FINAL SPECIES STATUS ASSESSMENT FOR THE PACIFIC WALRUS (*Odobenus rosmarus divergens*), May 2017 (Version 1.0)

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LIST OF ACRONYMS

ADEC – Alaska Department of Environmental Conservation
ADFG – Alaska Department of Fish and Game
AK – Alaska

BBN – Bayesian Belief Network
BOEM – Bureau of Ocean Energy Management

$CACO_3$ – calcium carbonates
CCR – calf:cow ratio
CMIP – Coupled Model Intercomparison Project
CO_2 – carbon dioxide
CPT – Conditional Probability Table

ESA – Endangered Species Act
EWC – Eskimo Walrus Commission

GCM – Global (or General) Circulation Model
GHG – Greenhouse Gas

IPCC - Intergovernmental Panel on Climate Change
ITR – Incidental Take Regulation

LOA – Letter of Authorization
LTK – local and traditional ecological knowledge

MMPA – Marine Mammal Protection Act

NSR – Northern Sea Route
NWP – Northwest Passage

OA – ocean acidification

RCP – Representative Concentration Pathway

SSA – Species Status Assessment
SST – Sea Surface Temperature

TEK – traditional ecological knowledge
USFWS – US Fish and Wildlife Service
USGS – US Geological Survey
USSR – Union of Soviet Socialist Republics

YBP – years before present

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EXECUTIVE SUMMARY

In 2011 an Endangered Species Act 12-month finding concluded that listing the Pacific walrus as threatened or endangered was warranted but precluded by higher priority listing actions, placing the subspecies on the candidate list. Shortly thereafter, the U.S. Fish and Wildlife Service agreed to a court settlement to decide whether to propose a listing rule or remove the Pacific walrus from the candidate list by September 2017. This Species Status Assessment was prepared to provide the best available information to help with that decision. The assessment considers the needs of the subspecies, the current conditions that allow the subspecies to meet those needs, and the effects of future conditions on the ability of walruses to meet those needs. A Species Status Assessment estimates the ability of a population to persist by consideration of the concepts of resiliency (the ability of a species to withstand disturbances), redundancy (having multiple, resilient populations distributed within the species ecological settings and across the species range), and representation (the breadth of genetic and environmental diversity within and among populations).

We found that environmental changes over the last several years such as sea ice loss and associated stressors are impacting Pacific walruses, but that other stressors that were identified in 2011 have declined in magnitude. Despite the current ice-free period of about 2 months in the summer/fall, we found that the population is currently under low levels of stress and recovering from a population decline that started about 1980 when the population was likely near the carrying capacity of the environment. Population modeling indicates that the current population growth rate is equivocal suggesting stability within the Pacific walrus population during the current time period.

We used model projections of ice-free months; sea surface temperatures; benthic productivity, and expert judgments (including local and traditional ecological knowledge) to estimate how stressors will change over time and the responses of Pacific walruses to those stressors during three seasons in 2015 (baseline) as well as at four future time periods and three Representative Concentration Pathways developed for the 5th Intergovernmental Panel on Climate Change assessment. We utilized the best available information, empirical data, modeled sea ice projections, and expert judgment, including that of Alaska Native Pacific walrus hunters and community members. We included projections out to 2100 but caution that we had low confidence in our ability to predict how Pacific walruses will respond to stressor levels projected for 2100. A sensitivity analysis and influence runs of a revised Bayesian belief network model indicated that ice-free months, subsistence harvest, and incidental takes influenced model outcomes the most. Consistent with trends in Representative Concentration Pathways, the probability of moderately high to high abundance stressors increases over time and is estimated to be 50% in 2060 and 66% in 2100 under RCP 8.5. The probability of moderately high to high stressors was lowest for RCP 2.6.

We used the sea ice models discussed above as well as travel distances of Pacific walruses from ice haulouts and land haulouts to assess changes in availability of habitat through time. Overall, we found that availability of preferred sea ice habitat for Pacific walruses would decline in the future but the magnitude of the decline was dependent upon year and season. In winter, declines in availability of preferred sea ice habitat range from 2% to 24% while in summer/fall declines range from 85% to 100% in 2060 and 2100 respectively.

The results of the BBN clearly demonstrate that stressor levels are likely to increase in the future. The increased use of coastal haulouts by Pacific walruses through time increases the probability of disturbance related mortality events and will also likely result in increased energy expenditure of Pacific walruses to access preferred foraging areas. Furthermore, the BBN demonstrated that increased energetic costs associated with feeding from coastal haulouts are likely to lead to declines in body condition and vital rates over the long term. These factors suggest that increased stress on abundance of the Pacific walrus population will likely result in future population declines, but the magnitude of the decline is unknown.

While declining sea ice habitat is likely to negatively affect the Pacific walrus population, other stressors that are likely to have a population-level effect have diminished since the original 2011 finding. Oil and gas exploration, particularly in the eastern Chukchi Sea, has declined in recent years within the range of Pacific walruses. Additionally, subsistence harvest is at historically low levels and is unlikely a significant abundance stressor at the present time, although we lack confidence in our ability to accurately predict future harvest trends and numbers.

The Pacific walrus population has persisted through past climate change events however, the ability of the Pacific walrus population to adapt to or cope with increasing stress in the future is uncertain. The increasing trend in stressors identified in our analyses closely follows the projected trend of decreasing sea ice. Although Pacific walruses are adapted to living in a dynamic environment and have demonstrated the ability to adjust their distribution and habitat use patterns in response to recent shifting patterns of sea ice, the BBN demonstrated increasing abundance stressors will negatively affect the population but to an unknown extent. Overall, this will likely result in a population decline and a reduction in resiliency and redundancy but not representation of the population.

1. INTRODUCTION

1.1 Review of Previous Listing Actions

On February 7, 2008, the Center for Biological Diversity (CBD) filed a petition with the Secretary of the Interior and the U. S. Fish & Wildlife Service (USFWS) to list the Pacific walrus (*Odobenus rosmarus divergens*) as threatened or endangered and to designate critical habitat (Center for Biological Diversity 2008, pp. 6-83) pursuant to the U.S. Endangered Species

Act (ESA) of 1973, as amended (16 U.S.C. 1531 et seq.). On September 10, 2009, the USFWS published a positive 90-day finding stating that the CBD petition presented substantial scientific or commercial information indicating that the petitioned action *may be* warranted. To assist in determining whether listing the Pacific walrus under the ESA was warranted, the USFWS convened an expert panel to conduct a status review for this subspecies (see Garlich-Miller et al. 2011a, inclusive). That review identified the loss of sea ice habitats, calf mortalities at coastal haulouts, and potentially, the future subsistence harvest as the primary stressors to the population. Secondary stressors included oil and gas development activities as well as the potential for a large oil spill; commercial shipping; commercial fishing; and ocean acidification.

On February 10, 2011, the USFWS issued a 12-month finding that listing the Pacific walrus as threatened or endangered was warranted but precluded by higher priority listing actions, designated it as a candidate species, and assigned a listing priority number of nine out of 12 (USFWS 2011, p. 7674). Shortly thereafter, the USFWS entered into a settlement agreement that established timelines for addressing the backlog of more than 250 candidate species. The status of the Pacific walrus was to be determined by the end of Fiscal Year 2017 per the terms of the settlement.

1.2 Purpose of this Assessment

The purpose of this document is to synthesize the best scientific and commercial information available for assessing the current and future status of the Pacific walrus. In preparing it, we followed guidance for conducting a Species Status Assessment (SSA; USFWS 2016g, inclusive), which was recently developed and adopted by the USFWS specifically for considering the status of a species (or subspecies) under the ESA. The SSA approach involves identifying vital needs of the species and evaluating the current and future conditions affecting those needs at the individual, population, and species levels. Ultimately, the SSA culminates in a characterization of the species viability using the conservation biology principles of representation, redundancy, and resilience. The SSA then will be used to inform the USFWS's decision as to whether or not the Pacific walrus warrants listing under the ESA; it does not constitute a decision document. Instead, it forms the scientific basis from which the USFWS will draw conclusions and make a decision.

As part of the SSA process, concurrent with reviewing the best available science, we initiated three primary efforts to further our current understanding of the conditions affecting the vital needs of Pacific walruses. First, we revised and updated a Bayesian belief network (BBN) model initially developed by Jay et al. (2011, p. 1065) as a tool to assess persistence of the Pacific walrus under varying conditions (Section 4.4 Bayesian Belief Network Expert Elicitations and Appendix A). We convened a science team (ST) led by USFWS staff in the Marine Mammals Management Office, Region 7–Alaska, with the assistance of Pacific walrus researchers with the U.S. Geological Survey (USGS) and Alaska Department of Fish and Game (ADFG), to revise and update the BBN. Second, USFWS staff completed a spatial analysis of accessible habitats under the same conditions evaluated in the BBN to complement the BBN outcomes (Appendix B). Third, we held a workshop in June 2016 to update, collate, and review local and traditional ecological knowledge (LTK) held by Alaska Natives on Pacific walruses (Appendix C).

Alaska Native Pacific walrus hunters and coastal community members have accumulated substantial knowledge of Pacific walruses and their environment over many generations. The value of the observations of local resource users in enhancing and supplementing scientific observations has received increased attention over the last few decades (Berkes et al. 2000, p. 1251; Huntington 2000, p. 1270; Huntington et al. 2004, p. 18; Ambrose et al. 2014, p. 1; Beaudreau and Levin 2014, p. 244; Mistry and Berardi 2016, p. 1274). The local knowledge base has been described as traditional ecological knowledge (TEK), indigenous ecological knowledge, and local ecological knowledge (LEK). Huntington et al. (2013a, p. 312) combined TEK and LEK into local and traditional knowledge (LTK). Although TEK helps with context (Huntington et al. 2016, p. 1), contemporary observations by residents of coastal communities in Alaska in regards to Pacific walruses and the environment may be most pertinent to a SSA. Accordingly, we have incorporated LTK into this assessment as appropriate. Thus, this document and its appendices summarize the best scientific, commercial, and local information available regarding the status of the Pacific walrus and should prove useful for management and research actions in the future.

2. DESCRIPTION OF THE PACIFIC WALRUS

In this chapter, we describe the taxonomy, life history, and resource needs of the Pacific walrus. The purpose of this chapter is to provide the necessary biological information from which to evaluate the current and future conditions at the individual, population, and subspecies levels in subsequent chapters. The information in this chapter is not exhaustive (i.e., everything known about the Pacific walrus), but instead provides the information necessary to achieve the objectives of this SSA. Due to a lack of expertise on the Science Team concerning specific subjects like ocean acidification, ocean primary productivity, sea ice trends and modeling, etc. we had subject matter experts review drafts of those specific sections to insure that our literature reviews were complete, accurate, and resulted in proper inferences. A complete list of subject matter experts can be found in the Acknowledgements.

The Pacific walrus is one of the largest extant pinnipeds in the world. At birth, calves are approximately 65 kg and 113 cm long (Fay 1982, pp. 30-35). Adult females can reach lengths of up to 3 m and weigh up to 1,100 kg. Adult males can reach lengths of 3.5 m and can weigh more than 2,000 kg (Fay 1982, pp. 30-35). Walruses are readily distinguished from other Arctic pinnipeds by their enlarged upper canine teeth which form prominent tusks. Males, which have relatively larger tusks than females also tend to have broader skulls (Fay 1982, pp. 30-35).

2.1 Taxonomy

Generally, three extant subspecies of walrus (*O. rosmarus*) have been recognized (e.g., Fay 1982, pp. 5-6; Garlich-Miller et al. 2011a, p. 2): the Atlantic walrus (*O. r. rosmarus*), which ranges from the central Canadian Arctic eastward to the Kara Sea (Reeves 1978, pp. 2-20), the Pacific walrus (*O. r. divergens*) which ranges across the Bering and Chukchi seas (Fay 1982, pp. 7-21), and the Laptev walrus (*O. r. laptevi*), which is represented by a small, geographically isolated population in the Laptev Sea (Heptner et al. 1976, p. 34; Vishnevskaia and Bychkov 1990, pp. 155-176; Andersen et al. 1998, p. 1323; Wozencraft 2005, p. 595; Jefferson et al. 2008, p. 376; Figure 2.1). The Atlantic and Pacific walruses are widely recognized to be valid subspecies based on morphological (e.g., Allen 1880, pp. 20-147) and genetic characteristics (e.g., Cronin et al. 1994, p. 1035) with divergence likely resulting from range fragmentation and differentiation during phases of glacial maxima with extensive Arctic sea-ice cover. However, the validity of the subspecific designation of the Laptev walrus is less certain, largely owing to few published studies and small sample sizes.

The Laptev walrus was first described by Chapskii (1940, p. 80) based on morphology, primarily body size, but its status has not yet been supported (or refuted) with compelling genetic evidence. Lindqvist et al. (2009, pp. 119-121) used molecular and mophometric methods to evaluate the taxonomic status of walruses in the Laptev Sea. Based on their results, the authors recommended abandoning the Laptev walrus as a subspecies and instead recognizing these walruses as the westernmost population of the Pacific walrus (Lindqvist et al. 2009, pp. 119-121). However, their genetic analysis was based on only 12 museum specimens that were collected prior to 1936, and these older samples resulted in a failure to amplify many alleles and instances of missing data (Lindqvist et al. 2009, p. 115). Thus, the usefulness of their analyses is limited and we have determined that their interpretation of the results was not supported due to the issues identified above. We agree with the authors that this topic warrants further investigation, but based on our evaluation as part of this SSA process, and given the issues with the study identified above, the results do not provide persuasive evidence to justify abandoning the subspecific designation of the Laptev walrus.

In 2013, the World Wildlife Fund-Russia, collected 29 new samples of walruses in the Laptev Sea for use in a genetics study (WWF-R 2016, inclusive), but results appear preliminary, have apparently not undergone peer review, and also do not provide conclusive evidence of a genetic basis to revise the subspecific designation of the Laptev population based on an independent assessment by a panel of USFWS and USGS geneticists and biologists. The panel noted that the information provided was not conclusive as to the subspecific status of walruses occupying the Laptev Sea. Thus, for the purposes of this SSA, we do not consider walruses in the Laptev Sea to be part of the Pacific walrus population and therefore, they are not considered further in this assessment.

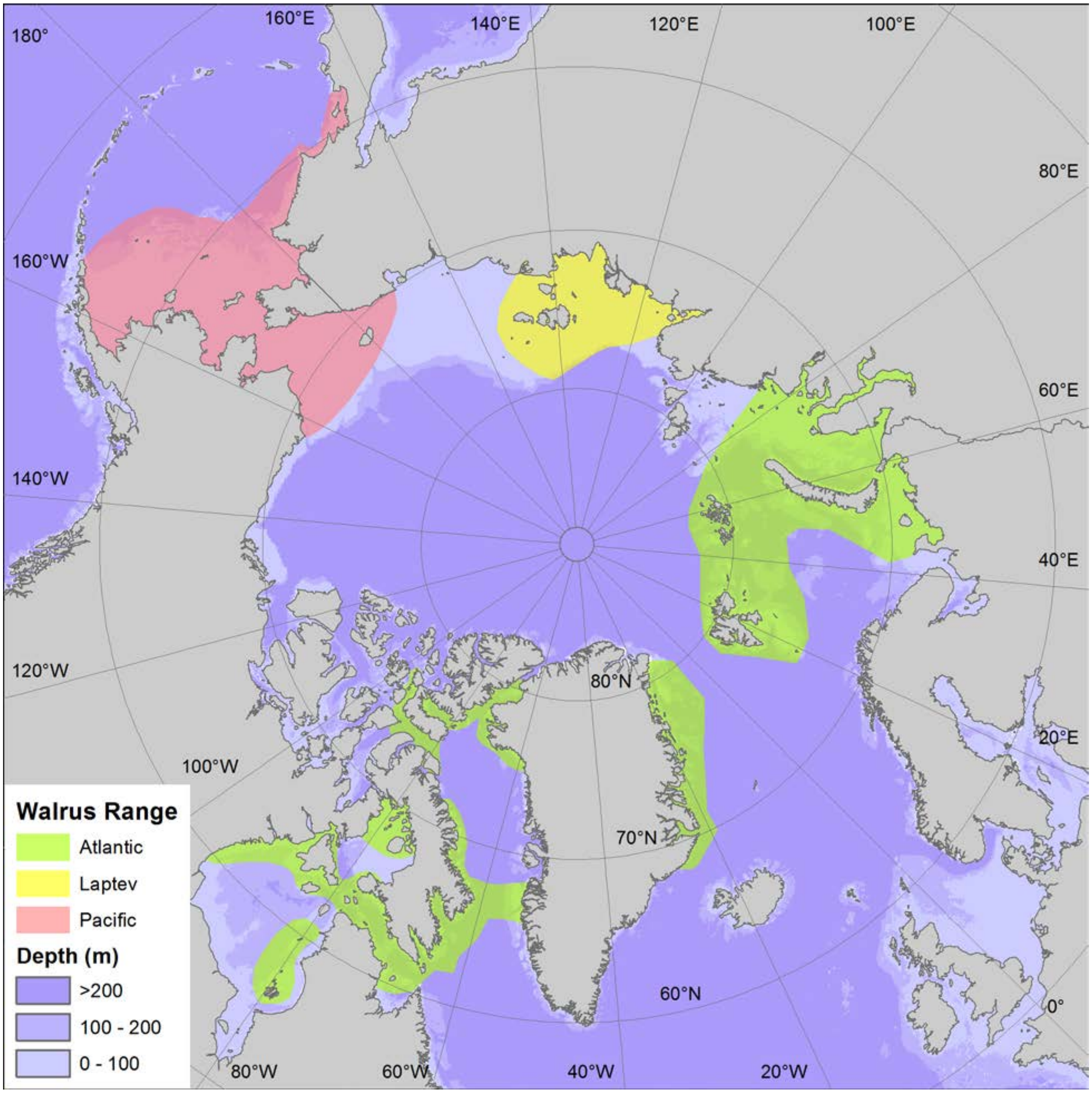


Figure 2.1. A map of the range of three subspecies of walrus (*Odobenus rosmarus*); the Atlantic (*O. r. rosmarus*), the Pacific (*O. r. divergens*), and the Laptev (*O. r. laptevi*). Map source: https://en.wikipedia.org/wiki/Walrus#/media/File:Odobenus_rosmarus_distribution.png. Source: Kovacs et al. (2016, p. 67).

Currently, the Pacific walrus is identified and managed as a single panmictic population. This assumption has been supported by several genetic studies that found high levels of genetic diversity and low levels of genetic differentiation among breeding populations (Cronin et al. 1994, p. 1035; Scribner et al. 1997, p. 176; Lindqvist et al. 2009, pp. 120-121; Sonsthagen et al. 2012, p. 1512). In addition, population substructuring appears unlikeley even though it was put forth as a possible explantion for some of the results in both Sonsthagen et al. (2012, pp. 1512, 1519-1520) and Jay et al. (2008, pp. 939, 941). Therefore, based on the best available information, the Pacific walrus is likely a single panmictic population.

2.2 Subspecies Description and Needs

2.2.1 Behavior

Pacific walruses are social and gregarious animals. They tend to travel in groups and haul out of the water to rest on ice or land in densely packed groups. When hauled out, Pacific walruses tend to lie in close physical contact with each other. Young animals often lie on top of adults. Haulout group size can range from a few individuals up to 10s of thousands and even in excess of 100,000 animals (Gilbert 1999, p. 80; Kastelein 2002, p. 1298; Jefferson et al. 2008, p. 378; Monson et al. 2013, p. 1).

The reaction of hauled out Pacific walruses to disturbance ranges from no reaction to escape into the water (Fay et al. 1984a, pp. 13-14). Many factors play into the severity of the response, including the age and sex of the animals, and the size and location of the group (i.e., on ice or in water; Fay et al. 1984a, pp. 14, 114-119). Females with calves appear to be most sensitive to disturbance, and animals on shore are more sensitive than those on ice (Fay et al. 1984a, p. 114).

Calves typically remain with the mother for two years, but sometimes longer (Fay 1982, pp. 206-211). Independent young females tend to remain with groups of adult females, whereas young males associate with groups of other males. Individual social status appears to be based on a combination of body size, tusk size, and aggression (Fay 1982, p. 136). Individuals do not necessarily associate with the same group of animals and must continually reaffirm their social status in each new aggregation (NAMMCO 2004, p. 45).

2.2.2 Feeding and Prey

Pacific walruses feed primarily on benthic invertebrates (Fay 1982, p. 139; Bowen and Siniff 1999, p. 457; Born et al. 2003; Dehn et al. 2007, p. 176; Sheffield and Grebmeier 2009, pp. 766-767). However, seals, fish, and other vertebrates are occasionally eaten (Fay 1982, p. 153; Sheffield and Grebmeier 2009, p. 767). Pacific walruses feed in bottom sediments to obtain prey buried at depths $\leq$ 32 cm in the sediment (Fay 1982, p. 163; Oliver et al. 1983, p. 504; Kastelein 2002, p. 1298; Levermann et al. 2003, p. 8). The foraging behavior of Pacific walruses can impact benthic communities (Oliver et al. 1983, pp. 507-509; Klaus et al. 1990, p. 480; Ray et al. 2006, pp. 412-413). Ray et al. (2006, pp. 411-413) estimated that Pacific walruses consumed approximately three million metric tons of benthic biomass and that thousands of square kilometers are affected by Pacific walrus foraging annually. Consequently, Pacific walruses play a major role in benthic ecosystem structure and function, which Ray et al. (2006, pp. 415) suggested increased nutrient flux and productivity.

The stomach contents of Pacific walruses included over 100 taxa of benthic invertebrates from all major phyla (Fay 1982, p. 145; Sheffield and Grebmeier 2009, p. 764). However, mollusks are the primary component of the Pacific walrus diet (Sheffield and Grebmeier 2009, pp. 764-768). Bivalves and gastropods occurred most frequently in stomachs of Pacific walruses in the Bering Sea and gastropods and polychaete worms occurred most frequently in stomachs from the Chukchi Sea (Sheffield and Grebmeier 2009, p. 767). There does not appear to be a significant difference in prey selection between males and females (Sheffield and Grebmeier 2009, pp. 765, 768). No recent studies of Pacific walrus diets have occurred, but Pacific walrus hunters who often eat the contents of the stomachs of the Pacific walruses they harvest have not noted changes in Pacific walrus stomach contents (Huntington et al. 2012, p. 8).

Noren et al. (2014, p. 851) estimated that a pregnant Pacific walrus would need to consume 7,831 clams per day at the height of her energetic demand when simultaneously pregnant and nursing. Kastelein et al. (2015, p. 14) reported that a captive female Pacific walrus consumed 4,500–7,000 kg annually (12–19 kg per day), which increased by 30% during a 15-month gestation. Adult males feed little during the breeding period (Fay 1982, pp. 142, 159-161; Ray et al. 2006, p. 411). Calves up to a year old depend primarily on their mother’s milk (Fay 1982, p. 138).

Although capable of diving to depths of more than 250 m (Born et al. 2005, p. 30), Pacific walruses usually feed in waters of $\leq$80 m (Fay and Burns 1988, p. 239; Born et al. 2003, p. 348; Kovacs and Lydersen 2008, p. 138), presumably because of higher productivity of their benthic foods in shallower waters (Fay and Burns 1988, pp. 239-240; Carey 1991, p. 869; Jay et al. 2001, p. 621; Grebmeier et al. 2006a, pp. 334, 346; Grebmeier et al. 2006b, p. 1461). Pacific walruses make foraging trips from land or ice haulouts that range from a few hours up to several days (Jay et al. 2001, p. 626; Born et al. 2003, p. 349; Ray et al. 2006, p. 406; Udevitz et al. 2009, p. 1122). Satellite telemetry data indicate that Pacific walruses occupying broken pack ice spend, on average, 46 hrs in the water between resting bouts on ice (Udevitz et al. 2009, p. 1122).

The shallow, ice-covered waters of the Bering and Chukchi Seas support some of the highest benthic mass in the world (Grebmeier et al. 2006b, p. 1461; Ray et al. 2006, p. 404; Grebmeier et al. 2015a, p. 93). Sea-ice algae, phytoplankton, and benthic organisms are tightly linked through the export of algae and phytoplankton to the sea floor (Grebmeier et al. 2006a, p. 339). Sea-ice algae provide a highly concentrated and high-quality food source for zooplankton food webs in the spring and benthic organisms (Grebmeier et al. 2006a, p. 339; McMahon et al. 2006, pp. 2-11; Gradinger 2009, p. 1211).

Spatial variability in benthic abundance and mass across the Bering and Chukchi seas is influenced by a variety of ecological, oceanographic, and geomorphic features (Grebmeier et al. 2015a, pp. 92-114). Within the range of the Pacific walrus, the marginal sea ice zones, consistent polynyas, and convergence of nutrient rich currents generate “hot spots” of high benthic diversity and mass (Grebmeier and Cooper 1995, p. 4439). Benthic mass is particularly high in the northern Bering Sea, the southern Chukchi Sea, the northeastern Chukchi Sea, and the Gulf of Anadyr, Russian Federation, while benthic communities are sparser across the near-shore eastern Chukchi Sea influenced by the nutrient poor Alaska Coastal Current (Fay et al. 1977, p. 12; Grebmeier et al. 1989, p. 261; Feder et al. 1994, p. 176; Grebmeier et al. 1995, p. 243; Grebmeier et al. 2006a, p. 346; Bluhm and Gradinger 2008). However, some Native Alaskan residents of the northeastern Chukchi Sea question that conclusion and indicate that Pacific walrus prey is also abundant in the nearshore area off the coast near Point Lay, Alaska (USFWS 2016b).

Robust pelagic food webs that include epifaunal invertebrates, demersal fishes, and zookplankton communities limit the availability of organic carbon to benthic organisms in areas south of 60^{o} N. Seasonal sea ice cover generates a persistent bottom cold water pool north of 60^{o} N in the Bering and Chukchi sea, which limits pelagic species (Sigler et al. 2011, p. 254; Stabeno et al. 2012, p. 25; Renaud et al. 2015, p. 245). Northward advances in the cold pool occur in warm years and southward advances occur in cold years. Consequently, the temperature-delineated ecological boundary between subarctic (i.e. pelagic-dominated) and arctic (i.e., benthic-dominated) marine food webs is a function of the seasonal ice cover. In the Arctic gray whales, Pacific walruses, seals, and birds are the primary consumers of benthic invertebrates (Grebmeier et al. 2006b, pp. 1461-1463).

2.2.3 Seasonal Distributions

Pacific walruses range across the continental shelf waters of the northern Bering Sea and Chukchi Sea, using broken ice habitat and coastal haulouts to access feeding areas (Fay 1982, pp. 7-21; Figure 2.2). Figure 2.3 illustrates some important geographical features of the northern Bering and Chukchi Seas and important coastal communities within the range of the Pacific walrus. These places are referenced in various sections of this document.

Pacific walruses are highly mobile, and their distribution varies markedly in response to seasonal and annual variations in sea-ice cover. During the winter breeding season, Pacific walruses congregate in the Bering Sea pack ice in areas where open leads, polynyas or thin ice allow access to water (Fay 1982, p. 21; Fay et al. 1984b, pp. 89-99). The specific location of winter breeding aggregations varies annually depending upon ice characteristics. Breeding aggregations have been reported south of St. Lawrence Island, Alaska; south of Nunivak Island, Alaska; and south of the Chukotka Peninsula in the Gulf of Anadyr, Russian Federation (Fay 1982, p. 21; Mymrin et al. 1990, pp. 105-113; Garlich-Miller et al. 2011a, p. 4).

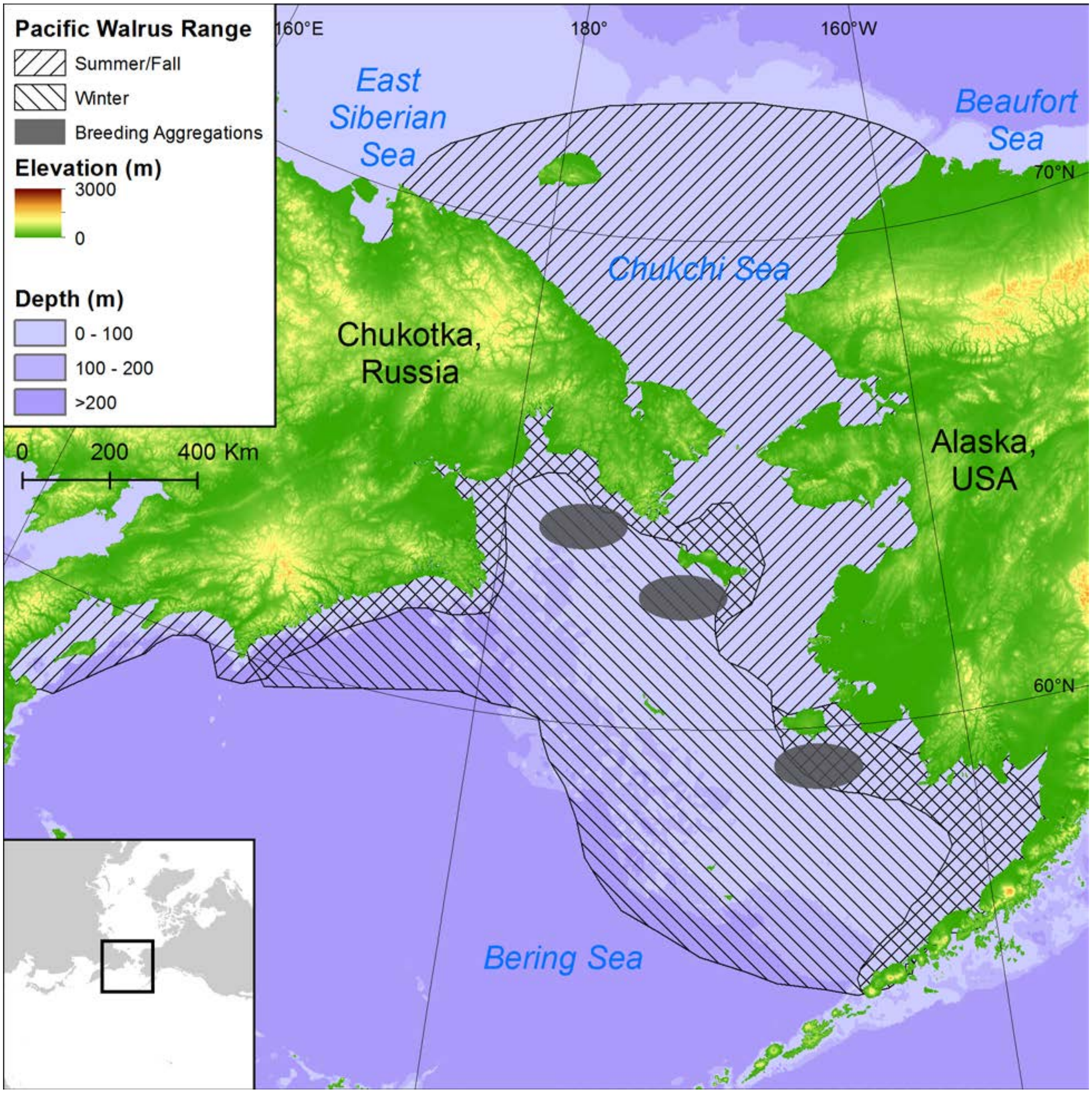


Figure 2.2. Map of the current annual distribution of Pacific walruses, following Fay (1982, p. 24) showing generalized winter and summer range and sites of breeding aggregations.

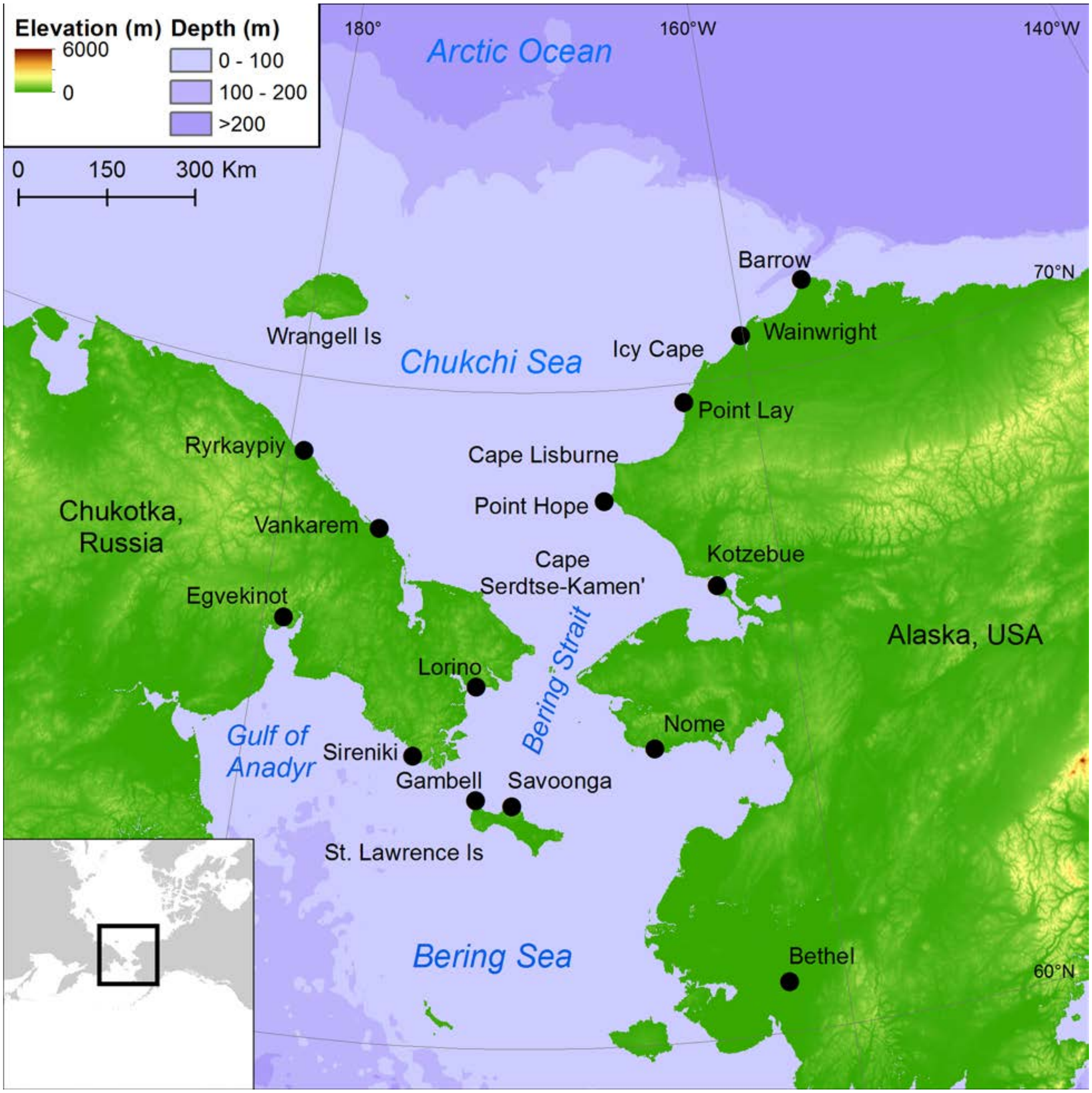


Figure 2.3. Geography of the northern Bering and Chukchi Seas as well as select coastal communities within the range of the Pacific walrus.

As Bering Sea ice deteriorates in the spring, most of the Pacific walrus population (including most adult females and juveniles, and some adult males) migrate northward to summer feeding areas in the Chukchi Sea. Most adult males and some females and juvenile Pacific walruses remain in the Bering Sea and occupy terrestrial haulouts through the ice-free season (June through October) ((Mymrin et al. 1990, p. 105; Garlich-Miller and Jay 2000, p. 8). Subsistence hunters from St. Lawrence Island also report that some Pacific walruses (sex not given) can be found near St. Lawrence Island year round (Garlich-Miller 2012, p. 10).

The distribution and habitat use patterns of Pacific walruses in the Chukchi Sea varies seasonally and annually with sea ice extent. When broken sea ice is abundant, Pacific walruses are typically found in patchy aggregations over continental shelf waters. Individual groups may range from less than 10 to more than 1,000 animals (Gilbert 1999, pp. 75-84; Ray et al. 2006, p. 405). Summer concentrations have been reported in loose pack ice off the northwestern coast of Alaska between Icy Cape and Point Barrow, and along the coast of Chukotka, Russian Federation as far west as Wrangel Island (Fay 1982, pp. 16-17; Gilbert et al. 1992, pp. 1-33; Belikov et al. 1996, pp. 267-269). In years of low ice concentrations in the Chukchi Sea, some animals move into the Beaufort Sea (ADFG 2014) and Pacific walruses have also been observed in the Eastern Siberian Sea in late summer (Fay 1982, pp. 16-17; Belikov et al. 1996, pp. 267-269). Chukchi Sea ice usually reaches its minimum extent in September. As sea ice recedes northward off of continental shelf waters of the Chukchi Sea, females and dependent young begin to occupy coastal haulouts at several sites along the northern coast of the Chukotka Peninsula and Wrangel Island, Russian Federation, and northwestern Alaska (Fay 1982, pp. 16-17; Belikov et al. 1996, pp. 267-269; Kochnev 2004, pp. 284-288; Ovsyanikov et al. 2007, pp. 1-4; Kavry et al. 2008, pp. 248-251; Jay et al. 2012, p. 1; Monson et al. 2013, p. 1).

In late September and October, Pacific walruses that summered in in the eastern Chukchi Sea typically begin moving south in advance of developing sea ice and eventually join Pacific walruses at coastal haulouts in Chukotka, Russia (Fay et al. 1984a, p. 74; Jay et al. 2012, p. 7). Large mixed herds of Pacific walruses are reported at coastal haulouts in the southern Chukchi Sea until developing sea ice forces them south sometime in October through December (Fay et al. 1984a, p. 74; Robards and Garlich-Miller 2013, p. 60) Robards and Garlich-Miller 2013, p. 60). Satellite telemetry data indicates that male Pacific walruses that summered at coastal haulouts in the Bering Sea also begin to move north towards winter breeding areas in November (Jay and Hills 2005, p. 197). The northward movement of male Pacific walruses appears to be driven primarily by the presence of females at that time of year (Jay and Hills 2005, p. 197; Freitas et al. 2009, pp. 248-260).

2.2.4 Habitat Use

Pacific walruses typically use areas of shallow continental shelf waters that support a productive benthic invertebrate community, that also contain open water and have suitable ice floes or land nearby on which they can rest (Kelly 2001, p. 44). A recent analysis of resource selection patterns of adult females in the southern and eastern Chukchi Sea indicated that proximity to ice had a greater influence on foraging space use patterns than proximity to land and benthic biomass (Beatty et al. 2016, p. 28). Proximity to human settlements or other chronic sources of disturbance, such as shipping and commercial fishing may also play a role in habitat selection (See Appendix C; Gadamus et al. 2015, p. 118).

2.2.4.1 Benthic Habitats

The preferred prey of Pacific walruses is generally abundant in finer grained silt/clay sediments high in total organic carbon (Blanchard and Feder 2014, p. 143; Grebmeier et al. 2015a, p. 102). Bottom water temperatures, salinity, and inorganic nutrients are also important characteristics of benthic habitats influencing invertebrate community metabolism and productivity (Grebmeier et al. 2015a, p. 96). Four hotspots of high benthic productivity were identified in Grebmeier et al. (2015a, p. 94) that have persisted through 40 years of sampling and are seasonally important to Pacific walruses and include the St. Lawrence Island polynya, the Chirikov Basin, the southeastern Chukchi Sea, and the northeastern Chukchi Sea.

2.2.4.2 Sea Ice Habitats

Pacific walruses use sea ice as a platform to carry out a number of important behaviors. Floating pack-ice serves as a substrate for resting between feeding bouts (Ray et al. 2006, p. 404), breeding behavior (Fay et al. 1984b, pp. 89-99), birthing (Fay 1982, p. 199), and nursing and care of dependent young (Kelly 2001, pp. 43-55). Pacific walruses have not been observed breeding from coastal haulouts or giving birth in the water or on land. Sea ice provides resting platforms proximate to foraging areas (Richard 1990, p. 21; Ray et al. 2006, pp. 403-419) as well as isolation from terrestrial predators (Kochnev 2004, p. 286; Ovsyanikov et al. 2007), and shelter from rough seas (Fay 1982, p. 25; Richard 1990, p. 23). Females with dependent young generally spend the summer months in ice habitats of the Chukchi Sea where they feed between bouts of resting and suckling their young (Kelly 2001, p. 50). The importance of sea ice in isolating Pacific walruses from human hunters was also noted by Fay (1982, p. 26).

Sea ice habitats used by Pacific walruses are in close proximity to polynyas (open areas within ice), leads, or other areas of open water that provide access to the water and food. Pacific walruses require ice thicknesses of 60 cm or more for support (Richard 1990, pp. 21-26). They generally occupy first-year ice and are not found in areas of extensive, unbroken ice (Fay 1982, p. 26; Richard 1990, p. 23; Barber et al. 1991). Thus, in winter, Pacific walruses concentrate in areas of broken pack ice associated with divergent ice flow or along the margins of persistent polynyas (Burns et al. 1981, pp. 781-797; Fay et al. 1984b, pp. 89-99; Richard 1990, p. 23). Areas of broken ice are also often associated with abundant food (Ray et al. 2006, p. 406). The size and topography of individual ice floes may also be important features in the selection of ice haulouts (Gadamus et al. 2015, p. 118) however, Pacific walruses are likely able to exploit a fairly broad range of ice types and ice concentrations to stay in preferred forage or breeding areas (Freitas et al. 2009, p. 247; Jay et al. 2010, p. 1066). Pacific walruses tend to make shorter feeding excursions when they are using sea ice rather than land haulouts as these ice floes are typically closer to areas of high food abundance (Udevitz et al. 2009, p. 1122).

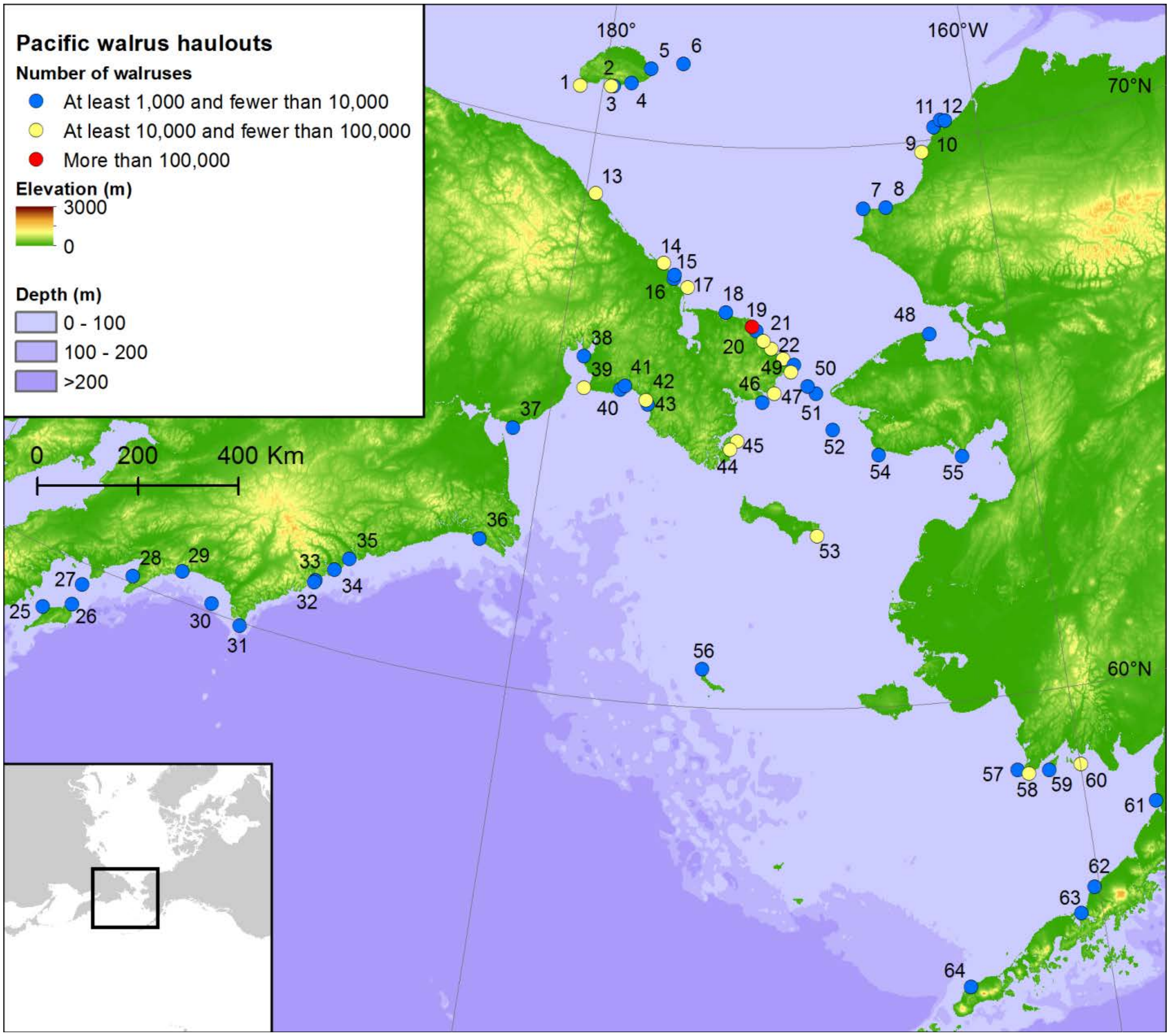
2.2.4.3 Coastal Habitats

When sea ice is not available, Pacific walruses haul out to rest on land. The physical locations of

Pacific walruses land aggregations are termed coastal haulouts (Figure 2.4). A wide variety of substrates, ranging from sand to boulders, are used. Factors thought to influence coastal haulout site selection include: protection from strong winds and surf, proximity to food resources, isolation from disturbances and predators, as well as social factors and learned behaviors (Burns et al. 1981, pp. 781-797; Fay et al. 1984b, pp. 89-99; Richard 1990, p. 23, Garlich-Miller and Jay 2000, p.19).

Adult male Pacific walruses routinely forage from coastal haulouts in the Bering Sea through the ice-free season (Figure 2.4). Female Pacific walruses and their dependent young generally prefer to remain in broken pack ice habitats when available. Although coastal haulouts provide an alternative resting platform during the ice-free season, the use of coastal haulouts may increase risks to juvenile animals from terrestrial predators and trauma associated with disturbance events (Nikiforov et al. 2007, p. 1; Kochnev 2008, pp. 17-20; Robards and Garlich-Miller 2013, pp. 62-85).

The use of coastal haulouts by female and juvenile Pacific walruses is more common in the western (Russia) part of their range than in the eastern (U.S.) portion. Some females and dependent young occupy terrestrial haulouts in the Gulf of Anadyr (western Bering Sea) through the ice-free season (typically June through October) (Mymrin et al. 1990, p. 105; Garlich-Miller and Jay 2000, p. 8). In the western Chukchi Sea, core area of abundance occur along the coast of the Chukotka Peninsula and the waters surrounding Wrangel Island where Pacific walruses are reported to use sea ice and land habitats interchangeably in late summer (August-September) conditional upon regional ice conditions (Gilbert et al. 1992, pp. 9-10; Garlich-Miller and Jay 2000, pp. 9-10; Udevitz et al. 2001, pp. 614, 615). By late September, sea ice has generally retreated from coastal feeding areas in the western Chukchi Sea and most animals, including females and juvenile animals move to coastal haulouts (Tomilin and Kibal'chich 1975, p. 282; Gilbert 1999, pp. 80-81; Garlich-Miller and Jay 2000, pp. 8-9). In contrast, female Pacific walruses that summer in the eastern Chukchi Sea have historically remained in offshore sea ice habitats which generally persisted through the entire melt season (Gilbert 1999, pp. 80-81). In recent years (since 2007), sea ice has withdrawn from continental shelf regions of the eastern Chukchi Sea in late summer, and Pacific walruses have begun to occupy coastal haulouts along the Chukchi Sea coast of Alaska (Figure 2.4) (Jay et al. 2012, p. 9). Based on data collected from the 1950 to 1970s, Fay (1984 p.74), suggested that most Pacific walruses that summered in the eastern Chukchi sea eventually moved to coastal haulouts along the Chukotka Peninsula in the fall and occupied these haulout sites until forced out by developing sea ice in October or November. The pattern appears to persist today (Jay et al. 2012, p. 9), however the period of haulout occupancy appears to have increased with some coastal haulouts occupied well into December in recent years (Robards and Garlich-Miller 2013, p. 60). Based on the information in



Map key:

1 Cape Blossom
2 Somnitel'naya Spit
3 Davydov Spit
4 Rogers Spit
5 Cape Waring
6 Herald Island
7 Cape Lisburne
8 Corwin Bluff
9 Point Lay Barrier Island
10 North of Point Lay
11 Icy Cape
12 East of Icy Cape
13 Cape Schmidt
14 Cape Vankarem
15 Cape Onmyn

16 Cape Kel'enevyt
17 Kolyuchin Island
18 Idlidlya Island
19 Cape Serdtse-Kamen'
20 Cape Inkigur
21 Chegitun River mouth
22 Cape Unikyn
23 Cape Inchoun
24 Cape Kekurny
25 Cape Semenov
26 Cape Golenishchev
27 Verkhoturova Island
28 Cape Galinvilan
29 Somneniya Bay
30 Cape Seryy

31 Cape Olyutorsky
32 Cape Zosima
33 Bogoslov Island
34 Anastasii Bay
35 Dezhnev Bay
36 Pica Creek Mouth
37 Russkaya Koshka Spit
38 Erulya Spit
39 Me'eskyn Spit Island
40 Cape Retkyn
41 Kitovaya Spit
42 Retkyn Spit
43 Kaymatkyn Bay
44 Nuneangan Island
45 Cape Kygynin

46 Cape Kriguigun
47 Cape Nunyamo
48 Cape Espenberg
49 Cape Pe'ek
50 Ratmanov Island
51 Fairway Rock
52 King Island
53 Punuk Islands
54 Sledge Island
55 Cape Darby
56 Hall Island
57 Cape Newenham
58 Cape Peirce
59 Hagemeister Island
60 Round Island
61 Cape Greig
62 Cape Seniavin
63 Port Moller
64 Oksenof Point

Figure 2.4. Map of all known coastal haulout locations used by Pacific walruses from historic records through 2016. Further details are available in Fischbach et al. (2016, inclusive; https://erma.noaa.gov/arctic/erma.html#/x=1.39770&y=66.82653&z=5&layers=1+9736+9731+12873+17383).

the sections above, we have summarized the needs of Pacific walruses in Table 2.1.

Table 2.1. Summary of food, habitat needs, and shelter locations of Pacific walruses.

Season[a]	Food	Habitat Need	Location
Winter	Primarily bivalves, gastropods, and polychaetes; sometimes seals, fish, and birds	Bering Sea broken ice, Access to open water (polynyas and leads) and sufficient prey for activities including breeding.	Bering Sea ice
Spring	Primarily bivalves, gastropods, and polychaetes; sometimes seals, fish, and birds	Bering and Chukchi Sea broken ice, Access to open water (polynyas and leads) and sufficient prey for activities including parturition.	Bering and Chukchi Sea ice
Summer/fall	Primarily bivalves, gastropods, and polychaetes; sometimes seals, fish, and birds	Males: Bering Sea coastal haulouts, access to areas of sufficient prey; Females: Chukchi sea broken ice and coastal haulouts, access to areas of sufficient prey	Males: coastal haulouts Females: Chukchi sea ice and coastal haulouts

[a] winter is December–March, spring April–June, and summer/fall July–November.

2.3 Vital Rates

Empirical estimates of Pacific walrus vital rates have been obtained from the reproductive tracts of harvested females (Fay 1982, pp. 258-261; Garlich-Miller et al. 2006, pp. 880-896), ship-based age and sex composition surveys that occurred in 1981–1984, 1998–1999, and 2013–2015 (Fay and Kelly 1989, p. 1; Citta et al. 2013, p. 20; Taylor and Udevitz 2016, p. 3), and calf:cow ratios from harvested animals (MacCracken et al. 2014, p. 39). In addition, several modeling exercises have provided insights into vital rates (DeMaster 1984, p. 77; Fay et al. 1997, p. 537; Taylor and Udevitz 2015, p. 231; Taylor and Udevitz 2016, p.3).

2.3.1 Reproduction and Productivity

Mating occurs primarily from January to February in broken pack ice habitat in the Bering Sea (Fay 1982, p. 191). Pacific walruses are polygynous (Fay 1985, p. 4). Breeding bulls follow herds of females and compete for access to groups of females hauled out on sea ice. Males perform visual and acoustical displays in the water to attract females and defend a breeding territory. Sub–dominant males remain on the periphery of these aggregations and apparently do not display. Intruders into display areas are met with threat displays and physical attacks. Individual females leave the resting herd to join a male in the water where copulation occurs (Ray and Watkins 1975, p. 526; Fay et al. 1984b, pp. 89-99; Sjare and Stirling 1996, p. 900).

Walruses have the lowest rate of reproduction of any pinniped (Fay 1982, pp. 172-209). Pacific walruses typically give birth to a single calf in May (Fay 1982, pp. 172-209; Fay et al. 1984b, p. 99). Pacific walruses have a pregnancy that extends through the following breeding season resulting in a birth interval of two or more years (Garlich-Miller and Stewart 1999, p. 188). Thus, the theoretical maximum reproductive rate is 0.5 calves per year and estimates range from 0 for young or senescent females to 0.45 for prime age animals (Fay et al. 1997, p. 555; Appendix D). We are not aware of any recent direct estimates of reproductive rates for Pacific walruses, although, calf:cow ratios can serve as an index. Calf:cow ratios estimated from composition counts of Pacific walrus groups at sea resting on ice flows (Fay and Kelly 1989, p. 1; Citta et al. 2013, p. 33) and the composition of the harvest by St. Lawrence Island hunters (MacCracken et al. 2014, p. 41) have both been used as surrogates for reproductive rates, however both data types have inherent directional biases of an unknown magnitude. Specifically, calf:cow ratios estimated from harvest data are biased high as a reproductive rate measure due to hunter selection for adult females with calves (Garlich-Miller et al 2006, p. 889). In contrast, calf:cow ratios estimated from age structure data may be biased low as a reproductive rate measure because calves must survive the period from birth to sampling (Citta et al. 2014, p. 40)**.** The minimum age at which females first produce a calf, or age at first reproduction (AFR), ranges from 3–10 years of age (Fay et al. 1989b, p. 7; Chivers 1999, pp. 240-243).

2.4 Population Abundance and Trends

Estimates of the size of the Pacific walrus population have always been imprecise (Table 2.2). Based on large sustained harvests in the 18th and 19th centuries, Fay (1982, p. 241) speculated that the pre-exploitation population was represented by a minimum of 200,000 animals. Since that time, population size is thought to have fluctuated in response to varying levels of human exploitation. Large-scale commercial harvests are believed to have reduced the population to 50,000–100,000 animals in the mid-1950s (Fay et al. 1997, p. 539). The population is thought to have increased rapidly in size during the 1960s and 1970s in response to harvest regulations that limited the take of females (Fay et al. 1989b, p. 4; Fay et al. 1997, p. 539; Garlich-Miller et al. 2006, p. 892; Taylor and Udevitz 2015, pp. 250-251; MacCracken and Benter 2016, p. 588).

Table 2.2. Estimates of the size of the Pacific walrus population from aerial surveys, 1975–2006 and preliminary results of a genetic mark-recapture study for 2014. Comparisons of estimates across years (population trends) are not appropriate due to differences in methods.

Year	Population Size	95% confidence interval
1975[b]	199,783	112,000–330,000[a]
1980[c]	254,890	184,000–344,000[a]
1985[d]	242,882	125,000–427,000[a]
1990[e]	201,039	88,000–397,000[a]
2006[f]	129,000	55,000–507,000[f]
2014[g]	283,213	93,000–478,975[g]

[a] Taylor and Udevitz (2015, p. 242)
[b] Udevitz et al.(2001, p. 608) and Estes and Gol'tsev (1984, p. 75),
[c] Udevitz et al. (2001, p. 608), Johnson et al. (1982, p. 26), and Fedoseev (1984, p. 78),
[d] Udevitz et al. (2001, p. 608), Gilbert (1989, p. 17), Fedoseev and Razlivalov(1986, p. 7),
[e] Gilbert et al. (1992, p. 11),
[f] Speckman et al. (2011, p. 517)
[g] Beatty (2017, p. 3).

Between 1975 and 1990 observer based aerial surveys conducted jointly by the United States (U.S.) and Russia at 5-year intervals produced population estimates ranging from approximately 200,000 to 255,000 (Table 2.2). However, efforts to survey the Pacific walrus population were suspended by both countries after 1990, due to unresolved problems with survey methods that produced population estimates with unknown bias and large variances that severely limited their utility (Speckman et al. 2011, p. 516).

In 2006, a joint US and Russian Federation survey was conducted in the pack ice of the Bering Sea, using thermal imaging systems to detect Pacific walruses hauled out on sea ice and satellite transmitters to account for Pacific walruses in the water (Speckman et al. 2011, p. 517). The number of Pacific walruses within the surveyed area was estimated at 129,000 with 95% confidence interval of 55,000 to 507,000 individuals (Table 2.2). This is a minimum estimate, as weather conditions prevented a significant portion of potential habitant from being surveyed.

In 2013, we began a genetic mark-recapture project to estimate population size and vital rates. An analysis of preliminary data from the first 3 years of the project (2013–2015) estimated a total population size of 283,213 Pacific walruses with a 95% credible interval of 93,000 to 478,975 individuals (Beatty 2017). However, the abundance estimate should be interpreted with caution due to the preliminary nature of the estimate and low precision of parameter estimates in the model. We also note that the relatively large credible intervals preclude any conclusions regarding population trend based on previous abundance estimates.

2.4.1 Population Modelling

Several studies have estimated Pacific walrus population demographics and trends with modeling (DeMaster 1984, p. 78; Fay et al. 1997, p. 550; Udevitz et al. 2013, p. 295; Taylor and Udevitz 2015, p. 241) and provide some insight on population size, trends, and vital rates. They all noted significant challenges in modeling the population that included biases in available data (DeMaster 1984, p. 80; Fay et al. 1997, pp. 539-546) and lack of direct empirical estimates for vital rates (Fay et al. 1997, pp. 539-546). The results of Fay et al. (1997, pp. 539-546) indicated the population increased from 1950 to 1980 and then declined. Udevitz et al. (2013, pp. 292-294) found that calf mortalities at haulouts could have a greater effect on population trend than an equivalent level of female harvest across all other age classes. Taylor and Udevitz (2015, p. 241) and a recent update (Taylor and Udevitz 2016, inclusive) indicated that abundance was relatively high around 1980 with a subsequent decline occurring into the 2000s with current population trend equivocal (Taylor 2017).

2.4.2 Population Indices

Changes in Pacific walrus population levels have also been investigated by examining biological parameters and indices of population status and those indices are valuable in assessing the population trend over time; calf:cow ratios as presented above are one example. Two other indices discussed below include asymmetry in walrus tusk circumference (MacCracken and Benter 2016, inclusive), a measure of developmental instability, and hormone levels in walrus bones (Charapata 2016, inclusive); both an index of population stress. All indices of population status assume a strong correlation with population size and that the correlation does not vary substantially over time (Eberhardt and Simmons 1987, p. 665). Few indices have been tested directly and attempts to calibrate indices are also generally lacking due to the associated expense (Eberhardt and Simmons 1987, p. 665). Johnson (2008, p. 857) noted that in general, indices apply only to a portion of the population and that the proportion can change across habitats and over time. It is also difficult to identify causal agents with indices.

MacCracken et al. (2014, p. 40) reported a strong correlation (r_s = -0.91) between calf:cow ratios and estimates of Pacific walrus population size lending support to the efficacy of those ratios as an index to population status. However, they cautioned that biases in aerial survey results could confound that interpretation.

MacCracken and Benter (2016, p. 588) examined fluctuating asymmetry (FA) in Pacific walrus tusks from 1990–2014. In Pacific walrus, FA was advanced as an index of developmental instability due to stressors when the population was near or at carrying capacity (K) in the 1970s–1980s and food limited. The expectation, and outcome, was that FA would be greater at the beginning of the time series and subsequently decline as the population declined, food resources recovered, and stress declined. There was a declining linear trend in the FA of male tusks from 1990–2014. The correlation between Pacific walrus population estimates (Table 2.2) and male FA is moderate (r_s = 0.50). If FA is primarily driven by stressors associated with large population size relative to carrying capacity, then we would expect a positive correlation with population size. A similar overall negative trend was also observed for females but the decline was not as steep after 1996, then reversed and became positive around 2011 (MacCracken and Benter 2016, p. 596, 597). The correlation between female FA and population size (r_s = -0.50) was negative, indicating that another stressor was also important, most likely the loss of sea ice habitat in the summer/fall. Nonetheless, measures of FA in both males and females are 38% and 49% smaller, respectively in 2015 than in 1990.

Few studies have directly linked FA to other measures of stress. Reactive oxygen species (ROS) are free radicals that are frequently linked to oxidative stress (Devasagayam et al. 2004, p. 796). Elevated ROS concentrations have been linked to starvation, radiation exposure, and infectious diseases in humans (Halliwell and Cross 1994, pp. 8–9). Fluctuating asymmetry (FA) in wild boar (*Sus scrofa*) has been linked to the concentrations of ROS (Cánovas et al. 2015, p. 287). Thus, linkages among oxidative stress, environmental conditions, and tusk asymmetry have been explored in other species.

Caveats that may be associated with FA as an index to population status in Pacific walruses include the potential effects of measurement error and observer error. MacCracken and Benter (2016, pp. 590, 592) assessed both and found that neither was an important potentially confounding issue.

Charapata (2016, pp. 79, 80) found that cortisol levels in Pacific walruses sampled in 2014–2015 were similar to archaeological (3,450–200 years before present) and historic (200–20 years before present) samples, concluding that the Pacific walrus population was physiologically resilient to current levels of sea ice loss, consistent with MacCracken and Benter (2016, p. 588). However, elevated bone cortisol levels are expected as a result of a chronic, long-term stressor over the lifetime of an individual (Charapata 2016, p. 103). Sea ice loss is currently acting as a seasonal acute stressor rather than a consistent, chronic stressor (Sections 3.1.1 and 3.1.2). Charapata (2016, p. 80) also noted that reproductive hormones were low in walruses sampled in 2014–2015 compared to archaeological and historical samples, suggesting reproduction was currently low relative to the two other time periods. However, hunter observations and population modeling suggest current reproductive rates are elevated compared to values in the 1980s (Taylor and Udevitz 2015, pp. 246–247) in contrast to Charapata (2016, p. 80). The contrasting conclusions could be due to the broad temporal time scales and limited number of samples considered in Charapata (2016, pp. 142–149).

Linking physiological stress measures to anthropogenic disturbances and other environmental conditions can be difficult. For example, intrinsic, environmental, and ecological factors can interact with anthropogenic factors to confound interpretations of physiological stress measures (Dantzer et al. 2014, p. 10). Furthermore, the relationship between fitness and stress measures is inconsistent, and studies with zoo animals are required to validate species-specific relationships among species (Dantzer et al. 2014, pp. 5-10). However, recent declines in reproductive hormones are in agreement with the trend in female Pacific walruses tusk FA as described above.

In considering all of the demographic and population status information collectively (Figure 2.5), we conclude that the Pacific walrus population increased from 1960 until approximately 1980. The population then declined sharply in the 1980s with the decline moderating in the 1990s. Recent modeling suggests the population approached stability in the 2000s, possibly as early as 2004 (Taylor and Udevitz 2016). Evidence suggests the population decline from 1980–2003 was due to the combined effects of high harvests in the 1980s with a food-limited population near carrying capacity. For example, Alaska Natives reported lean Pacific walruses in the harvest beginning in 1976 as well as unusual stomach contents (Fay et al 1989a, p. 5). Fay et al (1989a, p. 5–6) confirmed these local traditional knowledge (LTK) observations, and concluded Pacific walruses were leaner in the 1980s than the late 1950s to early 1970s. In addition, research also demonstrated that non-bivalve prey occurred more frequently in Pacific walrus stomachs in the late 1970s and early 1980s compared to previous years (Fay and Stoker 1982a, p. 44, Fay and Stoker 1982b, pp. 28–30). Furthermore, Alaska Native hunters reported fewer calves in the late 1970s and early 1980s, and further research confirmed reduced reproductive rates in adult females (Fay et al 1989a, pp. 6–7). Thus, the Pacific walrus population decline in the 1980s and 1990s was due to density-dependent mechanisms regulating a food-limited population coupled with high harvests in the 1980s.

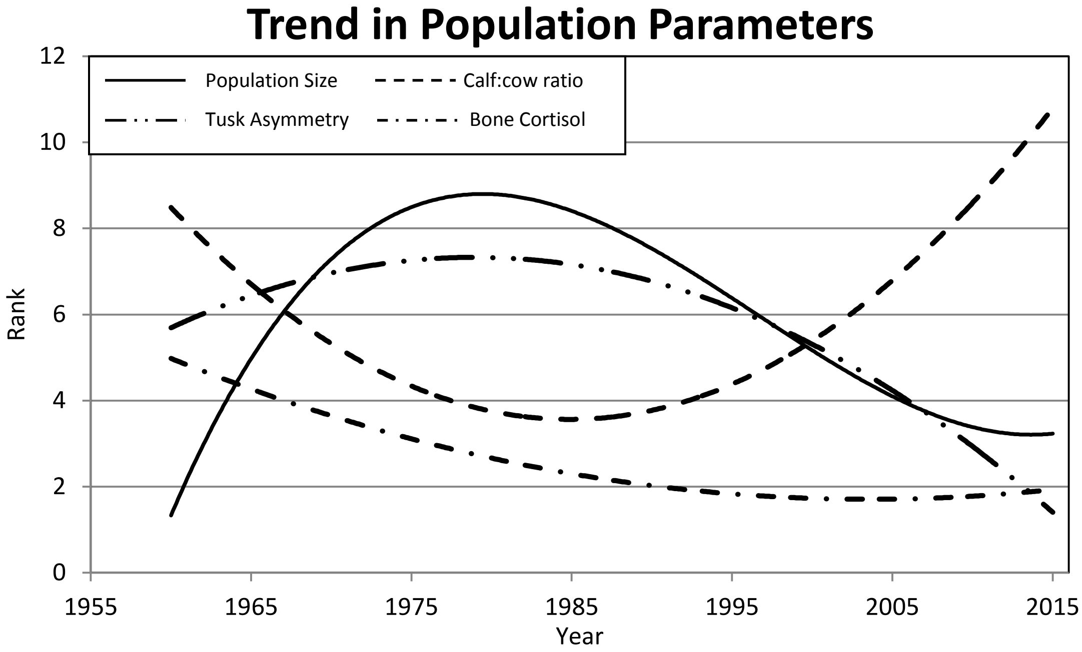


Figure 2.5. Trend in Pacific walrus population size (Taylor and Udevitz 2015, p. 241; Taylor and Udevitz 2016), calf:cow ratios (MacCracken et al. 2014, p. 41), tusk asymmetry (MacCracken and Benter 2016, inclusive), and bone cortisol levels from 1960–2015 (Charapata 2016, pp. 79, 80). Data are rank-transformed for comparison and trend lines are based on quadratic smoothing.

2.5 Adaptive Capacity of Pacific Walruses

The adaptive capacity of a species is founded in its evolutionary history that gave rise to traits resulting in its continued persistence. An assessment of the adaptive capacity of a species is critical to an accurate evaluation of the viability of a species (Dawson et al. 2011, p. 53; Glick et al. 2011, pp. 48-50; Sydeman et al. 2015, p. 775; Beever et al. 2016, p. 1; Wade et al. 2016, p. 1). In a broad sense, adaptive capacity has been defined as a species' ability to adjust to environmental change, moderate potential damages, and take advantage of opportunities (Glick et al. 2011, p. 48). Elements of adaptive capacity include a species evolutionary potential and phenotypic plasticity (a function of standing genetic diversity), the ability to adjust their range in response to environmental changes and stressors (dispersal ability), and the ability to adjust behaviors in response to environmental changes (behavioral plasticity) (Beever et al. 2016, p. 2).

2.5.1 Evolutionary History of the Pacific Walrus

Evolutionary potential is typically assessed based on generation length, genetic diversity, rate of favorable mutations, and selective forces. In general, widespread, large, or well-connected populations (e.g., the Pacific walrus) possess greater evolutionary potential than small, localized, or isolated populations (Sydeman et al. 2015, p. 776). The persistence of walruses through past events of climatic and sea ice increases and decreases suggests that they likely possess the evolutionary potential to cope with the seasonal loss of sea ice as a selective force (Hendry et al. 2011, p. 159; Sih et al. 2011, p. 367; but see Albalat and Canestro 2016, p. 379 for evidence of adaptation through gene loss). However, those environmental changes occurred at slower rates than today and the long generation length (15 years) and slow population growth of Pacific walruses are not conducive to rapid microevolution (Sydeman et al. 2015, p. 776).

2.5.2 Behavioral Adaptation of Pacific Walruses

Change in behavior, a form of phenotypic plasticity, is often the first response by animals to changing environmental conditions (Candolin and Wong 2012, p. xv; Stamps 2016, p. 535). Success of a population under changing environmental conditions likely depends on the plasticity of individual traits that have evolved under past environmental conditions (Van Buskirk 2012, p. 145) which can both be adaptive and maladaptive to the new conditions (Candolin and Wong 2012, p. xv; Van Buskirk 2012, pp. 152-154). Pacific walruses have recently altered their behavior in response to changing sea ice dynamics. For example, the spring migration occurs earlier in the year and females and young have shifted their summer distribution northward (Jay et al. 2012, pp. 3, 10; MacCracken 2012, pp. 2076, 2080; Ray et al. 2016, p. 32). In September, females and young now utilize coastal haulouts more often in the Chukchi Sea and fall migration occurs later in the year (Garlich-Miller et al. 2011a, p. iv; MacCracken 2012, p. 2082; Appendix C). Coastal haulouts are not preferred habitat for females and juvenile Pacific walruses for many reasons as discussed in section 3.2. Consistent summer/fall use of coastal haulouts by females and juveniles has only occurred since 2007 in the U.S. and the long-term consequences of this behavior are unknown. However, female and juvenile Atlantic walruses appear to have successfully used coastal haulouts over the last several years in Svalbard, Norway (Kovacs et al. 2014, p. 3).

Alaska Native hunters and subsistence users hold that the current Pacific walrus population is generally healthy; they indicated that walruses had moved north but that their numbers had not declined (Appendix C), however inferences to population size are likely limited to the area of observation. However, Ray et al. (2016, p. 24) hypothesized that dispersal mortality associated with recent sea ice changes in the Bering Sea would increase along with reduced availability of Pacific walruses to subsistence hunters. The latter has been observed, particularly since 2013 (see section 3.3.2 Harvest Patterns), but the subsistence hunting community suggest that this is due to restricted access to Pacific walruses as a result of changes in Pacific walrus migration patterns, sea ice patterns, and inclement weather (Appendix C). The observations of individual subsistence hunters are limited in spatial extent; however, consistent narratives among communities along the Alaskan coast offset that limitation.

In contrast to shifts in distribution and timing of migration, increased use of Chukchi Sea coastal haulouts in the summer/fall may be maladaptive at the population level due to mortality events and increased energetics associated with use of coastal haulouts (Jay et al. 2012, p. 10; MacCracken 2012, p. 2085). Disturbance events at coastal haulouts in both the U.S. and Russian Federation resulted in thousands of mortalities in 2007–2009, although disturbances since that time have declined likely due to management actions (USFWS 2016c). In addition, Jay et al. (2017, p. 386) demonstrated that female Pacific walruses spend more time swimming and less time feeding and resting when using coastal haulouts than when hauled out on ice floes. However, population level consequences of the changes in behavior associated with use of coastal haulouts needs to be determined.

2.5.3 Intrinsic Adaptive Capacity of Pacific Walruses

Pacific walruses have several intrinsic life history characteristics that allow them to persist in a highly seasonal and stochastic environment which may provide capacity to adjust to, or moderate potential stressors associated with future environmental changes.

2.5.3.1 Body Size and Energy Stores

Pacific walruses are large animals with considerable seasonal and individual variation in blubber stores (Fay 1982, pp. 30-34). Large body size and the ability to store and access energy reserves are adaptations that provide a buffer against periods of energy deficit in seasonal or unpredictable environments (Zeveloff and Boyce 1988, pp. 123–146).

2.5.3.2 High Rates of Survival

Pacific walruses are longed lived animals with high rates of adult survival (Fay et al. 1997, pp. 537-565) and therefore, environmental stressors tend to disproportionally affect reproduction and juvenile survival. Long-lived species with overlapping generations can withstand relatively high rates of juvenile mortality provided that the breeding population is maintained (Eberhardt and Siniff 1977, pp. 208-209).

2.3.3.3 Prolonged Periods of Parental Care

The evolution of precocious young, aquatic nursing and an extended period of parental care are adaptations that help to buffer Pacific walrus neonates from variable environmental conditions and enhance juvenile survival rates (Kovacs and Lavigne 1992, p. 1960). Female Pacific walruses forage during an extended nursing period which allows them to spread out the costs of lactation over a prolonged period of time and provides offspring the opportunity to develop swimming and foraging skills while still dependent upon their mother for energy reserves (Kovacs and Lavigne 1992, p. 1953). The nursing period of walruses also appears to be highly variable (ranging from 1-3 years) (Fay 1982, p. 132; Kovacs and Lavigne 1992, pp. 1954-1955; Fisher and Stewart 1997, p.1172) and the ability to delay weaning may provide energetic benefits to neonates during periods of food shortages (Fay 1982, p. 132; Kovacs and Lavigne 1992, pp. 1954-1955; Fisher and Stewart 1997, p.1172). However, extending pre-natal care comes at the cost of the reproductive rates of adults and therefore additional investment in current reproduction comes at the cost of future reproduction.

2.5.3.4 Flexible Spatial Use Patterns

Over the past century, the spatial distributions of Pacific walruses across the Bering and Chukchi Seas has varied on a seasonal, inter-annual and decadal scale, presumably in response to variations in ice cover (Brooks 1954, p. 16; Fay 1982, pp. 7-29; Garlich-Miller and Jay 2000, p. 9), human disturbances and hunting pressure (Fay 1957, pp. 432-437; Fay et al. 1984a, pp. 22-28), and regional trends in prey abundance (Jay and Hills 2005, p. 98). This flexibility in spatial use patterns provides a mechanism by which Pacific walruses can moderate potential consequences associated with regional changes in environmental conditions and other stressors, and seek out and colonize new favorable habitats where they exist.

2.5.3.5 Flexible Habitat Use Patterns

Although Pacific walruses are dependent on sea ice for some aspects of their life history including breeding, birthing, and the first couple of weeks of post-natal care, they also use terrestrial habitats to rest and nurse their young during the summer melt season. The use of terrestrial haulout sites appears to vary within different demographic segments of the Pacific walrus population and across the circumpolar range of the species. While the use of terrestrial haulouts in summer is relatively common among adult male Pacific walruses and Pacific walruses of all age and sex classes in other parts of the Arctic (Kovacs et al. 2011, p. 183; Laidre and Regehr 2017, p. 519), female Pacific walruses and their dependent young generally prefer to remain in broken pack ice habitats when available.

Based on data collected from the 1950s to 1970s, Fay (1984 p.74) suggested that most Pacific walruses that summered in sea ice habitats in the eastern Chukchi sea moved to coastal haulouts along the Chukotka Peninsula in the fall and occupied these haulout sites until forced out by developing sea ice in October or November. The pattern of shifting from sea ice habitats to coastal habitats in the fall appears to persist today (Jay et al. 2012, p. 9), however the period of haulout occupancy has increased and some coastal haulouts have now been occupied well into December in recent years (Robards and Garlich-Miller 2013, p. 60).

Range shifts: Walruses have persisted through several climate transitions over the past 100,000 years (Cronin and Cronin 2015, pp. 2-18). Consolidated sea ice is thought to serve as a barrier limiting walrus distribution (Harrington 2008, pp. 26-28). Today, Pacific walruses generally range across the continental shelf waters of the northern Bering Sea and Southern Chukchi Seas (Figure 2.2). Although summer sea ice conditions in the adjacent Beaufort and East Siberian Seas have moderated significantly in recent years, Pacific walruses have not been documented in significant numbers in either region. This suggests that there may be factors besides sea ice cover influencing their current distribution. We found no reason for evaluating the quality of potential future habitats outside of the present range of Pacific walruses.

In summary, we have identified some of the fundamental and realized adaptive capacity of Pacific walruses to cope with the changes produced by a warming climate, and Pacific walrus hunters suggest that the fundamental adaptive capacity of Pacific walruses will allow them to successfully adjust to the environmental changes that have occurred over the last decade (Appendix C). However, the long generation time of the Pacific walrus may preclude us from observing any negative consequences at the population-level for decades (Armbruster et al. 1999, p. 69; Turkalo et al. 2016, p. 1; see section 4.4.3 Trend in All Season Abundance Stressors). In addition, the long generation time will likely limit the ability of walruses to develop new adaptations within a short time frame.

3. CURRENT RESOURCE CONDITIONS

In this chapter, we describe the current condition of resources needed to fulfill essential life functions of the Pacific walrus at the individual and population levels. We consider the spatial and temporal variability of those resources and the stressors that may have affected their current condition. We address the scope and magnitude of stressors to Pacific walruses in the future in Chapter 4.

3.1 Marine Habitats

3.1.1. Sea Ice

This section documents the trends in sea ice extent and thickness over the last several decades and includes discussions of ecosystem changes that are directly linked to sea ice dynamics such as seawater temperature, primary productivity, Pacific walrus prey abundance, etc. Sea ice extent, thickness, and age have been declining Arctic-wide since at least 1979 (Meier et al. 2014, inclusive), the beginning of the satellite record. In the Bering Sea, sea ice extent has increased slightly in winter and spring and declined slightly in summer/fall (Figure 3.1). In the Chukchi Sea, ice extent has declined in summer/fall, but has been relatively stable in winter and spring (Figure 3.2). For this SSA we defined winter as December–March, spring as April–June, and summer/fall as July–November, consistent with Jay et al. (2011, p. 1068). Historically the Bering Sea, and since 2011 the Chukchi Sea, have been dominated by first year ice (Meier et al. 2014, p. 185; Stroeve et al. 2014, p. 1216; Frey et al. 2015, p. 32; Walsh et al. 2016, p. 16). First year ice is relatively thin and more susceptible to rapid melting as ocean and air temperatures increase in the spring. In general, ice retreat has been more rapid and occurred earlier than in the past.

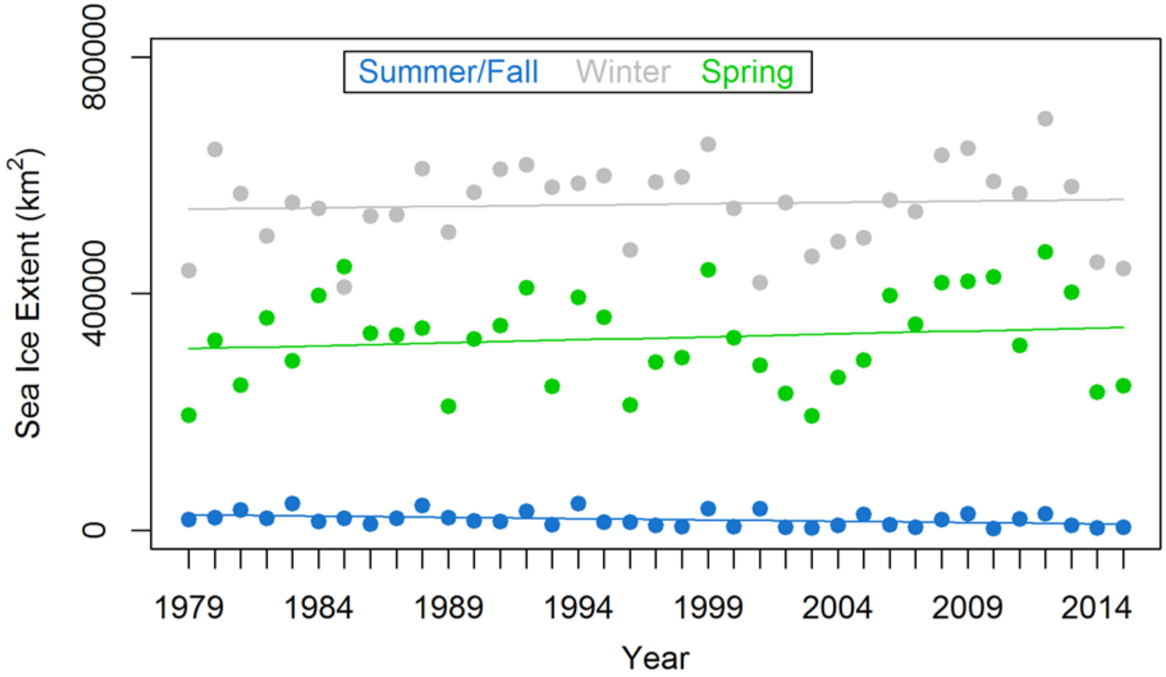


Figure 3.1. Mean seasonal sea ice extent for summer/fall (July–November), winter (December–March), and spring (April–June) from 1979 to 2015 in the Bering Sea. Seasonal means were derived from mean monthly sea ice data from the National Snow and Ice Data Center, Sea Ice Index Version 2.0 (Fetterer et al. 2016, inclusive; doi: http://dx.doi.org/10.7265/N5736NV7). Points represent mean values by season and year and lines represent least squares trends.

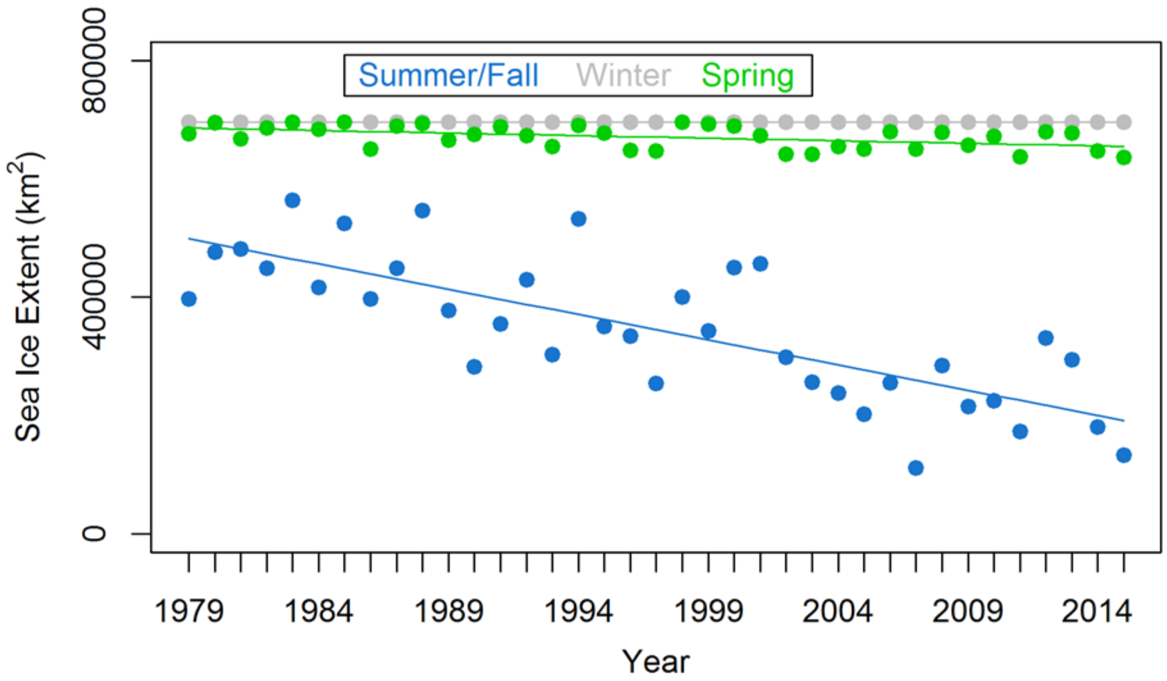


Figure 3.2. Mean seasonal sea ice extent for summer/fall (July–November), winter (December–March), and spring (April–June) from 1979 to 2015 in the Chukchi Sea. Seasonal means were derived from mean monthly sea ice data from the National Snow and Ice Data Center, Sea Ice Index Version 2.0 (Fetterer et al. 2016, inclusive; doi: http://dx.doi.org/10.7265/N5736NV7). Points represent mean values by season/year and lines represent least squares trends.

