult male and subadult polar bears are the most common cases of polar bears entering towns and the most likely cause of human-bear interactions (whereas females only attack in defense of their cubs); they act like predators in search of food and are less cautious of humans. Adult male and subadult polar bears that enter town may endanger human lives and damage property (Miller et al. 2013, Wilder et al. 2017, Laforest et al. 2018). Human-bear conflicts can lead to lack of faith and confidence in polar bear management (Schmidt and Clark 2018). Local communities associate increased polar bear sightings near their communities with increasing polar bear populations (instead of sea ice loss forcing them onto land), which prompts locals to want to increase their hunting quotas (Regehr et al. 2007, Lokken et al. 2019). This increased presence in human civilizations may also decrease human tolerance for polar bears, leading to more dead bears in defense of life and property (Clark et al. 2008, Wilder et al. 2017). However, polar bear harvest quotas limit how local communities take action against bear encounters in towns (Clark et al. 2008). Decreased tolerance of problem bears, and increased defense kills will eventually lead to conflicts with polar bear conservationists and managers. Locals, such as Churchill townsfolk, believe that increased human-bear interactions are a result of the Polar Bear Alert (PBA) Program patrol officers and personnel not properly and consistently removing problem bears (or bears with a history of conflict) from the population (Schmidt and Clark 2018), allowing for those bears to return to the town multiple times. Dissolving trust and increased frustration towards management agencies’ inability to address problem bears in town deters local communities from collaborating or aiding future polar bear management (Clark et al. 2008, Schmidt and Clark 2018, Lokken et al. 2019). This creates rifts between local communities, management agencies, scientific parties, and polar bear conservationists, and hinders advances in polar bear management (Clark et al. 2008).
4. Discussion

4.1 Potential Extirpation of Hudson Bay Polar Bears

A polar bear’s fitness is directly related to sea ice conditions (Moore and Huntington 2008). Polar bears are documented to respond to climate change through behavioral rather than physiological features (Whiteman et al. 2017). As Arctic temperatures continue to rise, sea ice melts earlier, and open water periods increase, migratory and even temperate animals may expand and establish their range into the Arctic, increasing competition for food and habitat with polar bears (Peacock et al. 2010). The biggest threat to polar bears is not just sea ice loss, but the increased energetic costs that result from it (Molnár et al. 2010). Therefore, learning about polar bears’ dietary and foraging behavior changes is key in the species’ conservation and management (Petherick et al. 2021). Arctic sea ice is not only becoming increasingly fragmented but is also experiencing volume loss as well, which can decrease stability and thickness of sea ice platforms used for polar bears and their ringed seal prey (Overland et al. 2019). Sea ice will continue to decline, eventually extirpating polar bears in the southern regions of the Arctic (i.e., HB), with the more northern regions soon to follow (Johnson et al. 2019). In the potential extirpation of southern polar bear populations, the range of polar bears may be reduced with only the northern parts of the Arctic housing the remaining polar bears.

4.1.1 Nutritional Stress

Although modern day polar bears are known to consume tougher terrestrial material, polar bears 1,000 years ago did not utilize these food resources because of their specialized skull and jaw structure (Petherick et al. 2021); it was only in the recent century when polar bears began to diverge from soft foods, indicating that climate change may be a factor that pushes this dietary change onto polar bears. This is correlated with the prolonged onshore periods and extended fasts where polar bears utilize birds, eggs, and carcasses of both marine and terrestrial prey (e.g., caribou, bowhead whales) to sustain their fast (Brook and Richardson 2002, Gormezano and Rockwell 2013). Because the WHB and SHB polar bear populations experience complete ice melt in the summer, they are feeling the heaviest consequences by relying on suboptimal terrestrial resources that their morphological features do not efficiently allow them to. This can result in nutritionally stressed bears throughout the entire Arctic that contribute to
declining body condition, health, reproductive success, and population size, and can result in potential subpopulation extirpation (Clark et al. 2008, Johnson et al. 2019).

4.1.2 Future of the Polar Bears Under Current Rates of Global Warming

With current rates of GHG emissions, the WHB polar bears are highly unlikely to last until the end of the current century (Chervinski 2021). Air temperatures in WHB have increased by 2-3°C in the past fifty years (Table 3) and sea ice has been breaking up three weeks earlier than nearly half a century ago (Regehr et al. 2007). It is predicted that the world will lose about two-thirds of all polar bears by 2050 if temperatures continue to increase and if GHG emissions are not reduced (Derocher et al. 2013); this means that the HB polar bear subpopulations will be extirpated from the region (Table 4). The WHB subpopulation has already declined approximately 30% since 1987, from 1,200 bears to approximately 800 remaining (Laforest et al. 2018, Chervinski 2021). In the second half of the century, it is predicted that we will only see one-third of the 20,000-25,000 polar bears remaining in the High Arctic (i.e., Canadian Arctic Archipelago and northern Greenland) (Peacock et al. 2011, Chervinski 2021). Furthermore, the entire Arctic is likely to experience ice-free summers for the first time ever within the next few decades (Wunderling et al. 2020). This may also mean we may potentially lose all polar bears in the Arctic by the second half of the century if no action is done to reduce GHG emissions (Miller et al. 2013). The HB subpopulation declines foreshadow the potential consequences of climate change for the High Arctic subpopulations if no aggressive GHG mitigation action is taken.

