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Status Review of the Bearded Seal (*Erignathus barbatus*)

by
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and J. M. Wilder

U.S. DEPARTMENT OF COMMERCE
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STATUS REVIEW OF THE BEARDED SEAL (*Erignathus barbatus*)


NOAA photo by John Jansen

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EXECUTIVE SUMMARY

On March 28, 2008, the National Marine Fisheries Service (NMFS) initiated a status review of the bearded seal under the U.S. Endangered Species Act (ESA) (73 FR 16617). Then on May 28, 2008, we received a petition from the Center for Biological Diversity to list the bearded seal as a threatened or endangered species under the ESA, primarily due to concern about threats to this species' habitat from climate warming and loss of sea ice. To assist with determining whether listing of the bearded seal under the ESA is warranted, a Biological Review Team (BRT) was convened by the NMFS to assess the best available information concerning the status of ringed seals (*Erignathus barbatus*) and past, present, and future threats to the species.

The BRT's review included delineating population structure within the species and assessing the risk of extinction at present and in the foreseeable future. The review is intended to inform NMFS's decision about whether to list the species as endangered or threatened. The ESA defines an *endangered species* as "any species which is in danger of extinction throughout all or a significant portion of its range". A *threatened species* is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range". The foreseeable future was not considered to be fixed but, rather, threat specific. Ice habitats are affected by climate which is forecast to continue changing directionally at least until the end of the century in response to greenhouse gas forcing. Variability in the magnitude—but not the directionality—of projected climate change increases over time and is reflected in inter-model variability and in levels of certainty assigned to the BRT's assessments of threats and demographic risks.

Species Background: The bearded seal is a member of the true seals (Phocidae), a group of mammals highly adapted for a primarily aquatic existence. The species diverged about 11 million years ago from its nearest common ancestor with other extant seal species, prior to the emergence of the white fetal or natal coat that is typical of most northern phocid species and thought to be a specific adaptation to reproducing on sea ice. Nevertheless, they inhabit the seasonally ice-covered seas of the Northern Hemisphere where they whelp and rear their pups, and molt their coats on the ice in the spring and early summer. After reaching sexual maturity— typically at 5-6 years—most female bearded seals produce a single pup each year. Most pups are born in April, but March and May births are common in some areas. The pups are able to enter the water within hours of birth. They begin to forage while still under maternal care during a nursing period of about 24 days. Males typically attain sexual maturity at 6-7 years. A lifespan of about 20-25 years is normal, with a maximum of about 30 years. Like all phocids, bearded seals shed and regenerate their hair and epidermis annually but the process is more prolonged and diffuse than in other species. The timing and duration of molting seems to vary substantially among regions and individuals, but molting generally occurs in April to June or July. Bearded seals feed primarily on benthic organisms, including epifaunal and infaunal invertebrates, and demersal fishes and so are closely linked to areas where the seafloor is shallow. However, they are also able to switch their diet to include schooling pelagic fishes, when advantageous.

Species Delineation: Two subspecies of bearded seals are widely recognized: *E. b. barbatus* often described as inhabiting the Atlantic sector, and *E. b. nauticus* inhabiting the Pacific sector. The geographic distributions of these subspecies are not separated by conspicuous gaps, and there are regions of intergrading generally described as somewhere along the northern Russian and central Canadian coasts. The BRT defined longitude 112° W in the Canadian Arctic Archipelago as the North American delineation between the two subspecies and 145° E as the Eurasian delineation between the two subspecies. Based on evidence for discreteness and ecological uniqueness of bearded seals in the Sea of Okhotsk, the *E. b. nauticus* subspecies was further divided into an Okhotsk DPS and a Beringia DPS, so named because the continental shelf waters of the Bering, Chukchi, Beaufort, and East Siberian Seas that are the bearded seals range in this region overlie much of the land bridge that was exposed during the last glaciation and that has been referred to as Beringia.

Extinction Risk Assessment: The BRT evaluated 19 specific threats to bearded seals grouped by the ESA Section 4(a)(1) factors:

- the present or threatened destruction, modification, or curtailment of its habitat or range,
- overutilization for commercial, recreational, scientific, or educational purposes,
- disease or predation,
- the inadequacy of existing regulatory mechanisms, or
- other natural or manmade factors affecting its continued existence.

Present or threatened destruction, modification, or curtailment of the species' habitat or range: The BRT assessed the observed and projected changes with significant potential to impact the bearded seal's range and habitat, including both the physical and biological components of habitat, such as changes in sea ice, ocean temperature, ocean pH (acidity), and associated changes in bearded seal prey species.

The main concern about the conservation status of bearded seals stems from the likelihood that their sea-ice habitat has been modified by the warming climate and, more so, that the scientific consensus projections are for continued and perhaps accelerated warming in the foreseeable future. A second major concern, related by the common driver of carbon dioxide (CO_2) emissions, is the modification of habitat by ocean acidification, which may alter prey populations and other important aspects of the marine ecosystem. A reliable assessment of the future conservation status of each bearded seal species segment requires a focus on projections of specific regional conditions, especially sea ice. Global climate models selected for their consistency with the observed records of regional sea ice were used to project mean, minimum and maximum ice extent in each of the months of March, April, May, June, and July, for each of the decadal periods centered on the years 2030, 2050, and 2090. In a few regions, where the global climate models were poor at hindcasting the observed sea ice, less direct means of predicting ice cover—such as comparison of air temperature predictions with past climatology—were necessary.

For bearded seals, the presence of sea ice is considered a requirement for whelping and nursing young. Similarly, the molt is believed to be promoted by elevated skin temperatures that, in polar regions, can only be achieved when seals haul out of the water. Thus, if suitable ice cover is absent from shallow feeding areas during times of peak whelping and nursing (April/May), or molting (May/June and sometimes through August), bearded seals would be forced to seek either sea-ice habitat over deeper waters (perhaps with poor access to food) or coastal regions in the vicinity of haul-out sites on shore (perhaps with increased risks of disturbance, predation, and competition). Both scenarios would require bearded seals to adapt to novel (i.e., suboptimal) conditions, and to exploit habitats to which they may not be well adapted, likely compromising their reproduction and survival rates. Research suggests that, during the time of whelping and nursing, bearded seals prefer areas where the percent concentration of sea ice is >25%. Lacking a more direct measure of the relationship between bearded seal vital rates and ice coverage, the BRT assumed that this preference relationship reflects the species requirements for sea-ice coverage and defined areas within the current core distribution of bearded seals where the ice projections were below 25% concentration, as inadequate for whelping and nursing. The BRT also assumed that ice coverage <15% would be insufficient for molting. In the Chukchi, Beaufort, East Siberian, Kara, Laptev, and Greenland Seas, as well as Baffin Bay and the Canadian Arctic Archipelago, little or no decline in ice extent is expected for the months of March – May during the remainder of the century; in most of these areas there will be a moderate decline of June ice cover and a substantial decline of July ice cover. More southerly waters, such as the Sea of Okhotsk, Bering Sea, Hudson Bay, and Barents Sea, are expected to have substantial reductions in average and minimum March - May ice extents by the middle or end of this century; June and July ice cover in these areas has historically been sparse and variable in June – July and will be even more so in the future. Although the distribution of bearded seal breeding and molting areas are not well documented, these more southerly parts of their range are likely to very important.