3.1.2 Annual Trends in Sea Ice

From 1979–2013, there was a general trend toward earlier onset of ice melt and later onset of freeze-up in the Arctic, with the exception of the Sea of Okhotsk (Markus et al. 2009, pp. 1-14; Stroeve et al. 2014, p. 1216). For the entire Arctic, the melt season length has increased by 5.0 days per decade over the last 34 years, due to the combined earlier melt and later freeze-up. The largest increases have been in the Chukchi (13.2 days per decade), Kara (11.8 days per decade), East Siberian (9.7 days per decade), and Beaufort (9.2 days per decade) seas (Stroeve et al. 2014, p. 1219). From 1979–2013, there was also a general trend toward earlier onset of ice melt and later onset of freeze-up in the Bering Sea of 2.6 days per decade, which is the smallest increase of any Arctic sea (Stroeve et al. 2014, p. 1219).

3.1.3 Effects of Sea Ice Changes on Pacific Walruses

During the current time period, loss of sea ice during the summer/fall period is the primary concern for Pacific walruses because substantial amounts of sea ice remains over continental shelf regions in winter and spring (Douglas 2010, pp. 25, 26; Garlich-Miller et al. 2011a, pp. 24, 32; Appendix A). Starting in 2007, sea ice in the Chukchi Sea began to recede north of the continental shelf in August or September for durations lasting up to 2 months (Wang and Overland 2015, p. 50), resulting in Pacific walruses coming to shore in large numbers. Several thousand animals (primarily juveniles) have been reported to have died at coastal haulouts due to disturbance related stampedes (section 3.2.3 Haulout Mortalities; USFWS 2016c). While the most notable impact of declining sea ice has been mortality events associated with increased use of coastal haulouts, concerns remain about other effects including increased energetic costs associated with coastal haulout use, changes in subsistence harvest patterns, increased rates of predation and disease, and changes in shipping traffic and resource development. A detailed discussion of these topics can be found below.

3.1.4 Ocean Warming

Sea surface temperatures (SST) have increased worldwide since the 1970s by 0.2 to 0.4^{o} C (IPCC 2013, p. 190). For the last several decades, surface air temperatures throughout the Arctic, over both land and water, have warmed at a rate that exceeds the global average (Comiso and Parkinson 2004, pp. 38-39; Lawrence et al. 2008, p. 1; Serreze et al. 2009, pp. 11-12; Bhatt et al. 2014, p. 59). In addition, the subsurface and surface waters of the Arctic Ocean and surrounding seas, including the Bering and Chukchi seas have also warmed (Steele and Boyd 1998, p. 10419; Zhang et al. 1998, p. 1745; Overland and Stabeno 2004, p. 309; Stabeno et al. 2007, pp. 2607-2608; Steele et al. 2008, p. 1; Mueter et al. 2009, p.96; Stabeno et al. 2012, p. 14). However, this warming trend was interrupted in the Bearing Sea in 2010–2012 in association with a negative trend in the Pacific Decadal Oscillation (Wendler et al. 2014, p. 393) in contrast to the Chukchi Sea which continued to warm at a rate of 0.5^{o} C per decade (Timmermans and Proshutinsky 2015, p. 42). There are several mechanisms working in concert to cause these increases in ocean temperature, including: warmer air temperatures (Comiso and Parkinson 2004, pp. 38-39; Overland and Stabeno 2004, p. 310), an increase in the heat carried by currents entering the Arctic from both the Atlantic (Zhang et al. 1998, p. 1745; Drinkwater et al. 2009, p. 25) and Pacific oceans (Stabeno et al. 2007, p. 2599; Woodgate et al. 2010, pp. 1-5), and a shorter ice season, which decreases the albedo (reflection of light and heat) due to diminished ice and snow (Comiso and Parkinson 2004, p. 43; Moline et al. 2008, p. 271; Markus et al. 2009, p. 13).

3.1.4.1 Effects of Ocean Warming on Pacific Walruses

Due to their biological characteristics which include tolerance of considerable variations in water temperature (Rodríguez-Prieto et al. 2013, p. 174; Noren et al. 2014, p. 844; Kastelein et al. 2015, p. 10; Noren et al. 2015b, p. 661), the recent 2–4^{o} C increases in water temperatures (Stabeno et al. 2012, pp. 14, 20) since 2004 are unlikely to cause direct stress effects on Pacific walruses. However, sea water temperature increases may affect the abundance, distribution, composition, and the quality of Pacific walrus prey (Wassmann et al. 2011, p. 1235; Renaud et al. 2015, p. 244). In recent years, three species of benthic invertebrates (*Podoodesmus macrochisma*, *Oregonia gracilis,* and *Telmessus cheiragonus*) have either moved into or expanded to the north within the Chukchi Sea (Sirenko and Gagaev 2007, p. 361), providing an example of the change in benthic species composition.

In the eastern Bering Sea, reductions in sea ice have been responsible for shrinking a large subsurface pool of cold water with temperatures less than 2° C (Stabeno et al. 2007, p. 2605; Mueter and Litzow 2008, p. 313). The southern edge of the cold pool, which defines the boundary region between the Arctic and subarctic communities, had retreated approximately 230 km north since the early 1980s (Mueter and Litzow 2008, p. 316). The northward expansion of warmer water resulted in a northward expansion of pelagic species as subarctic fauna colonized newly favorable habitats (Overland and Stabeno 2004, p. 309; Mueter and Litzow 2008, pp. 316-317). However, more recent data indicates that the bottom cold water pool has also moved south (Sigler et al. 2011, p. 261; Stabeno et al. 2012, p. 14).

3.1.5 Ocean and Benthic Productivity

Pacific walruses are the top predator of a simple food web in which the primary constituents are bacteria, sea-ice algae, phytoplankton (small floating plants), zooplankton (small pelagic animals), and benthic invertebrates (Horner 1976, p. 179; Lowry and Frost 1981, p. 820; Grebmeier and Dunton 2000, p. 370; Aydin and Mueter 2007, p. 2507; Tu et al. 2015, p. 19). Sea ice is important to this food web because: (1) it is a substrate for ice algae and phytoplankton (Horner 1976, pp. 168-171; Kern and Jr. 1983, p. 161; Grainger et al. 1985, pp. 25-27; Melnikov 2000, pp. 79-81; Gradinger 2009, p. 1201; Boetius et al. 2013, p. 1430; Arrigo and van Dijken 2015, p. 68); (2) it influences nutrient supply and phytoplankton bloom dynamics (Lovvorn et al. 2005, p. 136; Arrigo et al. 2012, p. 1048; Palmer et al. 2014, p. 85; Arrigo and van Dijken 2015, p. 68); and (3) it determines the extent of the bottom cold-water pool on the southern Bering Sea shelf (Aydin and Mueter 2007, p. 2503; Coyle et al. 2007, p. 2900; Stabeno et al. 2007, p. 2615; Mueter and Litzow 2008, p. 309; Sigler et al. 2011, p. 250; Stabeno et al. 2012, p. 14).

Ice algae can contribute up to 50% of the total annual primary productivity in the Arctic (Kohlbach et al. 2016, p. 1). Ice algae can be released into the water through turbulence below the ice, through brine drainage from the ice, or when the algal mats are sloughed off as the ice melts (Cota and Horne 1989, p. 117; Renaud et al. 2007, p. 7; Boetius et al. 2013, p. 1430). Sea-ice algae provide a highly concentrated food source for the benthos and zooplankton as the ice melts and the algae sinks to the bottom (Grebmeier et al. 2006a, p. 339; McMahon et al. 2006, pp. 1-2; Renaud et al. 2007, pp. 8-9; Gradinger 2009, p. 1211; Arrigo et al. 2012, p. 1408; Arrigo and van Dijken 2015, p. 60; Kohlbach et al. 2016, p. 1).

Primary productivity in the Arctic Ocean is limited by light and nutrients (Boetius et al. 2013, p. 1430). Sea ice and snow cover restrict the penetration of light, particularly photosynthetically active radiation (PAR), to the water column. As a consequence of Arctic warming, primary production in and under the ice has been boosted by greater PAR transmission through thinning ice and melt-ponds in the summer (Arrigo et al. 2008, p. 1; Arrigo et al. 2012, p. 1480; Boetius et al. 2013, p. 1432; Arrigo and van Dijken 2015, p. 60; Holding et al. 2015, p. 1079).

Phytoplankton blooms that occur near the ice edge comprise approximately 50 to 65% of the total primary production in Arctic waters (Coyle and Pinchuk 2002, p. 188; Bluhm and Gradinger 2008, p. S84) which sinks to the benthos, particularly when zooplankton populations are low. Recently blooms have been documented under the ice in the Chukchi Sea greater than 100 km into the ice pack (Arrigo et al. 2012, p. 1408). This finding suggests that productivity estimates based on open water sampling may be 10-fold too low (Arrigo et al. 2012, p. 1408).

Regions with the highest masses of benthic invertebrates occur in the northern Bering Sea southwest of St. Lawrence Island, Alaska (the St. Lawrence Island Polynya); in the central Gulf of Anadyr, Russia, north and south of the Bering Strait (the Chirikov Basin), especially in the southern Chukchi Sea (the Southeastern Chukchi Sea); at a few offshore sites in the East Siberian Sea; and in the northeast Chukchi Sea (Figure 3.3; Grebmeier and Dunton 2000, p. 61; Dunton et al. 2005, pp. 3468; Carmack et al. 2006, p. 165; Grebmeier et al. 2006a, pp. 346-351; Aydin and Mueter 2007, pp. 2505-2506; Bluhm and Gradinger 2008, p. S86; Grebmeier et al. 2015a, p. 92). Some of these benthic hotspots have been persistent over the last 40 years of sampling due to favorable ice conditions, primary productivity, sediment grain size, and bottom water temperatures (Grebmeier et al. 2015a, p. 92). Although the data are too spatially variable over the large scale of the Pacific Arctic region to estimate a trend in benthic mass (Grebmeier et al. 2015a, p. 94), focused regional studies do indicate a decline in benthic mass in the region just southwest of St Lawrence Island (Grebmeier 2012, pp. 67-69; Grebmeier et al. 2015a, p. 94) and in the southern Chukchi Sea (Grebmeier et al. 2015b, p. 117) that may impact upper trophic level benthivores such as Pacific walruses.

The difference in timing of ice melt may be important to benthic productivity and food stores, because when the phytoplankton bloom occurs later in the spring the surface water temperatures are warmer (Hunt and Stabeno 2002, p. 11). Warmer temperatures result in increased zooplankton growth rates, reduction in their time to maturity, and increased production rates (Coyle and Pinchuk 2002, p. 177; Hunt and Stabeno 2002, pp. 12-14). Consequently, when zooplankton populations are high, instead of the primary production being directly exported to the benthos, it becomes captured by pelagic food webs, which reduces the amount of primary production delivered to the benthos, which may eventually reduce the amount of prey available to Pacific walruses (Tynan and DeMaster 1997, p. 316; Carmack et al. 2006, p. 169; Grebmeier et al. 2006b, p. 1462). However, detritus from other carbon sources (e.g., pelagic organisms)

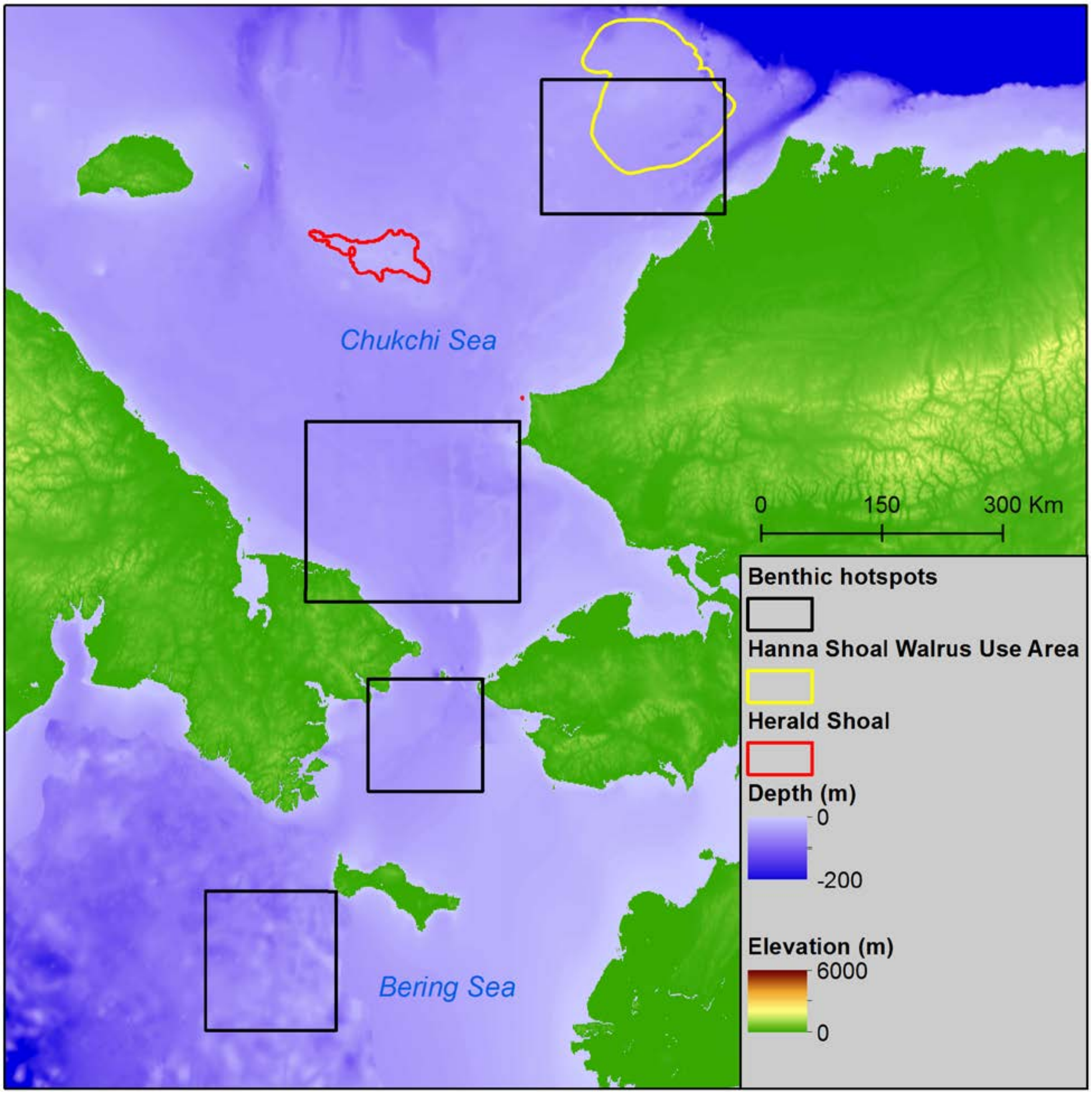


Figure 3.3. Location of four benthic productivity hotspots in the Bering and Chukchi seas as defined by Grebmeier et al. (2015a, p. 94) and the Hanna Shoal Pacific walrus Use Area as defined by USFWS (2013a, p. 35371). The Herald Shoal 40 m contour is also displayed. The benthic hotspots from south to north are the St. Lawrence Island Polynya, the Chirikov Basin, the Southern Chukchi Sea, and the Northeast Chukchi Sea.

also reaches the benthos and the potential disruption of the tight pelagic-benthic coupling in productivity due to changes in sea ice dynamics has yet to be documented in the Chukchi Sea (Strong et al. 2016, p. 88). There may be sufficient organic carbon stored in the sediments to act as a “food bank” to offset this disruption (Weems et al. 2012, p. 41) or the disruption may not be occurring (Holding et al. 2015, p. 1081). The physical and biological factors that result in areas of high benthic productivity in the Bering and Chukchi Seas are complex, interact in a variety of ways, and are site-specific (Arrigo and van Dijken 2015, p. 60; Grebmeier et al. 2015a, p. 109). Thus, the results of these changes are uncertain and both positive and negative effects have been observed or postulated (Grebmeier et al. 2015a, p. 109; Holding et al. 2015, p. 1081; Renaud et al. 2015, p. 247). Benthic productivity on the northern Bering Sea shelf had fluctuated 5-fold from 1988–2004 with less variable estimates from 1998–2004 (Grebmeier et al. 2006b, p. 1462). The data indicate an overall 2-fold decline in macrofaunal benthic mass (Grebmeier 2012, p. 71). Mass estimates were derived from sampling gear that cannot penetrate sediments to depths where many Pacific walrus prey species reside, and thus represent underestimates of benthic mass in this area (Jay et al. 2017, p. 389). However, comparisons among years may provide an unbiased estimate of trends.

Overall, the potential effect of the timing and increases in primary productivity in the Arctic Ocean on the benthos and Pacific walrus prey is uncertain and an area of continuing debate (Post et al. 2013, p. 520; Mathis et al. 2014, p. 227; Yamamoto-Kawai et al. 2016, p. 9). Observations of lower trophic productivity declines (Lee et al. 2007, p. 2231; Yun et al. 2014, p. 1; Grebmeier et al. 2015b, p. 117), increases (Arrigo et al. 2012, p. 1408; Arrigo and van Dijken 2015, p. 60) and both (Grebmeier et al. 2015a, p. 109) are indicative of a highly variable and uncertain environment.

3.1.6 Ocean Acidification

Since the beginning of the industrial revolution, the release of carbon dioxide (CO_2) from human activities (anthropogenic CO_2) has resulted in an increase in atmospheric CO_2 concentrations, from approximately 280 to over 400 parts per million (ppm) currently, with 30% of the increase occurring in the last three decades (NOAA 2016c).

Over the industrial era, the ocean has been a sink for anthropogenic CO_2, absorbing about one-third of the atmospheric CO_2 (Feely et al. 2004, p. 362; Canadell et al. 2007, pp. 18867-18868), and the Arctic Ocean alone may account for one-half of that (Mathis et al. 2014, p. 123). When CO_2 is absorbed by seawater, chemical reactions occur that reduce seawater pH and the concentration of carbonate ions, in a process known as ocean acidification (OA). The pH of ocean surface waters has already decreased by about 0.1 units since the beginning of the industrial revolution (Caldeira and Wickett 2003, p. 365; Orr et al. 2005, p. 681; NOAA 2016b).

The absorption of carbon dioxide by seawater reduces the concentration of carbonate ions, while decreasing saturation states of calcium carbonate minerals. Calcifying marine organisms, like clams, snails, crabs, and corals, require carbonate minerals, specifically aragonite, to form and maintain their shells and skeletons. As saturation states of aragonite decrease, these species may be at risk as it becomes more energetically costly for organisms to construct and maintain their shells and skeletons (Gazeau et al. 2007, p. 2-5; Fabry et al. 2008, p. 415; Talmage and Gobler 2009, p. 2076; Findlay et al. 2010, pp. 680-681; Waldbusser et al. 2015a, p. 275).

Due to their naturally low carbonate ion concentrations, the waters of the Arctic Ocean and adjacent seas are among the most vulnerable to ocean acidification (Qi et al. 2017, pp. 1, 2). In nature, there are two common biogenic calcium carbonate structures, aragonite and calcite. The aragonite mineral is less stable and more soluble in seawater than calcite. Aragonite undersaturation has already been observed to occur seasonally and locally (Orr et al. 2005, p. 683; Chierici and Fransson 2009, pp. 4972-4973; Steinacher et al. 2009, p. 522; Yamamoto-Kawai et al. 2016, p. 10). To date, aragonite saturation has decreased in the top 50 m in the Canadian Basin (Yamamoto-Kawai et al. 2009, p. 1099), and undersaturated waters have been documented on the Mackenzie shelf (Chierici and Fransson 2009, p. 4974), Chukchi Sea (Bates and Mathis 2009, p. 2441; Yamamoto-Kawai et al. 2016, p. 1), and Bering Sea (Fabry et al. 2009, p. 164). From 1994–2010 there was an increase in the extent of water that is undersaturated in aragonite to the north and 300 m depth in the western Arctic Ocean starting near the shelf edge (≈71.5^{o} N) of the northern Chukchi Sea, but areas sampled to the south remained saturated during that period (Qi et al. 2017, pp. 1, 2).

Throughout the Arctic, the loss of sea ice (causing greater ocean surface to be exposed to the atmosphere), the retreat of the ice edge past the continental shelf break that favors upwelling, increased river runoff, and increased sea-ice and glacial melt are additional forces that are currently occurring that decrease aragonite saturation (Bates and Mathis 2009, pp. 2446, 2449-2450; Yamamoto-Kawai et al. 2009, pp. 1099-1100; Mathis et al. 2015, p. 126). However, large temporal and spatial variability could potentially reduce impacts on calcifying organisms (Mathis et al. 2015, p. 131; Yamamoto-Kawai et al. 2016, p. 10). Therefore, we found that the weight of evidence suggests that aragonite saturation state has likely declined to corrosive levels (< 1, which can result in shell erosion and structural changes) in the Bering and Chukchi Seas but the extent and duration of the decline is spatially and temporally variable.

3.1.6.1 General Effects of Ocean Acidification on Calcifying Organisms

Because acid-base balance is critical for all organisms, changes in carbon dioxide concentrations and pH can affect reproduction, larval development, growth, behavior, and survival of marine organisms (Green et al. 1998, p. 23; Kurihara and Shirayama 2004, pp.163-165; Berge et al. 2006, p. 685; Fabry et al. 2008, pp. 420-422; Kurihara 2008, pp. 277-282; Pörtner 2008, pp. 209-211; Ellis et al. 2009, pp. 44-45; Talmage and Gobler 2009, p. 2076; Findlay et al. 2010, pp. 680-681; Kroeker et al. 2010, p. 1419; Kroeker et al. 2013, p. 1; Kroeker et al. 2016, p. 771). Pörtner (2008, p. 211) suggested that heavily calcified marine groups may be among those with the poorest capacity to regulate acid-base status. Although some animals have been shown to be able to form a shell in undersaturated conditions, it comes at an energetic cost which may translate to reduced growth rates (Talmage and Gobler 2009, p. 2075; Findlay et al. 2010, p. 679; Gazeau et al. 2010, p. 2938; Waldbusser et al. 2015a, p. 273), muscle wastage (Pörtner 2008, p.

210), or potentially reduced reproductive output. If aragonite undersaturation inhibits planktonic larval bivalves from constructing shells (Kurihara 2008, p. 277; Waldbusser et al. 2015a, p. 273) or inhibits them from settling (Hunt and Scheibling 1997, pp. 274; Green et al. 1998, p. 26; Green et al. 2004, p. 730; Kurihara 2008, p. 278), the increased mortality would likely have a negative effect on bivalve populations.

Since 2011 when the last Status Review for Pacific walrus was completed, there has been an exponential increase in the publication of ocean acidification research on calcifying organisms (Appendix E). There are three strongly correlated constituents of the OA process: (1) increased partial pressure of CO_2 in seawater (pCO_2), (2) a decline in pH, and (3) a decline in calcium carbonates ($CaCO_3$) saturation state. Most studies measure or manipulate only one of these components of seawater when assessing the effects of OA, but as Waldbusser et al. (2015a, p. 273; 2015b, p. 1) noted these sea water constituents may affect different physiological processes in different ways, which may account for some conflicting results among some studies.

Four meta-analyses of OA research on calcifying organisms have been conducted to date (Hendriks et al. 2010, p. 157; Kroeker et al. 2010, p. 1419; Harvey et al. 2013, p. 1016; Kroeker et al. 2013, p. 1884). Kroeker et al. (2013, p. 1884) conducted the most comprehensive meta-analysis to date, examining 288 papers. Their conclusions were: (1) when the broad range of marine organisms is pooled together, results reveal decreased survival, calcification, growth, development and abundance in response to acidification, however, the magnitude of these responses varies among taxonomic groups, (2) there was an enhanced sensitivity of mollusk larvae, but it is not universal across all taxonomic groups, (3) the variability in species' responses is enhanced when they are exposed to acidification in multi-species assemblages, (4) other factors, such as nutritional status or source population cause substantial variation in organisms' responses, and (5) there was a trend towards enhanced sensitivity to acidification when taxa are concurrently exposed to elevated temperatures.

While a number of organisms appear to be able to adapt over the long-term or are resistant to declining pH levels (Lohbeck et al. 2012, p. 346; Parker et al. 2012, p. 92; Jin et al. 2013, p. 1; Pespeni et al. 2013, p. 1; Schluter et al. 2014, p. 1024; Kroeker et al. 2016, p. 777; Ramajo et al. 2016, p. 19374; Ventura et al. 2016, p. 23728), this often comes at the expense of other processes such as growth or reproduction (Gazeau et al. 2010, p. 2060; Small et al. 2010, p. 11; Winans and Purcell 2010, p. 39; Fitzer et al. 2014, p. 6218). A detailed discussion of the effects of OA on bivalves, gastropods, and polychaetes can be found in Appendix E.

3.1.6.2 Effects of Ocean Acidification on Pacific Walruses

It is unlikely that OA will directly affect Pacific walruses, but may result in change to their prey base. However, studies of invertebrates and fish show that OA can alter sensory abilities and behavior, affecting feeding (Clements et al. 2016, p. 2) and antipredator defenses (Simpson et al.

2011, p. 917; Ferrari et al. 2012, p. 553; Pistevos et al. 2015, p. 1), but similar behavioral studies on marine mammals are lacking.

In general, most OA studies indicate that the early life stages of bivalves and gastropods, particularly broadcast spawners with an extended pelagic larval phase, are likely to be negatively impacted by OA. However, individuals and populations that are periodically exposed to acidified conditions either daily or seasonally (e.g., tidal habitats, areas of upwelling, deep sea habitats, and high latitude areas) may be more tolerant. In addition, increased primary productivity may give some species the extra energy needed to balance the costs of compensating for altered acid-base metabolism, shell formation, and shell protection/repair.

Aragonite saturation state of seawater is important to bivalve larval shell development, growth, and survival (Waldbusser et al. 2015b, p. 1). Seasonally low aragonite saturation has been documented in areas occupied by Pacific walruses (Bates and Mathis 2009, p. 2441; Fabry et al. 2009, p. 164; Mathis et al. 2015, p. 125; Yamamoto-Kawai et al. 2016, p. 1) and may have occurred in the Chukchi Sea prior to the industrial revolution (Yamamoto-Kawai et al. 2016, p. 9). Therefore, while we have found that the weight of evidence indicates that Pacific walrus prey has likely been negatively impacted by OA, the taxa affected, magnitude, and spatial extent of that affect is uncertain.

3.2 Coastal Habitats

3.2.1 Use of Bristol Bay Haulouts

Coastal haulouts in Bristol Bay, and along the Bering Sea coast of Russia, are used almost exclusively by male Pacific walruses (see Figure 2.4). In recent years, haulout use in Bristol Bay has changed in terms of temporal patterns of occupancy (decline in duration and shift in dates), number of animals (declined), and specific haulouts occupied (Collins and Winfree 2015, pp. 10-12; Lowe 2015, pp. 1-2; Weiss 2015, pp. 3-4; Appendix C; Fischbach et al. 2016, p. 1; Walsh et al. 2016, p. 7) and Russia has also reported declines in recent years (Robards and Garlich-Miller 2013, p. 59). However, because these haulouts are dominated by male Pacific walruses, and the demographic group that has the largest effect on Pacific walrus population dynamics (i.e. females and dependent young) follows the retreat of the pack ice into the Chukchi Sea, we focus our analyses on Chukchi Sea coastal haulout use.

3.2.2 Use of Chukchi Sea Haulouts

Pacific walruses congregate in large numbers at coastal haulouts on Wrangel Island and other sites along the northern coast of the Chukotka Peninsula during the ice-free season (Robards and Garlich-Miller 2013, p. 59). In the 1950s-1970s, these haulouts typically persisted from September through October but more recently these haulouts have been occupied from August through December (Robards and Garlich-Miller 2013, p. 59). Numerous haulouts sites are currently being used, with Cape Schmidt, Cape Vankarem, Cape Onmyn, and Cape Serdtse-

Kamen’ receiving the most use (Fischbach et al. 2016). In Alaska, Pacific walruses have hauled out at Icy Cape, the barrier islands near the community of Point Lay, and at Cape Lisburne (Figure 2.4). The barrier island near Point Lay has seen consistent use by large numbers of Pacific walruses since 2010 from as early as mid-August to early-October when ice becomes unavailable.

The northern most haulouts are typically occupied first, with Pacific walruses moving to southern haulouts as sea ice begins to form again, and the fall migration begins (Fischbach et al. 2016). Large haulouts have also been reported intermittently in the Bering Strait Region (Big Diomede, King Island, St Lawrence Island, and the Punuk Islands) in late fall and early winter, prior to the onset of ice formation (Fay and Kelly 1980, p. 1; Fischbach et al. 2016). As sea ice expands southward in the winter, Pacific walruses move with it to winter breeding areas in the Bering Sea.

3.2.3 Haulout Mortalities

One consequence of large aggregations of females and young animals at coastal haulouts is the potential for mortalities and injuries associated with trampling events due to disturbances. Pacific walruses often flee land and ice haulouts in response to disturbances from a variety of sources (e.g., hunters, airplanes, ships, predators, etc; Fay et al. 1984a, pp. 114-118; Kochnev 2004, p. 286) but the impact of disturbances is more pronounced when occupying coastal haulouts (Fischbach et al. 2009, inclusive; Garlich-Miller et al. 2011a, p. 29). When Pacific walruses are disturbed on ice floes, they can escape into the water easily because animals are less concentrated in a single area (i.e., the respective ice floe). In comparison, aggregations of Pacific walruses on land are often very large in number, densely packed, and layered several animals deep (Nikiforov et al. 2007, p. 2; Monson et al. 2013, p. 6). Consequently, the probability of direct mortality or injury due to trampling during stampedes is greater at coastal haulouts than it is on pack ice (USFWS 1994, p. 12).

Disturbance-related mortalities at all male haulouts are less common (Fay and Kelly 1980, p. 244; Kochnev 2004, p. 285) likely due to their large size and smaller discrepancies in size among the animals. However, the situation at haulouts dominated by females and dependent young is different as the smaller size of calves and juveniles makes them more susceptible to trampling injuries and mortalities (Fay and Kelly 1980, pp. 226, 244).

Disturbance frequency and sources are likely greater at coastal haulouts than in pack ice habitats, because the level of human and other activity is greater along the coast. For example, hunting activity at coastal haulouts is of concern as it increases the probability of stampede caused injuries or mortalities (Kochnev 2004, p. 285). These concerns prompted the Eskimo Walrus Commission (EWC) to adopt a non-binding resolution in 2008 (EWC 2008, p. 1) advising hunters to avoid hunting at haulouts along the Chukchi Sea coast and to use extreme caution if they choose to hunt at a haulout. Another concern is an increase in nearby air and vessel traffic (Appendix C).

Interactions between polar bears, grizzly bears, and other carnivores (wolverines, wolves) and Pacific walruses at haulouts could increase Pacific walrus mortalities due to predation attempts resulting in stampedes, the direct takes of smaller animals, increased energy expenditure, increased stress levels, and haulout abandonment (Garlich-Miller et al. 2011a, p. 9; Jay et al. 2011, p. 1072; MacCracken and Benter 2016, p. 558).

A few large mortality events at coastal haulouts have been documented in the past (Fay 1982, p. 226). For example, Fay and Kelly (1980, p. 230) examined several hundred Pacific walrus carcasses on St. Lawrence Island and the Punuk Islands in the fall of 1978. Approximately 15% of those carcasses were aborted fetuses, 24% were calves, and the others were older animals (mostly females) ranging in age from 1–37 years old. The principal cause of death was trampling, possibly from disturbance-related stampedes (Fay and Kelly 1980, p. 230).

Large mortality events also occurred at coastal haulouts in 2007 along the coast of Chukotka, Russia. Coastal aggregations that year ranged in size from 4,500 to 40,000 animals (Ovsyanikov et al. 2007, inclusive; Kochnev 2008, inclusive). Hunters from the Russian coastal villages of Vankarem and Ryrkaipii reported more than 1,000 Pacific walrus carcasses (mostly calves and aborted fetuses) at coastal haulouts (Nikiforov et al. 2007, p. 1; Kochnev 2008, pp. 17-20). Approximately 1,500 Pacific walrus carcasses (predominately adult females) were also reported near Cape Dezhnev in late October (Kochnev 2008, pp. 17-20). Russian investigators estimate that between 1,000–10,000 animals died along the Chukotka coastline during the summer and fall of 2007, primarily from trampling associated with disturbance events (Kochnev 2010). On the selected haulouts that have been monitored, mortalities due to disturbance have moderated in Russia since 2007 (Table 3.1).

Remnant ice in 2008 and 2012 reduced Pacific walrus use of coastal haulouts and in 2009–2015 haulout management programs in Russia and the U.S. reduced the number of mortalities range wide (Garlich-Miller et al. 2011b, p. 10; Kochnev 2012).

Udevitz et al. (2013, p. 291) modeled the effects of calf mortalities at haulouts on the Pacific walrus population by recreating the results of the model of Fay et al. (1997, p. 539) and then projecting the population trend based on a range of assumptions about the future harvest of adult females and calf mortalities. They found that mortalities of calves at coastal haulouts had a greater effect on population trajectory than equivalent increases in the harvest of adult females.

Table 3.1. Minimum estimates of Chukchi Sea coastal haulout mortalities in the United States and Russian Federation from 2007–2016.

Year	United States[a]	Russia[a]
2007	100–200	1039–3200
2008	0[b]	165
2009	133–200	453
2010	100–200	680
2011	100–200	376
2012	0[b]	5–15[c]
2013	16	305
2014	50–60	589
2015	50–70	No data
2016	6[b]	No data

[a] Estimated numbers should be considered minimums as systematic surveys were not conducted to determine true haulout mortality rates. Furthermore, not all haulouts are monitored across their range and haulout related mortalities have likely been missed. Therefore, these numbers represent an underestimate of the true number of animals that die at coastal haulouts each year.
[b] No large haulouts were observed in the United States.
[c] Haulouts were sparsely attended by Pacific walruses in Russia and no disturbance related mortalities were observed. The 5-15 mortalities in 2012 were likely due to normal herd interactions.

In summary, we found that large mortality events from trampling have occurred at coastal haulouts as recently as 2007. Large, sustained calf mortality events in combination with a large harvest of adult females would likely have significant population-level effects (Udevitz et al. 2013, p. 296). Importantly, while haulout mortality numbers in Table 3.1 are a minimum estimate of the total number of mortalities, the trend suggests that management programs in the U.S. and Russia have been effective at reducing disturbances and haulout related mortalities in recent years. However, in spite of these efforts, it is likely that mortalities among younger animals at coastal haulouts will always occur where large aggregations form on land and the number of mortalities is likely a function of the duration of time spent hauled out.

3.3 Harvest

For thousands of years, Pacific walrus hunting has been an important component of the economy and culture of Native communities along the Bering and Chukchi Sea coasts (Ray 1975, p. 10). In addition, commercial hunting of Pacific walruses by whalers began in the 19th century and following the decline in whaling persisted in Russia until 1990 (Fay 1957, p. 437; Bockstoce and Botkin 1982, p. 183; Garlich-Miller et al. 2011a, pp. 40, 41). Harvest resrictions in the 1960s led to a population increase and higher harvests in the 1970s and 1980s when restrictions in the U.S. were ended.

3.3.1 History of Harvest

In the 19th century Pacific walruses were killed in large numbers for tusks, hides, and oil that could be sold or traded on the world market (Fay 1982, p. 241). Scammon (1874, p. 181) reported that from 1868 to 1872 a minimum of 60,000 Pacific walruses were taken in conjunction with the Bering Sea whale fishery (Drew et al. 2016, p. 4). In response to the large commercial harvests in the late 1800s the population was soon depleted, declining to an estimated 80,000 animals by 1880 (Fay 1957, p. 435) and Pacific walrus harvests associated with the whaling dropped dramatically in the 1890s (Bockstoce and Botkin 1982, p. 183). Fay (1957, p. 437) estimated annual harvest levels of 5,000–7,000 animals from all sources occurred during the period 1910 to 1950. In the 1960s, in an effort to accelerate recovery of the population, the State of Alaska restricted the harvest of female Pacific walruses to five to seven per hunter per year while continuing to allow for an unlimited harvest of males. Concurrently, the USSR also implemented harvest restrictions and a prohibition on shooting animals in the water to reduce lost animals (Fay et al. 1989b, p. 4). The quotas of the 1960s markedly reduced harvest levels and the composition of the harvest shifted (Fay et al. 1989b, p. 1; Garlich-Miller et al. 2006, p. 880). Total harvest removals (i.e., combined commercial and subsistence harvest in the U.S. and Russia) in the 1960s and 1970s averaged 5,500 Pacific walruses per year.

In 1972, with enactment of the MMPA, Pacific walruses became federally protected and the hunting of Pacific walruses for other than handicraft or subsistence purposes by Alaska Natives was generally prohibited. In 1975, responding to a petition by the State of Alaska, the USFWS returned management authority of Pacific walruses to the State of Alaska. However, in July 1979, the State of Alaska terminated its Pacific walrus management activities, and the USFWS issued an emergency rule suspending all taking of Pacific walrus, other than the non-wasteful taking by Alaska native hunters for purposes of subsistence or the creation and selling of handicrafts (44 FR 45565). The 1980s saw an increase in harvest, with total annual removal averaging approximately 11,000 Pacific walruses per year (Garlich-Miller et al. 2011a, p. 41; USFWS 2011, p. 7638). The increased harvest rate in this decade may reflect several factors including the absence of a harvest quota (USFWS 1994, p. 2), commercial harvest in Russia, and increased availability of Pacific walruses (Fay and Kelly 1989, p. 1; Fay et al. 1997, p. 558). The high harvests in the 1980s likely contributed to the population decline at that time (section 2.4.1). Harvest levels in the 1990s were about half those of the previous decade, averaging approximately 6,000 Pacific walruses per year. This was followed by a further decline in harvest from 2000–2014 with an average harvest of less than 5,000 Pacific walruses per year (USFWS 2016f).

3.3.2 Harvest Patterns

In 2010–2014, the U.S. accounted for approximately 56% of the total harvest of Pacific walruses while Russia accounted for the other 44% (Figure 3.4). The U.S. harvest is approximately 59% males over this time period; the sex composition of the Russian harvest is unknown. Current

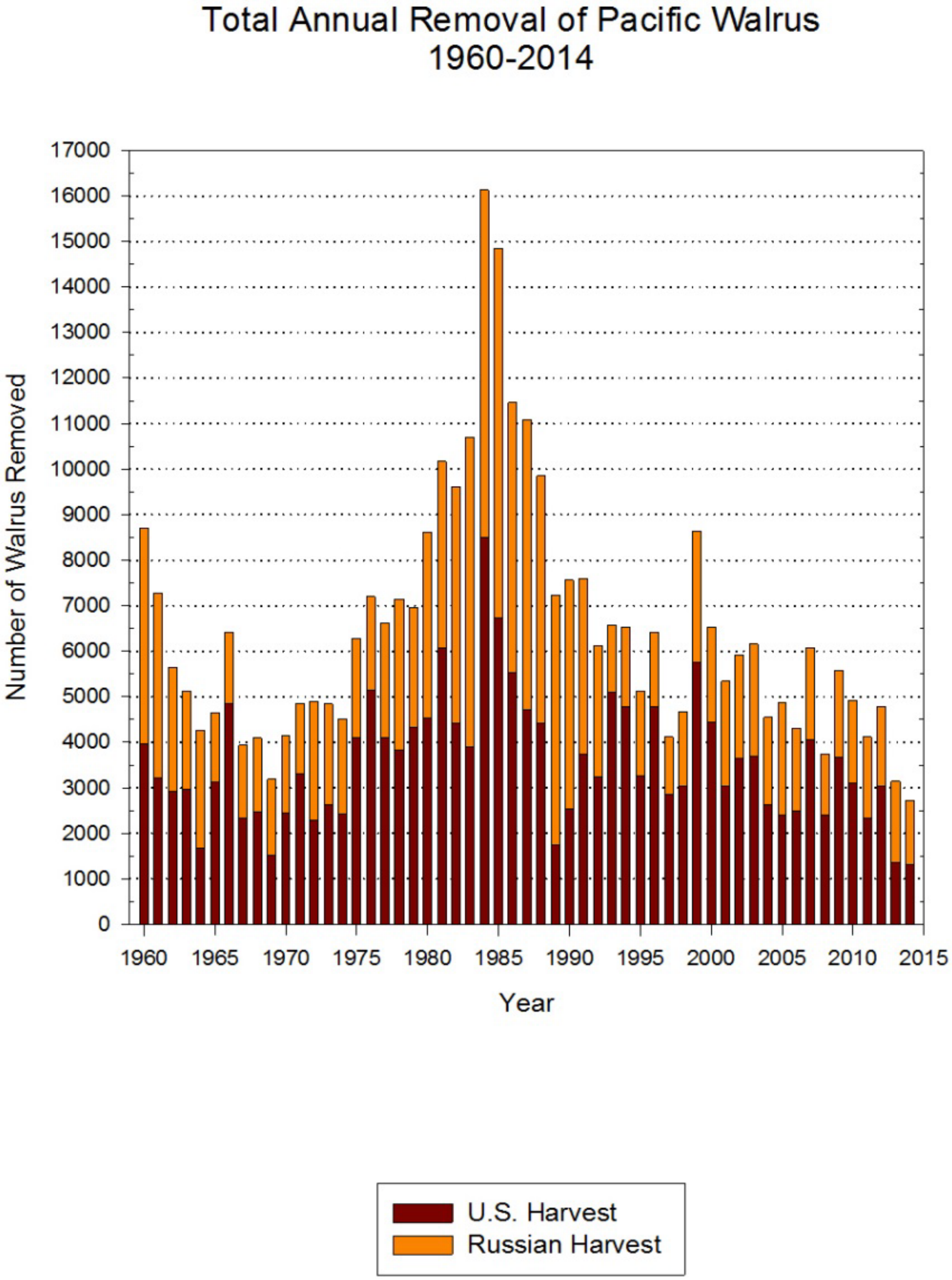


Figure 3.4. Total annual removal estimates of Pacific walruses by subsistence hunters in the United States and the RF from 1960–2014. Estimates include a struck and lost factor of 42% and correction for reporting bias (number of animals harvested vs. number reported) for the United States harvest**.**

harvest practices in both countries primarily involve targeting Pacific walruses hauled out on sea-ice using small skiffs, but some hunting also occurs at coastal haulouts in the fall, primarily in Chukotka, Russia.

Although subsistence Pacific walrus hunting in Alaska is carried out in coastal communities stretching from Bristol Bay to Point Barrow, the bulk of the harvest occurs in the Bering Strait region. Between 2010 and 2014, the average reported annual harvest from St. Lawrence Island (Gambell and Savoonga) was 821 Pacific walruses; accounting for approximately 84 % of the reported U.S. harvest.

3.3.3 Harvest Sustainability

The lack of empirical information on population size and vital rates makes it difficult to accurately quantify sustainable removal levels for the Pacific walrus population (Garlich-Miller et al. 2011a, p. 59). Recent (2010–2014) annual harvest removals in the U.S. and Russia have ranged from 2,723 to 4,927 Pacific walruses per year (Figure 3.5). Using the Speckman et al. (2011, p. 515) estimate of a minimum population size of 129,000 Pacific walruses, this level of harvest would represent a harvest rate of 2.1–3.6% during this period (USFWS 2016f) and based on a population estimate of 280,000 (Beatty 2017, p. 3) the harvest rate would range from 0.9–1.8%.

Chivers (1999, p. 239) modeled Pacific walrus population dynamics and estimated the maximum net productivity rate (R_{max}) for the Pacific walrus population at 8% per year. Wade (1998, p. 21) notes that one half of R_{max} (4 % for Pacific walruses) is a conservative potential biological removal (PBR) level for marine mammal populations, as it provides a reserve for population growth or recovery. Given that the rates presented above are below the 4% provided by Wade (1998, pp. 5, 6), and that the 2006 population estimate used in the calculation has a known negative bias, we conclude that the current Pacific walrus harvest levels are sustainable.

The changes in sea ice dynamics over the last decade have directly influenced the spring Pacific walrus hunt (Brinkman et al. 2016, p. 1; Appendix C). The period of time that Pacific walruses are within range of Gambell and Savoonga hunters has declined due to a more rapid migration of Pacific walruses to the north because of the rapid retreat of ice (EWC 2003, pp. 21, 28, 35, 42, 59; Oozeva et al. 2004, p. 196; Appendix C). In addition, poor weather (high winds and rough seas) during that window has limited the number of days that hunters can hunt (EWC 2003, pp. 21, 28, 35, 42, 59; MacCracken 2012, p. 2079; Huntington et al. 2013a, p. 315; Appendix C). Overall, harvests have been declining since 1990 (Figure 3.5). Hovelsrud (2008, p. S135) predicted that changes in sea ice dynamics would limit the success of subsistence hunters and reduce the harvest of marine mammals in the Arctic. The last several years of Pacific walrus harvest numbers support this prediction.

In addition, The Native Villages of Gambell and Savoonga on St. Lawrence Island formed Marine Mammal Advisory Committees (MMAC) in 2010 which established and implemented local ordinances limiting the harvest to four or five Pacific walruses per hunting trip. Pacific walruses that are struck and lost, as well as calves, do not count against this limit and there is no limit on the total number of trips. The effect of these ordinances on the total harvest is dependent on the total number of hunting trips and it is rare for hunting Captains and crew to make more than two trips in a day (USFWS 2016e). However, there is no overall limit on the number of Pacific walruses that can be taken.

Hunting ordinances were implemented in 2010 in Gambell and Savoonga, providing a mechanism for self-regulation of the harvest. Monitoring indicates that the ordinances have a high compliance rate (Table 3.2). The existing harvest reporting and monitoring programs provide reliable information on harvest levels, trends, and composition.

Table 3.2. Estimates for the compliance of Pacific walrus hunters with the hunting trip limits adopted by the Marine Mammal Advisory Committees of the Native Villages of Gambell and Savoonga.

	Gambell		Savoonga		
Year and program	Number of trips	Number of violations	Number of trips	Number of violations	Percent compliance
2010	110	2	115	27	87
2011	88	0	67	10	94
2012					
WHMP	218	4	61	10	95
TM	212	0	68	2	99
2013					
WHMP	133	0	83	0	100
TM	113	0	76	0	100
2014	87	0	150	4	98
2015	33	0	67	11	89
2016	111	3	90	4	97

[a] in 2010, 2011, 2014–2016 compliance data was collected only by the Pacific walrus harvest monitoring program (WHMP). In 2012 and 2013 compliance data was collected by both the WHMP and local tribal monitors (TM).

3.4 Disease and Parasites

3.4.1 Infectious Disease

During our review of the literature, we found limited information describing the prevalence, exposure pathways, and risks of infectious diseases to Pacific walruses. Based on serological testing of harvested animals, researchers reported previous exposure of Pacific walruses to several viral pathogens including Caliciviruses (Smith et al. 1983, p. 86; Fay et al. 1984a, p. 140; Barlough et al. 1986, p. 166), Brucella (Quakenbush 2014, pp. 2-3), Leptospirosis (Calle et al. 2002, p. 96; Quakenbush 2014, pp. 2-3), seal herpes virus (Quakenbush 2014, pp. 2-3) and Influenza A (Calle et al. 2002, pp. 95-96). Although these pathogens likely affect some individual Pacific walruses, none are likely to have resulted in significant or population-level mortality; in fact, infections may be enzootic, i.e. a disease that regularly affects animals in a particular district or during a particular season. However, Pacific walruses may be at risk to outbreaks of some epizootic diseases, i.e. a disease that is temporarily prevalent and widespread in an animal population. For example, Atlantic walruses have antibodies to phocine distemper virus and other morbilliviruses, yet Pacific walruses appear to be immunologically naïve to these viral pathogens (Duignan et al. 1994, p. 90). We found inconclusive evidence that infectious diseases may impact portions of the Pacific walrus population. In August 2011, members of the community of Point Lay reported several Pacific walrus carcasses with unusual skin lesions at a nearby haulout site (Garlich-Miller et al. 2011b, p. 2). Of the carcasses examined (n = 28), 50% of them had ulcerated skin legions of unknown origin and 75% of them were calves and sub-adult animals that also had signs of trampling-related injuries. In addition, elevated numbers of ringed seal (*Phoca hispida*) carcasses with unusual skin lesions were reported across northern Alaska during summer 2011; most affected seals had signs of ulcerative dermatitis (skin lesions) and delayed or interrupted molt with patchy alopecia (hair loss). Both species were included in a multi-species Unusual Mortality Event investigation. Despite extensive analytical testing of tissue samples, the pathological agent(s) affecting Pacific walruses and ringed seals was never identified. Although no Pacific walrus cases were reported from Russia during the course of the investigation, photographs of moribund calves taken at Russian haulouts in the 1990s appear to have similar lesions to those documented at the Point Lay haulout in 2011. The pathological agent(s) contributing to the event remain unknown, but it does not appear to be a significant and regular source of mortality of Pacific walruses.

3.4.2 Parasites

Pacific walruses host a variety of parasites that can affect both individuals and populations. Although effects can be severe, most tend to be mild and localized (Fay 1982, p. 228; Dubey et al. 2003, p. 275). For example, the ectoparasite *Antarctophthirus trichchi* is an anopluran (sucking) louse that lives in the skin folds of Pacific walruses (Fay 1982, p. 228), causing external itching, but no serious health issues (Fay 1982, p. 228). Endoparasites, protozoa, and helminthes (microorganisms and parasitic worms) also are known to parasitize Pacific walruses, although their impacts on Pacific walrus health are less understood. Of the 17 species of helminthes known to parasitize Pacific walruses, two species are endemic (Fay 1982, p. 228; Rausch 2005, p. 134): The cestode *Diphyllobothrium fayi,* found only in the small intestine, and the nematode *Anisakis rosmari*, found only in stomachs (Heptner et al. 1976, p. 52).

Other parasites known to infect Pacific walruses do so at low rates and therefore are not having a population-level effect. Only 6% of Pacific walruses (3 of 53) tested positive for *Toxoplasma* *gondii*, an intracellular parasite that causes encephalitis and internal lesions in other marine mammals (Dubey et al. 2003, pp. 276-281). In the same study, Dubey et al. (2003, p. 281) reported that 6% of Pacific walruses (3 of 53) hosted *Neospora caninum*, a protozoan parasite with unknown health implications to infected Pacific walruses. In addition, only 0–1.5% of Pacific walruses were found to host *Trichinella spiralis nativa* (Bukina and Kolevatova 2007, p. 14; Seymour et al. 2014, p. 941), a parasitic roundworm that does not appear to cause any ill effects in Pacific walruses, but is of particular concern to some subsistence hunters because of possible effects to humans (Rausch et al. 2007, p. 1249). Thus, although these parasites infect individual Pacific walruses at low rates demonstrating a history of exposure, we found no evidence that they have had a population-level impact; and we are not aware of any large Pacific walrus mortality events attributed to parasite infection.

3.5 Predation

Owing to their large size and use of tusks for defense, Pacific walruses have few predators. Their principal non-human predators are polar bears (*Ursus maritimus*) and killer whales (*Orcinus orca*), both of which typically prey on Pacific walruses opportunistically and focus on younger animals rather than adults. Other possible predators include brown bears (*U. arctos*) while Pacific walruses are on land and sharks (unidentified species), which recently were identified by Alaska Native hunters as a potential new predator of Pacific walruses (Appendix C).

Estimating rates of predation is challenging for several reasons including difficulty in discerning proximate and ultimate causes of mortality. For example, a Pacific walrus may have been more vulnerable to predation because it was unhealthy or wounded previously; or, presence of a predator near a haulout site could instigate a stampede event, which may result in injury and death of some Pacific walruses. We are not aware of any studies that quantified predation rates or assessed impacts to the Pacific walrus population. Here, we summarize information on observed or suspected predation of Pacific walruses by polar bears and killer whales; currently, we are not aware of similar predation events by brown bears or sharks.

3.5.1 Polar Bears

Direct predation of Pacific walruses by polar bears is likely increasing although the evidence is circumstantial. Polar bears have shifted their habitat-use patterns in response to changing sea ice conditions and access to food resources, including Pacific walruses (Kochnev 2006, p. 1). As the ice-free months in summer/fall increase, increasing numbers of polar bears are spending longer periods of time on land (Rode et al. 2015, p. 138). For example, in the 1990s, polar bears arrived onshore at Wrangel Island in fall and early winter with numbers peaking at about 50 animals in late October. More recently, large numbers of polar bears (up to 500–600) have begun to arrive in August, about one month before Pacific walruses, which now represent an important food resource for polar bears in fall and early winter (Kochnev 2002, p. 137; Ovsyanikov and

Menyushina 2007, p. 1; Ovsyanikov 2012, p. 144). Based on these observations alone, it is difficult to determine whether or not overall predation rates of Pacific walruses by polar bears have increased. Nonetheless, the information is suggestive of a behavioral change in polar bears that may have direct effects on individual Pacific walruses but population-level effects remain uncertain.

In addition to direct predation, indirect effects of polar bear predation on Pacific walruses also may be increasing. More frequent interactions with Pacific walruses on land based haulouts likely increases the number of mortality events. However, the number of mortalities from these events is unknown and unpredictable. Garlich Miller et al. (2011a, p. 66) postulated that the presence of polar bears along the coast during ice-free months may be influencing selection and patterns of Pacific walrus haulout use. Because polar bears are discouraged from entering coastal villages for human safety reasons, Pacific walruses may select for haulout sites near villages (e.g., Point Lay) as opposed to more remote sites (e.g., Icy Cape) to reduce the possibility of disturbance from polar bears. Fischbach et al. (2009, pp. 1, 4) speculated that a polar bear (or other large predator) may have caused a stampede of about 3,000 Pacific walruses at Icy Cape, resulting in 131 Pacific walrus carcasses on the beach that were consumed partially by polar bears. Although indirect effects of polar bear predation on Pacific walruses have likely increased with increasing ice-free months, we are unable to assess the magnitude of potential impacts to the Pacific walrus population with these anecdotal observations.

3.5.2 Killer Whales

Killer whales are not able to penetrate far into the ice pack and therefore, sea-ice habitat provides Pacific walruses with some protection from killer whales. Nonetheless, killer whales have been observed preying on both young and adult Pacific walruses (Fay 1982, pp. 216-220; Fay and Stoker 1982, p. 2; Appendix C). Based on examination of 67 Pacific walrus carcasses washed ashore at various times, researchers reported that 13–33% of them had injuries consistent with killer whale predation (Fay and Kelly 1980, p. 235; Fay 1982, p. 220). However, these data and the inferences we can draw from them are severely limited, especially because it is unclear whether or not these Pacific walruses actually died from killer whale predation. Thus, although killer whales occasionally pursue and kill Pacific walruses, we found no evidence to suggest that killer whale predation has had population-level effects to date.

Breed et al. (2017, p. 1) found that the presence of killer whales modified narwhal (*Monodon monoceros*) habitat use and behavior in the Eastern Canadian Arctic which has also seen a rise in killer whale occurrence as sea ice has declined. However, there is no evidence that a similar situation exists between Pacific walruses and killer whales at the current time period.

3.6 Contaminants and Biotoxins

Compared to other Arctic marine mammals, Pacific walruses have relatively low levels of contaminants (Robards et al. 2009, p. 1; Quakenbush et al. 2016, p. 2). The potential impact of contaminants to the health and fitness of individual Pacific walruses, however, is poorly known. To date, most contaminant studies of Pacific walruses are based on limited and periodic screening of tissues obtained from hunters or opportunistically. Importantly, few of these studies identified thresholds where negative effects to Pacific walruses are realized, making it difficult to assess potential population-level impacts of contaminants. Here, we summarize the best available information on contaminants in Pacific walruses and, when possible, relate this information to other Arctic marine mammals.

3.6.1. Persistent Organic Pollutants

Persistent organic pollutants (POP), including polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDT), chlordanes, toxaphene, Lidane, and mirex, are of particular concern for marine mammals in the Arctic. First, these pollutants are prevalent in the Arctic because they do not break down easily and they can be transported readily to the Arctic via food webs and atmospheric circulation. Second, POPs tend to bioaccumulate and therefore are of greatest concern for species feeding at higher trophic levels such as marine mammals, including Pacific walruses. Further, POPs have been linked to increased risks of cancer, immunotoxicity, endocrine disruption, and neurotoxicity (Egeland et al. 1998, pp. 87-117).

Concentrations of POPs vary regionally across the Arctic as well as among marine mammal species. They tend to be higher in eastern Canada, Greenland, Svalbard (Norway), Russia, and northern Europe compared to Alaska, presumably reflecting differences in atmospheric transportation patterns (Muir et al. 1995, p. 335). For example, Quakenbush et al. (2016, pp. 1-8) found that concentrations of organochlorine compounds in Pacific walrus and seal blubber sampled from subsistence-harvested animals in Alaska were lower than values reported for Arctic Canada. Moreover, Pacific walruses have lower POP concentrations than other Arctic marine mammal species (Born et al. 1981, p. 255; Seagars and Garlich-Miller 2001, p. 129; Kucklick et al. 2006, pp. 851, 852; Robards et al. 2009, p. 1; Quakenbush et al. 2016, p. 3). Some Atlantic walruses have higher concentrations of POPs than Pacific walruses likely due to feeding on pelagic fish and ringed seals, which are higher on the trophic scale than most Pacific walrus prey (Muir et al. 1995, p. 335; Dietz et al. 2000, p. 221).

3.6.2 Heavy Metals

Most studies aimed at quantifying heavy metal concentrations in Pacific walruses have been conducted with tissues of subsistence-harvested animals. These studies have been focused primarily on mercury, cadmium, arsenic, and lead because they are non-essential elements that can be toxic in elevated concentrations. Some of these elements have multiple forms of varying toxicity. For example, mercury can be methylated (bound to CH_3^-) by micro-organisms in the marine environment and concentrated in fish and marine mammal tissues up the food chain; methylmercury is the most toxic form of mercury.

Prolonged exposure to high concentrations of mercury has been linked with neurological and developmental disorders in humans (Egeland et al. 1998, pp. 87-117). Quakenbush et al. (2016, pp. 20-22) recently found elevated concentrations of methylmercury in liver, kidney, and muscle tissue of Pacific walruses, although levels were lower than other subsistence-harvested marine mammals in Alaska and Arctic Canada (Quakenbush et al. 2016, pp. 1-8). We found no information describing potential health effects of mercury exposure (all forms) on Pacific walruses; however, marine mammals are thought to have some capacity to demethylate mercury into inorganic compounds (Nigro and Leonzio 1996, p. 137), which would inherently reduce any potential toxicological effects on Pacific walruses.

Cadmium accumulates in tissues, particularly kidneys, over the lifetime of an animal and chronic exposure can lead to kidney damage. In the 1980s and 1990s, researchers reported elevated concentrations of cadmium in liver and kidneys of Pacific walruses (Taylor et al. 1989, p. 465; Warburton and Seagars 1993, p. 4; Seagars et al. 1994; Egeland et al. 1998, p. 67; Quakenbush et al. 2016, pp. 20-24), but no evidence of pathological effects (Lipscomb 1995, p. 39). The sources of cadmium in Pacific walruses are unknown, but are likely of natural origin (Miles and Hills 1994, p. 458). Marine animals may possess detoxification mechanisms for some naturally occurring metals, having evolved in the ion-rich ocean environment (Dietz et al. 1998, p. 221). Thus, cadmium concentrations that may be toxic to freshwater or terrestrial organisms may not have the same magnitude of effect in marine organisms such as Pacific walrus.

3.6.3 Radionuclides

Potential sources of radioactive contaminants in the Bering and Chukchi Seas include atmospheric fallout associated with nuclear weapons testing programs in the mid-1900s, point source releases from contaminated nuclear waste sites, and atmospheric and marine releases associated with nuclear power plant accidents (e.g., Chernobyl in the Russian Federation in 1985 and Fukushima Daiichi in Japan in 2011). There are few studies concerning radionuclide exposures in Pacific walruses or other sympatric species in the Bering and Chukchi Seas. Hamilton et al. (2008, p. 1158) reported that concentrations of Cesium-137 in sampled tissues of Pacific walruses and bearded seal (*Erignathus barbatus*) from the Bering Sea were significantly lower than values reported for marine mammals in other parts of the Arctic. More recently, several ringed seal samples were analyzed for radioactivity as a potential causal factor in a 2011 Unusual Mortality Event (UME) that caused patchy alopecia and ulcerative dermatitis in ringed seals and Pacific walruses in Alaska. Results suggest that radionuclide concentrations in tested samples were too low to cause the observed symptoms (Dasher et al. 2014, p. 1). The underlying cause of the UME remains unknown. Although radiation associated with the 2011 Fukushima Daiichi power plant release remains an issue of concern in many coastal communities across Alaska, testing programs for fish, shellfish, and other organisms across the State have consistently reported little to no exposure to radionuclide contaminants (ADEC 2016a; Ruedig et al. 2016, p. 1).

3.6.4 Biotoxins

Biotoxins associated with harmful algal blooms can cause significant illness and mortality in some marine mammals and are an emerging concern in Alaskan waters (Burek et al. 2008, p. S130). Two of the most common toxins reported in the North Pacific Ocean are the neurotoxins domoic acid and saxitoxin. Domoic acid has caused significant illness and mortality in some marine mammal species along the western coast of the United States, but has not yet been reported to impact marine mammals in Alaskan waters.

Lefebvre et al. (2016, p. 21) found detectable concentrations of domoic acid and saxitoxin in 13 marine mammal species (including Pacific walruses) sampled in Alaskan waters indicating that harmful algal blooms are occurring in the seasonally ice-covered habitats of the Pacific walrus. Stomach contents from Pacific walruses sampled near St. Lawrence Island in the Bering Sea had the highest concentrations of domoic acid and saxitoxin of any marine mammal species examined in the study (Lefebvre et al. 2016, p. 13). Although domoic acid values in Pacific walruses were similar to those detected in California sea lions (*Zalophus californianus*) suffering from domoic acid toxicosis, subsistence Pacific walrus hunters collecting the samples did not report any abnormal behavior in any of the sampled animals (Lefebvre et al. 2016, p. 21).

In summary, based on the best available information, Pacific walruses likely have low levels of exposure to contaminants as evidenced by their comparatively low concentrations relative to other Arctic marine mammal species (Robards 2006, p. 1). Although Pacific walruses have had elevated concentrations of some heavy metals such as mercury and cadmium, researchers did not report any correlated pathological effects in Pacific walruses (e.g., Lipscomb 1995, p. 39). Similarly, Pacific walruses tested positive for domoic acid and saxitoxin, two of the most common harmful algal bloom toxins in Alaska, yet it is unlikely that toxicological effects to individual Pacific walruses have occurred (e.g., Lefebvre et al. 2016, p. 21). Thus, we conclude that pollution and contaminants are unlikely to be affecting Pacific walruses at the individual or population level at the current time.

3.7 Oil and Gas Exploration, Development, and Production

The oil and gas economy, challenging Arctic environment, technical limitations, as well as legal and political circumstances influence oil and gas activities in the Beaufort and Chukchi seas. The National Petroleum Council (2015, p. 6) indicates that the pace of offshore oil and gas activities is typically slow in "frontier" regions such as the Beaufort and Chukchi seas. Oil and gas-related activities have been conducted in the Beaufort and Chukchi seas since the late 1960s, with most activity occurring in the Beaufort Sea (USFWS 2008, p. 33212) where Pacific walruses do not regularly occur. In the Chukchi Sea, exploration and lease sales occurred in the late 1980s through the early 1990s, and more recently in 2008 with Lease Sale 193 (MMS 2008, p. 1). To date, numerous seismic surveys have been conducted and several exploratory wells were drilled in the Chukchi Sea, but no development activities have occurred. Leases under Sale 193 expired in 2016 and future offshore leasing in the Arctic was canceled in late 2016.

In the Chukotka Russia region, the oil and gas industry has targeted regions of the western Bering and Chukchi Seas for exploration. In 2006, seismic exploration was conducted in the Russian Chukchi Sea (Frantzen 2007, p. 1). In addition, in 2012, ExxonMobil and Rosneft (a Russian company) announced a joint venture to explore several large areas around Wrangel Island and Herald Shoal as well as in the Kara and Laptev seas (Rosneft 2013) with an eye toward developing a large liquefied natural gas (LNG) project. Most of Rosneft's activities in 2014 were in the Kara and Barents seas and near Sakhalin Island. Rosneft's plans for 2015 included preparation for offshore drilling in 2016 in the Murmansk and Magadan fields (Rosneft 2015). Some of these plans have proceeded with the greatest activity in Russia occurring in the Pechora Sea. These areas are not within the range of the Pacific walrus. It appears that Russian activities in the Chukchi Sea have also been suspended (Maritime Executive 2016).

3.7.1 Effects of Oil and Gas Activities on Pacific walruses

Exposure to and effects of oil and gas activities varies across the range of the Pacific walrus. Few Pacific walruses occur in the Beaufort Sea, although individuals and small groups are observed there periodically. As a result, impacts to the Pacific walrus population appear to have been minimal in this region (USFWS 2013a, p. 35393). In contrast, exploratory operations in the Chukchi Sea have routinely encountered Pacific walruses although potential impacts to Pacific walruses that result from these encounters are likely reduced through regulations under the MMPA. In a detailed analysis of the effects of exploration activities, including noise, physical obstructions, human encounters, and oil spills, the USFWS concluded that exploration activities, over a five year period, would be sufficiently limited in time and space and would result in the non-lethal take of only small numbers of Pacific walruses with no more than a negligible impact on the population (USFWS 2013a, p. 35364).

Monitoring conducted pursuant to MMPA incidental take authorizations has documented minimal effects of various exploration activities on Pacific walruses (USFWS 2013a, p. 35392). In 1989 and 1990, aerial surveys and vessel-based observations of Pacific walruses on the surface were carried out to examine the animals' response to drilling operations at three Chukchi Sea prospects, documenting several thousand Pacific walruses in the vicinity of the drilling operations. The monitoring reports concluded that: (1) Pacific walrus distributions were closely linked with pack ice; (2) pack ice was only near active drilling operations for short time periods; and (3) ice passing near active operations contained few animals. The effects of the drilling operations on Pacific walruses were limited in time, area, and proportion of the population (USFWS 2013a, p. 35381, 35382). More recently, Shell drilled two wells in the Chukchi Sea in 2015 in the Burger Prospect. Protected Species Observers on support vessels or drill rigs associated with those activities recorded 500 groups comprised of a total of 1,397 Pacific walruses. Fifty-two percent of sightings were of small groups in the water and the balance of individuals was on ice. Approximately 50% of the animals seen had no observable reaction to the vessels (Ireland and Bisson 2016, p. xiv), similar to observations made since 2008 (USFWS 2013a, p. 35370), and the majority of others exhibited only mild reactions such as alert postures and swimming away at a normal speed.

Disturbances caused by vessel and air traffic may cause Pacific walrus groups to flee ice or land haulouts, increasing the risk of stampedes. However, Pacific walruses in the water or on ice appear to be tolerant of ship traffic associated with oil and gas activities, based on short-term observations from vessels. Brueggeman et al. (1991, p. 139) reported that 75% of Pacific walruses within 1 km of vessels in the Chukchi Sea exhibited no reaction. This conclusion was also reached by Fay et al. (1984a, p. 118), which reported observations that Pacific walruses in water generally show little concern about potential disturbance from approaching vessels but will dive or swim away if a vessel is nearing them. The consequences of Pacific walruses moving away from vessels are unknown.

Open-water seismic exploration, which produces underwater sounds typically with air gun arrays, may potentially affect Pacific walruses. The effects of seismic surveys on Pacific walruses hearing and communications have not been studied in detail; however, studies of pinnipeds have been used to set seismic survey mitigation measures for Pacific walruses (USFWS 2013a, p. 35381). Seismic surveys could result in Pacific walruses avoiding areas of activity, masking Pacific walrus communications, changes in Pacific walrus' calling behavior, and permanent or temporary shifts in threshold hearing levels (Delarue et al. 2012, p. 109; Hermannsen et al. 2015, p. 1). Using acoustic monitors placed throughout the Chukchi Sea near active seismic exploration areas, Delarue et al. (2012, pp. 109-110) found that as air gun pressure levels increased, the detectability of underwater vocalizations by Pacific walruses decreased and at 140 dB were no longer detectable. The lack of Pacific walrus call detections at that level could have been due to Pacific walruses leaving the area, the masking of Pacific walrus vocalizations by the air gun noise, and changes in calling behavior by Pacific walruses. The possible consequences of masking and reduced vocalizations could include separation of herd members or mother-calf pairs (Delarue et al. 2012, pp. 110).

Seismic surveys will likely not affect vocalizations associated with breeding activity (one of the most important times for communication), because seismic surveys are not currently occurring in or near Pacific walrus winter breeding aggregations in the U.S. Bering Sea. In addition, Executive Order 13689 created the Northern Bering Sea Climate Resilience Area that prohibits oil and gas leasing and includes the major breeding areas in Alaska. There is no information available on Russian activities in the Gulf of Anadyr.

Injury from seismic surveys likely would occur only if animals entered the zone immediately surrounding the sound source (Southall et al. 2007, p. 441) or were in the area when surveys started if ramp-up procedures (gradually increasing decibel levels) are not implemented. Pacific walrus behavioral responses to vessels associated with seismic surveys were monitored in the

Chukchi Sea offshore continental shelf in 2006–2012. Based upon the transitory nature of the survey vessels, and the behavioral reactions of the animals to the passage of the vessels, interactions likely resulted in temporary changes in animal behavior with no lasting impacts to the subspecies (Ireland et al. 2009, pp. xiii-xvi; USFWS 2013a, p. 35392).

Incidental take regulations (ITRs) have been promulgated for oil and gas exploration activities in the Chukchi Sea beginning in 1991, current regulations cover a 5-year period ending in June 2018 (USFWS 2013a, p. 35364). Prior to commencing activities, operators currently are required by BOEM to obtain letters of authorization (LOA) pursuant to the ITRs or an incidental harassment authorization (IHA). If operators commence operations without such authorization, their operations may be shut down, and any incidental take of Pacific walruses would be in violation of the MMPA. As part of the ITR and LOA permitting process, industry has collected data on the response of Pacific walruses to seismic surveys in the Chukchi Sea from 2006 to 2012 and exploratory drilling in 2012 and 2015. Sixty-six percent of the animals observed from 2006–2012 (2015 data not yet analyzed) showed no reaction to the vessels and 10% either undertook mild avoidance behaviors or vigorously fled (USFWS 2013a, p. 35393). The rest of the animals either looked at the vessels or moved toward them. During the 2012 Shell drilling operation at the Burger A prospect, which included a drill ship and several support vessels, some of which were involved in ice management (scouting, deflecting, and breaking small floes) there were 385 encounters of Pacific walrus groups, involving 8,068 animals. Sixty-three percent of individuals exhibited no reaction to the operations, while again 10% exhibited avoidance or flight behavior. These data indicate that <10% of Pacific walruses that encounter oil and gas operations exhibit avoidance behaviors and that by extrapolation, the impacts of industry activities on Pacific walruses to date have been negligible in terms of the impact to reproduction and survival at the individual and population levels (USFWS 2013a, p. 35393).

A large oil spill could result in acute mortalities as well as chronic exposure that could substantially reduce the Pacific walrus population for many years (Garlich-Miller et al. 2011a, pp. 94-97). In addition a spill could affect benthic communities on which Pacific walruses depend. Arctic drilling regulations developed by BOEM in 2016 (BOEM 2016, pp. 46478-46566) featured a number of new provisions such as redundancy in the bottom blowout preventers, a capping system in place on the well pipe at the ocean surface, an on-site relief well drilling vessel, and on-site containment equipment and tankers. In addition, Alaska Clean Seas, an industry funded oil spill response and clean-up organization has equipment and personnel stationed at Prudhoe Bay and are tasked with responding to incidents in the Chukchi Sea. Furthermore, the Alaska Department of Environmental Conservation has spill response equipment stationed in Kotzebue, AK (ADEC 2016b). Nonetheless, the likely responsible parties and government agencies are not well prepared to deal with an oil spill in the Arctic (O'Rourke 2013, inclusive; NRC 2014, pp. 5-8).

In summary, oil and gas activities have occurred sporadically throughout the range of the Pacific walrus, although exposure of Pacific walruses to these activities varies greatly in both space and time. Exposure has been greatest in the Chukchi Sea during the summer/fall, as there is little overlap between Pacific walruses and oil and gas activities in the Beaufort Sea where most exploration and production occurs. Monitoring of the effects of exploratory activities has documented minimal effects on Pacific walruses – namely, no response or temporary behavioral changes. Exploration activities are conducted following minimization and mitigation measures provided under the MMPA, and a LOA or an IHA is required in order to obtain authorization for the incidental take of Pacific walruses during exploration activities. These authorizations are only issued for the non-lethal, incidental take of Pacific walruses, where the activities are considered likely to only affect small numbers of Pacific walruses with a negligible impact on the population. Similar to contaminants, oil and gas exploration activities are a major concern of some subsistence hunters (Gadamus and Raymond-Yakoubian 2015b, p. 93; Gadamus et al. 2015, p. 120; Appendix C). While exploration in the recent past is thought to have contributed to the redistribution of some Pacific walruses and affected hunting opportunities (Appendix C), based on the available information, we conclude that oil and gas exploration likely had minor impacts on individual Pacific walruses, and does not appear to have had a negative impact on the Pacific walrus population.

3.8 Commercial Fisheries

Commercial fisheries occur primarily in ice-free waters during the open-water season, limiting the overlap between fishery operations and Pacific walruses. In areas where overlap does occur, fisheries may impact Pacific walruses through interactions that result in the incidental take (collisions, entanglements, and disturbance while resting, foraging, or travelling) of Pacific walruses through competition for prey resources or modification of benthic habitats. Each year the National Marine Fisheries Service (NMFS) publishes a List of Fisheries (LOF) which classifies U.S. commercial fisheries that occur in federal waters according to the level of interactions that result in incidental mortality or serious injury of marine mammals (NOAA 2016a, pp. 20562-20566). Although approximately 24 listed fisheries occur within the range of the Pacific walrus only one, the Alaska Bering Sea, Aleutian Islands flatfish trawl fishery is identified as having interactions with Pacific walruses (NOAA 2016a, p. 20563).

The mean number of observed mortalities associated with the flatfish trawl was one Pacific walrus per year, ranging from 0–3 (USFWS 2013b, p. 14). Short of mortality, no injuries to Pacific walruses from commercial fishing were recorded for the same time frame. State-managed near-shore herring and salmon gillnet fisheries also have the potential to take Pacific walruses. However, ADFG personnel that manage the fisheries do not believe that gear interactions with Pacific walruses have occurred in the recent past (Murphy 2010; Sands 2010).

Fisheries occurring near coastal haulouts in the Bristol Bay region of the Bering Sea likely have the greatest potential for causing disturbance due to their overlap with large haulouts. Fishery vessels and spotter planes may disturb Pacific walruses at haulouts resulting in trampling injuries and haulout abandonment. To help mitigate this potential, we have developed and distributed guidelines for appropriate use of aircraft within the vicinity of Bristol Bay Pacific walrus haulouts (USFWS 2009, p. 1), and have worked with the ADFG to minimize Pacific walrus-fishery interactions. However, these guidelines are not codified into regulation, and we have no mechanism to access compliance.

Commercial fisheries also may impact Pacific walruses indirectly through depletion of prey resources through by-catch or destruction of benthic prey habitat. These potential impacts to Pacific walruses are a concern of subsistence hunters in Bristol Bay and the Bering Strait (Gadamus 2013, p. 93; Gadamus et al. 2015, p. 122; Appendix C).

Non-pelagic trawl fisheries have the potential to indirectly affect Pacific walruses by destroying or modifying benthic prey, prey habitat, or both (Mecum 2009, p. 57). Numerous studies on the effects of trawl gear on benthic infauna have been conducted, and all note a reduction in overall abundance (Brylinsky et al. 1994, p. 650; Bergman and van Santbrink 2000, p. 1321; McConnaughey et al. 2000, p. 1054; Kenchington et al. 2001, p. 1043). Two such studies comparing macrofaunal populations between unfished and heavily fished areas in the eastern Bering Sea reported that overall, the heavily-trawled and untrawled areas were significantly different (McConnaughey et al. 2000, p. 1385). In relation to Pacific walrus prey, the abundance of neptunid snails was significantly lower in the heavily trawled area and mean body size was smaller, as was the trend for a number of bivalves (*Macoma*, *Serripes*, *Tellina*) (McConnaughey et al. 2000, p. 1385; McConnaughey et al. 2005, p. 430). The abundance of *Mactromeris* was greater in the heavily trawled area but mean body size was smaller (McConnaughey et al. 2000, p. 1386; McConnaughey et al. 2005, p. 430). The final environmental impact statement for Essential Fish Habitat Identification and Conservation in Alaska (NMFS 2005, p. ES10) concluded that nonpelagic trawling in the southern Bering Sea has long-term effects on benthic habitat features. It should be noted that these studies were conducted prior to the required modifications to non-pelagic trawl gear in 2010.

Wilson and Evans (2009a, p. 14) reported on the bycatch of Pacific walrus prey items in the non-pelagic trawl fishery in the Northern Bristol Bay Trawl Area. Data was collected through the NMFS Fisheries Observer program and is aggregated for the years 2001 to 2008. Bivalves (mussels, oysters, scallops, and clams) accounted for 99 kg of the 430 kg (23%) of total bycatch reported. It should be noted that snails which are consumed by Pacific walruses were listed as a bycatch species, but the amount is listed as confidential under National Oceanic and Atmospheric Administration (NOAA) confidentiality guidelines. Net mesh size is large enough to allow mollusks and other infauna to escape, but it is believed that bycatch of these species is extremely low because the footrope and bobbins dislodge few of them from the bottom sediments (Rose 2010).

Recently, McConnaughey and Syrjala (2014, p. 2469) conducted a more rigorous study with the modified trawl gear and reported mixed results with 15 of 24 taxa declining in mass, and nine increasing. Of potential Pacific walrus prey that was captured, two taxa increased and two declined following the trawl, however, none of these changes were statistically significant (*P* = 0.11-0.87; McConnaughey and Syrjala 2014, p. 2477). In addition, a major storm event occurred in the area during the study which had a greater overall impact on the benthos (-22%) than the commercial trawls (-14%) (McConnaughey and Syrjala 2014, p. 2477). We did not find data indicating direct competition for prey from commercial fisheries to be problematic for Pacific walruses.

Further, although commercial fisheries using non-pelagic trawl gear have the greatest potential for impact on the benthos, they have limited spatial or temporal overlap within the range of the Pacific walrus. The management plan for groundfish in the Bering Sea and Aleutian Islands management area states that non-pelagic (bottom) trawl gear used for flatfish species in the Bering Sea subarea must be modified to reduce the potential impacts of non-pelagic trawl gear on bottom habitat (NOAA 2010, p. 31). Bristol Bay is covered by a near shore trawl closure which prohibits non-pelagic trawling with the exception of a small area known as the Nearshore Bristol Bay Trawl Area which is open to fishing from April 1 to June 15 each year (Wilson and Evans 2009b, pp. 7, 8). Although Jay and Hills (2005, p. 199) did not specifically analyze telemetry data in relation to areas open or closed to non-pelagic trawling, their data suggests that Pacific walruses were using foraging areas both within and outside non-pelagic trawl closure areas. The remainder of the Bering Sea not covered by the numerous trawl closures receives directed pelagic and non-pelagic trawl effort throughout ice free season for several species of federally managed fish.

Pelagic (mid-water trawl) fisheries also have the potential to indirectly affect Pacific walruses through destruction or modification of benthic prey or their habitat. The NMFS estimated that approximately 44% of the sea floor below trawl gear is contacted by the footrope (NMFS 2005, pp. B-11). The majority of the pelagic trawl effort in the eastern Bering Sea is directed at walleye pollock in waters of 50–300 m (Olsen 2009, p. 1), although Pacific cod are also taken through a trawl fishery over continental shelf waters. However, the majority of pelagic trawl effort occurs on the periphery of Pacific walrus-preferred habitat, as Pacific walruses are usually found over the continental shelf in waters of 100 m or less (Fay and Burns 1988, pp. 239-240; Jay et al. 2001, p. 621).

In summary, commercial fisheries have limited spatial overlap with Pacific walruses due to the various southern Bering Sea conservations areas, the Northern Bering Sea Research Area, and all U.S. waters of the Chukchi being closed to commercial trawling, and reported direct takes are nominal (Garlich-Miller et al. 2011a, p. 80). We found that the effects of commercial fisheries on Pacific walruses are limited, with some site-specific effects on Pacific walruses near coastal haulouts in Bristol Bay. Prey and benthic habitats of Pacific walruses are likely affected by trawling activities, but the effects are limited in space with little overlap of Pacific walruses and fishing areas. Additionally, the five Arctic nations have banned commercial fisheries in Arctic waters for the next several years. However, commercial fishing remains a serious concern among Alaskan Natives who hunt Pacific walruses (Gadamus et al. 2015, p. 122; Appendix C). Based on the limited fishing-related impacts to Pacific walruses that have occurred to date, and the active engagement of the North Pacific Fisheries Management Council (NPFMC) and State of Alaska to consider and mitigate Pacific walrus-fishery impacts, we conclude that commercial fishing currently has few impacts on individuals and is unlikely to be having a negative impact on the Pacific walrus population.

3.9 Ship and Air Traffic

3.9.1 Shipping

Commercial shipping and marine transportation vessels include oil and gas tankers, container ships, cargo ships, cruise ships, research vessels, icebreakers, and commercial fishing vessels. These vessels may travel to or from destinations within the Arctic (destination traffic), or may use the Arctic as a passageway between the Atlantic and Pacific Oceans (non-destination traffic). At the present time, most shipping within the range of the Pacific walrus population is destinational in nature. There is little to no shipping traffic occurring during the winter and spring seasons and traffic levels during the summer/fall season are relatively modest due to persistent sea ice cover.