Table 3: Average global atmospheric temperature changes. The 2-3°C noted from Regehr et al. 2007 is the temperature increase for the Western Hudson Bay only. The effects of temperature increases have caused sea ice quality, extent, and duration to decrease in the Arctic.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Findings</th>
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<tbody>
<tr>
<td>Stirling et al. 1999</td>
<td>0.2-0.3°C increase per decade</td>
</tr>
<tr>
<td>Regehr et al. 2007</td>
<td>2-3°C increase in the last 50 years</td>
</tr>
<tr>
<td>Post et al. 2009</td>
<td>0.4°C increase past 150 years</td>
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<tr>
<td>Wassman et al. 2011</td>
<td>0.4°C increase past 150 years</td>
</tr>
<tr>
<td>Wunderling et al. 2020</td>
<td>0.9°C increase past 170 years</td>
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Table 4: Polar bear population declines and predictions for the Hudson Bay and the Arctic.
Extirpation of polar bears in the southernmost Arctic are predicted to occur by the end of this century; the declines of the WHB subpopulation foreshadow the effects of climate change for the more northern polar bear subpopulations.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Findings</th>
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<tbody>
<tr>
<td>Thiemann et al. 2008</td>
<td>WHB population: 22% decline since 1987</td>
</tr>
<tr>
<td>Laforest et al. 2018</td>
<td>30% WHB decline since 1987</td>
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<table>
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<tr>
<th>Authors</th>
<th>Predictions</th>
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<tr>
<td>Molnar et al. 2010</td>
<td>-Hudson Bay: gone by 2050</td>
</tr>
<tr>
<td></td>
<td>-Lose 2/3 of all polar bears by 2050</td>
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<tr>
<td>Derocher et al. 2013</td>
<td>Lose 2/3 of all polar bears by 2050</td>
</tr>
<tr>
<td>Miller et al. 2013</td>
<td>-Lose almost all/most polar bears within 100 years (if no reduction in current GHG emissions)</td>
</tr>
<tr>
<td></td>
<td>-Extinct in the 21st century possible (even with without reducing GHG emissions)</td>
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4.1.3 Polar Bear Extirpation Consequences

Without polar bears in the southern Arctic, the food web will shift, potentially creating an imbalance in available prey. Extirpation (or localized extinction) of polar bear populations can cause a trophic cascade for the Arctic ecosystem. Polar bears are not only indicator species, but also serve as keystone species for keeping the Arctic ecosystem in balance (Thiemann et al. 2008). If there are no more polar bears, food web changes and range shifts of other species may occur (Johnson et al. 2019). The Arctic marine food web can also be disrupted and altered with these changes. Longer open water periods combined with increased temperatures promote primary productivity in the water (Johnson et al. 2019), increasing the amount of food for primary consumers such as fish. This increase in abundance of prey for marine mammals such as ringed seals will cause their population numbers to increase out of control without polar bears keeping their numbers in check. In the long run, too many ringed seals can quickly deplete the fish supply, causing disruptions in the food web (Pagano and Williams 2021). Decreased sea ice cover attracts migratory species; reduced ice volumes and cover allow for migratory species like killer whales to expand their ranges into polar bear range (i.e., Hudson Bay and Foxe Basin) and
allows them to stay in the Arctic year-round (Peacock et al. 2010). Killer whales and polar bears have similar prey of seals and this new encroachment into polar bear foraging range can cause competition between these two top predators (Galicia et al. 2016).

4.2 Outdated Polar Bear Management Guidelines

Polar bear management plans for the past 40 years have been primarily focused on harvest quotas of aboriginal communities (Peacock et al. 2011, Elvin 2014). Polar bear managers are challenged to balance conservation with consumption, and the concern for excessive harvesting sparked the demand for more polar bear knowledge (Vongraven et al. 2018). The 1973 Agreement is a treaty that has an emphasis on science-based management as the only viable method of polar bear conservation (Clark et al. 2008). However, the Agreement started the implementation of polar bear subsistence harvesting quotas and is currently outdated as the guidelines do not account for current threats and factors of polar bear population declines such as GHG emissions and pollution (Elvin 2014). The anthropogenic effects of climate change currently outweigh the consequences of harvesting and are now the primary cause of population decline in polar bears in the HB; it is now prevalent that global warming is the main cause of Arctic sea ice decline and polar bear population declines (Miller et al. 2013, Laforest et al. 2018). Because the Agreement primarily focused on harvest policies, it did not account for and provide guidelines for ecosystem assessment and management (Elvin 2014). Therefore, harvest management only serves as mitigation for polar bear loss (Peacock et al. 2010).

