

Assessing the Vulnerability of Marine Mammal Subsistence Species in the Bering Sea to
Climate Change

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Abstract

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The Bering Sea is a highly productive region of the Pacific Arctic. Native Alaskan communities rely heavily on the marine resources of the Bering Sea for survival. The timing of the formation and thaw of sea ice each year has a significant impact on the structure of the Bering Sea ecosystem. In its current state, the northern Bering Sea is a benthic-dominated ecosystem that supports many species of marine invertebrates, fish, birds, and mammals. Eight of these mammal species are relied on heavily by Native Alaskans for subsistence. However, this region is already experiencing the effects of climate change in ways that threaten the persistence of these communities as a result of changes in the timing of sea ice advance and retreat. As these changes progress, understanding the ways in which the ecosystem is vulnerable to climate change will be essential for resource managers and local communities to prepare to adapt. Climate change vulnerability analyses (CCVAs) provide a framework for quantifying vulnerability that can be useful for developing, implementing, and monitoring management

solutions to reduce vulnerability. This study uses a CCVA to quantify the vulnerability of eight species of marine mammals in the Bering Sea as a first step in understanding how the communities that rely on them for subsistence are also vulnerable. Although some species are more vulnerable than others, this method allows managers to pinpoint sources of vulnerability for each one to develop strategies for reducing their vulnerability.

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INTRODUCTION

The continental shelf of the Bering Sea is home to some of the most productive fisheries in the world. The benthic habitat in this region supports an abundance of demersal fish and invertebrates, making it an ideal foraging area for Arctic and subarctic marine mammals (Meuter and Litzow 2008). However, climate change threatens this ecosystem and the structure that supports marine mammal populations. Anthropogenic carbon emissions have resulted in a warming global climate, a trend that is expected to continue and amplify in the near future (IPCC 2014). The Arctic Ocean is experiencing increased ocean temperatures, changes in sea ice extent, and increased freshwater input (Stroeve *et al.* 2007; Polyakov *et al.* 2010; Steele *et al.* 2008). Changes in ice extent have been the most dramatic on the Pacific side of the Arctic, especially over the continental shelves of Alaska and Russia (Steele *et al.* 2008; Wang *et al.* 2012). Over the last two decades, winter ice cover in the Bering Sea has retreated earlier and returned later each year, changing the landscape of this diverse region (Grebmeier *et al.* 2006; Steele *et al.* 2008; Grebmeier *et al.* 2010). Marine mammal populations and the communities depending on sea ice have already begun to experience the negative effects of this change (e.g. Oceana and Kawerak, Inc. 2014). However, predicting species' responses to climate change is a major challenge for scientists, managers, and subsistence harvesters. This study focuses on designing a climate change vulnerability analysis (CCVA) for eight species of Bering Sea marine mammals. We use available data to predict which species are more vulnerable to climate change and identify specific sources of vulnerability that can be addressed through management. This tool can assist Native Alaskan subsistence harvesters and marine resources managers in preparing for the challenges ahead.

CLIMATE CHANGE AND BERING SEA ICE

First-year winter sea ice cover is a defining characteristic of the Bering Sea marine ecosystem. Sea ice forms in the Chukchi Sea, expanding south as dropping air temperatures and wind from the north create favorable conditions for ice formation. Ice begins to form in the eastern Bering Sea in December, extending further and further south until maximum sea ice extent is reached in March (Wang *et al.* 2012). Winter ice formation patterns have changed over the last twenty years as sea surface temperatures continue to rise. The biggest change has been observed in fall as sea ice begins to form again (Steele *et al.* 2008; Kovacs *et al.* 2011; Wang *et al.* 2012). Figure 1 shows that the minimum sea ice extent in the Chukchi has shifted significantly in the last decade, which delays the formation of ice through the Bering Strait in the fall and winter.

Although the increase in ocean temperature in the Bering Sea is relatively new compared to other regions, this pattern has already resulted in a geographic shift in the benthic ecosystem (Grebmeier *et al.* 2006; Steele *et al.* 2008; Grebmeier 2012). Winter ice cover defines the boundaries of arctic and

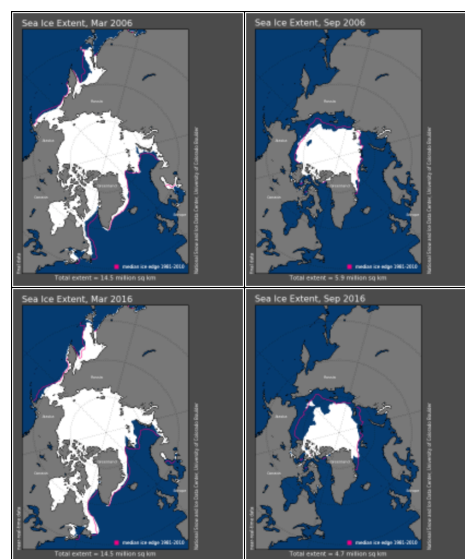


Figure 1. Minimum and maximum sea ice extent in the Arctic from in 2006 and 2016, as compared to the 30-year average (red line). (NSIDC 2016).

subarctic demersal communities by creating a pool of cold water that sinks to the ocean floor and acts as a barrier between Arctic and sub-Arctic benthic communities (Meuter and Litzow 2008). The marginal ice zone in this region also experiences a high level of vertical nutrient transport as ice algae falls to the benthos after growth is stimulated by increased solar input. As the marginal ice zone shifts, vertical transport of nutrients decreases in areas that were once driven by the input of ice algae to the benthos while pelagic phytoplankton production increases (Grebmeier 2012). The movement of the cold pool and decreased vertical nutrient transport result in a shift from a benthic-dominated to a pelagic-dominated ecosystem and a northward shift in sub-Arctic species distribution. This geographic shift in important prey species is resulting in a bottom-up trophic cascade with negative impacts top predators like marine mammals (Grebmeier *et al.* 2006; Grebmeier 2012). Highly vulnerable species that are unable to adapt in time to the effects of a warming climate may be threatened with extirpation (Kovacs *et al.* 2011).

A decrease in first-year ice also represents a loss in habitat for ice-dependent mammals that use sea ice as places of refuge (Laidre *et al.* 2008; Huntington 2009; Wang *et al.* 2012). Marine mammal migration, foraging, and reproduction patterns rely heavily on the seasonality of sea ice in this region. Ice not only supplies a resting place during long foraging periods and seasonal migrations, but also provides protection from predators and rough seas (Laidre *et al.* 2008; Kovacs *et al.* 2011). In the absence of fall ice, marine mammals have already begun to succumb to the negative impacts of climate change, showing shifts in range, compromised body condition, and declines in abundance and reproduction. Changing temperatures in the Arctic are also likely to alter the timing of seasonal migrations of mobile species of marine mammals such as pinnipeds and cetaceans and impose new threats from disease, parasites, invasive species, and pollution (Meuter and Litzow 2008; Kovacs *et al.* 2011; Oceana and Kawerak, Inc. 2014).

With the reduction of sea ice in the Bering Strait and Arctic Sea, human activities such as shipping and resource extraction are expected to become more frequent and widespread, increasing the number of human interactions with marine mammals in the form of ship strikes, noise pollution, and competition for space (Hovelsrud *et al.* 2008; Alter *et al.* 2010; Kovacs *et al.* 2011). Fishing activities in the southern Bering Sea interact with some marine mammals, resulting in mortality from entanglement and incidental catch (NPRB 2005). The North Pacific Fishery Management Council closure of the northern Bering Sea to certain kinds of fishing is an example of precautionary and adaptive management in this respect. As habitat degradation and human activities intensify, identifying and closing gaps in marine mammal management may be crucial to ensuring the survival of the Bering Sea's vulnerable marine mammal populations.