Ocean acidification, a result of increased carbon dioxide in the atmosphere, may impact bearded seal survival and recruitment through disruption of trophic regimes that are dependent on calcifying organisms. The nature and timing of such impacts are extremely uncertain. Changes in bearded seal prey, anticipated in response to ocean warming and loss of sea ice, have the potential for negative impacts, but the possibilities are complex. Ecosystem responses may have very long lags as they propagate through trophic webs. Because of bearded seals' apparent dietary flexibility, this threat may be of less immediate concern than the threats from sea-ice degradation.

Overutilization for commercial, subsistence, recreational, scientific, or educational purposes: Recreational, scientific, and educational utilization of bearded seals is currently at low levels and is not projected to increase to significant threat levels in the foreseeable future for any of the DPSs. Bearded seals' solitary nature has made them less suitable for commercial exploitation than many other seal species. Still, they may have been depleted by commercial harvests in some areas of the Sea of Okhotsk and the Bering, Barents, and White Seas during the mid-20th century. There is currently no significant commercial harvest of bearded seals and significant harvests seem unlikely in the foreseeable future. Bearded seals have been a very important species for subsistence of indigenous people in the Arctic for thousands of years. The current subsistence harvest is substantial in some areas but there is little or no evidence that subsistence harvests have or are likely to pose serious risk to the species.

Diseases, parasites, and predation: A variety of diseases and parasites have been documented to occur in bearded seals. The seals have likely co-evolved with many of these and the observed prevalence is typical and similar to other species of seals. Abiotic and biotic changes to bearded seal habitat potentially could lead to exposure to new pathogens or new levels of virulence, but the BRT considered the potential threats to bearded seals as low.

Polar bears are the primary predators of bearded seals, but other predators include brown bears, killer whales, sharks, and walruses. Predation under the future scenario of reduced sea ice is difficult to assess; polar bear predation may decrease, but predation by killer whales, sharks and walrus may increase.

Inadequacy of existing regulatory mechanisms: Harvests and incidental takes by fisheries and commercial activities are reasonably well regulated throughout the range of bearded seals. Currently, however, there are no effective mechanisms to regulate the global greenhouse gas emissions that are driving—via climate warming—destruction of ringed seal habitat. The BRT implicitly considered impacts of inadequate regulation of greenhouse gas emissions by way of the emissions scenarios used in forecast models; the scenarios were all “non mitigated”, meaning that they assumed no globally-significant framework for regulating or reducing emissions would be implemented.

Other natural or human factors affecting the species’ continued existence: Contaminants, oil and gas industry activities, fisheries, and shipping all have potential to impact bearded seal populations. Compared to the far-reaching changes expected in sea ice and ocean conditions, the future changes and impacts from these other factors were judged by the BRT as likely to be more localized and less significant.

Status of the bearded seal species segments: The BRT reviewed published data and consulted with other experts to evaluate the specific threats to population persistence for the *E. b. barbatus* subspecies and the Beringia and Okhotsk DPSs of bearded seals. Threats were scored quantitatively and the level of certainty in scores was recorded. Risks posed by the inadequacy of existing regulatory mechanisms were not included as part of this scoring. The BRT also assessed the risks to population persistence posed by those threats in demographic terms (abundance, productivity, spatial structure, and diversity).

<u>*E. b. barbatus*</u>: The present population size is very uncertain, but was estimated to be about 188,000 individuals. Sea ice of sufficient concentration is expected to persist in the Canadian Arctic Archipelago and Baffin Bay through the end of the century. Throughout the rest of *E. b. barbatus*’s range, however, the reduction in sea ice is expected to be more dramatic, particularly in the Barents Sea which will become ice free in June within the next few decades. The impacts of the loss of sea ice in the Barents Sea, and the reduction of sea ice in the Kara Sea, could theoretically be offset by the creation of more suitable sea ice habitat in the Laptev Sea which currently has high concentrations of ice and low numbers of bearded seals, though we are not aware of past examples in which similar mitigative shifts in habitat have occurred during rapid climatic changes.

The BRT judged the decoupling, or spatial separation of sea ice from benthic feeding habitat to be a moderate to high threat to the subspecies *E. b. barbatus*; this, and a decrease in sea-ice habitat suitable for molting were judged to be nearly the same strength and the most significant threats to the subspecies. Both threats stem from the anticipated reduction in sea ice area and seasonal persistence, and these combined with other sea-ice, climate, and ocean acidification threats were reflected in a moderate to high score overall for threats associated with habitat modification or loss. Threats within the other ESA Section 4(a)(1) factors were judged to be low or moderate.

The present risks that this subspecies is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low or very low in severity, reflecting the evidence that the population is large and apparently occupying its historic range. Within the foreseeable future, the risks that demographic problems might place the population in danger of extinction were consistently judged to be higher than at present (medium in severity), reflecting the anticipated decline in sea ice habitat over the remainder of the 21st century and consequent impacts on spatial structure (loss of habitat patches) and productivity (changes in vital rates of reproduction and survival).

<u>Beringia DPS</u>: The present population size is very uncertain, but was estimated to be about 155,000 individuals. In the East Siberian, Chukchi and Beaufort Seas the average ice extents during the whelping, nursing, mating and part of the molting period are all predicted to be very close to historical averages out to 2095 with typically 25% or greater ice concentration over the entire shelf zones. End of century projections for the Bering Sea in April-May suggest that there will be sufficient ice only in small zones of the Gulf of Anadyr and in the area between St. Lawrence Island and Bering Strait. In June, suitable ice is predicted to disappear as early as mid-century. To adapt to this regime, bearded seals would likely have to shift their nursing, rearing and molting areas to the ice covered seas north of the Bering Strait.