4.3 Need Global Action in Addressing the Root Cause

Given the known causes of Arctic sea ice loss, and its impacts on polar bear populations and body conditions, we need more action than extensive research if the world wants to save its polar bears. We already know that polar bear populations are declining, harvesting is going to continue, and that habitat is rapidly declining in quantity and quality. Therefore, to mitigate sea ice loss and the switches to suboptimal foraging methods and diet compositions, the only long-term solution to saving the polar bears is to aggressively reduce GHG emissions (U.S. Fish and Wildlife Service 2016). However, monitoring is still essential (and should continue to be used) in learning about polar bear characteristics (e.g., population and movement trends, foraging methods, diet compositions) and for predicting or detecting population decline risks. This will allow for immediate management actions, such as implementing bear deterrents in human
communities (Peacock et al. 2011, Derocher et al. 2013). Andrew Derocher, a world-renowned scientific advisor, professor, and author of numerous polar bear studies state that continued monitoring is useful for keeping track of sea ice and polar bear population trends, but “we actually know what’s going on with the polar bears” (Chervinski 2021). Therefore, the main concern and priority for polar bears should be reducing and mitigating climate change impacts, not reducing indigenous harvest (Kakekaspan et al. 2013). Since we now know that GHG emissions are the root cause of these impacts for polar bears and their Arctic home, it should be top priority to tackle the origin of these problems instead of trying to understand the details around various implications (i.e., diet and foraging changes, diet composition alterations). The listing of polar bears under the 2008 ESA as “threatened” also served as a nudge to encourage the U.S. government to begin GHG emission reductions to conserve the polar bears and their habitats (Clark et al. 2008).

Greenhouse gas emissions and climate warming has been the main cause of sea ice decline of up to 10-12% per decade (Table 1) (Elvin 2014). The large-scale impacts of climate change on the Arctic are thought to be profound and irreversible (Wunderling et al. 2020), and this polar region will become unrecognizable even if most of the world decides to implement aggressive GHG emission policies (Overland et al. 2019). Although the northern Arctic is also experiencing declines in sea ice (Galicia et al. 2016), albeit not as dramatic as the southern Arctic, further warming will eventually cause the north to experience the same level of sea ice loss and dietary shifts as the southern regions (Regehr et al. 2007). Even by maintaining a global temperature increase of 2°C by 2100, the entire Arctic may become ice-free for multiple months of the year within the next few decades (Overland et al. 2019). However, if GHG emissions are aggressively reduced, climate warming and global temperature may decrease, and Arctic sea ice may freeze up or break up on time to continue to support polar bears. To even begin implementing and acting on GHG reduction policies, there needs to be significant optimism about humans’ ability and dedication in reducing GHG emissions (Peacock et al. 2011). This means that there needs to be action done on the global scale, not just on the local scale. Global warming is caused by actions from all around the globe, and its effects are prominent worldwide. Local actions cannot fix global problems; for example, if I were to drive an electric vehicle, I would not make as big of an impact in mitigating GHG emissions as if an entire country were to drive electric vehicles. Therefore, large-scale impacts require large-scale actions and solutions.
Meeting with human industrial and commercial companies that may be sources of heavy GHG emissions and setting limits or compromises in their activities may be a good place to start the large-scale GHG reduction initiative. By being proactive in mitigating GHG emissions, it is more likely to stabilize the polar bear populations (and their habitats) in the long-term.

4.4 Habitat Monitoring

Habitat fragmentation is one of the biggest threats to specialist species like polar bears, decreasing the amount of preferred habitat (Sahanatien and Derocher 2012). Habitat fragmentation is also the main culprit of increased energy expenditure because it decreases habitat connectivity. Habitat connectivity allows for bears to efficiently move across the sea ice in search of mates and food, and fragmenting habitat and connectivity causes more movement in their search (Sahanatien and Derocher 2012). Despite the priority of action over research, there are uncertainties in sea ice habitat studies and monitoring that, if revealed, will aid in furthering our understanding of polar bears. Most polar bear studies and management have been primarily focused on population dynamics, harvest, and habitat protection (Clark et al. 2008, Derocher et al. 2013, Elvin 2014). However, we need to shift away from just population research and monitoring and integrate more biological and habitat factors (i.e., ecosystem factors) and studies to better understand population and foraging trends (Elvin 2014). Habitat breakup and habitat loss most negatively affect large specialist carnivores like polar bears. Studies of sea ice declines are shown to cause the survival and reproductive rates of the polar bears to decline (Peacock et al. 2010), but most management plans do not consider the ecological, behavioral, and habitat aspects that also affect polar bear populations’ resilience under such impactful changes (Peacock et al. 2011).

The most common research method in monitoring polar bear populations is the mark and recapture method. Mark and recapture methods can estimate abundance, reproduction, and survival for subpopulations, but do not factor in habitat influences on these variables (Peacock et al. 2011). Therefore, by implementing habitat fragmentation analyses, it will help us understand how habitat connectivity and habitat quality affect polar bear foraging success and energy usage (and thus population survivability and numbers), and aids in linking foraging success, to food intake, and finally to polar bear health (Sahanatien and Derocher 2012). Habitat preference models can also aid in determining which areas are frequented by polar bears, and habitat
distribution models help set those boundaries of high-density areas. Climate warming influences habitat characteristics, and in-depth studies of habitat characteristics may reveal and bring into light factors that may further or strengthen polar bear management actions. By incorporating these two habitat assessments, these data can reveal to polar bear managers which areas or regions they can devote their conservation efforts towards (Bailey and Thompson 2009).