BERING SEA SUBSISTENCE HARVESTING

Planning for climate change in the Bering Sea and the potential for decreased population size and reduced biodiversity among Arctic marine mammals requires a consideration of the human dimension. Subsistence communities rely on marine mammals for food, tools, clothing, and income from the sale of handicrafts made from bones and pelts. The Marine Mammal Protection Act (MMPA) includes provisions exempting Native Alaskans from prohibitions on hunting marine (16 USC §1361-1421h). Section 119 of the Act also provides Native Alaskans with the opportunity to participate in the management of subsistence species through co-management agreements, offering them a voice in decision-making processes that have significant impacts on their lives (16 USC §1388). There are currently five Alaska Native co-management committees:

the Alaska Beluga Whale Committee, the Alaska Eskimo Whaling Commission, the Eskimo Walrus Commission, the Ice Seal Committee, and the Alaska Nanuuq Commission.

The loss of vital subsistence species as a result of climate change would also mean a loss of indigenous culture, household income, and food security (Hovelsrud *et al.* 2008; Bering Sea Elders Advisory Group 2011; Oceana and Kawerak, Inc. 2014). Access to some of these species such as walrus and ice seals is already becoming more limited and treacherous (Hovelsrud *et al.* 2008; Kovacs *et al.* 2011). The traditional knowledge that subsistence hunters rely on to find marine mammals is becoming obsolete due to rapid change in the Bering Sea. Without this knowledge, hunters must dedicate more time and money and take greater risks in order to catch fewer animals. For some species, a loss of sea ice means that they cannot be harvested at all (Hovelsrud *et al.* 2008). For other species, such as bowhead whales, and the communities that rely on them for subsistence, however, climate change may have resulted in improved conditions (Kovacs *et al.* 2011; George *et al.* 2015). These impacts must be studied and anticipated. Currently, little is known about how the Bering Sea's marine mammal-dependent communities will be impacted by the loss of biodiversity expected in this region. This is an important consideration in assessing management structures aimed at minimizing the threats posed by climate change.

SUBSISTENCE SPECIES

Of the eight species focused on in this analysis, four are ice-dependent and four are ice-associated. Polar bears, walrus, bearded seals, and ringed seals rely on sea ice as a platform for resting, hunting, and breeding (Fay 1982; Fay 1974; Kelly 1988). Bowhead whales, beluga whales, ribbon seals, and spotted seals, on the other hand, are considered ice-associated because they do not require sea ice year-round. Ribbon and spotted seals do, however, require sea ice for whelping. It is less clear how the ice-associated whales depend on sea ice (Laidre *et al.* 2008; Moore and Huntington 2008). The predicted outcomes for ice-dependent species are somewhat clearer, as their fitness relies directly on the presence of sea ice (Laidre *et al.* 2008). However, these four ice-associated species rely less heavily on sea ice for survival, and prey on pelagic species that may increase in abundance as a result of changes in primary productivity, but those predictions have a high level of uncertainty, as discussed above (Laidre *et al.* 2008; Moore and Huntington 2008). One conceptual model developed by Moore and Huntington (2008) predicts that reduced sea ice will have negative effects on both ice-dependent and ice-associated species, but that there is more uncertainty associated with the predicted outcomes for ice-associated species (Figure 2).

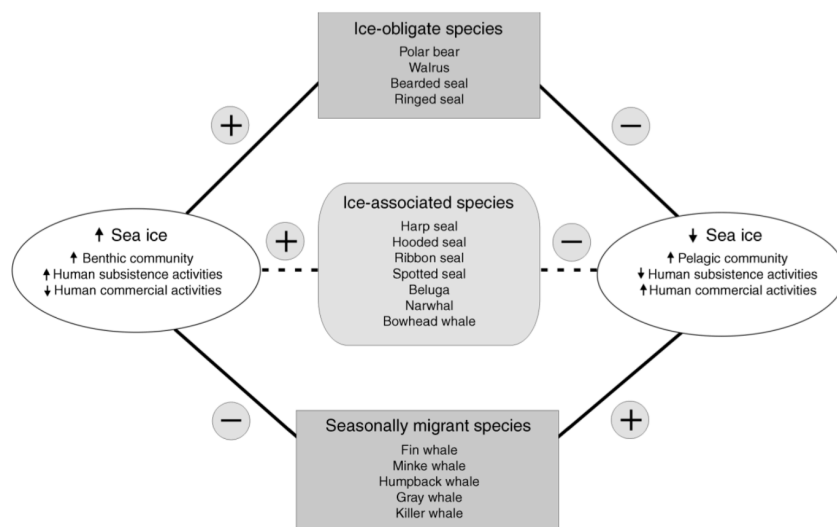


Figure 2. A conceptual model developed by Moore and Huntington (2008) to depict impacts of changes in sea ice extent on ice-obligate, ice-associate, and seasonally migrant species. The positive impacts are indicated using plus signs while negative impacts are indicated using minus signs. Solid lines connecting ice-obligate and seasonally migrant species to changes in sea ice indicate a low level of scientific uncertainty in the predicted outcomes, while the dashed lines used for ice-associated species indicate greater uncertainty.

Polar Bear (Ursus maritimus)

Polar bears in the northern Bering Sea follow the edge of the sea ice as it advances and retreats each year. The ice brings them to the coast in the winter and spring, and then draws them back into the Chukchi and Beaufort seas during the summer. Polar bears are opportunistic predators and usually hunt for ice seals, walruses, and even whales on the pack ice. As ice retreats earlier and earlier each year, bears become more likely to get stuck on land during the summer, often coming into conflict with local communities as they search for food (USFWS 2015a).

Polar bears have great nutritional and cultural significance to the communities of the northern Bering Sea. The annual harvest rate of polar bears for subsistence is estimated at roughly 37 bears. This is slightly above the potential biological removal (PBR) level set for polar bears at 30 individual per year, however the uncertainty of this level is high due to low confidence levels associated with the overall population estimate (Wade and Angliss 1997; Muto *et al.* 2016). Polar bear hunts play an important role in building social capital, as they bring the community together in social gatherings to distribute the meat, talk about the hunt, and celebrate the success. Inuit people use as much of the bear as possible, reserving the blubber and meat for food, making clothing with the pelt, and using the bones and teeth to make tools, handicrafts, and artwork (Oceana and Kawerak, Inc. 2014). Hunters prefer to take the bears on sea ice, as hauling their carcass out of the water can prove difficult or even impossible. As such, the availability of polar bears to subsistence harvesters depends on the presence and quality of sea ice. Although the main hunting season is in the winter and spring, bears are becoming stranded on land more frequently, especially on St. Lawrence Island where they may be killed during the summer to protect the community (Oceana and Kawerak, Inc. 2014).

Bowhead Whales (*Balaena mysticetus*)

The Bering-Chukchi-Beaufort (BCB) Bowhead Whale stock spends winter in the Bering Sea before migrating through the Bering Strait to the Chukchi and Beaufort Seas as the sea ice retreats (Braham *et al.* 1980; Moore and Reeves 1993; Quakenbush *et al.* 2010). They are most often associated with 100% ice cover while in the Bering Sea, even when polynyas are present (Quakenbush *et al.* 2010). During the summer, they are most associated with open water, making them particularly vulnerable to the effects of shipping and oil spills (Muto *et al.* 2016).

Bowhead whales are typically harvested by four communities in the Bering Sea: Wales, Little Diomed, Gambell, and Savoonga. The harvest rate is approximately 41 whales each year—which equates to about 1% of the known population—well below the quota set by the International Whaling Commission at 306 whales (Suydam *et al.* 2012; Muto *et al.* 2016). Although bowhead whales are hunted in the fall and spring around St. Lawrence Island during their migration, fall hunts are preferred due to more favorable sea ice conditions (Suydam *et al.* 2012; Oceana and Kawerak, Inc. 2014). Bowhead whale hunting plays a significant role in practicing and passing down traditional knowledge from generation to generation. The knowledge that Native Alaskans possess of bowheads only exists in their cultures and languages, and has been accumulated over thousands of years. Annual rituals associated with bowhead hunting are key components of teaching younger generations how to survive in the Arctic (Oceana and Kawerak, Inc. 2014). Bowhead whales are managed through a co-management agreement between the Alaska Eskimo Whaling Commission and NOAA Fisheries with oversight from the International Whaling Commission (NMFS 1998).