The level of non-destinational (trans-arctic) shipping activity presents the greatest potential for increased shipping and marine transportation within the range of the Pacific walrus population (Laughlin et al. 2012, p. 12; Huntington et al. 2015, p. 120; Hansen et al. 2016, pp. 10-14). Two major trans-artic shipping lanes intersect the range of the Pacific walrus. The Northern Sea Route (NSR) runs from the Atlantic Ocean to the Bering Strait, parallel to the northern Russian coast. The Northwest Passage (NWP) runs from the Atlantic Ocean through the Canadian Arctic Archipelago and parallel to the Alaskan coast to the Bering Strait (Figure 3.5). Shipping levels in the NSR and NWP are both currently limited by the seasonal extent of sea-ice cover. Most shipping activity through the Chukchi Sea occurs from June through November (Marine Exchange of Alaska 2015, pp. 8-13; Eguíluz et al. 2016, p. 3). There was a 17-fold increase in the number of ships using the NSR from 2010 (4) to 2013 (71), but use declined in both 2014 (31) and 2015 (18) (Lavelle 2013, p. 1) (Figure 3.6).

The Marine Exchange of Alaska has recently begun compiling automatic identification system (AIS) data of ship traffic through the Bering Strait (Figure 3.7). There was a spike in transits through the Strait in 2015 mostly comprised of destinational trips associated with bulk carriers

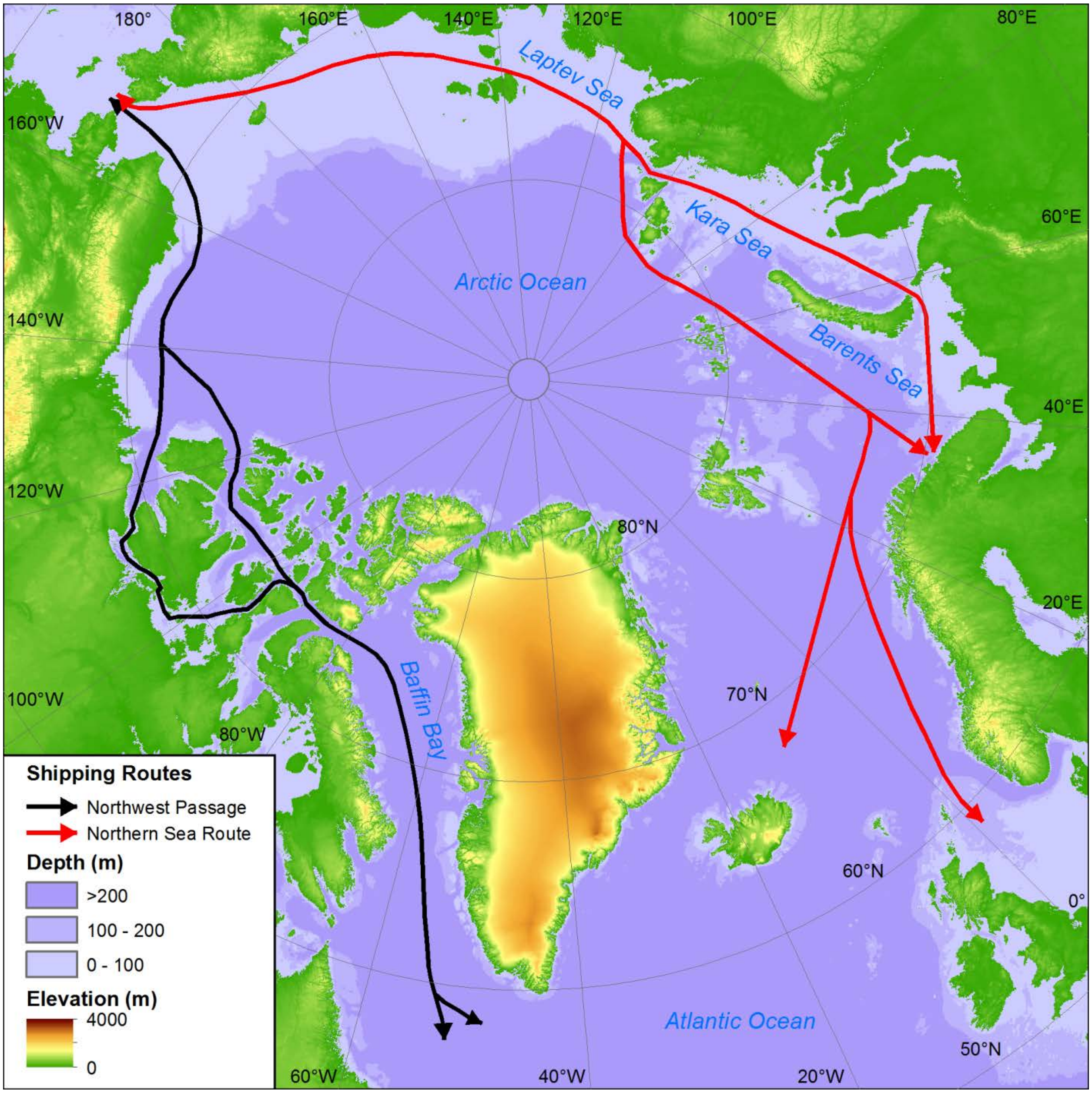


Figure 3.5. Map of the locations and variations of the Northwest Passage and Northern Sea Route.

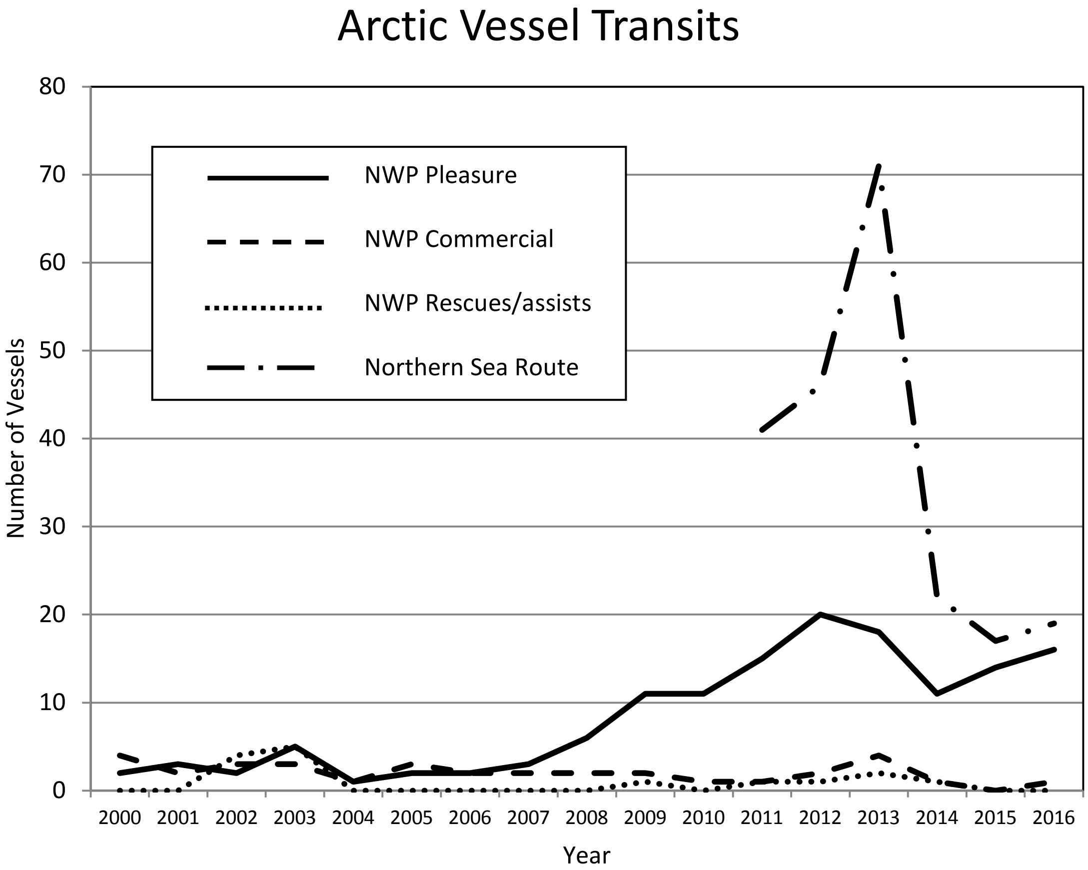


Figure 3.6. Number of pleasure and commercial vessels and number of vessels rescued or assisted along the Northwest Passage (NWP; Headland 2016, inclusive) from 2000–2016 as well as total transits of the Northern Sea Route (http://www.arctic-lio.com/nsr_transits) from 2010–2016.

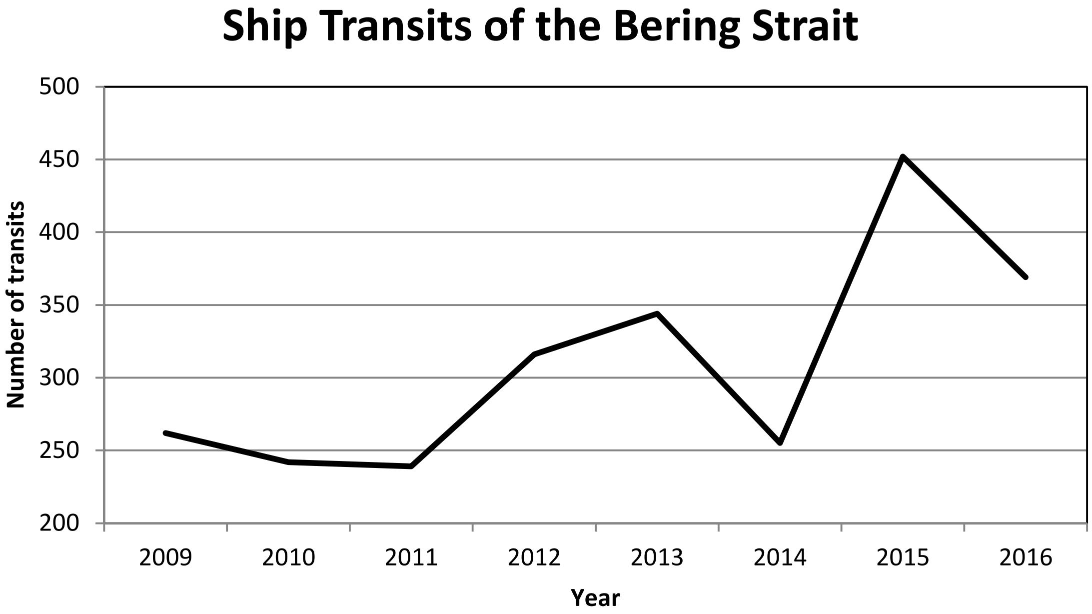


Figure 3.7. Number of ship transits through the Bering Strait from 2009–2016 as documented by the Marine Exchange of Alaska (2015, p. 1); preliminary data for 2016 provided by the Marine Exchange of Alaska.

servicing the Red Dog mine, general Russian cargo, and tug boats associated with decommissioning Shell drilling operations (Marine Exchange of Alaska 2015, pp. 2, 3). However, AIS coverage has also increased during this same time and likely accounts for some of the observed increase in transits.

3.9.1.1 Effects of Shipping on Pacific walruses

Shipping in the Bering and Chukchi seas has the potential to impact Pacific walruses, particularly during the spring and summer/fall seasons. Increases in shipping result in increased potential for disturbance in the water, on ice, and at coastal haulouts. According to Garlich-Miller et al. (2011a, p. 97), recent trends in sea ice suggest that most of the Pacific walrus population will need to forage in open water from coastal haulouts along the Alaska and Chukotka coast during the ice-free shipping season. The NSR and NWP parallel the Chukotka and Alaska coasts, respectively. Thus, it is likely that ships will encounter Pacific walruses along these routes (Garlich-Miller et al. 2011a, p. 97). Several studies found that Pacific walruses in water generally show little concern toward approaching vessels, unless the ship comes in close proximity to them, in which case they generally dive or swim away (Fay et al. 1984a, p. 118; Brueggeman et al. 1991, p. 139; USFWS 2013a, p. 35392). However, Alaska

Native hunters are very concerned about the observed increase in ship traffic over the last several years and have suggested that Pacific walruses have been displaced from traditional feeding areas and migration routes due to disturbance from ships (Garlich-Miller 2012, p. 22; Gadamus et al. 2015, p. 121; Appendix C). This may have resulted in an increase in the effort needed by Alaska Native hunters to reach Pacific walruses (Garlich-Miller 2012, p. 11; Gadamus 2013, p. 4; Raymond-Yakoubian et al. 2014a, p. 42; Appendix C).

Another potential impact from increased shipping is increased noise, including from ice breaking activities. Icebreaking activities can create noise that causes marine mammals to avoid areas where these activities are occurring. Increased noise may also result in masking of Pacific walrus underwater calls (Delarue et al. 2012, p. 21). As previously stated, the possible consequences of masking and reduced vocalizations could include separation of herd members or mother-calf pairs (Delarue et al. 2012, p. 110). However, Pacific walrus underwater vocalizations can only be detected within a few kilometers and their gregarious nature presumably precludes the need to communicate over long distances (Mouy et al. 2012, p. 1350). Thus, the masking of Pacific walrus calls by ship noises would only occur in close proximity and would be short-lived, likely not posing a problem for herd cohesion or mother-calf communications.

Icebreaking activities may also increase the risk of oil spills by increasing vessel traffic in ice-filled waters. Given that marine mammals, including Pacific walruses, concentrate in and around temporary breaks in the ice created by icebreakers, there may be greater environmental impact associated with an oil spill involving an icebreaker or a vessel operating in a channel cleared by an icebreaker (Garlich-Miller et al. 2011a, p. 90). To date, there have been relatively few oil spills caused by vessels in the Bering and Chukchi seas. Within the range of Pacific walruses, nine vessel oil spill incidents were reported from 1995–2015 (USFWS 2016d). These incidents were small in scale and did not cause widespread impacts to Pacific walruses or their habitat. Currently, icebreakers are used along the NSR and within the NWP to clear passageways utilized by commercial shipping vessels (Arctic Council 2009, p. 74), primarily in the summer months. For example, several ice hardened vessels and icebreakers traversed the NSR and NWP since 2013. The U.S. does not currently engage in icebreaking activities for navigational purposes in the Arctic (NRC 2005, p. 16). However, in the last few years, oil and gas exploration activities in the Beaufort and Chukchi seas have used privately contracted icebreakers in support of their operations. In general, these icebreaking activities are better described as ice management as solid pack ice was not broken to clear a path for other vessels to follow. Ice management involves scouting for ice and deflecting or breaking floes that could intercept an active drill rig (Brueggeman et al. 1990, pp. 1-6; Brueggeman et al. 1991, pp. 2-7; USFWS 2013a, p. 35394; Ireland and Bisson 2016, pp. 2-8). Although limited ice management has been conducted in recent years as a part of Shell’s exploration activities (Ireland and Bisson 2016, pp. 2-5), icebreaking and ice management have not been regular or common activities in this area.

The available information suggests that shipping and associated stressors occurring within the range of the Pacific walrus population are currently limited in intensity and extent, but have increased since 2010. Based on our review, we conclude that shipping currently has minor impacts on individual Pacific walruses and does not appear to be having a negative impact on the Pacific walrus population.

3.9.2 Air Traffic

Aircraft have the potential to disturb Pacific walruses and alter their behavior, particularly when they are using coastal haulouts. Hunters have observed Pacific walruses reacting to helicopters from more than a mile away (Garlich-Miller 2012, p. 11). Due to this potential disturbance, the USFWS and ADFG have developed guidelines for pilots that specify altitudes and distance buffers when near Pacific walruses (USFWS 2016a).

The potential effects of prolonged or repeated disturbance from aircraft include displacement from preferred feeding areas, increased stress levels, increased energy expenditure, masking of communication, and the impairment of thermoregulation of neonates that are forced to spend too much time in the water (Garlich-Miller et al. 2011a, p. 69). In addition, disturbance generated stampedes can result in injury and death of smaller animals (Garlich-Miller et al. 2011a, p. 5) which can have population-level effects (Udevitz et al. 2013, p. 291). However, disturbances from air traffic are relatively infrequent, and do not have population-level effects at this time. Although air traffic near coastal haulouts is largely unregulated, outreach programs by the Federal Aviation Administration and USFWS have been underway for many years.

3.10 Existing Regulatory Protections

The following is a brief description of the important laws and regulations that protect Pacific walruses and their habitats. For more details see Garlich-Miller et al. (2011a, pp. 54-62). There is a diverse network of international and domestic laws and regulations that provide conservation benefits and protections to the Pacific walrus population. In the U.S., key protections to Pacific walruses and other marine mammals are provided by the MMPA, which prohibits the unauthorized take of marine mammals in U.S. waters. Specific protections to Pacific walruses on terrestrial haulouts in the U.S. are provided through protected status for some areas, notably the haulouts on Togiak NWR, Round Island State Game Refuge, and specific prohibitions of harassment contained within the MMPA. Russian haulouts also have a variety of protections, with some haulouts occurring on protected lands and others protected by local conservation organizations. Pacific walrus harvests in Russia are managed for sustainability that includes an annual quota. Harvest in the U. S. is well monitored and limited to subsistence activities by Alaska Native hunters with restrictions on use and sale. The USFWS is committed to working with the Alaska Native community to ensure that the subsistence harvest of Pacific walruses remains sustainable. The MMPA provides a mechanism for the USFWS to develop limits on Pacific walrus take, if we find that the Pacific walrus population is depleted.

3.11 Local and Traditional Ecological Knowledge

People who regularly interact with the environment through hunting, fishing, recreation, and commercial activities often have decades of experience and accumulated knowledge of the environment (Gadamus 2013, p. 2; Raymond-Yakoubian et al. 2014a, pp. 8, 11; Mistry and Berardi 2016, p. 1274). This knowledge is important in assessing the status of the Pacific walrus population.

The local knowledge base has been described as traditional ecological knowledge (TEK), indigenous ecological knowledge (IEK), and local ecological knowledge (LEK). Huntington et al. (2013a, p. 312) combined TEK and LEK into local and traditional knowledge (LTK). Although TEK helps with context (Huntington et al. 2016, p. 2), contemporary observations by residents of coastal communities in Alaska in regards to Pacific walruses and the environment may be most pertinent to a Species Status Assessment. This information is often specific to local conditions and observations and may not apply throughout the range of the Pacific walrus. However, consistent LTK from disparate regions within the range of the Pacific walrus has widespread application.

An important advantage of the SSA process and the revised BBN was the incorporation of the insights and knowledge of Alaska Native subsistence resource users (see Jay et al. 2011, p. 1068). The BBN model was developed considering both western science and the LTK of Native Alaskan subsistence resource users. In addition to the published literature and several reports, a two-day workshop was held in June 2016 with 20 subsistence resource users from 15 communities along the coasts of the Bering and Chukchi Seas to gain additional information on Pacific walrus health, abundance, trends, and the effects of stressors on Pacific walruses based on the knowledge and experience of workshop participants. Findings from the literature (see below) and from the June 2016 workshop were integrated into the BBN model (see Appendices A and C). Here we review the published literature on Pacific walrus specific LTK and also incorporate the key findings of the LTK workshop held in June 2016 (Appendix C).

Several studies have been conducted that document LTK of Pacific walrus hunting communities in Alaska, some with an explicit emphasis on Pacific walruses, Pacific walrus hunting, and environmental change (EWC 2003, pp. 1-91; Oozeva et al. 2004, pp. 35-189; Krupnik and Ray 2007, p. 2946; Kapsch et al. 2010, pp. 115-144; Northern Bering Sea Elders Advisory Group 2011, pp. 14-17; Gadamus 2013, p. 1; Huntington et al. 2013a, pp. 312-322; Huntington et al. 2013b, pp. 292-300; Huntington and Quakenbush 2013, pp. 1-9; Raymond-Yakoubian et al. 2014a, pp. 1-117; Raymond-Yakoubian et al. 2014b, pp. 2-67; Gadamus and Raymond-Yakoubian 2015a, p. 87; Gadamus et al. 2015, p. 116; Huntington et al. 2016, p. 1). Alaska Native LTK is frequently included in research and management programs to support and supplement western science (Krupnik and Ray 2007; Polfus et al. 2013, p. 112; Beaudreau and Levin 2014, p. 244). LTK also can provide insights to natural resource issues that otherwise might not be considered (Gadamus and Raymond-Yakoubian 2015a, p. 87; Gadamus and Raymond-Yakoubian 2015b, p. 76; Gadamus et al. 2015, p. 116; Huntington et al. 2016, p. 1).

Alaska Native hunters have reported that ice conditions have changed over the last several decades and that they have gotten worse in terms of extent, thickness, and predictability (EWC 2003, pp. 12-91; Oozeva et al. 2004, p. 200; Krupnik and Ray 2007, p. 2951; Krupnik 2009, p. 138; Gadamus 2013, p. 4; Raymond-Yakoubian et al. 2014a, p. 20; Raymond-Yakoubian et al. 2014b, p. 20; Gadamus and Raymond-Yakoubian 2015b, p. 82; Gadamus et al. 2015, p. 119; Huntington et al. 2016, pp. 2-3). These changes in Arctic sea ice conditions have also been extensively documented in the scientific literature (Serreze and Barry 2011, p. 88; Maslowski et al. 2012, pp. 626-628; Meier et al. 2014, p. 185; Frey et al. 2015, p. 32). Changes in sea ice dynamics influence many aspects of Pacific walrus ecology and the lives of native hunters.

Pacific walrus migration patterns have changed and hunters have noted that animals are appearing earlier and moving by villages faster than in the past (EWC 2003, pp. 1-91; Oozeva et al. 2004, pp. 35-189; Raymond-Yakoubian et al. 2014a, pp. 1-117; Raymond-Yakoubian et al. 2014b, p. 2-67; Gadamus and Raymond-Yakoubian 2015a, p. 87). However, some hunters along the northwest coast have not noticed much change and others have emphasized that conditions have always been variable from year to year (Huntington and Quakenbush 2013, p. 2). Huntington et al. (2016, pp. 2, 3) reported a 75% decrease in the amount of time available for spring hunting in the Bering Strait and Chukchi Sea due to ice changes, faster migrations, and poor weather. Hunters are now hunting multiple species at the same time, possibly to compensate for reduced Pacific walrus hunting opportunities. A change in the timing and speed of Pacific walrus migrations is a common theme among hunters and scientists (Garlich-Miller et al. 2011a, p. 46; MacCracken 2012, p. 2076; Brinkman et al. 2016, p. 1; Appendix C; Huntington et al. 2016, p. 2) and likely influences hunter success.

Weather conditions also play a major role in Pacific walrus hunting opportunities and success (Oozeva et al. 2004, p. 122; Kapsch et al. 2010, p. 115; Huntington et al. 2013a, p. 312; Raymond-Yakoubian et al. 2014b, pp. 41-43; Gadamus et al. 2015, p. 119; Huntington et al. 2016, p. 1). Many Pacific walrus hunters feel that weather conditions are less favorable (windier, rougher seas) for hunting than in the past, that it is warmer, and the weather more unpredictable (EWC 2003, p. 99; Oozeva et al. 2004, pp. 61-126; Krupnik and Ray 2007, p. 2952; Kapsch et al. 2010, p. 116; Huntington et al. 2013a, p. 312; Raymond-Yakoubian et al. 2014b, pp. 41, 42; Gadamus et al. 2015, p. 119; Huntington et al. 2016, p. 2), all of which combine to reduce hunter success (see section 3.3.3 Harvest Sustainability).

Due to changes in ice conditions and Pacific walrus migrations, the majority of hunters in the Bering Strait region indicated that they were having to travel further from their communities to access Pacific walruses (EWC 2003, pp. 12-91; Oozeva et al. 2004, pp. 101, 125; Gadamus 2013, p. 4; Raymond-Yakoubian et al. 2014b, p. 33; Gadamus and Raymond-Yakoubian 2015b, pp. 82, 84; Huntington et al. 2016, p. 2). In addition, the cost of gas negatively affects hunting effort (Brinkman et al. 2014, p. 1). However, in many cases, ice and weather precluded hunting, rather than the cost of gas (see section 3.3.2 Harvest Sustainability).

There are many cultural, traditional, and educational values associated with Pacific walrus hunting that also influence hunting practices (Gadamus 2013, p. 3; Raymond-Yakoubian et al. 2014b, pp. 45-47; Gadamus and Raymond-Yakoubian 2015a, pp. 91-95; Huntington et al. 2016, p. 1). Some traditional conservation practices involve only harvesting what is needed and consideration of the effective storage of meat (Gadamus and Raymond-Yakoubian 2015a, pp. 91-95) as well as tribal based trip limits that are now in place in Gambell and Savoonga. There were many situations or conditions in which hunters avoided harvesting Pacific walruses. Herds that were too large, composed primarily of subadults or too far into the ice were often passed due to potential loss of animals, aggressiveness of animals, and danger of being trapped or boats crushed by shifting ice (EWC 2003, inclusive). The location of individual Pacific walruses within a herd or on a floe was also important because those at the edge when shot had a good chance of both falling in the water or being pushed in by fleeing animals and sinking out of reach (Raymond-Yakoubian et al. 2014b, pp. 30-31). Gadamus and Raymond-Yakoubian (2015a, p. 89) noted that following hunting traditions was a form of respect for Pacific walruses.

The importance of Pacific walrus hunting to Alaska Native coastal communities has been documented in many LTK studies (EWC 2003, pp. 12-99; Oozeva et al. 2004, p. 200; Krupnik and Ray 2007, p. 2951; Krupnik 2009, p. 138; Gadamus 2013, p. 3; Huntington and Quakenbush 2013, p. 5; Raymond-Yakoubian et al. 2014b, pp. 45-47). Several hunters in the Bering Strait region indicated that hunting had declined, but this was often linked to decreased opportunities due to poor weather, lack of animals in the area, and cost rather than a lack of need or interest (Raymond-Yakoubian et al. 2014a, pp. 29-34). Gadamus and Raymond-Yakoubian (2015a, p. 89) reported that some hunters felt that a lack of hunting takes would lead to increased population size, which would then ultimately result in a decreased population size due to density-dependent regulation.

The health and condition of Pacific walruses is an important topic for hunters (Gadamus 2013, p. 4; Huntington and Quakenbush 2013, pp. 5, 8; Raymond-Yakoubian et al. 2014a, pp. 29-34; Raymond-Yakoubian et al. 2014b, pp. 27-29; Gadamus and Raymond-Yakoubian 2015a, p. 97; Appendix C). In general, hunter observations indicate that the Pacific walrus population is large with the majority of animals in good condition (Raymond-Yakoubian et al. 2014a, pp. 27-29; Gadamus et al. 2015, p. 119; Huntington et al. 2016, p. 2). Quakenbush et al.(2016, p. 6) asked walrus hunters participating in sample collections to rate the overall body condition of walruses as unhealthy, average, or very healthy during the 2012–2016 seasons; indicating that 98% of sampled Pacific walruses were rated healthy or very healthy (Quakenbush et al. 2016, p. 14). Alaska Native hunters have also noted that skinny (malnourished or poor body condition) Pacific walruses are always present at a low level (Huntington and Quakenbush 2013, p. 6; Raymond-Yakoubian et al. 2014b, pp. 28).

In regards to population size and trend most hunters felt that there were many Pacific walruses in the population, and that the population had not changed in recent years (EWC 2003, pp. 1-91; Huntington and Quakenbush 2013, p. 4; Appendix C). In addition, in the studies of Gadamus et al. (2015, p. 119) and Huntington et al. (2016, p. 2), and the 2016 workshop (Appendix C), the majority of hunters felt the population was large, had changed little, but have redistributed in relation to changing ice dynamics and disturbance. In contrast, most elders from Diomede stated that Pacific walrus numbers had declined (Raymond-Yakoubian et al. 2014a, pp. 16, 17). There are many possible reasons why hunters are seeing fewer animals and most attribute this to changes in migration patterns due to ice dynamics and disturbances, or simply where communities are located (Raymond-Yakoubian et al. 2014a, pp. 29-34).

In summary, LTK holders have witnessed changes in sea surface temperatures, ocean currents, sea ice extent, thickness, and concentration, weather patterns, and marine mammal responses to those changes. Most Pacific walrus hunters and other users assert that the Pacific walrus population is large, healthy, and will adapt to the environmental changes that are currently occurring. However, they also express concerns about impacts to Pacific walruses from immediate stressors like bottom trawl fisheries, commercial shipping, increased noise, and a large oil spill (Appendix C).

3.12 Resiliency, Representation, and Redundancy of the Pacific walrus

The factors that make up the adaptive capacity of a species are reflected in the concepts of resiliency, representation, and redundancy which serve as a measure of viability (USFWS 2016g, pp. 5-16). Our approach to assessing the influence of these measures on the persistence of the Pacific walrus population was to define the current state of each and then compare that to how resiliency, representation and redundancy are likely to be realized in the future.

3.12.1 Resiliency

Resiliency describes the ability of a species to withstand disturbances, including habitat change. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need to be abundant within habitat patches of adequate area and quality to maintain survival and reproduction in spite of disturbances.

Weaver et al. (1996, p. 964) describe three mechanisms that influence the resilience of large carnivores to disturbances that may affect their persistence: (1) plasticity in foraging behavior that ameliorates changes in food availability, (2) density-dependent demographic rates that compensate for various sources of mortality, and, (3) dispersal that provides connectivity between fragmented populations. Another trait that also influences a species resilience to change is their longevity (Ziuganov et al. 2000, p. 102). Species with long life spans such as Pacific walruses are better able to persist through short-term perturbations as well as make incremental behavioral, physiological, and genetic adjustments to long-term change. Plasticity in foraging behavior of Pacific walruses was addressed in section 2.2.2 (Feeding and Prey) and is characterized by a wide variety of taxa found in Pacific walrus stomachs and increases in alternate foods when their preferred foods were depleted. Nonetheless, Pacific walrus stomach contents are typically dominated by bivalves, gastropods, and polychaetes. The ability of the Pacific walrus population to compensate for increased exploitation or other mortality sources appears limited based on their low reproductive rates relative to other pinnipeds, but evidence indicates that once a limiting mortality factor is relaxed walrus populations can reach theoretical maximum growth rates (Kovacs et al. 2014, p. 4) and more than double in 20 years as seen in an Atlantic walrus population. However, as noted in Section 2.5.3.6, while Pacific walruses have the ability to move great distances, habitat outside of their current range has become available as sea ice declined, but Pacific walruses have failed to move into these habitats in any significant number suggesting factors other than their physical ability to move long distances could be limiting their dispersal ability (section 2.5.2 Dispersal Ability of Pacific walruses).

3.12.2 Representation

Representation is characterized by the breadth of genetic and environmental diversity within and among populations (USFWS 2016g, p. 12). The genetic diversity of Pacific walruses is high despite periodic and prolonged decreases in population size due to commercial exploitation (Sonsthagen et al. 2012, p. 1512). Three breeding aggregations form each winter in the polynyas south of St. Lawrence and Nunivak Islands in U.S. waters and the Gulf of Anadyr in Russian waters (Fay 1982, p. 194) (Figure 2.2). Sonsthagen et al. (2012, p. 1512) found low genetic differentiation among Pacific walruses sampled at U.S. breeding sites, suggesting mixing of individuals between these sites. However, there was greater differentiation among animals sampled in the spring and summer in the Chukchi Sea when breeding aggregations disperse and individuals congregate during the northward migration, suggesting the possibility of a genetically distinct cohort (Sonsthagen et al. 2012, p. 1512). This is supported by the tooth element analysis of Jay et al. (2008, p. 933) that also suggested the possibility of separate stocks. The implications for population fitness of a separate breeding group are unknown, but in general should increase representation and the ability of the species to adapt to changing environmental conditions.

Environmental diversity of areas occupied by the Pacific walrus population varies by season. In winter, when the majority of animals are on pack ice in the Bering Sea, environmental diversity is lowest. For example, Pacific walruses occupy suitable ice floes near high mass prey patches in waters <100 m deep. As sea ice melts, females and juveniles move north and males disperse toward Bering Sea coastal haulouts; thus environmental diversity increases as ice melts in the spring and summer/fall. At that time, males that remain in the Bering Sea spend a high percentage of time in the water feeding and traveling to and from coastal haulout sites (Jay and Hills 2005, pp. 197, 200).

3.12.3 Redundancy

Redundancy is characterized by having multiple, resilient populations distributed within the species ecological settings and across the species range (USFWS 2016g, p. 12). This assessment explores the influence of the distribution and connectivity of the population on the species ability to withstand catastrophic events (i.e., rescue effect). We measure redundancy of the Pacific walrus based on the spatial extent of the population in different seasons.

The degree of redundancy of the Pacific walrus population varies by season. Winter may be the season of least redundancy as the majority of the population is in the Bering Sea due to a solid ice pack in the Chukchi Sea. However, the distribution of the population among three distinct breeding sites provides a buffer to more localized catastrophic events (e.g., volcanic eruptions). In addition, Ray et al. (2016, p. 24) suggested that the recent change in sea ice from a “plastic continuum” to a “fractured mixing bowl” in the Bering Sea may result in more, but smaller breeding concentrations, which will likely increase redundancy.

Generally, redundancy is greater in spring, moderate in summer/fall and lowest in winter. The population is largely centered in three to four areas in spring and summer/fall: Bristol Bay (adult males), the Gulf of Anadyr (adult males), the Bering Strait region (adult males), the eastern Chukchi Sea (adult females and juvenile animals), and the western Chukchi Sea (adult females and juveniles). These general distributions seem to hold for periods when ice is present or not, the major difference being that animals are more spread out on the ice front than when concentrated at coastal haulouts. In the Chukchi Sea, these temporally and spatially disjunct distributions may be more connected than previously assumed as several tagged animals have moved from one area to the other in both directions (Jay et al. 2012, p. 7; ADFG 2016; USGS 2016). In contrast, Jay and Hills (2005, p. 198) suggested that the adult males in Bristol Bay from spring to autumn did not move from the area and also indicated that fidelity to specific haulout sites was high among some individuals (Jay and Hills 2005, p. 196).

3.12.4 Summary

The adaptive capacity of Pacific walruses has allowed them to persist in the face of climate driven habitat changes to date as well as the associated anthropogenic stressors. Currently, the population exhibits degrees of resiliency, representation, and redundancy that have likely facilitated population persistence through past climate warming and cooling and population bottlenecks over longer periods with no detectable loss of genetic diversity (Sonsthagen et al. 2012, p. 1512). In addition, the population experienced a period of growth where it eventually was likely near or at the carrying capacity of the Bering and Chukchi seas (Fay et al. 1989a, pp. 5-7; Garlich-Miller et al. 2006, p. 888; MacCracken et al. 2014, p. 41; MacCracken and Benter 2016, p. 588) which was followed by a population decline of about 40% (Taylor and Udevitz 2015, p. 246) from 1980–2003. Model-derived estimates of current vital rates indicate that density-dependent constraints have likely relaxed, and vital rates have increased (Taylor and

Udevitz 2016). Indices of population status (CCRs, tusk FA, and bone cortisol levels) suggest the population is demographically and physiologically resilient to the current levels of sea ice loss.

3.13 Summary of Current Conditions

We provide a summary of the conclusions of the discussions of the topics addressed above in Table 3.3.

The Bering and Chukchi seas have experienced environmental changes over the last several decades, particularly the loss of sea ice in the summer/fall. Based on the available information, we found indications that the carrying capacity of the northern Bering Sea (e.g., declines in benthic mass) for Pacific walruses has likely declined, but recent increases in primary productivity and the opening of inaccessible habitat due to increases in useable sea ice habitats in spring and winter may mitigate those trends, particularly if the observed tight pelagic-benthic coupling continues to occur. The Pacific walrus population decline in the 1980s and 1990s was likely primarily due to density-dependent declines in vital rates, but high harvests in those years also contributed. Taylor and Udevitz (2015, p. 251) used an integrated population model that included harvest data, age composition surveys, and population size estimates to describe a declining trend in abundance of the Pacific walrus population in the 1980s and 1990s. The authors attributed this decline to one of two factors: high harvests of an aging population (as described by Fay et al. 1989a, pp. 5-7), or ecosystem changes that reduced the environment's capacity to support Pacific walruses (Taylor and Udevitz 2015, p.251). They hypothesized that a change in sea ice cover could potentially reduce access to prey, lowering body condition of females, and concomitantly, population vital rates (Taylor and Udevitz 2015, p.251). It is noted that their modelled vital rates improved significantly in later years leading to a stabilizing population trajectory (Taylor and Udevitz 2016); however potential mechanisms for the apparent increase in reproduction and calf survival rates were not described. This is further supported by the results of Garlich-Miller et al. (2006, pp. 892-893) demonstrating a decline in the age of first reproduction of sampled female Pacific walruses in the 1990s, consistent with a hypothesis of reduced density-dependent pressures. Vital rates began to increase in the 1990s (Taylor and Udevitz 2015, p. 247) as sea ice continued to decline in summer/fall in the Chukchi Sea (Figure 3.2). Vital rates are currently high (Taylor and Udevitz 2016) and measures of stress are currently low (Charapata 2016, p. 80; MacCracken and Benter 2016, pp. 594, 595), yet sea ice in the Chukchi Sea has continued to decline. However, stress may be increasing in female Pacific walruses, likely due to the loss of sea ice in the summer/fall (MacCracken and Benter 2016, p. 595). The potential negative effects of OA on the species of benthic invertebrates that Pacific walruses feed on have yet to be documented. Species responses to OA vary and periodic exposure to low pH waters affords some species some resistance to OA. In addition, the increased primary productivity that has been observed in the Arctic may allow some species to cope better than others with the increased energetic costs of internal acid-base regulation and

Table 3.3. List of primary potential stressors to the Pacific walrus population, current condition of each stressor, the current intensity of each stressor.

Potential Stressor	Possible Effect on Pacific walruses	Current Condition	Current Intensity of Stressor
Loss of summer/fall ice in Chukchi Sea.	Injury and death from trampling; primarily females and juveniles. Change in distribution. Increased energy expenditure.	2.2 ice-free months per year.	Low–moderately low.
Change in winter sea ice, both seas.	Change in distribution.	0 ice-free months per year.	Low.
Change in spring sea ice, both seas.	Change in distribution.	0 ice-free months per year.	Low-moderately low
Subsistence harvest.	Injury and direct mortality.	Lowest harvest levels on record.	Low.
Ocean warming and acidification.	Changes in benthic species composition and area specific declines in mass.	Temperature increases of 2 – 4^{o} C. pH within range of natural variation. Aragonite saturation within range of natural variation.	Low.
Ship and air traffic.	Displaced from some areas; increased energy expenditure; altered migration routes; potential for stampedes and death of juveniles.	Ship transits of Bering Strait are 44% > the 2010–2015 average. Air traffic levels unknown, but likely greater.	Low–moderately low.
Commercial fisheries.	Displaced from some areas, increased energy expenditure, may affect prey abundance in some areas.	Limited to Bristol Bay. Little overlap with Pacific walruses. 0–3 Pacific walruses taken per year.	Low.

Table 3.3 Continued.

Potential Stressor	Possible Effect on Pacific walruses	Current Condition	Current Intensity of Stressor
Climate change on benthos.	Decrease in prey in portions some areas.	Northern Bering Sea declines; Chukchi Sea stable/decline	Low–moderately low.
Disease and parasites.	Potential for outbreaks. Morbidity and death.	At low levels.	Low.
Predation.	Injury and direct mortality	At low levels.	Low.
Pollution.	Injury and direct mortality	Present at low levels.	Low.
Oil and gas exploration.	Displaced from some areas. Increased energy expenditure. May affect prey abundance in some areas.	No activity.	None.

repair shell dissolution as pH and aragonite saturation declines. Additionally, Pacific walrus hunters have not observed any changes in Pacific walrus diets or that prey have declined.

Pacific walruses use coastal haulouts when sea ice is lacking or sea ice is far from areas of high prey abundance. Pacific walrus coastal haulout use has changed in both the Bering and Chukchi seas. The cause of the re-occupation of more southerly haulouts (e.g., Amak Island, Cape Greig) and declining use of some Bristol Bay haulouts is unknown, but is likely due to localized prey depletion near haulouts that have had decades of use in concert with the effects of increased SST on their prey, and benthic habitat changes associated with bottom trawl fisheries. Alaska Natives also believe that commercial fishing activities disturb Pacific walruses, altering their distribution in Bristol Bay.

Pacific walruses come to shore to rest when ice melts over the continental shelf of the Chukchi Sea. The barrier island haulout near Point Lay has been occupied each summer/fall in seven of ten years from 2007–2016. Stressors associated with coastal haulout use and disturbance events have likely been mitigated to date through collaborative efforts with coastal communities in both the U.S. and Russian Federation (Robards and Garlich-Miller 2013, p. 84) with less than 1,000 mortalities recorded per year since 2008. However, MacCracken and Benter (2016, p. 595) noted a leveling off and four percent increase in female tusk asymmetry starting around 2011, which is likely related to summer/fall sea ice loss and the use of coastal haulouts. Although female tusk FA indicates a possible increase in stressors, FA is still an order of magnitude below levels found in 1990.

The subsistence harvest of Pacific walruses has been declining since 1990, with the greatest declines in the U.S. harvest since 2013. We found that the harvest is likely sustainable at this time.

We found no evidence that disease, parasites, and predation is limiting the population or that rates have changed substantially since 2010. Pollution also does not appear to be a regular stressor to Pacific walruses, and the recent suspension of oil and gas exploration in the Chukchi Sea has further reduced exposure to this potential stressor. However, Alaska Natives are concerned that pollution may harm Pacific walruses and other organisms and biological components of the Bering and Chukchi Sea ecosystems. It is also unlikely that commercial fisheries are a serious problem at this time and management agencies are committed to mitigating Pacific walrus-fishery interactions. However, the potential effects of bottom trawling on benthic habitats, Pacific walrus prey populations, and Pacific walruses are concerns among Alaskan Natives where trawling currently occurs and in areas where it is perceived to potentially spread further north.

Commercial shipping has seen rapid expansion as sea ice declines increase shipping opportunities, particularly along the NSR. However, transits have declined along the NSR since the peak in 2013. Ship transits through the Bering Strait follow the same general trend as the NSR. Many coastal residents in the Bering Strait region note that increases in ship traffic have altered Pacific walrus migration patterns, interfered with subsistence hunting, and increased trash and contaminants in the ocean (Appendix C).

There is no information on rates of air traffic for the region. Air traffic around coastal haulouts is unpredictable and without restriction, but outreach programs by the FAA and USFWS have been underway for many years. However, it is difficult to determine the number of pilots reached and their compliance with the guidelines.

The weight of evidence from several indices and population modeling efforts indicate that the population of Pacific walruses was likely at or near K in the late 1970s-early 1980s (Fay et al. 1997, p. 546; Taylor and Udevitz 2015, p. 241). The population subsequently declined and recent evidence suggests that the decline has moderated and perhaps approached stability (Taylor and Udevitz 2016). We found that the Pacific walrus population appears to possess degrees of resiliency, representation and redundancy that have allowed it to cope with the changing environments of the last decade, although changes to resiliency, representation and redundancy during this time would be hard to detect for a species with a fifteen year generational timeframe. Coastal haulouts are not preferred resting sites for females and juveniles and could be considered ecological traps (scenarios in which rapid environmental change leads organisms to settle in poor-quality habitats) and a maladaptive behavior due to the potential for disturbance related mortalities, increased energetic costs, and increased predation attempts. However, collaborative efforts with local communities in limited areas have likely reduced the negative impacts of disturbance related mortalities. Few malnourished and/or diseased animals are observed and reproduction is higher than in the 1970s–1980s. Survival rates are also higher than in the 1970s–1980s and harvest levels have also decreased. These observations mirror those of Alaskan Native hunters, who assert that the population is large and stable, that Pacific walruses are intelligent, adaptable, and able to make the necessary adjustments needed to persist, and are not being negatively impacted in a significant way at this time. However, concerns remain about pollution, bottom trawl fisheries, increases in ship and air traffic, and other potential commercial developments.

The best available information suggests that the Pacific walrus population has sufficient levels of resiliency, representation, and redundancy in the current time period. However, stressors have emerged that Pacific walruses have not experienced for millennia (e.g., sea ice loss in summer/fall), are relatively new (e.g., international shipping), and are developing at an unprecedented rate. How Pacific walruses will cope with these emerging and cumulative stressors is the subject of the remaining chapters.

4. FUTURE RESOURCE CONDITIONS

In this chapter, we describe the future condition of resources needed to meet the essential life functions of Pacific walruses at individual and population levels. We consider the spatial and temporal variability of those resources and the factors that may alter their future condition. The potential impacts to Pacific walruses at individual and population levels were assessed and summarized by the outcomes of the revised BBN model.

4.1 Revised Bayesian Belief Network Model

4.1.1. Purpose, Structure, and Assumptions

To help assess the future viability of the Pacific walrus population, the USFWS assembled a Science Team comprised of USFWS Pacific walrus program staff and Pacific walrus researchers from the USGS and ADFG. The task of the Science Team was to develop and implement a method to assess the future persistence of the Pacific walrus population. Compass Resource Management of Vancouver, British Columbia was contracted to facilitate this process.

The use of a Bayesian Belief Network (BBN) model was chosen to aid in compiling and quantifying expert opinion, along with existing information, and then to summarize the level of stressors that the Pacific walrus population may face in the future. Two BBN models were previously developed in 2010 and used in the 2011 ESA finding for Pacific walruses by the USFWS (USFWS 2011, p. 7640). The USFWS developed a BBN model that linked the ESA five-factor analysis to an outcome at the population-level (positive, neutral, negative; MacCracken et al. 2013, p. 226). That model indicated that threats to the population were projected to become increasingly negative out to the end of the century. Sea ice loss, subsistence harvest levels, and calf mortalities at coastal haulouts had the greatest influence on the outcomes of that model.

The other Pacific walrus BBN evaluated the effects of potential anthropogenic and environmental stressors on habitat, mortality, prey, Pacific walrus physiology, and Pacific walrus behavior (Jay et al. 2011, p. 1065). The model evaluated stressors in three separate seasons linked to the Pacific walrus annual cycle (winter, spring, and summer/fall), and included a final outcome of Pacific walrus population status (robust, persistent, vulnerable, rare, and extirpated states; Jay et al. 2011, p. 1065). Model projections to 2095 indicated an increasing trend of worsening conditions represented by a shift in probabilities primarily from a robust/persistent status to a nearly equally robust/persistent/vulnerable status by 2095 (Jay et al. 2011, p. 1076). Sea ice loss and harvest levels had the greatest influence on the outcomes of that model.

Both BBN models identified the projected loss of sea ice as a the primary stressor to the Pacific walrus population (USFWS 2011, p. 7649) and demonstrated a trend of worsening conditions over time. The BBN model of Jay et al. (2011, p. 1065) was used as the foundation for our current assessment process (USFWS 2016g, p. 3) because it was more comprehensive in terms of potential population stressors, focused on how stressors affected ecological processes and interactions, and helped inform population status. We revised and updated the model of Jay et al. (2011, p. 1065) to assist in projecting future states of environmental and anthropogenic factors influencing individual Pacific walruses and the population. Details of that process can be found in section 4.4 (Bayesian Belief Network Expert Elicitations), section 4.5 (Bayesian Belief Network Model Outcomes) and Appendix A.

The Science Team thoroughly reviewed the Jay et al. (2011, p. 1065) model and made a number of revisions and updates (Table 4.1) as well as new elicitations of the conditional probability tables (CPT) for some nodes (Appendix A). However, the rationale for the arrangement of nodes and most linkages remained unchanged as well as the seasonal sub-model structure (Appendix A). We removed the Sea Ice Cover node and the Shelf Ice Extent node (Jay et al. 2011, p. 1069) from the model and conducted a separate spatial analysis of sea ice extent and concentration as a surrogate for potential Pacific walrus habitat extent (see section 4.3.2.1 Habitat Access and Appendix B). Therefore, sea ice changes in the BBN are integrated solely through the Ice-Free Months node.

For the purpose of our BBN we assumed no difference in habitat suitability between the Chukchi and Bering Seas. As the location of Pacific walrus sea ice habitats shifts over time, we also assumed that Pacific walruses would respond by adjusting their seasonal ranges accordingly. Therefore, all assumptions, variables, and linkages in our models apply to the entire study area.

Our analysis of abundance stressors acting on the Pacific walrus population was restricted to the current range of the Pacific walrus population (Figure 2.2). Pacific walruses were historically distributed beyond the limits of their current range (Section 2.2.3 Seasonal Distributions), however we found no basis for modeling or quantifying potential future range adjustments beyond their current range. The potential of Pacific walruses to respond to environmental stressors via range adjustments is addressed in Section 5 (Viability assessment).

We relied on monthly projections of sea ice extent from a 13-model ensemble of the most recent Global Circulation Models (GCMs) and three Representative Concentration Pathways (RCP) to populate the input tables for the Ice-Free Months node (only nine of these models were used for RCP 2.6) (see section 4.3.1 Representative Concentration Pathways). Full conditional probability tables and descriptions of assumptions and rationale for each input, intermediate, and outcome nodes can be found in Appendix A.

To document differences among Science Team members in conditional probability table elicitations for each node, the full range of expert judgments for each elicited node's conditional probability table were analyzed. This analysis was undertaken to understand the similarities and differences in expert judgments and to understand the effect that the range of judgments had on model outcomes. Details of that analysis are provided in Appendix A.

Table 4.1. The revised Pacific walrus Bayesian belief network model node type and name, node definition and states for each node.

Node Type and Description	Node Definition	Node States
Input Nodes		
Climate Change on Benthos	Cumulative impact of various factors related to climate change on the production of benthic prey. Reduced sea ice and ocean acidification are assumed to have the greatest potential to influence benthic prey production	Positive Neutral Negative
Human Settlements	Population size of humans along the coast of Alaska.	Low (<65,000) Moderate (65,000–80,000) High (>80,000)
Ice-Free Months	Mean number of months within a season with no sea ice to support Pacific walruses for hauling out over the continental shelf of the Chukchi and Bering seas.	Summer/Fall: 0–0.5, 0.5–2.0, 2.0–3.5, 3.5–5.0 Winter: 0–0.5, 0.5–2.0, 2.0–4.0 Spring: 0–0.5, 0.5–2.0, 2.0–3.0
Incidental Takes	Number of Pacific walruses killed from illegal activities and incidentally from fishing, industry, and research activities in Russia and Alaska.	Low (<2580) Moderate (2580–5160) High (5160–7740) Very High (>7740)
Resource Utilization	Impact on benthic prey production from activities that can perturb the seafloor from extraction of natural resources, such as from commercial fishing and oil and gas development.	Positive Neutral Negative
Ship and Air Traffic	Amount of ship and air traffic from commercial shipping, tourism, and fishing, and oil and gas development.	Low (<300) Moderate (300–600) High (>600)
Subsistence Harvest	Number of Pacific walruses killed by Native subsistence hunting in Russia and Alaska.	Low (<2580) Moderate (2580–5160) High (5160–7740) Very High (>7740)
Intermediate Nodes		
Benthic Prey Abundance	Abundance of benthic prey resources.	High Moderate Low
Birthing Platform	Adequacy of ice or other habitat for birthing, nursing, and providing protection to newborn calves during severe storms.	Adequate (fully sufficient to support birthing) Less than Adequate (partially sufficient) Severely Reduced (largely insufficient)
Body Condition	Amount of body reserves of individuals in the population, particularly in the form of fat and muscle.	High Medium Low

Table 4.1. Continued.

Breeding Environment	Adequacy of ice or other habitat for breeding.	Adequate (fully sufficient to support breeding) Less than Adequate (partially sufficient) Severely Reduced (largely insufficient)
Crowding	Number of adult female and juvenile Pacific walruses at a haulout.	Low (groups in the 10's or 100's) Moderate (groups in the 1000's) High (groups in the 10,000's)
Crowding and Disturbance	Intensity of disturbance on a haulout.	Low Medium High
Disease and Parasites	Incidence of disease and parasites in the Pacific walrus population.	Low (endemic levels) Moderate (pandemic levels) High (epidemic levels)
Energy Expenditure	Energy expended by Pacific walruses while foraging and swimming.	Low Medium High
Haulout Disturbance	Level of disturbance to hauled out Pacific walruses on ice, and particularly, on coastal haulouts.	Low Moderate High
Human-caused Direct Mortality	Total number of Pacific walruses directly killed by humans in Russia and Alaska as a result of subsistence harvest and incidental takes	Low to moderate High Very High
Oil Spills and Other Pollution	Regularity and severity of hydrocarbons and other pollutants released into the water.	Low Moderate High
Predation and Associated Mortality	Number of Pacific walruses killed by predators (excluding humans), which are primarily polar bears and killer whales.	Low Moderate High
Total Mortality	Total number of Pacific walruses killed as a function of the nodes "Predation and Associated Mortality", "Crowding and Disturbance" and "Human-caused Direct Mortality".	Low Moderate High
Output Node		
All Seasons Relative Abundance Stressors	Processes or events that may negatively influence the abundance of Pacific walruses.	Low Moderately Low Moderately High High

To test and calibrate the revised BBN, Compass Resource Management developed a number of test cases where inputs were set at various states to investigate model accuracy. While testing the model response to the best- and worst-case states, the intermediate nodes and abundance stressor outcome nodes were assessed based on whether or not the probabilities of the node states were representative of those inputs. Tests indicated that some of the nodes were not having the magnitude of effect on their child nodes that was representative of how the nodes and states were defined. For example, very high and high Subsistence Harvest states were defined as being unsustainable, but the effect on Total Mortality did not reflect that characterization. Therefore, adjustments were made to a few conditional probability tables by differential weighting of node states or the parent nodes such that the model reflected the appropriate magnitude of the node states under the specified scenario. Circularity in this process was minimized by only assessing changes in immediate child nodes rather than the final output node.

Sensitivity analyses were conducted on the revised BBN model using the procedure in the Netica software that calculates entropy reduction (i.e., reduction in the disorder of variation) of the All Seasons Relative Abundance Stressors outcome node relative to the information represented in input nodes (see Marcot et al. 2006, p. 3063 for method and equation). To understand the influence of each input node on the model, we set all prior probabilities of the input nodes to uniform distributions to reflect total uncertainty among states before conducting the analysis. The analysis indicated that the revised BBN model was most sensitive to Ice-Free Months, Subsistence Harvest levels, and Incidental Takes specifications (Appendix A). The spring and winter sub-models are most sensitive to Ice-free Months, likely due to the addition of the Birthing Platform and Breeding Environment nodes for those seasons, respectively.

To determine the relative impact that each input node had on model outcomes, a number of ‘influence runs’ were developed to test the sensitivity of the model to those input nodes when set to best- or worst-case states (Appendix A). These runs provided insight into the degree of influence that each input node had on the model, and to how the model responded to extreme cases. The majority of influence runs involved sequentially setting input nodes to their best-case and then worst-case while holding all other inputs at the 2015 estimated state (the normative case). All runs were made assuming the RCP 8.5 forcing level. We compared the influence runs against the normative case. Ice-Free Months had the greatest influence on the model outcome likely owing to its linkages with numerous intermediate nodes (Appendix A). Subsistence Harvest also had a high degree of influence on the outcomes, though the scale of that influence diminished at future time steps when Ice-Free Months approached the worst case scenario (Appendix A). Ship and Air traffic had a moderate degree of influence, again due to linkages with numerous intermediate nodes. Importantly, the additional link of Ship and Air Traffic to Energy Expenditure as suggested by the LTK workshop increased the influence of that node. This linkage was an addition to the revised model beyond that of Jay et al. (2011, p. 1069).

4.2 Time Frame

Stressors acting on a species and the species response to those stressors are not, in general, equally predictable. Even though future warming and correlated environmental changes are likely to occur, the behavioral, physiological, demographic, ecological, and adaptive responses of Pacific walruses are difficult to predict. Observations of Pacific walrus's responses to the effects of climate change from 2007 (the first summer/fall that ice receded beyond the continental shelf) to the present are likely the most realistic information when evaluating the future. However, even these observed responses have changed as Pacific walruses have adapted their behaviors (e.g., migration patterns, coastal haulout locations, and feeding patterns within that period which is less than one generation). In addition, it is likely that further changes in Pacific walrus behaviors will occur as they refine responses, as stressors intensify, or new stressors emerge.

For this assessment we made projections at a 15-year time step, which is roughly a Pacific walrus generation length, beginning in 2015 and continuing through 2060 and then for 2100. The Science Team generally felt that forecasts of Pacific walrus's responses to various environmental changes up to 2060 were more reliable that those beyond that time period. However, because most climate change projections are made to the end of the century, we also included a projection at 2100. Ice modeling results are available out to 2100 which forms the basis for our projections for that timeframe. We have less confidence in our ability to predict the potential behavioral and physiological adaptations of Pacific walruses, and the resulting consequences for reproduction and survival under the sea ice conditions projected for 2100 because of the extensive time between now and 2100. In the following sections, we provide additional information on the projected future conditions of each abundance stressor that was incorporated into the BBN model.

4.3 Model Projections

We used several modeling experiments based on the GCMs from the latest version of the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al. 2012, p. 485) in our analyses; the most important of these being sea ice projections. We were able to obtain sea ice projections for the 2.6, 4.5, and 8.5 RCPs at the 15-year time steps identified above as well as for winter (December–March), spring (April–June), and summer/fall (July–November), which correspond to the seasonal submodels of the revised BBN model developed for our assessment (see section 4.1. and Appendix A).

Several other projections such as sea surface temperature, benthic mass, and ocean aragonite saturation state that are important to our analyses have also been completed, but do not precisely fit our seasonal or time period specifications (Wang et al. 2012, pp. 53-55; Arctic Ocean Observing System, www.aoos.org; Mathis et al. 2015, p. 132). For example, published projections of these topics based on GCMs typically provide monthly data only for RCPs 4.5 and 8.5 and only at mid-century and late-century time steps. In general, these provided useful information for our assessment despite mismatches with our time steps and were incorporated through examination of figures and graphs and in some cases, extraction of data points with digitizing software (Rohatgi 2016).

4.3.1. Representative Concentration Pathways

The CMIP5 represents a coordinated effort among global research institutions to develop and execute the most state-of-the art ensemble of global coupled ocean-atmosphere GCMs under a common set of greenhouse gas forcing conditions. For the CMIP5 models (i.e. the GCMs), the different forcing conditions were termed Representative Concentration Pathways (RCPs). The RCPs describe timelines for defined levels of atmospheric GHG concentrations and other pollutants over time. The emissions necessary to obtain RCP rates can be realized by a variety of socio-economic scenarios, thus the term pathway instead of scenario. In addition, RCPs include trajectories for land use and land cover change to account for carbon flux and storage in terrestrial and aquatic systems (van Vuuren et al. 2011, p. 5). The RCPs are named according to the amount of net radiative forcing attained at the end of the century (2100) relative to pre-industrial levels: 2.6 Watts per m^2 (W m^{-2}), 4.5 W m^{-2}, 6.0 W m^{-2}, and 8.5 W m^{-2}.

Under the RCP 2.6 forcing, most GCMs project that average global warming will remain below 2°C above preindustrial levels, so RCP 2.6 most closely adheres to the goals of the Paris Agreement. The Paris Agreement is a global framework to reduce greenhouse gas emissions to limit the increase in global temperatures to ≤2°C compared to pre-industrial temperatures. Under RCP 8.5, recent GHG emission rates continue unabated through century's end, resulting in the greatest levels of atmospheric GHG concentrations and the greatest increases in global temperature (van Vuuren et al. 2011, p. 21). The intermediate pathway, RCP 4.5, requires prompt and prudent GHG mitigation in the coming decades. Differences in atmospheric GHG concentrations among the RCPs are subtle through about 2030, but by 2045, all three RCPs are widely separated, with 2.6 most divergent and continuing to decline, 4.5 relatively stable, and 8.5 continuing to increase (Figure 4.1). By 2100, RCP 8.5 has reached CO_2 levels far beyond 4.5 and 2.6 (Figure 4.1). The RCPs are not forecasts, absolutes, or prescriptive and none was considered more likely than another when developed (van Vuuren et al. 2011, p. 26). However, RCP 2.6 will require unprecedented global commitments and technologies that raise doubts about its relative likelihood (Tollefson 2015, p. 436).

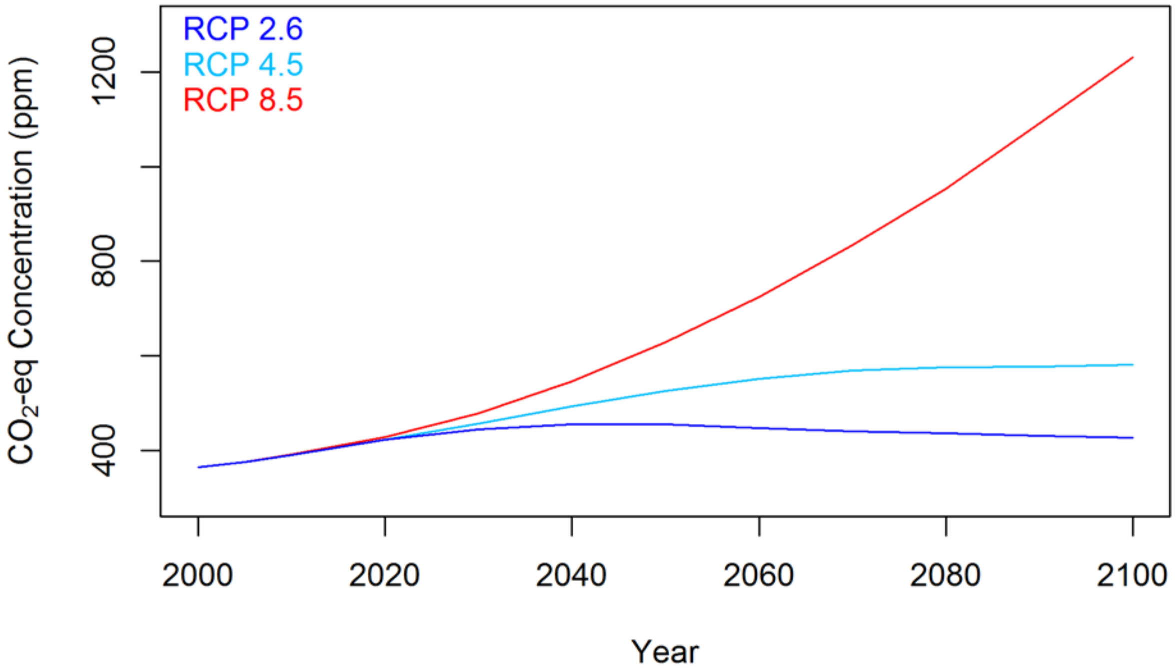


Figure. 4.1. Projections of greenhouse gas concentrations as measured in CO_2-equivalents for three representative concentration pathways (Smith and Wigley 2006, inclusive; Clarke et al. 2007, inclusive; Riahi et al. 2007, inclusive; Wise et al. 2009, inclusive; van Vuuren et al. 2011, inclusive).

4.3.2 Sea ice

The analysis and synthesis of information presented by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) in 2013 represents the scientific consensus for RCP 8.5. Consequently, substantial increases in the ice-free season in the Chukchi Sea are expected, even with moderate abatements of global emissions.

A recent study analyzed the projected ice-free seasons in the Alaskan arctic based on 12 CMIP5 GCMs (Wang and Overland 2015, p. 50) . Wang and Overland (2015, p. 50) only considered two greenhouse gas forcing scenarios: RCPs 4.5 and 8.5. Means across models projected that the Chukchi Sea ice-free season will extend from the current 2–4 months to 6–7 months by 2040 with a negligible difference between RCPs (Wang and Overland 2015, p. 57). Thereafter, however, RCPs diverge substantially in projections of the ice-free season. GCMs project a 6–8 month ice-free season in the Chukchi Sea by 2090 for RCP 4.5 and a 9–11 month ice-free season.

We used the mean number of ice-free months (Table 4.2, Figure 4.2) from the GCM projections to parameterize the revised BBN of Jay et al. (2011, p. 1065; see section 4.4 Bayesian Belief Network Expert Elicitations and Appendix A; Figure 4.3) for three RCPs and three seasons (winter, spring, summer/fall). We also acquired observed data on sea ice concentration from the National Snow and Ice Data Center for 2008–2012. We selected 13 GCMs based on their reported ability to simulate observed sea ice dynamics in the Chukchi and Beaufort seas (Wang and Overland 2015, p. 50; Atwood et al. 2016, pp. 5-6).

The study area for the BBN was restricted to pixels that were categorized as marine in all 13 GCMs to ensure a consistent model sample size for each pixel (Figure 4.3). We resampled native GCM spatial grids that contained projected values for sea ice concentration to a polar stereographic projection with 25-km resolution using nearest neighbor sampling (Atwood et al. 2016, pp. 5-6). We classified pixels with ice concentration ≥15% as "ice" and pixels with <15% ice concentration as "ice-free" in the resampled grid. We defined an ice-free month as a month when the percent of pixels with ice in the study area was <5%. We summed ice-free months within season and year to obtain seasonal estimates of ice-free months in each year. For each GCM, we then calculated the mean number of ice-free months within each of three seasons and five 15-year time periods. We performed the same procedure for each RCP (2.6, 4.5, and 8.5). Consequently, this analysis generated estimates of mean ice-free months for each GCM, RCP, season, and time step (13 GCMs × 3 RCPs × 3 seasons × 5 time steps = 585 values). GCMs varied in their projections of ice-free months with the largest variance among GCMs in the summer/fall season. To represent this uncertainty in the BBN, we used the proportion of models that projected mean ice-free months within specific ranges (number of months) for each season and time step as the BBN input variable (Figure 4.2).

4.3.3 Habitat Access

We conducted a spatial analysis aimed to identify and project potential accessible areas of the continental shelf by Pacific walruses from sea ice and land haulouts. Our analysis was intended to serve as a spatial complement to the revised BBN model described above (Section 4.1). The original BBN model developed by Jay et al. (2011, inclusive) included a spatial component that was removed during model revision; our analysis described here was intended to compliment the revised BBN, and the two independent projects are not linked directly.

Specifically, our objectives of the spatial analysis were to (1) identify potential habitats based on observed or justified behavioral criteria (movements and distributions relative to sea ice features); (2) quantify these habitats given projected sea ice conditions across seasons, years, and under different greenhouse gas forcing scenarios (RCPs); and, (3) generate maps of these

Table 4.2. Mean number of ice-free months in the Bering and Chukchi Seas for five time periods, 3 seasons, and 3 greenhouse gas representative concentration pathways (RCP).

	Time period and RCP														
	2015			2030			2045			2060			2100		
Season[a]	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5	2.6	4.5	8.5
Winter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.6	0.1	0.3	1.9
Spring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	1.1
Summer/fall	2.2	2.2	2.0	3.0	2.8	3.0	3.5	3.5	3.9	3.6	4.0	4.5	3.6	4.5	5.0

[a] Winter is December–March and encompasses the Pacific walrus southern migration and breeding, spring is April–June and encompasses calving and the start of the northward migration, and summer/fall is July–November.

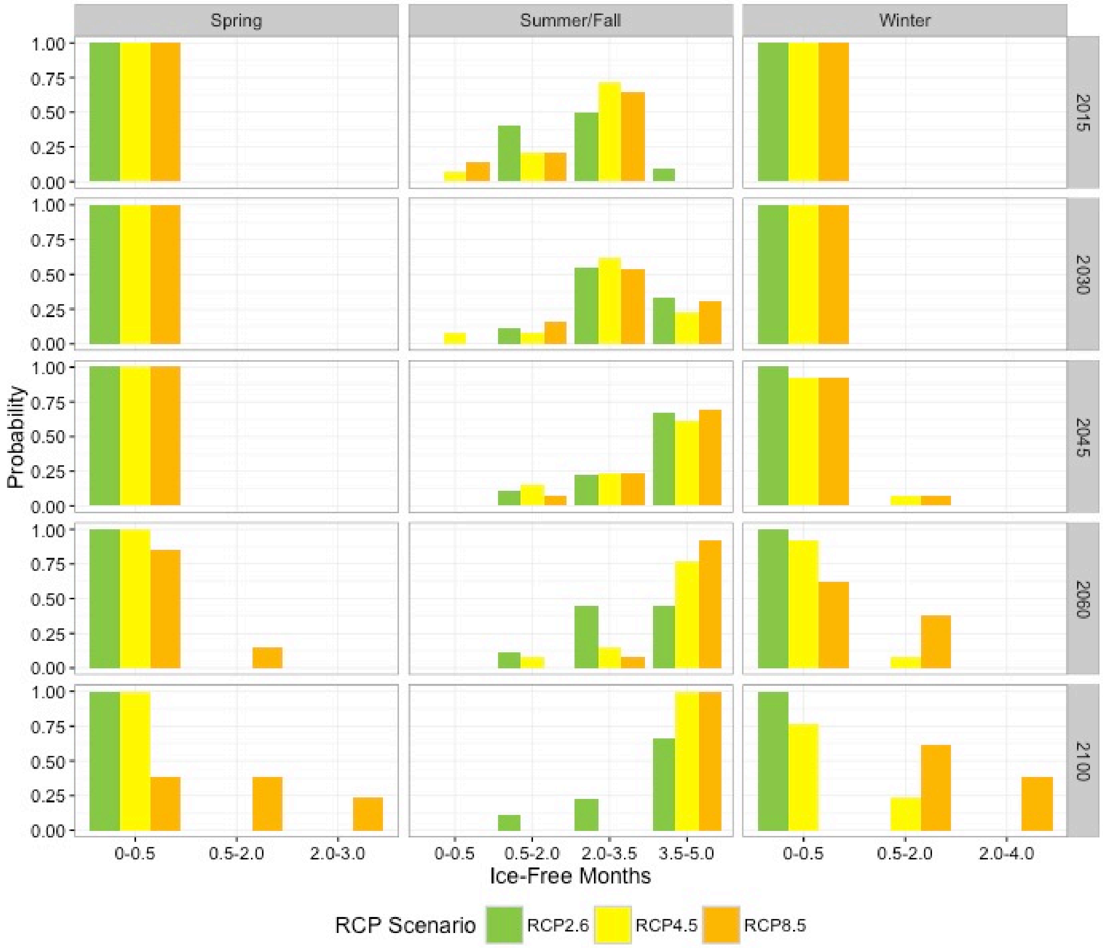


Figure 4.2. Proportions of 13 CMIP5 models that projected mean ice-free months in the Bering and Chukchi seas within specific ranges (number of months) in each of three seasons during five time periods for each of three greenhouse gas representative concentration pathways (RCP). Spring is April–June, summer/fall July–November, and winter December–March.

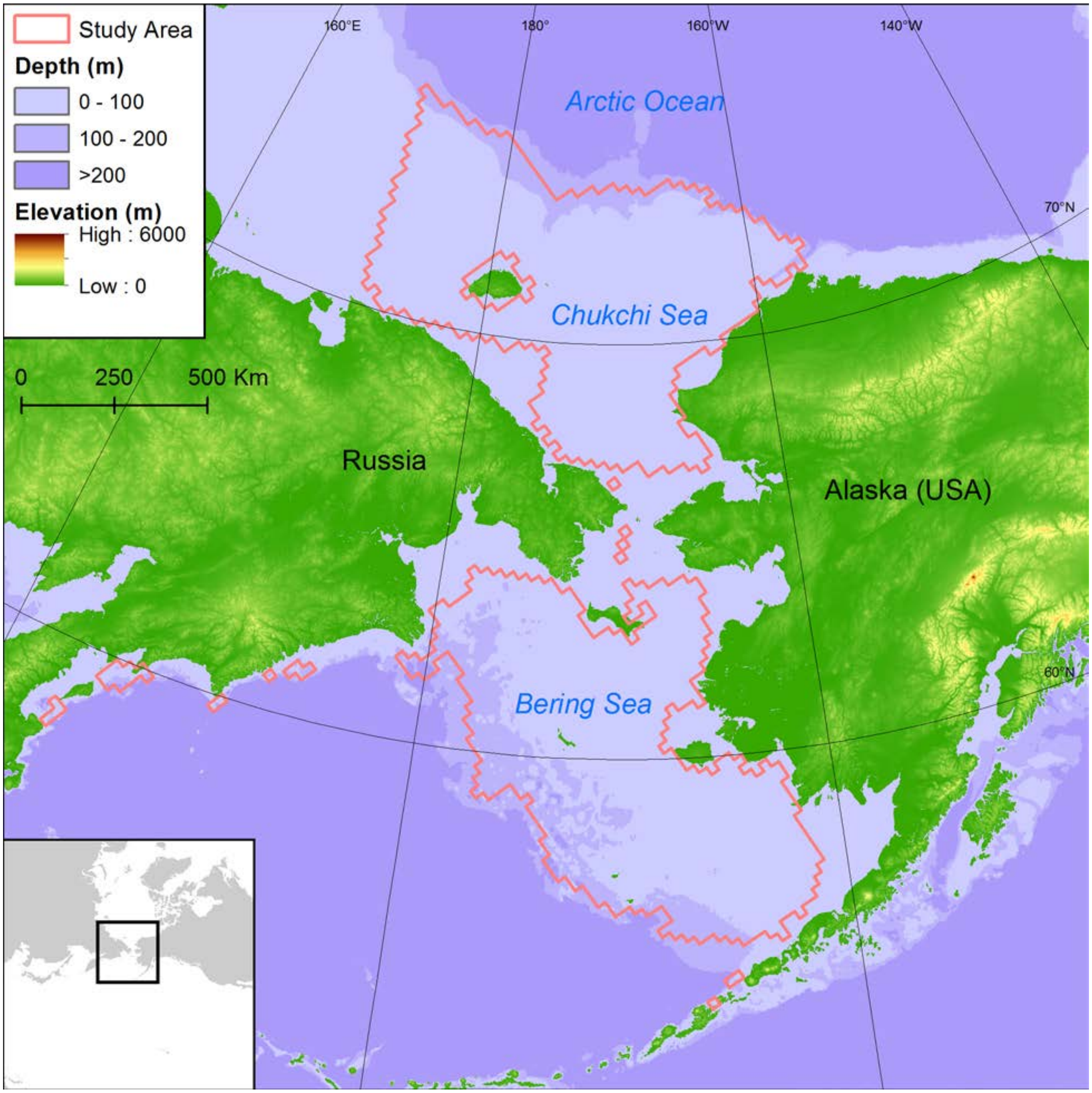


Figure 4.3. Study area for Bayesian Belief Network sea ice submodel (orange outline (Jay et al. 2011, p. 1066)).

habitats as a proxy to Pacific walrus distribution. Here, we briefly summarize our approach and results; see Appendix B for more details on the analysis and a more comprehensive presentation and interpretation of results.

To be consistent with the BBN, we conducted our analysis of habitat access using the same framework. We analyzed potential Pacific walrus habitat in the same three seasons (winter, spring, summer/fall), five time steps (2015, 2030, 2045, 2060, and 2100), and three RCPs (2.6, 4.5, 8.5). We also restricted our analysis to the current range of the Pacific walrus (Figure 4.3) and then, to review results at a finer spatial scale, divided it into four subregions using the international boundary (U.S. and Russia) and the Bering Strait, which separates the Bering and Chukchi seas. See Appendix B for an explanation on subregion delineation.

We defined potential habitat to be marine water, sea ice, or land within the study area that could be accessed and used by Pacific walruses within a particular season. We distinguished potential habitat from non-habitat using a set of decision rules based on observed or suspected behaviors and then determined the type of potential habitat as either ice-accessible or land-accessible. We included foraging distance from exposed shoreline into open water, foraging distance from sea ice into open water, percent sea ice concentration (SIC), and ocean depth (Appendix B). We did not include factors contributing to habitat quality such as benthic prey abundance and productivity because of analytical time constraints and lack of uniform coverage of these covariates within our study area. To determine the decision rules criteria, we reviewed published literature, unpublished reports, draft manuscripts, and current data sets. We also consulted with several Pacific walrus experts. We emphasize that potential habitat does not equate to suitable habitat, nor does it take habitat quality into account.

In combining these decision rules, we developed three scenarios to identify potential habitat for Pacific walruses (Appendix B). The only decision rule that varied among scenarios was the travel distance from exposed shoreline into open water. For Scenario 1, this distance was limited to ≤ 70 km; Scenario 2 was limited to ≤ 140 km; and, Scenario 3 contained all area ≤ 210 km from land into open water. The remaining three decision rules remained the same across all scenarios.

Similar to the BBN, we present results from all five time periods. We also present results both pooled across potential habitat types (ice-accessible and land-accessible) and separated by potential habitat type. Although ice-accessible habitat appears to be preferred by Pacific walruses, we did not consider habitat quality in our analysis because we were unable to quantify the level of preference under varying sea ice conditions and across seasons. We present selected pooled results here for simplicity, especially when results varied little between habitat types; see Appendix B for more comprehensive presentation of results.

Total potential habitat is likely to increase in spring and winter, and ice-accessible habitat will decrease in all seasons, scenarios, and RCPs (Figure 4.4). As ice-accessible habitat decreases, it is likely that land-accessible habitat will increase. The largest predicted changes in the shift of habitat type occurred under RCP 8.5 and the smallest under RCP 2.6. Under RCP 8.5, it is likely that the greatest shift will occur in summer/fall under Scenario 1 when the proportion of ice decreases from 0.47 in 2015 to 0.09 in 2060; conversely, the smallest shift is expected to occur in

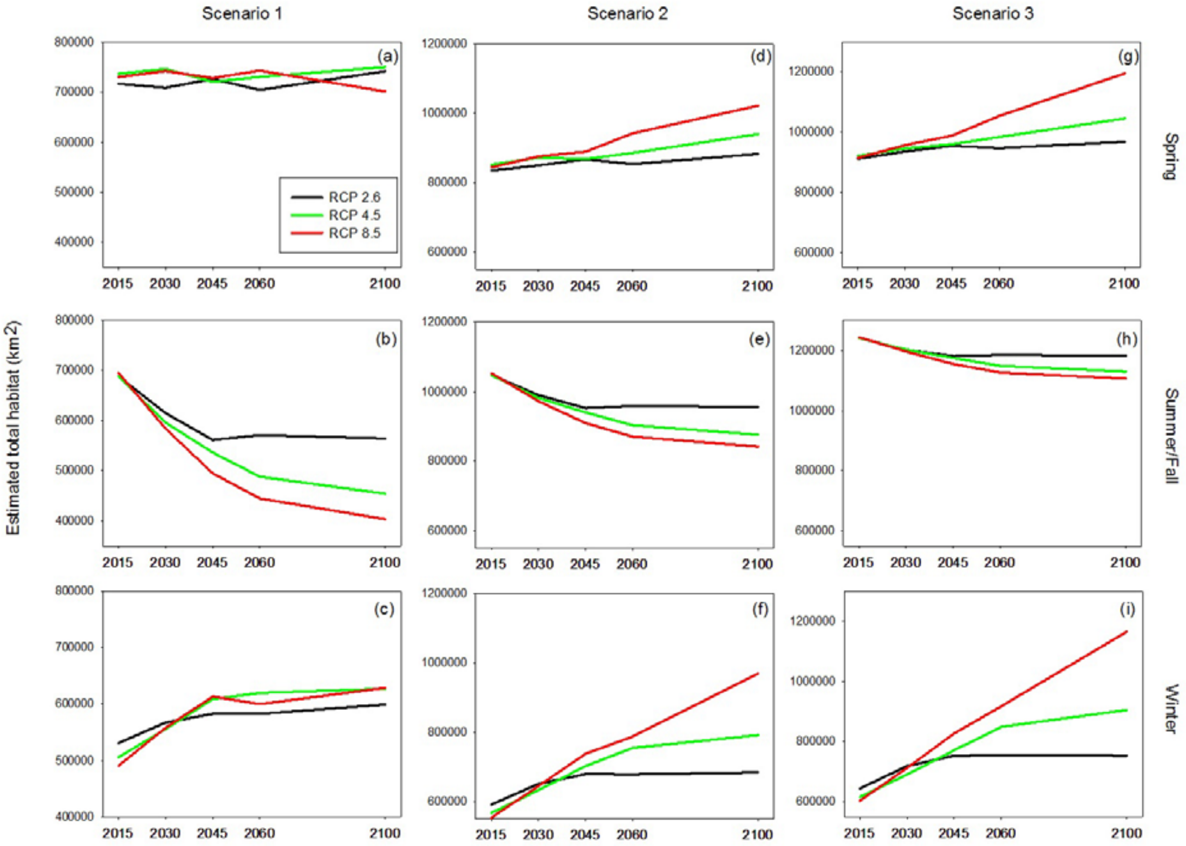


Figure 4.4. Estimated total potential habitat for Pacific walruses under three representative concentration pathways (RCP), three seasons, three scenarios, and five time periods for the total study area. Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km. Seasons are defined as spring (April–June; panels a, d, and g), summer/fall (July–November; panels b, e, and h), and winter (December–March; panels c, f, and i).

spring under Scenario 1 (0.87 and 0.74, respectively). Under all 3 scenarios in summer/fall, the proportion of ice-accessible habitat is predicted to be ≤ 0.09 in 2060 and 0.00 in 2100 (Figure 4.5).

Among subregions, we detected large variation in trajectories of total potential habitat for Pacific walruses. The greatest overall negative changes in total potential habitat occurred in the U.S. Bering subregion and the greatest overall positive changes occurred in the U.S. and Russia Chukchi subregions; however, these changes were highly dependent on the season (Table 4.3). For example, in spring and winter, it is very likely that increases in total potential habitat for both the U.S. and Russia Chukchi subregions will occur, yet total potential habitat will decline in these subregions in summer. Conversely, notable declines in total potential habitat in the U.S.