The most significant threats to the persistence of bearded seals in the Beringia DPS were judged to be the same ones as for the *E. b. barbatus* subspecies, plus the threat of a decrease in prey density or availability due to changes in ocean temperature and ice cover. These and other threats related to loss of sea ice habitat and climate-related changes in ocean conditions were scored in the moderate to high range, leading to an overall score of high for threats of habitat modification or loss. Threats within the other ESA Section 4(a)(1) factors were judged to be low or moderate. The threat-specific and overall habitat factor scores were generally higher for the Beringia DPS than for *E. b. barbatus*, likely a measure of greater concern about declines in ice extent that would separate sea ice suitable for pup maturation and molting from benthic feeding areas. The risk of this is likely greater in the range of the Beringia DPS, where the spring and summer ice edge may retreat to deep water of the Arctic Ocean basin, than in much of the range of *E. b. barbatus*, where summer ice refugia are anticipated to occur in the Canadian Arctic Archipelago and northern Greenland.

The present risks that the Beringia DPS is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low or very low in severity, again on the basis of a large population occupying its historic range. Within the foreseeable future, the risks that demographic problems might place the population in danger of extinction were consistently judged to be higher than at present (medium to high in severity), and higher than the corresponding risks to *E. b. barbatus*.

Okhotsk DPS: The present population size is very uncertain, but was estimated to be about 95,000 individuals. By the end of this century, the Sea of Okhotsk is predicted to frequently be ice free, or nearly so, during April – June, the crucial months for those important life history events. The ice-covered area is much smaller in the Sea of Okhotsk than the Bering Sea and, unlike in the Bering Sea, there is no marine connection to the Arctic Ocean. Over the long-term, bearded seals in the Sea of Okhotsk do not have the prospect of following a shift in the average position of the ice front northward as seals in the Bering Sea would. The greatest threats to the persistence of bearded seals in the Okhotsk DPS were judged to be decreases in sea ice habitat suitable for whelping, nursing, pup maturation, and molting. These threats, which were scored as high, are more severe in the range of the Okhotsk DPS than in the ranges of the Beringia DPS and *E. b. barbatus.* The overall score for habitat-related threats also was greatest for the Okhotsk DPS (high, tending toward very high). Although the scores for the other ESA Section 4(a)(1) factors were in the low to moderate range, they tended to be higher than those for *E. b. barbatus* and the Beringia DPS.

The present risks that the Okhotsk DPS is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low in severity but the numerical scores were somewhat higher than for the other species segments. This may be a result not only of stronger threats identified above, but also of the somewhat lower confidence (certainty scores) ascribed to the threats scores for the Okhotsk DPS. Within the foreseeable future, the risks that demographic problems might place the Okhotsk DPS in danger of extinction were consistently judged to be higher than at present (high for abundance, productivity, and spatial structure; medium for severity), and the highest of the three species segments.

1 INTRODUCTION

On March 28, 2008, the National Marine Fisheries Service (NMFS) initiated conservation status reviews of the bearded seal (*Erignathus barbatus*), ringed seal (*Phoca hispida*), and spotted seal (*Phoca largha*) (National Marine Fisheries Service 2008b). Then on May 28, 2008, the Center for Biological Diversity (CBD) filed a petition with the Secretary of Commerce (Secretary) and NMFS to list the three species as threatened or endangered species and to designate critical habitat for these species pursuant to the U.S. Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 et seq.) (Center for Biological Diversity 2008).

Section 4(b)(3)(A) of the ESA requires the Secretary to determine, to the maximum extent practicable, within 90 days of receiving a petition to list a species under the ESA, whether the petition presents substantial scientific or commercial information indicating that the petitioned action may be warranted. This finding is to be promptly published in the *Federal Register*. On September 4, 2008, NMFS published a positive 90-day finding stating that the CBD's petition presented substantial scientific or commercial information indicating that the petitioned action *may be* warranted (National Marine Fisheries Service 2008b). To assist in determining whether listing the bearded seal under the ESA *is* warranted, NMFS convened an expert panel (the 2010 Bearded Seal Biological Review Team, or BRT) to conduct an ESA status review for this species. The BRT was composed of 8 marine mammal biologists, 1 climate scientist, 1 marine chemist and 1 fishery biologist. A status review (Boveng et al. 2009) and 12-month finding (National Marine Fisheries Service 2009b) on spotted seals were published in October 2009, and a status review of ringed seals was conducted concurrent with this status review of bearded seals.

There are two key tasks associated with conducting an ESA status review. The first task is to delineate the taxonomic group under consideration. To be considered for listing under the ESA, a group of organisms must constitute a "species", which according to the ESA includes "any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature". The BRT applied the joint U.S. Fish and Wildlife Service (USFWS)-NMFS *Policy Regarding the Recognition of Distinct Population Segments Under the Endangered Species Act* (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1996) to determine whether either of the subspecies of bearded seals (i.e., *E. b. barbatus* and *E. b. nauticus*) merits delineation into distinct population segments (DPSs). This analysis can be found in Section 3 of the review.

The second key task of a status review is to conduct an extinction risk assessment to serve as the scientific basis for determining whether the petitioned species is threatened or endangered. The ESA defines the term *endangered species* as "any species which is in danger of extinction throughout all or a significant portion of its range". The term *threatened species* is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range". To make this assessment, the BRT evaluated the time frames over which future events can be reasonably said to be "foreseeable", and assessed the risks based on specific demographic factors of the species, such as abundance, productivity, spatial structure, and diversity, as well as specific threats faced by the species, as outlined in Section 4(a)(1) of the ESA:

- the present or threatened destruction, modification, or curtailment of its habitat or range,
- overutilization for commercial, recreational, scientific, or educational purposes,
- disease or predation,
- the inadequacy of existing regulatory mechanisms, or
- other natural or manmade factors affecting its continued existence

This analysis can be found in Section 4.2 of the review.

This document is intended to be a compilation of the best available scientific and commercial data and a description of past, present, and likely future threats to the bearded seal. It does not represent a decision by NMFS on whether these taxa should be proposed for listing as threatened or endangered under the ESA. That decision will be made by NMFS after reviewing this document, other relevant biological and threat information not included herein, efforts being made to protect the species, and all relevant laws, regulations, and policies. The result of the decision will be posted on the NMFS website (http://www.nmfs.noaa.gov/pr/species/) and announced in the *Federal Register*.