Beluga Whales (*Delphinapterus leucas*)

There are five populations of Beluga whales in the Bering Sea. These populations remain geographically isolated in the summer, and then mix in the fall and winter (Frost and Lowry 1990; Richard *et al.* 2001). Three of these populations—the Eastern Bering Sea, Bristol Bay, and Cook Inlet stocks—occur in the Bering Sea year-round (Muto *et al.* 2016). These are the nonmigratory stocks that occupy shallow, estuarine habitats. The other two—the Eastern Chukchi and Beaufort stocks—are migratory stocks that spend the summer in the Chukchi and Beaufort Seas and the winter in the Bering Sea (Hazard 1988; Frost and Lowry 1990; Muto *et al.* 2016). This study focuses on two of the three nonmigratory species, as they are most likely to fall within range of subsistence harvesters. The Cook Inlet population was excluded because there is a moratorium on their harvest (Muto *et al.* 2016). Belugas are present in the winter in the Bering Sea along the fast ice and near openings in the pack ice (Hazard 1988; Bering Sea Elders Advisory Group 2011; Oceana and Kawerak, Inc. 2014). Belugas undertake long seasonal migrations and can be found in coastal areas near estuaries and river mouths in the warmer months where they molt, give birth, and care for their calves (Sergeant and Brodie 1969; Finley 1982; Reeves 1990).

The annual harvest rate for Eastern Bering Sea and Bristol Bay beluga whales is 181 and 24 respectively (Muto *et al.* 2016). Although Belugas can be hunted year-round, the best time to catch them is in the fall when their *muktuk*, the skin and topmost layer of blubber, is the thickest. Whale *muktuk* is an important source of vitamins and energy for producing body heat during the winter months. The meat and *muktuk* are shared by the entire community (Bering Sea Elders Advisory Group 2011). Beluga whales are co-managed by the Alaska Beluga Whale Committee and NMFS (NMFS 1999).

Pacific Walrus (*Odobenus rosmarus divergens*)

Pacific walrus range extends from Alaska to Russia, from Bristol Bay and Kamchatka in the south to the Beaufort and East Siberian Seas in the north (Fay 1982). Although the males and females separate during the spring and summer, the entire population spends winter in the Bering Sea (Fay *et al.* 1984). Walruses feed mostly on benthic invertebrates on the continental shelf, although the occasional sea bird and small seal does show up in their diet (Jay *et al.* 2001; Sheffield and Grebmeier 2009). Hauling out and floating on sea ice helps walruses to expend minimal energy getting to and from feeding grounds as well as during migrations, and allows them to exploit a large geographic area of the continental shelf in the Bering Sea (Fay 1960; Jay *et al.* 2001). Walruses also use sea ice for giving birth, nursing calves, and to avoid predators such as killer whales (Fay 1982).

From 2006 to 2010, walruses were harvested by subsistence hunters at a rate of approximately 3,828 to 6,119 walruses per year (USFWS 2014). Hunting in the Bering Sea takes place primarily in the spring during the animals' northward migration to the Beaufort, Chukchi, and East Siberian Seas (Bering Sea Elders Advisory Group 2011). Some hunters will travel up to 100 miles to participate in hunts. Hunters prefer to kill walruses on the ice to avoid losing their catch. The ice must be stable enough to support the weight of the walrus and allow hunters to butcher it in place, as they are too heavy to haul back to the community whole (Oceana and Kawerak, Inc. 2014). The meat is distributed among the community and the hide and bones are used to make various tools and handicrafts, but the most valuable parts of the walrus are their ivory tusks. Tusks are carved into artwork and sold to provide an income to the community (Bering Sea Elders Advisory Group 2011; Oceana and Kawerak, Inc. 2014). Walruses are co-managed by the Eskimo Walrus Commission and the U.S. Fish and Wildlife Service (USFWS 1997).

Ice Seals

There are four species of pinnipeds in the Bering Sea collectively known as the ice seals. These are ribbon seals (*Histiophoca fasciata*), bearded seals (*Erignathus barbatus nauticus*), ringed seals (*Phoca hispida hispida*), and spotted seals (*Phoca largha*). All four species depend on sea ice for vital life history stages during the spring months, including molting, pupping, and nursing. They also rely on sea ice to rest and avoid predators (Muto *et al.* 2016). However, each species relies on different sea ice conditions for survival, and they occupy different parts of the sea ice. In the spring during the breeding and pupping season, ribbon seals occupy the ice edge associated with the edge of the continental shelf, as they are deep divers and prefer to forage on the continental slope (Boveng *et al.* 2013). Bearded seals, on the other hand, prefer to remain near the ice edge in shallower waters more suitable for their foraging needs and capabilities. Bearded seals also show strong site fidelity (Cameron *et al.* 2010). Ringed seals largely occupy the fast ice and, unlike the other Bering Sea ice seals, maintain breathing holes in the ice during the winter. Because of this, they are not necessarily bound to the ice edge. They do, however, require a layer of snow at least 45cm thick for creating lairs to protect themselves and their pups during the breeding season (Kelly *et al.* 2010a). Finally, spotted seals stay closer to land, hauling out on shore in the spring and summer before traveling further out to sea as the ice forms to forage off the ice edge (Boveng *et al.* 2009).

Ice seals are one of the primary subsistence resources for Native Alaskans. In the Bering Sea region alone, 99 communities participate in seal hunting, several of which travel many miles across land to reach hunting grounds (Ice Seal Committee 2017). Each species is harvested at a different rate. Ice seal hunting is opportunistic and often occurs during walrus hunts (Oceana and

Kawerak, Inc. 2014). Bearded seals are prized for their size and the quality of their meat, although they are more dangerous to catch. Only about 379 bearded seals are harvested annually for subsistence, roughly 0.001% of the estimated population. Ringed seals are more abundant and often easier to catch, therefore they play a relatively larger role in the subsistence economy, with about 1,040 individuals or 0.003% of the population harvested annually. Spotted seals are hunted for their skins at a rate of 5,265 seals annually, or 0.01% of the population, and ribbon seals are rarely taken due to their distribution (Oceana and Kawerak, Inc. 2014; Muto *et al.* 2016). As with other harvested species, the meat and oil of each seal harvested is shared among members of the community, fostering strong connections between members. Seal hunts are also often a cooperative process and provide ample opportunity for passing TEK down to younger generations (Bering Sea Elders Advisory Group 2011; Oceana and Kawerak, Inc. 2014). Ice seals are co-managed by the National Marine Fisheries Service (NMFS) and the Ice Seal Committee, a Native Alaskan organization representing the communities relying on ice seals for subsistence (NMFS 2006).

CLIMATE CHANGE VULNERABILITY ANALYSIS (CCVA)

Climate change is progressing in the Arctic at a rate that is two times faster than the rest of the world (IPCC 2014). The implications of such rapid change for marine mammals in the Bering Sea can be translated to the communities that rely on them for subsistence. Understanding how climate change will impact subsistence species, how reliant communities are on those species, and how able they are to adapt to living without them can shed light on the vulnerability of Native Alaskan communities in the Bering Sea region to climate change. Once this vulnerability is understood, management solutions can be developed to mitigate the impacts of climate change on those communities. Climate change vulnerability analyses (CCVAs) can be useful tools in determining which species or communities are vulnerable to climate change, and how they are vulnerable (Glick *et al.* 2011).

CCVAs have been used over the past two decades in a number of sectors including public health and agriculture (Fussler and Klein 2006). In 2001 and then again in 2007 and 2014, the IPCC produced a set of principles for assessing climate vulnerability that have been widely adopted in studying many ecosystems experiencing the impacts of climate change. Predicting future effects of climate change poses an immense challenge to natural resource managers, yet it is essential in determining the risk of extinction and impacts on the ecosystem (Foden and Young 2016). CCVAs use specific indicators of exposure, sensitivity, and adaptive capacity to quantify vulnerability. Breaking the analysis down into these indicators allows managers to discern the ways in which species are vulnerable so that appropriate management solutions may be developed (IPCC 2007; Johnson and Welch 2010; Foden and Young 2016; Johnson *et al.* 2016). CCVAs can also be applied to human systems to assess community vulnerable by replacing sensitivity to climate change with dependence on natural resources for the survival of the community and their culture (Himes-Cornell and Kasperski 2015).