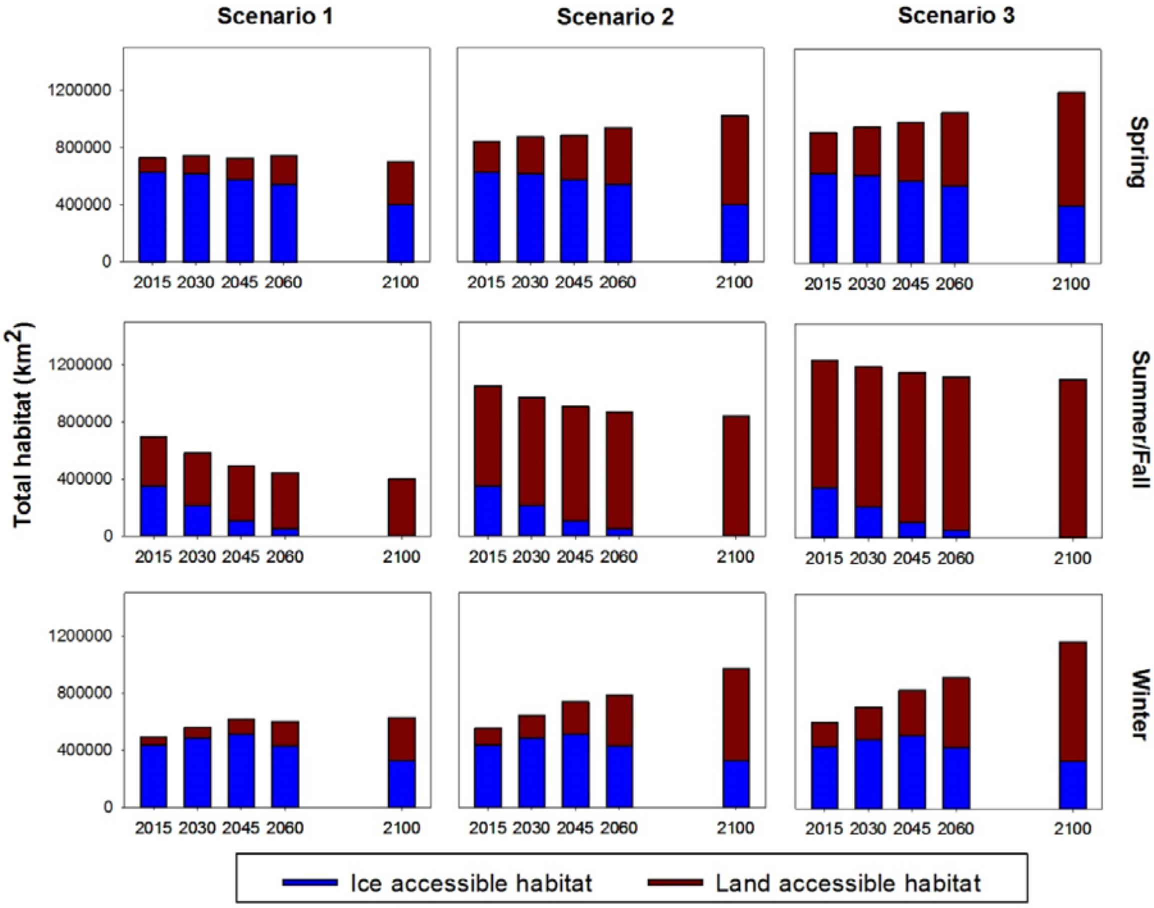


Figure 4.5. Estimated potential ice- and land-accessible habitat for Pacific walruses by season and scenario within the project area and across 5 time periods under representative concentration pathway (RCP) 8.5. Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km. Seasons are defined as spring (April–June), summer/fall (July–November), and winter (December–March).

Bering subregion in spring and winter and a stable trajectory in summer are very likely owing to the absolute absence of sea ice throughout all five time periods. In all seasons, total potential habitat in the Russia Bering subregion varied little. Similar to the whole study area, ice-accessible habitat decreased in all subregions with all seasons, scenarios, and RCPs (Table 4.3).

Overall, we found that total potential habitat for Pacific walruses will change by -10% to 10% between 2015 and 2060, and by -13% to 21% between 2015 and 2100 under RCP 8.5 (Table 4.3). The greatest decreases in total potential habitat will occur in summer/fall, though we

Table 4.3. Percent change in total potential habitat (except where identified as ice-accessible habitat only) for Pacific walrus between 2015 and 2060 (labeled as 2060) and 2015 and 2100 (labeled as 2100) by season and scenario, based on decision rules and thresholds used in our analysis. Results included for representative concentration pathway (RCP) 8.5 only. Shading added for organization only.

Scenario	Geographic Area	Spring		Summer/Fall		Winter		All Seasons[s]	
		2060	2100	2060	2100	2060	2100	2060	2100
1	Whole Project Area	2	-4	-36	-42	22	28	-10	-13
	Russia Chukchi	73	91	-60	-72	287	492	-7	2
	U.S. Chukchi	45	39	-48	-51	117	222	3	16
	Russia Bering	-8	-26	-1	-1	40	6	9	-7
	U.S. Bering	-38	-51	0	0	-24	-46	-22	-35
2	Whole Project Area	12	21	-17	-20	42	75	3	11
	Russia Chukchi	74	116	-36	-43	329	662	7	31
	U.S. Chukchi	57	79	-25	-27	159	315	15	38
	Russia Bering	6	3	0	0	61	57	16	15
	U.S. Bering	-18	-19	0	0	-2	-5	-6	-7
3	Whole Project Area	15	31	-9	-11	52	93	10	21
	Russia Chukchi	74	141	-20	-24	373	807	19	52
	U.S. Chukchi	57	93	-16	-17	181	361	21	48
	Russia Bering	9	10	0	0	68	71	18	19
	U.S. Bering	-9	-10	0	0	9	9	0	2
Ice-accessible habitat only[b]	Whole Project Area	-13	-36	-85	-100	-2	-24	-33	-53
	Russia Chukchi	73	76	-82	-100	269	393	-18	-21
	U.S. Chukchi	35	9	-96	-100	88	161	-12	-9
	Russia Bering	-43	-93	-100	-100	4	-87	-23	-90
	U.S. Bering	-69	-96	0	0	-51	-92	-59	-94

[a] Values calculated from monthly averages over a calendar year (January–December).

[b] Values are the same under all scenarios because the travel distance from sea into open water did not vary among scenarios.

expect increases in spring and winter. Compared to total potential habitat, however, we found more pronounced changes in ice-accessible habitat only (Table 4.3). Across the whole project area and all seasons, we found a decrease in ice-accessible habitat of -33% by 2060 and -53% by 2100 under RCP 8.5 will occur. Also, contrary to the changes expected for total potential habitat, decreases in ice-accessible habitat will occur in all seasons.

Pacific walruses currently use sea ice for courtship and breeding from December to March with a core period occurring from January to February.   In addition, Pacific walruses currently use sea ice for birthing in the spring from April to June with a core birthing period occurring in May. Furthermore, calves nurse on the sea ice exclusively for 2–4 weeks after birth, and this critical period in post-natal care occurs from May–June. Given our results, we found that Pacific walruses habitat needs will be met during the core breeding and birthing portions of the annual cycle under all RCP and time periods except for RCP 8.5 at 2100. In 2100 under RCP 8.5, the peripheral birthing (June) and breeding (December) periods as well as a portion of the core post-natal care period will likely be impacted by sea ice loss (Figure 4.6).

We found that total potential habitat for Pacific walruses in summer/fall will decrease by up to 60% by 2060 and up to 72% by 2100 (Table 4.3), depending on the travel distances of foraging trips that Pacific walruses, especially females with dependent young, are willing to take. During this time, Pacific walruses require habitat for resting, foraging, nursing, and other maintenance-related activities that are necessary for their survival. Although Pacific walruses prefer sea ice habitat, they also use land habitat during summer/fall, but likely not without tradeoffs related to energetic costs and other risks of using coastal haulouts (e.g., trampling events). Nonetheless, if land habitat proves to be comparable in quality to ice habitat, including access to foraging sites, behavior to occur in areas where animals are already concentrated by suitable ice and forage conditions.

Our analysis of future sea-ice conditions under various emission scenarios suggests that broken sea ice habitats, a substrate typically used during courtship, will likely persist through the breeding season into the future, although the location of broken sea ice habitats will likely shift northward over time into the Southern Chukchi Sea (Appendix B, Figure 6). It should be noted that some model projections under the RCP 8.5 forcing scenario project ice free conditions in December and January at 2100 in the Bering and Chukchi Seas (Figure 4.6) which could potentially limit opportunities to form Pacific walrus breeding aggregations in sea ice habitats. We found no information for predicting how Pacific walruses are likely to respond to a scenario with little to no sea ice during the breeding season. We assume that the availability of suitable breeding habitat would decline as the number of ice free winter months increased (Appendix A).

During the spring, Pacific walruses typically give birth to a single calf in May (Fay 1982, pp. 172-209; Fay et al. 1984b, p. 99). Calving typically occurs on sea ice (Fay 1982, p. 202) and mothers and newborn calves tend to remain on ice floes during the first few weeks of life (Fay and Ray 1968, p. 9; Fay et al. 1984a, p. 82). The location of calving is highly variable,

Figure 4.6. Schematic of the timing of breeding, birthing, and nursing behaviors of Pacific walruses in relation to ice-free months in the Bering and Chukchi seas for 2015 as well as projections for 2060 and 2100 under climate forcing scenario Representative Concentration Pathways (RCP) 4.5 and 8.5. Pie charts are the probabilities of four states of the all season abundance stressor node of the revised Bayesian belief network model for each time period and RCP.

presumably reflecting the influence of large variations in sea ice cover and the timing of migration (Fay et al. 1984a, pp. 82-83).

By 2060, sea ice extent in the Bering Seas is expected to be markedly reduced in May under all RCP forcing scenarios examined; however, consolidated sea-ice in the southern Chukchi Sea is expected to moderate over time, and extensive areas of broken sea ice habitats are expected to persist in this region (Appendix B, Figure 7; Figure 4.64). As is the case with breeding, the birth of a calf does not appear to be tied to specific geographic locations (Fay et al. 1984a, pp. 82-83), and we expect that the location of favorable ice conditions for calving will shift northward over time. Some model projections under the RCP 8.5 forcing scenario project ice free conditions occurring in June at 2100 across the Bering and Chukchi Seas (Figure 4.6) which could limit opportunities for ice associated neonatal care. Although female Pacific walruses and calves are occasionally reported at coastal haulouts in June (Mymrin et al. 1990, p. 105; Smirnov et al. 2002, p. 19; Smirnov et al 2004, p 24), they are more typically associated with sea ice at this time of the year. We assume that the adequacy of suitable birthing habitat would decline as the number of ice free spring months increased (Appendix A).

Key considerations for adult females during the summer/fall include the ability to obtain sufficient food resources to fuel their own metabolic demands and to meet the energetic demands of lactation. Key considerations for juvenile animals at this time of the year include obtaining sufficient energy to sustain growth and development; and avoiding direct mortality associated with predation, disturbances and other factors. At the present time, most adult females and dependent young spend the summer/fall months in the Chukchi Sea. They tend to occupy sea ice habitats in early summer (typically June-August), and terrestrial haulouts in the fall (typically September-November). By 2060, the duration (Table 4.2) and extent (Appendix B, Table 4) of summer/fall sea ice habitats in the Chukchi Sea are projected to be markedly reduced under all climate forcing scenarios examined. By 2100, ice free conditions across continental shelf waters of the Chukchi Sea may persist through the entire summer/fall season conditional upon the underlying assumptions associated with the various climate forcing scenarios.

As sea-ice withdraws from offshore feeding areas in the Chukchi Sea, female Pacific walruses and juvenile animals are expected to become increasingly dependent on terrestrial haulouts as a foraging base. While female Pacific walruses and juveniles appear to be capable of using terrestrial haulouts at this time of year (Mymrin et al. 1990, p. 105; Garlich-Miller and Jay 2000, p. 8; Kovacs et al. 2014, p. 3) they generally prefer to rest on sea ice when available. Broken sea ice habitats provide access to offshore feeding areas and may also serve as a refuge from terrestrial predators (Kochnev 2004, p. 286; Ovsyanikov et al. 2007) and reduce rates of juvenile mortality associated with disturbance events at crowded coastal haulouts (Fay and Kelly 1980, pp. 226, 244). The potential demographic consequences of increased use of coastal haulouts by female Pacific walruses and dependent young are examined further in Section 4.4.1.

4.3.4 Ocean Warming

Polar amplification, i.e. enhanced high latitude warming (Arrhenius and Holden 1897, p. 23) is expected to continue through end of century, although, the CIMP5 GCMs tend to underestimate SSTs at the higher latitudes (IPCC 2013, p. 778). Global SST changes to 2060 and beyond are projected to be greatest under RCP 8.5 and least under RCP 2.6 (IPCC 2013, p. 993; Carton et al. 2015, p. 7684). Downscaled regional projections of SSTs for the Bering and Chukchi seas were provided by Wang et al. (2012, pp. 53-55) based on the CMIP3 models. SSTs in the Bering and Chukchi seas reach the maximum in August and minimum in March or April (Wang et al. 2012, p. 52). Wang et al. (2012, pp. 53-55) illustrate projected trends for December (winter), May (spring), and July and September (summer/fall) to 2100 for the Chukchi Sea, the western Bering Sea, and the eastern Bering Sea. All three regions have a similar pattern of increasing SSTs over time but vary substantially by season, rate, and magnitude ranging from ≤0.5–1.4° C for 2060 and about 2.5° C by 2100. As noted in the current conditions section (3.1.4 Ocean Warming), Pacific walruses are tolerant of a wide range of water temperatures and these small projected increases in average temperatures that are historically a few degrees above and below zero are not likely to have an impact on Pacific walrus physiology or behavior.

The potential indirect effects of SST increases on Pacific walrus prey are more difficult to assess (Fields et al. 1993, p. 361; Lovvorn et al. 2015, p. 19; Renaud et al. 2015, pp. 249-250). Renaud et al. (2015, p. 244) suggested that as Arctic shelf seas warm, the range of Arctic benthic fauna will contract and sub-Arctic fauna will expand. The Barents and Chukchi seas are predicted to be a major route of faunal expansion into the Arctic both through natural distributional changes and anthropogenically assisted dispersal such as through ship ballast water (Renaud et al. 2015, p. 249). In the near future, as species adapt, and ecological processes evolve, the benthic community may become more homogenized with sub-Arctic species exchange between the Atlantic and Pacific oceans. However, there are substantial uncertainties about the potential ecological interactions, anthropogenic forces, and specific environmental changes both in space and time (Renaud et al. 2015, p. 253). In summary, based on the best available information, we conclude that there likely will be some distribution and species composition shifts with subarctic species moving north and arctic species declining. In addition, benthic species richness is also likely to decline. However, the lack of information on the thermal tolerances of Pacific walrus prey makes predictions about their viability under future ocean SSTs difficult.

4.3.5 Ocean and Benthic Productivity

Many simultaneous changes (e.g., ocean currents, temperature, sea ice extent, wind patterns) are occurring in Pacific walrus-occupied habitats. Although there is uncertainty about the specific consequences of these changes, future benthic productivity in the Bering and Chukchi seas may partly hinge on the strength of the pelagic-benthic coupling in primary production observed for the region (Grebmeier et al. 2015a, p. 109). The available information suggests a continuing, but regionally variable, increase in the export of primary production to the benthos, but as warming continues along with seawater stratification and nutrient depletion, export to the benthos may decline (Grebmeier et al. 2015a, p. 109). Modeling of the Bering Sea ecosystem indicates that the ratio of benthic to pelagic production decreased during past warm conditions, but increased during cooling periods (Hermann et al. 2013, p. 138).

Projections of benthic invertebrate infauna mass (g C m^{-2}) (original macrofaunal data from Grebmeier and Cooper 2014) were produced by NOAA's Pacific Marine Environmental Laboratory based on three GCMs that are available for the Bering Sea out to 2040 (http://portal.aoos.org/arctic#module-metadata/4f706756-7d57-11e3-bce5-00219bfe5678/ea47bfaf-0928-49bb-a437-2d39ff6aced4). Both the St. Lawrence Island Polynya and the Chirikov Basin benthic hotpots are covered by those projections. These areas are thought to be more susceptible to warming conditions than the hotspots further north (Grebmeier et al. 2015a, p. 110). We determined the centroid of each hotspot as mapped in Grebmeier et al. (2015a, p. 94) and downloaded the data from the Arctic Ocean Observing System web site for the central location of each hotspot of each GCM projection. Those data were then summarized by year and averaged over the three GCMs. The projections under the A1B forcing scenario (Hermann et al. 2013, p. 122) indicate large year-to-year variation with extended periods of both lower and higher mass, resulting in a stable trend for both areas from 2015 to 2040 (Figure. 4.7). However, localized declines in mass and changes in species composition in the St. Lawrence Island Polynya and southern Chukchi Sea hotspots have been observed (Grebmeier et al. 2015a, p. 109). The benthic mass projections largely incorporate the effects of variation in SSTs and primary productivity (Gibson and Spitz 2011, p. 220). We could not find model projections for the Chukchi Sea, although a decadal time series in the southern Chukchi Sea at select stations indicate regional declines in benthic macrofaunal biomass (Grebmeier et al. 2015a, p. 102), while the limited time series of benthic data in the northeastern Chukchi Sea prevented any trend analysis.

Thus, benthic infauna mass in the Bering Sea likely will fluctuate in the near term with consecutive years of lower and higher mass relative to the overall mean, depending on regional scaling, but the longer term trend is unknown. Although the precise effects of possible decreases in preferred prey and habitat on the Pacific walrus are uncertain, we expect any large decreases that may occur in benthic prey due to climate change and declining sea ice to have negative impacts on the Pacific walrus population. The magnitude of that effect likely increases through time though it cannot be assessed with certainty due to overall lack of information on the magnitude of the effect on Pacific walrus prey and Pacific walrus responses.

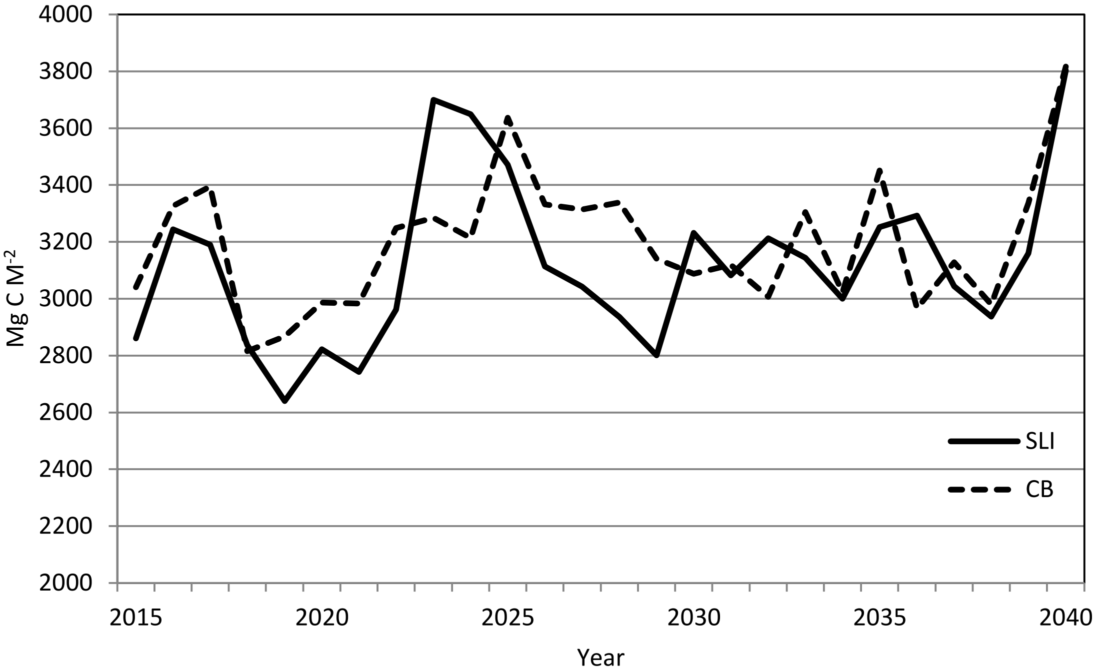


Figure 4.7. Estimates of benthic infauna mass (mg C m^{-2}) for the St. Lawrence Island Polynya (SLI) and Chirikov Basin (CB) hotpots as defined by Grebmeier (2015a, p. 94) (2015a, p. 94) for 2015–2040. Data were acquired from the Arctic Ocean Observing System (www.aoos.org).

4.3.6 Ocean acidification

The extended open water season projected for the Bering and Chukchi seas (Table 4.2) will increase the potential for CO_2 absorption in the region over the next century (Mathis et al. 2015, p. 123). However, increases in production via phytoplankton photosynthesis and warmer ocean temperatures may mitigate undersaturation to some extent (Bates and Mathis 2009, p. 2451; Cai et al. 2010, p. 556). Thus, researchers emphasize uncertainty on the magnitude, spatial extent, and temporal scale at which undersaturation may occur in the Arctic (Steinacher et al. 2009, p. 530). Qi et al (2017, p. 197) concluded that if trends observed from 1994–2010 continued, the entire Arctic Ocean would be undersaturated in aragonite in about 20 years to a depth of 250 m. However, spatial and temporal variation is also likely to persist and changes in ocean circulation patterns could reverse the trend (Qi et al. 2017, p. 197).

Mathis et al. (2015, p. 126) used the observed range of variability in aragonite saturation to estimate when conditions may become detrimental to marine calcifiers in the Bering and Chukchi seas. Those model projections indicate that aragonite saturation will fall below minimum levels of natural variability based on the average for 2012 by 2044 in the Bering Sea and 2027 in the Chukchi Sea, and below the minimum observed for any month in 2012 by 2085 and 2059, respectively (Mathis et al. 2015, p. 132). The projected years when aragonite saturation reaches the <1 threshold are 2062 for the Bering Sea and 2033 for the Chukchi Sea. Aragonite undersaturation states will likely be reached sooner in the Chukchi Sea and may occur by 2027 (Mathis et al. 2015, p. 132).

The best available information suggests that many calcifying invertebrates will be negatively impacted by OA, but the magnitude of that impact is unknown. Many factors influence the severity of OA impacts on different species and life stages, including previous exposure to acidified seawater, natural variation in aragonite saturation, and available food resources. We do not know which species of Pacific walrus prey may adapt to OA conditions and thrive, or which may decline. Research indicates that Pacific walrus prey with a pelagic larval stage may be impacted to a greater extent than those that brood larvae. However, diet studies of Pacific walruses do not have the taxonomic resolution to determine which prey items have these reproductive strategies (Sheffield and Grebmeier 2009, pp. 761-777). Studies indicate that portions of the Chukchi Sea are seasonally undersaturated and organisms in those areas may be more tolerant of OA. Although Pacific walruses are adapted for eating bivalves, they also have the potential to eat other items if bivalves and other calcifying invertebrate populations decline. For example, even though bivalves are abundant in the Chukchi Sea, polychaetes were the most abundant food item in the stomachs of Pacific walruses from the Chukchi Sea (Sheffield and Grebmeier 2009, p. 770) and many polychaetes are not calcifiers. However, the decline in the Pacific walrus population in the 1980s when the population appeared food limited and the dietary breadth expanded (Fay et al. 1989b, pp. 4-10), suggests that a shift to alternate foods may result in negative consequences to the population.

4.3.7. Climate Change on Benthos

In the revised BBN the effects of sea ice loss, SST increases, change in benthic productivity, and OA, were captured in the Climate Change on Benthos node (Table 4.1; Appendix A). In general, the Science Team felt that the effects of climate change on the benthos would become increasingly negative over time. However, variation among Science Team members (uncertainty) also increased with time, particularly in 2100.

4.4 Bayesian Belief Network Expert Elicitations

For several important stressors that make up the nodes of the revised BBN model there is little or no data available for developing the Conditional Probability Tables (CPTs) of the relevant nodes. The following discussions, in addition to the information from the modeling exercises described above, provide the basis for the development of those CPTs by the Science Team in the revised BBN model (Appendix A).

4.4.1 Coastal Haulout Use by Pacific Walruses

In this section, we focus on coastal haulout use by females and young as they are the demographic segment of the population that are very likely impacted the most as coastal haulout use increases. Our projections of sea ice loss in the Chukchi Sea indicate that by 2100, Pacific walruses will be experiencing an ice-free period that lasts up to five months under RCP 8.5 (Table 4.2). Thus, we expect the use of coastal haulouts to increase in duration, likely forming earlier than currently observed.

Several authors have identified the likely negative effect of declining sea ice on Pacific walrus energetics (Jay et al. 2011, p. 1067; Jay et al. 2012, p. 11; MacCracken 2012, p. 2085; Noren et al. 2012, p. 273; Beatty et al. 2016, p. 30; Jay et al. 2017, p. 386). Declining sea ice and an extension of the open water period in the Chukchi Sea results in an increase in use of coastal haulouts by Pacific walruses (Jay et al. 2012, p. 10). This increased use of land-based haulouts in the northeastern Chukchi Sea places Pacific walruses further from foraging areas than when hauled out on ice (Jay et al. 2012, pp. 10-11) resulting in an increase in time Pacific walruses spend swimming at the cost of a reduction in time Pacific walruses spend foraging and resting (Jay et al. 2017, p. 386) . These changes in behavior associated with increased use of coastal haulouts likely results in increased energy expenditures to access foraging areas (Jay et al. 2011, p. 1065; Jay et al. 2012, p. 11).

The demographic groups most vulnerable to increased energetic demands are lactating females and young (Jay et al. 2012, p. 11; Noren et al. 2012, p. 261; Noren et al. 2014, p. 851). Lactating females have double the energy demand when compared to non-reproductive females (Noren et al. 2012, p. 272). This increased energy demand can be partially met by utilizing stored energy in the form of blubber (Noren et al. 2014, p. 851). Younger Pacific walruses (i.e., ages 2–5) are also disproportionally impacted by increased energy demands associated with increased use of coastal haulouts as they have higher mass-specific metabolic rates (Noren et al. 2012, p. 271), likely have been weaned recently and are therefore inexperienced foragers (Jay et al. 2012, p. 11; Noren et al. 2015a, p. 3326), and have considerably lower dive capacity when compared to adults (see Noren et al. 2012, p. 11; Noren et al. 2015a, pp. 3325-3326) all of which limit their foraging efficiency and competitive ability against conspecifics (Jay et al. 2012, p. 12; Noren et al. 2015a, p. 3325). Importantly, while the increased use of coastal haulouts is negatively correlated with Pacific walrus energetics, the magnitude of the effect and the concomitant population level implications remain unknown (Jay et al. 2017, p. 394) .

As Pacific walruses become increasingly dependent on coastal haulouts, the potential for disturbances that result in mortality events increases. Chronic levels of disturbance related mortalities at coastal haulouts that result in large mortality events could have large negative population level effects over time (Udevitz et al. 2013, p. 291). If a disturbance occurs at a coastal haulout, the level of mortality is likely proportional to the size of the haulout. Based on the current response of Pacific walruses to declining sea ice, it is likely that Pacific walruses will continue to haulout in large aggregations along the coast when sea ice retreats north of continental shelf waters (Jay et al. 2011, p. 1065).

While there is disagreement as to the severity of the effect, in general the Science Team found that as the ice-free season increases in the future, Pacific walruses will spend more time at coastal haulouts resulting in increasingly negative effects on the population manifested through increased energy expenditure and disturbance related mortality events (Appendix A).

4.4.2 Subsistence Hunting

There is a great deal of uncertainty surrounding predictions of Pacific walrus harvest levels into the future. For example, Jay et al. (2011, p. 1078) and the current Science Team did not attempt to predict future harvests but instead focused on the influence that harvest had on model outcomes. In contrast, USFWS (2011, p. 7675) assumed that total harvest levels would remain the same as observed at that time and that with a declining population, harvest rates may become unsustainable in the future.

In developing the revised BBN (Appendix A), the Science Team agreed that it was not possible to predict future harvest levels and therefore decided to set harvest at the current level (low), in terms of numbers harvested, for all model runs (Appendix A). In sensitivity analyses of the revised BBN model, the harvest node also had a large influence on the model outcomes (Appendix A).

4.4.3 Disease and Parasites

Our ability to predict potential impacts of disease and parasites on the Pacific walrus population in the future is limited for two primary reasons. First, we lack information on current pathological effects of various infectious diseases and parasites on Pacific walruses (see Section 3.4 Disease and Parasites) and are unable to predict their future effects on the population. Second, the possible influence of climate mediated environmental changes on potential disease vectors is largely hypothetical. Although climate mediated changes in the Bering and Chukchi Seas could potentially result in significant health consequences for Pacific walruses, the extent to which negative health consequences will be realized in the future remains uncertain.

Increased water temperatures and the retreat of sea ice habitats could result in a northward advance of marine species into the Bering and Chukchi Seas and an influx of novel pathogens. Some pathogens could experience increased survival rates due to a warming water temperatures. Diseases could potentially interact to lower Pacific walrus body condition and suppress immune systems (Burek et al. 2008, p. S129). The moderation of sea ice in the high Arctic could also increase opportunities for pathogen transfer associated with dispersal between the Pacific and Atlantic Oceans. Increased dependency on terrestrial haulouts during the summer months could also increase intraspecific interactions and exposure to fecal-borne pathogens (Sonsthagen et al. 2014, p. 498). It has been noted that Pacific walruses, like other arctic marine mammals, have limited genetic diversity in their major histocompatibility complex; suggesting they may be immunologically naïve to pathogens more prevalent in temperate climates and may have a reduced capacity to respond to novel immunological challenges (Sonsthagen et al. 2014, p. 498). Although the introduction of a novel diseases or parasites to an immunologically-naïve population could cause an initial pulse of high morbidity or mortality, once the population develops immunity (or is reduced below a critical population threshold) the epidemic may resolve itself (Burek et al. 2008, p. S129). While all of these consequences to Pacific walruses are plausible, we have no basis from which to predict their likelihood of occurring, or the scale of likely population level effects.

Although the potential for disease and parasite infections can reasonably be expected to increase in the future, our current understanding of disease vectors and their effects on Pacific walruses is rudimentary. Noting that diseases and parasites do not appear to have significant population level effects at the present time, the Science Team weighted the influence of disease and parasites on the current population as relatively low in the revised BBN model. The potential for diseases and parasites to occur within the Pacific walrus population was assumed to increase in the future in concert with projections of future sea ice losses in the Bering and Chukchi Seas.

4.4.4 Predation

We anticipate increased potential for interactions between Pacific walruses and predators, specifically polar bears and killer whales, in the future owing to predicted changes in sea ice and the marine environment. As the number of ice-free months increase, both Pacific walruses and polar bears are expected to spend even more time on land. Coastal haulouts of Pacific walrus may become important feeding areas for polar bears; in fact, the presence of polar bears along the coast during ice-free months may influence selection and patterns of haulout use by Pacific walruses (Garlich-Miller et al. 2011a, p. 66). If Pacific walruses are disturbed by polar bears (or other potential predators) while hauled out on land, stampedes can occur resulting in Pacific walrus mortalities and energetic costs of Pacific walruses can increase, especially without adequate rest in between disturbance events (Kochnev 2004, p. 286). In addition, persistent presence of polar bears at a haulout could lead to Pacific walruses abandoning that area.

Pacific walruses also may spend more time in water transiting between foraging areas as the number of ice-free months increase. This change in Pacific walrus behavior may result in increased susceptibility to predation by killer whales, as suggested for seals (Boveng et al. 2009, p. 169), as mammal-eating killer whales commonly exploit pinnipeds in the near-shore waters around dense haulouts (elephant seals, harbor seals, various sea lions, and fur seals). Killer whales typically do not penetrate far into the ice pack, but as sea ice concentration is reduced, killer whales have potential to expand their range northward as evidenced by recent sightings during aerial surveys for marine mammals (Clarke et al. 2012, p. 103; Clarke et al. 2014, p. i; also see Breed et al. 2017, p. 1).

Based on the results of the BBN, the Science Team found that Pacific walrus mortalities from direct and indirect predation will increase as the number of ice-free months increases (Appendix A). Science Team members diverged on the magnitude of increase in predation-related mortalities. Some members expected the increase to be gradual, while others expected it to be more rapid, especially when the number of ice-free months exceeded two. We attribute this variation to the lack of historical or recent information about Pacific walrus behavior and predation rates under prolonged ice-free conditions. Thus, we concluded that Pacific walruses will likely experience a minor to moderate increase in predation in the future as sea ice decreases; in the revised BBN model sensitivity analyses, predation and related moralities had little influence on the model outcome (Appendix A), suggesting that any overall effect would be small.

4.4.5 Contaminants and Biotoxins

We found that contaminants and biotoxins likely do not pose a threat to Pacific walruses at the present time. Sampled tissues indicate relatively low exposure rates and no pathological effects have been reported. Climate-related changes may affect long-range and oceanic transport of contaminants and may provide new sources of contaminants. For example, melting pack ice may release contaminants into the marine environment (Metcalf and Robards 2008, p. S153) and increasing water temperatures may increase methylation of mercury thereby increasing the availability of mercury for bioaccumulation (Sunderland et al. 2009, p. 1). In addition, Cesium 137 from nuclear weapons testing fallout and Chernobyl may be liberated from storage in trees as forest fires increase due to climate change (AMAP 2009, pp. 66).

However, because Pacific walruses are primarily benthic feeders that specialize on low trophic level prey, we found that future increases in exposure to organochlorine or heavy metal contaminants will be minor unless they begin feeding regularly at a higher trophic level (e.g., seals) similar to Atlantic walruses. Although some individual Pacific walruses feed on fish and seals, this type of behavior does not appear to be common (Seymour et al. 2014, p. 941). Biotoxins in the marine environment are an emerging concern and Pacific walruses have likely been exposed to algal toxins, although toxosis has not been reported. While increasing ocean temperatures may increase exposures to algal toxins in the future, we found no basis for evaluating potential future effects on the population.

Within the revised BBN model, potential effects of pollution and contaminants on Pacific walruses was not considered explicitly, but instead are incorporated into multiple parent and child nodes, most notably the node that captures oil spills (Appendix A). In addition, we considered impacts of pollution and contaminants in the nodes for Resource Utilization and Ship and Air Traffic. None of these nodes ranked high (within the top three) during sensitivity analyses of the revised BBN model (Appendix A). Overall, the Science Team found that Pacific walruses may experience increased exposure to pollution and contaminants in the future, but because we lack information on concentration thresholds beyond which negative effects to

Pacific walruses have been observed, we are unable to predict the magnitude of any potential future effects.

4.4.6 Oil and Gas Exploration, Development, and Production

The USGS suggests that approximately 30% of the world's undiscovered gas and 13% of the undiscovered oil are north of the Arctic Circle, mostly offshore under less than 500 m of water (Gautier et al. 2009, p. 1175). These extensive reserves coupled with rising global demand and increased access as sea ice declines make it likely that oil and gas activity will increase in the Arctic in the future. However, we found that the near future oil and gas activity, at least in the Chukchi Sea, is unlikely due to the termination of Lease Sale 193 and the cancelation of other lease sales and exploration in Russian Federation waters.

The Bureau of Ocean Energy Management (BOEM) has cancelled future offshore leasing in the Arctic through 2022 (BOEM, 2017-2022 Outer Continental Shelf Oil and Gas Leasing Proposed Final Program, Nov. 2016). Even if lease sales are prioritized in the Bering and Chukchi seas, it is unlikely that oil prices will reach levels in the near future that will make active exploration and development feasible (National Petroleum Council 2015, p. 10).

Unlike the Chukchi Sea, oil and gas production and exploration is expected to continue in the Beaufort Sea. Recently, a Texas based company announced their discovery of approximately six billion barrels of light crude oil to the east of Utiagvik, AK in the Beaufort Sea (DeMarban 2016). As previously discussed, Pacific walrus are not commonly found in the Beaufort Sea. Given the limited spatial overlap between Pacific walruses and oil and gas development, a large spill in the Beaufort Sea that reaches the Chukchi Sea represents the greatest risk to Pacific walruses from development in this area. BOEM (2011, p. 3.2) estimated the chance of a large spill occurring in the Beaufort Sea at <0.1% per year. Simulated spills from existing Beaufort Sea production facilities indicated that oil could move westward and reach Point Barrow in eight days with a relatively narrow slick extending into the Chukchi Sea (McCay et al. 2016, pp. iv, 57). The simulation described here occurred in October, a time when Pacific walruses are moving or have already moved out of the Chukchi Sea. Should a similar accident occur in June through September when Pacific walrus are actively using the area, an oil spill reaching the Chukchi Sea could have injurious consequences to Pacific walruses, their prey, and their habitat. In addition, the lingering effects of any spill would likely impact Pacific walruses in the long-term.

Spill response for wildlife can be broken into three phases (ARRT 2010, p. G1). Phase one is focused on eliminating the source of the spill, containing the spilled oil, and protecting environmentally sensitive areas. Phase two involves efforts to herd or haze potentially affected wildlife away from the spill area. Phase three includes the capture and rehabilitation of oiled individuals. Currently, phase one action is likely the only viable option for protecting Pacific walruses. Hazing animals or the capture and cleaning of oiled Pacific walruses has never been tried and presents several challenges (DOW 2015, p. 6).

Our analysis of oil and gas development potential was based on the analysis by BOEM (BOEM 2014, pp. 156-157) conducted for the Chukchi Sea lease sales. As a result, we anticipate that the potential for a significant oil spill, if activities resume in the area, will remain small (0.75–7.5%) over the 70-yr. development period; however, we recognize that should a spill occur, the effectiveness of oil spill cleanup in the broken-ice conditions that characterize Pacific walrus habitat is minimal. The impacts to Pacific walruses from a large spill could be substantial, particularly if subsequent cleanup efforts are ineffective. Impacts would be greatest if Pacific walruses are aggregated at coastal haulouts where oil comes to shore.

As described in Chapter 3, increased oil and gas exploration and development in the Arctic will also likely result in an increase in shipping and seismic noise levels in the marine environment. While the effects of marine noise on Pacific walruses are not fully understood, the available information suggests that future seismic surveys will have minimal impacts to Pacific walruses for three reasons; (1) most surveys will occur in areas of open water away from sea ice and coastal haulouts, where Pacific walrus densities are relatively low; (2) monitoring requirements (vessel-based observers) and mitigation measures (operations are halted when close to Pacific walruses) in U.S. waters are expected to minimize negative interactions with Pacific walruses, and; (3) seismic operations would be concentrated in one area and would likely affect a small number of individuals, and thus are unlikely to have a population-level impact.

Oil and gas exploration and development were captured in the revised BBN model through the Resource Utilization, Oil Spills and Pollution, and Haulout Disturbance nodes (Appendix A). The results of the revised BBN model found that oil and gas exploration will result in increasing stress on the Pacific walrus population as a result of an increasing risk of spills and disturbance over time. However, these factors had little impact on the cumulative stress to Pacific walrus abundance compared to those originating from the Ice-free Months, Subsistence Harvest, and Ship and Air Traffic nodes (Appendix A).

4.4.7 Commercial Fisheries

Commercial fisheries in all U.S. waters north of the Bering Strait are regulated by the Fishery Management Plan for Fish Resources of the Arctic Management Area, which was released by the NPFMC in 2009. Management policy for this region prohibits all commercial harvest of fish until sufficient information is available to support the sustainable management of a commercial fishery (NPFMC 2009, p. 3). It is unclear whether the Arctic Management Area will open to commercial fishing at all, and if so, when it would be opened. In addition, in 2015, the five Arctic nations banned commercial fisheries in Arctic waters, although the declaration (Arctic Arctic Nations 2015, inclusive) does not prevent non signatory nations from fishing in Arctic waters. Fishing for scientific purposes is also not prohibited which could leave the door open to research that could support sustainable fisheries in the future.

Because we currently lack the needed information on benthic habitats and community ecology of the northern Bering Sea, we are unable to forecast the specific impacts that may occur from nonpelagic bottom trawling (NOAA 2009, pp. 1-10) and how it may affect Pacific walruses in the future. At present non-pelagic trawling in U.S. waters is extremely limited in geographic and temporal scope and well regulated. Little information is available concerning current or projected non-pelagic trawl effort which overlaps with Pacific walrus habitats within Russian waters.

In light of the low level of current effects, the Arctic Council fishing ban and the Arctic Fisheries Management Plan, we do not anticipate that commercial fishing will rise to the level of a large stressor in the future, particularly at the population level. In addition, we expect that any increase in the level of fishery-related mortalities of Pacific walruses will occur at a low level relative to the total Pacific walrus population. The Science Team therefore found that commercial fishing would have small impacts on the Pacific walrus population. The effects of commercial fishing were captured in the revised BBN model through the Incidental Takes, Ship and Air Traffic, and Resource Utilization input nodes (Appendix A).

4.4.8 Shipping and Air Traffic

By 2045, the summer/fall ice-free season is projected to extend from the current 2.0 months to 3.5 (RCPs 2.6 and 4.5) and 3.9 months (RCP 8.5). By 2060, the ice-free season could extend to 3.6 (RCP 2.6) to 4.5 months (RCP 8.5), with further increases in 2100 (Table 4.2). Based on predicted sea-ice loss (Douglas 2010, p. 12; Wang et al. 2012, p. 50), the navigation period for the Northern Sea Route is projected to increase from the current 20–30 days to 90–100 days per year by 2100 (Laughlin et al. 2012, p. 14). Furthermore, a recent analysis of future climate mediated sea ice projections suggests that while considerable inter-annual variability in sea route accessibility will likely persist for much of the 21st century, Arctic shipping routes are expected to open more frequently, for longer periods of time, and become increasingly shorter due to the ability to transit directly across the polar sea (Melia et al. 2016, p. 1).

The projected increase in the number of ice-free days in the Chukchi Sea presents the opportunity for the expansion of resource development projects within the range of the Pacific walrus and will also improve the commercial viability of trans-arctic shipping routes through the Bering Strait, either of which could lead to increases in ship and air traffic across the summer range of the Pacific walrus (Melia et al. 2016, p. 1). Increases in oil and gas development, Arctic community population growth and associated development, and tourism are other factors that may lead to increased vessel and air traffic in the Arctic (Brigham and Ellis 2004, pp. 8-9; Arctic Council 2009, p. 5). For example, The U.S. Committee on the Marine Transporation System, using ice projections from GCMs, projects 877 to 2,673 Bering Strait transits by 2025, a 100 percent to 500 percent increase respectively over current day numbers (USCMTS 2015, p. 60).

As discussed in Chapter 3, icebreaking activities can disturb Pacific walruses through increased noise and facilitating increased shipping traffic. Icebreaking activities may increase in the future, given increases in commercial shipping and marine transportation that may want to or be required to be accompanied by icebreakers. In particular, the establishment of the Northern Sea Route as a viable alternative trade route connecting the Atlantic and Pacific oceans is contingent on, among other factors, the availability of a reliable government or private icebreaking fleet to clear the entire route and provide predictable open shipping lanes (Brigham and Ellis 2004, pp. 8, 9; Arctic Council 2009, p. 20).

Alaska Native subsistence users are concerned about the potential effects of increased shipping traffic on both Pacific walruses and the availability of Pacific walruses for hunting. We found that shipping will likely increase in the future. However, shipping lanes are typically several kilometers from shore and traffic is episodic. Therefore, disturbance from such activities is expected to be low because of its small footprint in both time and space. Pacific walruses making feeding trips from shore or during migrations could encounter vessels in open water but for relatively brief periods. Additionally, most shipping routes are far enough offshore to not disturb Pacific walruses at coastal haulout areas. While the relationship between vessel traffic levels and potential impacts to the Pacific walrus is difficult to quantify, we found that increased shipping traffic as a result of declining sea ice is likely to result in a moderate increase in stress on the Pacific walrus population over time.

With the suspension of oil and gas exploration activities in the Bering and Chukchi Seas, the risk of a contaminants spill in the near future is primarily associated with commercial shipping activities. A variety of goods are shipped through the region ranging from fuels to minerals and general cargo (Marine Exchange of Alaska 2015, pp. 8-13). An accident could result in the release of fuel and other contaminants powering the vessel as well as any cargo, ballast, or waste. Although this issue was part of the Science Team deliberations, the unpredictability of such an event and its localized nature resulted in the Shipping and Air Traffic nodes influence on the revised BBN model outcomes ranking fourth (Appendix A).

4.5 Revised Bayesian Belief Network Model Outcomes

The revised BBN model outcomes are not absolute and do not represent a time series in the usual sense as the outcomes of a previous time step do not influence the outcomes of a subsequent time step. The probability distributions of the abundance stressors at any time step are relative to other time steps through the projections of each RCP, the coupled GCMs, and links to models of relevant conditions such as sea ice and sea surface temperatures. Changes in probabilities among states in output nodes from one time step to the next should be viewed as relative changes and referenced to the 2015 outcomes.

The primary outputs of the revised BBN model were the probabilities of the states (low, moderately low, moderately high, and high) of three seasonal relative abundance stressor nodes (winter, spring, and summer/fall). Each of those was a parent node of the final output node - the all season abundance stressors which represented the overall stressors on Pacific walrus abundance throughout the year as the probabilities of the states of the input and intermediate nodes propagate through the network. A discussion of those outcomes follows.

4.5.1 Trends in Seasonal Relative Abundance Stressors

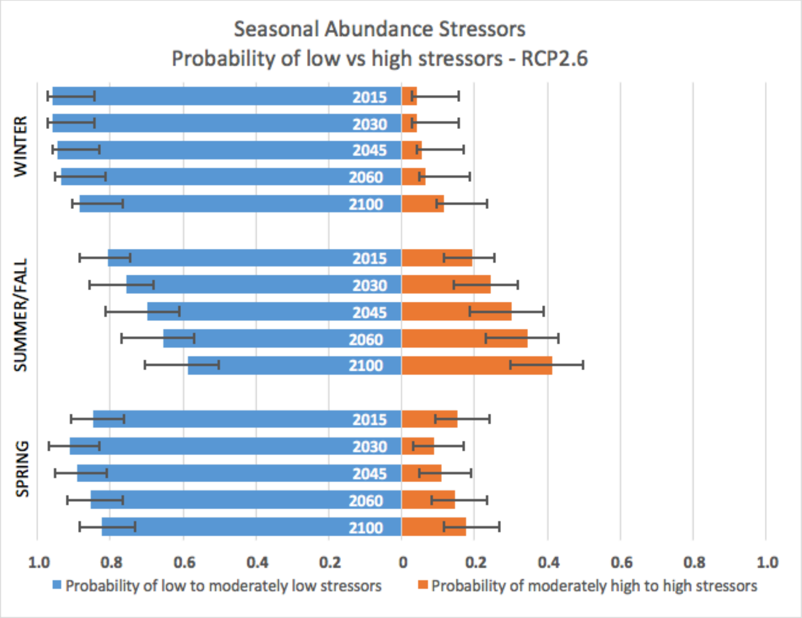
Overall, seasonal abundance stressor outcomes vary similarly by season and time step for each RCP, with probability distributions for the spring and winter seasons generally showing a greater proportion of low to moderately low stressors, and distributions for summer/fall showing larger probabilities of moderately high to high stressors (Figure 4.8). This trend closely follows that observed in the sea ice estimates for RCP 2.6, RCP 4.5, and RCP 8.5 (Figure 4.3) and reflects the large influence that Ice Free Months had on model outcomes owing to its linkages to numerous intermediate nodes. As noted in the sensitivity analysis of the revised BBN model (Appendix A) the influence of Subsistence Harvest, Incidental Takes, and Ship and Air Traffic nodes was smaller overall than Ice-Free Months.

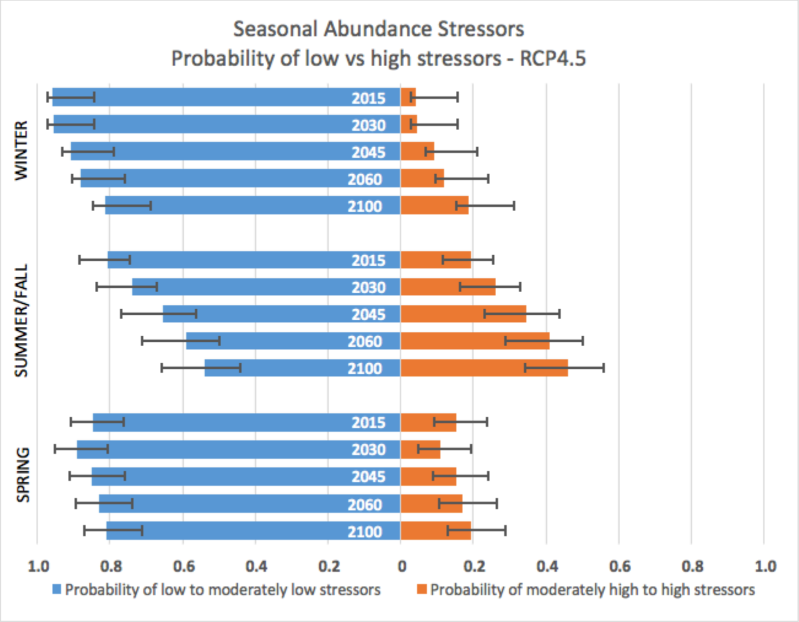
4.5.2 Trend in All Season Relative Abundance Stressors

The all-season abundance stressor outcomes illustrate a large range of probability distributions from primarily low and moderately low stressors in 2015, up to near 50% probability of moderately high and high stressors under RCP 8.5 in 2060, increasing to > 60% by 2100 (Figure 4.9). RCP 2.6 resulted in the lowest proportion of moderately high and high stressors across time steps, while RCP 4.5 showed slight increases, and RCP 8.5 resulted in the greatest proportion of moderately high to high stressors.

Consequently, the greatest proportion of moderately high to high stressors was associated with RCP 8.5 where CO_2 emissions and concentrations increase through 2100 (Meinhausen et al. 2011, pp. 228, 229). A modest proportion of moderately high to high stressors were associated with a pathway (RCP 4.5) where CO_2 emissions peak in 2040 and CO_2 concentrations peak around 2080 and stabilize through the end of the century (Meinhausen et al. 2011, pp. 228-230).

The lowest proportion of moderately high to high stressors was associated with a pathway (RCP 2.6) where CO_2 emissions peak in 2020 and CO_2 concentrations peak slightly before 2050 and decline thereafter (Meinhausen et al. 2011, pp. 228, 229). Thus, each pathway (RCPs 2.6, 4.5, 8.5) is associated with progressively less sea ice through the end of century.





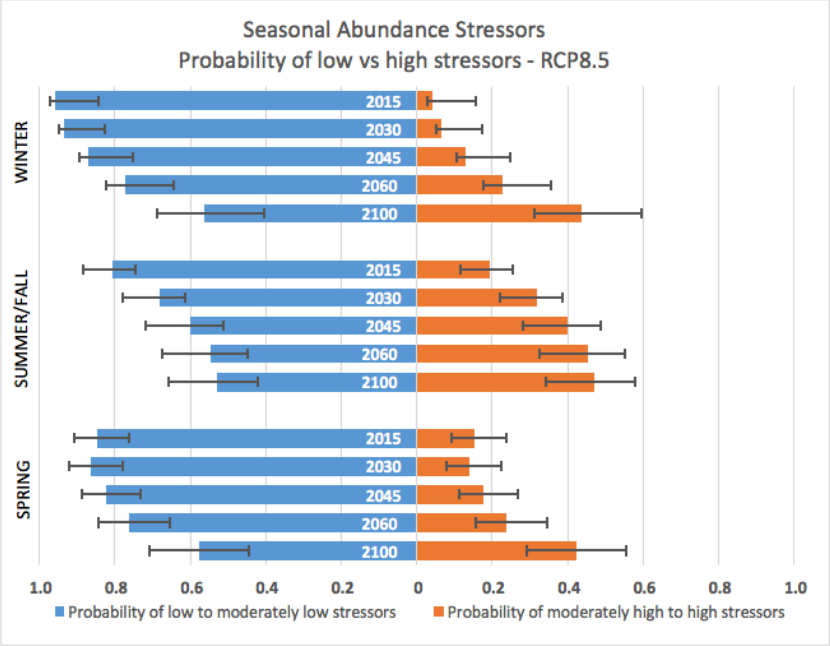


Figure 4.8. Mean probabilities of abundance stressor outcomes (low and moderately low combined and moderately high and high combined) for the revised Pacific walrus Bayesian belief network model for three seasons (winter, summer/fall, spring) under RCP 2.6, RCP 4.5, and RCP 8.5 and five time periods from 2015–2100. Bars at both ends of each row are based on minimum and maximum judgments by Science Team members when estimating probabilities of low, moderately low, moderately high, and high outcomes.

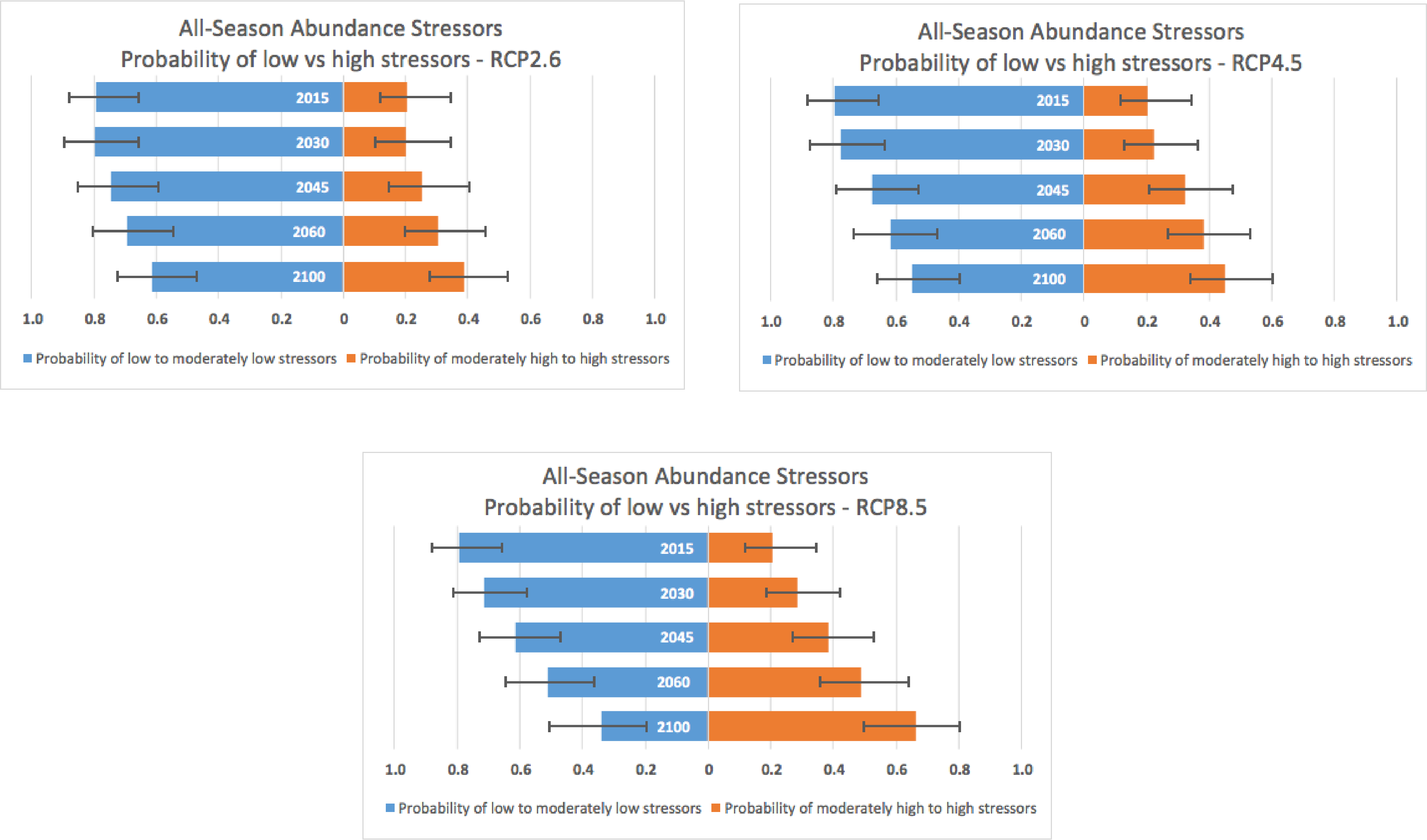


Figure 4.9. Mean probabilities for the All Season Abundance Stressors node outcomes (low and moderately low combined and moderately high and high combined) of the revised Pacific walrus Bayesian belief network model under RCP 2.6, RCP 4.5, and RCP 8.5 and five time steps from 2015–2100. Bars at both ends of each row are based on minimum and maximum judgments by Science Team members when estimating probabilities of low, moderately low, moderately high, and high outcomes.

4.5.3 Comparisons of Revised BBN Model Results with Other Studies

The summed probability of low and moderately low stress for 2015 for the revised BBN model output is approximately 80%. Here we examine this model outcome for the year 2015 within the context of relevant peer-reviewed literature that was not available when the model was revised (Charapata 2016, p. iii; MacCracken and Benter 2016, p. 588; Taylor and Udevitz 2016; Taylor 2017).

One line of evidence that points to relatively low stress in the current population involves tusk asymmetry (MacCracken and Benter 2016, p. 588). Asymmetry in bilateral traits such as Pacific walrus tusks is a result of developmental instability that is often correlated with stress (see Section 2.4.2). Perfect symmetry is the expectation under optimum conditions as bilateral traits are regulated by the same genes. Developmental instability arises with unfavorable conditions such, food shortages, as resources are directed to other physiological demands such as reproduction, particularly if selection on a trait is not strong. The tusks of Pacific walruses develop from the apex of the clinical root where an internal layer of dentin is overlain with cementum in annual increments (Fay 1982, p. 108). Thus, natural variation in tusk circumference is additive, facilitating the detection of FA. This variation occurs over the lifetime of an individual and represents the cumulative stress an individual has experienced. Thus, FA should be less in individuals that have experienced good conditions, as well as a mix of good and stressful conditions when compared to animals under stress for a large portion of their life. Competitive interactions likely result in greater stress in some individuals than in others and as conditions such as prey abundance improve, the intensity, frequency, and number of individuals experiencing competition for food decreases. It is unknown if tusk FA in an individual declines as conditions improve or if previous FA levels persist throughout a lifetime. However, we are more interested in population level responses. At the population level, as stressors decrease or increase, average FA will also decrease or increase as individuals are recruited and others die. Summary statistics on tusk asymmetry provide some insight into overall stress levels in the population. Tusk asymmetry in female and male Pacific walruses was highest during the first year of the study (1990), but declined thereafter for males (MacCracken and Benter 2016, p. 588). Female FA declined from 1990–2011, but became slightly positive in 2011–2014 , but was still an order of magnitude below 1990 levels (MacCracken and Benter 2016, p. 595).

Another line of evidence about current stress levels in Pacific walruses is provided by Charapata (2016, p. iii) who measured cortisol levels (a stress hormone) in Pacific walrus bones. He found that cortisol levels in samples from 2014 and 2015 were similar to levels in bones from archaeological (3,450–200 years ago) and historical (200–20 years ago) time periods when the Pacific walrus population was assumed to not be in a stressed condition.

Taylor and Udevitz (2016) have updated their model (Taylor and Udevitz 2015, inclusive) with more recent ship-based age composition surveys conducted in 2013–2015 and harvest data from 2006–2016. Estimates of Pacific walrus vital rates continued to improve from 2006–2015

(Taylor and Udevitz 2016). Thus, multiple lines of evidence indicate the Pacific walrus population is likely experiencing relatively low levels of stress (Garlich-Miller et al. 2006, p. 880; MacCracken et al. 2014, p. 43; Taylor and Udevitz 2015, p. 241; MacCracken and Benter 2016, p. 588). However, reproductive hormone levels in bones from harvested Pacific walruses are not consistent with this conclusion. Charapata (2016, p. 79) suggested that the population was currently near carrying capacity based on low levels of reproductive hormones in Pacific walrus bones. Consequently, conclusions based on reproductive hormones and conclusions from cortisol levels appear to at least partially contradict one another (Charapata 2016, pp. 79–80). The apparent disconnect between the two types of hormones underscores the complexity in interpreting these types of studies and reconciling potentially antagonistic environmental effects (Section 2.4.2). Changes in different hormones may not necessarily be synchronized; for example, food shortages could compromise reproduction before initiating a whole body stress response. The response of a population to changes in stressors in an environment scales with generation time (Armbruster et al. 1999, p. 69; Turkalo et al. 2016, p. 1). Generation time can be defined as the mean age of mothers that produce offspring (Caswell 2001, p. 128), and Pacific walrus generation time is approximately 15 years (Fay 1982, p. 181). Thus, we expect the response of the population in terms of changes in abundance to be lagged over at least a generation. The long generation time and expected time lag may account for the perceived disconnect between the low stress environment identified in 2015 in the revised BBN model and modeling efforts that indicate the Pacific walrus population is likely to be stable(Taylor and Udevitz 2016; Taylor 2017).

Pacific walruses forage in continental shelf waters in the Chukchi Sea, and sea ice remained over the shelf through the 1980s and 1990s until 2007. In 2007, sea ice retreated beyond the continental shelf for the first time since satellite data has been collected (i.e., 1979), and similar ice conditions occurred in 2009–2011 and 2013–2015 (Section 3.1.3). Consequently, ice retreat beyond the shelf is a relatively recent phenomenon, routinely occurring within the last 10 years (i.e., less than one Pacific walrus generation). Thus, although the Pacific walrus population appears to be under low stress at the present time, increases in abundance stressors over time, as projected in the revised BBN model, will likely limit population growth. For example, carrying capacity could be reduced due to climate-mediated changes in sea ice habitats and benthic productivity, resulting in declining abundance (Garlich-Miller et al. 2011a, p. iv; Taylor and Udevitz 2015, p. 232; Charapata 2016, p. 79).

Another factor that may partially account for the perceived discrepancy between the revised BBN model results and Taylor and Udevitz (2016) involves the structure of the model itself. The revised BBN contains information on ice-free months only, but does not contain information on sea ice extent, distribution, or concentration and its possible effects on the Pacific walrus population. Science Team members agreed that the revised BBN model likely represents an underestimate (magnitude unknown) of stress to the population because the effects of changes in sea ice extent and concentration were not included in the revised BBN model. However, the habitat analysis as detailed in Appendix B was designed to address this issue and was compared alongside the revised BBN model results (Section 4.3.3).

4.6 Uncertainty

Assessing uncertainty is a requirement of future projections (Cheung et al. 2016, p. 1284; Payne et al. 2016, p. 2172). There are several sources of uncertainty in this SSA that we have addressed including the lack of information on current conditions for some potential stressors (e.g., disease and parasite levels and predation rates), the short and long term responses of Pacific walruses to stressors, our confidence in projecting conditions for stressors based on model results or expert judgments – particularly to the end of the century, and uncertainties affecting model results. In this SSA, GCMs link climate changes to physical attributes such as SST and sea ice and those are then linked to effects on Pacific walruses and Pacific walrus responses through the revised BBN model and the habitat analysis. Each link brings with it a set of unique uncertainties (Cheung et al. 2016, p. 1285) including (1) structural (i.e., model uncertainty), (2) initialization and internal variability uncertainty, (3) parametric uncertainty, and (4) scenario uncertainty (Payne et al. 2016, p. 2172). All of these sources of uncertainty are part of this assessment and are discussed below.

The CMIP5 GCMs are large and complex with several submodels (e.g., SST and sea ice). There are over 30 models in the CMIP5 group with some modeling different aspects of the climate system better than others, producing a large range in outputs (uncertainty) when taken as a whole. Cheung et al. (2016, pp. 1283-1296) provide an analysis of uncertainties associated with climate projections on the harvest of sablefish (*Anoplopoma fimbra*) that are illustrative of the uncertainties relevant to our analyses. Using a 15 CMIP5 GCM model ensemble and the RCP 2.6 and 8.5 scenarios they note that model uncertainty in SST projections arising from the internal variability of the climate system and initializing conditions outweighs uncertainties associated with the alternative scenarios to about mid-century, but by late century scenario uncertainty takes over (Cheung et al. 2016, p. 1286). In addition, there were large differences in regional projections due to different sources of uncertainty in phenomena such as the North Atlantic Oscillation, the Pacific Decadal Oscillation, and the El-Niño Southern Oscillation. Furthermore, they noted that in the short term, the large natural variability within the region of inference made it difficult to separate the effects of natural variation from those related to GHG emissions.

Another source of uncertainty associated with GCMs is model selection or model culling as a way to reduce the uncertainty associated with the wide range of projections when all models are considered as a group (Notz 2015, p. 1; Stroeve and Notz 2015, p. 127; Cheung et al. 2016, p. 1293; Payne et al. 2016, p. 1274). One of the most popular methods of GCM model selection for sea ice studies is to backcast model outcomes, compare those outcomes to observed data, develop a rule (e.g., model estimates within the two standard deviations bound of observations) for model selection, and base projections on the ensemble of GCMs that meet the rule criteria

(Massonnet et al. 2012, p. 1383; Snape and Forster 2014, p. 1; Wang and Overland 2015, p. 51). The shortcomings of this approach were discussed in detail by Notz (2015, pp. 5-11) and Stroeve and Notz (2015, pp. 127-129) and generally revolve around issues of internal variability, observational uncertainty, metric relevance, model tuning, and the lack of a strong link between the past and the future. Both Notz (2015, p. 12) and Stroeve and Notz (2015, p. 127) suggest that a more realistic portrayal of model uncertainty may be possible by retaining the majority of GCMs.

The revised BBN model and the habitat access analysis (Appendix B) used ice-free months and sea ice extent and concentration projections as described in section 4.3.2 (Sea Ice). These projections were quantitatively linked to responses by Pacific walruses in the revised BBN model and the habitat analysis based on a number of assumptions and expert opinion that likely represent the greatest source of uncertainty in this analysis. Predicting the direction of long-term effects (negative, neutral, positive) of these sea ice projections on Pacific walruses (Table 4.4) is possible, but estimating the magnitude of the effects is confounded by unknowns about the responses of organisms making up the food web of Pacific walruses as well as the adaptive capacity of Pacific walruses themselves. In addition, how subsistence hunters will respond to these changes may greatly influence the effects of the harvest on the population.

5. VIABILITY OF THE PACIFIC WALRUS

In this chapter, we assess the ability of the Pacific walrus population to persist. To do this we draw on climate models and our analyses predicting Pacific walrus response to those projected changes. We consider the Pacific walrus population response to projected changes, primarily sea ice, within the context of resiliency, representation, and redundancy as previously described (section 3.11 Resiliency, Representation and Redundancy of the Pacific walrus). We assume that the characteristics of Pacific walruses that contribute to their resiliency, representation, and redundancy facilitated population persistence through periods of past climate change (section 2.5 Adaptive Capacity of Pacific walruses), commercial exploitation (section 3.3.1 History of Harvest), and a period of population growth then decline as the population appears to be approaching carrying capacity (section 2.4 Population Abundance and Trends). Current population vital rates indicate the Pacific walrus population has recovered from density-dependent effects that contributed to the population decline. However, the rates of climate change today exceed past rates and those changes will create new stressors which are reflected in the revised BBN model and habitat change analyses.

Table 4.4. List of primary potential stressors to the Pacific walrus population, future condition of each stressor, the projected future intensity of each stressor at 2060 and 2100 under RCP 8.5.

Potential Stressor	Possible Effect on Pacific walruses	Future Condition	Future Intensity of Stressor	
			2060	2100
Loss of summer/fall ice in Chukchi Sea.	Injury and death from trampling. Increased energy expenditure.	4.5–5.0 ice-free months per year. Marginal ice occasionally present. Potential decline of 82–100%. Increased coastal crowding.	Moderately high–high.	High.
Decline in winter sea ice, both seas.	Northward shift in distribution; Decline in breeding platforms.	Potential decline of 2–24%. 0.6–1.9 ice-free months per year.	Low.	Low–moderately low.
Decline in spring sea ice, both seas.	Northward shift in distribution. Decline in birthing habitat.	Potential decline of 13–36 %; 0.1–0.2 ice-free months per year.	Low–moderately low.	Low–moderately low.
Subsistence harvest.	Injury and direct mortality.	Harvest levels remain stable.	Low.	Low–moderately low.
Ocean warming and acidification.	Changes in prey abundance and species composition.	$\geq 2.5^{o}$ C increase in SST. pH and aragonite saturation < natural minimums.	Low–moderately low.	Moderately high–high.
Commercial fisheries.	Displaced from some areas. Increased energy expenditure. May affect prey abundance in some areas.	Continues in Bristol Bay. Potential expansion northward. $\leq$ 3 Pacific walruses taken per year.	Low–moderately low.	Moderately low.
Climate change on benthos.	Changes in prey abundance and species composition.	Arctic species decline. Sub-Arctic species increase.	Low–moderately low.	Moderately low–moderately high.

Table 4.4. Continued.

Potential Stressor	**Possible Effect on Pacific walruses**	**Future Condition**	**Future Intensity of Stressor**	
			2060	**2100**
Disease and parasites.	Potential for outbreaks, morbidity and death.	Increased likelihood of disease and parasites due to increased haulout crowding.	Low–moderately low.	Low–moderately low.
Predation.	Injury and direct mortality.	Increased likelihood of predation at coastal haulouts and potential new marine predators.	Low.	Low.
Pollution.	Injury and direct mortality.	Increased likelihood of pollution from increased shipping and potential oil and gas development.	Low.	Low–moderately low.

5.1 Resiliency

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population demographics; for example, birth versus death rates and population size. For Pacific walruses, we characterize resiliency in terms of future stressors and the population's response to those stressors. The revised BBN model indicated a high likelihood that Pacific walruses will experience a steady and substantial increase in abundance stressors compared to the level of stressors experienced today (Appendix A). These results are consistent with the outcomes of the previous BBN models of Jay et al. (2011, p. 1065) and MacCracken et al. (2013, p. 226) as estimates of negative impacts to the population increased with time becoming most intense at the end of the century.

The ability of the Pacific walrus population to adapt to or cope with increasing stressor levels in the future is a topic of great uncertainty. The increasing trend in stressors closely follows the estimated trend in decreasing sea ice. While Pacific walruses are adapted to living in a dynamic environment and have demonstrated the ability to adjust their distribution and habitat use patterns in response to shifting patterns of sea ice, it is likely that increasing abundance stressors will negatively affect the population to an unknown extent. Overall, this will likely result in a population decline and a reduction in resiliency.

5.2 Representation

Representation describes the ability of a species to adapt to changing environmental conditions and is measured by the breadth of genetic or environmental diversity within and among populations. While changes in the distribution, breeding aggregations, and calving are projected to occur, it is unlikely these changes will result in a change in the high level of genetic diversity of the population that Pacific walrus currently have (see Sonsthagen et al. 2012, p. 1512; Section 3.12.2). It is also unlikely that sea ice decline, harvest levels, or other stressors will reduce the population to the point where inbreeding would become a factor or individual fitness is reduced as reproduction and survival decline (Courchamp et al. 2008, pp. 2-17).

Since it is thought that the Pacific walrus currently occurs as a single panmictic population, the ecological diversity of the population is currently characterized by little variability in the ecological setting where the species is found. Though habitat shifts are projected in the future, variability in the ecological setting where the species is found is unlikley to change. Accordingly, representation is not expected to change under future conditions.

5.3 Redundancy

As previously described, redundancy is typically characterized by having multiple, resilient populations distributed within the species ecological settings and across the species range. However, because the Pacific walrus appears to currently occur as a single panmictic population, we measured the redundancy of the species and its ability to withstand catastrophic events by the distribution of the single population across the sea/landscape.

We conducted an analysis of potential habitat to make predictions about distribution of the Pacific walrus population across its range in 2030, 2045, 2060, and 2100 under three RCP scenarios (Section 4.3.1 Representative Concentration Pathways). For our analysis, we defined potential habitat as marine water, sea ice, or land within the study area that could be accessed and used by Pacific walruses to fulfill their life history needs within a particular season. Thus, our definition was broad and included both ice- and land-accessible habitat, even though Pacific walruses prefer to use sea ice as a haulout substrate (Fay 1982, pp. 7, 25–26), presumably because sea ice supports more life history needs such as breeding and birthing and minimizes risks associated with land haulouts such as trampling events caused by disturbance and increased energy expenditure associated with foraging. For these reasons, we focused our assessment of future redundancy on changes in sea ice habitat as a proxy to preferred distribution of Pacific walruses. We did not consider factors related to habitat quality such as benthic productivity in our analysis of potential ice-accessible habitats, likely resulting in an overestimation in redundancy of Pacific walrus, though our approach was consistent, transparent, and represents the best available information (see Appendix B for more details on our analysis).

Overall, we found a consistent decline in ice-accessible habitat for Pacific walruses in all seasons and RCPs considered in our analysis, though the magnitude of the decline varied spatially across the study area and temporally across seasons. Under RCP 8.5 with all seasons combined, we expect a decline in ice-accessible habitat of 33% by 2060 and 53% by 2100, representing a notable reduction in future redundancy.

In spring, our analysis demonstrated a decrease in potential ice-accessible habitat of 13% by 2060 and 36% by 2100, thereby reducing the redundancy of Pacific walruses. We expect to see large declines in ice-accessible habitat in the spring in the Bering Sea, and increases in the Chukchi Sea, but those increases are not large enough to offset the declines in the Bering Sea. During spring, male and female Pacific walruses begin to separate with females migrating northward to the Chukchi Sea with the retreating sea ice edge and males remaining in the Bering Sea. Therefore, we expect redundancy of male and female Pacific walruses to be affected differently. The distribution of female Pacific walruses, which give birth on sea ice in the spring, will likely shift northward and will become more restricted as ice-accessible habitat declines. However, sea ice suitable for birthing is projected to occur through 2060 under all RCPs and therefore, losses of spring sea ice likely will not be a limiting factor at that time. Conversely, the distribution of male Pacific walruses potentially could increase as additional land-accessible habitat is exposed in the Bering Sea (see Appendix B). Nonetheless, given the critical life history event that females complete in the spring, a more restricted distribution and reduction in redundancy has the potential to have a greater effect on the Pacific walrus population than the increased availability of land-accessible habitat (in the form of coastal haulouts) for male Pacific walruses.

In summer/fall, we predict a decline in future redundancy for Pacific walruses. Presently, the ice-free season in the Chukchi Sea is approximately 2.0 months and we expect it to increase to

4.5 months by 2060 and up to 5.0 months by 2100 (under RCP 8.5; Table 4.2). When sea ice is not available, Pacific walruses haulout on land; thus, we predict that Pacific walruses will use land haulouts for an additional 2–3 months compared to 2015, resulting in a decrease in redundancy as Pacific walruses are confined to land-accessible habitat and nearshore foraging areas unless greater energetic costs are incurred. Our analysis confirms this predicted pattern as we found that ice-accessible habitat will decrease by 85% by 2060 and 100% by 2100 (i.e. no summer sea ice available to Pacific walruses). One potential response by Pacific walruses during this time is that they can distribute themselves among several haulouts located along both the U.S. and Russian coasts (as males do), which can lessen the decline, at least until fall when most of the Pacific walruses in the Chukchi Sea typically move to the Russian coast. However, the use of multiple haulouts currently does not occurred along the Alaskan Chukchi Sea coast. The fall concentration of Pacific walruses on the Russian coast probably represents the lowest redundancy of the species across all seasons. We are uncertain whether Pacific walruses will continue to use a few coastal haulout sites where the impacts of potential disturbance are high (e.g., trampling) or if they will adapt to the negative consequences of large aggregations by occupying more areas in smaller groups as they do on sea ice and as observed for Atlantic walruses at coastal haulouts. However, to date, we have not observed Pacific walruses adopting this strategy even though declines in ice-accessible habitat have occurred already.

MacCracken (2012, p. 2083) suggested that Pacific walruses could potentially respond to the loss of summer sea ice in the Chukchi Sea by shifting their range to sea ice refugia in the Canadian Arctic Archipelago and the Siberian-Laptev Seas. It should be noted that they have not done so in any meaningful numbers to date, despite a general pattern of sea ice presence in summer these regions. This suggests that other factors are likely restricting their colonization of these areas and may ultimately place bounds on range expansion as a response to climate change and reduced redundancy. In winter, we detected a trend similar to spring with decreases in ice-accessible habitat in the Bering Sea and increases in the Chukchi Sea, though an overall net decrease of 2% by 2060 and 24% by 2100 was found to occur across the study area, reducing redundancy. During this time, Pacific walruses use ice to rest offshore and, in late winter, courtship and breeding occur in the broken ice pack (Fay 1982, pp. 191-192). Male Pacific walruses perform courtship displays in the water near groups of female Pacific walruses on sea ice and, when appropriate, a female Pacific walrus enters the water, joins the male, and mating occurs (Fay 1982, pp. 193-194). Thus, sea ice serves an important role in successful courtship and mating of Pacific walruses. A decrease in ice-accessible habitat in winter could result in Pacific walruses congregating in fewer areas in larger numbers compared to today to mate, resulting in a reduction in redundancy. Ice model projections indicate that ice will not be present for up to half of the breeding season by 2100 (Figure 4.6) and it is unknown if Pacific walruses will adapt to carrying out mating behaviors from the coast.

We assume that Pacific walruses will continue to select for sea ice habitats as long as they are nearer to areas of high prey mass than coastal haulouts based on the current spatial distribution of the population and habitat use patterns. However, when sea ice over the continental shelf is too sparse and far from feeding sites their range will likely contract and redundancy will be reduced. A decline in Pacific walrus distribution would make them more susceptible to large scale stochastic events (e.g., tsunamis, oil spills, and volcanic eruptions); though, the magnitude of this decline and thus their increased susceptibility is uncertain. Nonetheless, based on observed Pacific walrus behavior and habitat use, we expect changes in the location of accessible potential habitat, (i.e., a general shift northward annually) and type of habitat, (i.e., shift towards the coast), will result in a reduction in redundancy in the Pacific walrus population, though more so in the summer/fall season than winter and spring and more so at 2100 than 2060.

5.4 Conclusions

As identified in our 2011 assessment, declining sea ice habitat has the greatest potential to negatively affect the Pacific walrus population. Other stressors identified in our 2011 assessment as potentially having a population-level effect have diminished over the last six years. Oil and gas exploration is no longer occurring within the current range of the Pacific walrus population in both the U.S. and Russia. Commercial fisheries have been banned in the Arctic by the Arctic nations and any northward expansion of fishing in the U.S. is dependent on actions by the North Pacific Fisheries Management Council. The best available information suggests that commercial fisheries will effect few individual Pacific walruses and not have population-level effects on survival and productivity in the future. Additionally, subsistence harvest levels are at historically low levels and not considered to be a significant abundance stressor at the present time. Hunters report that changing weather patterns and ice conditions have negatively impacted their ability to harvest Pacific walruses in recent years. Although we do not foresee significant increases in future harvest levels. Repeated harvests that are greater than four percent of the population per year would be considered unsustainable and would have a negative impact on the population.

The revised BBN model results suggest that abundance stressors are low at the present time which is consistent with modeled vital rates, calf:cow ratios, tusk fluctuating asymmetry, bone cortisol levels, and body condition observations, but stressor levels are likely to increase in the future, becoming most intense by 2100 in the summer/fall season, under the RCP 8.5 scenario. Under RCP 8.5, modeling indicates that the ice-free period could extend to up to eight months or more and impinge on traditional breeding and birthing periods. The associated increased use of coastal haulouts increases the probability of disturbance related mortalities and increased energy expenditure. Observations of subsistence hunters and modeled survival and productivity rates suggest that the recent shift in habitat use patterns has not negatively impacted body condition; however, increased energetic costs associated with foraging from coastal haulouts could lead to declines in body condition and vital rates over the long term.

The increasing trend in the negative effects of abundance stressors on the population over time as identified by the revised BBN model suggests that the potential for population growth will be compromised, particularly by 2100. Under all three RCPs considered, we would expect the Pacific walrus’ viability to be characterized by lower levels of redundancy and resiliency than it currently has, although the magnitude of change is unknown, while representation will remain relatively unchanged. The predicted changes in resiliency and redundancy vary across RCPs, with the RCP 8.5 scenario resulting in the greatest predicted reductions.

6. MANAGEMENT RECOMMENDATIONS

The strength of many abundance stressors examined in the revised BBN model is influenced either directly or indirectly by predicted levels of GHG emissions. Therefore, mitigation measures that reduce future global GHG emissions could also reduce levels of abundance stressors acting on the Pacific walrus population. Ongoing Pacific walrus management efforts in the U.S. and Russia are designed to mitigate some of the impacts associated with increased abundance stressors. This section explores the potential influence of conservation and management efforts on future population outcomes.

6.1 Mitigation of Global Greenhouse Gas Emissions

We considered three RCP forcing levels in our revised BBN model. Predicted abundance stressor levels vary among the three RCPs examined with large differences in later time steps (Appendix A). Low (RCP 2.6) and moderate (RCP 4.5) GHG forcing levels were associated with reduced probabilities of moderate to high abundance stressors in the future compared to high (RCP 8.5) GHG forcing. Consequently, mitigating GHG emissions would reduce future long-term levels of abundance stressors acting on the Pacific walrus population.

In December 2015, 192 parties to the United Nations Framework Convention on Climate Change signed a landmark agreement in Paris, France addressing global GHG emissions. The central aim of the agreement is to keep the global temperature rise this century below 2^{o} C above pre-industrial levels. The agreement was ratified by the international community and took effect on November 4, 2016. However, the agreement is nonbinding and the nation-specific GHG emissions targets pledged to date are not sufficient to meet the 2^{o} C goal.

6.2 Mitigation of Other Anthropogenic Stressors

The efficacy of management efforts to protect important habitat areas from disturbances and maintain sustainable harvest levels in the face of climate-mediated changes in Pacific walrus distributions and abundance will be important factors influencing future population trends and outcomes (Garlich-Miller et al. 2011a, p. 112; Udevitz et al. 2013, p. 291). In 2014, we undertook a strategic planning exercise to identify future threats to the Pacific walrus population and identify practicable (i.e., within the bounds of existing regulatory authorities) management actions with the greatest potential conservation benefit for the species (USFWS 2014, p. 5).

6.2.1 Maintain Sustainable Harvest Levels

An effective harvest management strategy would include multiple components. Population monitoring and modeling could track population changes and define sustainable harvest levels.

International harvest monitoring programs could track the size and demographics of harvests. Community-based harvest management agreements that limit the number of hunting trips a hunter can make in a day (Appendix C) could be used to implement harvest goals and quotas if needed (USFWS 2014, p. 5). Many of these components are already in place. Limits on the number of females harvested per year per hunter in the 1960s were perhaps a major factor in the population increase in the 1970s. If limits were needed, the most equitable and successful approach would be developed in close collaboration with Pacific walrus hunting communities in order to set quotas, season, or harvest restrictions on any cohort.

6.2.2 Mitigate Human Caused Disturbances at Coastal Haulouts

Management actions that help to mitigate potential sources of disturbances near coastal haulout sites could help to reduce mortalities and ensure that animals are not displaced from important resting and feeding areas. Haulout monitoring programs in the U.S. and Russia can identify sources, impacts, and targeted mitigation of disturbances at coastal haulouts. Mitigation of human-caused disturbances can be accomplished through outreach, education, and regulatory actions under the MMPA in the U.S.

Many of the components identified above are already in place in the U.S. and Russia and have been successful in recent years (Robards and Garlich-Miller 2013, p. 77). Community leaders from rural villages along the Chukchi Sea coast of Alaska recommend continued investment in outreach and education programs in rural communities to communicate the effects and consequences of disturbances at Pacific walrus haulouts (Garlich-Miller 2012, p. 27). The EWC has also called upon coastal communities in Alaska to work towards developing local management and response plans to reduce disturbances to Pacific walruses resting on the coast (Garlich-Miller 2012, p. 26).

7. ACKNOWLEDGEMENTS

We thank Dr. Chadwick Jay with the US Geological Survey and Lori Quakenbush with the Alaska Department of Fish and Game for participating on the Science Team and efforts in revising the BBN model. Christian Beaudrie and Phillip Halteman were also instrumental in the development of the revised BBN model. Robin Gregory and Nicole Kaechele helped organize and lead the Alaskan Native ecological knowledge workshop and we thank all the coastal community members that participated in that workshop and shared their knowledge of Pacific walruses and their habitats.

Resit Akçakaya, Paul Conn, and Megan Ferguson reviewed a draft of the revised BBN model and their input was greatly appreciated.

David Douglas shared his analysis of Bering and Chukchi seas sea-ice trends which was extremely useful and valuable in our assessment. He has reviewed the sea ice portions of a draft SSA.