2 SPECIES BACKGROUND

2.1 Taxonomy and Phylogeny

The bearded seal, *Erignathus barbatus*, is a member of the order Carnivora, family Phocidae, and subfamily Phocinae (Rice 1998). Bearded seals originated in the deepest branch within the extant Phocinae. They have a gray-brown fetal pelage (lanugo) rather than the white lanugo that is thought to be an adaptation for protection from predators when breeding on ice, and that emerged later within the remaining Phocinae (Árnason et al. 2006). Bearded seals retain the ancestral trait of four mammary teats rather than the two found in the other Phocinae. They also have a karyotype of $2n=34$ chromosomes, a trait shared with hooded seals (*Cystophora cristata*) but not the remaining Phocinae (tribe Phocini), which have a reduced karyotype of $2n=32$ chromosomes.

The oldest known fossils of bearded seals, found in Alaska and England, are from the Pleistocene, approximately 1-2 million years ago (mya) (Harington 2008). However, the time of divergence of the bearded seal lineage from its sister group, hooded seals plus the tribe Phocini, has recently been estimated by a variety of phylogenetic techniques calibrated by points in the fossil record. The estimates include values of 17 mya (Árnason et al. 2006), 13 mya (Higdon et al. 2007), and 11.4 mya (Fulton and Strobeck 2010a). This latter estimate—based on mitochondrial and nuclear genetic markers, and the largest sample of individuals and greatest number of fossil calibration points employed thus far—is consistent with a North Atlantic origin of bearded seals and corresponds to the time of development of a general pattern of surface circulation and ice transport from the Arctic to the North Atlantic that persists today (Haley et al. 2008, Fulton and Strobeck 2010a, Fulton and Strobeck 2010b).

Two subspecies of bearded seals are widely recognized; *E. b. barbatus* often described as inhabiting the Atlantic sector, and *E. b. nauticus* inhabiting the Pacific sector (Rice 1998). The geographic distributions of these subspecies are not separated by conspicuous gaps. The validity of the division into subspecies has been questioned (Kosygin and Potelov 1971), though recent research on skull morphology and genetics tend to support their continued recognition (Manning 1974, Burns 1981, Davis et al. 2008). The subject is considered in detail in Section 3.

The common name, bearded seal, derives from the prominent, light-colored, down-sweeping vibrissae (whiskers) that often curl when dry. Bearded seals are also called squareflipper, lassie (English), phoque barbu (French), remmesael (Danish), storkobbe or blåsel (Norwegian for “large seal” or “blue seal”), bartrobbe (German), lakhtak (Russian Far East), morski zaits (Russian for “sea hare”, used in western Russia), mukluk (Yupik Eskimo term in southwest Alaska, St. Lawrence Island, and southern Chukchi Peninsula), and oogruk or similar Inupiat or Inuit terms used from the Chukchi Peninsula east to Greenland (Chapskii 1955, Burns and Frost 1979).

2.2 Species Description

Bearded seals are distinctive in appearance by virtue of their generally unpatterned, gray to brown coat (though the dorsal surface can be slightly darker) of short straight hair; wide girth; small head in proportion to body size; long mystacial vibrissae; square-shaped fore flippers; and the presence of four teats, rather than two, the usual number in other Phocinae species. Some individuals may have a rust-colored head and fore flippers (Figure 1). This coloration is believed to be the result of oxidized ferrous compounds trapped on the hair while foraging on the seafloor (Lydersen et al. 2001). The bearded seal's skull is wide and stout, which Burns (1981) suggests assists in breaking breathing holes through sheets of newly formed sea ice. Like another benthic feeder the walrus (*Odobenus rosmarus*), the bearded seal has adaptations for hydraulic jetting and suction feeding in the form of an arched palate and enlarged buccal cavity (Burns 1981, Marshall et al. 2008). When bearded seals are on the ice, they are readily recognized by their large size and their habit of resting singly at the edge of floes, oriented toward the water. Adults average 2.1-2.4 m in standard length and weigh up to 360 kg (Chapskii 1938, McLaren 1958b, Johnson et al. 1966, Burns 1967, Benjaminsen 1973, Burns 1981). In some regions females appear to be slightly larger than males, but the differences are not statistically significant (Chapskii 1938, Benjaminsen 1973, Burns 1981).

NOAA photo by Gavin Brady

Figure 1. -- Adult bearded seal with a face stained red from foraging in iron rich sediments.

A single pup (rarely twins) is born on the ice, in varying stages of molt. Neonates are often in the process of molting and are born with a mix of soft, wavy, gray hair (lanugo) and an emerging coat of stiff hair

(Kovacs et al. 1996). Molted pups are counter-shaded with blue-gray to gray-brown above and a lighter ventral surface. There are distinctive, lighter markings on the back, crown and face often forming a characteristic “T” shape on the head (Figure 2)(Chapskii 1938, Burns and Frost 1979, Burns 1981, Kovacs et al. 1996, Kovacs 2002). About the time of weaning, all lanugo is shed and the seal’s pelage more closely resembles an adult’s. Among Arctic phocid seals, bearded seal newborns are relatively large, averaging 33.6 kg in mass and 131.3 cm in length, representing about 9-13% of maternal mass. They are also comparatively lean at about 10% body fat, and grow comparatively fast at an estimated 2.8 to 3.6 kg per day (Burns 1967, Kovacs and Lavigne 1986, Lydersen et al. 1996, Kovacs 1997, Lydersen and Kovacs 1999). At birth, in the Bering and Chukchi Seas, pups average 131.6 cm in standard length and 33.6 kg in weight; their weight increases to about 85 kg by the time they are weaned in 12-18 days (Burns 1981). This is in contrast to more recent studies in Svalbard where pups were born weighing about 38 kg and were weaned approximately 24 days later at well over 100kg (Lydersen and Kovacs 1999, Gjertz et al. 2000).


NOAA photo by Michael Cameron

Figure 2. -- Male, 4-month old bearded seal, with the characteristic “T” pelage pattern on the head.