This study aims to develop a CCVA framework for assessing the vulnerability of eight species of ice-dependent and ice-associated marine mammals in the Bering Sea to climate change. These eight species are important for Native Alaskan subsistence harvesters. The changes in species ranges predicted by Grebmeier *et al.* (2006) and many other studies would put these species out of the range of Bering Sea harvesters, effectively removing those communities from the

subsistence economy they rely heavily on for survival (Bering Sea Elders Advisory Group 2011; Oceana and Kawerak, Inc. 2014).

METHODS

The evaluation of existing management structures in the Bering Sea requires a systematic empirical approach to assessment. This study focused on eight key ice-dependent subsistence species in the Bering Sea: ribbon seals, bearded seals, spotted seals, and ringed seals (collectively referred to as ice seals) as well as Pacific walrus, bowhead whales, beluga whales, and polar bears. Over 100 communities along the Alaskan coast of the Bering Sea rely on these species for subsistence. Here we propose a climate change vulnerability assessment (CCVA) framework for conducting a semi-quantitative analysis of marine mammal vulnerability to climate change, which can later be used to quantify subsistence community vulnerability.

The vulnerability of marine mammals to climate change was assessed as a function of exposure, sensitivity, and adaptive capacity (Figure 3; IPCC 2007; Johnson and Welch 2010; Glick *et al.* 2011; Johnson *et al.* 2016). Indicators of each of these three components were developed and quantified using data from primary literature. Exposure refers to the stressors imposed on marine

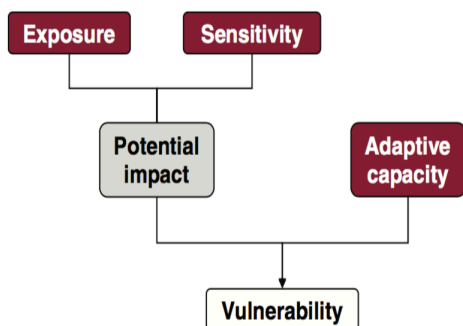


Figure 3. Components of vulnerability, as adapted from IPCC 2007 by Johnson and Welch (2010).

mammals by climate change and carbon emissions, such as sea surface temperature rise, changes in precipitation, and ocean acidification (Table 1). Although ocean acidification is not an effect of climate change itself but rather of anthropogenic carbon emissions, the two are linked enough to include acidification in this analysis. Sensitivity was described as the response of each species to climate change as observed and predicted by previous studies, as well as by local fishermen and subsistence harvesters. The indicators chosen to describe species' sensitivities included vital rates, migration, prey availability, and body condition (Table 2). These indicators are characteristics of each species that have the potential to

be altered in response to climate change, exposing the sensitivity of the species to that change. Exposure and sensitivity combined represented the potential impact of climate change on marine mammals.

Adaptive capacity was defined as the ability of a species to withstand environmental change with little to no disruption (IPCC 2007; Johnson *et al.* 2016). Adaptive capacity can be broken into three main categories: evolutionary potential, behavioral plasticity, and the presence of external pressures not related to climate change (Glick *et al.* 2011). The indicators chosen to measure evolutionary potential included stock status, reproductive potential, and population size. Behavioral plasticity was quantified by studying habitat specialization, site fidelity, and prey specialization. Indicators of external pressures have not yet been identified in the literature to a degree that is quantifiable and applicable across all eight species. Potential impact and adaptive capacity together determined vulnerability (IPCC 2007; Johnson and Welch 2010; Glick *et al.* 2011; Johnson *et al.* 2016).

Criteria specific to each indicator were developed to assign a score of 1 to 3 for that indicator for each species. These scores represent the extent to which each species is exposed to or sensitive to climate change, and what level of adaptive capacity it possesses, based on that

indicator. A 3-score index of low-medium-high was chosen as the best fit with the species data available (Johnson and Welch 2010). Total scores for exposure, sensitivity, and adaptive capacity were calculated for each species by summing their scores for all of the indicators. Scores were classified as high, medium, or low if they were in the top third, middle third, or lower third of the range of possible scores. Exposure and sensitivity scores were then combined qualitatively to determine potential impact, also described as high, medium, or low. Potential impact was then compared against adaptive capacity to determine vulnerability.

RESULTS

EXPOSURE

Each of these Arctic species, although geographically coincident, occupies a different niche within the ecosystem. As such, each experiences the various physical effects of climate change to a different degree. Exposure to climate change in the northern Bering Sea can be quantified through three indicators: sea ice loss, ocean acidification, and changes in precipitation. Each indicator was scored on a scale of 1 to 3 from low to high. The total possible score range was from 3 to 9. Score of 3 and 4 were labeled as low exposure, 5 and 6 as moderate exposure, and 7 through 9 as high exposure. Both cetacean species experience low levels of exposure to the effects of climate change while polar bears and spotted seals experience moderate levels and the rest of the pinnipeds experience high levels (Table 1).

SENSITIVITY

The sensitivity index developed here quantifies species' responses to climate change. Indicators of sensitivity in this analysis were vital rates, migration, changes in prey availability, and body condition. The minimum possible score for sensitivity was 4, with 12 being the maximum. Scores of 4-6 were labeled as low sensitivity, 7-9 as moderate sensitivity, and 10-12 as high sensitivity. Although none of the species scored in the low sensitivity range, not enough is known about beluga reproduction and how it might be impacted by climate change to give a score to their vital rates indicator (Hauser *pers. Comm.*). Polar bears, walruses, ribbon seals, and bearded seals scored in the high sensitivity range, while bowhead whales, ringed seals, and spotted seals scored in the moderate sensitivity range (Table 2).

If more data were available, vital rates could be broken down into reproductive success, juvenile survival, and adult survival. However, because those data are not available with much certainty in the existing literature, they were grouped together for a more general analysis appropriate for the data available. More migratory species are thought to have a higher sensitivity due to their seasonal reliance on different habitats, which could be disrupted as a result of climate change (Laidre *et al.* 2008). Prey availability was scored on the basis of predicted trophic changes identified in the literature. Finally, body condition is often a reliable estimate of assessing individual and population health in the face of certain pressures, and several studies have already identified changes in body condition in several of these species in response to climate change so it was included in this analysis as well (e.g. George *et al.* 2015).

Table 1. Marine mammal exposure to climate change and carbon emissions

Species	Sea Ice Loss	Ocean Acidification	Changes in precipitation	Total
Polar Bears ¶	3	1	2	6
Bowhead whales §	2	1	1	4
Beluga whales †	2	1	1	4
Walruses	3	3	1	7
Ribbon seals ✦	3	3	1	7
Bearded seals	3	3	1	7
Ringed seals	3	2	3	8
Spotted seals ✧	2	2	1	5

Criteria:

1: Not dependent on sea ice for life cycle
 2: Changes in ice would moderately influence life cycle
 3: Critically dependent on sea ice to complete life cycles

1: Not dependent on calcareous organisms
 2: Indirectly dependent on calcareous organisms
 3: Highly dependent on calcareous organisms

1: Not dependent on snowpack
 2: Indirectly dependent on snowpack
 3: Directly dependent on snowpack

High: Red
 Moderate: Orange
 Low: Yellow

*See Appendix A for explanation of exposure scoring results

Table 2. Marine mammal sensitivity to climate change

Species	Vital Rates	Migration	Prey availability	Body Condition	Total
Polar Bears ¶	3	3	3	3	12
Bowhead whales §	2	3	3	3	11
Beluga whales †	No Data	3	1	1	5
Walruses	3	3	3	3	12
Ribbon seals ✦	3	2	3	2	10
Bearded seals	3	3	3	3	12
Ringed seals	3	2	1	2	8
Spotted seals ✧	2	3	1	1	7
Criteria:	1: Vital life stages are unaffected 2: Some vital life stages are affected 3: Most vital life stages are affected	1: Remain in the same region year-round 2: Undertake small seasonal migrations, <1000km 3: Migrate >1000km seasonally	1: Predicted changes in prey availability would not affect carrying capacity 2: Predicted changes in prey availability moderately impact carrying capacity 3: Changes in prey availability would significantly impact carrying capacity	1: No affect on body condition resulting from climate change 2: Weak coorelation between body condition and climate change 3: Strong correlation between body condition and climate change	High: Red Moderate: Orange Low: Yellow Data Deficient: Grey

*See Appendix B for explanation of sensitivity scoring results

POTENTIAL IMPACT

Potential impact was determined by analyzing exposure in combination with sensitivity in a qualitative manner. Walruses and ribbon seals received high scores for both exposure and sensitivity, so they received high scores for the potential impact of climate change. Spotted seals received moderate scores in both exposure and sensitivity, so they also received a moderate score for potential impact. Polar bears received a high potential impact score due to their high sensitivity. Although exposure was only moderate, a high sensitivity would maximize the effects of that exposure. Bowhead whales, on the other hand, were moderately sensitive but only mildly exposed to climate change, so they received a low potential impact score. Ringed seals' high exposure and moderate sensitivity to climate change put the potential impact to that species in the high range. Finally, because beluga whale sensitivity could not be determined, neither could their potential impact (Table 3).