The following individuals graciously agreed to provide expert subject matter, in parentheses, reviews: Jackie Grebmeier (benthic changes and productivity), Natalie Monacci (ocean acidification), Aaron Poe (commercial shipping), Christopher Putnam (oil and gas exploration), and Lori Quakenbush (contaminants and biotoxins). Robert Lynn's assistance with the literature cited was greatly appreciated.

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9. APPENDICES

9.1 Appendix A. Revised Bayesian Belief Network Model

OVERVIEW

Environmental changes due to climate warming and declines in availability of sea ice habitats present a difficult challenge for the conservation of Pacific walruses (*Odobenus rosmarus divergens*). In February 2008, the U.S. Fish and Wildlife Service received a petition to list the Pacific walrus as a threatened or endangered species under the U.S. Endangered Species Act (Act), citing concern over increasing stressors due to climate change and their effect on the population. After reviewing information in the petition and in existing files, the Service concluded that listing under the Act may be warranted (74 FR 46548 [September 10, 2009]) and initiated a status review. In February 2011, based on careful review of the best available information, the Service determined that listing the Pacific walrus as a threatened or endangered species was warranted, but precluded by higher priorities [76 FR 7633 (February 10, 2011)]. This determination largely was attributed to projected declines in Pacific walrus abundance as a result of predicted loss of sea ice. Because the finding was warranted but precluded, the Pacific walrus did not receive immediate protections under the Act, but instead was considered a candidate to listing; essentially, a proposed and final rule still needed to be developed.

In July 2011, the Service reached a multi-district litigation settlement with the Center for Biological Diversity, one of the original petitioners, that required the Service to address the needs of over 250 Candidate species, including the Pacific walrus. This settlement requires the Service to submit a proposed rule (and designation of Critical Habitat) or not-warranted finding for Pacific walrus to the Federal Register on or before September 30, 2017. Thus, the Service currently is updating the 2011 status review with new information available since it was completed and is reformatting it to adhere to the Service's guidance for conducting a Species Status Assessment (SSA; Service 2015). The SSA will be used to inform the decision on whether to propose Pacific walrus for protections under the Act, as determined in 2011, or conclude that listing is not warranted.

This document reports on a Bayesian belief network (BBN) model developed to support the Service's work to assess potential effects of reduced sea ice and other stressors on the Pacific walrus population in the future. The BBN will support the SSA currently being developed by the Service, which aims to bring together the best available information about Pacific walruses (hereafter, "walrus") and serves as a compendium of available information to support the listing decision process.

The BBN presented here is based on a model developed by Jay et al. (2011), though it has been modified to address questions pertinent to the current SSA, and to take into account the latest scientific studies and Local and Traditional Ecological Knowledge (LTK). The BBN provides an estimate of the level of stressors on walrus abundance over time and across various greenhouse gas concentration scenarios. In turn, these estimates are intended to help the Service understand the cumulative effect that known stressors might have on the trajectory of the walrus population and subsequently, walrus abundance[1]. Specifically, the BBN was designed to address the question, *what level of abundance stressors might Pacific walruses face under various representative concentration pathway (RCP) scenarios (IPCC, 2014) today and into the future (from 2015 to 2060[2])?*

A BBN was chosen because it can accommodate in combination both the complexity of stressors that may affect walrus abundance, and uncertainty due to scarce data on walrus vital rates and demographic response to such stressors. The Pacific walrus BBN represents linkages between environmental and anthropogenic stressors and walrus responses using a probabilistic framework to evaluate the level of abundance stressors that walrus may encounter from the present day to 2060. A team of seven walrus experts (the Science Team) from the US Fish and Wildlife Service (USFWS), Alaska Department of Fish and Game (ADFG), and US Geological Survey (USGS), developed the model. Compass Resource Management Ltd and Value Scope Research facilitated the development and led the analysis and peer review.

The BBN was developed utilizing the best available information, empirical data, modeled sea ice projections, and expert judgment in lieu of incomplete data, including that of Alaska Native walrus hunters and community members. Because data to support projections of trends to abundance stressors is relatively scarce, expert judgment played a large role in model structure and parameter estimation. Experts from the Science Team (ST) used their knowledge from scientific research, experience as biologists, and traditional ecological knowledge of Alaskan Natives from a variety of sources to estimate a BBN model structure and the conditional probabilities that form the basis of the BBN. Additionally, information was elicited from Alaska Native walrus hunters and community members through a two-day workshop, where participants shared experiences and knowledge to better inform BBN model estimates.

METHODS

Study Area

The study area is as defined in Jay et al. (2011). It includes the Chukchi and Bering seas, and is bounded by the edge of the continental shelf and approximately represents the known range of the Pacific walrus (Fay et al. 1982, Jay et al. 2011). We assumed no difference in habitat suitability between or within the Chukchi and Bering seas, and that as the location of the ice front shifts over time, walruses will follow those shifts accordingly. Therefore, all assumptions, variables, and linkages in the model apply to the entire study area, except as they may vary by season.

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[1] Walrus abundance is not predicted by this BN model. Abundance stressor estimates generated from the BN will be considered in conjunction with other available information to help the Service estimate how walrus abundance may be affected in the future.

[2] Because most model projections are run through the end of the century (2100) we also include an analysis for that time period. However, ST members felt that those forecasts were highly uncertain.

Figure 1. Study area for assessing the response of Pacific walrus to stressors (from Jay et al., 2011)

Model Structure and description

The influence diagram detailing the structure of the BBN is shown in Figure 2. The model structure largely follows that of Jay et al. (2011), and the rationale for the arrangement of nodes remains unaltered. Based on the levels of specific stressors (represented as inputs in the model, yellow boxes, Figure 2), the model characterizes the intermediate effects of these stressors (beige boxes, Figure 2) on walrus mortality and body condition. Because the intensity of some stressors is seasonally-dependent, the model contains three seasonal sub-models, each of which characterizes the collective effects of stressors on the population within that season (green boxes, Figure 2). These seasonally-specific effects are aggregated to provide an estimate of the rate of population change (purple boxes, Figure 2). The aggregation method assumed that each season has equal influence on all-season abundance stressors regardless of differences in season length, though high levels of abundance stressors from more than one season were considered to have a greater negative influence than high levels of abundance stressors from a single season (See All Season Abundance Stressors in Appendix A1). Since an aggregated result across seasons could hide seasonal choke points or minimum thresholds, both the seasonal abundance stressors and all-season abundance stressors are presented in this report. Consistent with Jay et al. (2011), the spring season was defined as April through June, the summer/fall season as July through November, and the winter season as December through March.

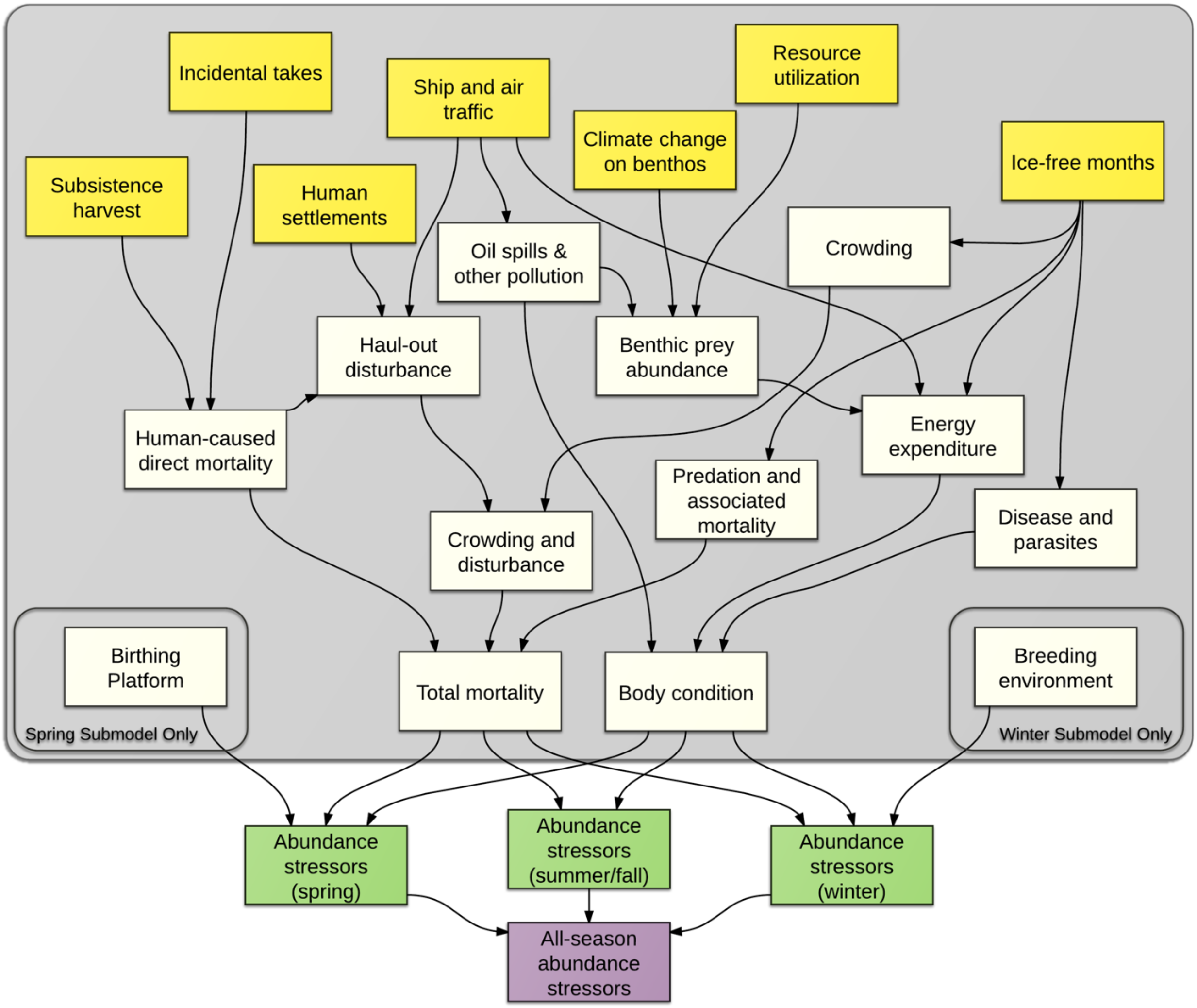

Figure 2. Pacific Walrus BBN Influence Diagram. The summer/fall seasonal sub-model is shown in the large grey box. The winter and spring sub-models are identical, with the addition of the nodes shown the lower left and lower right insets; "Ice-Free Months" is the sole input to each of these additional nodes. Seasonally-aggregated effects are shown in green and key model outputs are shown in purple.

We made two key structural changes to the model relative to the one presented in Jay et al. (2011). The first change was to remove a component of the model that characterized the distribution of sea-ice habitat, which the Science Team opted to treat in a separate, parallel analysis (not presented here). The 'ice-free months' node, however, was retained from the 2011 model to characterize the availability of sea-ice habitat for each season.

The second change was to include a link between the 'ship and air traffic' node and the 'energy expenditure' node to capture effects of ship traffic on walrus migration and avoidance behavior during feeding. This link was the result of input from Alaska Native subsistence users that have observed ships displacing animals from traditional feeding and migration areas.

Node descriptions

Table 1 provides brief definitions and possible states for each node in the model. See Appendix A1 for more detailed descriptions of the nodes and states.

Table 1. Definitions and states for each node in the BBN.

Node Title	Node Definition	Possible States
Input Nodes		
Climate Change on Benthos	Cumulative impact of various factors related to climate change on the production of benthic prey. Reduced sea ice and ocean acidification are assumed to potentially have the greatest influence on benthic prey production	Positive Neutral Negative
Human Settlements	Population size of humans along the coast of Alaska.	Low (<65,000) Moderate (65,000-80,000) High (>80,000)
Ice-Free Months	Mean number of months within a season with no sea ice to support walruses for hauling out over the continental shelf of the Chukchi and Bering Seas.	Summer/Fall: 0-0.5, 0.5-2.0, 2.0-3.5, 3.5-5.0 Winter: 0-0.5, 0.5-2.0, 2.0-4.0 Spring: 0-0.5, 0.5-2.0, 2.0-3.0
Incidental Takes	Number of walruses killed from illegal activities and incidentally from fishing, industry, and research activities in Russia and Alaska.	Low (<2580) Moderate (2580-5160) High (5160-7740) Very High (>7740)
Resource Utilization	Impact on benthic prey production from activities that can perturb the seafloor from extraction of natural resources, such as from commercial fishing and oil and gas development.	Positive Neutral Negative
Ship and Air Traffic	Amount of ship and air traffic from commercial shipping, tourism, and fishing, and oil and gas development.	Low (<300) Moderate (300 - 600) High (>600)
Subsistence harvest	Number of walruses killed by Native subsistence hunting in Russia and Alaska.	Low (<2580) Moderate (2580-5160) High (5160-7740) Very High (>7740)
Intermediate Nodes		
Benthic Prey Abundance	Abundance of benthic prey resources.	High Moderate Low
Birthing Platform	Adequacy of ice or other habitat for birthing, nursing, and providing protection to newborn calves during severe storms.	Adequate (fully sufficient to support birthing) Less than Adequate (partially sufficient) Severely Reduced (largely insufficient)

Body Condition	Amount of body reserves of individuals in the population, particularly in the form of fat and muscle.	High Medium Low
Breeding Environment	Adequacy of ice or other habitat for breeding.	Adequate (fully sufficient to support breeding) Less than Adequate (partially sufficient) Severely Reduced (largely insufficient)
Crowding	Number of adult female and juvenile walruses at a haulout.	Low (groups in the 10’s or 100’s) Moderate (groups in the 1000’s) High (groups in the 10,000’s)
Crowding and Disturbance	Intensity of disturbance on a haulout.	Low Medium High
Disease and Parasites	Incidence of disease and parasites in the walrus population.	Low (endemic levels) Moderate (pandemic levels) High (epidemic levels)
Energy Expenditure	Energy expended by walruses while foraging and swimming.	Low Medium High
Haulout Disturbance	Level of disturbance to hauled out walruses on ice, and particularly, on terrestrial haulouts.	Low Moderate High
Human-caused Direct Mortality	Total number of walruses directly killed by humans in Russia and Alaska as a result of subsistence harvest and incidental takes	Low to moderate High Very High
Oil spills and other pollution	Regularity and severity of hydrocarbons and other pollutants released into the water.	Low Moderate High
Predation and Associated Mortality	Number of walruses killed by predators (excluding humans), which are primarily polar bears and killer whales.	Low Moderate High
Total Mortality	Total number of walruses killed as a function of the nodes “predation and associated mortality”, “crowding and disturbance” and “human-caused direct mortality”.	Low Moderate High
Output Node		
Abundance Stressors	Processes or events that may negatively influence the abundance of walruses.	Low Moderately Low Moderately High High

Incorporation of Local and Traditional Ecological Knowledge (LTK)

Compiling and incorporating the insights and knowledge of Native Alaskan subsistence users is an important component of the SSA process. The BBN model was developed considering both western science and Local and Traditional Ecological Knowledge (LTK) consisting of the insights and knowledge of

Native Alaskan subsistence users. Science Team members reviewed LTK literature and other information prior to developing the model, and integrated those findings along with all other available resources when eliciting CPTs. A two-day LTK workshop was conducted in June 2016 with 20 subsistence users from communities along the Bering and Chukchi Sea coasts, along with seven staff of the U.S. Fish and Wildlife Service, to understand walrus health, abundance, trends, and the effects of stressors on walrus, based on the knowledge and experience of workshop participants. A review of the LTK literature was conducted prior to the workshop and a white paper (Gregory et al., 2016) was written to summarize key findings with respect to Pacific walruses. Workshop participants expanded on these findings and provided additional insight into the current state of walrus, key stressors, and effects on health and abundance. The findings from the LTK literature and the June 2016 LTK workshop were integrated into the BBN model through variable cause and effect linkages, conditional probability table adjustments, input scenarios, and influence runs, as summarized in Appendix B. A complete report of workshop findings can be found in Appendix C.

Model parameterization

Time Periods and RCP Scenarios

To evaluate the effects of changing environmental conditions on abundance stressors, we parameterized the model for the current conditions and four future time steps. Because this BBN is not a dynamic, process-driven model, the Science Team chose to capture average conditions at each future time period. Fifteen-year periods were chosen for each time step (equivalent to roughly one walrus generation) and were centered on 2015, 2030, 2045, and 2060. The ST felt that forecasts made for this time frame were more rigorous and certain than those beyond 2060. However, because most model projections are run through the end of the century (2100) we also include an analysis for that time period, but note that ST members felt that those forecasts were highly uncertain.

Scenarios describing future climate change differ considerably, so we chose three RCP scenarios from the Fifth IPCC Assessment Report (AR5) as a basis for evaluating the BBN model. Model inputs were estimated for each future time period for RCP8.5, RCP4.5, and RCP2.6. RCP8.5 represents the business-as-usual scenario, while RCP4.5 and RCP2.6 represent moderate and aggressive carbon emission reductions scenarios (IPCC, 2014). For the purposes of model testing, validation, and sensitivity analyses, RCP8.5 was chosen as the 'normative' case for comparisons. The RCP8.5 'business-as-usual' scenario reflects expected outcomes should little to no additional climate change mitigation take place, and thus, in that regard, represents a worst case scenario.

Input Node Elicitations

Recognizing that expert judgment is subjective and prone to bias (Tversky and Kahneman, 2000; Burgman, 2004; Morgan et al., 2001; Beaudrie et al, 2016), we used structured methodologies (Burgman, 2005; Runge et al, 2011; Meyer et al., 2001) to elicit expert's judgments in a rigorous and transparent manner that controlled for biases and allowed experts to share the rationale for their judgments, learn from one another, and refine judgments with new information. Elicited judgments can often differ from expert to expert, introducing a dimension of subjective uncertainty into analyses.

Differences in judgments across experts were preserved here to communicate where judgments agreed or diverged, and we also present aggregated judgments (averaged across experts) to indicate mean estimates. When elicited using rigorous and widely accepted elicitation techniques, expert judgment can be a reliable source of data when scarce empirical data is available.

At the outset of the expert elicitation process, the Science Team participated in a training and calibration exercise to help minimize biases and prepare the team for the elicitation tasks (O'Hagan et al, 2006; Morgan et al., 1990). The inputs to the BBN were defined using the best available information and expert judgment to interpret the available data and estimate parameters for each input node. Individuals from the Science Team[3] developed initial data tables for the input nodes by estimating the relative likelihood that the input would be in each of several possible states given each combination of time step and RCP scenario. For example, for the Ship and Air Traffic input node, experts were tasked with estimating the likelihood that Ship and Air Traffic would be 'low', 'moderate', or 'high' (defined as <=300, 301-599, and >=600 ship transits[4] in the Bering Strait annually), for each combination of time period and RCP scenario (see example Table 2). These initial data tables were then reviewed by the full Science Team and revised based on team discussion of the available data, assumptions, and estimates. A detailed description for each node including resources used, assumptions, rationale, and full data tables can be found in Appendix A1.

Table 2. Example data table for the Ship and Air Traffic input node for the spring seasonal sub-model

Period	**RCP**	**Ship and Air Traffic**		
		low	**moderate**	**high**
2015	Observed	100	0	0
2030	RCP2.6	90	10	0
2030	RCP4.5	70	25	5
2030	RCP8.5	50	35	15
2045	RCP2.6	80	20	0
2045	RCP4.5	50	35	15
2045	RCP8.5	40	35	25
2060	RCP2.6	55	35	10
2060	RCP4.5	45	35	20
2060	RCP8.5	35	35	30
2100	RCP2.6	40	35	25
2100	RCP4.5	35	35	30
2100	RCP8.5	35	35	30

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[3] Data tables for Human Settlements, Ship and Air Traffic, and Resource Utilization were initially elicited by single members of the Science Team. Because of a greater degree of uncertainty around the effects of climate change on food sources, the Climate Change on Benthos data table was elicited by several members of the ST.

[4] The annual number of ship transits through the Bering Strait was used as an index of current and future levels of ship and air traffic within the study area.

In contrast to most inputs, which were driven primarily by expert judgment, we relied on monthly projections of sea ice extent from a 13-model ensemble of the most recent Global Circulation Models (GCMs) running the RCP scenarios to populate the input tables for "Ice-free Months" (only 9 of these models were used for RCP2.6). Using each GCM in the ensemble, the proportion of ice cover in the study area defined by Figure 1 was estimated for each month between 1979 and 2100. Following Douglas (2010), "ice-free months" were defined in a two-step process: first, individual map pixels (roughly 1-degree latitude by 1-degree longitude) were classified as "ice-free" when estimated ice concentration in a given pixel was less than 15%. Next, "ice-free months" were identified as those months in which the proportion of ice-free map pixels were ≥ 95% across the entire study area. After these months were identified, ice-free months were summed within season and year for each combination of GCM and RCP scenario. We then averaged those seasonal summaries within the 15-year windows to yield average ice-free months by GCM, RCP scenario, season, and time step. To represent the variation between individual GCM projections, the number of individual models (out of the 13 we used) that predicted values for average ice-free months falling within specific ranges (given in Table 1) were used to define the input probability tables.

Intermediate CPT Elicitations

We developed the conditional probability tables (CPTs) that define the relationships between nodes in the influence diagram using an expert elicitation protocol that controlled for biases, minimized cognitive burden, and provided transparency. The protocol allowed individual experts (the ST) to produce (i.e., elicit) CPTs independently, and then share them with the group for review and deliberation on what information was considered in their development, what assumptions were made, and an individual's rationales. This process enabled the team to identify similarities and differences in how information was used, and to identify strengths and weaknesses in individual elicitations. The ST members were provided an opportunity to revise their CPTs given the discussion, and a second round of deliberation was undertaken before individual CPTs were finalized.

This process of elicit-discuss-revise was designed to help experts cope with the challenging task of eliciting complex conditional probabilities (Meyer and Booker, 2011). Experts are first provided an opportunity to develop CPTs based on information they considered relevant, and to use their best interpretation of this information to make judgments on probabilities with little influence from peers. Through group review of individual's CPTs, experts then share information used in making judgments to identify what information might have been missed, misinterpreted, or interpreted differently among individuals. This provides valuable feedback for calibrating judgments and ensuring that CPTs are well founded based on available information and best judgment. This method minimizes biases that can occur with group-based elicitations, such as 'group-think' or having one expert dominate discussions, and thus leads to well-reasoned CPTs that are minimally biased (Beaudrie et al, 2016; Burgman, 2004).

To further control for biases in the elicitation process, we developed a Microsoft Excel-based CPT elicitation tool. This tool was used to facilitate the process of eliciting expert judgment on likely probability distributions across node states for each combination of parent states. The tool was designed to control for ‘anchoring’ and ‘overconfidence’ biases by requiring experts first to elicit probability distributions for the ‘best case’ and then ‘worse case’ combination of input states, followed by elicitation of the remaining state combinations. This forces experts to think about how high the probability distribution might be in the best case, and how low it might be in the worst case, thereby widening the boundaries between best and worse. This helps to overcome order effects and the common bias of anchoring on a particular set of values, as well as overconfidence which results in providing very narrow bounds on probability distributions (Tversky and Kahneman, 2000; Morgan et al., 1990).

To minimize cognitive burden and speed the development of CPTs, an interpolation tool was developed as part of the elicitation tool. This tool allowed experts to specify probability distributions for key combinations of parent node states (e.g., the combinations that result in the ‘best case’ and ‘worst case’ outcomes for the node), and then specify a small number of parameters to guide the interpolation. These include the mean and standard deviation for normal distributions defining best and worst case combinations, a set of weights describing the relative influence of the parent nodes on the child node (between-node weights), and the relative influence of each state in a parent node on the child node (within-node weights). The interpolation tool then interpolates truncated-normal distributions across the remaining parent state combinations to fill out the remaining rows in the CPT. These final CPTs can then be adjusted manually as needed.

Full CPTs and descriptions of assumptions and rationale for each intermediate and outcome node can be found in Appendix A.

Model Testing and Calibration

To test and calibrate the BBN, we ran the model using a number of test cases where inputs were set at various states to investigate whether the model responds to input signals in a way that is expected given what is known about walrus behavior and their response to stressors. Test cases included setting all inputs to their worst case and best case (Table 3), setting all inputs to current (2015) estimated states (Table 3), and testing combinations with one or two input nodes set to their worst case while all others are held at the current estimated state (Table 4).

While testing the model response to the worst and best case states (i.e. ALL_WORST and ALL_BEST in Table 3), the abundance stressor outcomes were analyzed to determine whether the level of estimated stressors was similar to what was expected from each case. For example, under the worst case scenario, a high probability of moderately high to high stressors was expected, while under the best case scenario a high probability of low to moderately low stressors was expected. Adjustments were made to various CPTs to calibrate the model response such that overall the model outcomes reflected the definition of low stressors under the best case scenario and high stressors under the worst case scenario.

Table 3. BBN testing and calibration scenarios. 'B' is 'best case', ‘w’ is worst case, and ‘~’ represents the current state for the normative run for each time step (current estimated state under RCP8.5).

Test Scenario	Description	Resource Utilization	Climate on Benthos	Ship & Air Traffic	Human Settlements	Subsistence Harvest	Incidental Takes	Ice-free Months
Model validation runs								
ALL_CURRENT	All input nodes set to state at 2015	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**
ALL_WORST	All input nodes set to WORST state	**W**	**W**	**W**	**W**	**W**	**W**	**W**
ALL_BEST	All input nodes set to BEST state	**B**	**B**	**B**	**B**	**B**	**B**	**B**
IFM_SUBS _WORST	Ice-free months and subsistence harvest set to WORST, all others at normative run levels for each time period	**~**	**~**	**~**	**~**	**W***	**~**	**W**

* Subsistence harvest is set to 'very high' only for summer/fall and spring. Winter is kept at "Low".

Next, this calibration step was repeated with the current estimated input states (in 2015; Table 3) as well as combinations of key inputs set to their worst state (e.g., ice-free months and subsistence harvest set to their worst state, with all other inputs set to their current estimated level). This was done to determine whether the model could predict current estimated stressor levels, and whether it was sensitive to changes in individual input nodes. Finally, individual model components were isolated (e.g., all nodes feeding into 'total mortality'; Table 4) to understand how sub-components of the model respond to the test cases, and small adjustments were made to CPTs such that the response was in line with expected outcomes for the tests.

Given the scarcity of data linking the effects of model input stressors to walrus abundance stressors, it is not possible to formally 'validate' the model against empirical data. The methods used here were intended to calibrate model test outputs against expert judgments (in lieu of empirical data) of what abundance stressors might reasonably be under the test case scenarios. The calibration process was performed only on the test scenarios, and no model adjustments were made once the Science Team began analyzing model outcomes based on the time step and RCP scenario combinations (see Figure 3). This allowed the ST to calibrate the model independently from the analysis of scenarios, thereby minimizing bias introduced by adjusting model outcomes to meet expectations.

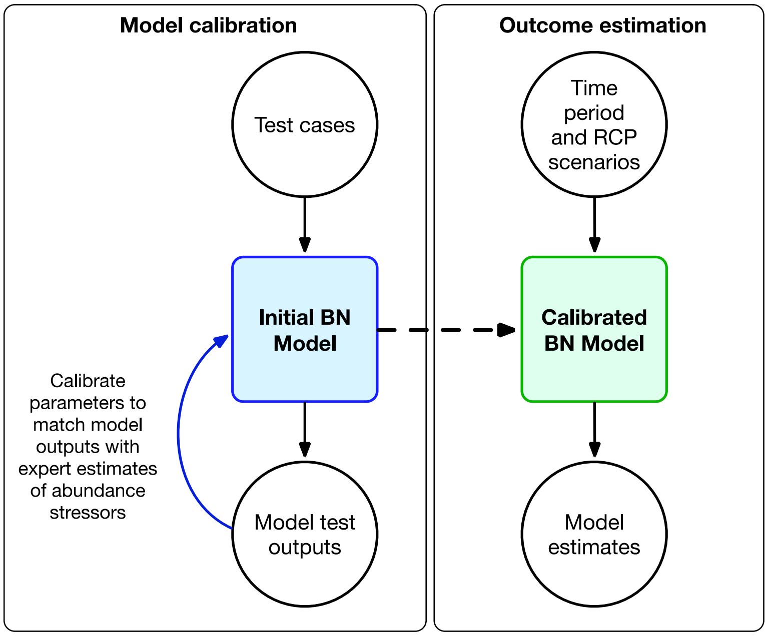

Figure 3. Model calibration and outcome estimation. The left panel illustrates the process used to calibrate the initial BBN model to match model test case outputs against expert judgments, while the right panel shows the calibrated model used to estimate model outcomes (abundance stressors) based on separate time period and RCP scenarios.

Influence Runs

To determine the relative impact that each input (stressor) has on model outcomes, we used a number of ‘influence runs’ to test the sensitivity of the model to these inputs when set to extreme (best or worst) states. These influence runs provided insight into the degree of influence that each input node has on the model, and how the model responds to extreme cases. Influence runs (Table 4) involved setting one or more input nodes to their best and worst cases while holding all other inputs at their current estimated state for the normative case (RCP8.5). We then compared these influence runs against the normative case to understand how sensitive the model is to changes in those inputs. These tests provided insight into which inputs have the largest influence on the model, and which inputs have the least influence.

Due to the difficulty and uncertainty in estimating harvest levels relative to walrus abundance into the future, the ST did not make explicit predictions about future states for the subsistence harvest input node. Instead, probability distributions were set at ‘low’ for all seasons, meaning that estimated harvest is assumed to be well below a sustainable harvest threshold of 4% removal for all RCP scenarios for all future time periods. An influence run was used to test the model’s sensitivity to subsistence harvest. Similarly, incidental takes are estimated to be in the range of 10 or so each year, and so projecting forward all future states for incidental takes are expected to be ‘low’.

Table 4. BBN influence run scenarios. 'B' is 'best case', ‘w’ is worst case, and ‘~’ represents the current state for the normative run for each time step (current estimated state under RCP8.5).

Influence Run	Description	Resource Utilization	Climate on Benthos	Ship & Air Traffic	Human Settlements	Subsistence Harvest	Incidental Takes	Ice-free Months
Influence of resource utilization								
RU_min	Influence of minimal resource utilization	**B**	~	~	~	~	~	~
RU_max	Influence of maximal resource utilization	**W**	~	~	~	~	~	~
Influence of climate change on benthos								
CCB_min	Influence of positive effects of climate change on benthos	~	**B**	~	~	~	~	~
CCB_max	Influence of negative effects of climate change on benthos	~	**W**	~	~	~	~	~
Influence of human settlements								
HS_min	Influence of minimal effects of human settlements	~	~	~	**B**	~	~	~
HS_max	Influence of maximal effects of human settlements	~	~	~	**W**	~	~	~
Influence of ship and air traffic								
SAT_min	Influence of minimal effects of ship and air traffic	~	~	**B**	~	~	~	~
SAT_max	Influence of maximal effects of ship and air traffic	~	~	**W**	~	~	~	~
Influence of sea ice								
IFM_min	Influence of effects of maximal sea ice	~	~	~	~	~	~	**B**
IFM_max	Influence of effects of minimal sea ice	~	~	~	~	~	~	**W**
Influence of subsistence harvest								
SUBS_low	Influence of low harvest	~	~	~	~	**B**	~	~
SUBS_high	Influence of high harvest	~	~	~	~	**High***	~	~
SUBS_vhigh	Influence of very high harvest	~	~	~	~	**Very High***	~	~
Influence of anthropogenic stressors								
ANTH_min	Influence of minimal anthropogenic stressors and low harvest	**B**	~	**B**	**B**	**B**	**B**	~
ANTH_max	Influence of maximal anthropogenic stressors and very high harvest	**W**	~	**W**	**W**	**Wϕ**	**W**	~

* Subsistence harvest is set to ‘high’ and ‘very high’ only for summer/fall and spring. Winter is kept at “Low”.

ϕ Subsistence harvest is set to ‘very high’ only for summer/fall and spring. Winter is kept at “Low”.

Sensitivity Analysis

Sensitivity analyses were conducted on the BBN model using Netica to calculate entropy reduction[5], characterized as a reduction in the amount of mutual information held in the abundance stressor outcome node relative to the information represented in the input nodes (see Marcot et al. 2006 for method and equation). To understand the influence of each input node on the model, we set all prior probabilities of the input nodes to uniform distributions to reflect total uncertainty among states before conducting the analysis.

A second analysis was conducted to test the sensitivity of the abundance stressor outcome node to alternative CPTs for the breeding environment and birthing platform nodes. Because there is a high degree of uncertainty over whether walruses will be able to meet their birthing and breeding needs in the absence of ice, we tested the assumptions made in developing the breeding environment and birthing platform CPTs using alternate CPTs that assume that walruses will have a more difficult time meeting breeding and birthing requirements in the absence of sea ice than assumed by the ST. This is reflected in CPTs that place greater probability on breeding environment and birthing platform to be 'less than adequate' to 'inadequate' as the number of ice-free months increases (See Appendix A1).

Model Runs and Uncertainty Analysis

Since the majority of model nodes are developed using expert judgment, the degree of disagreement between experts is a key source of uncertainty in this model. An uncertainty analysis was performed by exploring the range of elicited probability distributions across experts for each CPT. To illustrate similarities and differences across experts, probability distributions for each expert were converted to average probabilities (from 0 to 1) and plotted on the same chart. **Error! Reference source not found.** illustrates both the range of average probability estimates across experts, as well as the mean ('aggregated') estimate. The distance between points indicates disagreement between experts, where the further the points are apart, the greater the disagreement. A summary of how expert judgments differ from node to node can be found below, and detailed analyses, as well as an example of how averages were calculated, can be found in Appendix D.

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[5] Entropy reduction is characterized as a reduction in the amount of "mutual information" (or uncertainty) held in the model outcome node relative to the information represented in the input nodes. It is a measure of how much one random variable tells us about another, and so a higher level of entropy reduction (mutual information) indicates a stronger relationship between an input node and the output node. Similarly, low mutual information indicates a weaker relationship, and zero mutual information between two random variables means the variables are independent.

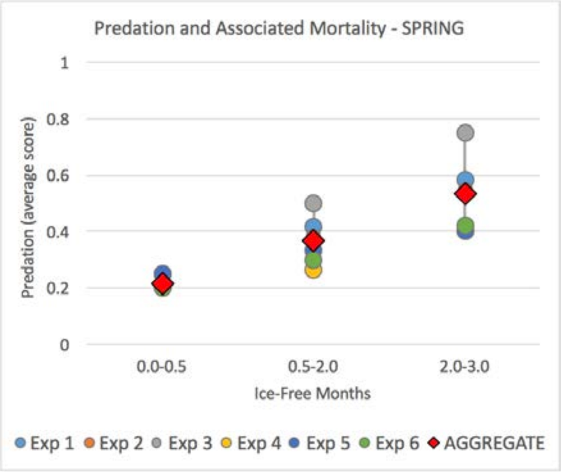

Figure 4. Example chart comparing average estimated probabilities for multiple experts. Coloured circles represent the average probability estimate for each expert, while the red diamonds represent the average probability of the aggregated judgments across experts.

Three BBN models were developed to facilitate an analysis of model responses based on the range of judgments across experts. We first developed a model in which expert's CPTs were aggregated using a simple average (referred to here as the 'Aggregated' model). This allowed us to estimate model outcomes based on the mean judgments across experts. Next, to characterize the range of model outcomes based on differences in expert judgments, two additional models were developed that used the minimum and maximum estimated probability distributions across experts for each CPT ('Min model' and 'Max model' respectively). These models allowed us to characterize the full range of outcomes based on differences in expert judgments. All three models were evaluated using the same time steps and RCP scenarios, and results are reported below. Further details of the methods and rationale for this approach are described in Appendix D.

Uncertainty is also expressed in the model in the probability distributions defined for each CPT. A CPT with an equal distribution of probability across all outcome states indicates complete uncertainty – there is an equal probability of the outcome being any of these states. A CPT with 100% of the probability assigned to one outcome state (and zero probability to all other states) indicates complete certainty in the estimate. Most estimates here incorporate some degree of uncertainty with probability estimates typically distributed across a number of states. The narrower the distribution of probability (over one or a few states), the more certainty is implied; the wider the distribution across multiple states, the more uncertainty is implied.

Also note that a number of nodes used in the current model were initially developed in the 2011 Jay et al model (Jay et al, 2011), and were not modified here since the ST reviewed these CPTs and felt they aligned with the currently available literature and their judgments. These include: Benthic Prey Abundance, Oil Spills and Other Pollution, Human Caused Direct Mortality, and Haul-Out Disturbance. Additionally, several CPTs were based on those developed in the 2011 model, but minor modifications were made by the Science Team through a deliberative process rather than a full elicitation process with each individual. These include Body Condition, Total Mortality, Crowding and Disturbance, seasonal

Abundance Stressors, and All-Season Abundance Stressors. Because these nodes were not elicited across a number of experts, they do not contribute uncertainty to the model as a result of variation in expert judgments, and are not explored in the uncertainty analysis below. Details related to each node, including CPTs and rationale, can be found in Appendix A1.

RESULTS

Uncertainty in CPTs

In analyzing uncertainties in probability estimates for input data tables and CPTs, disagreements in estimates across experts reflect uncertainty among experts. A narrow spread in expert estimates mean that judgments are generally in agreement. A wider spread in expert estimates indicates disagreement and a greater level of uncertainty between experts. The results below characterize uncertainty introduced into the model as a result of differences in expert judgments. See Appendix A1 and Appendix D for additional details.

Climate Change on Benthos

The Climate Change on Benthos input node is a measure of the cumulative impact of various factors related to climate change (e.g., reduced sea ice, ocean acidification) on the production of benthic prey. A comparison of average probability estimates across experts for the Climate Change on Benthos node (Figure 5) shows that, with the exception of the 2030 time period, estimates across experts follow a similar pattern of increasing probability of negative climate related effects across time RCP scenarios and time periods. A sizable range of estimates is also seen, with the largest ranges occurring in 2015, 2030, and 2100. Uncertainty tends to decrease moving from RCP2.6 to RCP8.5 for 2030 and 2045, but increases with RCP scenarios in 2060 and 2100.

For the 2030 time period, the majority of experts estimate that the average probability for Climate Change on Benthos is roughly the same across RCP scenarios, with one expert estimating a substantially lower average for RCP2.6 and an increasing trend towards RCP8.5. For 2045 to 2060, all experts generally estimate increasing probabilities from RCP2.6 to RCP8.5. However, in 2100 the range of judgments is the greatest for RCP8.5 as experts tended to estimate wider probability distributions in their CPT estimates, indicating a higher level of individual uncertainty for this time period and RCP scenario. Overall, a substantial degree of uncertainty is seen across experts, though the experts generally agree upon the trend across time and RCP scenarios.

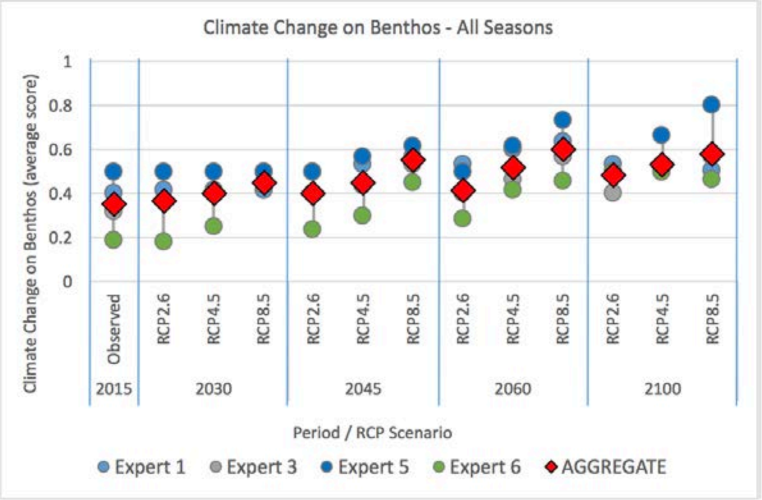

Figure 5. Comparison of estimated average probabilities for the Climate Change on Benthos input node.

Crowding

Crowding refers to the number of female and young walruses at terrestrial haulouts, and is particularly relevant to juvenile survival when disturbances occur and animal stampedes ensue. Crowding is generally expected to increase as sea ice concentrations decrease and walruses rely more heavily on terrestrial haulouts in place of ice haul outs.

Comparing estimated probabilities for the Crowding node (Figure 6), the greatest area of agreement across experts is for probability estimates when the ice-free months state is 0.0-0.5 months. This agreement is strongest in the spring, but diminishes somewhat in summer/fall and winter. Across seasons, disagreement, or uncertainty among the group, increases with increasing ice-free months. This is especially true in spring and winter, though a narrower range of estimates is found in the summer/fall season.

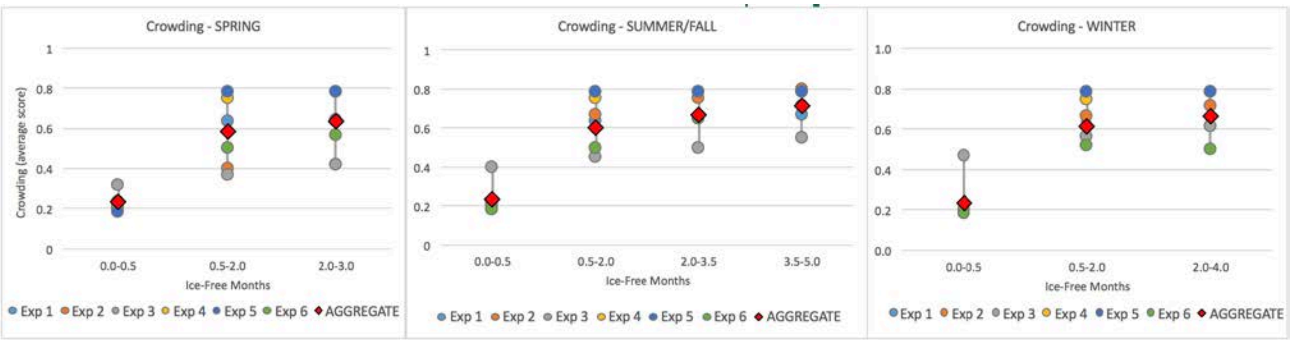

Figure 6. Comparison of estimated average probabilities for the Crowding node.

There are two possible explanations for the trends observed in Figure 6. First, expert estimates appear to converge when ice-free months is 0.0-0.5, a state that is typically observed across seasons every year, and diverge when ice-free months increase, a condition that is rarely observed outside of the summer/fall season. For spring and winter, there is little historical data to suggest how crowding may be affected if and when more than 0.0-0.5 ice-free months are experienced in these seasons. Similarly, while there is a history of ice-free months in the summer season, summers with more than two ice-free months are rare, providing little data from which to predict crowding effects as ice diminishes. This lack of data from which to make an estimate may lead to the significant differences in expert estimates observed here as there is little information available to guide their judgments.

Second, experts discussed walruses' ability to adapt to changing conditions, and noted that there is considerable uncertainty as to the size of haulout groups that will form – particularly for ice-free time between 0.5 and 2 months – because life-history events and local (and difficult to predict) factors may play a role in determining the size of haulout groups across seasons. Group sizes (and crowding) may be significantly smaller in the spring than other seasons because of the focus on calving, active migration, and protection of dependant calves. Walruses may also use adjacent haulouts that are less crowded, thus reducing crowding at large haulouts as ice becomes scarce. The degree to which an expert assumes that walruses will adapt to minimize crowding, and the difficulty with which to make an estimate given scarce data, may together explain the range in estimates observed for this CPT.

Predation and Associated Mortality

The Predation and Associated Mortality node captures the potential for walruses to be killed directly by a predator, or indirectly such as from a stampede caused by a predator's presence at a haul-out. Estimated probabilities for the Predation and Associated Mortality node (Figure 7) follow a similar pattern to that of the Crowding node. Average probability estimates for predation increase with increasing ice-free months, as does divergence in expert estimates. All experts' judgments of the impact of '0.0-0.5 ice-free months' on 'predation and associated mortality' are similar across seasons, though judgments begin to diverge when ice-free months increases to 0.5-2.0 and beyond. This indicates that there are differing interpretations of how a change in sea ice will affect predation as the number of ice-free months increases. As described above, one explanation for this range of judgments is that currently there are no ice-free months observed in spring and winter, and few ice-free months observed in summer/fall, so all experts have a similar interpretation of how predation is affected when ice is present based on current observations. However, there is little historical evidence to suggest how the effects of predation may change if and when ice-free months are experienced, and so experts' interpretations of how predation is affected differs widely.

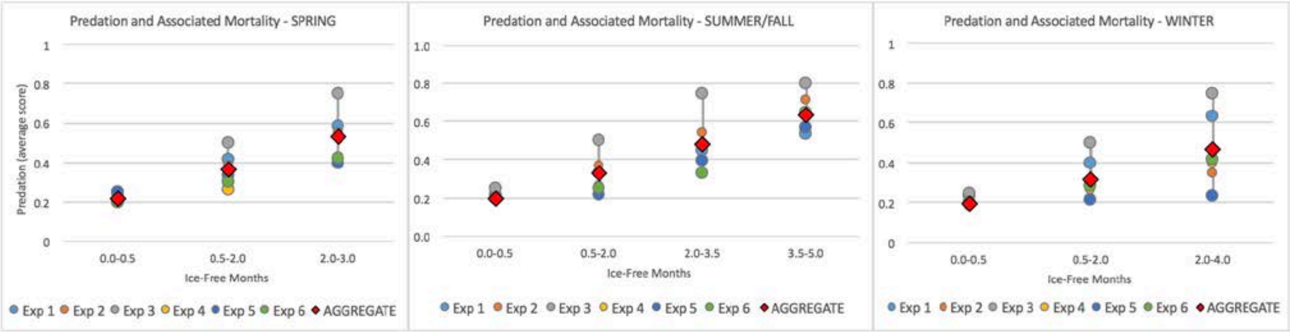

Figure 7. Comparison of estimated average probabilities for the Predation and Associated Mortality node.

Disease and Parasites

The Disease and Parasites node captures the potential for walrus to be affected by disease and parasites, particularly as sea ice becomes more scarce and walruses spend more time in close proximity to one another. Comparing probabilities for the Disease and Parasites node, average probability estimates across experts for all three seasons and all ice-free months states tend to group tightly with little variation in estimates. An increasing level of variation is seen beyond 0.0-0.5 ice-free months, similar to that described for the Crowding and Predation nodes, suggesting increasing divergence in expert judgments for ice-free months states for which little data is available to aid their judgments. Overall, a reduction in sea ice is believed to have a minor effect on the potential for increases in disease and parasites.

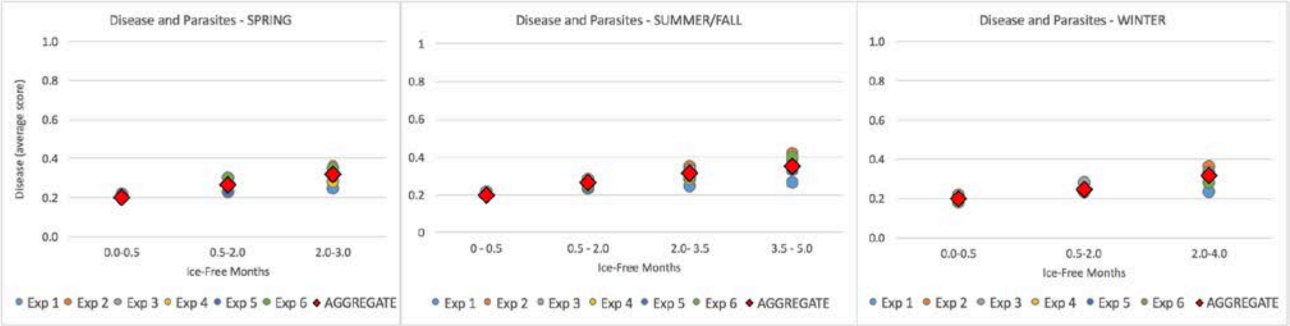

Figure 8. Comparison of estimated average probabilities for the Disease and Parasites node.

Breeding Environment and Birthing Platform

The Breeding Environment node reflects the adequacy of ice habitat for breeding. Estimated probabilities across experts for all three ice-free months states indicate a high degree of agreement, with a slight widening in the range of estimates beyond 0.5-2.0 ice-free months. Similar to other nodes described above, these estimates tend to diverge slightly as ice-free months increase, likely because of an increasing level of uncertainty over how walrus breeding environment will be affected under these conditions. Science Team members noted that very little is known about whether walrus are dependent on sea ice for breeding, or simply associated with sea ice and have the ability to breed without ice. Walrus currently stage from ice for courtship, but there is a high degree of uncertainty about to what degree walrus require or prefer ice for breeding. Because walruses actually breed in the water adjacent to areas where they've congregated on ice, the ST agreed that likelihood is low that the environment, under ice-free conditions, would be inadequate to support breeding needs.

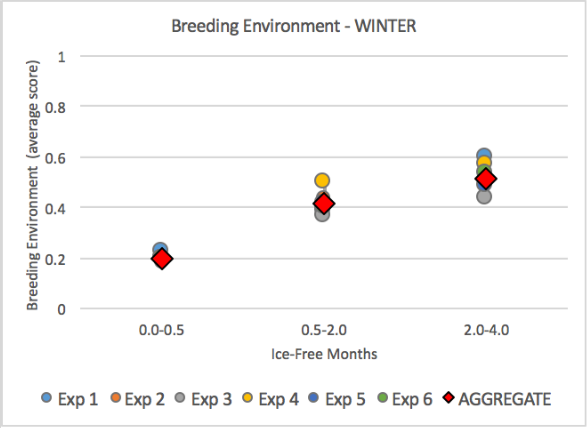

Figure 9. Comparison of estimated average probabilities for the Breeding Environment node.

The Birthing Platform node reflects the adequacy of spring ice habitat as substrate for walruses to give birth to calves and provide protection during severe storms. This node follows a similar trend as Breeding Environment, however with a steeper increase in average probability scores with increasing ice-free months. A small degree of divergence in estimates occurs across experts for 0.0-0.5 ice-free months, and that divergence increases for 0.5-2.0 ice-free months, then converges again at 2.0-3.0 ice-free months. As above, this indicates an increased level of uncertainty over how walruses will respond as ice begins to retreat in the spring. A small amount of ice loss may be tolerated, though it is uncertain how walruses will respond with up to two ice-free months. There is agreement among the team, however, that greater than two ice-free months will be problematic for walruses. While walruses may be able to meet some birthing requirements on land in situations where there are two or more ice-free months, the dominant expectation among the ST is that the birthing environment will not be adequate.

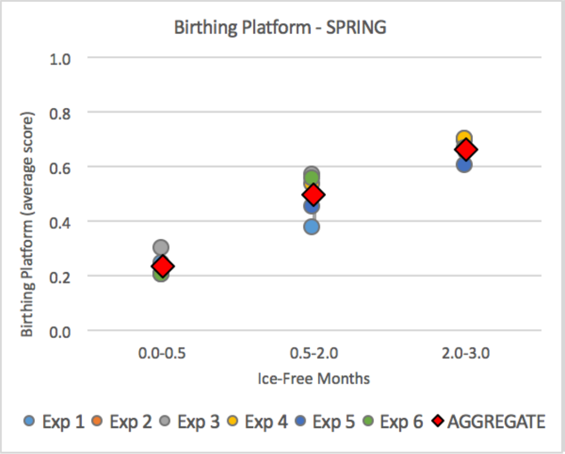

Figure 10. Comparison of estimated average probabilities for the Birthing Platform node.

Energy Expenditure

The Energy Expenditure node reflects the amount of energy walruses may need to expend for migration and foraging activities. This is a function of benthic prey abundance (i.e., how much food is available), ship and air traffic (i.e., whether vessels impact walrus feeding or migration activities), and ice-free months (i.e., reduced access to areas for foraging). Expert estimates for Energy Expenditure indicate a sharp but consistent increase in energy expenditure with decreasing benthic prey abundance across each season (see multiple groups of three in each sub-figure of Figure 11). However, only a slight increase is seen with increasing Ice-Free Months and Ship and Air Traffic (SAT). Additionally, estimates are grouped very tightly indicating a high degree of agreement among experts. The greatest divergence in estimates occurs in the spring, though the spread between estimates is less than 20% average score.

Overall, the sensitivity analysis conducted here indicates that there is sizable divergence in estimates across experts for the Crowding node and the Predation and Associated Mortality node, and general agreement for the Disease and Parasites, Birthing Platform, Breeding Environment, and Energy Expenditure nodes. Uncertainty increases with increasing ice-free months, likely because there is little historical data to suggest how sea ice will affect these nodes, leaving experts to make judgments under high uncertainty. When uncertainty is high, people often look for cues (from available information or elsewhere) as to how information should be processed and what implications should be drawn from it. Different experts may use different cues, and judgments and forecasts may differ as a result. (Lichtenstein and Slovic 2006).

Figure 11. Comparison of estimated average probabilities for Energy Expenditure. Three inputs influence Energy Expenditure: Ice-Free Months, Benthic Prey Abundance (BPA), and Ship & Air Traffic (SAT).

Abundance Stressors Outcomes

To analyze the effect of expert disagreement on seasonal abundance stressor outcomes, comparative charts were created to illustrate the probability estimates for 'low to moderately low stressors' vs 'moderately high to high stressors' for each time period based on the ‘aggregate’ CPTs (where judgments were aggregated across experts). Whiskers on the bars represent the range of model outcomes based on the range of expert judgments using the Min and Max models described above.

Seasonal abundance stressor outcomes for scenarios RCP2.6 (Figure 12) show a trend in probability distributions across both seasons and time steps. Distributions range from approximately 95% mean probability of low to moderately low stressors in winter 2015 to higher than 40% mean probability of moderately high to high stressors in summer/fall 2100. Seasonally, stressors are generally low to moderately low for both spring and winter, with an increasing proportion of moderately high to high stressors in the summer/fall season. Whiskers indicate two distinct trends. First, whiskers for the spring and winter seasons skew substantially toward 'moderately high to high stressors'. This is interpreted in part as an artifact of the majority of probability being in the 'low to moderately low' states, with little room for variation in expert estimates toward 'low to moderately low'. Second, the spread in whiskers is substantially higher in the summer/fall season, and in general the spread in whiskers increases over time periods from narrower bars in 2015 to wider bars in 2100. This indicates an increasing level of uncertainty across members of the ST as predictions for input nodes extend into the future (also reflected above in the Climate Change on Benthos node – Figure 5). This can also be explained by a greater spread in expert probability estimates for CPTs as node input levels increase (e.g. with higher numbers of ice-free months per season, expert judgments diverge further, as seen in the Predation and Associated Mortality node – Figure 7).

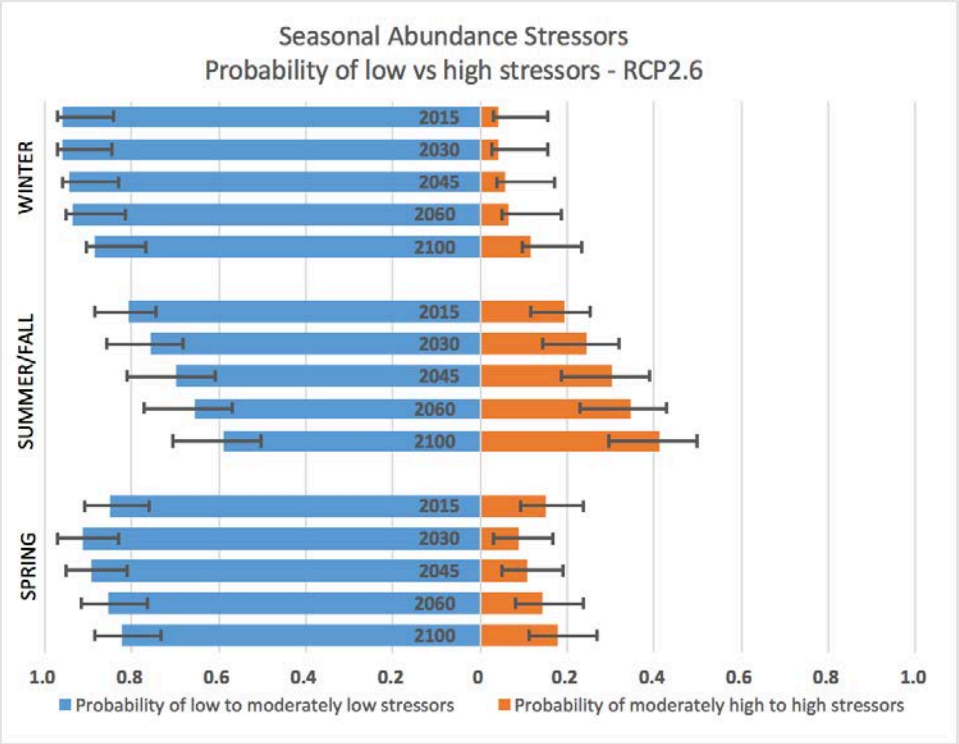

Figure 12. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for seasonal Abundance Stressors, by season for 2015-2100 time periods and RCP2.6. Blue and orange bars represent the probability distributions for the BBN model based on the 'aggregate' CPTs, while whiskers indicate the model runs based on minimum and maximum judgments across experts (Min and Max models).

Scenario RCP4.5 shows a similar trend (Figure 13), with only a slight increase in proportion of moderately high and high stressors across seasons and time steps. A similar increase is noted for scenario RCP8.5 (Figure 14), however, the greatest increases in moderately high to high stressors occur in the 2030 and 2045 time steps in summer/fall, and in the 2060 and 2100 time steps in spring and winter. This trend reflects the predicted trend in sea ice reduction in the RCP8.5 scenario.

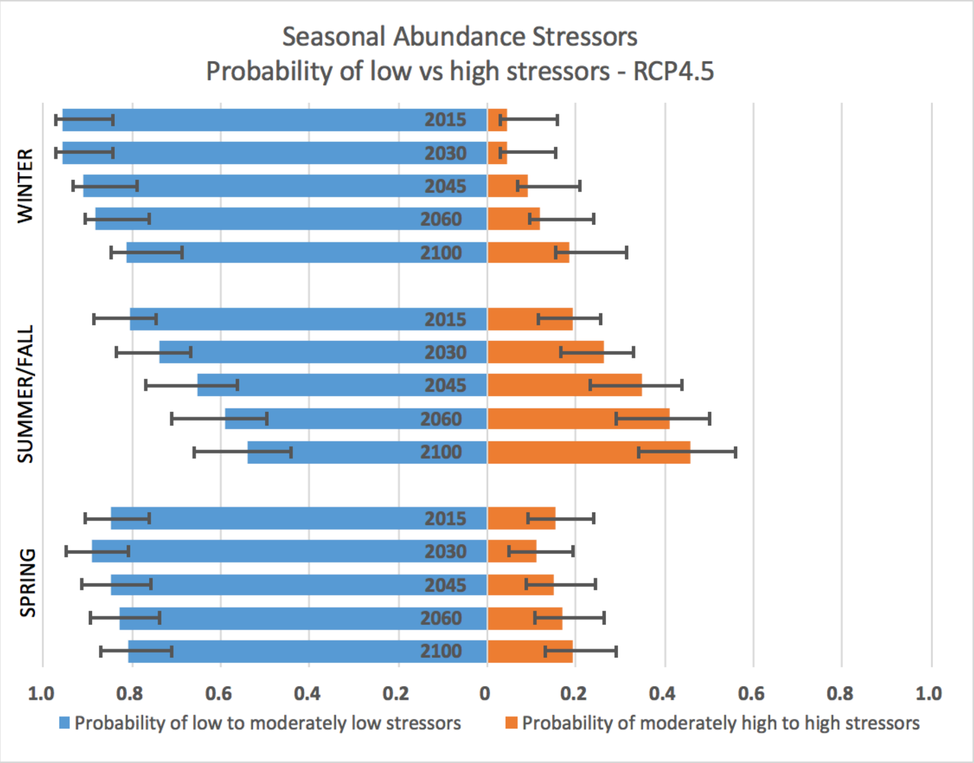

Figure 13. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for seasonal Abundance Stressors, by season for 2015-2100 time periods and RCP4.5. Blue and orange bars represent the probability distributions for the BBN model based on the ‘aggregate’ CPTs, while whiskers indicate the model runs based on minimum and maximum judgments across experts (Min and Max models).

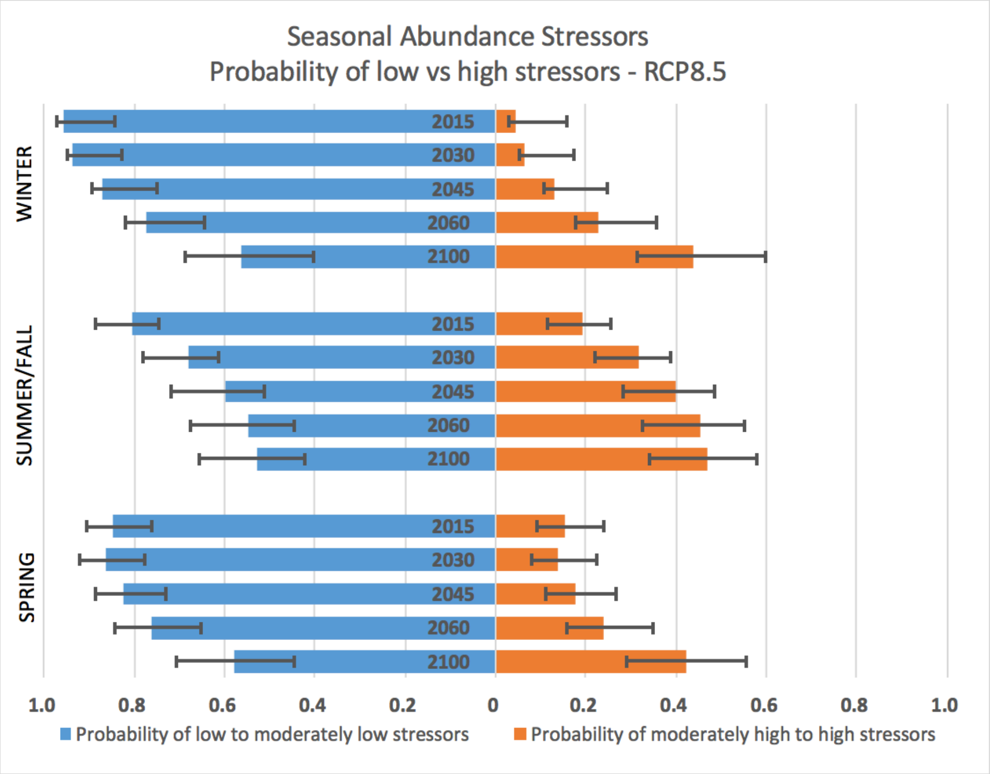

Figure 14. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for seasonal Abundance Stressors, by season for 2015-2100 time periods and RCP8.5. Blue and orange bars represent the probability distributions for the BBN model based on the ‘aggregate’ CPTs, while whiskers indicate the model runs based on minimum and maximum judgments across experts (Min and Max models).

The observed seasonal trend indicates that the highest levels of abundance stressors are anticipated in the spring and summer/fall seasons where sea ice and other stressors place the greatest cumulative stress on the walrus population. Winter sees the lowest levels of overall abundance stressors, largely due to a relatively lower anticipated retreat of sea ice combined with limited resource utilization and ship and air traffic during that season. Similarly, looking across RCP scenarios, the greatest increases in probability of moderately high to high stressors in RCP4.5 and RCP8.5 compared to RCP2.6 occur in the winter and spring seasons. These seasons experience no-ice-free months in RCP2.6, so there is a sizeable increase in abundance stressors for these seasons when the number of ice-free months for RCP4.5 and RCP8.5 increase from 2045 onward.

All-season abundance stressors

The all-season abundance stressor outcomes illustrate a large range of probability distributions from primarily low to moderately low stressors in 2015 (Figure 15 through Figure 17), up to a 65% mean probability of moderately high to high stressors under RCP8.5 in 2100 (Figure 17).

Under RCP2.6, All-Season Relative Abundance Stressors do not change significantly between 2015 and 2030, with approximately 20% mean probability of moderately high to high stressors. This proportion increases to approximately 25% mean probability of moderately high to high stressors in 2045, then to 30% in 2060, and approximately 40% in 2100. Whiskers indicate a substantial range due to differences in CPT estimates across experts, with lower bounds indicating a shift towards low to moderately low stressors of approximately 10%, and upper bounds indicating a shift towards moderately high to high stressors of approximately 15%. All-Season Relative Abundance Stressor estimates in 2060 range from 20% probability of moderately-high to high stressors under the low-bounds, to greater than 45% probability of moderately-high to high stressors under the high-bounds. Slight increases in the spread of whiskers occurs with increasing time steps, indicating a greater degree of uncertainty among expert probability estimates for CPTs as node input levels increase (as described above).

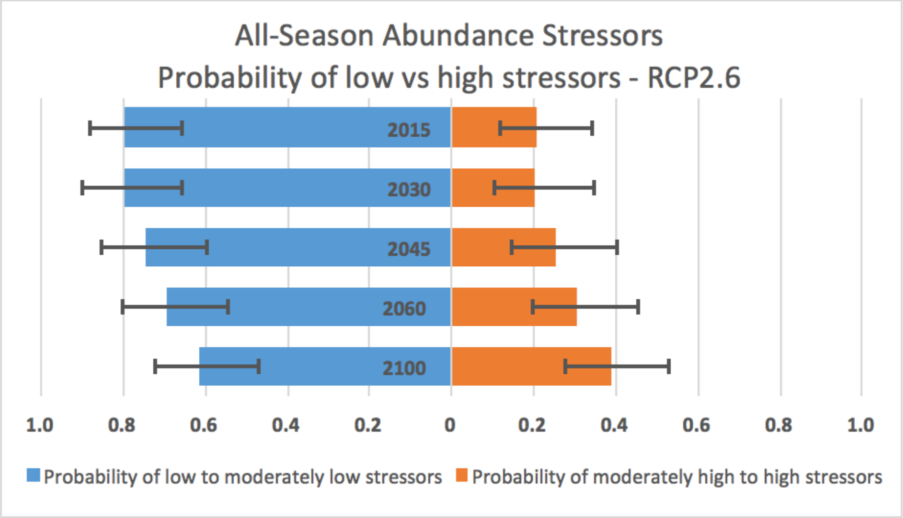

Figure 15. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for All-Season Abundance Stressors, by season for 2015-2100 time periods for RCP2.6. Blue and orange bars represent the probability distributions for the BBN model based on the ‘aggregate’ CPTs, while whiskers indicate the model runs based on minimum and maximum judgments across experts (Min and Max models).

All-Season Relative Abundance Stressors estimates for RCP4.5 mirror the trends found in RCP2.6, but with greater probabilities estimated for moderately-high to high stressors for time periods 2030 to 2100 (Figure 16). All-Season Relative Abundance Stressor estimates in 2060 range from greater than 25% probability of moderately-high to high stressors under the low-bounds, to greater than 50% probability of moderately-high to high stressors under the high-bounds. In 2100, this range increases from approximately 35% to 60% probability of moderately-high to high stressors.

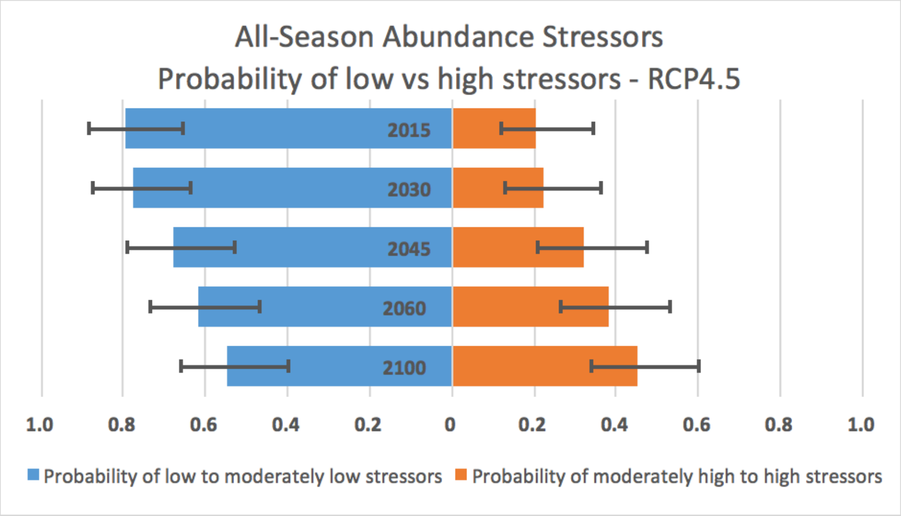

Figure 16. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for All-Season Abundance Stressors, by season for 2015-2100 time periods for RCP4.5.

For RCP8.5, All-Season Relative Abundance Stressors estimates for RCP8.5 also mirror those of RCP2.6 and RCP4.5, but with a substantial increase in probabilities of moderately-high to high stressors for time periods 2030 through 2100. By 2030, All-Season Relative Abundance Stressors estimates of moderately-high to high stressors range from approximately 20% to 42%, while by 2060 this range increases to approximately 35% to 65%. By 2100, this range increases to approximately 50% to 80% probability of moderately-high to high stressors.

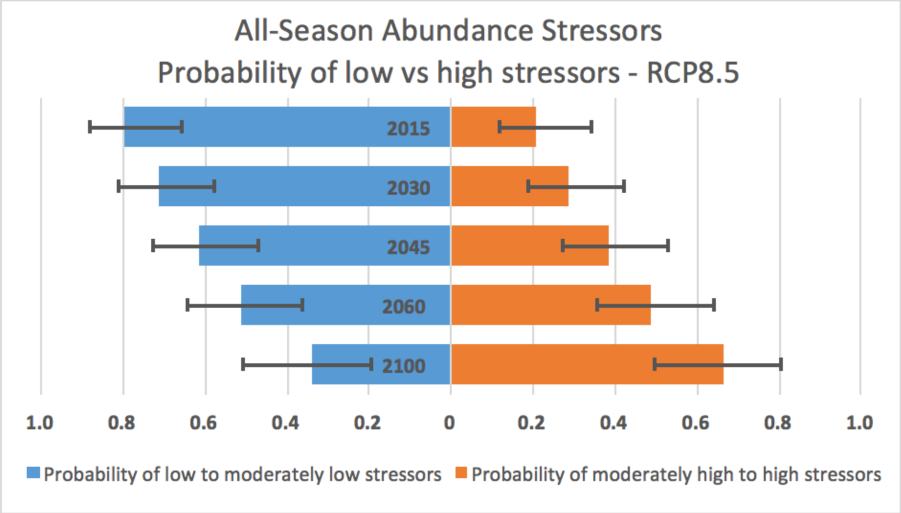

Figure 17. Comparison of probability of 'low to moderately low stressors' vs 'moderately high to high stressors' for All-Season Abundance Stressors, by season for 2015-2100 time periods for RCP8.5.

Overall, RCP2.6 resulted in the lowest proportion of moderately high to high stressors across time steps, while RCP4.5 showed slight increases and RCP8.5 resulted in the greatest proportion of moderately high to high stressors.

Population Change

An attempt was made in previous iterations of the BBN to incorporate an output node to estimate the population finite rate of increase (lambda [λ]) that would occur as a result of estimated abundance stressors for each time period. This attempt was problematic for a number of reasons. First, because the BBN model does not incorporate feedback loops from one time period to the next, it cannot take into account density dependent effects in its estimates. Second, how walrus population abundance is likely to respond to stressors was the topic of much deliberation, with a range of opinions emerging among the ST. One view was that a direct one-to-one relationship between stressors and population response would occur. That is, the walrus population would respond to an increase or decrease in stressor levels with a commensurate increase or decrease in abundance. A second view was that walrus have some adaptive capacity to cope with increased stressor levels which can moderate effects on walrus abundance. This view also took into consideration that density dependent processes would moderate rapid and large population changes. Under this view the walrus population would not likely experience a commensurate decrease in abundance when stressors are high. The ability of the walrus population to adapt to or cope with increasing stressor levels in the future is a topic of great uncertainty, and one that should be kept in focus when considering the implications of the abundance stressor estimates produced by this BBN model.

Influence Runs

Results of the influence runs are shown in Figure 18. Generally, the degree of influence of an input node on the model outcome is characterized visually by the difference between the “decreased stressor” (best case) and “increased stressor” (worst case) lines, such that a larger range in the probability of a particular outcome indicates more influence. Resource utilization, for example ((a) top left panel), has the lowest influence on the model outcome (measured here as the probability of moderately high to high abundance stressors), with a range of 5% probability or less within any given time period between best and worst case. Subsistence harvest ((f) lower right) demonstrates the greatest influence on abundance stressors, with a shift of nearly 70% probability between best case and worst case. Ice-free months ((e) left, lower middle panel) similarly has a strong influence on abundance stressor outcomes, with a shift of about 60% probability between best and worst ice conditions. Climate Change on Benthos, Resource Utilization, and Human Settlements show a small degree of influence on abundance stressors, while Ship and Air traffic shows a moderate degree of influence.

Mechanistically, some nodes have a lesser influence on the BBN model because they are linked to fewer child nodes and/or there are many nodes between the input and the abundance stressors output node. These inputs have a smaller ‘signal’ in the model than other nodes that link to many children, or that have a more direct influence on the output. Climate Change on Benthos, Resource Utilization, and

Human Settlements are an example of this, where each input links to just one child node, and there are several nodes between those inputs and the output node. Naturally, an input node with a larger number of connections (e.g., Ice-Free Months links to six nodes) will have a greater influence on the model mechanistically than an input with one connection.

It is important to note, that an input's low level of influence on the model outcome is not necessarily indicative of its influence biologically. There is a substantial amount of uncertainty in how much of an influence each input node has on its child nodes, as captured in the probability distributions of the child node CPTs. Additionally, the probability distributions for input tables for Climate Change on Benthos, Resource Utilization, and Human Settlements, are broad (See Appendix A1 for CPTs), indicating a relatively high degree of uncertainty over what level each of these stressors may be at over time and RCP scenario. This high degree of uncertainty also contributes to a low influence on the model outcome. However, since the scenario estimates for each input node are only used in the scenario analysis (the influence runs bypass the scenario estimates and instead set each node to its best or worst case), this effect is not seen in the influence runs. If the uncertainty in these nodes could be reduced (by collecting additional information about the relationships between the input and child nodes, and improving estimates for time and RCP scenarios), the influence of these inputs may be more sizable than is observed here.

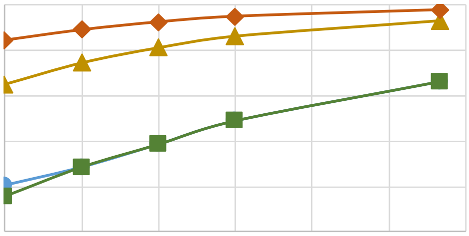

Figure 18. Change in probabilities of moderately high to high All-Season Abundance Stressors produced by a shift from best case to worst case for each input, and for the collection of anthropogenic inputs (excludes ice-free months and climate change on benthos). Results are based on model runs under RCP8.5.

Sensitivity Analyses

A sensitivity analysis using entropy reduction[6] suggested that the BBN model is most sensitive to ice-free months, subsistence harvest levels, and incidental takes (Table 5). In the spring and winter seasonal sub-models the BBN is most sensitive to sea ice, likely due to the addition of the birthing platform and breeding environment nodes in these seasons which are influenced by the ice-free months node. Ship and air traffic has a lesser influence on the model overall, with the largest influence found in the summer/fall sub-model, reflecting a greater number of ship and aircraft in use during that season. Human settlements, climate change on benthos, and resource utilization all have a minimal influence on the BBN overall. As described below, input nodes with a lower level of influence on the model tend to link to just one child node, and/or there are many nodes between the input and the abundance stressors output node. This diminishes the magnitude of the input signal that propagates through the model, and hence the decreases influence that they have on the model outcome relative to inputs with a greater number of linkages and/or fewer nodes between input and output.

Table 5. Entropy Reduction listed in decreasing order of effect from most to least influence. Higher levels of entropy reduction represent a stronger relationship between the input node and the outcome, and hence a greater degree of sensitivity of the outcome (All-Season Abundance Stressors) to the input.

Spring

Node	**Name**	**Entropy reduction**
IceMspr	Ice-free months	0.01208
TASspr	Subsistence harvest	0.00371
TAOspr	Incidental takes	0.00371
SATspr	Ship & air traffic	0.00126
HUMspr	Human settlements	0.00027
CCBspr	Climate change on benthos	0.00007
Ruspr	Resource utilization	0.00002

Summer/fall

Node	**Name**	**Entropy reduction**
TASsumfal	Subsistence harvest	0.00644
TAOsumfal	Incidental takes	0.00644
IceMsumfal	Ice-free months	0.00513
SATsumfal	Ship & air traffic	0.00189
HUMsumfal	Human settlements	0.00039
CCBsumfal	Climate change on benthos	0.0001
Rusumfal	Resource utilization	0.00002

Winter

Node	**Name**	**Entropy reduction**
IceMwin	Ice-free months	0.00763
TASwin	Subsistence harvest	0.00495
TAOwin	Incidental takes	0.00495
SATwin	Ship & air traffic	0.00168
HUMwin	Human settlements	0.00036
CCBwin	Climate change on benthos	0.00011
Ruwin	Resource utilization	0.00003

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[6] The results in Table 5 should be interpreted relative to one another – that is, an entropy reduction of 0.002 indicates twice the mutual information between the input and output nodes compared to 0.001. However, in absolute terms the difference in mutual information between 0.002 and 0.001 is very small.

A sensitivity analysis comparing breeding environment and birthing platform CPTs (normative) with alternative CPTs to test the sensitivity of the BBN outcome to assumptions made in these nodes shows little difference in abundance stressor outcomes under each scenario. The alternative CPTs resulted in an increase in abundance stressors of approximately 2% in 2030, up to 9% in 2100.

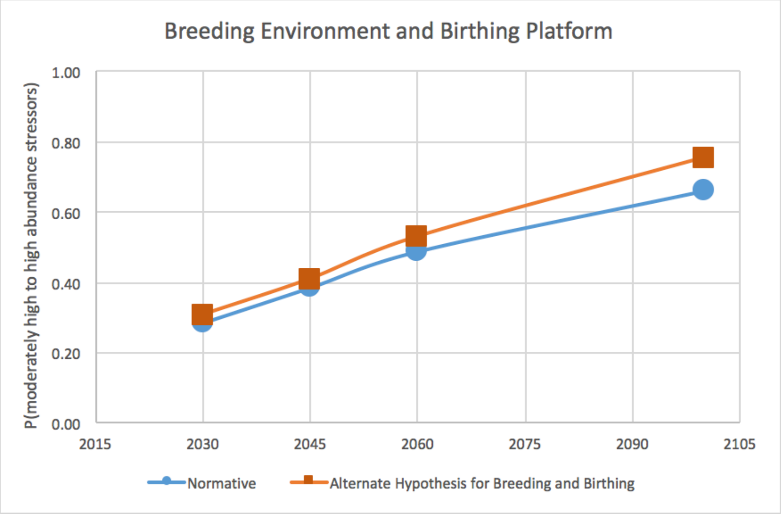

Figure 19. Birthing platform and breeding environment CPT sensitivity analysis under RCP8.5

DISCUSSION

The main intention of this BBN model is to describe the estimated level of abundance stressors on the Pacific walrus population as a result of known environmental and anthropogenic stressors. By analyzing the model response to these stressors using three variations on the underlying CPTs – the 'Aggregated' model based on mean probability distributions across experts, and the 'Min' and 'Max' models based on the highest and lowest probability distribution estimates across all experts - we are able to analyze both trends in abundance stressor outcomes and variations in the model estimates that take into account expert uncertainty.

Model estimates

Overall, the model outputs indicate a trend towards increasing abundance stressors over time, with an increasing degree of uncertainty in estimates for 2060 and 2100. Under all three RCPs the mean probability estimates (i.e., estimates based on the 'Aggregated' model) show greater than 50% probability of 'low to moderately low' stressors for time steps 2015 through 2060. In RCP2.6, the probability of 'moderately high to high' stressors does not exceed 40% for any time period, while this probability nears 50% in 2100 for RCP4.5 and in 2060 for RCP8.5. By 2100, there is a shift to greater than 65% probability of 'moderately high to high' stressors for RCP8.5. This trend shows that for RCP2.6 and RCP4.5, probabilities are estimated to be primarily weighted on 'low to moderately low' stressors for all time periods, while for RCP8.5 the abundance stressor outcomes shift more rapidly towards 'moderately high to high' stressors in 2060 and 2100.

These ‘Aggregated’ model responses, however, only paint part of the picture. Looking at the range of minimum and maximum abundance stressor estimates, there is a large variation in model outcomes due to the variation in expert derived CPTs. For example, for RCP8.5 in 2045 (Figure 17), the probability associated with ‘moderately high to high’ stressors is less than 30% under the minimum estimate (black whisker to the left of the mean estimate), but exceeds 50% for the maximum estimate (black whisker to the right of the mean estimate). The probability of ‘moderately high to high’ stressors for 2060 is less than 35% under the minimum estimate, and increases to approximately 65% under the maximum estimate. Similarly, the 2100 estimate of ‘moderately high to high’ stressors is below 50% probability for the minimum estimate, but greater than 80% for the maximum estimate. These findings indicate that uncertainty about the future levels of stressors is sizable. While under the minimum estimate, probabilities for ‘moderately high to high’ under RCP8.5 do not exceed 50% at any time period, the maximum probability estimate for this same state exceeds 50% as early as 2045.

Major drivers

The influence runs and sensitivity analysis paint a picture of which stressors are key drivers in the model. The trend of increasingly high levels of stressors through time is driven mainly by a projected reduction in extent of sea ice and, to a lesser extent, projected increases in ship and air traffic, particularly in the spring and summer/fall seasons. The effects of this seasonal decrease in sea ice and increase in ship and air traffic are reflected in the seasonal abundance stressor estimates in Figure 12 through Figure 14. The large influence of ice-free months on the model outcomes suggests that further decreases in sea ice beyond current estimates would have a significant negative effect on abundance stressors, and hence on the walrus population. This sensitivity suggests that it would be prudent to update model estimates at regular time intervals (e.g., every 5-10 years) to take into account new information and to reconsider implications for abundance stressors. This includes updating the model with the latest GHG projections and sea-ice models, as well as new data on the effects of climate change on benthos, trends in ship and air traffic and effects on walruses, and how walruses are able to cope via breeding and birthing platform. While subsistence harvest was found to have a sizable influence on abundance stressor outcomes in the influence runs (see Figure 18f), because harvest was set to ‘low’ for all model runs it contributes minimally to the model estimates presented here. The influence of subsistence harvest on abundance stressor outcomes is discussed further below. The remaining input stressors, Resource Utilization, Climate Change on Benthos, and Human Settlements, were found to have a minor influence on the model outcomes. The implications of this finding are explored below as well.

Sources and effects of uncertainty

The range of estimates observed in the model outcomes is indicative of a number of sources of uncertainty in the model, including model uncertainty and subjective uncertainty. Model uncertainty refers to uncertainty in the data (or scarcity of data) underlying judgments and estimates of model parameters and structure, as well as the resulting model outcomes based on this uncertainty. This uncertainty is manifest in the ice-free months model estimates and data underlying the input table and CPT estimates. There is substantial uncertainty about the effects that climate change will have over time, specifically on the timing and distribution of sea ice in the Bering and Chukchi Seas, and the magnitude of effect that changes to sea ice and ocean temperature and acidity will on various stressors such as benthic prey abundance. Subjective uncertainty refers to uncertainty introduced as a result of differences in expert judgments, expressed in the model through input data table and intermediate node CPT estimates. When data is scarce, it is difficult for experts to estimate how a stressor may change over time, and the range of differences in expert judgments indicate uncertainty among experts. Subjective uncertainty can also be introduced by differing interpretations of the science, leading to differences in probability estimates.