Growth is very rapid in the first 2 years. Burns' (1981) data showed an increase of 26% in standard length during the first year and 12% in the second year. Burns and Frost's (1983) data indicated a slower rate of 9% in the first year and 15% in the second year. The difference appeared to have resulted from the way the age classes were defined (Kelly 1988). Both reports showed the percentage increase in length slowing to less than 4% per year after the fourth year. The average length of adult bearded seals has been reported variously from 209 to 236 cm (Table 1). Some of the discrepancies might be attributable to regional differences, but McLaren (1958b) reported finding no evidence of regional variation in body size, and one of the greatest disparities is within data from the Bering and Chukchi Seas. It is difficult to reconcile the data since the studies differed in their methods of measurement, criteria for maturity, and sample size.

Table 1. -- Body lengths of adult bearded seals reported in the literature. Adapted from Kelly (1988).

Source	Area	Age Class	Mean length (cm)	Method*	*N*
Chapskii 1938	Kara and Barents Seas	"adult"	209-215	H.L.	26
			232-236	Z.L.	32
McLaren 1958b	East Canadian Arctic	9+ years	235	-	25
Tikhomirov 1966	Sea of Okhotsk	"mature"	214-225	Z.L.	-
Johnson et al. 1966	Chukchi Sea	"adult"	216-222	S.L.	40
Burns 1967	Bering and Chukchi Seas	10+ years	234	S.L.	13
Benjaminsen 1973	Svalbard, Norway	10+ years	225	S.L.	108
Burns 1981	Bering and Chukchi Seas	10+ years	233	S.L.	-
Burns and Frost 1983	Bering and Chukchi Seas	9+ years	220	S.L.	41
Andersen et al. 1999	Svalbard, Norway	Adult males	231.1 ±11.4	A.L.	41
		Adult females	233.1 ± 7.5	A.L.	43
Fedoseev 2000	Sea of Okhotsk	10+ years	216-233	-	-

* Z.L., zoological length: tip of nose to tip of tail over dorsal contour of the seal while on its belly; S.L., standard length: straight line distance from tip of the nose to tip of the tail with seal lying supine; H.L., horizontal length: straight line distance from tip of the nose to tip of the tail with seal lying prone; A.L., Asymptotic standard length as calculated from growth curve.

Weight varies considerably with seasonal changes in the thickness of the blubber layer, but few whole animal weights are available. Bearded seals tend to be leanest in the summer after the molt (Burns and Frost 1983). The maximum recorded weights are 432 kg and 375 kg (pregnant females collected in the Bering Sea in April, 1985 and 1991 respectively), and 360.5 kg (female collected in mid-June (Johnson et al. 1966) (K. Frost, Alaska Department of Fish and Game (*ret.*), June 29, 2010, pers. comm.) Judging from weights of small numbers of seals taken in late winter-spring and in summer in the Bering and Chukchi Seas (Burns 1967, Burns and Frost 1983), females lose about 9% and males about 37% of their body weight between late winter and summer. According to Burns (1981), blubber thickness decreases from an average of 7.2 cm to 4.4 cm over the same period. Females also lose weight in the springtime through parturition. An apparently near-term fetus measured by Burns and Frost (1983) accounted for 10.2% of the female's total weight.

2.3 Behavior

2.3.1 Hauling out, diving and foraging

There are only a few quantitative studies concerning the activity patterns of bearded seals. Based on limited observations in the southern Kara Sea and Sea of Okhotsk it has been suggested that from late May to July bearded seals haul out more frequently on ice in the afternoon and early evening (Heptner et al. 1976), a pattern similar to other ice-associated pinnipeds (Hoover 1983, Thomas and DeMaster 1983, Calambokidis et al. 1987, Mymrin et al. 1988, Bengtson and Stewart 1992, Lake et al. 1997, Jansen et al. 2001, Bengtson and Cameron 2004, Carlens et al. 2006). From July to April, three males (2 subadults and 1 young adult) tagged as part of a study in the Bering and Chukchi Seas rarely hauled out at all, even when occupying ice covered areas.[1] This is similar to both male and female young-of-year bearded seals instrumented in Kotzebue Sound, Alaska (Frost et al. 2008); suggesting that, at least in the Bering and Chukchi Seas, bearded seals may not require the presence sea ice for a significant part of the year. The timing of haulout was different between the age classes in these two studies however, with more of the younger animals hauling out in the late evening (Frost et al. 2008) while adults favored afternoon (Footnote 1). At haul-out sites ashore in the Sea of Okhotsk, activity patterns are believed to vary more with tidal cycles than diel periodicity (Heptner et al. 1976, Kosygin et al. 1986). Although there are many factors that influence haul-out behavior in other phocid seals, including date, time of day, weather, wave action, tide height and moonlight (Watts 1996), none of these factors have been examined rigorously in relation to bearded seal haul-out behavior. Overall, research on the behavior of bearded seals is limited, and the BRT recommends caution in generalizing the results of a few localized studies to the entire species.

Other studies using data recorders and telemetry on lactating females and their dependent pups showed that, unlike other large phocid seals, they are highly aquatic during a nursing period of about 3 weeks (Lydersen and Kovacs 1999). At Svalbard Archipelago, nursing mothers spent more than 90% of their time in the water, split equally between near-surface activity and diving/foraging (Holsvik 1998, Krafft et al. 2000), while dependent pups spent about 50% of their time in the water, split between the surface (30%) and diving (20%)(Lydersen et al. 1994b, Lydersen et al. 1996, Watanabe et al. 2009). The time spent in water during the nursing period is remarkable when compared to most other sympatric phocids, such as harp (*Pagophilus groenlandica)*; (71%:0%), grey (*Halichoerus grypus)*; (28%:0%), and hooded seals (0%:0%); however it is similar to that of ringed seals (*Phoca hispida)*; (mothers 82%:pups 50%) (Lydersen and Hammill 1993, Lydersen et al. 1994a, Lydersen 1995, Lydersen and Kovacs 1999, Krafft et al. 2000).

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[1] M. Cameron, Unpubl. data, National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115

In addition to acquiring resources for lactation, time spent in the water may function to minimize exposure to surface predators (Lydersen and Kovacs 1999, Krafft et al. 2000). Mothers traveled an average 48 km per day and alternated time in the water with one to four short bouts on the ice to nurse their pups usually between 0900 h and 2100 h (Krafft et al. 2000). This diurnal pattern also coincides with the timing of underwater mating calls by breeding males (Cleator et al. 1989, Van Parijs et al. 2001). In the spring, adult males are suspected to spend a majority of their time in the water vocalizing and defending territories, though a few observations suggest they are not entirely aquatic and may haul out near females with or without pups (Krylov et al. 1964, Burns 1967, Fedoseev 1971, Finley and Renaud 1980).