Table 3. Potential impact of climate change on marine mammals

Species	Exposure	Sensitivity	Potential Impact
Polar Bears	M	H	High
Bowhead whales	L	H	Low
Beluga whales	L	-	-
Walruses	H	H	High
Ribbon seals	H	H	High
Bearded seals	H	H	High
Ringed seals	H	M	High
Spotted seals	M	M	Moderate

ADAPTIVE CAPACITY

Adaptive capacity for all eight species was quantified as the combination of evolutionary potential and behavioral plasticity. Evolutionary potential for these species is largely related to genetic diversity, so stock status, reproductive potential, and population size were used as indicators to quantify genetic diversity. Due to the difficulty associated with estimating population size, there is a large amount of uncertainty associated with these indicators. Although marine mammals are k-selected and therefore less able to evolve quickly enough to withstand the rapid environmental changes associated with climate change, some behavioral plasticity related to habitat use and prey selection may result in the persistence of some species despite their evolutionary disadvantage. Therefore, the indicators of behavioral plasticity that were selected for this analysis include site fidelity, habitat specialization, and prey selection.

For both components of adaptive capacity, the minimum possible score was 3 while the maximum was 9. Scores of 3 and 4 were labeled as low, 5 and 6 as moderate, and 7 through 9 as high. Bowhead whales showed the lowest evolutionary potential, while polar bears, beluga whales, and walruses received intermediate scores. The four species of ice seals all received high evolutionary potential scores (Table 4). As for behavioral plasticity, polar bears, ribbon seals,

ringed seals, and spotted seals all scored in the high range, while bowhead whales, beluga whales, walrus, and bearded seals received moderate plasticity scores.

Table 4. Marine mammal evolutionary potential

Species	Stock status	Reproductive Potential	Population Size	Total
Polar Bears ☞	2	2	1	5
Bowhead whales §	1	1	1	3
Beluga whales †	3	1	1	5
Walruses	2	2	2	6
Ribbon seals ✚	3	3	2	8
Bearded seals ∩	3	3	2	8
Ringed seals †	3	3	2	8
Spotted seals ✚	3	3	2	8

Criteria:

1: Endangered	1: Rmax is 5% or less	1: <100,00	High: Green
2: Threatened	2: Rmax is 6-10%	2: 100,000 to 500,000	Moderate: Orange
3: Not listed	3: Rmax >10%	3: >500,000	Low: Red

*See Appendix C for explanation of adaptive capacity scoring results

Table 5. Marine mammal behavioral plasticity

Species	Site Fidelity	Habitat Specialization	Prey Specialization	Total
Polar Bears ☞	3	2	1	6
Bowhead whales §	3	2	1	6
Beluga whales †	1	2	3	6
Walruses	2	2	1	5
Ribbon seals ✚	3	3	3	9
Bearded seals ∩	1	2	3	6
Ringed seals †	1	3	3	7
Spotted seals ✚	3	3	3	9

Criteria:

1: Uses specific sites year after year	1: Utilizes 7 or fewer habitat types per year	1: 1 prey item makes up >20% diet	High: Green
2: Shows fidelity to many different sites	2: Utilizes 8 or 9	2: 2 prey items make up >20% diet	Moderate: Orange
3: Periods of life cycle lacked fidelity	3: Utilizes more than 9	3: 3 or more make up >20% diet	Low: Red

*See Appendix D for explanation of behavioral plasticity scoring results

Due to the rapid nature of climate change, evolutionary potential is less likely to play a role in marine mammal adaptive capacity in the Arctic, although it is still a relevant component. Therefore, it would be prudent to develop a weighting system that places more emphasis on behavioral plasticity. In order to create a quantitative weighting system for this analysis, however, better climate models need to be generated to determine the rate of change in the Arctic with less uncertainty to understand how the role of evolutionary adaptation fits into the equation. For now, we have kept the scores for evolutionary potential and behavioral plasticity separate and given more weight to behavioral plasticity in reconciling the two. Polar bears, ribbon seals, ringed seals, and spotted seals all exhibited a high adaptive capacity to climate change based on data from published literature. Bowhead whales, beluga whales, walruses, and bearded seals all received moderate adaptive capacity scores (Table 6).

Table 6. Adaptive capacity of marine mammals to climate change

Species	Evolutionary Potential	Behavioral Plasticity	Adaptive Capacity
Polar Bears	M	M	Moderate
Bowhead whales	L	M	Moderate
Beluga whales	M	M	Moderate
Walruses	M	M	Moderate
Ribbon seals	H	H	High
Bearded seals	H	M	Moderate
Ringed seals	H	H	High
Spotted seals	H	H	High

VULNERABILITY

Due to a lack of adequate data and a high level of uncertainty, final vulnerability scores were determined qualitatively by comparing potential impact and adaptive capacity. This analysis utilized a precautionary approach, placing high value on the potential impact scores and less on the adaptive capacity scores. This was because of the high degree of uncertainty associated with the adaptive capacity scores, especially with regard to the evolutionary potential indicators. Although the sensitivity indicators incorporated into the potential impact scores were based on predicted outcomes and were also therefore associated with a high level of uncertainty, it was more precautionary to assume high impact and lower adaptive capacity. Therefore, all species with a high potential impact score and a high adaptive capacity score were given a moderate vulnerability score, despite their predicted ability to adapt to rapid change. These species were polar bears, ribbon seals, and ringed seals. Bearded seals and walruses both received high potential impact and moderate adaptive capacity scores, so they were given a high vulnerability score. Spotted seals received a moderate potential impact score, but due to their high adaptive capacity score, they received a low vulnerability score. In this case, spotted seal behavioral plasticity has been observed and recorded with less uncertainty, so their adaptive capacity score was given slightly more weight than other species. Bowhead whales also received a low vulnerability score due to the low potential impact of climate change and their moderate adaptive capacity. Finally, beluga whales did not receive a vulnerability score because we were unable to estimate their potential impact score (Table 7).

Table 7. Marine mammal vulnerability to climate change

Species	Potential Impact	Adaptive Capacity	Vulnerability
Polar Bears	H	M	High
Bowhead whales	L	M	Low
Beluga whales	-	M	-
Walrus	H	M	High
Ribbon seals	H	H	Moderate
Bearded seals	H	M	High
Ringed seals	H	H	Moderate
Spotted seals	M	H	Low

DISCUSSION

Quantifying species' vulnerability to climate change using a rapid assessment tool like a CCVA provides a transparent, defensible way of evaluating the potential impact of climate change and the adaptive capacity of at-risk species. This analysis is particularly useful for identifying specific sources of vulnerability for each species, which can assist in the development of management solutions aimed at helping species adapt to rapid environmental changes. The framework outlined here, although still a preliminary attempt at measuring the vulnerability of these eight species to climate change, lays the groundwork for Bering Sea resource managers. This set of indicators can be added to or expanded on based on available data for each species and relevant pressures they face.