We were able to characterize uncertainty in the model due to uncertain data and differences in expert judgments in two ways. First, uncertainties due to the range of expert judgments are reflected in the minimum and maximum estimates (whiskers) for abundance stressors at each time period and for each RCP scenario. Second, CPTs reflect uncertainty through their probability distributions. When there is high uncertainty about the relationship between two variables, estimated distribution of probabilities (in the CPTs) are roughly equal (indicating that any value is equally possible), or broad distributions of probabilities are used (see Resource Utilization, Human Settlements, and Climate Change on Benthos CPTs in Appendix A1). This broad distribution indicates uncertainty over what outcome could be expected given input states, and this uncertainty diminishes the influence that those input nodes have on the BBN in our scenario runs. It is important to recognize that the relatively small influence that Resource Utilization, Human Settlements, and Climate Change on Benthos have on the model is a function of both uncertainty over how those input stressors may change over time (i.e., broad probability distributions in their CPTs), and of the few linkages that these inputs have in the model. It is not necessarily an indication of how important those stressors are biologically on the walrus population. This is an area of uncertainty that should be explored further to understand how these nodes contribute to overall abundance stressors and affect walrus population.

There is also the question of ecological uncertainty - how will walruses respond to changes in environmental and anthropogenic stressors? Will the population decline, or will they be able to adapt to changes? Central to this debate is whether walrus are strictly ice-dependent or simply ice associated; are Pacific walruses plastic enough in their diet, social grouping behaviour, and reproductive habits, to adapt to a loss of sea ice without negative effects to population-level vital rates? These uncertainties go beyond the scope of the model estimates presented here and extend towards the interpretation of how the abundance stressors estimated by this BBN model will affect walrus population. However, how walruses respond to stressors was the topic of expert deliberations during development of the model since walruses' adaptability affects how stressors are experienced. For example, walruses may or may not be able to adapt to increased walrus density and crowding at haul-out sites and distribute themselves more evenly across a larger number of sites, thereby reducing the risk of trampling and disease. Disagreement between experts over walruses ability to adapt contributes to the range in expert probabilities for the Crowding CPT (Figure 6). Walruses adaptability will be a central consideration when interpreting the impact of BBN estimated abundance stressors on the walrus population.

Other sources of uncertainty are not explicitly measured or characterized in the model, and so sensitivity analyses were conducted to understand how they impact abundance stressors. There is significant uncertainty surrounding to what extent a decrease in sea ice will impact walrus birthing platform needs in the spring, and breeding environment needs in the winter. While no walrus subspecies have been observed breeding and birthing on land, the working assumption in the model is that walruses will be able to adapt to a reduction in sea ice to some degree, and this is reflected in the CPTs for those nodes. However, the sensitivity analysis tested how the model would respond if that assumption was incorrect and walruses did not respond well to reductions in sea ice. The analysis found only a small difference in abundance stressor outcomes (between 2-9% increase in moderately high to high stressors) between these two hypotheses. At first glance, this result is surprising given the biological importance of breeding and birthing. However, the birthing and breeding stressors are a function of ice-free months, and in the scenarios that we ran fewer than 0.5 ice-free months are expected in winter and spring under RCP2.6, fewer than 0.5 ice-free months are expected in winter until 2045 under RCP4.5 and RCP8.5, and fewer than 0.5 ice-free months are expected in spring for RCP4.5 in all time periods, and not until 2060 in RCP8.5. The probability of ice-free months in each of these cases is fairly low, and it is not until 2100 that there is greater than 25% probability of >2 ice-free months in winter or spring (see ice-free months estimates in Appendix A1). As such, the impact of sea ice on birthing and breeding nodes, and hence on abundance stressors, is relatively low in this model for the scenarios tested. The results of this analysis, however, do not reflect in absolute terms the biological importance of ice for walrus breeding and birthing. The seemingly low influence that these nodes have on model outcomes is also a reflection of the birthing platform and breeding environment nodes being just two of many stressors that influence all-season abundance stressors. This model assumed a rapid decline in adequacy of birthing platform and breeding environment with greater than 0.5 ice-free months in the spring and winter seasons respectively, but did not assume a threshold or tipping point beyond which a reduction in sea ice would become potentially catastrophic for walruses. Whether or not walruses will be able to successfully breed, birth, and raise calves in the absence of sea ice is an area of uncertainty that is not easily resolved given the lack of data to demonstrate whether walruses can meet their needs as sea ice retreats. Further research is required to better understand the impact of a reduction in sea ice on walrus breeding and birthing.

Another significant source of uncertainty in the model is the effect of subsistence harvest on abundance stressors. Because of the difficulty in estimating the effects of subsistence harvest in the future in the absence of reliable abundance projections, subsistence harvest was kept at 'low' for all model runs. It is important to note that the effects of subsistence harvest are relative to the population size at the time of the hunt. If the walrus population declines over time but the number of walruses hunted annually is constant into the future, then the effects of subsistence harvest will increase over time (and perhaps change from the 'low' state to 'moderate' or higher). An increase in the subsistence harvest state beyond 'low' would translate into a shift towards 'moderately high to high' abundance stressors relative to results presented here (see section on Influence Runs for an analysis of model sensitivity to subsistence harvest). Sensitivity analyses on subsistence harvest presented in Figure 18(f) show the probability of 'moderately high to high' abundance stressors increasing substantially if subsistence harvest is set to 'high' or 'very high'. For example, in 2030 the probability of 'moderately high to high' abundance stressors is estimated at approximately 30% under RCP8.5 for the mean 'Aggregated' model. However, this probability jumps to approximately 75% 'moderately high to high' if subsistence harvest is 'high' and approximately 90% 'moderately high to high' if subsistence harvest is 'very high'. This indicates that abundance stressors, as modeled here, is highly sensitive to changes in subsistence harvest. If harvest remains at current numbers, yet the population declines as a result of changing environmental conditions and other anthropogenic stressors, then the harvest rate could exceed the threshold for sustainable harvest (assumed here to be a harvest of 4% of the population annually), and substantially increase the level of abundance stressors on the walrus population.

One major limitation of the structure of the model is that it does not incorporate feedback mechanisms, which introduces issues in interpretation of the results. It is conceivable that many of the effects captured in the model could exhibit density-dependent relationships – for example, the relationship between ice-free months and levels of crowding could vary depending on the walrus population, a parameter that is not included in the model. Capturing these kinds of changing responses of the walrus population to changing conditions over time is not possible without feedback mechanisms.

Finally, three additional factors should be taken into account when interpreting model outcomes. First, it is important to note that in addition to the uncertainties presented here, ice habitat extent is not included in the model (it is being explored in a separate analysis), and so estimates of abundance stressors are underestimated by this BBN model. Second, the members of the ST expressed low confidence in the abundance stressor estimates for 2100 because of a collective uncertainty about the validity of the assumptions the model makes about the response of walruses to the extremely poor ice conditions forecasted at the end of the century. This source of uncertainty, which exists in addition to the wide distributions used for defining input probabilities, is not captured explicitly in the model nor is it portrayed graphically in any of the charts. It is therefore important to consider the results for the 2100 time period highly uncertain. Third, when interpreting the impact of estimated abundance stressors on the walrus population, uncertainty over the current walrus population size will be a significant factor in understanding how the population will respond. Most recent estimates place the Pacific walrus population at between 55,000 to 500,000 animals (Speckman et al. 2012), but most managers and researchers use 200,000 as a working hypothesis. As such, it may be difficult to estimate how that population may change in the future as a result of the level of abundance stressors estimated here. The risk tolerance of the decision makers will also play a role in a deciding what level of abundance stressors is too high to sustain a viable walrus population. This risk tolerance may vary based on the population estimate and the level of uncertainty in that estimate, as well as the nature and degree of other uncertainties including those discussed here. It is important to be mindful of all of the factors that come into play when assessing 'how high is too high', and to clearly understand the uncertainties and impacts these may have on the estimates provided here.

CONCLUSIONS

This study developed a comprehensive probabilistic Bayesian Network (BBN) model that incorporates environmental and anthropogenic stressors to estimate abundance stressors on the Pacific walrus population. A BBN was chosen because it can accommodate both the complexity of stressors that may affect walrus abundance, and uncertainty due to scarce data on walrus vital rates and demographic response to such stressors. It also enables the transparent use of existing data as well as western scientific knowledge, expert judgment, and Local and Traditional Ecological Knowledge to inform estimates of stressors and population level effects. Several limitations of the model are acknowledged, including the appearance mechanistically that some input nodes have little influence on outcomes when biologically the influence is uncertain. Additionally, the model does not allow for feedback loops from one time period to the next, and so density dependent effects are not captured in the model.

The BBN model presented here captures the influence of key stressors on the Pacific walrus population in a way that enables an understanding of potential for population change (captured as estimates of all-season abundance stressors) from the current date to 2060 and beyond. The model results indicate primarily 'low to moderately low' abundance stressors out to 2100 under both RCP2.6 and RCP4.5, but with a steadily increasing probability of 'moderately high to high' abundance stressors beginning around 2030. A relatively steeper increase in probability of 'moderately high to high' stressors is observed under RCP8.5 beginning in 2030, with a 50% or greater probability of 'moderately high to high' stressors from 2060 onward. Together, these results show an increasing potential for 'moderately high to high' stressors out to the end of the century for all three RCP scenarios, indicating a high likelihood that Pacific walrus will experience a steady and substantial increase in abundance stressors compared to the level of stressors experienced today.

For the RCP8.5 scenario in particular, the estimated increase in stressors is more rapid and the overall probability for 'moderately high to high' stressors from 2060 onward equals or exceeds the probability of 'low to moderately' low stressors. Considering the range of estimates due to inherent uncertainties in the model, these probability estimates may be decreased or increased by as much as 10% beyond the mean estimates. At the high end of this range, abundance stressors are estimated to exceed 50% probability of 'moderately high to high' for RCP8.5 as early as 2045, with probabilities as high as 65-80% in 2060 and 2100. This trend closely follows the estimated trend in decreasing sea ice (i.e., increasing ice-free months), as well as increases in other stressors including ship and air traffic. With that said, as one predicts further into the future, uncertainty surrounding the results increases.

The implications of the estimated loss of sea ice and overall increase in abundance stressor levels remains a key uncertainty. Central to this uncertainty is the question of whether and to what degree walrus have the capacity to adapt to a loss of sea ice without negative effects to population-level vital rates. When interpreting the impact of BBN estimated abundance stressors on the walrus population, the adaptability of walrus to a changing climate will need to be a key consideration.

A number of anthropogenic stressors (Human Settlements, Resource Utilization, and Ship & Air Traffic), as well as Climate Change on Benthos, were found to have a minimal influence on abundance stressor estimates. However, improvements to anthropogenic stressors, such as a reduction in impacts from ship and air traffic on walruses, or limits to resource utilization in key feeding areas or migration routes, could together have a positive impact on the walrus population. The negligible impact that resource utilization, climate change on benthos, and human settlements have on population outcomes reflects both a mechanistically small influence on the model, as well as a high degree of uncertainty in future states of these variables and a poor understanding of the ways in which these variables may affect walrus body condition and mortality. These input nodes should not be interpreted as inherently having little effect biologically on the walrus population; rather, the true magnitude of their influence on walruses and how the walrus population will respond to changes in these stressors over time needs further investigation.

While high levels of subsistence harvest were found to have a strong influence on abundance stressors, indicating that harvest levels beyond a sustainable threshold could place significant stress on the population, current levels of subsistence harvest were found to have a minimal effect on abundance stressors. The current trend suggests that harvest levels may continue to decline in the future as walruses become harder to hunt; therefore, reducing harvest below current levels would have a minor positive effect on population outcomes in the future. However, if the walrus population declines beyond today's levels and harvest numbers remain the same as today, the relative harvest pressure will increase and may tip the harvest rate beyond a sustainable threshold. It will be important to keep this in mind when considering the implications of harvest on overall abundance stressors into the future.

Additional research, including study of the impacts on resource utilization on feeding and migration, research on the effects of climate change on food sources, and improved estimates of the degree to which human settlements are expected to grow and how settlements impact walrus behavior, is warranted to support an improved understanding of these stressors and their effects. Additionally, it will be necessary to obtain a population estimate with greater confidence in order to more confidently assess the implications of increasing abundance stressors on the overall walrus population. Another key area of uncertainty that warrants further research is the degree to which birthing and breeding are affected by changes in sea ice, and whether birthing and breeding needs can be met in the absence of ice. If walruses are not able to adapt as is assumed here, then the population may experience a significant challenge in meeting these needs as sea ice begins to diminish in the spring in summer from 2045 onward.

This BBN model provides insight into the effects that a reduction in sea ice and increases in other stressors will have on walrus abundance stressors over time, thus supporting the Service's work to assess population level-effects on Pacific walrus into the future. Future effort to improve model estimates should focus on monitoring of walrus abundance and distribution, and studying the response of walruses to changing Arctic conditions, including climate change effects on benthos and other anthropogenic stressors.

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9.1.1 Appendix A1 Revised Bayesian Belief Network Model Input and Conditional Probability Tables

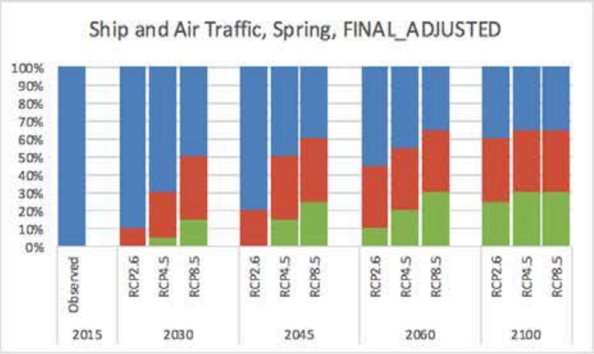
OVERVIEW

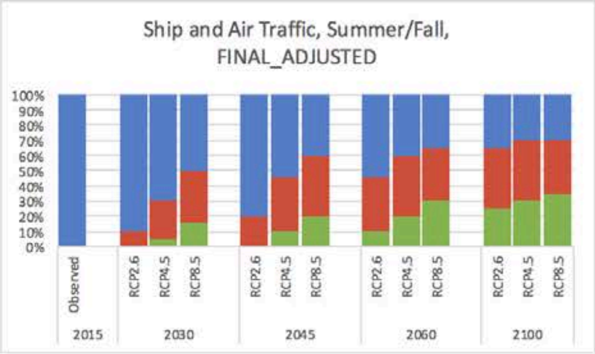
For the input nodes presented on page 2 through 11, the Science Team (ST) drew upon reports and published literature, as cited here, to inform their judgments on how to define input node states (aka 'bins'), and to help develop probability tables for each RCP and time period combination. For intermediate nodes (page 12 onward), the ST were asked to draw upon available studies, their field experience and training, and knowledge of walrus biology and that of other marine mammals, to make their best judgments on setting appropriate definitions for node states and probability distributions for conditional probability tables (CPTs). The ST noted that very few studies explicitly explored the linkages defined in this BN model (e.g., the influence of ice-free months on disease and parasites), and the available literature was limited in how it could directly inform judgments for these CPTs. Few citations to the scientific literature are found for the intermediate nodes since the ST members had to rely primarily on their best judgments in the absence of scientific studies to inform the development of CPTs.

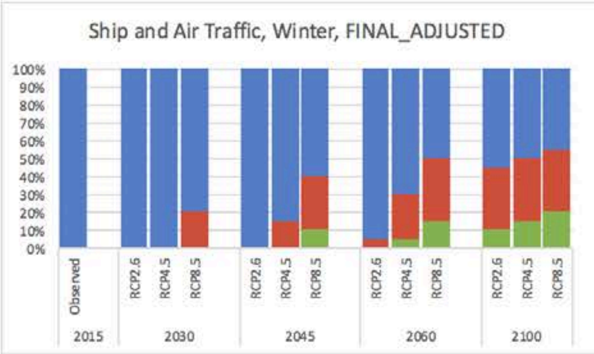
A number of node state definitions and CPTs were derived from a 2011 version of the BN model (outlined in Jay et. al. 2011), including Benthic Prey Abundance, Oil Spills and Other Pollution, Haul-Out Disturbance, and Crowding and Disturbance. The node definition, state definitions, and CPTs were reviewed by the ST and deemed to be in line with their best judgment, and so these definitions and CPTs were not revised. Two additional nodes, Body Condition and Total Mortality, were also derived from Jay et. al. 2011, though their CPTs were adjusted by the ST (through a deliberative process) to reflect their interpretations of how the parent nodes affect the CPTs for these intermediate nodes. State definitions for these nodes are unchanged from the 2011 model. Finally, a number of intermediate nodes were developed by the ST, and both the state definitions and CPTs were fully defined where possible. The ST found it difficult to explicitly define the node state definitions for Predation and Associated Mortality and Energy Expenditure, but through discussion were able to notionally agree on what these state definitions (e.g., low, moderate, high) mean.

SHIP AND AIR TRAFFIC

Definition: Amount of ship and air traffic from commercial shipping, tourism, and Fishing, and oil and gas development







Ship and Air Traffic (transits)

🟦	Low	<= 300
🟥	Moderate	301 - 599
🟩	High	>= 600

Description: Most shipping and air traffic in the Arctic today is destinational in nature- moving goods into the Arctic to re-supply communities, or moving natural resources out of the Arctic to supply world markets. There is little to no destinational ship traffic during the winter and spring seasons at present due to persistent sea-ice, and traffic levels during the summer/fall season are relatively low. We assumed that population growth in Arctic communities (*see human settlements for details*) would be the primary driver of future levels of destinational ship and air traffic in the Bering and Chukchi Seas.

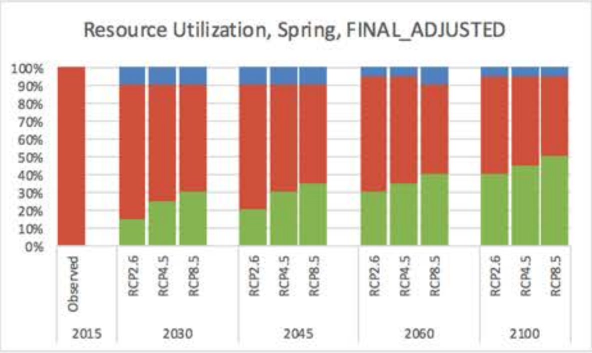
Projected sea ice losses, and the associated increase in the number of ice-free days, are expected to result in increased opportunities for new resource development projects in the Arctic. A prolonged open water season along the Northern Sea Route (northern Eurasian coast from Novaya Zemlya to the Bering Strait) and Northwest Passage (northern North American coast and through the Canadian Arctic Archipelago) could also eventually lead to a competitive advantage to shipping through these sea routes over the traditional Europe-Asia route through the Suez or Panama Canals (Arctic Council 2009).

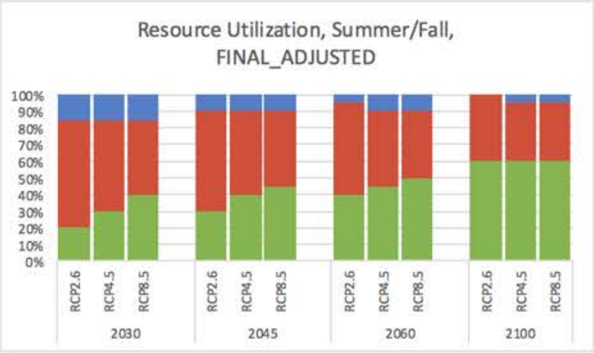
For the purposes of the model, we used the annual number of ship transits through the Bering Strait as an index of current and future levels of ship and air traffic. This is an index representing a number of human activities across the range of the Pacific walrus, including increased barge traffic, ice breakers, and commercial flights. Probabilities between best case and worse case scenarios were computed by interpolation. Time (period) was weighted more heavily than GHG emission scenarios as a predictor of future levels of ship and air traffic, because most of the projected increase in ship and air traffic in early time steps is expected to be limited to serving the needs of growing Arctic communities. Trans-Arctic shipping is not expected to become logistically or economically viable until mid-century (Hansen et al 2016). Beyond mid-century, there is a general pattern of increasing numbers of ice free days over time, irrespective of which GHG scenario is chosen (the probability of increased levels of Arctic shipping and/or resource extraction increases with time across all scenarios examined). Despite a clear trend toward greater marine accessibility during the summer/fall period, the economic viability of resource development and trans-Arctic shipping is also constrained by a complex set of economic (e.g. commodity prices, shipping schedules, port infrastructure, insurance premiums) and regulatory (icebreaker fees, ice-class vessel requirements, national, and international governance regimes) considerations (Stephenson et al 2015). Accordingly, we assigned input probabilities to reflect increasing uncertainty with each successive time step.

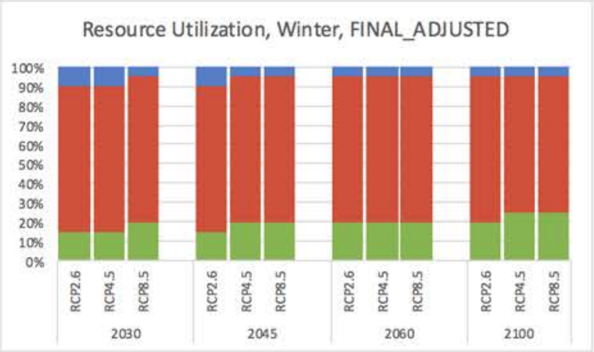
At present (current state) ship and air traffic (all sources) do not appear to be having significant effects on disturbance, oil spills, or energy expenditure, so our base index value (< 300) was set to ‘low’. Moderate (300-600) implies up to twice as much ship and air traffic in the arena; and High more than twice as much, and the effects of these levels are captured through the child node CPTs.

RESOURCE UTILIZATION

*Definition***:** Impact of benthic prey production from activities that can perturb the seafloor from extraction of natural resources, such as from commercial fishing and oil and gas development.







Resource Utilization

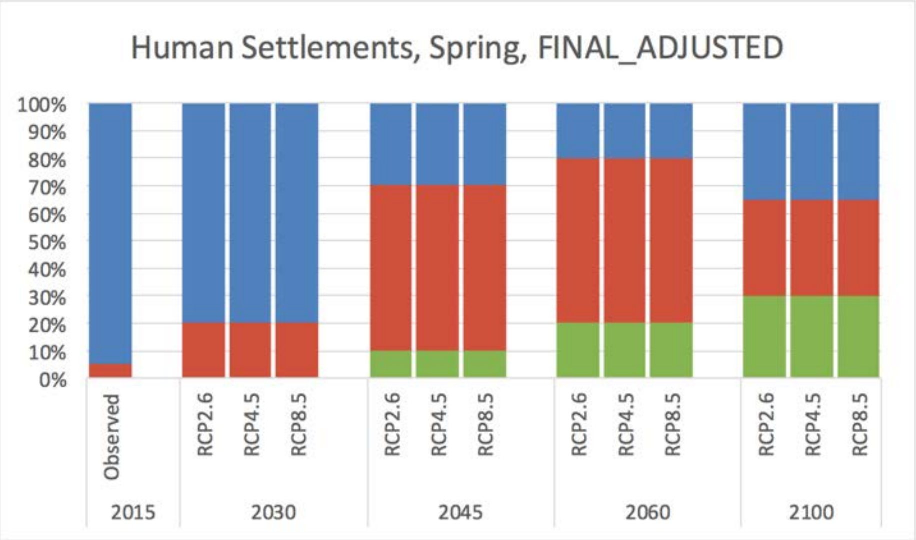
🟦	Positive	e.g., occasional, localized disturbance (see description)
🟥	Neutral	
🟩	Negative	e.g., widespread, regular disturbance (see description)

Description: The effect of perturbations to benthic communities is likely dependent on the magnitude, type, and frequency of the perturbation. These factors will be related to the level of resource utilization in an area. It is possible that perturbation to the seafloor at a low magnitude and frequency could enhance production by releasing nutrients from sediments and by allowing increased recruitment of juvenile organisms. Higher levels of perturbation could be detrimental to benthic communities from habitat degradation and high mortality of benthic organisms. Future summer sea ice losses, and associated increase in number of ice-free days during summer and fall, are likely to lead to future increases in fishing (e.g., trawling) and resource development activities in the Chukchi and Bering seas, including activities that impinge on the seafloor. These activities will be affected by the abundance of sea ice, but perhaps even more so from changes in human population size.

The RCP 2.6 scenario assumes a human population size of 10.1 billion by 2100, whereas the 4.5 scenario predicts a peak of above 9 billion by 2065, then declining to 8.7 billion by 2095. The 8.5 scenario predicts maximum population size of 12 billion by 2100 (Newbold et al. 2015). Under all three scenarios oil and gas are expected to make up a large portion of the world's energy sources (van Vuuren et.al. 2011). USGS suggests that about 30% of the world's undiscovered gas and 13% of the undiscovered oil are to be found in the area north of the Arctic Circle, mostly offshore under less than 500 meters of water (Gautier et al. 2009). The North Pacific Fisheries Management Council has suggested that longer ice-free seasons, warming waters, and changes in the range of fish species could create conditions that could lead to commercial fishery development in the U.S. Arctic Exclusive Economic Zone (EEZ). The Arctic Fisheries Management Plan adopted by NOAA-NMFS in 2009 placed a temporary moratorium on commercial fisheries in federal waters north of the Bering Strait, but allows for fisheries to be authorized in the future if they can be shown to be sustainable (NPFMC 2009). We assigned different input probabilities by season. For the summer season we assigned increasingly higher probabilities towards the negative state. For winter, ice is expected to form throughout the century, thus, hampering resource development and fisheries activities during this season, so probabilities were assigned more heavily toward the neutral state for winter. For spring, input probabilities were set somewhat between values assigned for summer and winter. Differences in human population sizes assumed for the RCP scenarios and differences in sea ice extent between the scenarios were considered in assigning the probabilities across periods. We assigned increasingly higher probabilities towards the negative state through the century.

HUMAN SETTLEMENTS

Definition: Population size of humans along the coast of Alaska.



Human Settlements		
🟦	Low	≤ 65,000
🟥	Moderate	65,001-80,000
🟩	High	≥ 80,001

Description: Time period was weighted more heavily than RCPs; growth will be a function of time, and no rationale exists for why a warmer Arctic will spur an influx of people. Growth will largely be due to *in situ* births and deaths with little immigration and emigration. No seasonal effects that is more than very small, thus all seasons were parameterized identically. In general rates are predicted to be low through 2030, then moderate to 2045 (see table A-1 below), and we assume that will continue to 2060, but with more uncertainty, then highly uncertain at 2100. The potential for new villages being established along the coast is assumed to be very low. The current trend is to propose moving villages inland due to rapid erosion, sea level rise, and flooding due to storm surges – some examples exist of this occurring already.

The 'moderate' state, defined as 65,001 – 80,000 people living along the coast is a threshold where the Science Team expects to see human activities (air and boat charters, ATV traffic, hunters, etc.) along the coast that could begin disturb walruses. The 'high' state, defined as > 80,000 people living along the coast, is a threshold where human activities are estimated to significantly disturb walruses.

State of Alaska numbers and projections for coastal census areas (Howell 2014):

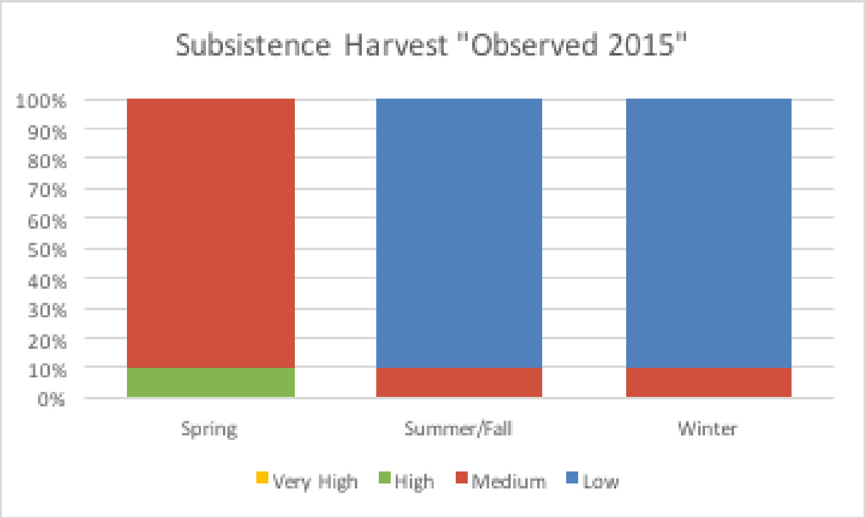
	2012	2017	2022	2027	2032	2037	2042	%Δ	GROWTH
Yukon-Koyukuk Census Area	5,682	5,414	5,161	4,927	4,701	4,520	4,411	-22%	-0.8%
Nome Census Area	9,869	10,283	10,688	11,103	11,597	12,211	12,997	32%	0.9%
North Slope Borough	9,727	9,638	9,544	9,465	9,460	9,563	9,757	0%	0.0%
Northwest Arctic Borough	7,716	8,032	8,333	8,625	8,949	9,369	9,926	29%	0.8%
Bethel Census Area	17,600	18,404	19,246	20,103	21,040	22,200	23,696	35%	1.0%
Bristol Bay Borough	987	961	933	897	851	818	779	-21%	-0.8%

Dillingham Census Area	4,988	5,027	5,066	5,104	5,151	5,221	5,341	7%	0.2%
Lake and Peninsula Borough	1,673	1,703	1,732	1,742	1,746	1,751	1,779	6%	0.2%
TOTAL	58,242	59,462	60,703	61,966	63,495	65,653	68,686		

SUBSISTENCE HARVEST

Definition: Number of walruses killed by Native subsistence hunting in Russia and Alaska.

Given that the current Pacific Walrus population size is uncertain, and that estimating whether future harvest levels will have a neutral or negative effect on the population requires knowledge of the population size in the future, this node was treated differently than other input nodes. The '2015 observed' period was estimated based on historical subsistence harvest data. However, probability distributions for future periods were not estimated, and instead will be held constant with 100% probability on 'low'. The magnitude of influence of this 'subsistence harvest' node will be determined using 'influence runs' where this input will be varied from 100% 'low' to 100% 'very high' to understand the effects of subsistence harvest on the overall model.



		No. of takes (based on 2006 population estimate)	
🟦	Low	<2,580	0%-2% removal, sustainable
🟥	Moderate	2,581 - 5,160	2%-4% removal, approaching max sustainable removal
🟩	High	5,161 - 7,740	4%-6% removal, potentially unsustainable
🟪	Very high	7,740 - 10,320+	6%-8%+ removal, unsustainable

Description: The low and high ranges of takes under low, moderate, high, and very high states are based on a sustainable harvest threshold of 4% annual removal of harvest based on 0.5*Rmax (Chivers 1999), and a 2006 walrus population estimate of 129,000 animals. Harvest between 4% and 6% is considered 'potentially unsustainable', while 6%-8%+ is considered 'very likely unsustainable'.

Estimated harvest in 2015 is approximately 3,300 (inclusive of harvest in Alaska and Russia), with a 5-year average of approximately 4,000 animals (U.S. Fish and Wildlife Service 2014). While these estimates, which are corrected for tagging compliance and struck and lost, fall within the 'moderate' state, there is still some uncertainty around the estimates which is reflected with a small probability that the population may lie in the 'high' range in the spring.

INCIDENTAL TAKES

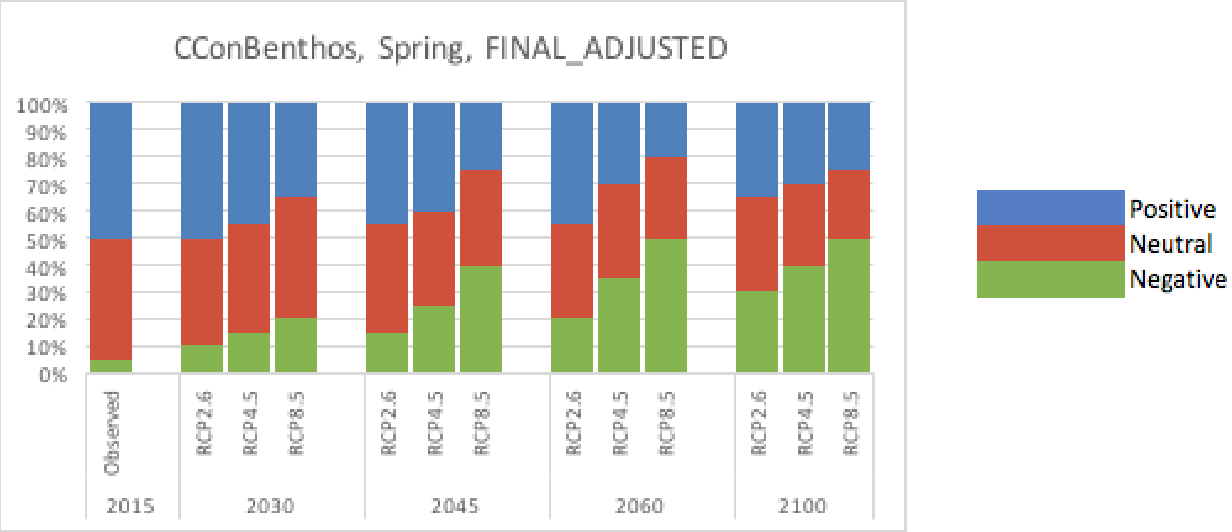
Definition: Number of walruses killed from illegal activities and incidentally from fishing, industry, and research activities in Russia and Alaska.

		No. of takes
🟦	Low	<2,580
🟥	Moderate	2,580 - 5,160
🟩	High	5,160 - 7,740
🟪	Very high	7,740 - 10,320+

Description: Current walrus mortality rates from fisheries interactions and other known human activities are estimated at about 3 walruses per year (U.S. Fish and Wildlife Service 2014) and typically have been low in the past. It is probable that decreasing sea ice will lead to increased shipping, oil and gas exploration, tourism, and research activities, which could result in a greater number of incidental takes in future years. Oil spills could result in the loss of a large number of walruses depending on the location, timing, and severity of a spill. Overall, we expect the level of take to remain in the low category (below 1,000 walruses).

CLIMATE CHANGE ON BENTHOS

Definition: Cumulative impact of various factors related to climate change on the production of benthic prey. Reduced sea ice and ocean acidification are assumed to potentially have the greatest influence on benthic prey production.



Description: Benthic biomass is primarily determined by the quantity and quality of benthic food supply, which originates mainly from the overlying water column (Grebmeier et al. 2006, Bluhm and Gradinger 2008) in the form of sea ice algae (found within or on the undersurface of the ice) and phytoplankton (in open water). The onset of sea ice melt and duration of open water plays an important role in the stability of the water column, and the timing and location of primary production and associated grazing by zooplankton. This has a direct influence on the relative amounts of organic carbon retained in the water column and exported to the sediments (Grebmeier et al. 2010).

It is suggested that annual net primary production increased 30% over the Arctic Ocean from 1998 to 2012 (Arrigo and van Dijken 2015). Massive under-ice phytoplankton blooms represent a marked shift in our understanding of Arctic marine ecosystems (Arrigo et al. 2014) and could play a substantial role in providing food to benthic communities in the future. However, it is not clear if increases in phytoplankton production would be exported to the benthos or simply recycled in the upper water column (Arrigo 2013) Furthermore, enhanced rates of primary production from sea ice loss and other changes in the future could be short lived or not occur at all, because mixing of nutrient-rich waters into the euphotic zone may be limited by stratification caused from warming surface waters and increases in freshwater runoff and sea ice melt (Mathis et al. 2014b). The biological processes that govern regional production are complex, and therefore, the effect of future sea ice loss and oceanographic conditions on primary production and its impact on benthic communities in the Chukchi and Bering seas is uncertain (Grebmeier et al. 2010, Arrigo 2013, Mathis et al. 2014b).

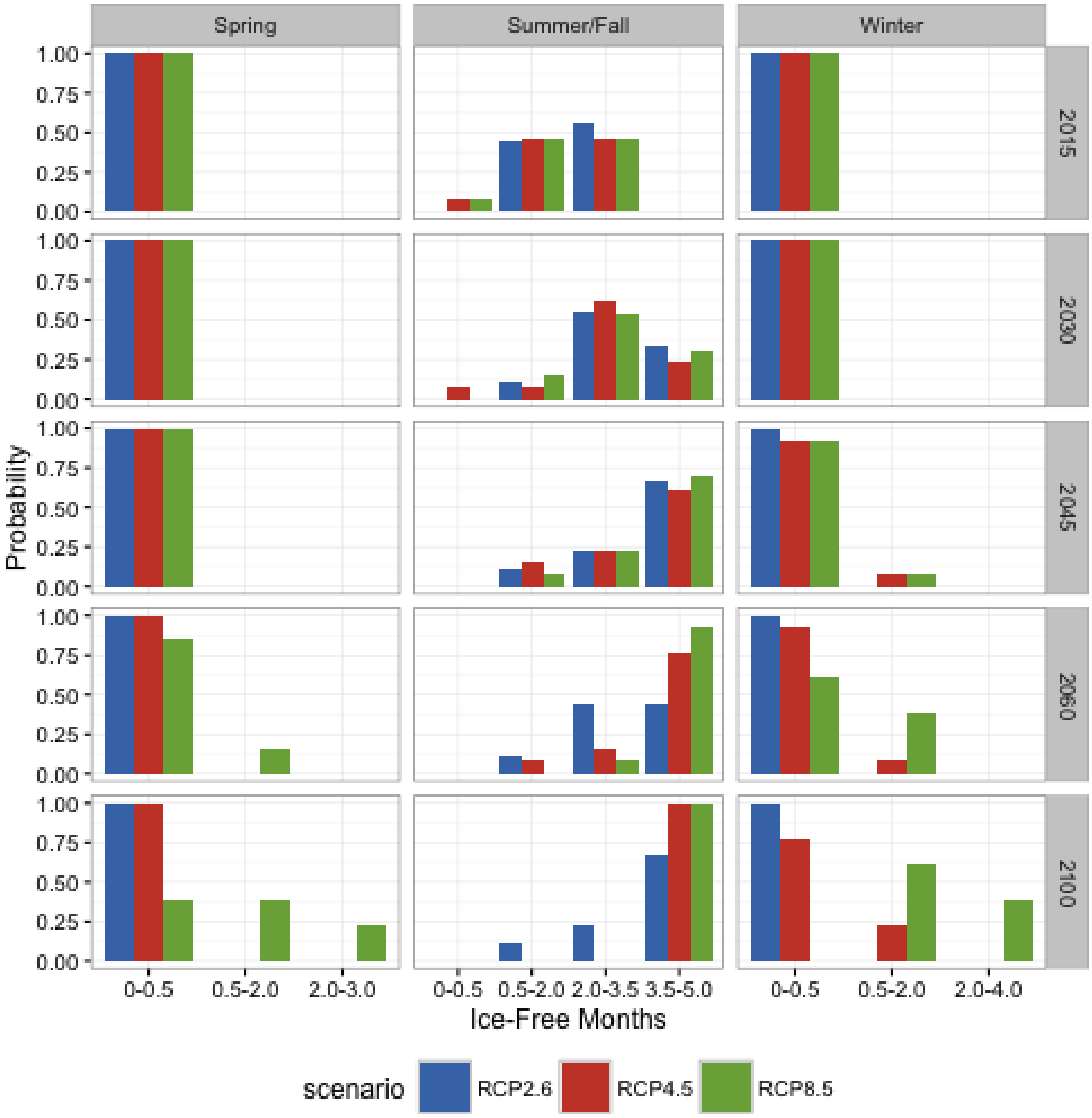
Model projected future saturation states of aragonite ($\Omega_{arag)}$ in the Bering, Chukchi, and Beaufort seas under the RCP8.5 scenario indicate that the average annual aragonite saturation horizon ($\Omega_{arag} = 1.0$) is projected to be reached in the Chukchi and Bering Sea by 2033 and 2062, respectively (Mathis et al. 2015a). RCP4.5 sea surface CO_2 level trajectories indicate aragonite undersaturation levels will be widespread in the Arctic by end of century (see Vuuren et al. 2011, Table 2, and IPCC 2014, Table SPM.1). The variable response across species to changing saturation states, with an increasing number of studies indicating that some species can tolerate undersaturation (Cross et al. 2015, Ramajo et al. 2016), creates greater uncertainty in predicting when declining saturation states will begin to have an impact on shelf ecosystems.

The complex interactions between the conditions that effect primary production, export of the organic carbon from the water column to the benthos, and the overriding consequences of predicted increases in ocean acidification to pelagic and benthic life stages of adult benthic organisms, make it very difficult predict the abundance and distribution of benthic prey of walruses. In addition, these processes operate differently among regions of the Bering and Chukchi seas (Mathis et al. 2014b, Grebmeier et al. 2015). In general, ocean acidification is predicted to increase and is likely to have a negative impact on walrus prey abundance, but the magnitude of its effect will be determined by the realized trajectory of $p\text{CO}_2$ into the future, and how much of the effect may be offset by potential increases in primary production from reduced sea ice. This is further complicated by the fact that increased food fall to the benthos from surface algal blooms also contributes to lower aragonite saturation levels near the bottom from increases in respired CO_2 from the benthos.

The CPT reflects estimates of increasing probability of negative climate related effects over time (from 2030 to 2100), and across GHG scenarios (from RCP2.6 to RCP8.5). However, scenario RCP2.6 shows a leveling off of arctic surface carbonate ion concentration from about 2030 to the end of the century, which is reflected in a slower rate of increase in probability of negative effects in the CPT. The trend out to 2100 is of increasing uncertainty overall. No significant difference in effects are expected from season to season.

ICE-FREE MONTHS

Definition: Mean number of months within a season with no sea ice to support walruses for hauling out over the continental shelf of the Chukchi and Bering Seas.



NOTE: 2015 runs use observed data from 2007-2012 and modelled data from 2012-2022.

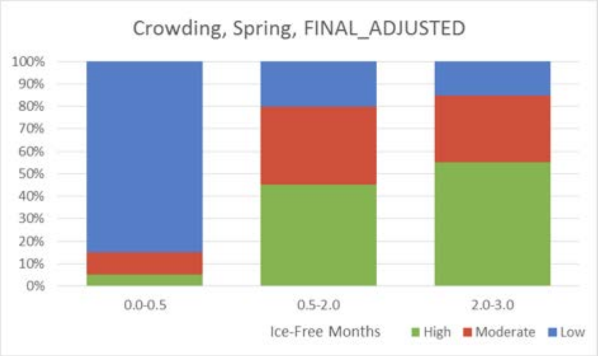
CROWDING (function of Ice-Free Months)

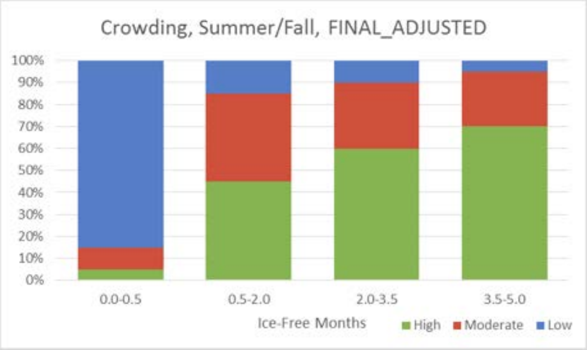
Definition: Crowding refers to the number of female and young walruses at terrestrial haulouts, and is particularly relevant to juvenile survival when disturbances occur and animal stampedes ensue at terrestrial haulouts and possibly at large haulouts on ice during much reduced sea ice concentrations. Walruses are very gregarious and most often haul out in close contact with one another, even when sufficient room exists to spread out.

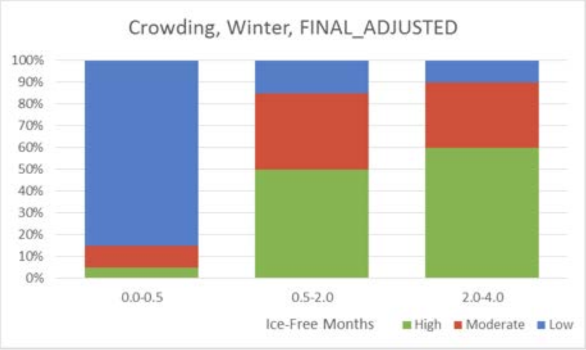
States: Low: 10’s to 100’s of animals per group
Moderate: 1000’s of animals per group
High: 10,000’s of animals per group

Description: As the number of ice-free months increases in any season, walruses are expected to form haulout groups in numbers significantly exceeding those found on ice, as has been observed in the recent decade. There is considerable uncertainty as to the size of haulout groups that will form – particularly for ice-free time between 0.5 and 2 months – because life-history events and local (and difficult to predict) factors may play a role in determining the size of haulout groups across seasons. Group sizes (and crowding) may be significantly smaller in the spring than other seasons because of the focus on calving, active migration, and protection of dependant calves.

Conditional Probability Tables:


Crowding, Spring, FINAL_ADJUSTED


Crowding, Summer/Fall, FINAL_ADJUSTED


Crowding, Winter, FINAL_ADJUSTED

DISEASE AND PARASITES (function of Ice-Free Months)

Definition: High levels of disease or parasites could cause a substantial loss of stored energy in individual. The incidence of disease and parasites have not been observed to have had a significant negative effect on walrus population, but disease and parasites might be expected to increase with poorer ice availability and a more restricted distribution of walruses. As walruses spend more time on coastal haulouts, new diseases that are transferred from soil may come into play. Increased time on coastal haulouts can lead to increased exposure to other species and terrestrial carnivores that walruses aren’t exposed to on sea ice (e.g., dogs, foxes). Increased transmittance of disease from one walrus to another may occur as well.

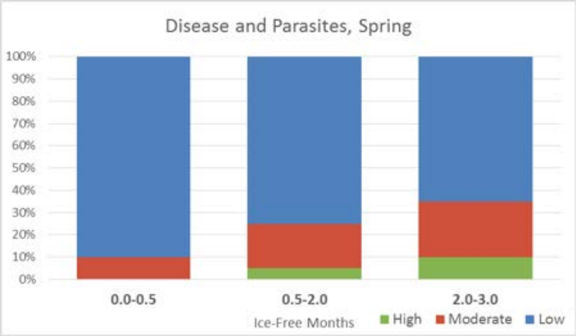
States: Low: Endemic levels of disease or parasitic infection, having a weak effect on body condition. Endemic refers to the constant presence and/or usual prevalence of a disease or parasitic infection in a population within a geographic area (for example, less than 5% of population directly affected).

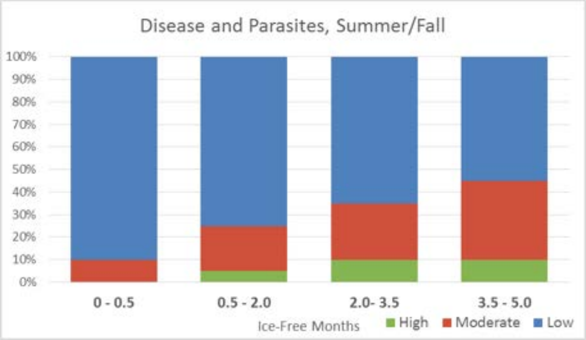
Moderate: Epidemic levels of disease or parasitic infection having a moderate effect on body condition (for example, between 5% and 50% of population directly affected). Epidemic refers to an increase, often sudden, in the number of cases of a disease or parasitic infection above what is normally expected in the population in a given area.

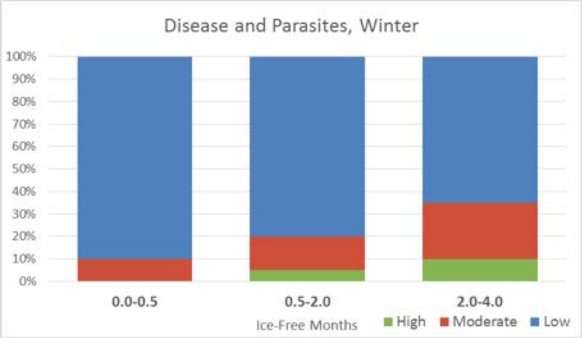
High: Pandemic levels of disease or parasitic infection having a strong effect on body condition (for example, greater than 50% of the population directly affected). Pandemic refers to an epidemic that has spread over a large portion of the geographical range of the species, affecting a large proportion of the population.

Description: Rates of disease are currently low, and there are no known existing diseases capable of reaching epidemic or pandemic levels. As increased ice-free time causes increases in the amount of time walruses are in close contact, the rates of epidemic disease could increase, but are most likely to remain at low levels even when ice-free conditions persist up to 5 months in the Summer/Fall season.

Conditional Probability Tables:







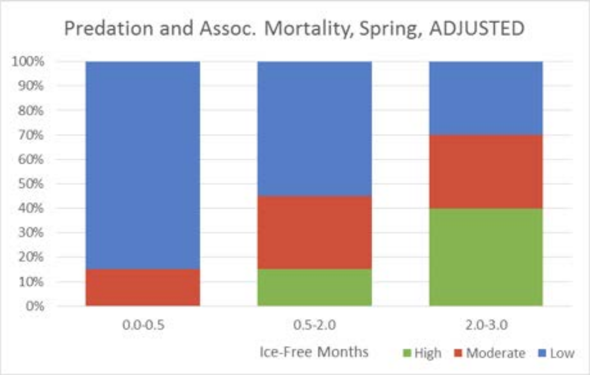
PREDATION AND ASSOCIATED MORTALITY

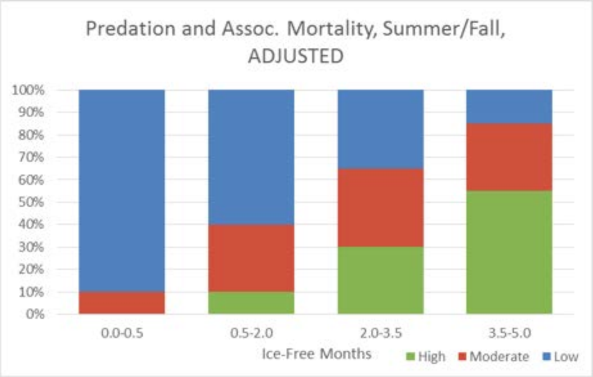
Definition: This includes the potential of walruses being killed indirectly from the predator, such as causing a herd to stampede, which can lead to mortalities from trampling (Kavry et al. 2008; Kochnev et al. 2008, A. Kochnev,pers. comm. 2009). In some circumstances, such as at Wrangel Island, polar bear predation can increase with increasing numbers of walruses using terrestrial haul-outs (Ovsyanikov et al. 2007).

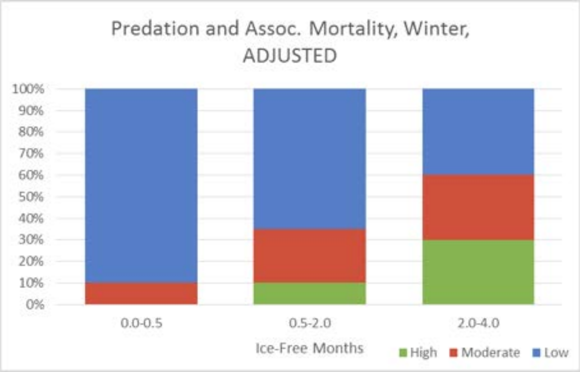
States: Low
Moderate
High

Description: Predation levels for current levels of ice-free months are assumed to be fairly low. As ice-free months increase, walruses exposure to polar bears and killer whales increase as well, but the overlap between those species varies by season and by amount of sea ice. As a result, there is significant uncertainty about the level of predation over increasing ice-free months.

Conditional Probability Tables:







ENERGY EXPENDITURE (function of Ship and Air Traffic, Benthic Prey Abundance, Ice-Free Months)

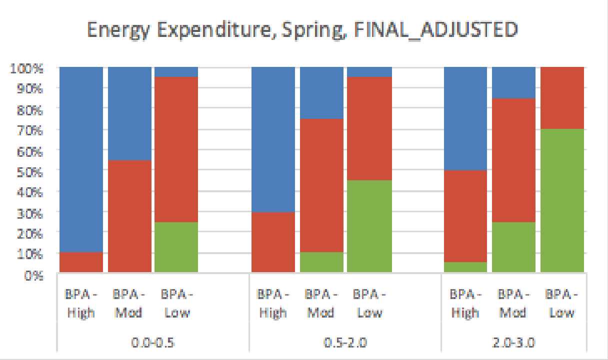
Definition: If benthic prey becomes less abundant, if ship traffic impact walrus migration or feeding activities, or if sea ice is less extensive to provide access to large areas of the continental shelf for foraging, walruses spend less time hauled out (resting) and more time in water without foraging (and expend more energy) than when only sea ice is accessible (Jay et al. 2016). This might be especially true when walruses (particularly females and young) are forced to use terrestrial haul-outs when ice is completely unavailable over the shelf. Walruses might also spend considerable effort swimming in open, rough seas compared to swimming in seas dampened by sea ice.

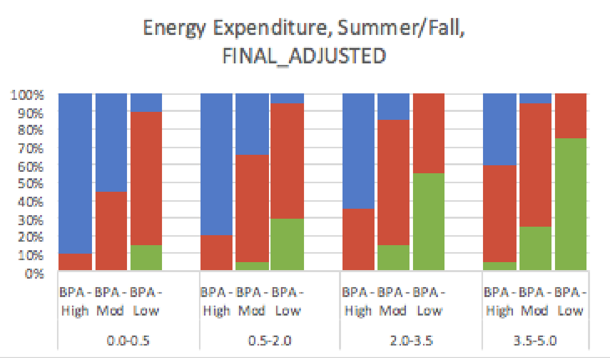
States: Low
Moderate
High

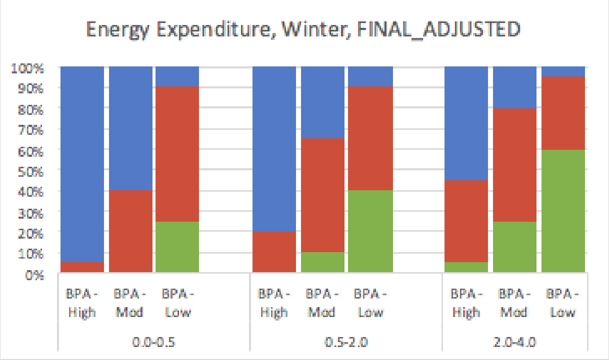
Description: Energy expenditure is likely to increase as sea ice declines, or as walrus are disturbed in the water by ship traffic, due to more time spent in the water travelling to feeding areas and/or avoiding ships. However, benthic prey abundance is generally considered to be as important or more important than ice-free months in determining the energy expenditure of walruses (individuals in the Science Team rated the relative importance between 1:1:2 to 1:1:3 for ice-free months, ship and air traffic, and benthic prey abundance respectively). Therefore, even when ice-free months or ship and air traffic are high, energy expenditure can remain low or moderate when benthic prey abundance is high. Combinations of low benthic prey abundance and long ice-free times are considered to result in high levels of energy expenditure.

Conditional Probability Tables

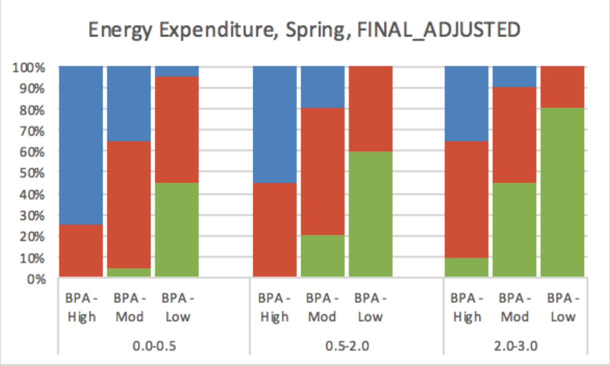
Ship & Air Traffic = Low

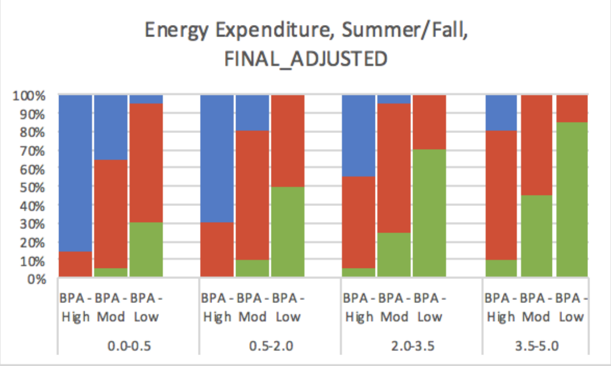


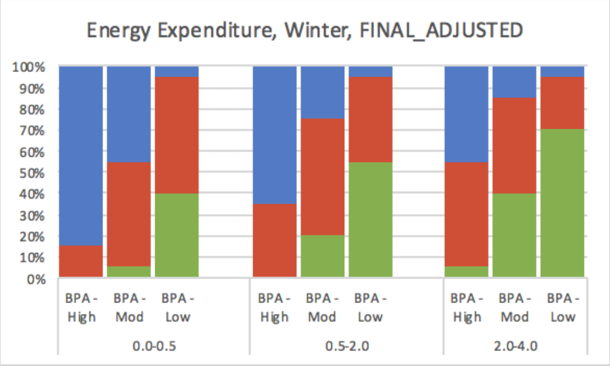




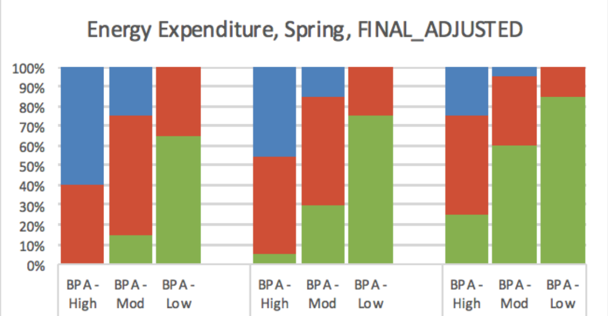
Ship & Air Traffic = Moderate

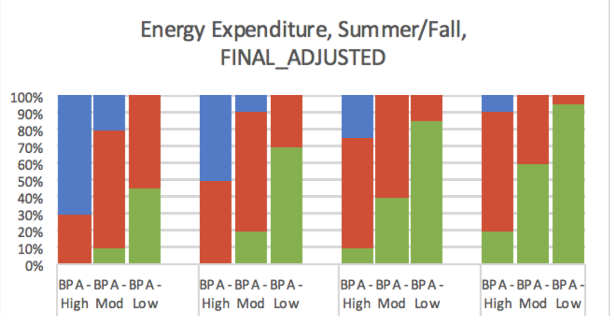


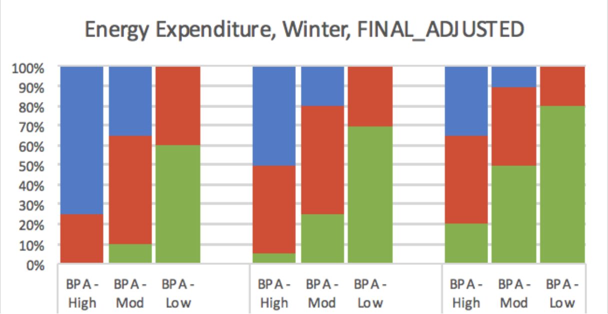




Ship & Air Traffic = High







BIRTHING PLATFORM (Spring Only) (function of Ice-Free Months)

Definition: This node reflects the adequacy of spring ice habitat as substrate for walruses to give birth to calves and provide protection during severe storms. Parturition occurs on the ice. We are assuming that if ice becomes unavailable in the Bering Sea in spring, but still available in the Chukchi Sea, that the Chukchi Sea would be equally adequate for this function. Sea ice availability does not account for ice qualities such as thickness. However, unlike the breeding environment in winter, spring sea ice could melt out quickly and provide less protection from waves with decreasing ice availability. Also, hunters from the village of Savoonga indicated that a low ice profile is important for calves to be able to move on and off of ice floes. Most calving occurs in April-June and mothers care for and nurse their newborn calves on the ice (Fay 1985). Little is known of ice preferences for calving activities; however, walruses require ice floes large enough to support their weight (Fay 1982; Simpkins et al. 2003).

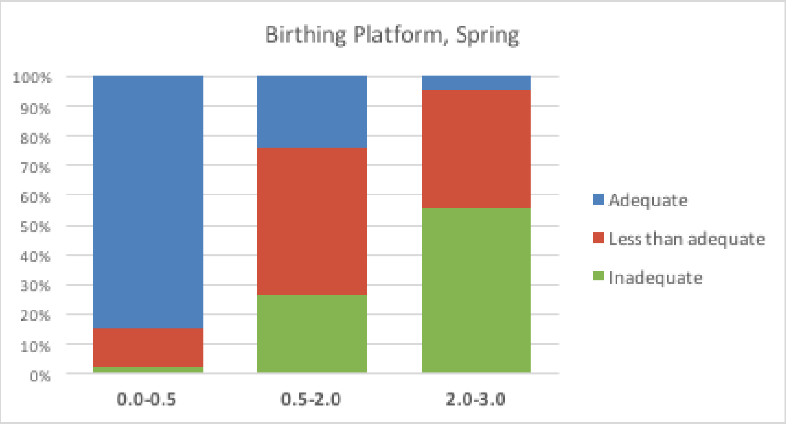
States: Adequate: Environment is fully sufficient to support walrus birthing
Less than adequate**:** Environment is partially sufficient to support walrus birthing
Severely Reduced**:** Environment is largely insufficient to support walrus birthing

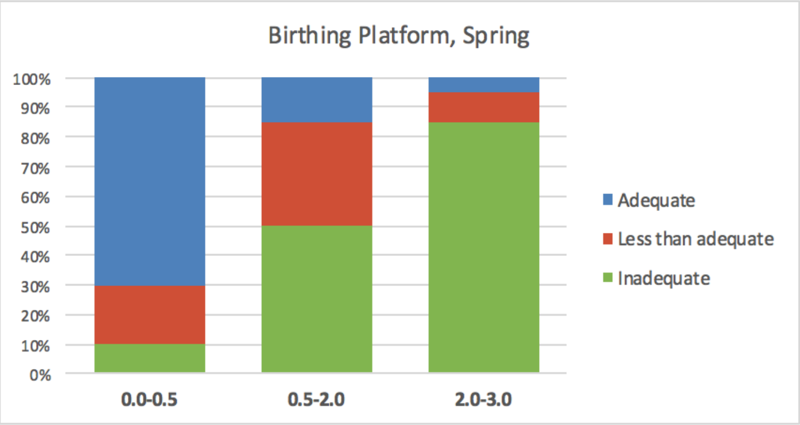
Description: The presence of ice is generally considered adequate for walrus birthing needs, and therefore the degree of adequacy is related to the duration of ice-free time in the spring. Though walrus may be able to meet some birthing requirements on land in situations where there are 2-3 ice-free months, the dominant expectation is that the birthing environment will not be adequate. This model is limited to the areas of the continental shelf waters of the Bering and Chukchi Seas. It seems improbable to some members of the group that walruses would not have shifted their range outside of this geographical area under a climate scenario where sea ice is no longer present in the spring.

Alternate CPT: To support a sensitivity analysis on the assumptions described above, an alternate CPT was developed to investigate how sensitive the population change outcome is to different assumptions about the adequacy of sea ice for birthing. In this alternate CPT, it is assumed that walrus would have a far more difficult time meeting birthing requirements in the absence of sea ice. This CPT is used for testing purposes only.

Conditional Probability Tables:

Alternate CPT (for sensitivity analysis ONLY):





BREEDING

BREEDING ENVIRONMENT (Winter Only) (function of Ice-Free Months)

Definition: This node reflects the adequacy of ice habitat for breeding. Male walruses court females with songs from the water to entice the females into the water from ice haulouts to mate. Ice haulouts provide large areas for territorial males to station. Breeding occurs in January-February. Leks are formed where breeding males display and vocalize from water alongside groups of females hauled out on sea ice to entice the females into the water to mate (Fay 1985). Little is known of ice preferences for breeding behaviors; however, walruses require ice floes large enough to support their weight (Fay 1982; Simpkins et al. 2003). We assumed that if ice becomes unavailable in the Bering Sea in winter but is still available in the Chukchi Sea, that the Chukchi Sea would be equally adequate for this function. Ice haul-outs provide large areas for effective leks to form. Sea ice availability does not account for ice qualities such as thickness.

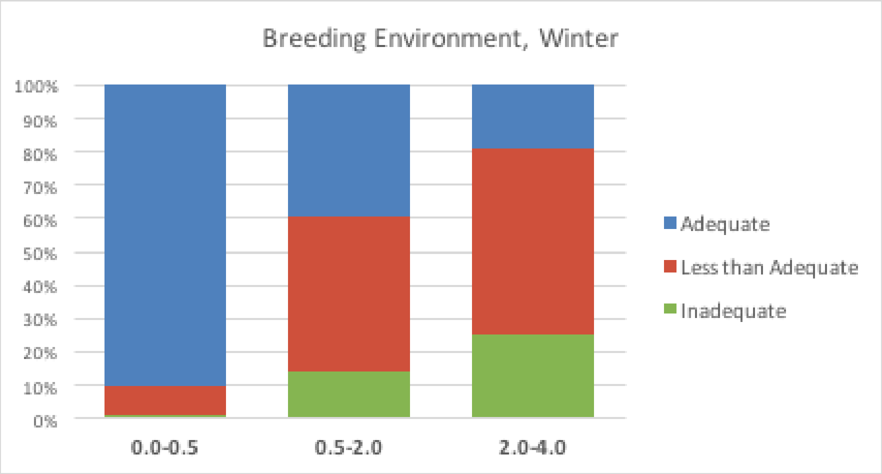
States: Adequate: Environment is fully sufficient to support walrus breeding
Less than adequate**:** Environment is partially sufficient to support walrus breeding
Severely reduced: Environment is largely insufficient to support walrus breeding

Description: Because walrus actually breed in the water adjacent to areas where they've congregated, the likelihood is low that the environment would be "largely inadequate" to support breeding needs. Walrus currently stage from ice for courtship, but there is a high degree of uncertainty about to what degree walrus require, prefer, or use ice because it exists, for breeding. This model is limited to the areas of the continental shelf waters of the

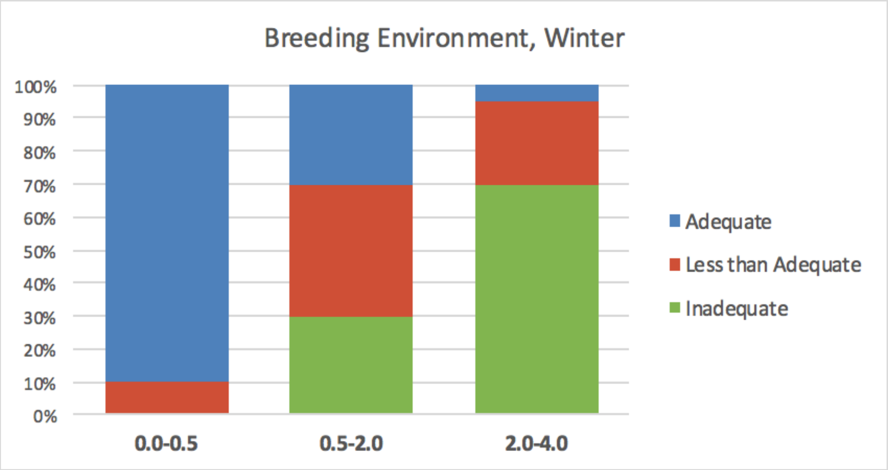
Bering and Chukchi Seas. It seems improbable to some members of the group that walruses would not have shifted their range outside of this geographical area under a climate scenario where sea ice is no longer present in the winter.

Alternate CPT: To support a sensitivity analysis on the assumptions described above, an alternate CPT was developed to investigate how sensitive the population change outcome is to different assumptions about the adequacy of sea ice for breeding. In this alternate CPT, it is assumed that walrus would have a far more difficult time meeting breeding requirements in the absence of sea ice. This CPT is used for testing purposes only.

Conditional Probability Tables:



Alternate CPT (for sensitivity analysis ONLY):



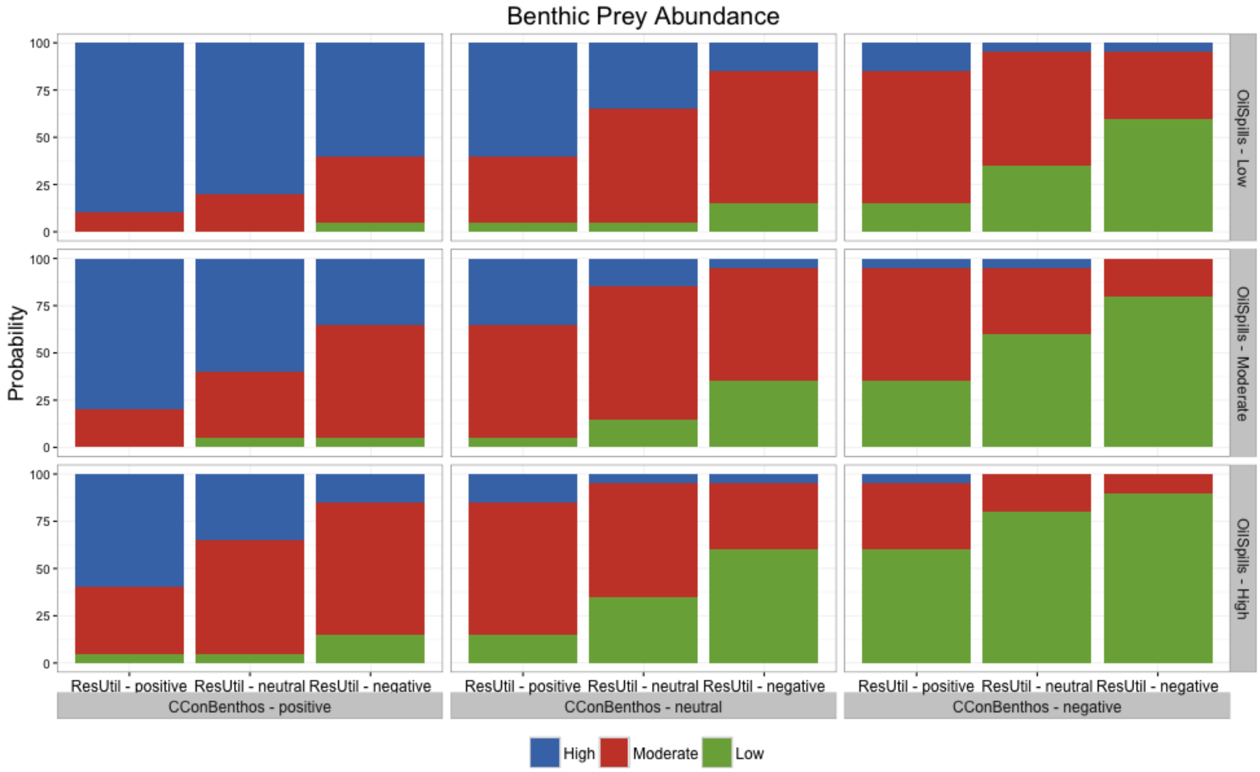
BENTHIC PREY ABUNDANCE (function of Climate Change on Benthos, Resource Utilization, Oil Spills)

Definition: Abundance of benthic prey.

States: High
Moderate
Low

Description: Benthic prey abundance can be affected by oil spills directly by fouling benthic organisms or indirectly by causing decreased production in the water column, thereby resulting in less food fall to the benthos. Potential effects on benthic prey abundance from “climate change on benthos” and “resource utilization” are described under their respective input node descriptions. We assumed that the effects from “climate change on benthos” will be more widespread and have a larger overall effect on prey density than “resource utilization” and “oil spills”.

Conditional Probability Table



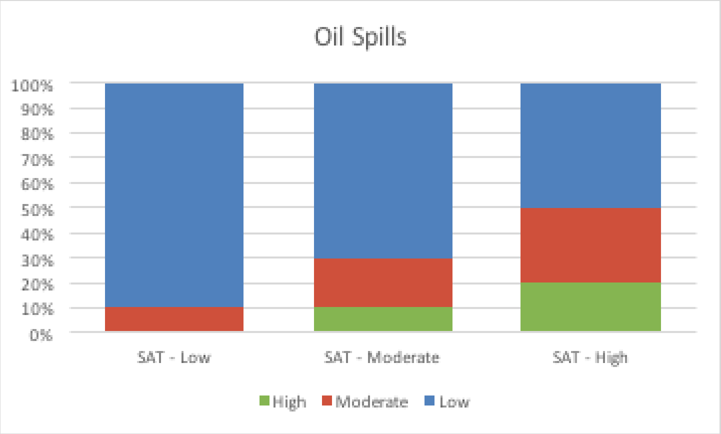
OIL SPILLS AND OTHER POLLUTION (function of Ship and Air Traffic)

Definition: Regularity and severity of hydrocarbons and other pollutants released into the water as a function of the node "ship and air traffic".

States: Low
Moderate
High

Description: Regulatory mechanisms may keep chances of regular and severe oil spills from reaching high levels, even at high ship traffic levels. Probability assignments for this node are highly speculative because they depend greatly on technology and policy. This node is not just an oil and gas extraction node, but is meant to account for all sources of ship traffic, and includes bilge and ballast emissions and introduction of invasive species, accidental spills from exploration, trash and debris, and potential radiation from the Fukishima disaster. With regards to oil production in the Chukchi Sea, the U.S. Minerals Management Service (MMS) predicted a < 10% chance that commercial fields will be leased, drilled, discovered, and developed in the Chukchi Sea; however, they noted that industry groups could have a much different view of oil potential (U.S. Minerals Management Service 2007, pg. IV-7). MMS also predicted a 40% chance of large oil spills occurring over the life of oil development (U.S. Minerals Management Service 2007, pg. IV-2). This suggests a less than 4% chance that commercial oil fields will be developed and large oil spills will occur during oil production in the Chukchi Sea in the future. Probabilities of oil spills were assigned to shift mostly from low towards moderate with increasing levels of "ship and air traffic".

Conditional Probability Table:



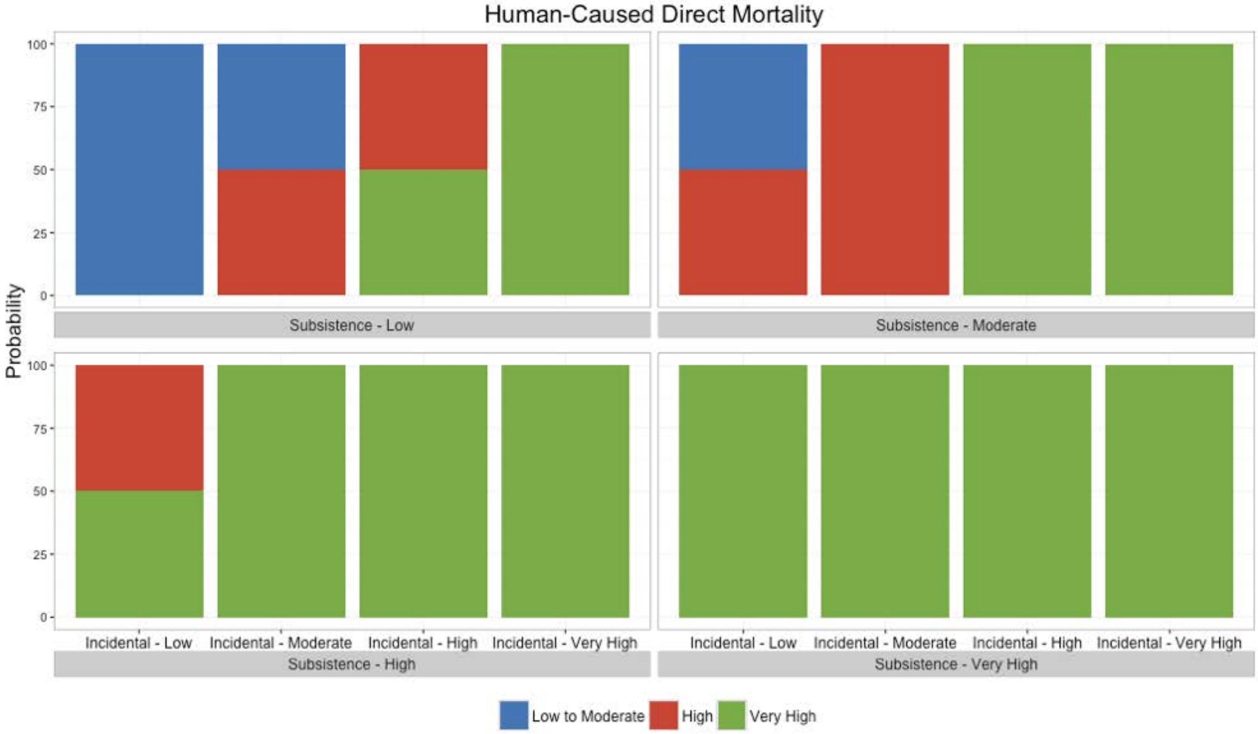
HUMAN-CAUSED DIRECT MORTALITY (function of Subsistence Harvest and Incidental Takes)

Definition: Total number of walruses directly killed by humans in Russia and Alaska

States: Low to moderate
High
Very high

Description: We used numerical ranges for each state as was prescribed for "subsistence harvest" and "incidental takes", except we combined the low and moderate states into a single state for this node (low to moderate). Probabilities were assigned across the human-caused direct mortality states based on the amount of overlap of the lowest possible combined take and highest possible combined take for "subsistence harvest" and "incidental takes" with the levels of take under human-caused direct mortality. For example, the lowest and highest possible combined take from a moderate level of take (2580-5160) from "subsistence harvest" and low level of take (0-2580) from "incidental takes" would be 2580 and 7740, respectively. For this combination, we assigned a probability of 0.5 for the low to moderate state for "direct mortality" (i.e. 0.5 of the range of combined possible take was within the range of the low to moderate state), 0.5 for the high state, and 0.00 to the very high state.

Conditional Probability Tables:



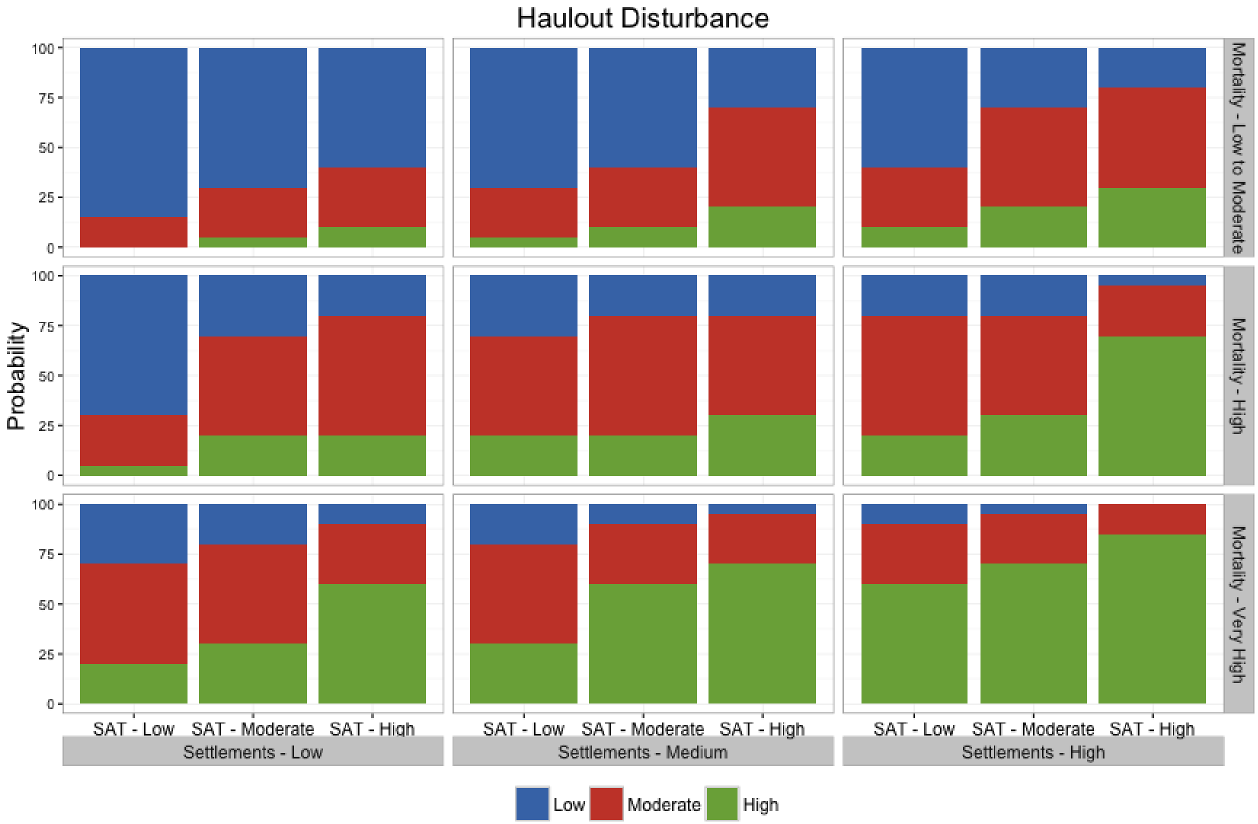
HAUL-OUT DISTURBANCE (function of Ship and Air Traffic, Human Settlements, and Human-Caused Direct Mortality)

Definition: Level of disturbances to hauled out walruses on ice, and particularly, on terrestrial haul-outs.

States: Low
Moderate
High

Description: Haul-out disturbances might increase with levels of ship and air traffic and seismic exploration, human settlements near haul-outs, and from human-caused direct mortality. We considered human-caused direct mortality to be a more severe disturbance because they are more invasive than disturbances from human settlements and ship and air traffic. We weighted "human-caused direct mortality" to have more influence on haul-out disturbance as "human settlements" and "ship and air traffic" during ranking of the parent node state combinations.