The diving behavior of adult bearded seals is closely related to their benthic foraging habits and in the few studies conducted so far, dive depths have largely reflected local bathymetry (Gjertz et al. 2000, Krafft et al. 2000). Studies using depth recording devices have until recently focused on lactating mothers and their pups. These studies showed that mothers in the Svalbard Archipelago make relatively shallow dives, generally <100 m in depth, and for short periods, generally less than 10 min in duration. Nursing mothers dived deeper on average than their pups, but by 6 weeks of age most pups had exceeded the maximum dive depth of lactating females (448-480 m versus 168-472 m)(Gjertz et al. 2000). Adult females spent most of their dive time (47-92%) performing U-shaped dives, believed to represent bottom feeding (Krafft et al. 2000); U-shaped dives are also common in nursing pups (Lydersen et al. 1994b). Unlike walrus that “root” in the soft sediment for benthic organisms, bearded seals are believed to “scan” the surface of the seafloor with their highly sensitive whiskers, burrowing only in the pursuit of prey (Marshall et al. 2006).

2.3.2 Mating, vocalizations and site fidelity

The social dynamics of mating in bearded seals are not well known because detailed observations of social interactions are rare, especially underwater where copulations are believed to occur. Theories regarding their mating system have centered around serial monogamy and promiscuity, and more specifically on the nature of competition among breeding males to attract and gain access to females (Stirling 1983, Budelsky 1992, Stirling and Thomas 2003). Bearded seals vocalize during the breeding season, with a peak in calling during and after pup rearing (Wollebaeck 1927, Freuchen 1935, Dubrovskii 1937, Chapskii 1938). Building evidence, especially from new acoustic technologies and captive studies, indicates these calls originate only from males (Burns 1967, Poulter 1968, Ray et al. 1969, Burns 1981, Stirling et al. 1983, Cleator et al. 1989, Cleator and Stirling 1990, Van Parijs et al. 2001, Van Parijs et al. 2003, Van Parijs et al. 2004, Davies et al. 2006, Van Parijs and Clark 2006, Risch et al. 2007). The predominant calls produced by males during breeding, termed trills, are described as frequency-modulated vocalizations. Trills show marked individual and geographical variation, are uniquely identifiable over long periods, can propagate up to 30 km, are up to 60 s in duration, and are usually associated with stereotyped dive displays (Cleator et al. 1989, Van Parijs et al. 2001, Van Parijs 2003, Van Parijs et al. 2003, Van Parijs et al. 2004, Van Parijs and Clark 2006).

Male vocalizations are believed to advertise mate quality to females, signal competing males of a claim on a female, or proclaim a territory. Recent studies in the fjords of the Svalbard Archipelago and shore leads in the Chukchi Sea of Alaska have suggested site fidelity of males within and between years supporting earlier claims that males defend aquatic territories (Cleator et al. 1989, Cleator and Stirling 1990, Van Parijs et al. 2003, Van Parijs et al. 2004, Van Parijs and Clark 2006, Risch et al. 2007). Males that exhibit territoriality maintain a single core area (of ≤ 12 km^2), a strategy that is contrasted by males that "roam" and call across several larger core areas (Van Parijs et al. 2003, Van Parijs et al. 2004, Van Parijs and Clark 2006, Risch et al. 2007). The efficacy of territorial versus roaming strategies is thought to be related to differences in ice regimes, as shown by inter-annual differences at Svalbard Archipelago and when comparing Svalbard with the Chukchi Sea. At the Svalbard Archipelago, more predictable ice conditions favor territorial males (71%), whereas in the coastal Chukchi Sea, less stable ice favors roaming males (66%) (Van Parijs et al. 2004, Van Parijs and Clark 2006). A higher proportion of males with "moving territories" was also noted in the Bering Strait (Burns 1967). Hence, largely unstable and seasonally-dynamic ice habitat, in concert with highly mobile females in estrus, may support alternative mating systems in bearded seals (Van Parijs 2003). Serial monogamy would be favored where sea ice is more predictable allowing a territorial male to pair-bond with a female (on the ice and/or by claiming the water around the female), mate, and then find another female. At Svalbard Archipelago, only territorial males (i.e., no roamers) were present when there was more than 60% land-fast ice (Van Parijs et al. 2004), and promiscuity in both males and females would be more common when unstable ice favors a roaming strategy (Van Parijs and Clark 2006). Whichever mating system is favored, sexual selection driven by female choice is predicted to have strongly influenced the evolution of male displays, and possibly size dimorphism, and caused the distinct geographical vocal repertoires recorded from male bearded seals in the Arctic (Stirling 1983, Atkinson 1997, Risch et al. 2007).

2.3.3 Breathing holes

Although bearded seals prefer sea ice with natural access to the water, observations indicate that bearded seals are able to make breathing holes in thinner ice (Fedoseev 1965, Burns 1967, Burns and Frost 1979, Burns 1981, Nelson et al. 1984). Reports on their methods and capabilities however, are somewhat conflicting. Fedoseev (1965) reported that bearded seals will abandon a hole if it cannot be maintained in thickening ice. However, Fay (1974) reported that bearded seals can use their heads to break holes in ice that is up to 10 cm thick and can maintain those holes in still heavier ice. Indeed some bearded seals in the Canadian Arctic have been found to overwinter in areas of thick fast ice (Smith 1981), with pressure ridges and refrozen leads, and yet were still able to create and maintain breathing holes using their strong fore flipper claws (Smith 1981, Cleator and Smith 1984).

2.4 Seasonal Distribution, Habitat-use, and Movements

Bearded seals are a boreoarctic species with a circumpolar distribution (Fedoseev 1965, Johnson et al. 1966, Burns 1967, Burns and Frost 1979, Burns 1981, Smith 1981, Kelly 1988). Their normal range extends from the Arctic Ocean (85°N) south to Sakhalin Island (45°N) in the Pacific, and south to Hudson Bay (55°N) in the Atlantic (Allen 1880, Ognev 1935, King 1983). Two subspecies have been described: *E. b. barbatus* from the Laptev Sea, Barents Sea, North Atlantic Ocean, and Hudson Bay (Rice 1998); and *E.*

b. nauticus from the remaining portions of the Arctic Ocean and the Bering and Okhotsk Seas (Ognev 1935, Scheffer 1958, Manning 1974, Heptner et al. 1976). The geographic distributions of these subspecies are not separated by conspicuous gaps. There are regions of intergrading generally described as somewhere along the northern Russian and central Canadian coasts (Figure 3)(Burns 1981, Kelly 1988, Rice 1998).