Due to the cryptic nature of marine mammal behavior and the difficult conditions in which these animals live, little is known about many species. This complicates quantitative analyses, and requires a more general and precautionary approach. This is the case with beluga whales, for which not enough data exists to quantify vulnerability in this analysis. However, it can also make the CCVA approach more appropriate than other traditional management methods, as the CCVA method also highlights gaps in knowledge that can be used to apply weights to different indicators or components of vulnerability. Identifying these gaps can also help assist in the prioritization of research needs.

The results of this analysis indicate that the three most vulnerable marine mammal subsistence species are polar bears, Pacific walrus, and bearded seals. These species occupy niches that are highly exposed to the direct physical effects of climate change (sea ice loss) and ocean acidification, and their ecology and life history makes them highly sensitive to that exposure. Unfortunately, their adaptive capacity does not appear to be high enough to offset the potential impact of climate change. This high vulnerability suggests that these species are likely to exhibit significant population-level changes as a result of climate change, such as shifts in range and distribution, reduced population size, or even extinction. It is possible that these species will disappear from the range in which they can be harvested by the Native Alaskan communities that currently rely on them for survival.

Although they ultimately received only a moderate vulnerability score, ribbon seal, and ringed seals should also be considered species of concern. The potential impact of climate change on both of these species is high. However their biology suggests that although climate change may have a strong impact, these species may be highly capable of adapting to those changes. This is

appears to be due to the plasticity of their behavior, allowing them to change prey species or utilize different habitats when one or more become unavailable. Still, it is unclear to what extent their adaptive capacity will aid in their survival in the face of climate change.

CHALLENGES ASSOCIATED WITH CCVAs

One major weakness of CCVA frameworks is that the results can often oversimplify the problem at hand. Although data-rich species or ecosystems can be evaluated with a lower level of uncertainty, those entities are more complicated and dynamic than they may seem when given a specific value for each indicator. Furthermore, assigning those values implies a level of certainty that may not exist. For example, in this analysis, walrus population size was given a score of 2 because the current population estimate is 129,000 animals (USFWS 2014). However, this estimate is based on a 2006 survey that has a 95% confidence interval of 55,000 to 507,000 (Speckman *et al.* 2011). Indicator values do not reflect uncertainty in the data, so that component may be lost in translation. One solution to this problem may be to develop an uncertainty coefficient or weighting system to account for the role of uncertainty in these analyses.

As is apparent in this analysis, CCVAs are very sensitive to the resolution of data available. In areas or ecosystems where lots of information exists regarding species and ecosystem processes, developing specific and relevant indicators can be much easier. This further assists the development of management solutions to vulnerability, as the specificity of the indicators sheds more light on the source of vulnerability. However, it is also possible for the CCVA to become too big and cumbersome, so scoping can be a challenge. Finer scoring criteria can also be developed in cases of high data resolution. Instead of qualitatively defined 3-point scales, quantitative 7- or 9-point scales can be used (IPCC 2007; Johnson and Welch 2010; Johnson *et al.* 2016). This can make the results of the CCVA more repeatable, as it relies less on anecdotal knowledge or data with high uncertainty.

UTILITY OF CCVAs

Once all indicators have been scored, resource managers can use those scores to identify weakness that lead to increased vulnerability for a species. These weaknesses will be reflected in high exposure or sensitivity scores and low adaptive capacity scores. Managers often turn to capacity building as a solution to decreasing vulnerability to environmental pressures, however in some cases, sensitivity or exposure may also be mitigated. For example, in this analysis, walrus received a high score in the sensitivity analysis for the impacts of climate change on their vital rates. Although this indicator was not broken down into its main components in this analysis due to limited data for several species, data and observations of juvenile mortality events do exist for walrus. During the calf rearing stage, females haul out on ice floes with their calves near rich foraging grounds while males haul out in large aggregations on shore (Fay 1982). However, decreased sea ice in some important foraging areas during seasonal migrations has forced many females onto shore with their calves as part of the large aggregations of males. This has resulted in large mortality events in the hundreds and even thousands from trampling (Jay and Fischbach 2008; Jay *et al.* 2011; McKracken 2012).

Although these events have not yet impacted overall population trends, this phenomenon is expected to continue as ice retreats earlier each year, and may even become amplified as more

females haul out with their young. This is one of the drivers of walrus vulnerability to climate change. In response, U.S. Fish and Wildlife has taken several steps to reduce human disturbance of large aggregations of walruses on shore (McKracken 2012). These include tracking sea ice extent and working with local communities to predict timing of haulouts, posting signs near haulout sites warning people (mostly eco-tourists) not to disturb the walruses, and developing guidance for pilots flying small aircraft to reduce their impact on the animals (McKracken 2012; USFWS 2015b).

This method of detecting vulnerability at the indicator level and developing management solutions to eliminate or reduce it is transferable to all species. For example, bearded seals show strong site fidelity, so regulations may be developed to protect or prevent barriers to migration to those sites. Ribbon seals rely heavily on benthic species, whose abundance is expected to decrease as a result of climate change. Therefore, fisheries may be managed such that they reduce their impact on benthic habitat to conserve vital marine mammal prey species. This process of identifying and responding to weaknesses in sensitivity and adaptive capacity is what makes CCVAs so useful.

NEXT STEPS: ASSESSING COMMUNITY VULNERABILITY

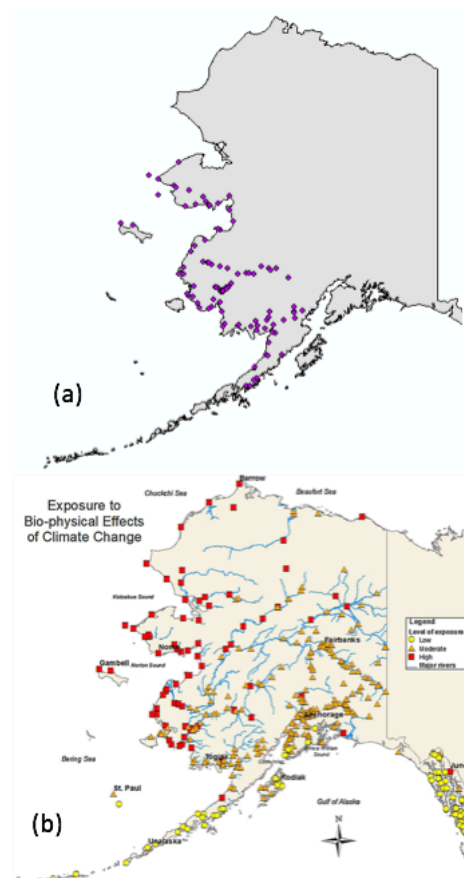


Figure 4. (a) Native Alaskan communities that rely on marine mammals for subsistence. (b) Distribution of the exposure of climate change to Native Alaskan communities (Himes-Cornell and Kasperski 2014).

CCVAs can also be useful in determining the vulnerability of the communities that rely heavily on natural resources to climate change. There are roughly 100 Native Alaskan communities that rely to some extent on these eight species of marine mammals for survival (Figure 4a). However, the effects of climate change on each of these communities will not be the same. In some areas, conditions may become more favorable as species distribution shifts ranges closer toward those communities. In others, however, vital subsistence species may move out of reach of the Native Alaskan communities that rely on them (Himes-Cornell and Kasperski 2014). Either way, it is reasonable to expect significant impacts on Native Alaskan communities as sea ice retreats further from traditional hunting grounds.

As with species vulnerability, community vulnerability is a function of three main components, however in the case of communities, vulnerability of the resources they depend on is a crucial component of exposure, and sensitivity is replaced with dependence on those resources (Allison *et al.* 2009; Himes-Cornell and Kasperski 2014). Adaptive capacity requires the development of another scoring index using specific indicators and well-defined scoring criteria. Some generic but useful indicators of adaptive capacity include education level, income, access to alternative economies or sources of income, social capital, the existence of and participation in government adaptation programs, etc (IPCC 2007; Allison *et al.* 2009).