Conditional Probability Table:



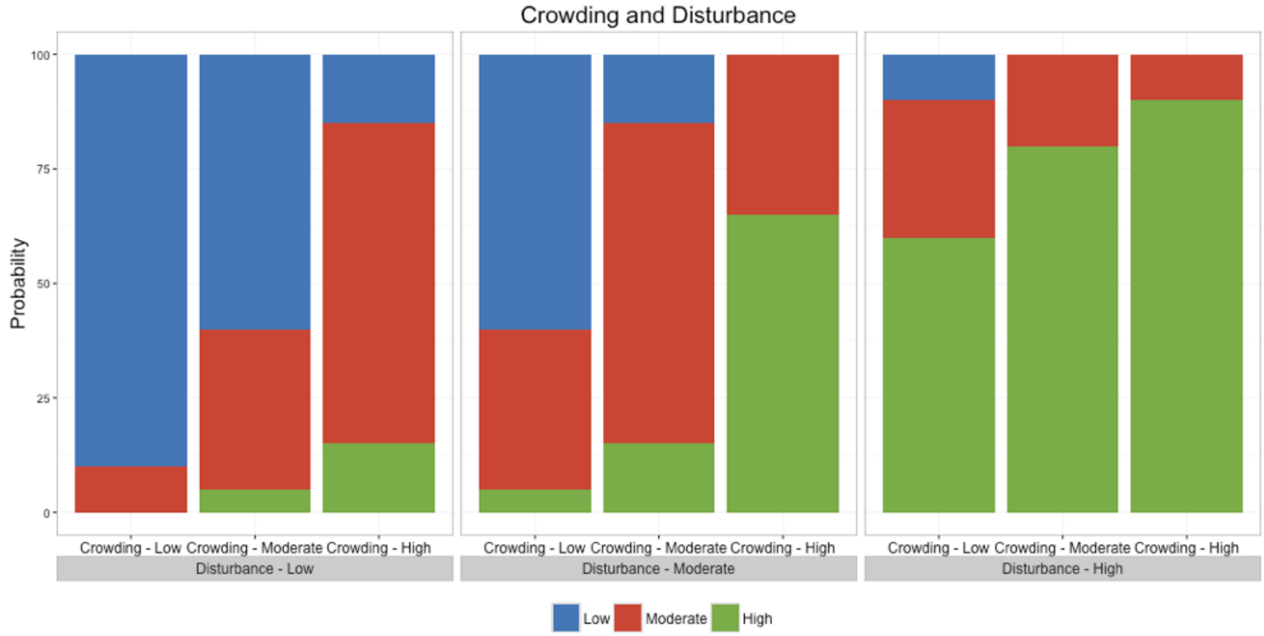
CROWDING AND DISTURBANCE (function of Crowding and Haul-Out Disturbance)

Definition: Intensity of a disturbance on a haul-out as a function of the nodes “crowding” and “haul-out disturbance”

States: Low
Medium
High

Description: The intensity of disturbances on haul-outs is expected to increase with the level of walrus crowding and the frequency and magnitude of disturbances on the haul-out. When we assigned probabilities, we weighted “crowding” and “haul-out disturbance” to have equal influence on “crowding and disturbance”, but high levels of “haul-out disturbance” were scaled further toward high levels of “crowding and disturbance” to increase the effect of regular disturbances on total mortality (downstream in the model).

Conditional Probability Table:



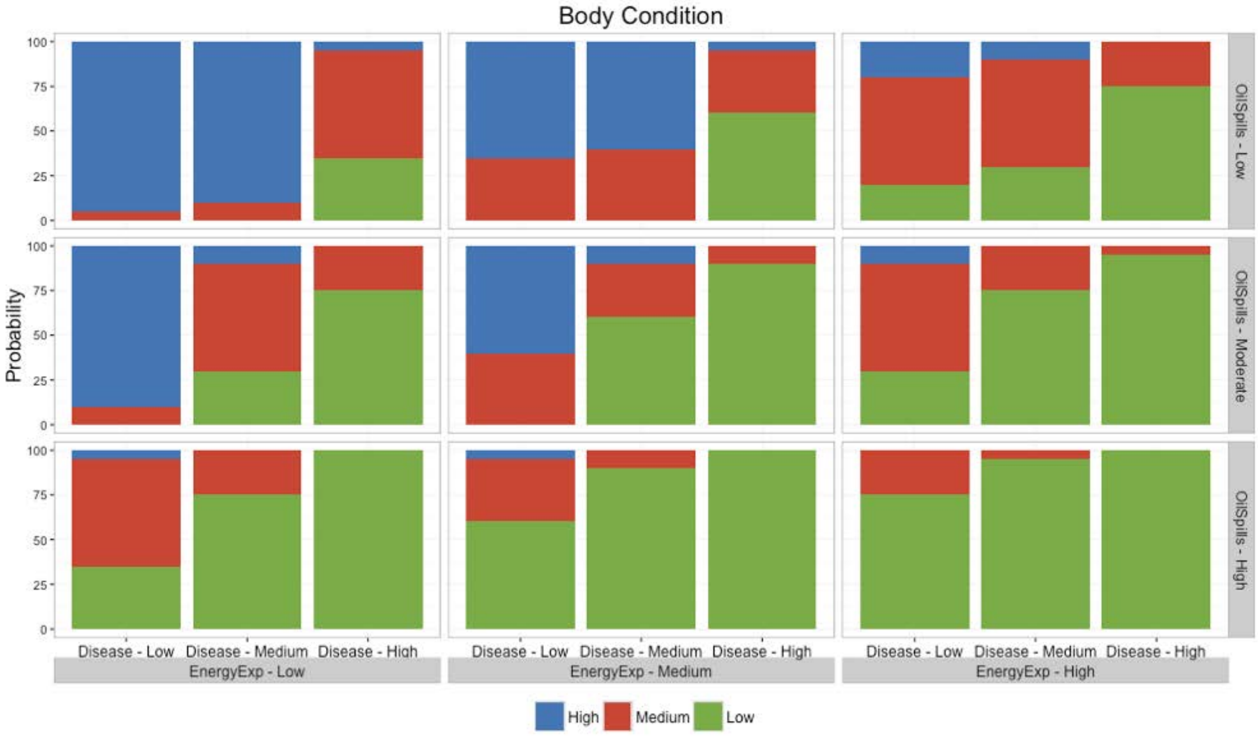
BODY CONDITION (function of Oil Spills, Disease and Parasites, Energy Expenditure)

Definition: Amount of body reserves possessed by animals in the population, particularly in the form of fat and muscle.

States: High
Medium
Low

Description: Contaminants from oil spills can affect walrus body condition through direct contact of oil with individuals or indirectly from its bioaccumulation through the food chain and into walrus prey. Although oil spills might influence a smaller segment of the walrus population than influences from walrus energy expenditure and disease and parasites, its influences could be high within those segments. Walruses are not as geographically confined as are many nearshore species and would be expected to be able to move away from a pollution source to some degree. Disease and parasites could have an influence on body condition throughout large segments of the population, particularly under crowding conditions. While the effects from “disease and parasites” and “oil spills” could have a larger influence than “energy expenditure” on the walrus population in any particular year, we weighted energy expenditure at twice each of the other two nodes to reflect its importance as a chronic stressor on the walrus population over the entire 15-year window. In assigning probabilities, high oil spills was given greater weight than moderate and low because of increased chance of bioaccumulation through the food chain with increased exposure. High disease given greater weight than moderate and low because of chance of transmission increases with prevalence. Weighting for low, moderate, and high states for energy expenditure are weighted equally. Combinations of moderate-moderate, moderate-high, and high-high “disease and parasites” and “oil spills” were weighted further because those combinations may result in an even greater and prolonged influence on body condition than other combinations.

Conditional Probability Table:



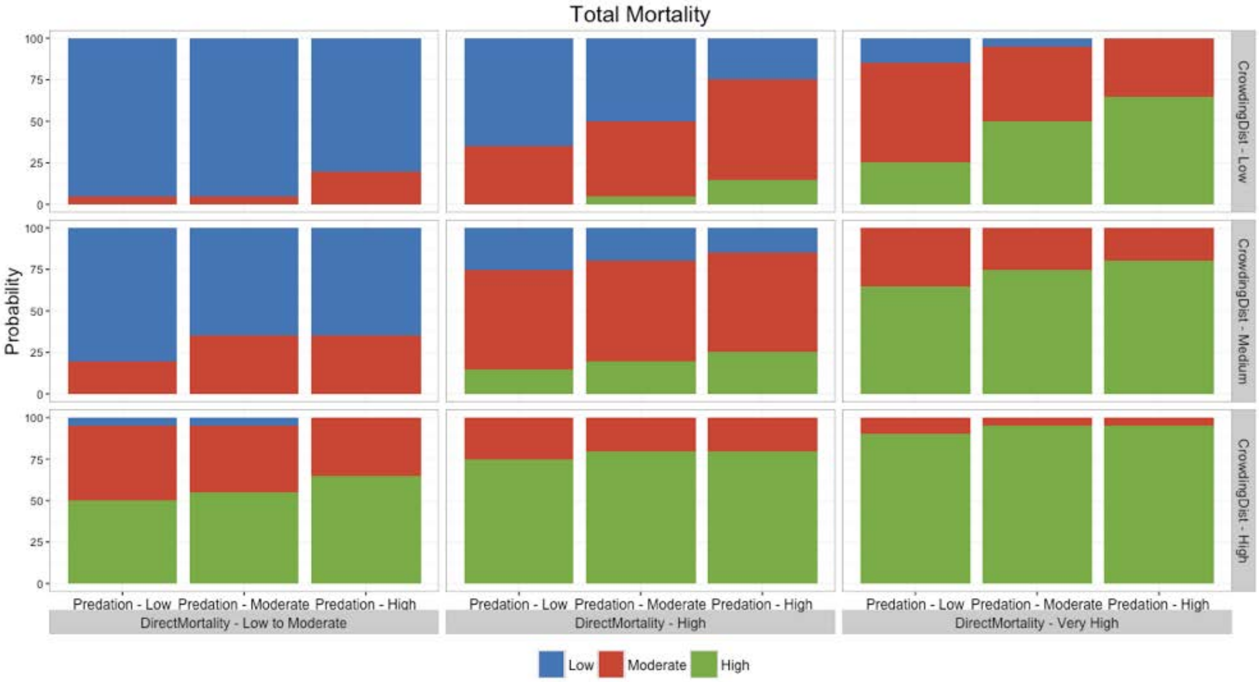
TOTAL MORTALITY (function of Crowding and Disturbance, Human-caused Direct Mortality, and Predation and Associated Mortality)

Definition: Total number of walruses killed as a function of the nodes "predation and associated mortality", "crowding and disturbance" and "human-caused direct mortality".

States: Low
Moderate
High

Description: We weighted "human-caused direct mortality" to have more influence than "crowding and disturbance", and both to have more influence on total mortality as "predation and associated mortality" when we assigned probabilities. Additionally, high levels of crowding and disturbance were weighted further toward high total mortality to reflect its influence on large segments of the population. We are assuming influence of predation, crowding and disturbance, and human-caused mort are roughly 1:2:4, respectively, based on total number of animals affected. Age class of animals affected is not considered here.

Conditional Probability Table:



ABUNDANCE STRESSORS (SUMMER/FALL, SPRING, WINTER) (function of body condition, total mortality, birthing platform [for spring submodel], and breeding environment [for winter submodel])

Definition: Processes or events that may negatively influence the abundance of walruses.

States: Low Stressors: Breeding and birthing habitats and food resources are sufficient to support high body condition, and mortality rates are low. In turn, maximum vital rates are realized and resilience to the effects of regional and/or widespread stochastic events is high. For these conditions to be realized, the population is at or close to Optimal Sustainable Population (OSP).

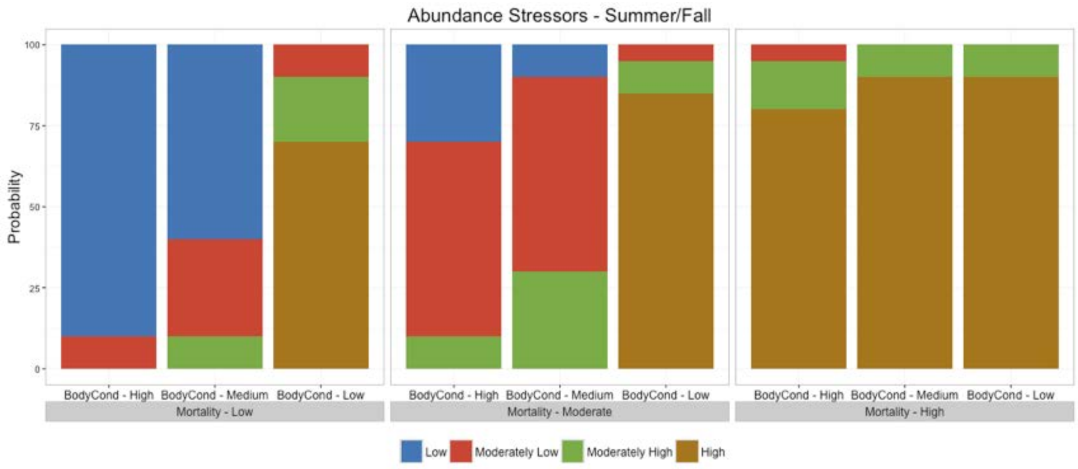
Moderately Low Stressors: Availability of breeding and birthing habitats and food resources results in medium body condition. Mortality rates are low-moderate, and in turn, near maximum vital rates are realized and resilience to the effects of regional and/or widespread stochastic events is moderate. For these conditions to be realized, the population is at or close to OSP.

Moderately High Stressors: The availability of breeding and birthing habitats and food resources contributes to medium body condition and mortality rates are high, and in turn, vital rates are about ½ of maximum and resilience to the effects of regional and/or widespread stochastic events is low. For these conditions to be realized, the population is outside of OSP.

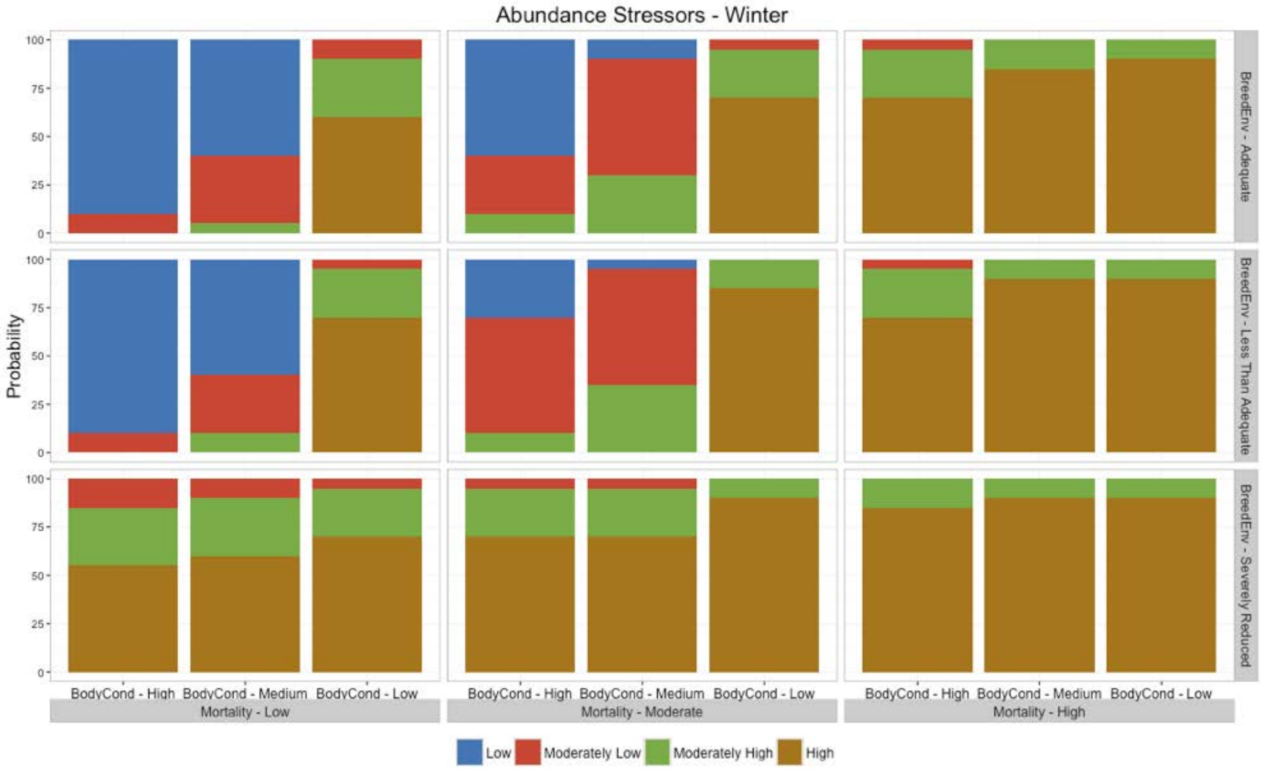
High Stressors: Availability of habitats and food resources result in low body condition and mortality rates are high-very high, resulting in low vital rates and low resilience to the effects of regional and/or widespread stochastic events. These conditions result in a population is outside of OSP

Description: Body condition reflects the level of individual fitness and is expected to have an impact on walrus reproduction and survival. For example, a decrease in body condition in the population could lead to decreased juvenile survival, decreased birth rate, and an increase in age of sexual maturity. Mortality of females might constitute a greater loss or reproductive potential in the population than changes in body condition, so we weighted “total mortality” to have more influence on abundance stressors than “body condition” when we assigned probabilities. In the winter submodel, “breeding environment” was weighted to have less influence on abundance stressors than “body condition” when we assigned probabilities. In the spring submodel, “birthing platform” was weighted to have an equal influence on abundance stressors to “body condition” when we assigned probabilities. For each season, combinations involving low body condition or high mortality were further weighted toward “high stressors” to reduce the compensatory effect of the other nodes.

Conditional Probability Tables:


Abundance Stressors - Summer/Fall
Probability
100
75
50
25
0
BodyCond - High
BodyCond - Medium
BodyCond - Low
Mortality - Low
Mortality - Moderate
Mortality - High
Low
Moderately Low
Moderately High
High


Abundance Stressors - Spring
Probability
100
75
50
25
0
BirthPlat - Adequate
BirthPlat - Less Than Adequate
BirthPlat - Severely Reduced
BodyCond - High
BodyCond - Medium
BodyCond - Low
Mortality - Low
Mortality - Moderate
Mortality - High
Low
Moderately Low
Moderately High
High



ALL SEASON ABUNDANCE STRESSORS (function of seasonal abundance stressors)

Definition: Overall stressors on walrus abundance throughout the year as a function of "abundance stressors" in summer/fall, winter, and spring.

States: Low Stressors: Breeding and birthing habitats and food resources are sufficient to support high body condition, and mortality rates are low. In turn, maximum vital rates are realized and resilience to the effects of regional and/or widespread stochastic events is high. For these conditions to be realized, the population is at or close to Optimal Sustainable Population (OSP).

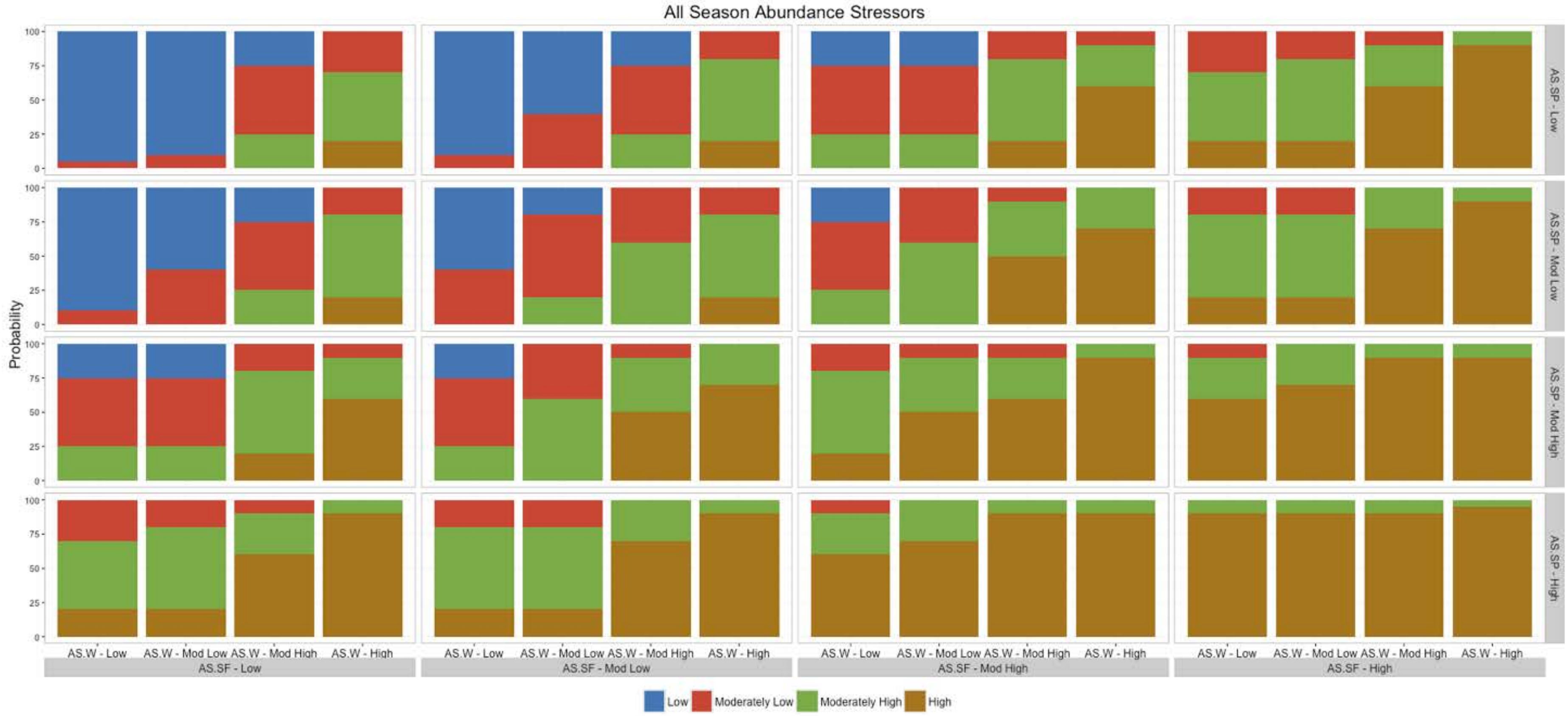
Moderately Low Stressors: Availability of breeding and birthing habitats and food resources results in medium body condition. Mortality rates are low-moderate, and in turn, near maximum vital rates are realized and resilience to the effects of regional and/or widespread stochastic events is moderate. For these conditions to be realized, the population is at or close to OSP.

Moderately High Stressors: The availability of breeding and birthing habitats and food resources contributes to medium body condition and mortality rates are high, and in turn, vital rates are about ½ of maximum and resilience to the effects of regional and/or widespread stochastic events is low. For these conditions to be realized, the population is outside of OSP.

High Stressors: Availability of habitats and food resources result in low body condition and mortality rates are high-very high, resulting in low vital rates and low resilience to the effects of regional and/or widespread stochastic events. These conditions result in a population is outside of OSP

Description: We weighted “abundance stressors” from each season to have equal influence on all-season abundance stressors during ranking of the parent node state combinations, because there was no reason to weight them otherwise. High levels of abundance stressors from more than one season were considered to have a greater negative influence than high levels of abundance stressors from a single season, and therefore, we weighted combined seasonal levels of stress of moderately high and high greater than levels of low and moderately low.

Conditional Probability Table:


All Season Abundance Stressors
Probability
100
75
50
25
0
AS.W - Low
AS.W - Mod Low
AS.W - Mod High
AS.W - High
AS.SF - Low
AS.SF - Mod Low
AS.SF - Mod High
AS.SF - High
AS.SP - Low
AS.SP - Mod Low
AS.SP - Mod High
AS.SP - High
Low
Moderately Low
Moderately High
High

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9.2 Appendix B. Habitat Analysis

FINAL REPORT: Current and future potential habitat for the Pacific walrus (*Odobenus rosmarus divergens*)

Prepared by: Michelle Kissling, Ryan Wilson, and William Beatty

Date: March 21, 2017 (v4)

INTRODUCTION

The Pacific walrus (*Odobenus rosmarus divergens*) is the largest pinniped inhabiting the Arctic and sub-Arctic regions of coastal Alaska and eastern Russia. Its range encompasses the continental shelf of the Bering and Chukchi seas, although its distribution varies seasonally and by gender with the annual advance and retreat of sea ice. In winter when the Chukchi Sea is covered in pack ice, the entire population occupies the Bering Sea. However, in summer as sea ice retreats, adult females and dependent young remain with the sea ice, traveling northward to the Chukchi Sea, while most adult males abandon the sea ice and remain in the Bering Sea where they use land haulouts along the coasts of Alaska and Russia (Fay 1982, pp. 7–29; Jay and Hills 2005, p. 1). In conjunction with the association with sea ice extent, the distribution of Pacific walrus is thought to be limited by bathymetry (Fay 1982, p. 23). Pacific walruses generally are restricted to the 100-m isobaths where they typically feed on benthic organisms such as bivalves, gastropods, and polychaete worms (Fay 1982, pp. 161–163; Fay and Burns 1988, p. 1; Sheffield and Grebmeier 2009, p. 766).

Although walruses spend most of their time in the water, they use land and sea ice haulouts throughout their annual cycle (e.g., Jay et al. 2001, p. 617; Lydersen et al. 2008, p. 124; Udevitz et al. 2009, p. 1119). Sea ice haulouts typically are used for birthing, nursing, resting, molting, access to offshore foraging areas, and refuge from predation and disturbance (Fay 1982, pp. 7, 21, 25–26), whereas land haulouts support only some of these activities (Table 1). Walruses have been observed using land haulouts for resting, molting, and nursing, as well as access to nearshore foraging areas (Fay 1982, p. 21). Generally, sea ice haulouts are thought to be preferred over land haulouts (Fay 1982, pp. 7, 25–26), presumably because they support more life history needs. Moreover, walrus energy demands are lower when sea ice haulouts are available and used compared to land haulouts. Tagged walruses spend more time hauled out (presumably resting) and less time in water but not foraging (presumably moving) when sea ice is available or when trips originate from sea ice opposed to land haulouts, thereby allocating a higher proportion of their energy to foraging (Udevitz et al. 2009, pp. 1120–1122, Jay et al. 2017, pp. 8–9).

An assessment of the possible individual- and/or population-level impacts of predicted sea ice loss on Pacific walruses requires a mechanistic link between sea ice and walrus fitness. However, a comprehensive model that links sea ice to fitness and/or reproduction is not available. Nonetheless, based on our knowledge of walrus behavior, we can analyze and predict changes in accessible foraging habitat to assess potential impacts of reduced sea ice to walruses.

Table 1. Key life history events of the Pacific walrus and the season and type of habitat in which they occur (described in Fay 1982, pp. 62, 138, 191–193).

Event	Season			Type of habitat used
	Spring	Summer/Fall	Winter	
Courtship			X	water, sea ice
Copulation (breeding)			X	water
Parturition (birthing)	X			sea ice
Nursing	X	X	X	sea ice, land
Molting	X	X		water, sea ice, land

Because Pacific walruses use both ice and land to meet some of their vital needs, it is challenging to assess possible individual- or population-level impacts of predicted loss of sea ice in the Bering and Chukchi seas. This type of assessment requires a clear, mechanistic understanding of walrus ability to maintain fitness with reduced sea ice habitat and currently our understanding of this topic is rudimentary and incomplete. Nonetheless, based on our knowledge of walrus behavior, we can assess potential impacts of reduced sea ice to walruses by analyzing and predicting changes in their accessible habitat.

Here, we describe results of a simple spatial analysis aimed to identify and predict potential accessible habitats for Pacific walruses. Our analysis was intended to complement a Bayesian Belief Network (BBN) model that was developed to project the possible influence of future stressors on the Pacific walrus (Appendix A). The original BBN model developed by Jay et al.

(2011) included a spatial component that was removed during model revision; our analysis described here serves as a spatial component to the revised BBN, although the two independent projects are not linked directly. Specifically, our objectives of the spatial analysis were to (1) identify potential habitats based on observed or justified behavioral criteria; (2) quantify these habitats given projected sea ice conditions across seasons, years, and under different greenhouse gas forcing scenarios, or representative concentration pathways (RCP); and, (3) generate maps of these habitats as a proxy to walrus distribution.

PROJECT AREA AND METHODS

We restricted our analysis to the current range of the Pacific walrus (Figure 1), which was the same approach taken in the BBN (and following Jay et al. 2011, p. 2). The overall project area was 1,665,170 km^2. To review results at a finer spatial scale, we divided the project area into four subregions using the international boundary (U.S. and Russia) and the Bering Strait, which separates the Bering and Chukchi seas (Figure 1). The international boundary (eastern and western) reflects differences in management (e.g., subsistence hunting) and regulations (e.g., U.S. Marine Mammal Protection Act) of walruses and their potential stressors; in addition, ocean currents and climate-associated factors differ in the eastern (U.S.) and western (Russia) portions of our study area, which can affect resource conditions such as availability of sea ice (Zhang et al. 2000, p. 3108; Gong and Pickard 2015, p. 19; Howell et al. 2016, p. 2659). The separation of the Bering and Chukchi seas recognizes these two marine systems as different ecological entities within the range of the walrus. The area of the subregions was 739,622 km^2 for the U.S. portion of the Bering Sea (45% of project area), 217,478 km^2 for the Russian Bering Sea (13%), 340,925 km^2 for the U.S. Chukchi Sea (20%), and 367,145 km^2 for the Russian Chukchi Sea (22%).

We conducted analyses during three seasons, at five time steps, and under three RCPs. All definitions were consistent with those used in the BBN. Seasons were winter (December through March), spring (April through June), and summer/fall (July through November). Time steps were 15-year periods centered on 2015 (2008–2022), 2030 (2023–2037), 2045 (2038–2052), and 2060 (2053–2067); the final time step of 2100 is asymmetrical (2086–2100) because ice projections are not readily available beyond 2100. We applied RCP 2.6, RCP 4.5, and RCP 8.5 (best case to worst case scenarios) and used RCP 8.5 as a basis for presenting results because it represents the "status quo" in terms of greenhouse gas emissions.

We considered potential habitats to be those that walruses have been observed using regularly for locating food, resting in between foraging bouts, or engaging in social activities, but not for seasonal movements or migration. By "regularly", we meant that the event or circumstance is not extreme or rare. Thus, for the purpose of our analysis, we defined potential habitat to be marine water, sea ice, or land within the project area that may be accessed and used by walruses to fulfill their life history needs within a particular season. We emphasize that potential habitat does not equate to suitable habitat, nor does it take habitat quality into account.

We distinguished potential habitat from non-habitat using a set of decision rules based on observed or suspected behaviors. We included foraging distance from exposed shoreline into open water, foraging distance from sea ice into open water, percent sea ice concentration (SIC), and ocean depth (Table 2). We did not include factors contributing to habitat quality such as benthic prey abundance and productivity because of analytical time constraints and lack of uniform coverage of these covariates within our project area. To determine the decision rules criteria, we reviewed published literature, unpublished reports, draft manuscripts, and existing data sets. We also consulted with several walrus experts. For most identified criteria, we found sparse and variable evidence; thus, these criteria are not definitive and certainly are debatable. However, we chose liberal criteria that describe activities of the majority of walruses most of the time, so as not to exclude potential habitat while also applying sufficient constraints for a meaningful analysis.

Figure 1. Map of project area and 4 subregions (Russia Chukchi, U.S. Chukchi, Russia Bering, and U.S. Bering) to identify and quantify potential habitat for Pacific walrus.

Table 2. Decision rules and criteria used to identify potential habitats of Pacific walrus. All decision rules must be satisfied in order for grid cell to be considered potential habitat.

Decision rule	Threshold	Description	Primary sources
Travel distance from exposed shoreline into open water	(1) ≤ 70 km (2) ≤ 140 km (3) ≤ 210 km	Most walruses on land travel <70 km to forage, although some travel further over multiple days. We used 70 km as a base travel distance (one-way) and doubled and tripled it to describe 2-day and 3-day trips.	Jay and Hill (2005 p. 196); Jay et al. (2012 pp. 15, 23); Beatty et al. (2016, Appendix A, p. 2); Jay et al. (2017, p. 3).
Travel distance from sea ice into open water	≤ 70 km	Most walruses on sea ice travel <70 km to forage and typically travel distances from sea ice into open water are shorter than those from land.	Estes and Gilbert (1978 p. 1134); Jay et al. (2010 p. 301); Udevitz et al. (2009 p. 1122); Jay et al. (2012 pp. 14, 23); Beatty et al. (2016 Appendix A, p. 2); Jay et al. (2017, p. 3).
Foraging depth	< 100 m	Most walruses forage at depths less than 100 m.	Fay (1982, pp. 23, 161–163); Fay and Burns (1988, p. 1).
Suitable sea ice concentration	< 90%	Most walruses typically are not found where heavy, snow-covered ice occupies more than 90% of the sea surface.	Fay (1982, p. 21), Jay et al. (2014, p. 8).

We found evidence indicating that most walruses forage within 70 km of their terrestrial and sea ice haulout locations. Beatty et al. (2016, Appendix A, p. 2) used 70 km as a radius to investigate resource selection of tagged walruses (mostly females) in the Chukchi Sea. They chose this value because it represents the 99th percentile of the distribution of daily movement distance of each tagged walrus, averaged over individuals (mean=65.5 km, SD=29.5, SE=1.7), and it corresponds well with the mean maximum daily movement distance across individuals (69.2 km, SD=32.1, SE=1.8). For context, the 95th percentile of the distribution of daily movement distance was 54.1 km (SD=24.2, SE=1.4) and the mean daily movement distance was 23.1 km (SD=9.8, SE=0.5). Similarly, and using the same dataset for analysis, Jay et al. (2017, pp. 3–4) used a distance of 50 km, roughly the 95th percentile of the distribution of daily movement distances, to define a day's reach (i.e. maximum distance an average walrus was likely to travel in a day) to investigate walrus activity levels relative to sea ice availability. However, neither Jay et al. (2017, entire) nor Beatty et al. (2016, entire) considered origin of trip (i.e. sea ice or land) in their analyses. Nonetheless, we found additional evidence suggesting that 70 km was an acceptable base threshold to describe walrus travel distances from land and sea ice into open water.

For foraging trips that originate on land, most walruses travel ≤ 70 km into open water, although some undergo multi-day trips over longer distances. Jay et al. (2012, p. 23) reported that 45 of 51 foraging trips by tagged walruses (mostly females) in the Chukchi Sea averaged only 33 km round-trip and lasted 2.2 days. However, the remaining six trips (12% of foraging trips originated from land) averaged 611 km round-trip and 14.2 days in duration, all of which involved traveling from Pt. Lay to the Hanna Shoal region roughly 210–230 km one-way linear distance. Although male walruses are thought to travel longer distances than females for foraging, Jay and Hills (2005, p. 196) found that trips of tagged male walruses in Bristol Bay ranged between only 10 and 130 km from the nearest land-based haulout site. Thus, in our analysis, we considered three travel distances from land into open water (i.e. 70, 140, and 210 km), which correspond to one-, two-, and three-day foraging trips (one-way) and encompass the observed variation in movement behavior of tagged walruses of both sexes.

Most walruses that originate foraging trips on sea ice travel shorter distances and for shorter duration than those that originate trips on land (Udevitz et al. 2009, p. 1122, Jay et al. 2012, pp. 14, 23). Tagged walruses (mostly females) using sea ice haulouts traveled only 22 km round-trip on average and trips typically lasted less than two days, as opposed to those using terrestrial haulouts that traveled 33 km round-trip over two-day periods (Jay et al. 2012, pp. 14, 23). Not surprisingly, during aerial surveys in the Chukchi Sea, Estes and Gilbert (1978, p. 1134) observed few walruses south of the immediate ice edge. Moreover, Beatty et al. (2016, pp. 28–29) found that tagged walruses demonstrated stronger selection for sea ice habitat than terrestrial habitat and Jay et al. (2017 pp. 8–9) reported lower energy demands for walruses with sea ice habitat available to them compared to walruses with terrestrial habitat only. For these reasons, in our analysis, we used a travel distance threshold of ≤ 70 km for walruses originating foraging trips from sea ice into open water.

In addition to travel distances from sea ice and land, we applied two other decision rules related to Pacific walrus behavior. First, we used a foraging depth threshold of < 100 m, which essentially encompasses the continental shelf region of our project area. Although physiologically walruses may be capable of diving deeper to search for food, most walruses forage in waters < 100 m in depth where benthic invertebrates are abundant (Fay 1982, pp. 23, 161–163; Fay and Burns 1988, p. 1). Second, we assigned a SIC threshold of < 90% because walruses are not able to access or forage efficiently in areas of dense pack ice (Fay 1982, p. 21; Jay et al. 2014, p. 8). Although walruses demonstrate strong selection for sea ice habitat (Beatty et al. 2016, p. 28), they also select for areas of low SIC as opposed to high SIC (Jay et al. 2014, p. 1), presumably in part because of gains in energy efficiency.

In combining these decision rules (Table 2), we developed three scenarios to identify potential habitat for Pacific walrus. The only decision rule that varied among scenarios was the travel distance from exposed shoreline into open water. For Scenario 1, this distance was limited to ≤ 70 km; Scenario 2 was limited to ≤ 140 km; and, Scenario 3 contained all area ≤ 210 km from land into open water. The remaining three decision rules remained the same across all scenarios.

We then applied the decision rules of Scenarios 1–3 to spatial data layers for shoreline, bathymetry, and SIC. We acquired geo-referenced, model-based monthly sea ice projections for the project area depicting SIC medians from among multiple models during each 15-year interval (Douglas 2016, p. 1). These median SIC were hyper-sampled to a cell size of 25 km by 25 km from the much coarser resolution climate model data (>1 degree resolution). Next, using the defined criteria of walrus behavior (Table 2), we determined whether or not each cell qualified as "potential habitat", or the area within our project area that met the criteria, for each month. We also classified potential habitat as either "land-accessible habitat" or "ice-accessible habitat" and refer to these designations as habitat type; if a cell qualified as both land- and ice-accessible habitat, we classified it as ice-accessible habitat. We then quantified the area of potential habitat (km^2) by month and averaged monthly results by season. Based on these seasonal averages, we calculated the percent change of potential habitat area for walruses in each season between 2015 and 2060 and between 2015 and 2100, collectively and within each subregion. This approach allowed us to quantify projected change in potential habitat used by foraging and resting walruses spatially and temporally. We also generated accompanying maps for visual interpretation.

Lastly, we offer two points on presentation and interpretation of our results. First, we present results from all five time periods, however, we think that the results for 2100 are less reliable than those from 2060 and earlier. Although sea ice projections are available out to 2100, we are less certain about the long-term response of walruses to reduced sea ice. For this reason, we urge focused consideration of results through 2060, though we include results for 2100 for context. Second, we present results both pooled across potential habitat types and separated by potential habitat type. Although ice-accessible habitat appears to be preferred by walruses, we did not consider habitat quality in our analysis because we were unable to quantify the level of preference under varying sea ice conditions and across seasons. We present selected pooled results here for simplicity, especially when results varied little between habitat types.

RESULTS

We found that total potential habitat for Pacific walruses isexpected to vary over time, seasons, RCPs, and scenarios, though patterns are somewhat consistent. We determined that total potential habitat remained stable or slightly increased during the spring, decreased during the summer/fall, and increased during the winter (Figure 2). Among RCPs, differences in total potential habitat were greatest in winter and divergence was most pronounced for all seasons beginning at about 2045. We also detected an interaction between season and RCP; in winter and spring, total potential habitat was greatest under RCP 8.5, but in summer/fall under this RCP, it was lowest compared to RCPs 2.6 and 4.5. Across scenarios, we found consistent and predictable patterns with the greatest decreases in total potential habitat occurring in Scenario 1 and the greatest increases occurring in Scenario 3.

Although we predict total potential habitat to increase in spring and winter, we expect ice-accessible habitat to decrease in all seasons, scenarios, and RCPs (Figure 3). As ice-accessible habitat decreases, we predict a concurrent increase in land-accessible habitat. The largest predicted changes in the shift of habitat type occurred under RCP 8.5 and the smallest under RCP 2.6. Under RCP 8.5, we predicted the greatest shift to occur in summer/fall under Scenario 1 when the proportion of ice decreases from 0.47 in 2015 to 0.09 in 2060; conversely, the smallest shift is expected to occur in spring under Scenario 1 (0.87 and 0.74, respectively). Under all 3 scenarios in summer/fall, the proportion of ice-accessible habitat is predicted to be ≤ 0.09 in 2060 and 0.00 in 2100 (Figure 3).

While the proportion of ice-accessible habitat for Pacific walruses is expected to decrease over time, we found differences in the spatial configuration and area of ice-accessible habitat across RCPs. For example, in May 2060 (spring), ice-accessible habitat actually increased from RCP 2.6 to RCP 8.5, as did land-accessible habitat (Figure 4). Under RCP 2.6, ice-accessible habitat was limited mostly to the northern Bering Sea and the eastern Chukchi Sea in all scenarios, but expanded to encompass increasing portions of the western Chukchi Sea under RCPs 4.5 and 8.5. In fact, Wrangell Island in the western Chukchi Sea is surrounded by potential habitat in all scenarios under RCP 8.5 (Figure 4p–r). We attribute this somewhat counter-intuitive pattern to reduced pack ice with SIC > 90%, which under our criteria did not constitute potential habitat for walruses. In contrast, in September 2060 (summer/fall), total potential habitat did not vary by RCP because no ice-accessible habitat is expected to exist; thus, the only variation during this time period was across scenarios (Figure 5).

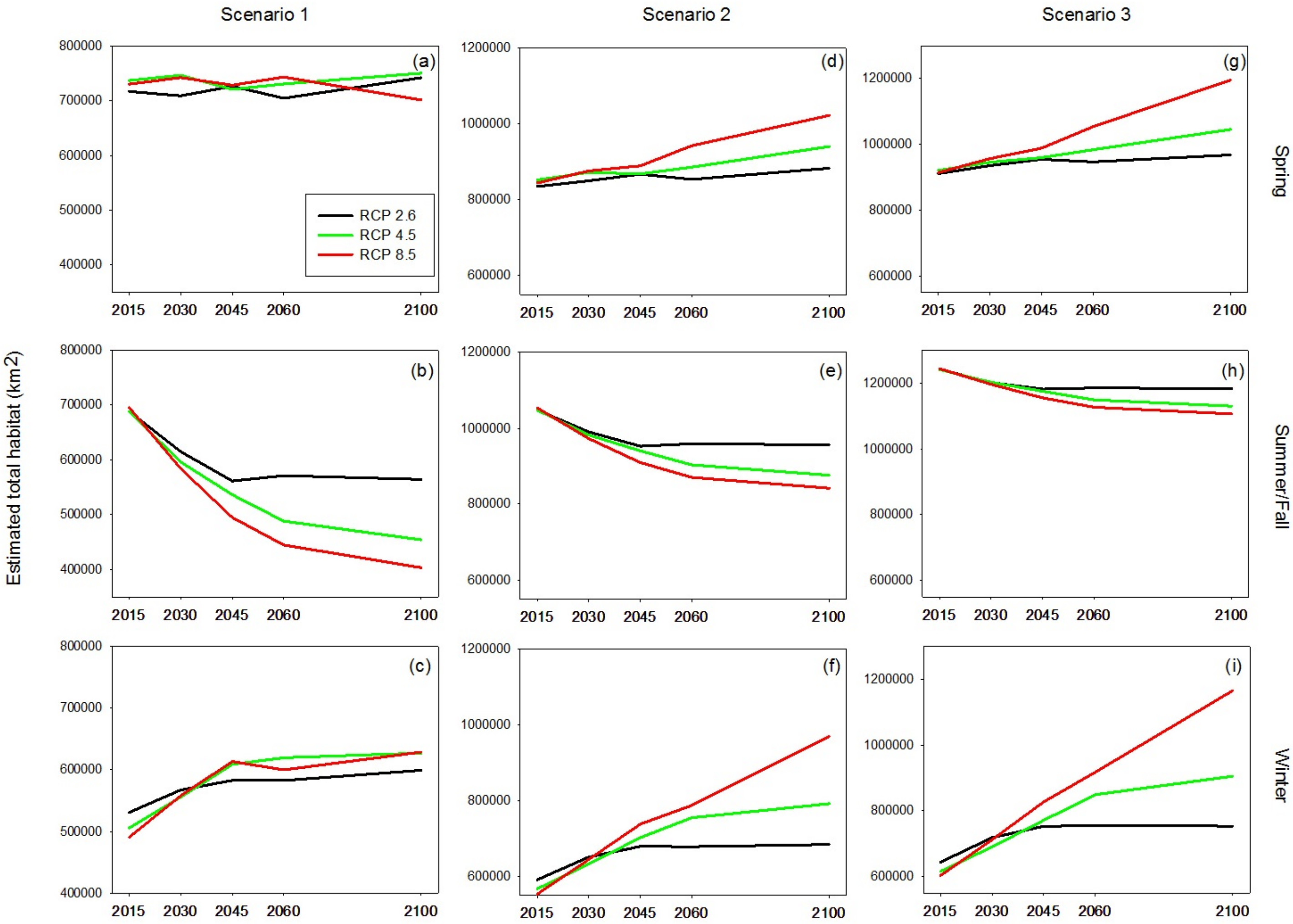


Figure 2. Estimated total potential habitat for Pacific walrus under 3 representative concentration pathways (RCP) by season and scenario within the project area and across 5 time periods. Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km. Seasons are defined as spring (April–June), summer/fall (July–November), and winter (December–March).

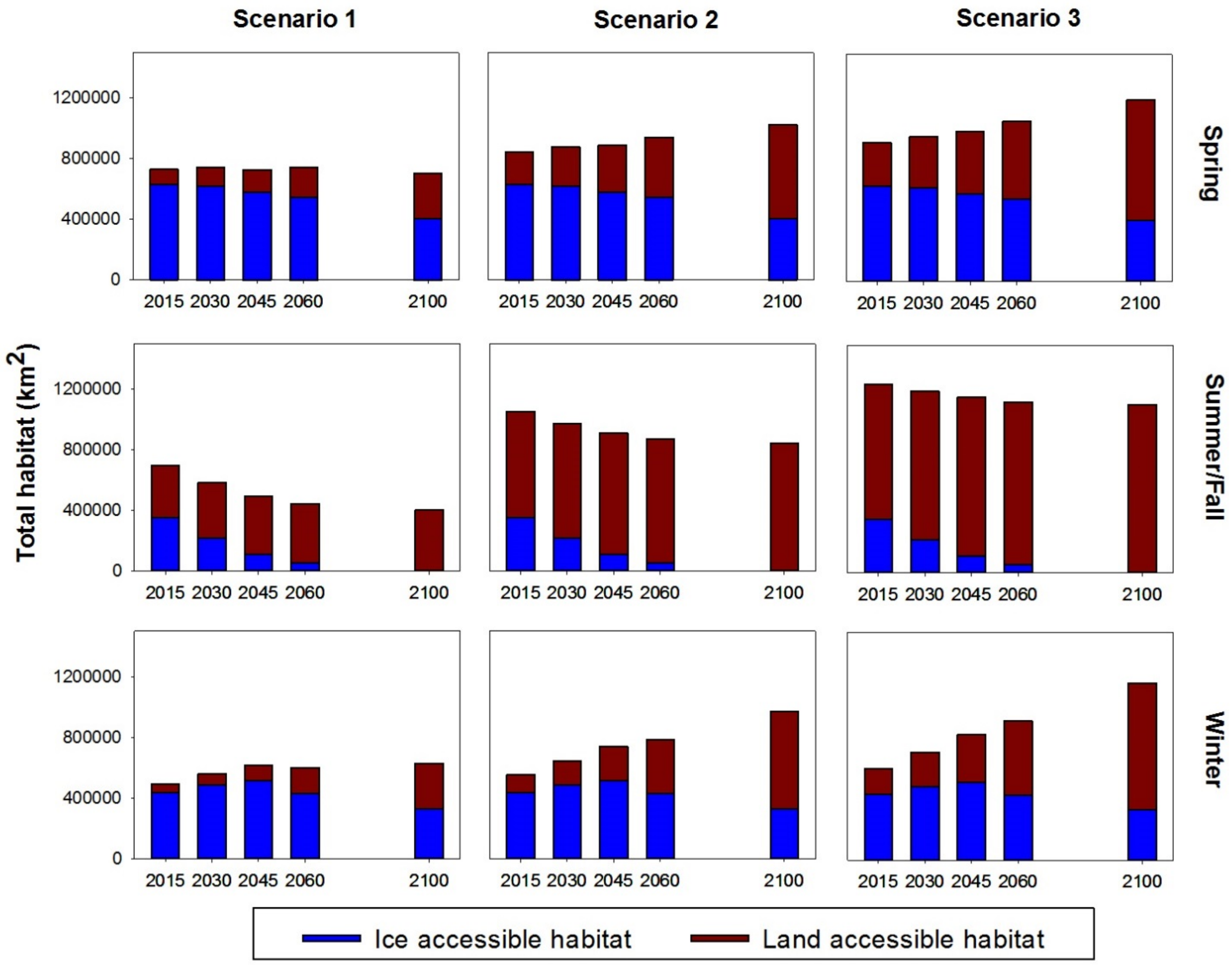


Figure 3. Estimated potential ice- and land-accessible habitat for Pacific walruses by season and scenario within the project area and across 5 time periods under representative concentration pathway (RCP) 8.5. Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km. Seasons are defined as spring (April–June), summer/fall (July–November), and winter (December–March).

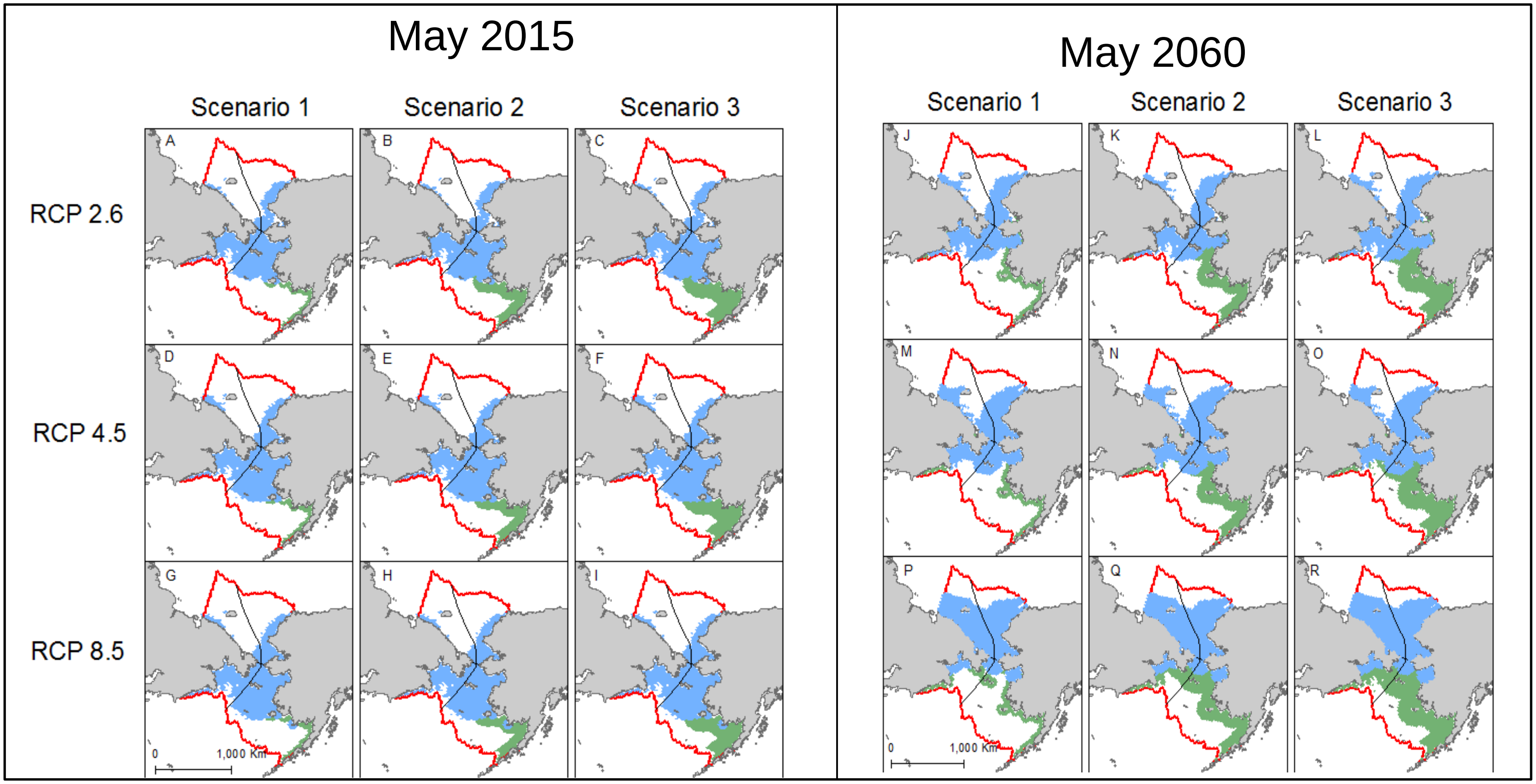


Figure 4. Potential habitat accessible from ice and land for Pacific walruses in May 2015 and 2060 (spring) by scenario and representative concentration pathway (RCP). Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km.

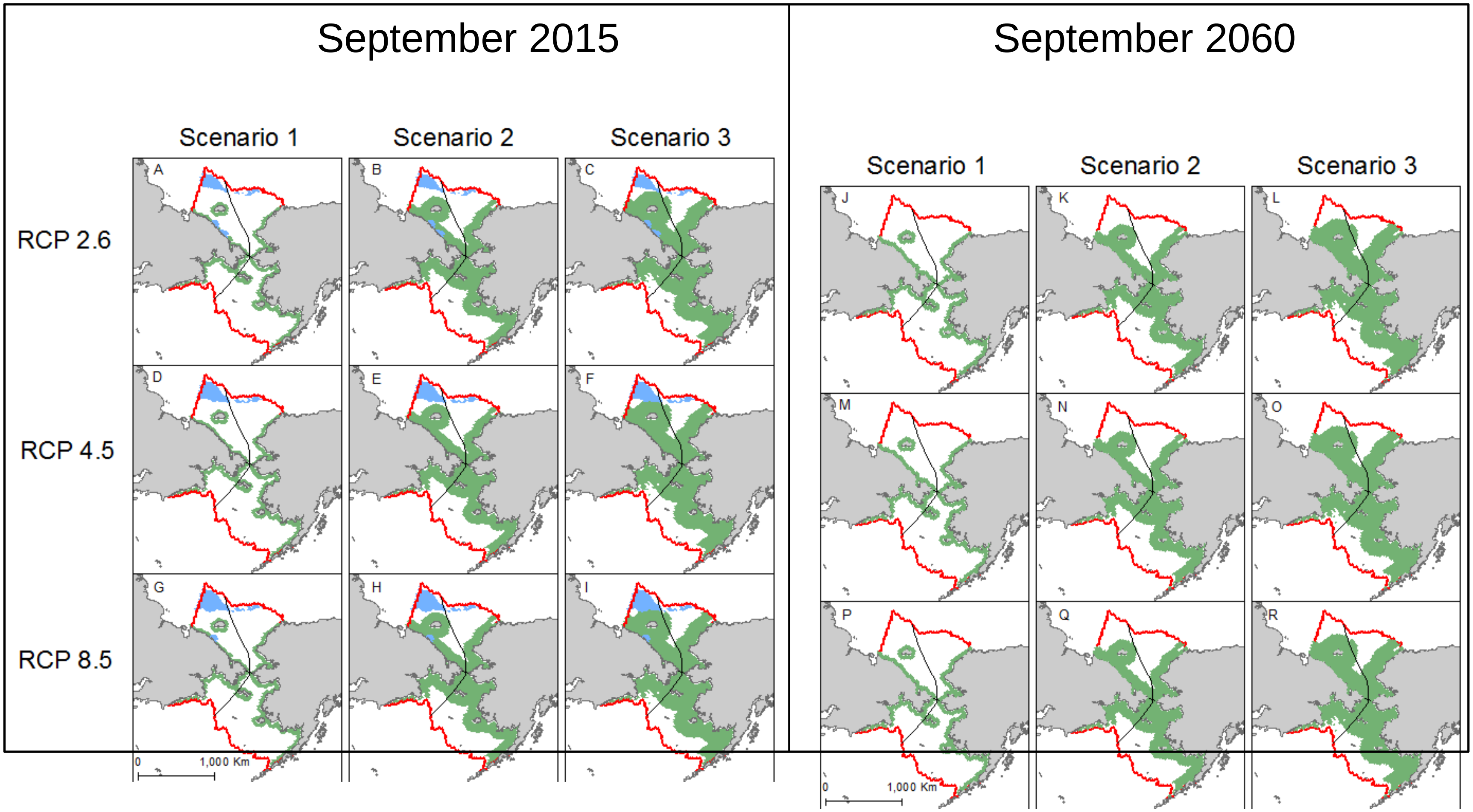


Figure 5. Potential habitat accessible from ice and land for Pacific walruses in September 2015 and 2060 (summer/fall) by scenario and representative concentration pathway (RCP). Scenarios 1–3 differ only in maximal travel distance from land into open water; Scenario 1 was limited to ≤ 70 km; Scenario 2 was ≤ 140 km; and, Scenario 3 was ≤ 210 km.

Across seasons and over time, ice-accessible habitat shifted northward with the loss of pack ice in the northern portion of our study area, exposing more land-accessible habitat, especially in the Bering Sea. In winter, we predicted that ice-accessible habitat will shift from the central Bering Sea in 2015 to the Bering Strait, straddling the southern Chukchi and northern Bering seas, in 2060 (Figure 6); consequently, in 2015, 25% of the study area consisted of total potential habitat (ice-accessible and land-accessible) and, in 2060, this value increased to 36%. Similarly, in spring, the majority of ice-accessible habitat occurred in the Bering Sea in 2015, but then moved to the Chukchi Sea by 2060 (Figure 7), resulting in an increase in total potential habitat from 47% to 61% of the project area, respectively. Conversely, our results demonstrated only minor changes to the distribution of total potential habitat in summer because ice-accessible habitat existed in 2015 only (Figure 8) when 56% of the project area contained total potential habitat, which then was reduced to only 51% by 2060. All of these results presented here correspond to Scenario 1 under RCP 8.5.

Among subregions, we detected large variation in trajectories of total potential habitat for Pacific walruses. The greatest overall negative changes in total potential habitat occurred in the U.S. Bering subregion and the greatest overall positive changes occurred in the U.S. and Russia Chukchi subregions; however, these changes were highly dependent on the season. For example, in spring and winter, our results demonstrate increases in total potential habitat for both the U.S. and Russia Chukchi subregions, yet total potential habitat declined dramatically in these subregions in summer (Figure 9). Conversely, we predicted notable declines in total potential habitat in the U.S. Bering subregion in spring and winter and a stable trajectory in summer owing to the absolute absence of sea ice throughout all 5 time periods. In all seasons, total potential habitat in the Russia Bering subregion varied little (Figure 9).

Within subregions, we attributed changes in total potential habitat for Pacific walrus over time to two different reasons. First, we predicted increases to be associated primarily with reduced SIC, which then qualified as potential habitat under our criteria. This situation was best illustrated in the Russia Chukchi subregion where ice-accessible habitat nearly doubled in spring and tripled in winter between 2015 and 2060 (Figure 10a). Second, we found that decreases were associated mostly with reductions in ice-accessible habitat and only minor increases in land-accessible habitat, resulting in a net loss of total potential habitat. This situation was best illustrated in the U.S. Bering subregion in spring and winter where less ice-accessible habitat led to less total potential habitat (Figure 10d).

Overall, we expect total potential habitat for Pacific walrus to change by -10% to 10% between 2015 and 2060, and by -13% to 21% between 2015 and 2100 under RCP 8.5 (Table 3). However, we found large variation in percent change of total potential habitat by all factors, especially season and subregion. Generally, the trajectory of percent change by scenario and time span (i.e. 2015 to 2060, 2015 to 2100) was consistent and comparatively small. We detected the greatest negative percent change in total potential habitat in summer/fall for the Russia and U.S. Chukchi subregions and the greatest positive change in winter for the same subregions. We also found primarily negative or stable percent change expected to occur in the U.S. Bering, which is the largest subregion in our project area (45% of project area).

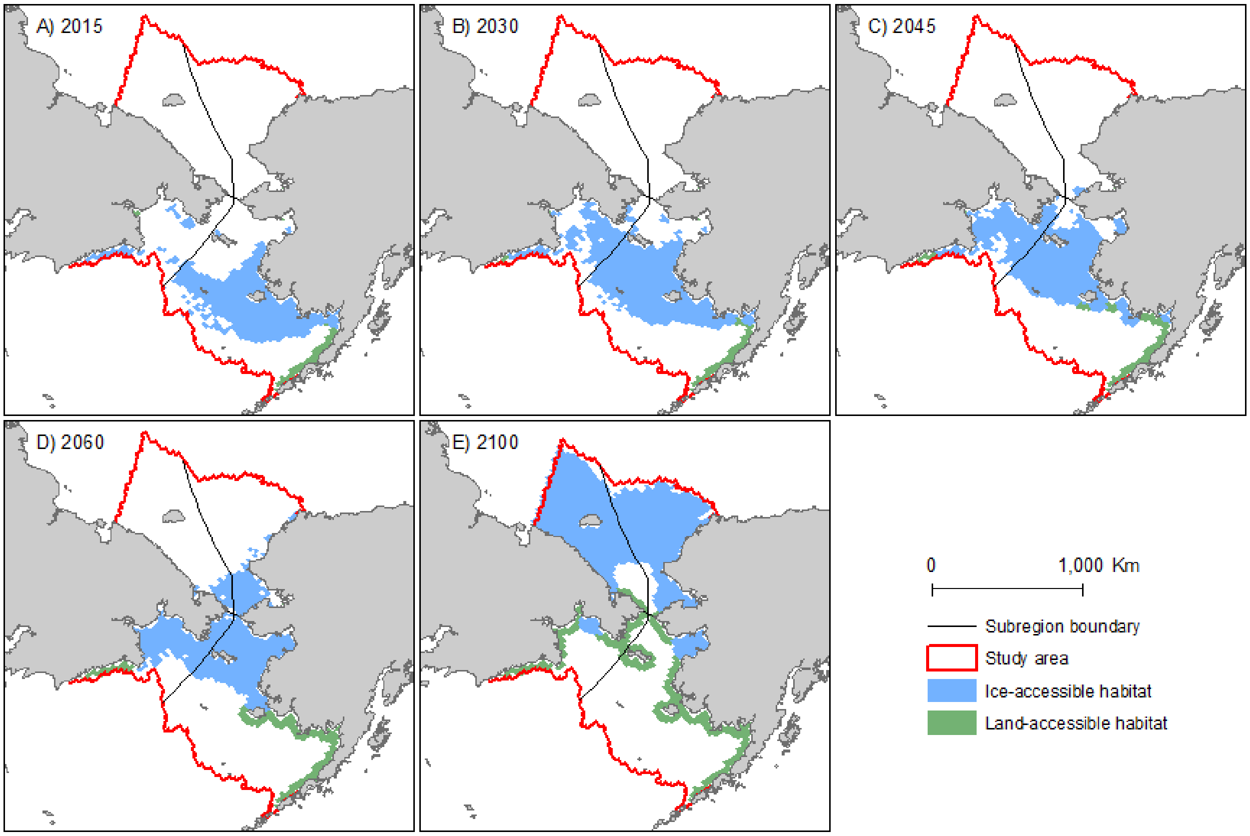


Figure 6. Potential habitat accessible from ice and land for Pacific walruses in February (winter) in 5 time periods. These maps were generated for Scenario 1 (≤ 70 km travel distance from land into open water) under representative concentration pathway (RCP) 8.5.

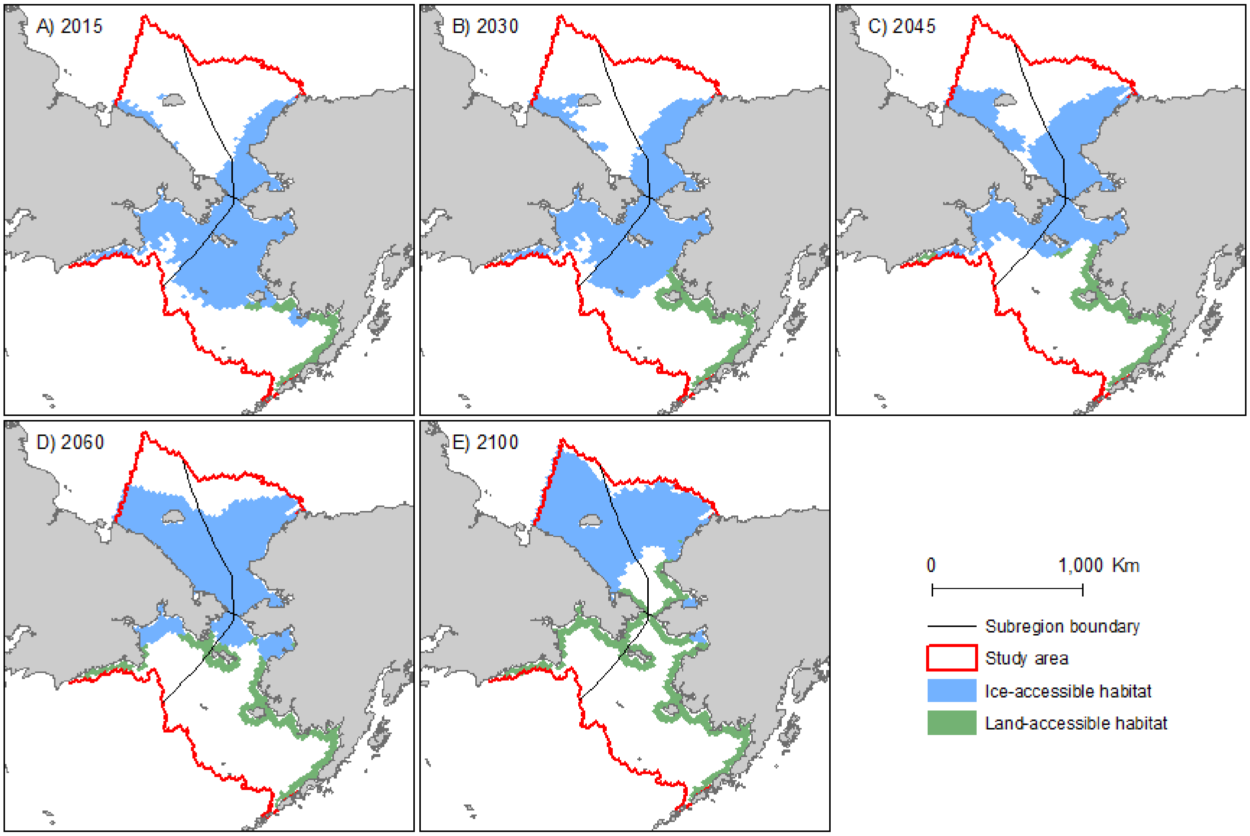


Figure 7. Potential habitat accessible from ice and land for Pacific walruses in May (spring) in 5 time periods. These maps were generated for Scenario 1 (≤ 70 km travel distance from land into open water) under representative concentration pathway (RCP) 8.5.

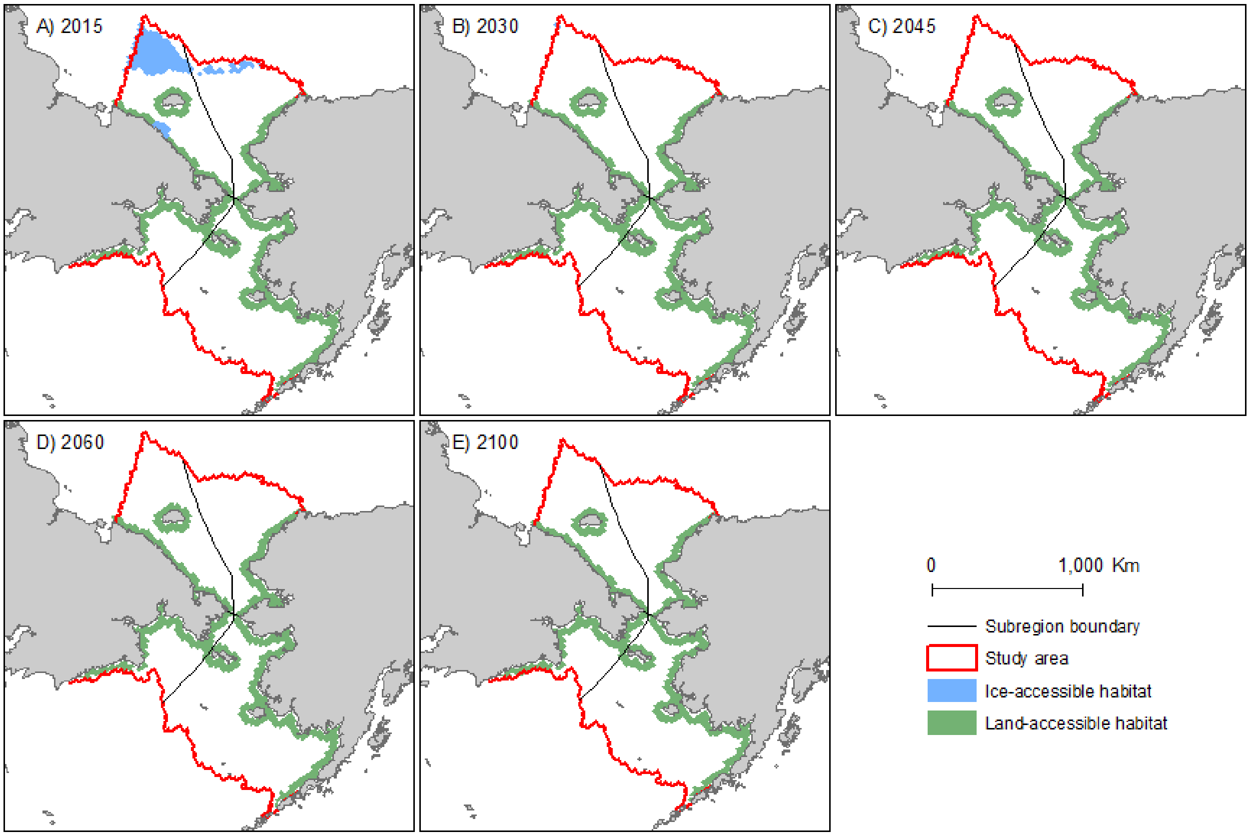


Figure 8. Potential habitat accessible from ice and land for Pacific walruses in September (summer/fall) in 5 time periods. These maps were generated for Scenario 1 (≤ 70 km travel distance from land into open water) under representative concentration pathway (RCP) 8.5.

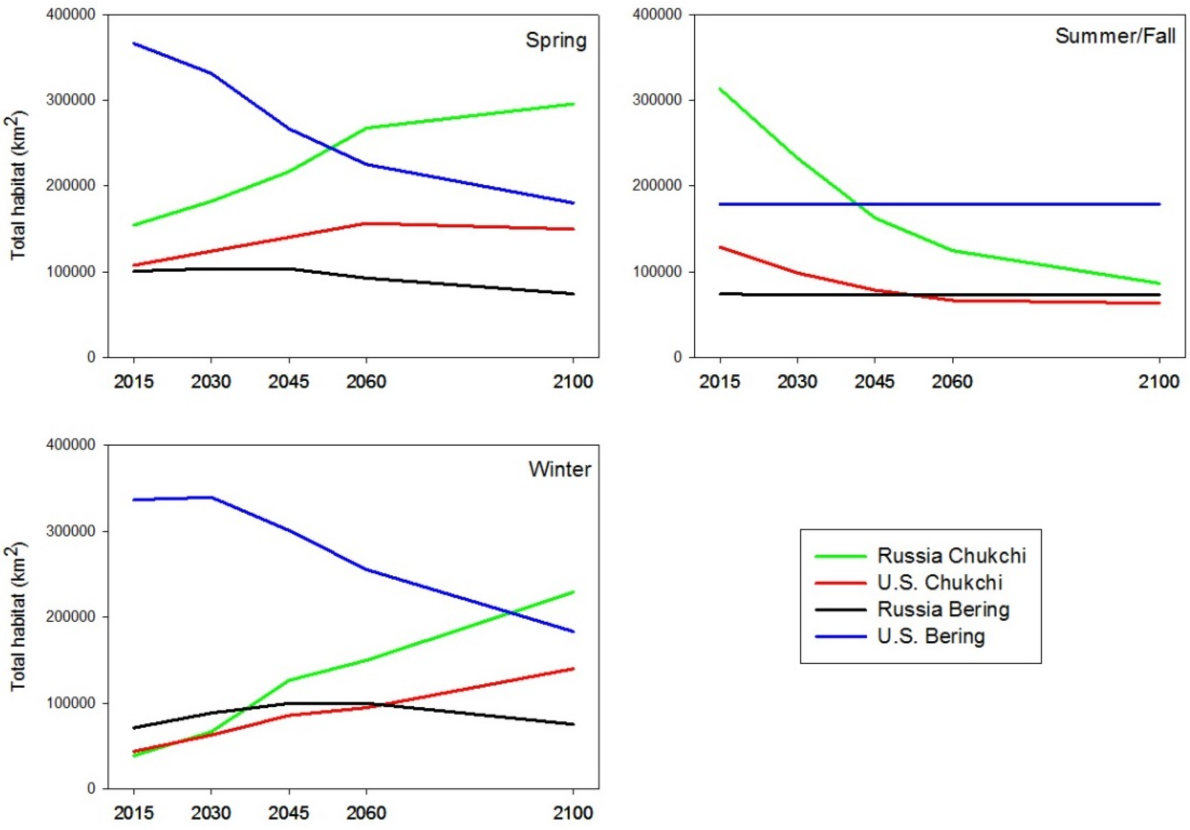
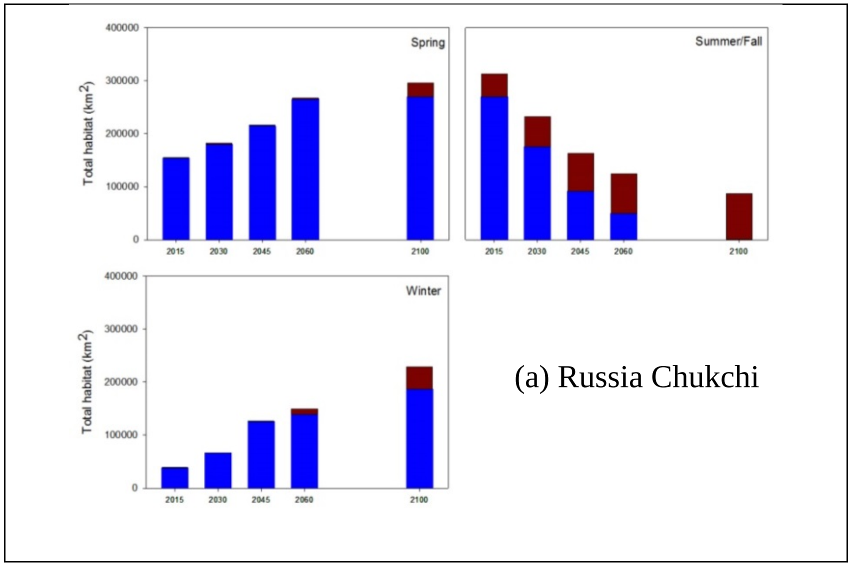
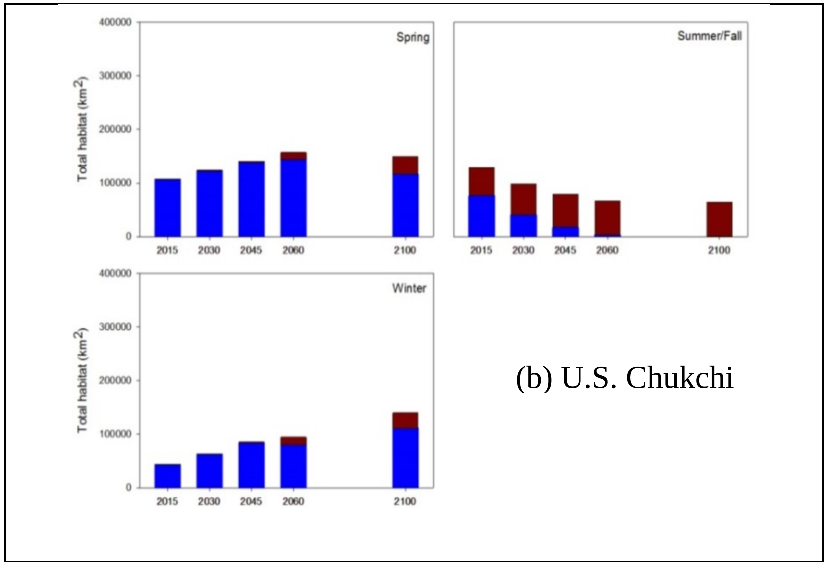


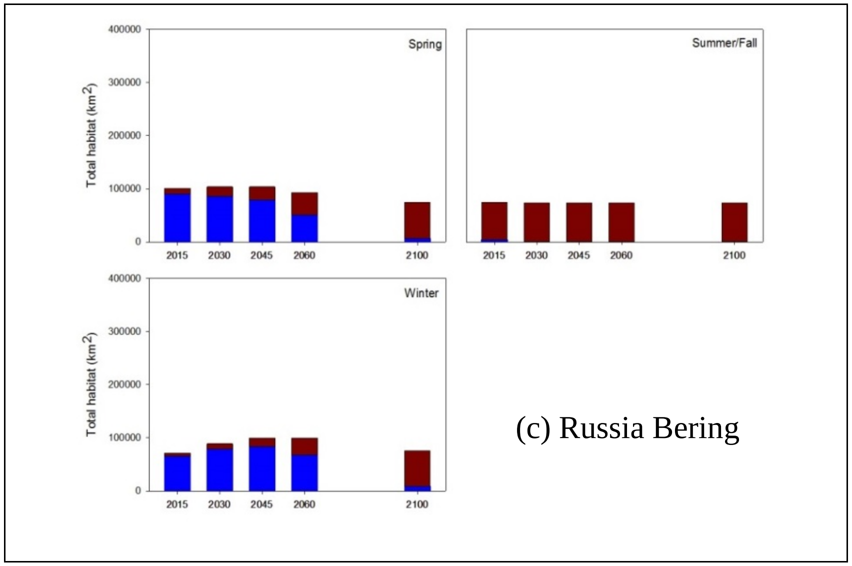
Figure 9. Estimated total potential habitat for Pacific walruses in four subregions by season and across five time periods. Seasons are defined as spring (April–June), summer/fall (July–November), and winter (December–March). These values were generated for Scenario 1 (≤ 70 km travel distance from land into open water) under representative concentration pathway (RCP) 8.5.



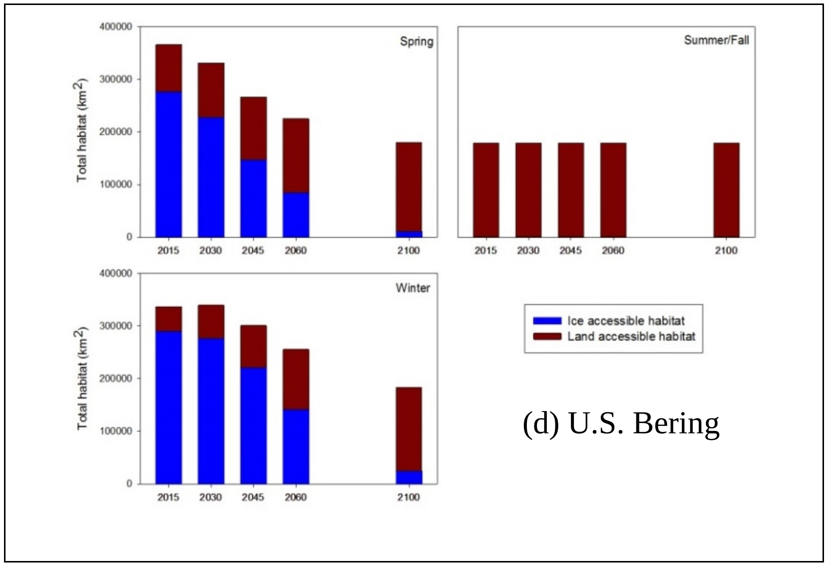
(a) Russia Chukchi



(b) U.S. Chukchi



(c) Russia Bering



(d) U.S. Bering

Figure 10. Estimated potential habitat for Pacific walruses by habitat type in the (a) Russia Chukchi, (b) U.S. Chukchi, (c) Russia Bering, and (d) U.S. Bering subregions by season and across 5 time periods. Seasons are defined as spring (April–June), summer/fall (July–November), and winter (December–March). The y-axis scale is similar in all panels to allow for comparison. These values were generated for Scenario 1 (≤ 70 km travel distance from land into open water) under representative concentration pathway (RCP) 8.5.

Table 3. Percent change in total potential habitat for Pacific walrus between 2015 and 2060 (labeled as 2060) and 2015 and 2100 (labeled as 2100) by season and scenario, based on decision rules and criteria used in our analysis. Results included for representative concentration pathway (RCP) 8.5 only. Shading added for organization only.

Scenario	Geographic Area	Spring		Summer/Fall		Winter		All Seasons[a]	
		2060	2100	2060	2100	2060	2100	2060	2100
1	Whole Project Area	2	-4	-36	-42	22	28	-10	-13
	Russia Chukchi	73	91	-60	-72	287	492	-7	2
	U.S. Chukchi	45	39	-48	-51	117	222	3	16
	Russia Bering	-8	-26	-1	-1	40	6	9	-7
	U.S. Bering	-38	-51	0	0	-24	-46	-22	-35
2	Whole Project Area	12	21	-17	-20	42	75	3	11
	Russia Chukchi	74	116	-36	-43	329	662	7	31
	U.S. Chukchi	57	79	-25	-27	159	315	15	38
	Russia Bering	6	3	0	0	61	57	16	15
	U.S. Bering	-18	-19	0	0	-2	-5	-6	-7
3	Whole Project Area	15	31	-9	-11	52	93	10	21
	Russia Chukchi	74	141	-20	-24	373	807	19	52
	U.S. Chukchi	57	93	-16	-17	181	361	21	48
	Russia Bering	9	10	0	0	68	71	18	19
	U.S. Bering	-9	-10	0	0	9	9	0	2

[a] Values calculated from monthly averages over a calendar year (January–December).

Table 4. Change in area (km^2) and percent change (in parentheses) in ice-accessible habitat only for Pacific walrus between 2015 and 2060 (labeled as 2060) and 2015 and 2100 (labeled as 2100) by season, based on decision rules and criteria used in our analysis. Values are the same under all scenarios because the travel distance from sea into open water did not vary among scenarios (Table 2). Results included for representative concentration pathway (RCP) 8.5 only.

Geographic Area	Spring		Summer/Fall		Winter		All Seasons[a]	
	2060	2100	2060	2100	2060	2100	2060	2100
Whole Project Area	-82,083 (-13%)	-223,125 (-36%)	-298,375 (-85%)	-351,000 (-100%)	-7,500 (-2%)	-105,625 (-24%)	-147,344 (-33%)	-237,240 (-53%)
Russia Chukchi	112,083 (73%)	116,458 (76%)	-220,750 (-82%)	-270,125 (-100%)	101,875 (269%)	148,750 (393%)	-30,000 (-18%)	-33,854 (-21%)
U.S. Chukchi	37,083 (35%)	9,792 (9%)	-73,500 (-96%)	-76,750 (-100%)	37,500 (88%)	68,594 (161%)	-8,854 (-12%)	-6,667 (-9%)
Russia Bering	-39,167 (-43%)	-83,958 (-93%)	-4,125 (-100%)	-4,125 (-100%)	2,500 (4%)	-56,406 (-87%)	-10,677 (-23%)	-41,510 (-90%)
U.S. Bering	-192,083 (-69%)	-265,417 (-96%)	0	0	-149,375 (-51%)	-266,563 (-92%)	-97,813 (-59%)	-155,208 (-94%)

[a] Values calculated from monthly averages over a calendar year (January–December).