Bearded seals primarily feed on benthic organisms that are more numerous in shallow water where light can reach the seafloor (Fedoseev 1965). As such, the bearded seals' effective range is generally restricted to areas where seasonal sea ice occurs over relatively shallow waters, typically less than 200 m, where they are able to reach the ocean floor to forage (Kosygin 1971, Heptner et al. 1976, Burns and Frost 1979, Burns 1981, Fedoseev 1984, Nelson et al. 1984, Fedoseev 2000, Kovacs 2002). Aerial surveys conducted in the Beaufort Sea indicated that bearded seals preferred areas of open ice cover and water depths primarily of 25-75 m (Stirling et al. 1977, Stirling et al. 1982), and aerial surveys in the Canadian High Arctic suggested that bearded seals in this region preferred water depths of less than 100 m (Kingsley et al. 1985). Tarasevich (1963) collected bearded seals in the Kara Sea in late September through the beginning of October. In areas with depths of 20-50 m, he collected mostly males, but in areas where water depth was less than 20 m, he collected males and females in similar numbers (Tarasevich 1963). In contrast, during winter surveys in northern Baffin Bay, most bearded seals were observed on ice in areas where water depths exceeded 200 m or even 500 m (Finley and Renaud 1980). Although these are much greater depths for bearded seal habitat than are usually reported, adults have been recorded to dive to depths near 300 m (Kovacs 2002, Cameron and Boveng 2009), and six of seven pups with dive recorders reached depths greater than 488 m (Gjertz et al. 2000).

Bearded seals are closely associated with sea ice - particularly during the critical life history periods related to reproduction and molting - and can be found in a broad range of different ice types (Fay 1974, Burns and Frost 1979, Burns 1981, Nelson et al. 1984). Ice provides a platform on which the seals haul out to bear and nurse pups and to rest and molt (Nelson et al. 1984). Of the ice-associated seals in the Arctic, bearded seals seem to be the least particular about type and quality of ice on which they are observed (Fay 1974). They appear to prefer low ice floes that have not become hummocky; however, the floes can be either very large or so small that it appears the seal is resting on the water (Heptner et al. 1976). They also seem to choose floes that are "clean" and white over those that are "soiled" or dirty. The seals are usually seen resting near the edges of ice floes, within a few feet of open water, with their heads facing the water and their bodies' perpendicular to the axis of the lead, and they avoid lying near large, highly compacted ice (Heptner et al. 1976, Burns and Harbo 1977). The presence or absence of snow cover is not normally a defining characteristic of bearded seal habitat. Smirnov (1927) and Rutilevskii (1939) reported that bearded seals occasionally make snow shelters or subnivean lairs on the ice like the ringed seal, though this behavior has never been described elsewhere and the reports are now considered to be unreliable (Heptner et al. 1976, Smith 1981).

Bearded seals generally prefer ice habitat that is in constant motion and produces natural openings and areas of open water, such as leads, fractures, and polynyas for breathing, hauling out on the ice, and access to water for foraging (Heptner et al. 1976, Fedoseev 1984, Nelson et al. 1984). They usually avoid areas of continuous, thick, shorefast ice and are rarely seen in the vicinity of unbroken, heavy, drifting ice or large areas of multi-year ice (Fedoseev 1965, Burns and Harbo 1977, Burns and Frost 1979, Burns 1981, Smith 1981, Fedoseev 1984, Nelson et al. 1984, Kingsley et al. 1985). In a study of bearded seal habitat use in the Bering Sea, ice floes were categorized into three size classes: brash ice (>2 m), cake floes (2-20 m), and large floes (>48 m); and mixed-floes habitat comprised a mix of floe sizes that could not be defined by a single size class (Simpkins et al. 2003). Aerial surveys conducted near St. Lawrence Island indicated that bearded seals selected habitat with medium ice coverage (70-90% cover) and mixed-floes habitat and avoided areas with heavy ice coverage (90-100% cover) and large floes. They appeared to prefer the transitional habitat between small and large floes (Simpkins et al. 2003). In a similar study in April and May, bearded seals in the Bering Sea were found to most likely occupy ice concentrations ≥75% (Ver Hoef et al. *In review*). The highest densities of bearded seals in the eastern Chukchi Sea in May and June were in the offshore pack ice where high benthic productivity has been recorded (Bengtson et al. 2005), and bearded seals in June and July in the Canadian Arctic Archipelago selected areas of ice concentration in the 6/8 to 7/8 range (Kingsley et al. 1985). In late fall and winter, as ice begins to freeze up at the coasts and moves into bays, seals are seen farther out to sea among areas of drifting, broken ice floes, and near open water (Heptner et al. 1976). In the Beaufort Sea, bearded seals are most numerous in a narrow flaw zone, which is an area where drifting pack ice interacts with fast ice, creating leads and other openings (Burns and Frost 1979).

Sea ice provides the bearded seal and its young some protection from predators during the critical life history periods of whelping and nursing (Burns 2002a). It also allows molting bearded seals a dry platform to raise skin temperature and facilitate epidermal growth (Feltz and Fay 1966), and is important throughout the year as a platform for resting and perhaps thermoregulation (Lydersen and Kovacs 1999). Being so closely associated with sea ice, particularly pack ice, the seasonal movements and distribution of bearded seals are linked to seasonal changes in ice conditions. Bearded seals generally move north in late-spring and summer as the ice melts and retreats and then move south in the fall as sea ice forms to remain associated with their preferred ice habitat (Johnson et al. 1966, Burns 1967, Potelov 1969, Fay 1974, Heptner et al. 1976, Burns and Frost 1979, Burns 1981, Nelson 1981, Simpkins et al. 2003, Frost et al. 2008).