Such habitat data can aid in the creation of protected polar bear habitats and ecosystems, such as marine mammal protection areas (MMPAs) or large marine ecosystems (LMEs) (Bailey and Thompson 2009, International Union for Conservation of Nature 2022). Local MMPAs help protect areas of high marine biodiversity and productivity and ideal habitat (Bailey and Thompson 2009, International Union for Conservation of Nature 2022). Large marine ecosystems (LME) are large coastal and oceanic regions that primarily encompasses coastal areas such as estuaries and continental shelves (Global Environment Facility 2022); an example is the Australian Great Barrier Reef, which is the largest LME in the world. LMEs are larger than MMPAs and can span across multiple national and political boundaries (Elvin 2014). Designating more MMPAs and LMEs may help polar bear managers monitor crucial polar bear habitat characteristics better.

4.5 Integrating Traditional Ecological Knowledge (TEK) and Fostering Indigenous Cooperation

However, for current and future polar bear management plans to succeed, there needs to be a larger focus on integrating TEK with Western scientific knowledge. Past polar bear management has marginalized indigenous voices, either through the lack of technology, funding, and language gaps, or through a larger bias towards science-backed research and management (Freeman and Wenzel 2006, Clark et al. 2008). The Agreement originated to manage indigenous over-harvesting of polar bears (Thiemann et al. 2008, Polar Bear Range States 2022). This instilled distrust and dissatisfaction in many local communities that have a direct relationship with the polar bears they hunt (Lokken et al. 2019). Traditional ecological knowledge and Inuit Qaujimajatuqangit (IQ) serves as a foundation of Inuit cultures, beliefs, society, well-being, and identity (Peacock et al. 2011). It also sets guidelines and values that are upheld through indigenous communities, such as respecting all living things and maintaining harmony and balance with the environment; IQ also provides the basis for spirituality (Tagalik 2009).
Indigenous knowledge and beliefs are based on information shared and passed down through generations, rather than scientific evidence, resulting in Western scientific communities often discrediting TEK and IQ (Peacock et al. 2011). In turn, Inuit communities disbelieve scientific findings because influential elders are less trusting of science (Clark et al. 2008, Lokken et al. 2019). Coastal areas of the Arctic are inhabited by indigenous people who are culturally resilient and have mixed acceptance of outside influences like technology and scientific knowledge (Elvin 2014). With both sides refusing to see the other, this creates multiple differing perspectives and divided social needs, creating tension that can ultimately harm polar bear conservation efforts (Clark et al. 2008).

Local communities and TEK also provide key insights on polar bear movement, population numbers, behaviors, and distribution in their regions, but their data are often overlooked because the data does not represent entire areas or subpopulations (Freeman and Wenzel 2006, Laforest et al. 2018). Western conservation groups like the Polar Bear Specialist Group (PBSG) also argued that TEK is only accepted and validated if the information is backed by scientific evidence (Lokken et al. 2019). However, the locals have direct although different relationships with the polar bears, meaning they may have a better understanding of the polar bears. By integrating TEK and observations with scientific research methods and studies through meetings or workshops, it allows for both sides to utilize an adaptive co-management approach that enables all stakeholders and jurisdictions to share power and responsibility (Kakekaspan et al. 2013).

5. Management Analysis and Recommendations

Now that we know the HB is the region most impacted by sea ice loss, female and subadult polar bears are the most vulnerable to sea ice loss and dietary change, the short and long-term impacts of such changes, and how it affects human civilizations and indigenous communities, I propose six management recommendations that may aid in the conservation and management of polar bears (Table 5). Each management recommendation is listed as “steps” to take; for example, defining polar bear health is necessary before grouping polar bears into similar units. These recommendations can also be interpreted as least to most important, and each will be discussed in further detail in the following sections.
Table 5: Management recommendations that may aid in polar bear conservation and management.

<table>
<thead>
<tr>
<th>Management Recommendations</th>
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<tr>
<td>Defining Polar Bear Health</td>
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<tr>
<td>Creating Genetically, Geographically, and Ecologically Similar Polar Bear Units</td>
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<tr>
<td>Determining and Protecting Vital Habitat Areas: MMPAs and LMEs</td>
</tr>
<tr>
<td>Collaborate with Human Industrial Companies</td>
</tr>
<tr>
<td>Increase Polar Bear Awareness, Education, and Deterrence Programs and Funding</td>
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<tr>
<td>Integration of TEK, Greater Indigenous Representation, and New Management Regimes in Polar Bear Management</td>
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5.1 Defining Polar Bear Health

Properly defining the term “health” as well as creating factors that gauge an individual or population’s resilience is the vital first step in understanding climate change impacts on a species. Being able to understand wildlife’s interactions with their environment as well as with humans have been key to successful management. The definition of “health” varies across disciplines; population experts define it as survival or recruitment, while veterinarians define it as sickness or disease (Patyk et al. 2015). There are countless studies on population trends and behaviors of polar bears but not much is known about polar bear health (Peacock et al. 2011, Patyk et al. 2015, Larson et al. 2020). Health is influenced by behavior, habitat choices, and diet choices, so properly defining “health” that includes these key aspects and works across multiple fields is a crucial first step that provides insight for polar bear management. Wildlife health is an animal’s interactions and responses to biological, social, and environmental factors and changes. Therefore, a polar bear’s health is measured by its resilience, vulnerability, and sustainability through change (Patyk et al. 2015). Resilience depends on how an animal responds to disturbances, how sensitive they are, and how easily they can recover from hardships (Moore and Huntington 2008, Moore and Reeves 2018). Using a few parameters (Figure 8) can serve as a
guideline to help categorize and gauge an animal or species’ resilience. Polar bears are less resilient to change for several reasons: they are specialists that are adapted to one ecosystem; they are only found in one region of the world; and they have a harder time adapting to new behaviors that climate change forced on them such as changes in foraging methods and diet composition (Moore and Huntington 2008, Tseng 2021). Being able to measure and understand polar bear health and resilience is essential in learning how we can integrate these parameters into polar bear management.