Himes-Cornell and Kasperski (2014) conducted one study of vulnerability in Alaskan fishing communities, many of which also rely on marine mammals for subsistence. They found that many of the communities in the Bering Sea region identified in this study as heavily reliant on marine mammals are also highly exposed to the bio-physical impacts of climate change (Figure 4b). This, combined with the results of the CCVA produced in this analysis for marine mammals suggest that exposure to climate change is high enough for these communities that their vulnerability warrants further study. As with the marine mammal assessment, a community CCVA could be used to identify weaknesses in community structure, functioning, or adaptive capacity that may be remedied in time to bolster them against the threats imposed by climate change (IPCC 2007).

In conducting a community CCVA, it is vital to incorporate community participation and the co-creation of knowledge so as to empower local communities and identify the most feasible solutions to reduce vulnerability (Whitney *et al.* 2017). For these Native Alaskan communities with strong cross-generational knowledge sharing platforms, CCVAs can capitalize on historical knowledge and become woven into the fabric of TEK. Collaborative efforts between government resource managers and Native communities such as these can also help strengthen co-management agreements and reach more practical conclusions regarding mitigation and adaptation strategy implementation (Berkes and Jolly 2001; Whitney *et al.* 2017)

CONCLUSIONS

As climate change progresses in the Arctic, understanding how species, ecosystems, and communities will respond is paramount to preparing for the changes to come. Although scientific research and data are limited in this remote, harsh environment, climate change vulnerability analyses can assist in managing species at risk of extinction and bolstering the communities that rely on them. As an iterative process, CCVAs can become more reliable with new knowledge in coming years, and can help empower communities to identify solutions to the pressures they face as a result of climate change. However, as is apparent in this study, CCVAs are only as reliable as the data that is used to conduct them. Strengthening monitoring programs and developing more focused ecological studies to collect the data that is necessary to reduce uncertainty will prove invaluable in planning for and adapting to climate change.

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APPENDIX

A. EXPOSURE

Explanation for Exposure scoring results by species (Table 1).
¶ Sea ice is the primary habitat of polar bears. Bears rely on sea ice as a platform for hunting ice seals, migration, mating, giving birth, and raising cubs (Stirling and Derocher 1993). Polar bears forage on the shore-fast ice where ringed seals build lairs in the snowpack (Stirling <i>et al.</i> 1993a; Kelly <i>et al.</i> 2010a).
§ Bowhead whales are closely associated with sea ice, following it south from the Beaufort and Chukchi Seas into the Bering Sea in the fall as it advances, and back north in the spring as it retreats. In the winter, they are usually found under 100% ice cover (Braham <i>et al.</i> 1980; Quakenbush <i>et al.</i> 2010). This suggests that changes in sea ice may alter the timing of migration and vital rates of this species. There is no evidence to suggest that they are dependent on calcareous species or snowpack
¶ Beluga whales are also associated with sea ice and follow the advance and retreat each year, however unlike bowhead whales, they are more found in open water leads and polynyas (Hazard 1988). There is no evidence to suggest that they are dependent on calcareous organisms or snowpack.
Walrus occupy sea ice during migration, breeding, nursing, molting, accessing foraging areas, resting, and avoiding predators (Fay 1982). Walrus rely heavily on benthic invertebrates for prey, especially bivalves, although small seals have also been found in their diet (Fay 1982; Rausch <i>et al.</i> 2007; Jay <i>et al.</i> 2011). There is no evidence that walrus rely on snowpack for any part of the life cycle.
❖ Ribbon seals are dependent on sea ice for breeding, pupping, nursing, molting, resting, and refuge from predators. Changes in ribbon seal diet due to ocean acidification are expected to have a high potential negative impact (Boveng <i>et al.</i> 2013). There is no evidence that ribbon seals rely on snowpack for any part of the life cycle.
⊥ Bearded seals rely heavily on sea ice for breeding, pupping, molting, resting, foraging, and refuge from predators, although they are not as dependent on ice during nursing as other ice seal species are (Fay 1974; Burns and Frost 1979; Nelson <i>et al.</i> 1984; Lydersen and Kovacs 1999). Their primary food source is benthic invertebrates and fish, exposing them to the effects of ocean acidification (Cameron <i>et al.</i> 2010; Muto <i>et al.</i> 2016). There is no evidence that bearded seals rely on snowpack for any part of the life cycle.
† Ringed seals are associated with sea ice year-round and use ice for pupping, molting, and resting (Kelly 1988; Kelly <i>et al.</i> 2010b). Ringed seals also require a snow depth of at least 45cm to excavate lairs for raising their pups (Smith and Stirling 1975). Ringed seals are likely to be affected indirectly by ocean acidification (Kelly <i>et al.</i> 2010a).
◇ Spotted seals are strongly associated with pack ice in the winter but can be observed hauling out on land in the summer. Recent evidence suggests that some populations in the Yellow Sea haul out on shore to breed, nurse, and molt in years when sea ice is less available (Boveng <i>et al.</i> 2009). Spotted seal diet is highly variable and consists mostly of fish species, so ocean acidification is not thought to pose a significant risk to this species (Boveng <i>et al.</i> 2009). There is no evidence that spotted seals rely on snowpack for any part of the life cycle.

B. SENSITIVITY

Explanation for Sensitivity scoring results by species (Table 2).
<p>☞ Access to sea ice directly impacts polar bear migration, prey availability, and body condition (Frost <i>et al.</i> 2004; Regehr <i>et al.</i> 2006; Cameron <i>et al.</i> 2010; Kelly <i>et al.</i> 2010a). These, in turn, also impact vital rates (Hunter <i>et al.</i> 2010; Regehr <i>et al.</i> 2010).</p>
<p>§ Close association with sea ice suggests that change in timing of migration and vital rates may result from changes in sea ice. They have long migrations from the Bering Sea to the Chukchi and Beaufort and back each year (Braham <i>et al.</i> 1980). As baleen whales, their diet consists largely of planktonic species, whose abundance is expected to increase as a result of climate change due to increased solar input (Grebmeier 2012). This will in turn have a significant impact on body condition.</p>
<p>¶ Little is known about how climate change will affect vital rates. These two populations are considered nonmigratory, as they occupy the same region year-round (Hazard 1988; Quakenbush 2003; Muto <i>et al.</i> 2016). Beluga whales mostly consume fish, which are not expected to diminish as a result of climate change, therefore body condition is also not expected to change (Grebmeier 2012; Quakenbush <i>et al.</i> 2015).</p>
<p> Walrus rely heavily on sea ice as resting platforms during seasonal migrations and foraging events, allowing them to access more plentiful foraging grounds further offshore (Fay 1982; Jay <i>et al.</i> 2010; Jay <i>pers. Comm.</i>). Without sea ice in these areas, body condition and reproductive success are reduced and mortality increases (Jay <i>et al.</i> 2011; McKracken 2012). Benthic invertebrates make up the majority of walrus diet, making the anticipated changes in the availability of these species a serious threat to the continued survival of Pacific walrus population (Fay 1982; Sheffield <i>et al.</i> 2001; Jay <i>et al.</i> 2011; Grebmeier 2012; McKracken 2012).</p>
<p>❖ Ribbon seals rely heavily on sea ice for most vital life stages and have not been observed to breed on shore (Burns 1970; Boveng <i>et al.</i> 2013). Although there is limited data on the movement of ribbon seals, particularly in the ice-free months, population movements are thought to be shorter in distance as they are not associated with sea ice outside of the breeding period and prefer to forage on the continental shelf slope (Boveng <i>et al.</i> 2013). Considering their dependence on benthic species as well as those that would be affected by ocean acidification, the predicted trophic changes resulting from climate change would likely have an impact on carrying capacity (Grebmeier 2012; Boveng <i>et al.</i> 2013).</p>
<p>⊘ Bearded seals do rely on sea ice for most vital life stages (Fay 1974; Burns and Frost 1979; Nelson <i>et al.</i> 1984; Lydersen and Kovacs 1999). Adult bearded seals in the Chukchi and Bering Sea undertake much longer migrations than those in the rest of the species' range (Fay 1974). Because bearded seals rely so heavily on benthic organisms, the predicted shift toward a pelagic-dominated ecosystem will likely result in a reduction in carrying capacity for this species (Grebmeier 2012; Fay 1974). Bearded seals require breeding areas on sea ice over shallow areas of the continental shelf. If ice were lost to these areas, as would be expected with a northward shift in sea ice extent, this would significantly impact body condition during breeding and nursing stages (Fedoseev 1965; Cameron <i>et al.</i> 2010).</p>
<p>‡ Ringed seals rely heavily on both sea ice and snow pack for reproduction and survival, therefore their vital rates are expected to be strongly influenced by changes in sea ice (Kelly <i>et al.</i> 2010a, 2010b). In the summer and fall, they have been known to range over greater distance, from 100km up to 1,800km, however longer migrations are rare (Kelly <i>et al.</i> 2010b). Ringed seals rely heavily on pelagic fish for food, and therefore are not expected to experience a significant change in carrying capacity in response to climate change, although some prey species may become more limited due to ocean acidification, potentially impacting body condition (Kelly <i>et al.</i> 2010a).</p>
<p>◁ Although spotted seals do utilize pack ice for most vital life stages, recent evidence suggests that they can adapt to shore-based haulouts. This may result in currently unobserved threats such as disease or increased predation, but it is too early to determine the impact of those potential threat (Boveng <i>et al.</i> 2009). Spotted seals move between the Bering and Chukchi Seas seasonally, with some migrating greater than 1000 km and others less (Lowry <i>et al.</i> 1998). This study uses the precautionary approach and</p>