Compared to changes in total potential habitat for Pacific walruses (Table 3), we predict more pronounced changes in ice-accessible habitat only (Table 4). Across the whole project area and all seasons, we predict a decrease in ice-accessible habitat of -33% by 2060 and -53% by 2100 with the greatest decrease to occur in summer/fall. We expect ice-accessible habitat to decrease up to 100% in the Russia and U.S Bering subsections by 2060 and 2100, yet we expect an increase in this habitat type by more than two-fold in the Russia and U.S. Chukchi subregions by 2060 and more than three-fold by 2100, demonstrating a northward shift in the availability of ice-accessible habitat for walruses. Despite the increases in ice-accessible habitat in the spring and winter in the Russia and U.S. Chukchi subregions, the concurrent decreases in the Russia and U.S. Bering subregions results in an overall net loss of ice-accessible habitat for walruses in spring and winter.

DISCUSSION

Our results demonstrate that the quantity, spatial configuration, and type of potential habitat for Pacific walrus are expected to change, sometimes greatly, in the future. The magnitude and direction of the projected change varied primarily by season and subregion. We expect total potential habitat for walrus to decrease in summer/fall and to increase in winter and spring. Among seasons, the greatest changes will occur in the Chukchi Sea subregions; however, within the annual cycle (i.e. all seasons combined), the greatest changes will occur in the Bering Sea. We detected a consistent decline over time in the proportion of ice-accessible habitat, which is offset to some extent by land-accessible habitat, in all seasons, subregions, RCPs, and scenarios. Although these results are informative regarding changes in potential habitat, inferences are limited to possible changes in walrus distribution and cannot be extended to abundance or other population metrics.

In spring, our results indicate that total potential habitat will increase in the Chukchi Sea, decrease in the U.S. Bering Sea, and remain mostly stable in the Russian Bering Sea. Male and female walruses typically congregate at the ice edge in early spring, which currently is located in the Bering Sea, but in late spring, females begin to separate from males, migrating northward with the retreating ice edge into the Chukchi Sea (Fay 1982, pp. 7–29). Also, during this time, most pregnant females give birth, a critical life history event that occurs on sea ice (Fay 1982, pp. 199–200). Therefore, female walruses probably would be affected more than males by changes in ice-accessible habitat in spring. Our results indicate that ice-accessible habitat in the Chukchi Sea will increase during this time (e.g., Figure 10a,b, Table 4), which theoretically should benefit female walruses. Conversely, we anticipate declines in ice-accessible habitat in the Bering Sea (e.g., Figure 10c,d, Table 4) where male walruses rest and forage offshore on sea ice in the spring. However, unlike females, males are not performing an essential life history function during this time that depends on the availability of sea ice; thus, we expect negative changes to male walruses to be minimal, especially given that they remain in the Bering Sea during the ice-free summer months. Across our project area, however, we predict a decrease of

-13% by 2060 and -36% by 2100 of ice-accessible habitat for walruses, reducing the amount of birthing habitat for female walruses.

In summer/fall, we found that total potential habitat will decrease in the Chukchi Sea and remain stable in the Bering Sea. During this time, females and dependent young occur primarily in the Chukchi Sea while male walruses occupy the Bering Sea (Fay 1982, pp. 7–29). Consequently, females and dependent young probably will be most affected by changes in potential habitat in summer/fall. We predicted that potential habitat will be reduced by 16–60% between 2015 and 2060 and 17–72% between 2015 and 2100 in the Chukchi Sea, depending on the distance that walruses are willing to travel to search for food. Jay et al. (2012, p. 23) reported that most (88%) foraging trips taken by tagged female walruses were less than 70 km in distance (Scenario 1), although some (12%) trips were more than 210 km (Scenario 3) and occurred over a few weeks, suggesting that walruses prefer to minimize foraging trip distance if possible, but are willing and capable to take longer trips if necessary. With our analysis, we cannot predict walrus response to future reductions in habitat in summer/fall, though female walruses likely will experience higher energetic demands associated with longer foraging trips unless foraging demands can be met nearshore and close to haulout sites (Jay et al. 2017, pp. 8–9). We do not anticipate any changes to male walrus distribution in summer/fall because their habitat in the Bering Sea is not expected to change over time (Figures 9 and 11).

In winter, our results suggest a similar pattern to those in spring; we expect an increase in total potential habitat in the Chukchi Sea, a decrease in the U.S. Bering Sea, and stability in the Russian Bering Sea. At the end of fall and in early winter, male and female walruses migrate southward with the advancing ice edge, eventually culminating in the Bering Sea where they remain for the winter (Fay 1982, pp. 7–29). During this time, walruses use ice habitat to rest and forage offshore and, in late winter, courtship and mating/breeding occur (Fay 1982, pp. 191–192). Male walruses perform courtship displays in the water near group(s) of female walruses on sea ice; when appropriate, a female walrus enters the water, joins the male, and mating occurs (Fay 1982, pp. 193–194). Thus, sea ice serves an important role in successful courtship and mating of walruses. We found that although ice-accessible habitat is expected to decrease in parts of the Bering Sea in winter (e.g., Figure 10c,d, Table 4), we expect some level of ice-accessible habitat to be available to walruses until the end of the century (Figure 3) and in some areas such as the Chukchi Sea, ice-accessible habitat is projected to increase (e.g., Figure 10a,b, Table). Nonetheless, across our project area, we predict a minimal decrease of ice-accessible habitat for walruses in the winter (-2% by 2060 and -24% by 2100). Therefore, in examining potential habitat alone, we do not anticipate that walruses will experience negative changes in winter, at least by 2060.

Our analysis has several key assumptions and limitations. First, we assumed that the identified criteria are appropriate to classify potential habitat for Pacific walrus. We relied on the best available information to inform decision rules with limited data (e.g., travel distances). In cases where no data existed to refine criteria, we assumed that all habitat was potential habitat. For example, although a database of known coastal haulout sites for walruses exists (Fischbach et al. 2016, entire), we are not aware of an analysis to identify preferred features or drivers of selection of these sites (e.g., slope, substrate, risk or level of disturbance); therefore, we assumed that the entire coastline within our project area served as potential land-accessible habitat for walruses, likely inflating our estimates of this habitat type. Second, we did not include any information to address factors related to habitat quality, most importantly benthic productivity, which was found to be a driver of walrus resource selection (e.g., Jay et al. 2014, p. 5; Beatty et al. 2016, p. 28). Therefore, our results should be considered a best-case prediction of potential habitat for walruses. Future analyses should aim to integrate available information on persistent benthic hotspots and walrus resource selection functions with factors considered in our analysis. Lastly, we limited our analysis to the current range of Pacific walrus; however, walruses may expand or shift their range in response to changing resource conditions. While these assumptions and limitations should be considered when interpreting our results, we used a simple and transparent method to evaluate changes in potential habitat of Pacific walruses and possible changes to its distribution.

Although sea ice plays a central role in the life history of the Pacific walrus (Table 1), it is unclear as to whether or not it is a requirement and, if so, to what extent. Some authors suggest that the Pacific walrus is simply an ice-associated species (e.g., Burns et al. 1981, p. 781), while others suggest it is an ice-obligate species (e.g., Moore and Huntington 2008, p. S158). Beatty et al. (2016, pp. 28–29) found that tagged walruses demonstrated selection for areas proximate to ice and land while foraging, although selection for areas proximate to ice was substantially stronger than land. An interaction term between ice and land also was included in the top model of resource selection, which suggests that walruses prefer to use ice habitat, but must make tradeoffs to ensure access to haulout habitat to rest in between foraging trips (Beatty et al. 2016, p. 28). Using the same dataset, Jay et al. (2017, p. 9) demonstrated that these tagged walruses experienced the lowest energy demands when ice habitat was available to them compared to land habitat or neither habitat type, providing an explanation for walrus preference for ice habitat. However, Jay et al. (2010, p. 293) reported that movements and activities of tagged walruses were independent of ice floe movements, at least at a local scale. Certainly, we need a better understanding of the underlying mechanisms of ice in walrus life history functions and the ecological criteria necessary to maintain individual and population health. Although our analysis was not aimed at addressing these important topics, we provide a basis from which to frame targeted questions regarding the future status of Pacific walrus and its habitat.

In conclusion, we expect total potential habitat for Pacific walrus to change by -10% to 10% by 2060 and by -13% to 21% by 2100 under current sea ice projections. We also anticipate a shift in type of habitat available to walruses over time, specifically, a decrease in ice-accessible habitat (-33% by 2060 and -53% by 2100) and a concurrent increase in land-accessible habitat. Across our project area, we found a decrease in total potential habitat in summer/fall only and an increase in winter and spring only, although the magnitude and direction of change varied considerably among subregions.

Walruses currently use sea ice in winter and spring to perform key life history functions (i.e. courtship, breeding, birthing), and given our results, we expect that their habitat needs mostly will be met during these critical periods of the annual cycle. Although birthing habitat in spring will be more limited (-13% by 2060 and -36% by 2100), most birthing events occur early enough in the spring (May) to avoid ice-free conditions or inadequate levels of sea ice availability. Because we conducted our analysis by season, not by month, we do not have sufficient temporal resolution to assess birthing habitat conditions directly. However, we postulate that walruses will have access to birthing habitat, though they may need to use different areas than previously observed (e.g., further north in the Chukchi Sea; Figure 7).

In summer/fall when total potential habitat is expected to decrease, we are less confident that walruses will be able to meet their life history needs. During this time, walruses require habitat for resting, foraging, nursing, and other maintenance-related activities that are necessary for their survival. Although walruses prefer sea ice habitat, they also use land habitat during summer/fall, but not without tradeoffs related to energetic costs and other risks of using coastal haulouts (e.g., trampling events). Nonetheless, if land habitat proved to be comparable in quality, including access to foraging sites, to ice habitat, then we postulate that their habitat needs should be met, but if land habitat is inferior to ice habitat for walruses in summer/fall, then survival and recruitment of walruses could decline and population-level effects eventually could occur. Based on our analysis, however, we are unable to speculate about the long-term response of walruses to reductions in potential habitat in summer/fall. Instead, we conclude that total potential habitat for walruses in summer/fall will change by up to -60% by 2060 and up to -72% by 2100 (Table 3), depending on the travel distances of foraging trips that walruses, especially females with dependent young, are willing to take.

ACKNOWLEDGEMENTS

We thank Dave Douglas, USGS–Alaska Science Center, for input during project development and for preparing sea ice projections specific to our analysis. We are grateful to Jim MacCracken, Joel Garlich-Miller, Jonathan Snyder, Drew Crane, Patrick Lemons, and Caitlin Snyder, all affiliated with the USFWS, for helpful suggestions and comments that improved this report greatly. We also thank several anonymous reviewers of the Pacific Walrus Species Status Assessment, which included this report as an appendix, for their thoughtful, constructive comments on our analysis.

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9.3 Appendix C. Alaskan Native Ecological Knowledge Workshop Report

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***Disclaimer**. This workshop report is written by consultants to the US Fish and Wildlife Service as a contribution to the determinationwhether Pacific walrus warrant listing under the Endangered Species Act (ESA). The authors are researchers and consultants with prior experience in the ESA decision-making process and in understanding the contributions of traditional ecological knowledge to resource management decisions. However, we are not members of an Alaskan Native community and we are not experts in the biology or behavior of walruses. This report was prepared by the three named consultants under contract to the US Fish and Wildlife Service, Alaska Region.*

***Acknowledgements.** We thank the community participants for their honest and open-hearted willingness to share their observations and experience and to be willing to travel to Anchorage to meet with us. We also thank the US Fish and Wildlife Service participants, and in particular Jonathan Snyder, for help in organizing the TEK workshop and for their participation and openness.*

Background

This workshop report summarizes findings from a two-day workshop held in Anchorage, Alaska June 7 & 8, 2016. The discussions provided information regarding the status of Pacific walrus from the perspective of coastal Alaska's Native subsistence resource users. This information will inform the decision whether Pacific walrus warrant listing under the Endangered Species Act (ESA). Workshop participants (see Appendix C1), representing fifteen villages from coastal Alaska, included twenty subsistence resource users (17 men and 3 women) from communities along both the Bering Sea and the Chukchi Sea; seven staff of the U.S. Fish and Wildlife Service (Service) also attended the workshop. Along with the results of other scientific studies, this knowledge and experience of Alaskan NativeAlaskan tribal members will inform the comprehensive Species Status Assessment (SSA) report and listing determination that must be completed by the Service by September 30, 2017.

Introduction

It is widely recognized that Pacific walruses are a culturally important subsistence species for coastal Alaska Native communities.   Changes to the natural environment over the past half-century, including changes to the distribution and quality of sea ice as a result of climate change, have created new stressors on the Pacific walrus population. Other sources of stress include increased shipping traffic, noise, and industrial activity in Alaskan and Russian waters. As a result, in 2008 the Service was petitioned by the Center for Biological Diversity to list Pacific walrus as a threatened or endangered species under the ESA. The Service reviewed the information available at the time and concluded that listing the Pacific walrus as a threatened or endangered species was warranted [76 FR 7633 (February 10, 2011)]. However, due to other priorities at the time, the Service designated the Pacific walrus a candidate species rather than adding it to the ESA list. The 2011 conclusion, that listing was warranted, was based on several factors including the determination that Pacific walrus numbers would decline in the future because of the ongoing loss of sea ice.

As the result of a court settlement with several conservation organizations, by September 30, 2017 the Service must evaluate all available information and decide whether to propose adding the Pacific walrus to the ESA list or determine that listing is no longer warranted. The Service is currently evaluating a number of factors influencing the health of the Pacific walrus population both now and in the foreseeable future, including the impacts of reduced sea ice and other stressors. In late 2015, the Service began a Species Status Assessment (SSA) review, which includes the best available information about the species and will serve as the foundation for the listing decision.[7]

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[7] Results of the decision-making process concerning whether listing is or is not warranted are scheduled to be submitted by September, 2017. If walrus are proposed for listing, this will be followed by a public comment period and, after review, by a final decision to either not list or to list Pacific walrus as a threatened or endangered species.

As part of this assessment process, the Service (with assistance from Compass Resource Management, a Vancouver-based consulting firm, and subcontractors) is conducting several parallel analyses. One analysis involves the development of a Bayesian Belief Network (BBN), which provides a graphical and numeric model showing the inter-relationships among a number of factors thought to affect the growth and abundance of walruses. The factors include sea ice extent, subsistence harvest, incidental takes, human settlements, shipping and air traffic, behavioral effects on walruses due to considerations such as haul-out disturbances and crowding, the availability of suitable birthing and breeding habitat, and effects on food sources. The model, based on previous work done by researchers in Alaska (see Jay et al. 2011; MacCracken 2012), focuses on the needs of walruses and the influence of known stressors starting in the present and extending over four time periods: 2030, 2045, 2065, and 2100.

Another component of the Assessment process is to compile and incorporate the insights and knowledge of Alaskan Native subsistence resource users. In this report, we refer to traditional ecological knowledge (TEK)[8] as the observations, knowledge, and cosmology acquired and utilized by Alaska's indigenous communities and individuals over time, referenced to time and place but also dynamic and adaptable so that it remains useful in contemporary life (see more complete definitions by Berkes [1999] and on the Kawerak, Inc. website http://www.kawerak.org/socialsci.html).

Through discussions with Alaskan Native tribal members and through the actions of groups such as the Eskimo Walrus Commission (EWC), Alaska Native subsistence users have provided important contributions to Pacific Walrus conservation and management programs over many years. The Service values the knowledge held by Alaska Natives and wants to include traditional knowledge as part of its SSA process. This includes both insights obtained directly

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[8] Traditional Ecological Knowledge, based on the observations of Tribal members and reflected in both oral and written documentation, is also termed Local Traditional Knowledge or Native Science Knowledge (e.g., to be compared directly with Western Science Knowledge).

from subsistence users and published TEK literature, some of which is summarized in this report.[9]

Insights from Traditional Ecological Knowledge

The TEK literature is extensive; in this brief review we highlight several areas related to TEK insights concerning Pacific walruses that we believe are particularly relevant to the Assessment process. This information was provided to participants in the form of a Background report, distributed in advance of the workshop with the anticipation that discussions at the workshop would provide additional details, permit corrections to any misunderstandings, and clarify the relationship of TEK to the Service's Assessment and listing decision process.

General TEK considerations

Five general considerations -- which in turn hold methodological, analytic, and political implications -- are central to the role of TEK in the walrus listing assessment.

- The information provided by TEK studies, as conducted in Alaska and elsewhere, highlights a wide range of traditional practices, beliefs, activities, intergenerational teachings, laws, and understandings that together form essential aspects of a traditional indigenous way of life and cosmology. In contrast, the context for these workshop discussions involving TEK -- the listing determination process under the ESA -- is more narrowly focused on biological and ecological considerations (under the mandate of the ESA as defined by Congress). Of necessity, this means that many important aspects and understandings of TEK are external to the mandate of the Service and, although of interest and often relevant to the ongoing work of government field staff and managers, have no standing as part of the assessment process to be conducted by the Service.
- TEK necessarily involves the joining of different types of knowledge that include ecological, social, health, and cultural values. This shared, multi-dimensional understanding of TEK in the face of both environmental and cultural adaptability has

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[9] A more complete listing of the relevant TEK literature has been compiled by the Service and was made available to participants to the June TEK workshop.

been emphasized in writings by Berkes (1999), Failing et al. (2007), Robards (2013), and others. As part of a comprehensive approach, the combination of scientific and traditional knowledge sources can enhance the understanding of both values and facts and encourage learning, leading to an improved management framework.

- In many cases, and despite the best intentions of all parties, there exists a tension between the insights of scientists and the insights of local traditional knowledge holders. The goal of a comprehensive management process is not to eliminate differences in perceptions of knowledge claims but to understand the reasons behind them and, with input from all participants, to make informed decisions concerning the future management of the resource and ecosystem.
- In making a listing decision, the Service must use the best information available at the time. In many cases, information gaps exist that create uncertainty about the future status of a species (Gregory et al. 2013); in the context of this workshop, there exists uncertainty about the future health and abundance of the Pacific walrus population. This uncertainty influences both the knowledge base relating to current conditions – today, next week, and next year – and the knowledge base relating to future conditions, with a focus on predictions regarding the health of the walrus population between 2030 and 2100. For both the insights of traditional knowledge holders and for the design and outputs of models, the degree of uncertainty is likely to become greater as the time period under study increases (e.g., 15 years into the future vs. 50 years into the future). Because uncertainty affects all predictions of future conditions, whether made by scientists or subsistence users, we see the benefit of information from different sources being combined and used in an integrated fashion (e.g., as part of narratives, scenarios, and sensitivity analyses) so that a more accurate understanding of likely future conditions can be obtained.
- There is a disconnect between the causes underlying walrus' population changes, in particular climate change, and the management capabilities of Alaskan Native communities or other subsistence resource users, which have some control over considerations such as disturbance levels at haulouts or subsistence hunting but very

little control over the rate or severity of climate change. As a result, there is a reported worry (Raymond-Yakoubian et al. 2014) on the part of some Alaskan Natives – who generally have been very concerned with long-term stewardship of marine mammals – that they may be asked to shoulder the burden of conservation initiatives through reductions in future subsistence harvests even though they are not responsible for the emission of the bulk of greenhouse gases or other sources of stress to walruses. This point was emphasized and clearly stated by participants in the TEK workshop.

Critical aspects of TEK for the ESA Listing Assessment

Prior to the start of the June workshop, several specific areas of interest – important to both the listing assessment studies of scientists and the observations or activities of subsistence hunters – were highlighted as critical to the SSA report and listing determination. These topics, many of which have been noted in the TEK literature or as part of earlier workshops, are summarized below because they helped to set the context and focus for the June TEK workshop discussions.

Changes to seasonal ice cover. Changes to sea ice as the result of climate change are of fundamental importance to the current and future health of the walrus population. In recent years, the Chukchi Sea shelf has become entirely ice-free by late summer; periods without ice cover have ranged from several weeks to several months. The related direct and indirect impacts include changes to the thickness, locations, and quality of sea ice; sea water temperature and acidity; the type and quantity of benthic food sources; storm surges and wave heights; the occurrence and strength of winds; and access to sites (which in turn influences commercial and recreational options) as well as access to clean areas (ice compared to sandy or rocky shores) for butchering walrus after harvest.

Changes in subsistence hunting of walruses. In many Northern and Western Alaska communities, walruses are a main source of subsistence food and raw materials for handicrafts. Yet many sources report that it has become more difficult to hunt walruses. This is in part due to changes to sea ice and in part due to other factors such as changes in the weather (which reportedly has become more variable, so that safety is now a more important concern). Earlier studies distinguish between physical environmental factors (e.g., wind speed, ice concentration and quality) and hunter effort in determining both whether to hunt and hunter success (Huntington et al. 2013).

Changes in walrus behavior. Alaska Natives have reported changes in the behavior of walrus. For example, residents of Little Diomede (Raymond-Yakoubian et al. 2014) noted that the spring migration of walrus heading north now occurs earlier in the year. June hunting activities now take place earlier in the spring. The earlier migration is reported to be associated with the movement of ice and, in particular, linked to the flow of ocean currents (Raymond-Yakoubian et al. 2014). Many other behavioral changes have also been reported: at the Point Hope workshop (Huntington and Quakenbush 2013), for example, it was noted that older male walrus have been observed to come out of the water onto the ice to take seals.

Changes in walrus prey and food sources. Concerns about climate change and ecosystem disruptions also extend to food sources used by walrus. For example, the 2012 Barrow workshop noted that, in the summer of 2010, a red tide algae bloom seen between Barrow and Wainwright may have adversely affected food sources used by walrus (Garlich-Miller 2012). However, participants at the 2013 workshop in Point Hope reported that seals seen in winter appeared to be healthy and abundant.

Changes in diseases and walrus health. Hunters are generally able to distinguish the health of walruses by visual factors that include the thickness of their blubber and condition of internal organs. Various signs of sickness or disease include observations made at haulout sites regarding an increase in the numbers of underweight and sick animals. Some observers in the past, including at the Point Lay haulout, are reported to have seen bleeding sores on the skin of walrus (which also may result from scraping against the sharp edges of ice). Other concerns reported at Point Hope, (Huntington and Quakenbush 2013) include yellow coloring on the flippers and around the mouths of some walrus, particularly during the spring migration.

Changes in the distribution & abundance of walrus. The spatial distribution and abundance of walrus is changing, in part due to changes in the extent and condition of sea ice (e.g., the loss of multi-year sea ice). For example, a workshop held in Point Hope in January 2013 (Huntington and Quakenbush, 2013) confirmed that fewer males are seen in the spring and, overall, there appear to be significantly fewer walrus – the change is from thousands of walrus in the past to only hundreds of walrus today. In addition, walrus are no longer coming as close to the shore in some areas but, instead, are traveling further offshore.

Differences among geographic regions and walrus communities. All Pacific walruses are considered to be part of the same species and the same population, and our understanding is that most subsistence hunters characterize walruses on the Russian and Alaskan sides of the Bering Strait as the same. However, there may be important differences among walrus communities depending on their location (e.g., Chukchi Sea vs. Bering Sea) and the time of year (e.g., winter, summer/fall, and spring) or other distinctions such as gender and age -- including the identification of baby walruses (calves), pregnant females, and young bulls with smaller tusks – or the food source of walrus (e.g., walrus that kill and eat seals). In some locations (e.g., Little Diomede Island), community members also distinguish “green flippers” (or “green palms”) walrus from others due to their having spent long periods of time on rocks covered with algae.

Impacts from shipping and air traffic and noise. The increased use of airplanes and of motorized boats & barges in shipping lanes are reported to be affecting walrus migrations. For example, the Point Hope workshop (Huntington and Quakenbush 2013) confirmed that some hunters attributed changes in both the number and location of walruses to the greater use of outboard engines as well as to increases in ship traffic. Participants noted that walrus are probably affected by the smell as well as the noise of the boats.

Disturbances to walrus from human intrusions at haulouts. There exist numerous community-based management initiatives intended to minimize disturbances at coastal walrus haulouts and reduce the potential for injuries and deaths (particularly among young animals) due to stampedes (Garlich-Miller 2012). These include modifying hunting practices (e.g., using spears rather than guns to take walrus near haulouts), discouraging aircraft over-flights, tying up stray dogs, and keeping vehicles off beaches (e.g., at Point Lay). Also, several Russian communities now assign local guides to ensure that visitors at haulout sites remain at a safe distance from walruses and are kept down-wind of animals. But human intrusions continue to be a problem at some haulout sites.

Impacts to walrus from pollution. Human intrusions include pollution in the form of routine emissions of oil and accidental spills of petroleum-based products that can adversely affect walrus. Pollution also takes the form of trash and debris and (e.g., after the tsunami in Japan), chemicals such as pesticides and flame retardants, and ocean-borne refuse such as empty water bottles, gas cans, household items, and floats.

Key Findings of TEK Workshop Discussions

The two days of discussions at the June, 2016 TEK workshop provided the Service with a wealth of information about observed changes to Alaska's coastal environment and its Pacific walrus population, the concerns and practices of Native Subsistence hunters, and the place of walrus in the lives of the Inupiaq and St. Lawrence island Yupik, Yup'ik and Cup'ik individuals and communities of coastal Alaska. Working both as a plenary and in facilitated break-out groups, participants discussed a wide range of questions relevant to the listing determination and also were able to ask questions of each other and of the attending Service staff, several members of whom (e.g., Jonathan Snyder) already were well known to participants due to visits to communities over many years.

It is recognized that the issues raised during the course of the workshop are fundamental to the identities and wellbeing of the participants. It is also recognized that these issues vary, in content and in importance, across the fifteen different Native villages of coastal Alaska represented at the workshop. Any overall summary of these issues, including the summary that follows, is therefore only partial and will fail to capture fully the depth of concern, passion, or understanding of the workshop participants in relation to the current and future abundance of Pacific walrus.

With these comments as caveats, this section provides an overview of twelve key issues discussed by workshop participants with regard to changes in the environment and in the walrus population that are relevant to whether the listing of Pacific Walrus under the ESA is or is not warranted.

Importance of walrus

Participants were very clear that all Federal and State management agencies need to recognize Alaskan Native's relationship to, respect for, and ongoing commitment to the continuing presence and good health of Pacific walrus. This fundamental importance rests on the many dimensions of value associated with walrus, including ecological, cultural, nutritional, mental and physical health, and spiritual. This importance also extends to other species, whose lives also are intertwined with those of the walrus, and to the powerfully intimate relationship held by Alaska Natives with the Creator and with Mother Earth.

Subsistence walrus harvests

Current levels of walrus subsistence harvests are generally lower than those of 10 to 30 years ago. Hunters from St. Lawrence Island, for example, reported that annual harvest levels have declined significantly from the yearly average of about 1000 walrus in the recent past, forcing several communities to declare a state of emergency and receive food aid. Even when large numbers of walrus are present, communities might be prevented from harvesting walrus for many reasons: because the sea ice is not of suitable quantity or quality, because the weather is highly unpredictable (which makes travel by small vessels unsafe or impossible), or because animals are present in such large numbers (as at Point Lay) that residents cannot harvest walrus without caution because it would be too dangerous for the walruses due to the greatly increased chances of a stampede and consequent trampling. In addition, the occurrence of walrus harvests in many (but not all) communities has become less predictable, largely due to shifts in seasons that influence the timing of when sea ice is present. Several communities reported very short windows during which harvest now needs to occur, from what just a few years ago was a one or two-month harvest window to only a one week (or even shorter) harvest window today.

Walrus abundance

Participants were unanimous in saying that the overall abundance of walrus has not changed significantly, but many walrus are moving to new locations and are using new haulouts. This means that walrus at many coastal sites are often not being seen in their historical numbers, because migration patterns have changed or because walrus have moved to other sites. Observations from many community members therefore support the general finding that the walrus population is redistributing itself, in general following the retreating ice north to the Chukchi Sea. One participant noted that, in the Bristol Bay area, walrus are redistributing themselves both north and south, with many males moving to new haulout areas along the Alaska Peninsula. Concern also was expressed that, looking ahead to future decades, it may be difficult to conserve the walrus population due to changes in sea ice conditions and due to the occurrence of juvenile deaths (e.g., because of stampedes at haulout sites); as expressed by some participants, the extent to which future generations of walrus will be able to adapt to the "new norm" created by the rapidly changing conditions in Alaska remains an open question.

Stressors to walrus

Changes in the quantity and quality of sea ice is the major factor contributing to the decline in subsistence harvest of walrus, but there are many other factors that also play important roles. These other contributing factors, discussed at some length by workshop participants, include the following:

- <u>ice cover</u>: participants were unanimous in reporting significant changes to ice cover in recent decades and have observed numerous related negative effects on walrus. As observed in many locations – incuding Togiak, Savoonga, Point Lay, Barrow, and Little Diomede – the ocean is freezing later and thawing earlier in the year, with ice now often far off the land and no longer freezing all the way to shore. The quality of the ice also is changing, becoming thinner and more brittle than in the past. As a result, walrus are migrating north earlier in the season (with the retreating ice) and the ice pack is no longer reliable for hunters to access walrus or to safely travel between coastal villages.

- shipping: this includes a variety of sources including oil industry ships of varying size, large cruise ships, barges and other commercial vessels, and recreational boats. Participants reported that the volume of shipping has increased greatly in recent years, with (for example) more than 700 vessels now passing by St. Lawrence Island in the course of one year. Numbers of commercial vessels are expected to increase over time, as the Arctic Ocean quickly moves to an ice-free state. A marked increase in the number of exploration and research vessels, all along the coast of Alaska, also was noted by participants. The hunters reported that ships interfere with walrus in many ways that include blocking of important migration routes, scaring walrus off the ice, and scaring walrus away from traditional feeding areas. Several participants expressed their concern, particularly in light of increased numbers of ships using coastal waters, that the rules and regulations now placed on vessel locations and activities are often not followed in practice.
- noise: a variety of sources are responsible for greatly increased noise levels, which adversely affect walrus and their ability to communicate among the different members of the herd. Noise sources include the ongoing (as one participant said, “24/7”) community-based sounds from snowmobiles or generators and the intermittent sounds of seismic exploration or passing vessels. Participants characterized walrus as highly social and caring animals, which means that high levels of noise are particularly disruptive and significant. Many participants noted that walrus are now choosing different haulout sites, in part due to the increased noise and disruption at previously used sites. For example, in some areas noise from vessels (principally fishing boats, barge traffic, and cruise ships) has encouraged walrus to redistribute themselves in smaller numbers at coastal haulouts as opposed to congregating in larger numbers as they previously have done.
- fisheries: several different sources of adverse impacts to walrus from fisheries were noted, including effects reported from both commercial and sport boats. The worst offenders were said to be the large trawlers that drag the ocean bottoms using heavy nets, in part because they routinely come into areas occupied by walrus and

operate closer to shore (e.g., less than 2 miles out in areas such as Bristol Bay) than allowed by regulations. This is believed to greatly disturb the substrate used by clams and other primary foods eaten by walrus and may diminish food sources if clams are caught as by-catch. Participants also noted that walrus are moving away from some of these areas (e.g., Round Island) and instead are using beach areas to avoid the interference from trawlers.

- air traffic: airplanes and helicopters flying above walrus haulouts can cause stampedes that injure or kill walrus, particularly juveniles. Planes flying above walrus on ice can disrupt walrus breeding, birthing, or feeding behaviors. Participants noted that several communities have made recommendations stating minimum heights for air traffic and locations where flyovers are not permitted, in an attempt to reduce these negative effects. For example, the Native Village of Point Lay has been working with the Service and the Federal Aviation Administration to develop guidelines for flights near their walrus haulout.
- warmer and more acidic waters: several participants expressed concern over potential problems associated with warmer and more acidic ocean waters (in addition to sea ice reductions). These include possible interference with walrus' migration patterns, reduced or relocated aquatic life that serves as food sources for walrus, and added physiological stress on walrus. The effects of ocean acidification on clams (and the integrity of their shells) was noted as a particular concern in light of the importance of clams to walrus' diets. Also noted were issues associated with changes in warm-water predator types and numbers, including recent increases in sightings of Orca whales and sharks.
- pollution: participants expressed concerns over potential adverse impacts on walrus from various sources of pollution that include routine emissions of oil from vessels, bilge and ballast emissions of water from vessels (with possible connections to invasive species), and accidental spills of petroleum-based projects. Participants also noted pollution in the form of trash and debris, including increases in ocean-borne refuse such as gas cans and water bottles. Several hunters also spoke about

their fears of increased radiation levels in the ocean after the tsunami in Japan. Community members from St. Lawrence Island noted that after large ships pass by they routinely notice increased amounts of trash and debris along their beaches and in the water. Several participants also expressed concern about an "unusual mortality event" (UME) that affected walrus in the recent past, resulting in walrus appearing to be sick and having lesions on their skin. The hunters' concern stems from uncertainty over what caused the event -- noting that it may have been from pollution, an oil spill, or a disease – and the related uncertainty over whether it might happen again.

- storm surges and wind: walrus at several haulouts near to coastal communities, already affected by rising sea levels, are at increased risk due to increased storm surges. This is of particular concern for juvenile and older walrus. Hunters noted that higher and more persistent winds have adversely influenced ice and harvest conditions at many sites; in some communities (e.g., Kwigillingok) hunters report that the wind direction has shifted, resulting in warmer temperatures.

Hunting

Subsistence hunting was not perceived by participants to be a significant source of stress to the size or health of walrus populations. Subsistence harvesting of walrus by Native community members has always been both difficult and dangerous, which has served to keep harvest levels by Alaska's subsistence hunters relatively low. Workshop participants reported that, in recent years, both US and Russian harvests of walrus are lower than they were two or three decades ago [10]and that, compared to the impacts of climate change, the influence of subsistence harvests – which have been occurring for many generations and are legally permitted under the Marine Mammals Protection Act – is negligible.

Many participants spoke eloquently about the essential connection between subsistence hunting of walrus and the identity and traditions of Alaskan Natives, respectfully reminding the

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[10] For example, annual US harvests in recent years are approximately 1300 - 2500 walrus, as compared to annual harvest levels 2-3 times higher 25-30 years ago.

Service staff in attendance that they would continue to hunt walrus – with or without the permission of US government agencies – because of the central place of walrus in their culture. Participants also noted that it was unfair to blame Native communities, who generally have been very concerned with long-term stewardship of marine mammals, for declines in ecosystem conditions and/or walrus populations caused by climate change: Alaska's Native communities should not be asked to take on the burden of conservation initiatives (e.g., through reductions in subsistence harvest levels) just because they are an "easy target" for regulators when the real source of the problem is the continuing emission of an excess of greenhouse gases by the non-Alaska, non-Native citizens of the industrialized world. Participants also noted that any suspension of subsistence activities would deprive community members of a major food source and an important part of their livelihood; effects would include reductions in the ability of elders to pass on essential cultural traditions to younger members of the community.

Food

The main food sources of walrus were said to be the same but many participants noted changes in their availability. In the past, for example, when sea ice generally was routinely deep, the ice sheet would get hung up on the ocean floor and walrus would feed as the ice dragged along the bottom. Today food is often more difficult to find. One example is that when walrus congregate at a mega-haulout (i.e., a haulout with thousands or tens of thousands of walrus) and want to feed in that area (e.g., at Point Lay), then some of the favorite feeding areas (e.g., Hannah Shoal) are a long way away – as a result, walrus are swimming farther to feed when they should be resting in order to have the energy to make their fall migration.

Feeding areas

Participants emphasized the importance of protecting the main feeding areas used by walrus. These areas have been used by walrus every year since time immemorial, yet participants stated that oil companies and fishing trawlers routinely are given permission to enter these areas and to destroy or alter the habitat as a result of dredging and exploration activities, many of which involve ongoing or intermittent loud noises, Some recent progress was noted (e.g., Shell Oil's donation to the Nature Conservancy of its offshore exploration rights in Lancaster Sound) but many participants – in light of recent and predicted future increases in vessel traffic -- remain concerned that high-quality feeding areas are unprotected and remain at risk. A particular concern is the status of outer continental shelf lease sales, which lead to exploration and can result in the development of off-shore oil production and a range of related activities that negatively impact walrus.

Haulouts

Several discussions noted the critical importance of reducing disturbances to walrus at haulout sites. Walrus were characterized as highly social animals who congregate in large numbers at haulout sites on land, but hunters routinely observe a heightened level of nervousness due to human activity and related disturbances, which is believed to take energy from walruses at times when they should be storing up for the winter and for migrations.

Community management

Representatives from the Native Alaska communities reported that they have initiated ways to reduce impacts on walrus through proactive community management plans. These include reducing disturbances at haulouts and by limiting the number of harvest trips; residents of Gambell, for example, have adopted a "marine mammal ordinance" that establishes trip limits and describes proper harvesting of walrus. These activities were both recognized and applauded by the attending Service employees. As discussed at the workshop, the village of Pt Lay is one of the leading communities for establishment of management plans to protect the local walrus population (including the use of video cameras to document walrus behavior); several other communities, including Gambell and Savoonga, also have implemented new management initiatives.

Walrus mortality

Even without the introduction of subsistence hunting, walrus deaths from various natural sources will continue. One important source is trampling in response to disturbances, which will happen in some cases even if a community management plan is in place. Other sources of walrus mortality include occasional collisions with vessels and attacks from predators (e.g., polar bears and orcas); several participants noted that predators observed near to their communities are generally left alone by community members because this is their natural environment. Participants at some locations also reported occasional increases in walrus mortality resulting from an increased number of sick and underweight walrus, perhaps related to stress; evidence includes observations of a reduction in the thickness of the blubber layer.

Lack of predictability

One of the most mentioned, and most severe, consequences of climate change is a marked decrease in the predictability of seasonal events. Events whose timing has stayed much the same for hundreds or thousands of years are reported to have changed dramatically over only the very short period of the past 10–20 years. These include the earlier retreat of ice in the spring and later arrival of ice in the fall, changes in the timing of walrus migrations (generally earlier), the more unpredictable timing of large fish runs near to communities, and the more frequent occurrence of high winds, large waves, and other adverse weather events. Several participants spoke to the large influence of unpredictable weather on their daily lives and on hunting, in that the more abrupt changes in weather now experienced over the course of a day or week make it far more dangerous (and sometimes impossible) to head out into the ocean in the smaller boats common to Native coastal communities. Climate and weather changes also are influencing the presence and quality of sea ice, with several participants noting that the ice now “disappears all at once” from their coastlines rather than leaving gradually and with other hunters noting that the mix of fresh-water ice, new sea ice, and older pack ice (i.e., thicker and stronger ice associated with floating icebergs) is shifting dramatically, with the generally thinner ice and larger areas of open water resulting in adverse consequences for walrus behavior and for hunter safety.

Future population and harvest estimates

Participants were informed that deciding whether Pacific walrus should be listed as a threatened or endangered species requires that the Service staff make predictions concerning the abundance of Alaska’s walrus populations in the future. Recognizing that this task is challenging and multiple sources of uncertainty are at play, the SSA will make estimates (and document underlying assumptions) of future conditions over four time periods: 2030, 2045, 2065, and 2100. Workshop participants were asked for their insights regarding several key predictions that will influence these estimates of future populations, including harvest levels and sea ice reductions.

In general, workshop members declined to review or edit the predictions of Service staff, citing (a) the multiple facets involved in making such predictions and (b) the newness of current conditions, with a “new world” coming into place over only the past 10-20 years that is replacing the more familiar world known to Alaskan Native communities over the past hundreds of years. As one example, estimates of future walrus harvests were noted as dependent in part on community population levels and in part of the tastes and preferences of community members, so that as community size grows or shrinks and as the diets of community members shift (e.g., from traditional foods such as walrus to newer foods such as hamburgers or chicken) then walrus harvests are likely to increase or decrease, in keeping with the Native subsistence hunters’ code of only harvesting the number of animals that is needed.

Remaining Issues

A number of important cultural, social, health, and lifestyle issues that were raised during the workshop discussions are outside the mandate of the Service and so will not be incorporated directly into the SSA. This does not in any way diminish their importance; rather, testimonies given at the workshop underscore the importance of walrus and subsistence hunting to the way of life followed by Alaska’s coastal native communities over hundreds and thousands of years. Some of these issues are now being more fully documented as part of initiatives sponsored by Alaskan Native communities or as part of the activities undertaken by Tribal, government, or academic sponsors.

In addition, there exist several topics related to the future health of walrus populations that are not currently understood by Western scientists and that, over time, may become better understood as the result of insights and contributions from Native knowledge holders as well as from new field studies and models. These include three important questions related to the behavior and adaptability of walrus over time.

- A first set of questions relates to the ability of walrus to adapt to changing ice conditions during several critical periods of their lives, including birthing and breeding. Workshop participants agreed that at present the walrus population continues to appear healthy, and they generally felt that walrus would continue to make the adjustments required by reductions in sea ice (e.g., by birthing on the land). However, it is recognized that if walrus need to expend more energy during critical times of their lives (e.g., because of needing to swim farther) or if the close bond between mothers and calves is compromised (e.g., by mothers needing to leave calves alone for longer periods in order to obtain sufficient food), then the health of walrus could decline.
- A second set of questions relates to walrus' behavior at haulouts and whether, in the face of reductions in sea ice quantity and quality, walrus will continue to congregate on land in large numbers at a small set of haulout sites or whether they may begin to haulout in smaller groups at a larger number of coastal sites.
- A third set of questions relates to whether walrus will, in general, continue to migrate (albeit with important differences in seasonality) between their familiar sites in the Bering and Chukchi seas or whether a large portion of the Alaskan walrus population might begin to either migrate west (to Russia) for a longer period of time or migrate east, to the Canadian Arctic and perhaps beyond, in the direction of Greenland.

Each of these topics holds important implications for the management of Pacific walrus and has the potential to influence the listing determination assessment. However, in these and other areas where scientists' uncertainty is high and, therefore, confidence in their own predictions tends to be low, the insights and understanding of subsistence walrus hunters is very important. The more structured conversations at the June TEK workshop are viewed as the next step in a long-term series of dialogues between the Service (and other federal or state management agencies) and knowledge holders or tribal governments representing Alaska's Native populations.

Several other topic areas were highlighted by workshop participants as part of an open-ended "question and answer" session that, on Day 1, listed topic areas needing further clarification from Service scientists. On Day 2, the topics were examined as part of interactive discussions among workshop participants and Service staff. These topics for further investigation included the following issues:

- the current (baseline) size of the walrus population in Alaskan and Russian waters, with the current best estimate of 129,000 animals (with a distribution of between 50,000 and 500,00 animals) based on a 2006 aerial survey that, from the standpoint of workshop participants, shows unacceptably wide confidence intervals. Service scientists noted that a new, 5-year genetic mark-recapture study of population size is now underway, with preliminary results likely to be available within 6–9 months.
- the size of annual harvests, in both Russia and the U.S. (this information was made available to participants, using a graph showing "total annual removal" of Pacific walrus, 1960–2014).
- the lack of information about ocean pollution coming from Russian sources and from both bilge and ballast water releases from vessels.
- the current location of walrus' primary breeding and birthing areas, based on information obtained by Service scientists
- the status of bans in several states on the sale or distribution of walrus ivory from tusks, which can have a detrimental effect on the economies of some coastal Alaska Native communities.
- the status of current and future co-management efforts, including shared Service – Alaska Natives work undertaken by the Eskimo Walrus Commission and several local communities (e.g., cooperative harvest and haulout monitoring), and the status of ongoing government-to-government resource consultations.

As part of an open discussion at the end of this Day 2 workshop session participants were reminded that the Species Status Assessment process, begun in 2015, is ongoing and no determinations have yet been made. The implications of the work completed to date will be summarized and submitted for peer review, then presented to a Service management team that will decide whether listing of Pacific walrus is either not warranted or warranted and in line for a proposed rule (which, after public comment, will result either in a decision not to list or a final rule). As discussed at the workshop, if Pacific walrus are listed then the FWS will develop a species recovery plan, propose areas of critical habitat, and be empowered to put in place additional management activities designed to ensure conservation of the species.

Conclusion

Differences of opinion are not uncommon in the context of ESA listing decisions. These differences can reflect variations in the importance assigned to the multiple values associated with a species, differences in the confidence given to the available information (e.g., as a result of biological uncertainty), or differences in how risks to the population are interpreted by the various stakeholders (Gregory et al. 2012). In 2011 the Service reviewed the information available at the time and concluded that listing the Pacific walrus as a threatened or endangered species was warranted but precluded by higher priority actions.

The Service is now undertaking an updated and more comprehensive review of the best available information. The TEK workshop summarized in this report, which included 20 Alaskan Native subsistence resource users from 15 coastal communities, provides important contributions to the current listing determination review. Although each participant holds unique knowledge and understanding, the prevailing view of the Alaskan Native subsistence participants at the workshop is that walrus populations remain generally healthy and with no significant change to date in walrus' abundance. Nevertheless, participants are worried that, looking ahead to future decades, it may be difficult for walrus to maintain their current population levels due to changes in sea ice conditions (stemming from climate change) and the occurrence of juvenile deaths (e.g., as the result of stampedes at haulout sites); the concern is whether walrus will continue to successfully adapt to the "new norm" created by rapidly changing conditions in coastal Alaska.

Participants emphasized the fundamental importance of walrus to their traditional way of life and to the identity and health of coastal Native communities in Alaska. Walruses are seen as social and curious creatures with whom Native communities have had a relationship based on respect over many centuries. Although harvests have been reduced in many locations over the past 10–20 years, this is not viewed as the result of changes in walrus' abundance but rather caused by changes in hunters' access to walrus that principally stem from sea ice reductions, increased inclement weather, changes to migration patterns due to shipping and noise, and changes in haulout size or location.

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Appendix C1: June, 2016 Pacific walrus TEK workshop participants

Community representatives

Raymond Seetook	Wales
Delbert Pungowiyi	Savoonga
Roy Waghiyi	Savoonga
Preston Rookok	Savoonga
Marie Tracey	Pt Lay
William Tracey	Pt Lay
Moses Toyukak	Manokotak
Albert Williams	Mekoryuk
Thomas Dock	Togiak
Deahl Katchatag	Unalakleet
Ahna Ozenna	Little Diomede
Willie Atti	Kwigillingok
Gayla Hoseth	Dillingham
Terry Tagarook	Wainwright
Michael James	Gambell
Melvin Apassingok	Gambell
Merlin Koonooka	Gambell
Frank Woods	Dillingham
Qaiyaan Harcharek	Barrow
Oral Hawley	Kivalina

US Fish and Wildlife Service

Jonathan Snyder	Anchorage
Mary Colligan	Anchorage
James MacCracken	Anchorage
Drew Crane	Anchorage
Joel Garlich-Miller	Anchorage
Caitlin Snyder	Washington DC
Jenifer Kohout	Anchorage

Attendees: Bottom row (left to right): Nichole Kaechele, Roy Waghiyi, Delbert Pungowiyi, Qaiyaan Harcharek, Willi Atti, Marie Tracey, and Thomas Dock;
Second row (left to right): Gayla Hoseth, Melvin Apassingok, Merlin Koonooka, Oral Hawley, Moses Toyukak , and Ahna Ozeena;
Third row (left to right): Christian Beaudrie, Jim MacCracken, Jenifer Kohout, Caitlyn Snyder, Mary Colligan, Drew Crane, and Robin Gregory;
Fourth row (left to right): Bill Tracey, Albert Williams, Frank Woods, Jonathan Snyder, and Preston Rookok.

9.4 Appendix D. Pacific Walrus Vital Rates Estimates

Table D1. Estimates of Pacific walrus vital rates by sex and age and the source of estimates.

Sex	Age	Reproductive rate	Survival	Recruitment	Maximum sustained yield (%N)	Age of first reproduction	r_{max} or λ	Percent pregnant	Calf:cow ratio	Reference
N/S[a]	Breeding			6.3-9.0%						Fay (1982, p. 260)
both	calves		0.90-0.95							Fay (1982, p. 260)
N/S	1-2 yr		0.80							Fay (1982, p. 261)
N/S	3-7 yr		0.90							Fay (1982, p. 261)
female	0-7 yr			40-50%						Fay (1982, p. 261)
males	0-15 yr		< ♀	10-20%						Fay (1982, p. 261)
female	N/A					4-9				Fay (1982, p. 182)
female	4-30							50-100	0.3	Fay (1982, pp. 211, 212)
female	0	0	0.94							Demaster (1984, p.78)
female	1	0	0.90							Demaster (1984, p.78)
female	2	0	0.96							Demaster (1984, p.78)
female	3	0	0.96							Demaster (1984, p.78)
female	4	0	0.96			5				Demaster (1984, p.78)
Female	5	0.10	0.96							Demaster (1984, p.78)

Table D1. Continued.

female	6	0.12	0.96		2-5					Demaster (1984, pp.78-79)
female	7	0.17	0.96		2-5					Demaster (1984, pp.78-79)
female	8-24	0.22	0.96		2-5					Demaster (1984, pp.78-79)
female	24-29	0.15	0.96		2-5					Demaster (1984, pp.78-79)
N/S	calves		0.20-0.80						0.15-0.40	Fay et al. (1989, p. 7)
female	N/A					8-10[d]		62-100		Fay et al. (1989, p. 7)
female	1 yr		0.66							Chivers et al. (1999, p. 241)
female	2-8 yr		0.83-0.97	45-61%		3-4	0.02-0.08			Chivers et al. (1999, pp. 240-243)
female	9-40 yr	0.60	0.0-0.98					20-36		Chivers et al. (1999, pp. 240, 242)
female	All, when @ K		0.87							Chivers et al. (1999, p. 240)
	?		0.97							Gilbert and Udevitz (1997)
N/S	all	0.50 maximum					0.07			Fay et al. (1997, pp.543-546)
N/S	0-2 yr		0.80-0.90[b]							Fay et al. (1997, p. 550)
both	calves		0.50-0.95							Fay et al. (1997, p. 550)
Female	juvenile		0.98							Fay et al. (1997, p. 550)

Table D1. Continued.

female	adult	0.20	0.98	6-9				Fay et al. (1997, pp. 555, 556)
female	5	0						Fay et al. (1997, p. 555)
Female	6	0-0.05[b]						Fay et al. (1997, p. 555)
female	7-9[c]	0.02-0.38						Fay et al. (1997, p. 555)
female	10-12	0.12-0.45						Fay et al. (1997, p. 555)
female	13-24	0.15-0.43						Fay et al. (1997, p. 555)
female	25-28	0.10-0.24						Fay et al. (1997, p. 555)
female	29-30	0.04-0.10						Fay et al. (1997, p. 555)
female	5-35					40-100		Garlich-Miller et al. (2006, p. 890)
female	N/S			4-6[e]				Garlich-Miller et al. (2006, p. 893)
female	all						0.57-0.73	Garlich-Miller et al. (2006, p. 889)
female	all				1.01[f]			Udevitz et al. (2013, p. 295)
female	calves ≤3 mo		0.2-0.8[g]					Taylor and Udevitz (2015, p. 239)
Female	calves >3 mo		0.5-0.8[g]					Taylor and Udevitz (2015, p. 239)
female	juveniles		0.9[g]					Taylor and Udevitz (2015, p. 239)

Table D1. Continued.

female	adults 6-29 yr	0.05-0.17[g]	0.95-0.99[g]			Taylor and Udevitz (2015, pp. 239-240)
female	adults ≥ 30 yr		0.50-0.60[g]			Taylor and Udevitz (2015, p. 239)
female	calves 0-3 mo		0.21-0.72[h]			Taylor and Udevitz (2015, p. 245)
female	calves >3 mo		0.31-0.95[h]			Taylor and Udevitz (2015, p. 245)
female	juveniles		0.94-0.99[h]			Taylor and Udevitz (2015, p. 245)
female	adults 6-29 yr	0.05-0.13[h]	0.97-0.99[h]			Taylor and Udevitz (2015, p. 245)
female	all	0.06-0.13[i]		0.92-1.00		Taylor and Udevitz (2015, p. 248)
female	all		0.99[i]	0.92-1.00		M.S. Udevitz 2016, USGS, pers. comm.
female	juveniles		0.90[i]			M.S. Udevitz 2016, USGS, pers. comm.
female	calves >3 mo		0.57-0.76[i]			M.S. Udevitz 2016, USGS, pers. comm.
female	all				0.41-0.87[j]	MacCracken et al. (2014
female	all				0.05-0.44	Fay et al. (1997, pp. 550, 552)
	all				0.03-0.17	Citta et al. (2014, p. 33)

Table D1. Continued.

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[a] Not specified.

[b] Lower and upper estimates are for periods when the population was at or exceeded the carrying capacity (K) of the environment, or below K, respectively.

[c] Age classes lumped based on minimal changes in estimates for those age classes.

[d] Age at which the cumulative frequency across younger age classes was > 50%.

[e] Lower and upper estimates are for periods when the population was below carrying capacity (K) of the environment, and at or exceeded K, respectively.

[f] based on density-independent, stable assumptions in the model.

[g] priors in a Bayesian analysis; range based on literature values.

[h] posterior 95% credible interval from a Bayesian analysis.

[i] posterior median from an updated Bayesian analysis.

[j] from harvest records from St. Lawrence Island 1960–2011.

9.5 Appendix E. Summary of Ocean Acidification Research

Effects of Ocean Acidification on Bivalves

We found 31 studies that have examined the response of bivalves to OA, often combined with warming and other environmental stressors (Table OA1). The majority were conducted on mussels (*Atrina* sp., *Unio* sp., *Mytellis* spp.) and oysters (*Crassostera* sp., *Saccostrea* sp., *Pinctada* sp., *Ostrea* sp. *Saccostrea* sp.). Scallops (*Agropecten* sp., *Amusium* sp.), a barnacle (*Semibalanus balanoides*) and four clams (*Macoma balthica*, *M. calcarea*, *Laternula elliptica*, *Ruditapes decussatus*) were the species in the others studies. *Mytellis* spp. is widespread, but generally inhabits rocky, tidally influenced shorelines. However, they also use algae as an attachment substrate (Feder et al. 2003, p. 391). *Macoma balthica* occurs in the eastern North Pacific Ocean (Colen et al. 2016, p. 2) and *M. calcera* in the North Atlantic Ocean. Several other species of *Macoma* occur in the Bering Sea (Weems et al. 2012, p. 32) and Chukchi Sea (Sirenko and Gagaev 2007, p. 360) and are eaten by walruses (Sheffield and Grebmeier 2009, p. 777).

Results of studies on bivalves are mixed and vary by species, response variables considered (survival, growth, development, respiration, biomineralization, etc.) the physical constituents of the OA process studied ($p\mathrm{CO}_2$, pH, and/or $\mathrm{CACO}_3\ \Omega$), life stages (embryo, larva, adult, etc.), environmental setting, exposure history, etc. Several studies reported abnormalities in shell shape, growth, chemical composition, and crystalline structure (Kurihara et al. 2008, p. 225; Sanford et al. 2013, p. 1; Fitzer et al. 2014, p. 6218; Frieder et al. 2014, p. 754; Fitzer et al. 2015, p. 4875; Waldbusser et al. 2015a, p. 273; Waldbusser et al. 2015b; Fitzer et al. 2016, p. 21076; Lagos et al. 2016, p. 357; Ventura et al. 2016, p. 23728), but others found that shells developed normally or there was little effect (Ventura et al. 2016, p. 23728; Li et al. 2016, p. 18943; Prado et al. 2016, p. 189). Most studies found that OA increased metabolic rates (Cummings et al. 2011, p. 1; Waldbusser et al. 2015b; Li et al. 2016, p. 18943), but this increased cost could be offset by greater amounts of food (Thomsen et al. 2013, p. 1017; Kroeker at al. 2016, p. 177; Ramajo et al. 2016, p. 2025). The survival of larval bivalves in the pelagic state was reduced due to OA (Colen et al. 2012, p. 1; Ventura et al. 2016, 23728), but Prado et al. (2016, p. 189) reported increased survival rates.

Because *Macoma* spp. and *Mytilus* spp. are more closely related to food items found in walrus stomachs than the other bivalve species studied (Sheffield and Grebmeier 2009, p. 777) we focus on those studies here. *Macoma balthica* were exposed to three pH treatments (8.1 [control], 7.8 and 7.5) and monitored for fertilization rates, embryonic development, shell characteristics, hatching success, larval growth, mortality, metamorphosis rate, and age at metamorphosis (Colen et al. 2012, pp. 2–4). Fertilization success, embryonic development, hatching success, shell size, larval shell length, and larval growth and survival were reduced at the lower pH levels compared to controls in a linear fashion (Colen et al. 2012, p. 4). There was no effect of decreased pH on metamorphosis rates, but larvae underwent metamorphosis at a smaller size and later in the development process. Colen et al. (2012, p. 5) concluded that the declines in growth and survival, and delayed metamorphosis could lead to a population decline. Vihtakari et al. (2016, p. 1) exposed the earliest life stages of *Macoma calcera* to two pCO_2 treatments (380 [control] and 1000 [end of century] ppm) and measured sperm activity and longevity, and fertilization success. Only sperm swimming speed was affected by high pCO_2 and they noted that individual variation was great suggesting that natural selection may lead to adaptation to near-future OA if sperm traits are heritable.

Sheffield and Grebmeier (2009, p. 777) found the remains of *Mytilus* sp. in walrus stomachs from both the Bering and Chukchi seas in relatively small amounts. Because of their widespread distribution and commercial importance many studies used *Mytilus* spp. as a model organism. In general, OA results in abnormal *Mytilus* spp. shell growth, size, and structure (Fitzer et al. 2014, p. 6218; Fitzer et al. 2016, p. 21076; Ventura et al. 2016, p. 23728; Waldbusser et al. 2015a, p. 273, Waldbusser et al. 2015b, p. 1), but not always (Ventura et al. 2016, p.23728). Abundant food counteracts the effects of increased metabolism required to compensate for lower Ω_A due to OA (Thomsen et al. 2013, p. 1017; Fitzer et al. 2015, p. 4875; Kroeker et al. 2016, p. 771; Ventura et al. 2016, 23728), but not for all species (Clements 2016, p. 2). Environmental heterogeneity appears to play a large role in the effects of OA on *Mytilus californicus* as populations in variable environments that are frequently exposed to low pH seawater and abundant food are more resistant (Kroeker et al. 2016, p. 771) and may have a greater capacity to adapt to changes as has been suggested for many calcifying species (Byrne 2011, p. 24; Gaylord et al. 2015, p. 21; Riebesell and Gattuso 2015, p. 13; Ramajo et al. 2016, p. 3).

Effects of Ocean Acidification on Gastropods

Gastropods (primarily snails of four genera) were found in the stomachs of Pacific walruses by Sheffield and Grebmeier (2009, p. 767) in samples from both the Bering and Chukchi seas. Snails were the most frequent items in both male and female samples from the Chukchi Sea but more prominent in female than male stomachs from the Bering Sea (Sheffield and Grebmeier 2009, p. 768).

We found 12 studies that examined the effects of OA on 13 different species of gastropods (Table OA1). Due to their importance in marine ecosystems, widespread distributions, and ease of collection, handling, and housing, six studies were conducted on pteropods (*Limacina* spp.; Bednaršek et al. 2012, p. 881; Lishka and Riebesell 2012, p. 3517; Bednaršek et al. 2014, p. 1; Peck et al. 2016, p. 14; Manno et al. 2016, p. 1). The effects of OA on pteropods could indirectly affect walruses through changes in marine food webs that could impact benthic productivity or other ecosystem properties. In general, decreased Ω_A or increased pCO_2 resulted in pteropod shell dissolution (Bednaršek et al. 2012, p. 881; Lishka and Riebesell 2012, p. 3517; Bednaršek et al. 2014, p. 1; Peck et al. 2016, p. 14; Lishka and Riebesell 2012, p. 3517) In addition, Manno et al. (2016, p. 1) studied the effect of three pCO_2 levels on *Limacina helicina antarctica* spawning, egg quality, and egg development, finding a decline in the carbon content of eggs, delayed and arrested egg development, and impaired gonad functioning. All authors cited above suggested that OA could have significant negative effects on pteropod populations and marine ecosystems and none speculated about the adaptive capacity of pteropods.

Seven of the 12 studies were conducted on snails of several species, but none were in the genera identified in walrus stomachs by Sheffield and Grebmeier (2009, pp. 767, 777). Because snails are a major food item for walruses, OA effects on snails could have an effect on walruses in terms of declines in prey abundance and declines in prey species diversity.

Most studies on snails examined the effects of OA on shell characteristics (Bibby et al. 2007, p. 669; Hall-Spencer et al. 2008, p. 97; Nienhuis et al. 2010, p. 2553; Macleod and Poluin 2015, p. 137) sometimes in combination with metabolism, abundance, or behavior. Decreased pH or increased $p\mathrm{CO}_2$ decreased shell growth, mass, strength, snail abundance, and increased shell abnormalities.

Many marine snails are predators of other invertebrates and are prey for a number of species, including Pacific walruses. Four studies of OA effects on snails examined predatory behaviors and antipredator responses (Bibby et al. 2007, p. 699; Watson et al. 2013, p. 1; Manríquez et al. 2014; Jellison et al. 2016, p. 1), finding that OA decreased the frequency or intensity of most antipredator behaviors. The above studies concluded that OA will have negative effects on shell formation and integrity making gastropods more susceptible to predator attacks or physical damage, as well as reduce the ability of snails to undertake some antipredator behaviors which may alter community dynamics. The adaptive capacity of the species studied was largely unknown but several authors noted that the variation in responses among individuals could be indicative of adaptive genetic variation which may be strongly selected for under future ocean conditions (Hall- Spencer et al. 2008, p. 97; Watson et al. 2013, p. 1; Jellison et al. 2016, p. 1).

Effects of Ocean Acidification on Polycheates

In general, marine worms were the third most frequent items found in walrus stomachs (Sheffield and Grebmeier (2009, p. 777); most are soft bodied and not affected by OA through declines in $\mathrm{CACO}^3\ \Omega$, but OA may nonetheless impact survival, reproduction, metabolism, abundance, etc. (Widdicombe and Needham 2007, p. 111; Calosi et al. 2012, p. 1; Gambi et al. 2016, p.1) and some polycheates are calcifiers (Lucey et al. 2016, pp. 1–2). Sheffield and Grebmeier (2009, p. 777) listed 11 genera of polychaetes from walrus stomachs from both the Bering and Chukchi seas.

Polychaetes are a popular model organism for studying the toxic effects of various pollutants in marine ecosystems (Lewis and Watson 2012, p. 11), and we found 11 studies on the effects of OA on polychaetes (Table OA1). None involved the genera listed by Sheffield and Grebmeier (2009, p. 777) and most studies took advantage of a natural seawater pH gradient generated by volcanic CO_2 vents near an island off the coast of Italy (Calosi et al. 2012, p. 1; Turner et al. 2015, p. 2148; Gambi et al. 2016, p. 1; Lucey et al. 2016, pp. 1–2). Three studies looked at the combined effects of OA and warming or copper pollution (Chakravarti et al. 2016, p. 1; Campbell et al. 2014, p. 9745; Lewis et al. 2103, p. 2089). Response variables in polychaete studies typically included survival, reproduction, metabolism, and growth and most studies focused on one or two species. However, Gambi et al. (2016, p. 1) examined polychaete community structure that included over 80 species.

Many of the species studied inhabited shallow, tidally-influenced areas that naturally experience wide fluctuations in pH and were assumed to be tolerant of OA conditions predicted for the future (Calosi et al. 2012, p. 1; Chakravarti et al. 2016, p. 1; Freitas et al. 2016, p. 152, etc.). In some cases, adaptation to OA effects were confirmed (Calosi et al. 2012, p. 1; Chakravarti et al. 2016, p. 1; Gambi et al. 2016, p. 1; Rodríguez-Romero et al. 2016, p. 1) but not in others (Lucey et al. 2016, pp. 1–2; Chakravarti et al. 2016, p. 1; Gambi et al. 2016, p.1). Gambi et al. (2016, p.1) identified several species that would likely decline under OA conditions, but also some that would likely persist, consistent with the notion that OA will result in winners and losers in an acidified ocean; they noted that relatively few of the species they studied would be categorized as winners.

The three studies that examined OA in combination with either warming or copper pollution reported mixed results. Chakravarti et al. (2016, p. 1) found negative effects of warming and OA, but no additive or synergistic effect of the two, and they also found that those effects were alleviated in subsequent generations. Lewis et al. (2103, p. 2089) reported that both fertilization and larval survival declined with pH, but only survival was also affected by copper toxicity. In contrast, Campbell et al. (2014, p. 9745) found both additive and synergistic effects of OA and copper toxicity, resulting in increased sperm DNA damage, and decreased fertilization and larval survival.

The effects of OA on polychaetes vary with species, environmental setting, the history of exposure to OA conditions (low pH, high $p\mathrm{CO}_2$, low Ω_A), and likely other factors. Transplant and trans-generational experiments suggest that many species are tolerant of OA conditions or have the ability to adapt to those conditions within three or more generations. As noted above, none of the studies on polychaetes to date have examined the genera that Pacific walruses typically feed on, and the effects of OA on those species are unknown.

Table E1. Summary of ocean acidification studies on bivalves, gastropods, and polychaetes.

Taxon	Study area or specimen source	Study setting, etc.	Explanatory variable(s)	Response variable(s)	Effect[a]	Reference
Bivalves						
Atrina pectinate, *Mytilus edulis,* *Hinnites gigantean,* *Unio pictorum,* *Mercenaria mercenaria,* *Tridacna gigas,* *Actica islandica*	China, UK, Canada, UK, UK, AU, UK	Laboratory, Calcite vs. aragonite in shell dissolution	pH	CACO$_3$ structures, Mass, Mg:Ca, Organic content	Varied by species ↓ all species Varied by species Varied by CACO$_3$ structures	Harper 2000
Mytilus galloprovincialis	Japan	Laboratory	pCO$_2$	Embryogenesis, Shell development, Shell height, Shell length	Delayed Abnormal ↓ ↓	Kurihara et al. 2008
Mercenaria mercenaria, *Argopecten irradians* (Arir), *Crassostrea virginica* (Crvi)	NY	Laboratory	pCO$_2$	Larval survival, Metamorphosis, Larval size	↓ for Meme &, Arir, ≈ Crvi Delayed for all species ↓ for all species	Talmage et al. 2009
Mytilus edulis	Baltic Sea	Laboratory	pCO$_2$	Shell length, Shell mass, Shell AFDM O$_2$ consumption, Ammonium excreta, O:N, Energy loss	↓ ↓ ≈ ∩ ↑ ∩ ↑	Thomsen & Melzner 2010

Table E1. Continued.

Ruditapes decussatus	Portugal	Laboratory	pH, Algae	Shell length, Shell width, Live mass, Condition index, Mortality	≈ ≈ ≈ ≈ ↑	Range et al. 2010
Semiblanus balanoides	UK	Model	Temperature (T), pH	Abundance	pH ≈, T↓, pH*T ↓	Findlay et al. 2010
Laternula elliptica	Antarctica	Laboratory	pH	O$_2$ consumption, Heat shock protein, Chitin synthate, Condition indices	U ∩ ↓ ↑	Cummings et al. 2011
Saccostrea glomerata	AU	Laboratory, Carry-over effects on larvae	pCO$_2$, Wild (W), selectively bred (B), & conditioned larvae (C)	Growth, Development rate, Shell length Survival, Metabolism	W↓, B↓, C↑ W↓, B↓, C↑ W↓, B↓, C≈ W↓, B↓, C≈ W↓, B↑, C (nd)	Parker et al. 2011
Macoma balthica	Netherlands	Laboratory	pH	Fertilization rate, Embryo development, Larval development, Larval survival Larval metamorphosis	↓ ↓ ↓ ↓≈	Van Colen et al. 2012
Mytilus edulis	Baltic Sea	Field (F) & Laboratory (L)	pCO$_2$ (p), Food amount (a)	Growth, Calcification	F:a↑, p↑; L: a↑,p≈ F:a↑, p↑; L: a↑,p≈	Thomsen et al. 2012

*Table E1.*Continued.

Mytilus galloprovincialis	Spain	Laboratory	pH, Temperature (T)	Sperm activity, Larval size, Larval survival, Larval respiration, Larval calcification	pH↓, T nd pH≈, T↓ pH≈, T↓ pH≈, T↑ pH≈, T↑	Vihtakari et al. 2013
Mytilus californianus (Myca) *Mytilus galloprovincialis* (Myga)	California	Laboratory	pH, O_2, pH flux	Larval survival, Larval development Larval shell size	≈ both spp, all treatments pH↓, O_2 ≈, pH flux ≈ pH↓, O_2 ≈, pH flux ≈ Myga	Frieder et al. 2014
Ostrea lurida	California	Laboratory, Predation by snails	$p\text{CO}_2$	Drilled shells, Consumption rates, Shell thickness, Shell size	↑ ↑ ≈ ↓	Sanford et al. 2014
Mytilus edulis	UK	Laboratory	$p\text{CO}_2$, Temperature (T)	Carbonic anhydrase rate, Shell growth Shell calcite Shell aragonite, Calcite growth patterns	$p\text{CO}_2\cap$, T≈ $p\text{CO}_2$U, T $p\text{CO}_2$≈ or ↑, T≈ $p\text{CO}_2$↓, T≈ Disorganized	Fitzer et al. 2014
Mytilus galloprovincialis (Myga)	OR	Laboratory	$p\text{CO}_2$, pH,	Shell abnormalities,	$p\text{CO}_2$≈, pH≈, Ω_A↑, $p\text{CO}_2{*}\Omega_A$≈	Waldbusser et al. 2015a
Crassostrea gigas			Ω_A	Shell length	$p\text{CO}_2$↑, Ω_A↓, $p\text{CO}_2{*}\Omega_A$≈	

Table E1. Continued.

Mytilus californianus	OR	Laboratory	$p\mathrm{CO}_2$, pH, Ω_A	Shell abnormalities, Shell length, Respiration, % feeding	$p\mathrm{CO}_2\approx$, $\Omega_A\uparrow$, $p\mathrm{CO}_2*\Omega_A \uparrow$ $p\mathrm{CO}_2\downarrow$, $\Omega_A\downarrow$, $p\mathrm{CO}_2*\Omega_A \downarrow$ $p\mathrm{CO}_2\downarrow$, $\Omega_A\approx$, $p\mathrm{CO}_2*\Omega_A\approx$ $p\mathrm{CO}_2\downarrow$, pH$\uparrow$, $\Omega_A\approx$, $p\mathrm{CO}_2*\Omega_A\approx$	Waldbusser et al. 2015b
Amusium balloti	AU	Expert based vulnerability assessment	pH, CO_2, Ω_c Ω_A	Distribution, Acid-base regulation, Calcification rate, Growth, Survival	↓ Uncertain, ↓ ↓ ↓	Richards et al. 2015
Mytilus edulis	UK	Laboratory	$p\mathrm{CO}_2$, Temperature (T)	Shell growth, Shell Ω_A & Ω_c thickness, Shell thickness index Shell shape	$p\mathrm{CO}_2$ & T $\approx$, $p\mathrm{CO}_2*$ T $\approx$ $p\mathrm{CO}_2$ & T$\downarrow\Omega_A$, $p\mathrm{CO}_2$&T$\approx\Omega_c$ $p\mathrm{CO}_2$ U, T $\approx$ $p\mathrm{CO}_2$ & T $\approx$	Fitzer et al. 2015
Mytilus edulis	UK	Laboratory, Pathogen resistance	pH, Temperature (T)	Haemolymph production, Mortality	pH ↓, T ↑, ph*T ↑ pH ↑, T ≈, ph*T ≈	Ellis et al. 2015

Table E1. Continued.

Saccostrea glomerata	AU	Laboratory, Trans-generational (TG) effects	$p\mathrm{CO}_2$	F1 extracellular pH (pH_e), F1 metabolism (M), F2 survival F2 larval development, F2 abnormal larvae F2 shell length, F2 heart rate	Control (C) ↓, TG ↓ C ↑, TG ≈ C & TG ≈ Delayed, TG>C C ↑, TG ≈ C ↓ & TG ↓ C ↑ & TG ↑	Parker et al. 2015
Mytilus californianus	WA	Field, Ancient and current samples	pH	Shell thickness Mass-length index	↓ from 2420 BP – 1970s ≈ last 10-40 years ≈ last 10-40 years	Pfister et al. 2016
Mytilus galloprovincialis (Myga) *Macoma calcarea* (Maca)	Spain	Laboratory	$p\mathrm{CO}_2$	Sperm speed, Sperm motility, Sperm longevity Fertilization	Myga ↓, Maca ↓ Myga ↓, Maca ≈ Myga ↓, Maca ≈ Myga ↓, Maca ≈	Vihtakari et al. 2016
Mytilus edulis	UK	Laboratory	$p\mathrm{CO}_2$	Amorphous CACO_3 in shell layers, Crystallographic control	↑ ↓	Fitzer et al. 2016
Argopecten purpuratus	Chile	Laboratory, Food effects	pH, Food supply	Mortality, Metabolism, Shell growth, Net calcification, Ingestion, Chitin synthase, Periostracum morphology	pH & food ≈ pH ↑, food ↑ pH ↑, food ↑ pH ↑, food ↑ pH ↑, food ↑ pH ↑, food ↑ pH = thicker, food = composition change	Ramajo et al. 2016

Table E1. Continued.

Crassostrea gigas	China	Laboratory, Immune response	pCO_2	Apotosis, Reactive O_2 production, Antioxidant enzymes, GSH level, mRNA expression	↑ ↑ ↓ ↓ ↓	Wang et al. 2016
Argopecten purpuratus	Chile	Laboratory	pH, Temperature (T)	Mortality Growth, Shell thickness, Shell dry mass, Shell wet mass, Shell dissolution, Calcification	pH & T ≈ pH ↓, T↑ pH ↓, T↓ pH ↓, T↓ pH ↓, T↓ pH ↑, T ≈ pH ≈, T↑	Lagos et al. 2016
Pinctada fucata	China	Laboratory	pH, Temperature (T)	Gene expression, Alkaline phosphate, Calcification, Calcium content, Shell structure Amino acids	pH up-regulated, T few changes pH ↓, T≈ pH ↓, T↑ pH ↓, T↑ pH & T ≈ pH ↑↓, T ≈	Li et al. 2016
Ostrea edulis	Spain	Laboratory, Life Stages, Bacterial growth	pH, Temperature (T)	Spat survival, Spat shell growth Veliger survival, Veliger shell growth Pediveliger survival Umbonate survival Umbonate shell growth Veliger shell length Shell width Bacterial growth	pH ≈, T≈ pH ≈, T≈ pH ↓, T∩ pH ↓, T∩ pH ≈, T↓ pH ≈, T↓ pH ≈, T∩ pH U, T↑ pH ↑, T∩ pH ∩	Prado et al. 2016

Table E1. Continued.

Mytilus edulis	Sweden	Laboratory		Mortality, Growth, Shell abnormalities, Feeding rates Calcification, Shell dissolution	↑ ≈ ↑ ↓ ↓ ↑	Ventura et al. 2016
Mytilus californicus, Nucella canaliculata (predator)	California	Field and laboratory, Environmental gradients	pH, Temperature Food, Predation	hell growth, Predation vulnerability	↑ in variable environments with consistent food ↓ in variable environments with consistent food	Kroeker et al. 2016
Ostrea lurida (Osla) *Crassostrea gigas* (Crgi)	OR	Laboratory, Brooder (Osla) vs. broadcast spawner (Crgi)	$p\text{CO}_2$ (pC), pH (p), Ω_A	Shell shape, Shell length, Calcification rate (Osla vs. Crgi), Lipid content (Osla vs. Crgi)	Osla: pC, p, & Ω_A ≈ Osla: pC↑, p ≈, Ω_A ↓ ↑ ↑	Waldbusser et al. 2016
Gastropods						
Littorina littorea	UK	Laboratory	pH, predator (P)	Shell thickness, O_2 consumption, Avoidance behavior	pH↓, P ↑, pH*P ↑ pH↓, P ↑, pH*P ↓ pH↓, P ↓, pH*P ↑	Bibby et al. 2007
Osilinus turbinate, *Patella caerulea,* *Hexaplex trunculus* *Cerithium vulgatum*	IT	CO_2 vent	pH	Density, Shell dissolution	↓ ↑	Hall- Spencer et al. 2008
Nucella lamellosa	BC	Field and Laboratory	$p\text{CO}_2$	Shell mass, Shell deposition, Shell dissolution	↓ ↓ ↑	Nienhuis et al. 2010

Table E1. Continued.

Limacina helicina	Antarctica	Field and Laboratory	Ω_A	Shell dissolution	↑ as Ω_A ↓	Bednaršek et al. 2012
Limacina helicina, *L. retroversa*	Spitzbergen	Field and Laboratory	$p\text{CO}_2$, warming (w)	Shell dissolution, Shell growth, Juvenile mortality	$p\text{CO}_2$ ↑, w ↑, $p\text{CO}_2$*w ↑ $p\text{CO}_2$ ≈, w ≈, $p\text{CO}_2$*w ≈	Lishka and Riebesell 2012
Gibberulus gibberulus gibbosus	AU	Laboratory	$p\text{CO}_2$	Predator escape behavior	Altered	Watson et al. 2013
Limacina helicina	Antarctica	Laboratory	Ω_A	Shell dissolution	↑	Bednaršek et al. 2014
Concholepas concolepas	Chile	Laboratory	$p\text{CO}_2$	Prey detection, Predator avoidance	≈ ↓ & ↑	Manríquez et al. 2014
Zeacumantus subarinatus	NZ	Laboratory	pH, Trematode infection (t)	Shell growth, Shell length, Shell strength, Shell dissolution	pH ↓, t ↑, pH*t ↓ pH ↓, t ↓, pH*t ≈ pH ↓, t ↓, pH*t ≈ pH ↑, t ↑, pH*t ≈	Macleod & Poluin 2015
Tegula funebralis	CA	Laboratory	pH	Predator avoidance, Refugia use	↓ ↓	Jellison et al. 2016
Limacina helicina antarctica	Antarctica	Laboratory	$p\text{CO}_2$	Spawning, Egg quality, Egg development	↓ ↓ ↓	*Manno et al. 2016*
Limacina helicina	Greenland & Barents Seas	Field and Laboratory	$p\text{CO}_2$	Shell dissolution	↑, repaired sites	Peck et al. 2016

Table E1. Continued.

Polychaetes						
Platynereis dumerlii	Italy	CO_2 vent	$p\text{CO}_2$	Metabolism		Calosi et al. 2012
Amphiglena mediterranea		Tolerant sp.,			≈	
		Sensitive sp.			↑	
Simplaria quasimilitaris	Italy	CO_2 vent	pH	Survival,	↓	Lucey et al. 2016
				Reproduction,	↓	
				Maturation,	↓	
				Population change,	↓	
				Tube growth	≈	
Ophryotrocha labronica	Italy	Laboratory, Trans-generational adaptation	warming (w), pH, warming*pH	Hatching success,	w ↓, pH ≈, w*pH ≈	Chakravarti et al. 2016
				Juvenile growth,	w ≈, pH ≈, w*pH ≈	
				Juvenile survival,	w ↓, pH ≈, w*pH ≈	
				Fecundity,	w ↑, pH ≈, w*pH ≈	
				Egg volume,	w ≈, pH ↓, w*pH ≈	
				Citrate synthase,	w ↑, pH ≈, w*pH ↑	
				Electron transport,	w ↑, pH ≈, w*pH ≈	
				ROS production	w ≈, pH ≈, w*pH ≈	
83 species in 19 families	Italy	CO_2 vent, Community ecology	pH	Abundance,	6 spp.↓, 8 spp. ≈	Gambi et al. 2016
				Distribution,	Changed	
				Species richness,	↓	
				Filter feeders,	↑	
				Herbivores,	↑	
				Sessile spp.,	↓	
				Brooding spp.	↑	
Dipotara neapolitana	Portugal	Laboratory	pH	Tissue regeneration,	↓	Freitas et al. 2016
				Oxidative stress,	↑	
				Protein,	↓	
				Glycogen	↓	

Table E1. Continued.

Sabella spallanzanii	Italy	CO_2 vent, In situ transplants	pH	Metabolism,	↑	Turner et al. 2015
				Metabolite,	↑	
				Carbonic anhydrase,	↓	
				Survival	≈	
Nereis virens	UK	Laboratory	pH	Survival,	≈	Widdicombe and Needham 2007
				Burrow morphology,	≈	
				Nitrate uptake,	↑	
				Ammonium release,	↑	
				Phosphate uptake	↑	
				Nitrite release	↓	
				Silicate release	≈	
Arenicola marina	UK	Lab	pH, Copper (Cu), pH*Cu	Sperm motility,	pH ↓, Cu ↓ pH*Cu ↓	Campbell et al. 2014
				Sperm DNA damage,	pH ↑, Cu ↑ pH*Cu ↑	
				Fertilization success,	pH ↓, Cu ↓ pH*Cu ↓	
				Larval survival	pH ≈, Cu ≈ pH*Cu ↓	
Galeolaria caespitosa	AU	Lab, Individual variation	pH	Sperm motility,	↓, CV = 0.55	Schlegel et al. 2014
				Sperm speed	↓, CV = 0.40	
Pomatoceros lamarckii	UK	Lab	pH, Cu, pH*Cu	Sperm motility,	≈	Lewis et al. 2103
				Sperm speed-straight,	≈	
				Sperm speed-curve,	↓	
				Fertilization,	pH↓, Cu ≈, pH*Cu ≈	
				Larval survival,	pH↓, Cu ↓, pH*Cu ↓	
				Larval morphology	pH ≈, Cu ↓, pH*Cu ≈	

[a] pCO_2 is partial pressure of carbon dioxide. Ω_A is aragonite saturation state. Ω_c is calcite saturation state. Arrows indicate direction of effect. For multiple comparisons, a bold arrow indicates strongest effect. ∩ and U indicate form of quadratic response across the treatment gradient. ≈ indicates no effect. CV is coefficient of variation (standard deviation ÷ mean). F# is generation in trans-generational studies.

9.6 Appendix F. List of sections and paragraphs in the Pacific Walrus Species Status Assessment where local and traditional ecological knowledge is referenced.

Executive Summary

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2.4.2 Population Indices

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2.5.3 Behavioral Adaptation of Pacific Walruses

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P. 29, ¶ 1

2.5.3.5 Flexible Habitat Use Patterns

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3.2.3 Haulout Mortalities

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3.4.2 Parasites

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3.11 Local and Traditional Ecological Knowledge

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3.6.4 Biotixins

P. 54, ¶ 3

4.3.2 Sea ice

P 85, ¶ 5

3.7.1 Effects of Oil and Gas Activities on Pacific Walruses

P. 58, ¶ 2

3.8 Commercial Fisheries

P. 59, ¶ 3

3.9.1.1 Effects of Shipping on Pacific walruses

P. 62, ¶ 2

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3.9.2 Air Traffic

P. 66, ¶ 3

3.13 Summary of Current Conditions

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4.4.2 Subsistence Hunting

P 94, ¶ 2

4.4.8 Shipping and Air Traffic

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4.6 Uncertainty

P. 116, ¶ 2

5.4 Conclusions

P 122, ¶ 1 & 2

6.2.1 Maintain Sustainable Harvest Levels

P 124, ¶ 1 & 3