Figure 8: Model of gauging resilience in animal populations (Moore and Reeves 2018). Species with characteristics like broader habitat choices, diet, and foraging behaviors are more resilient than species with restricted characteristics.

5.2 Creating Genetically, Geographically, and Ecologically Similar Units

Polar bear conservation can begin by creating designatable units (DU), or groups of polar bears that are similar based on genetics, geography, and ecology (Thiemann et al. 2008). The Agreement lays out the guidelines for protecting vital sea ice habitat (e.g., feeding areas) and onshore migration patterns, yet minimal action is being done to address these factors (Peacock et al. 2011). Because two-thirds of the world’s polar bear population resides in Canada, they make up approximately 70% of legal harvesting and thus need the most assistance with management than other Range States and their polar bear subpopulations (Peacock et al. 2011). The three HB subpopulations are grouped into the same DU because they have similar life history patterns and events, and health, that are determined by ice-free summers and onshore periods, and have distinct differences in their foraging behavior, diet compositions, and migratory patterns than other DUs. These DUs can help managers divide up and identify which regions or
subpopulations are the most at risk and/or require the most attention and conservation efforts (Thiemann et al. 2008). The effects of climate change impact the 19 polar bear subpopulations differently due to spatial and temporal variations. This causes different subpopulations to exhibit different rates and severities of declines, meaning that the entire polar bear population does not—and should not—share the same conservation status (Thiemann et al. 2008).

5.3 Determining and Protecting Vital Habitat Areas: MMPAs and LMEs

Determining areas and habitats of concern is crucial in our understanding of polar bear population dynamics, distribution, and abundance. After grouping polar bears into DUs, areas can be determined and protected for specific polar bear DUs. Climate change and habitat assessments (i.e., habitat loss and fragmentation analysis) took the polar bear research world by storm beginning in the 21st century when climate change and sea ice declines started to become prevalent (Sahanatien and Derocher 2012, Vongraven et al. 2018). Habitat fragmentation, preference, and distribution analyses and models aid in monitoring critical polar bear areas and habitats. Habitat fragmentation analysis uses microwave satellite earth observation data to examine sea ice degradation and habitat break up trends (Sahanatien and Derocher 2012). Habitat preference and distribution models provide insight on which areas contain high densities of animals and identify factors that affect distribution and boundaries (Bailey and Thompson 2009). These observed characteristics help to identify local MMPAs, which protect areas of high marine biodiversity and productivity and ideal habitat (Bailey and Thompson 2009, International Union for Conservation of Nature 2022). Polar bear management should include the use of MMPAs to designate critical habitat areas, such as denning, foraging, and resting areas, that would be protected from industrial human activities such as exploration and extraction (Peacock et al. 2011). These MMPAs would offer local protection and would be managed by local jurisdictions or the Range State that the MMPAs occur in (e.g., Canadian government and indigenous peoples would co-manage Canadian MMPAs).

Once these smaller immediate areas are delineated and protected, LMEs can be created to further ensure protection, often involving a larger and more intricate food web and greater biodiversity. Monitoring and management of LMEs are wholly dependent on multinational collaboration, and are based on five human factors: socioeconomics, governance, productivity, fisheries, and pollution and ecosystem health (Elvin 2014). Because LMEs have resources that
are shared by multiple nations, it is important for these nations to overcome any political or social barriers and conflicts to properly collaborate in managing the shared resources. Designating MMPAs and LMEs (as needed) allows for polar bear managers to properly evaluate, monitor, and manage critical polar bear habitat. Polar bears are shared and managed by the Range States and creating MMPAs and LMEs can help foster collaboration between the nations to better conserve the large marine carnivores.

To protect critical polar bear regions, it is crucial to follow the Lancaster Sound MMPA’s footsteps by incorporating habitat analysis and habitat preference and distribution models into polar bear management to determine vital areas in need of attention. The Lancaster Sound MMPA is Canada’s newest and largest MMPA that contains the largest density of polar bears. It is in the Canadian Archipelago, and the 131,000 square kilometers of protected coastal and oceanic areas was approved and passed in August 2017 (Wong 2017). It protects the region from human activities such as resource extraction and mining, while ensuring the continuation of human subsistence activities of the Inuit. Creating the Lancaster Sound MMPA is a large step in furthering polar bear conservation and management. The NFB was also proposed to be an MMPA, but no further action has been done to confirm and implement this suggestion (Peacock et al. 2011). By bringing into light the instability and decline of the HB subpopulations and proposing to create an MMPA and/or an LME (as needed) for the HB region, it will serve as a basis and a role model in furthering protection for polar bears.