therefore ranked spotted seals as undertaking seasonal migrations of greater than 1000km. Spotted seal diet is composed largely of fish species (Dehn *et al.* 2007; Quakenbush *et al.* 2009). As such, a shift toward a pelagic-dominated ecosystem is not likely to have adverse effects on carrying capacity (Grebmeier 2012). It is too early to determine if this shift might increase carrying capacity, however body condition is not predicted to be impacted by the predicted trophic shifts.

C. EVOLUTIONARY POTENTIAL

Explanation for Evolutionary Potential scoring results by species (Table 4).
¶ The Chukchi/Bering polar bear stock is currently listed as threatened under the ESA (Muto <i>et al.</i> 2016). A reliable population estimate for this stock does not exist, however the IUCN Polar Bear Specialist Group developed the current working estimate of 2,000 individuals. Still, there is low confidence in this estimate (IUCN 2006). This population estimate is not strong enough to set an R_{max} specific to this stock, however the R_{max} for the Southern Beaufort Sea population of 6% is reasonably applied to the Chukchi/Bering stock (Regehr <i>et al.</i> 2006; Muto <i>et al.</i> 2016).
§ Bowhead whales are listed as endangered under the ESA (Muto <i>et al.</i> 2016). The most recent abundance estimate was generated in 2011 and puts the BCB bowhead population size at 16,892 individuals with a confidence 95% confidence interval of 15,074 to 18,928 (Givens <i>et al.</i> 2013). An R_{max} of 4% is used for this stock (Wade and Angliss 1997).
¶ The Bristol Bay beluga stock is not listed under the ESA and has a population size of between 2,455 and 3,299 animals (Muto <i>et al.</i> 2016). The Eastern Bering Sea stock is also not listed under the ESA, and has a population of about 19,186 whales (Muto <i>et al.</i> 2016). An R_{max} of 4% is used for both of these stocks (Wade and Angliss 1997).
Walrus listing under the ESA was determined to be warranted but precluded in 2011 but their listing as threatened is being considered again (USFWS 2011; USFWS 2014). Since their listing was deemed warranted, for the purpose of this analysis we score them as such. Their population size is estimated at 129,000 with a 95% confidence interval of 55,000 to 507,000. The maximum population growth rate (R_{max}) for the species is 8% (USFWS 2014).
❖ Ribbon seals are not listed under the ESA (Muto <i>et al.</i> 2016). Population size is estimated at 184,000 with a 95% confidence interval from 145,752 to 230,134 (Conn <i>et al.</i> 2014). R_{max} for ribbon seals is estimated to be 12% (Wade and Angliss 1997).
⊥ Bearded seals are not listed under the ESA (Muto <i>et al.</i> 2016). The current population size is estimated at 299,174 with a 95% confidence interval of 245,476 to 360,544 (Conn <i>et al.</i> 2014). R_{max} for this species in 12% (Wade and Angliss 1997).
† Ringed seals are not currently listed under the ESA (Muto <i>et al.</i> 2016). Their population size is estimated at 170,000, although this estimate does not incorporate correction factor for availability bias so the actual number is likely much higher (Conn <i>et al.</i> 2014). R_{max} for ringed seals is 12% (Wade and Angliss 1997).
◁ Spotted seals are not listed under the ESA (Muto <i>et al.</i> 2016). Their population size is estimated at 233,700 individuals with a 95% confidence interval of 137,300 to 793,100 (Conn <i>et al.</i> 2014). R_{max} for spotted seals is 12% (Wade and Angliss 1997).

D. BEHAVIORAL PLASTICITY

Explanation for Behavioral Plasticity scoring results by species (Table 5).
<p>☉ Polar bears occupy many different habitat types, both marine and terrestrial (USFWS 2017). Although there is some evidence of site fidelity in other populations, this evidence is limited and data suggest that periods of the life cycle lack site fidelity (Ramsay and Stirling 1990; Laidre <i>et al.</i> 2008; Lone <i>et al.</i> 2013). Ringed seals are their primary prey item, however they also regularly feed on bearded seals and even walruses and belugas (Kiliaan and Stirling 1978; USFWS 2017). When stranded on land for extended periods of time in the summer, polar bears will also prey on terrestrial food items such as bird eggs and even plants, however those food sources are not reliable or abundant enough to sustain the species long-term (Russell 1975; Derocher <i>et al.</i> 1993, 2004; Rode <i>et al.</i> 2015).</p>
<p>§ There is little very little site fidelity among BCB bowhead whales, and they are able to utilize several habitat types (Taylor <i>et al.</i> 2007; Laidre <i>et al.</i> 2008). Zooplankton make up the majority of bowhead diet (Lowry <i>et al.</i> 2004).</p>
<p>‡ These two populations of beluga whales show strong site fidelity, occupying the same sites year after year (Hazard 1988; Quakenbush 2003; Muto <i>et al.</i> 2016). Within these sites, they occupy several habitat types and exploit many prey species (Laidre <i>et al.</i> 2008; Quakenbush <i>et al.</i> 2015).</p>
<p> Walruses show fidelity to several feeding areas, although these areas have changed over time as prey resource abundance changes (Fay 1982; Laidre <i>et al.</i> 2008; McKracken 2012). Bivalves make up greater than 50% of walrus diet (Fay 1982; Sheffield <i>et al.</i> 2001; Jay <i>pers. Comm.</i>)</p>
<p>❖ Although observations of ribbon seal migration and site use are limited, they are not thought to exhibit site fidelity (Davis <i>et al.</i> 2008; Boveng <i>et al.</i> 2013). Ribbon seals utilize many habitat types, and have a diverse diet (Laidre <i>et al.</i> 2008; Boveng <i>et al.</i> 2013)</p>
<p>⊥ Satellite tracking data shows that adult bearded seals return to the same breeding areas each winter, indicating strong site fidelity during vital life stages (Boveng <i>et al.</i> 2012). Bearded seals occupy several different habitat types and can utilize a wider range of sea ice conditions than other ice seal species (Fay 1974; Laidre <i>et al.</i> 2008). Bearded seals are considered dietary generalists, feeding on a wide range of benthic species (Dehn <i>et al.</i> 2007).</p>
<p>‡ Adult ringed seals return to the same areas every winter, showing strong site fidelity to those places (Kelly <i>et al.</i> 2010b). Ringed seals utilize many prey types and have a diverse diet (Laidre <i>et al.</i> 2008; Kelly <i>et al.</i> 2010a).</p>
<p>❖ Spotted seals are considered dietary generalists, with lots of prey items making up their diet (Dehn <i>et al.</i> 2007). They show very little site fidelity and are able to utilize many habitat types (Boveng <i>et al.</i> 2009; Laidre <i>et al.</i> 2008).</p>