5.4 Collaborate with Industrial Companies

If, and once, industrial activity expands into the Arctic, polar bear stakeholders and managers should meet with these companies prior to beginning operations to discuss the potential risks and implications on polar bears, the local communities, and protected areas. Human activity such as exploration, expansion, and resource extraction in the Arctic are becoming increasingly attractive to developers and resource companies (Gautier et al. 2009). Large oil and energy producing countries like Russia may want to maintain being the top supplier and may have to eventually expand into the Arctic to do so (Harsem et al. 2011). Because industrial activities and expansion are increasing in demand, the need for oil, gas, and other natural resources to do so may also increase (Harsem et al. 2011). Polar bears increasingly frequent land during ice-free periods, and the expansion of human activities and disturbances
from anthropogenic sources may disrupt polar bear behaviors and reproductive success (Larson et al. 2020). Therefore, during peak polar bear onshore periods (and if around human development areas), human activities should be temporarily halted until the bears return to the sea ice to minimize disruptions and stressors (Larson et al. 2020). Furthermore, if human exploration and expansion encroaches into indigenous community territories, any damages to the nearby environment or property that would negatively impact indigenous livelihoods would be compensated by the exploration and expansion companies. These companies can also pay or employ indigenous communities to expand, extract, and export resources. This collaboration may not only help indigenous communities build relationships with outside parties, but also provide insight and educate outsiders on the importance of the Arctic environment and wildlife for the indigenous cultures and livelihood. Future developments may utilize this local knowledge (and vital habitat areas assessments) to avoid expanding into and extracting from critical wildlife areas.

5.5 Increase Polar Bear Awareness, Education, and Deterrence Programs and Funding

To offer clarity and insight on human-bear interactions, education and proper deterrence methods should be prioritized, especially in local communities that polar bears may visit frequently during the onshore fasting period (Table 6). Such education and deterrence programs may also be used in human commercial activities in which they may encounter polar bears. Media sources often skew the public’s perception of polar bears, their behaviors, and their interactions with humans. Misinformation and misconceptions can be caused by polar bear interactions not being properly documented, or simply not enough effort being done to collect information and raise awareness about polar bear-human interactions (Wilder et al. 2017). Although starving polar bears encroach into human territories in search of food, humans must also play a part in being responsible and learning how to avoid conflict scenarios. To avoid painting polar bears in a negative image (e.g., highly aggressive human eaters), there must be education and awareness programs to help people understand the factors that cause these bear behaviors and promote human safety (Miller et al. 2013, Wilder et al. 2017). Although the PBA in Churchill, Manitoba aims to protect people and property in Churchill by deterring, capturing, relocating, and occasionally kill bears who wander into Churchill, the lack of education for outsiders and increased complacency of locals contributes to human-bear conflicts just as much as starving bears (Sahanatien and Derocher 2012, Schmidt and Clark 2018). Polar bear conflicts
happen when humans take risks trying to get close to the bear. Outsiders who do not frequently interact with polar bears may not understand the dangers or are familiar with the behavioral characteristics of the bears. Therefore, there needs to be adequately funded education and awareness programs in local communities (Miller et al. 2013).

Table 6: Causes of human-bear conflicts and interactions and solutions implemented by management agencies, modified from (Schmidt and Clark 2018). Education and increasing polar bear patrol personnel are the most advocated for—and most popular—solutions for reducing polar bear-human interactions and conflicts.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Implemented Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improper garbage/attractant management</td>
<td>New garbage bins</td>
</tr>
<tr>
<td>Risk-taking by outsiders</td>
<td>Education</td>
</tr>
<tr>
<td>Lack of bear safety education</td>
<td>Education</td>
</tr>
<tr>
<td>Bear behaviors</td>
<td>Increased hazing/patrols</td>
</tr>
<tr>
<td>Shortcomings of the PBA program</td>
<td>Increased hazing/patrols</td>
</tr>
</tbody>
</table>

I believe that some polar bear management funding should be allocated to local communities and towns in the Arctic to help them develop more efficient polar bear education and awareness programs. For instance, all outsiders visiting Arctic towns should be made to watch a pre-recorded video of polar bear behaviors and safety (either on flights prior to landing or land vehicles going into the Arctic towns). Hotels or lodgings could hand out polar bear safety brochures upon checking in. Tourists who visit the Arctic for polar bear viewing should be made to attend a mandatory group workshop or program conducted by local tour guides or hunters (increasing job opportunities for locals) to educate the visitors about polar bear behaviors and safety prior to going out on tours. Tourists would also be notified through email or text message whenever a bear is sighted near town to alert them to not stray too close to the bears. Emphasizing the safety of traveling in groups, during the day, and away from coastlines would aid in preventing human-bear interactions. Funding would also be used to purchase and temporarily loan out bear hazing tools, such as bear spray or noise deterrents, to visitors that come to town in case of unpredicted polar bear encounters. The visitors would also be required to attend a mandatory workshop to learn how to use bear hazing tools (U.S. Fish and Wildlife Service 2018).
Such tools would be returned to the town upon departure. Although preventing and reducing human-bear conflicts requires people to take responsibility of their own actions and safety, the chances of education succeeding in preventing human-bear conflicts may be low. Therefore, incentives such as discounts for future visits or tours, or complimentary meals and souvenirs may persuade people to want to act in learning about polar bear safety.

In addition to education and awareness programs, more deterrence methods should be implemented in local communities. Increasing the number of polar bear safety personnel around town during peak polar bear onshore periods would provide a sense of security for locals and visitors. They would be more active and consistent in using scare tactics, such as shotgun warning shots or patrolling the town in large, loud vehicles (e.g., all-terrain vehicles, trucks, snowmobiles). Permanent or long-time residents should always carry bear deterrents tools with them when outdoors. Because improper waste management and disposal is the main attractant for polar bears coming into town, management agencies or polar bear stakeholders could subsidize and require households, businesses, and restaurants to have bear-proof trash cans or dumpsters (Schmidt and Clark 2018). Subsidies can also be used to develop better garbage disposal, collection, and transport systems by enlisting the help of neighboring nations, provinces, or jurisdictions that would come weekly to pick up and transport garbage to proper disposal sites. Funding can also be acquired through taxing visitors (Schmidt and Clark 2018). Some of the recommendations (ex: education, awareness programs) in reducing human-bear conflicts have been previously suggested or implemented in local communities in various studies (Sahanatien and Derocher 2012, Miller et al. 2013, Wilder et al. 2017, Schmidt and Clark 2018), but I believe that these methods should be emphasized, prioritized, and funded to increase success in reducing human-bear interactions.

5.6 Integration of TEK, Greater Indigenous Representation, and New Management Regimes in Polar Bear Management

New management regimes should be created, or current regimes should be overhauled, to allow for the acceptance and incorporation of TEK with western science by finding common ground between each party’s differing perspectives and creating compromises that are acceptable for all parties. There needs to be a shift from the Agreement’s guideline of using science-based management as the only acceptable framework for polar bear management (Clark et al. 2008). In
a rapidly changing environment that inflicts dire implications for polar bears, polar bear conservation must be able to adapt quickly as new information and sources emerge (Clark et al. 2008). Adaptive co-management is a management regime that is inclusive and collaborative between all polar bear stakeholders (Kakekaspan et al. 2013). It allows for all stakeholders to have equal power and responsibility in sharing new information that benefits polar bear management decisions. However, adaptive co-management only works if it is multi-level, multi-agency, multi-disciplinary, and transboundary (Peacock et al. 2011, Kakekaspan et al. 2013, Elvin 2014, Moore and Reeves 2018). Therefore, each Range State should supplement their own data and research and integrate information from other parties to create the most efficient management guidelines (U.S. Fish and Wildlife Service 2016). Adaptive co-management should adopt the use of the Indigenous Stewardship Model (ISM) as its backbone (Kakekaspan et al. 2013). The ISM highlights the importance of a few key indigenous aspects: cultural and spiritual perspectives; economy (subsistence, jobs, wages); self-governance; and self-sufficiency. The ISM also emphasizes the involvement of indigenous peoples at all stages and decisions of polar bear management, securing equal input and authority in planning, implementation, and monitoring (Kakekaspan et al. 2013). Altering polar bear management regimes to better promote indigenous participation and representation may assist in reducing indigenous resistance to scientific knowledge and urge more indigenous peoples to have their voices heard in management processes (Peacock et al. 2011). Additionally, with the consequences of sea ice loss producing increasingly unfavorable conditions for polar bears, the sense of urgency may coax more indigenous peoples to become active participants of polar bear conservation and management (Derocher et al. 2013).

Modern and future management plans must realize that local communities are directly affected by sea ice changes, polar bear declines, and hunting and quota restrictions (Clark et al. 2008, Larson et al. 2020). Therefore, indigenous communities should be able to continue subsistence harvesting of polar bears because it is their traditional right and provides cultural importance (Kakekaspan et al. 2013). They should also be allowed to conduct their own research and collect data regarding polar bear characteristics and trends and subpopulation numbers (Freeman and Wenzel 2006, Laforest et al. 2018). The data would then be shared in annual meetings with western scientific groups and other agencies to analyze and integrate information and research from all stakeholders. Harvest quotas would be adjusted accordingly using the data
to allow for conservation as well as subsistence activities (Freeman and Wenzel 2006). Creating compromises regarding harvesting is crucial for arriving at a conclusion or finding common ground in management decisions (Kakekaspan et al. 2013). Frequent meetings between polar bear stakeholders minimalizes indigenous marginalization and allows for the integration of perspectives and actions across agencies (Clark et al. 2008, Vongraven et al. 2018). Because 11 out of the 13 Canadian subpopulations are within Nunavut boundaries, local communities should also be allowed more voices, larger representation, and greater power in management decisions regarding polar bears (Wenzel 2011, Peacock et al. 2011). Although Range States and agencies around the world hopes to save polar bears from extirpation and extinction, indigenous communities have the most direct interactions with polar bears. Scientific agencies and wildlife managers should strive to get understand, or at least get familiar with, traditional values and input (Peacock et al. 2011). Accepting that TEK and IQ can provide information on polar bears and the changing environment in different perspectives and interpretations that can aid polar bear management processes (Peacock et al. 2011, Moore and Reeves 2018).

The integration of TEK and scientific knowledge can create new ways to generate knowledge and study methods that can aid in the understanding of polar bears for all stakeholders. Samples from hunted polar bears can be used to further research and studies, and the local communities can share their concerns about the polar bears in their territories (Freeman and Wenzel 2006). Through this sharing and integration of information, this will increase local trust, participation, and collaboration in polar bear management. Data or information that is difficult to obtain through TEK (e.g., tracking polar bear movement patterns, onshore migration timing) can be assisted with scientific methods; results from scientific bodies can then be shared with local communities to make subsistence hunts more efficient (Laforest et al. 2018). Adaptive co-management can help foster relationships across nations and boundaries and allows for a wider variety of perspectives and interpretations. Once indigenous peoples feel like they have a voice and their thoughts are being heard in management regimes, they may be more willing to participate in the management process (Freeman and Wenzel 2006). The ultimate polar bear conservation goal is to maximize the chances of maintaining natural populations of polar bears in the Arctic while considering human safety and integrating science and TEK (Derocher et al. 2013). The future of polar bear conservation and management will only be successful if all
stakeholders have equal input, contribution, authority, and respect for differing perspectives throughout management processes (Freeman and Wenzel 2006, Clark et al. 2008).

6. Conclusion

The Arctic is especially vulnerable to climate change, warming two to three times faster than the rest of the world and causing large scale sea ice loss and reducing valuable habitat for polar bears (Moore and Huntington 2008, Johnson et al. 2019). Although sea ice is declining in regions across the Arctic, polar bears in each region have various prey availability and responses to a changing environment (Galicia et al. 2016). The HB region and its subpopulations (primarily the WHB bears) experience the most negative consequences of sea ice loss, resulting in large diet and foraging changes that decreases polar bear body condition, reproductive success, health, and population size and abundance. These impacts make this region’s bears the most at risk of climate change, and ultimately extirpation (Peacock et al. 2010, Johnson et al. 2019). Different age and sex groups within a polar bear subpopulation have varying diets, depending on the location and prey availability. Despite male polar bears being better at adapting to sea ice loss and dietary change than adult females and females with young due to their larger body size and broader diet composition, the long-term consequences of dietary change, increased terrestrial foraging, and consumption of suboptimal material creates bleak futures for both age/sex groups (Florko et al. 2020, Petherick et al. 2021). Specialized soft diets and morphological features create challenges for polar bears trying to adapt to a changing Arctic (Thiemann et al. 2008, Berta and Lanzetti 2020, Florko et al. 2020, Pagano and Williams 2021, Petherick et al. 2021, Tseng 2021). Energetic inputs gained from terrestrial (often harder and tougher) material are insufficient in sustaining this large marine carnivore through prolonged fasts and increased locomotion across fragmenting sea ice in search of marine mammal prey (Pagano et al. 2018, Pagano and Williams 2021). Therefore, the main source of declines in polar bear body condition and reproductive success are from increased energy expenditure (Sahanatien and Derocher 2012, Elvin 2014, Pagano et al. 2018).

The WHB region is the most accessible, thus most studied subpopulation (Thiemann et al. 2008), and has the greatest abundance of polar bears in the Arctic (Peacock et al. 2010). The numerous studies showcasing the decline of the HB polar bear subpopulations foreshadows the consequences for the regions and subpopulations further north in the Arctic. The HB’s southern
latitude makes it the first region to experience Arctic warming and complete summer ice melts, and this recent tipping point can be used to predict the consequences of sea ice dynamics in the High Arctic should warming continue (Peacock et al. 2011). With current rates of GHG emissions, the WHB polar bears are highly unlikely to last until the end of the current century (Chervinski 2021). Southern Arctic polar bear subpopulations will be extirpated from the region by mid-century as prolonged ice-free summer periods continue, leaving the High Arctic the only region where polar bears can be found (Chervinski 2021). Losing large numbers of polar bears will severely impact indigenous Inuit communities that have been relying on polar bears for economic and cultural identity for thousands of years (Laforest et al. 2018). Starving bears will also intrude into towns in search of food, increasing the changes of human-bear interactions, conflicts, and loss of life and property (Clark et al. 2008, Peacock et al. 2011, Miller et al. 2013, Patyk et al. 2015). Decline in polar bear productivity and numbers prompted the listing of the species under many nations’ species watch list, creating division between scientific and local polar bear stakeholders (Freeman and Wenzel 2006, Clark et al. 2008).

Current and future polar bear research, decision making, implementation, monitoring, and management must be carried out equally across all participating stakeholders. The importance of multi-agency, multi-level, multi-disciplinary, and transboundary should be emphasized to create and carry out equal (i.e., finding common ground) and efficient polar bear monitoring and management (Peacock et al. 2011, Kakekaspan et al. 2013, Elvin 2014, Moore and Reeves 2018). To mitigate large-scale loss of polar bear numbers, the most important matter is to take aggressive action on tackling the root cause of climate change, sea ice loss, and declining polar bear numbers and productivity: greenhouse gas emissions (Clark et al. 2008, U.S. Fish and Wildlife Service 2016). There needs to be proactive global action and optimism in making these large-scale changes that will save these marine carnivores (Peacock et al. 2011). Otherwise, polar bear ranges will shrink, and we may experience the species going extinct by the end of the 21st century (Clark et al. 2008, Miller et al. 2013). Losing a keystone species will not only disrupt the Arctic food web, but also establish new regimes with different top predators, causing irreversible changes to the environment and creating a new Arctic that has not been seen before (Peacock et al. 2010, Galicia et al. 2016, Wunderling et al. 2020).
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