The region that includes the Bering and Chukchi Seas is the largest area of continuous habitat for bearded seals (Burns 1981, Nelson et al. 1984). The Bering-Chukchi Platform is a shallow intercontinental shelf that encompasses about half of the Bering Sea, spans the Bering Strait, and covers nearly all of the Chukchi Sea. Bearded seals can reach the bottom everywhere along the shallow shelf and so it provides them favorable foraging habitat (Burns 1967). The Bering and Chukchi Seas are generally covered by sea ice in late winter and spring and are then mostly ice free in late summer and fall, a process that helps to drive a seasonal pattern in the movements and distribution of bearded seals in this area (Burns 1967, Burns 1981, Nelson et al. 1984). During the breeding season in May-June, bearded seals in the Bering Sea are near the ice front, but in contrast to ribbon (*Histriophoca fasciata*) and spotted seals (*Phoca largha*), which stay closer to the edge, bearded seals are usually farther north and in heavier pack ice (Fiscus and Braham 1976, Braham et al. 1981). As the ice retreats in the spring most adults in the Bering Sea are thought to move north through the Bering Strait where they spend the summer and early fall at the southern edge of the Chukchi and Beaufort Sea pack ice and at the wide, fragmented margin of multi-year ice (Fay 1974, Heptner et al. 1976, Burns and Frost 1979, Burns 1981, Nelson et al. 1984). A smaller number of bearded seals, mostly juveniles, remain near the coasts of the Bering and Chukchi Seas for the summer and early fall instead of moving with the ice edge (Burns 1967, Heptner et al. 1976, Burns 1981). These seals are found in bays, brackish water estuaries, river mouths, and have been observed to travel up some rivers (Burns 1967, Heptner et al. 1976, Burns 1981). As the ice forms again in the fall and winter, most seals move south with the advancing ice edge through Bering Strait and into the Bering Sea where they spend the winter (Burns and Frost 1979, Frost et al. 2005, Cameron and Boveng 2007, Frost et al. 2008, Cameron and Boveng 2009). This southward migration is less noticeable and predictable than the northward movements in late spring, early summer (Burns and Frost 1979, Burns 1981, Kelly 1988). During winter, the favorable conditions of shallow waters combined with broken, drifting and fractured pack ice, occur more often in the temperate Bering Sea than the Chukchi Sea (Burns 1981). These conditions may be related to the central and northern parts of the Bering Sea shelf having the highest densities of bearded seals at this time (Fay 1974, Heptner et al. 1976, Burns and Frost 1979, Braham et al. 1981, Burns 1981, Nelson et al. 1984). In late winter and early-spring, bearded seals are widely but not uniformly distributed in the broken, drifting pack ice ranging from the Chukchi Sea south to the ice front in the Bering Sea. In these areas, they tend to avoid the coasts and areas of fast ice (Burns 1967, Burns and Frost 1979). Young-of-the-year bearded seals seem to range widely through the Bering Sea at this time, with some travelling as far as the southern coast of the Kamchatka Peninsula (Cameron 2006, Frost et al. 2008). Despite this range, satellite tagging also indicates that adults, subadults and to some extent pups focus on localized feeding areas, often remaining in the same general area for weeks or months at a time (Cameron 2005, Cameron and Boveng 2009).

There are fewer accounts of the seasonal movements of bearded seals in other areas. Compared to the dramatic long-range seasonal movements of bearded seals in the Chukchi and Bering Seas, bearded seals are considered to be relatively sedentary over much of the rest of their range, undertaking more local movements in response to ice conditions (Vibe 1950, McLaren 1962, Krylov et al. 1964, Fedoseev 1973, Ray et al. 1982). These differences may simply be the result of the general persistence of ice over shallow waters in the High Arctic. In the region of the White, Barents, and Kara Seas, bearded seals also conduct seasonal migrations following the ice edge, and their distribution in this area follows the dynamics of the drifting ice (Potelov 1969, Wiig and Isaksen 1995). They move from the southeastern Barents Sea to the east and north in the spring-summer, and then travel in the opposite direction in the fall (Potelov 1969). In the Sea of Okhotsk, bearded seals also remain in broken ice as the sea ice expands and retreats, inhabiting the southern edge of the pack beyond the fast ice in winter and moving north toward shore in spring and summer (Fedoseev 1966, Heptner et al. 1976, Fedoseev 2000). Aerial surveys conducted in Baffin Bay from May through July indicated that bearded seals there may also move between coastal and more offshore areas in order to remain closer to the edge of the ice pack (Koski 1980). Excluded by shorefast ice from much of the Canadian Arctic Archipelago during winter, bearded seals are scattered throughout many of the inlets and fjords from July to October, though at least in some years, a portion of the population is known to overwinter in a few isolated open water areas north of Baffin Bay (Finley and Renaud 1980). And in Hudson Bay, two juveniles tagged with satellite tracking tags from September to February never left the waters off Belcher Island, despite the area becoming covered in sea ice during winter (University of Manitoba 2010).

Throughout most of their range, adult bearded seals are rarely found on land (Kovacs 2002). However, some adults in the Sea of Okhotsk, and more rarely in Hudson Bay (COSEWIC 2007), in the White and Laptev Seas (Heptner et al. 1976), Bering, Chukchi and Beaufort Seas, (Burns 1981, Nelson 1981, Smith 1981) and Svalbard (Kovacs and Lydersen 2008a) use haul-out sites ashore in late summer and early autumn until ice floes begin to appear at the coast. In these locations, sea ice either melts completely or recedes beyond the limits of shallow waters where seals are able to feed (Burns and Frost 1979, Burns 1981). This is most common in the western Sea of Okhotsk and along the coasts of western Kamchatka where bearded seals form numerous shore rookeries that can have tens to hundreds of individuals each (Tikhomirov 1961, Krylov et al. 1964, Chugunkov 1970, Tavrovskii 1971, Heptner et al. 1976, Burns 1981). In these areas, bearded seals are regularly found hauled out along the shores of shallow bays and river mouths (Heptner et al. 1976). The coastal rookeries are usually on low, pebbly banks or sandy shoals, often with silt and small boulders. Bearded seals in the Bering, Chukchi and Beaufort Seas, rarely haul out on land (Burns 1981, Nelson 1981, Smith 1981), presumably because in these areas they can move to remain with the ice where the water is shallow enough for them to forage on the sea floor (Fay 1974, Burns and Frost 1979, Burns 1981). However, younger bearded seals have been observed hauled out on land in lagoons and up rivers in some areas near Wainwright, Alaska (Nelson 1981), and on sandy islands near Barrow, Alaska (W. Adams, North Slope Borough, Department of Wildlife management, July 14, 2010, pers. comm.).

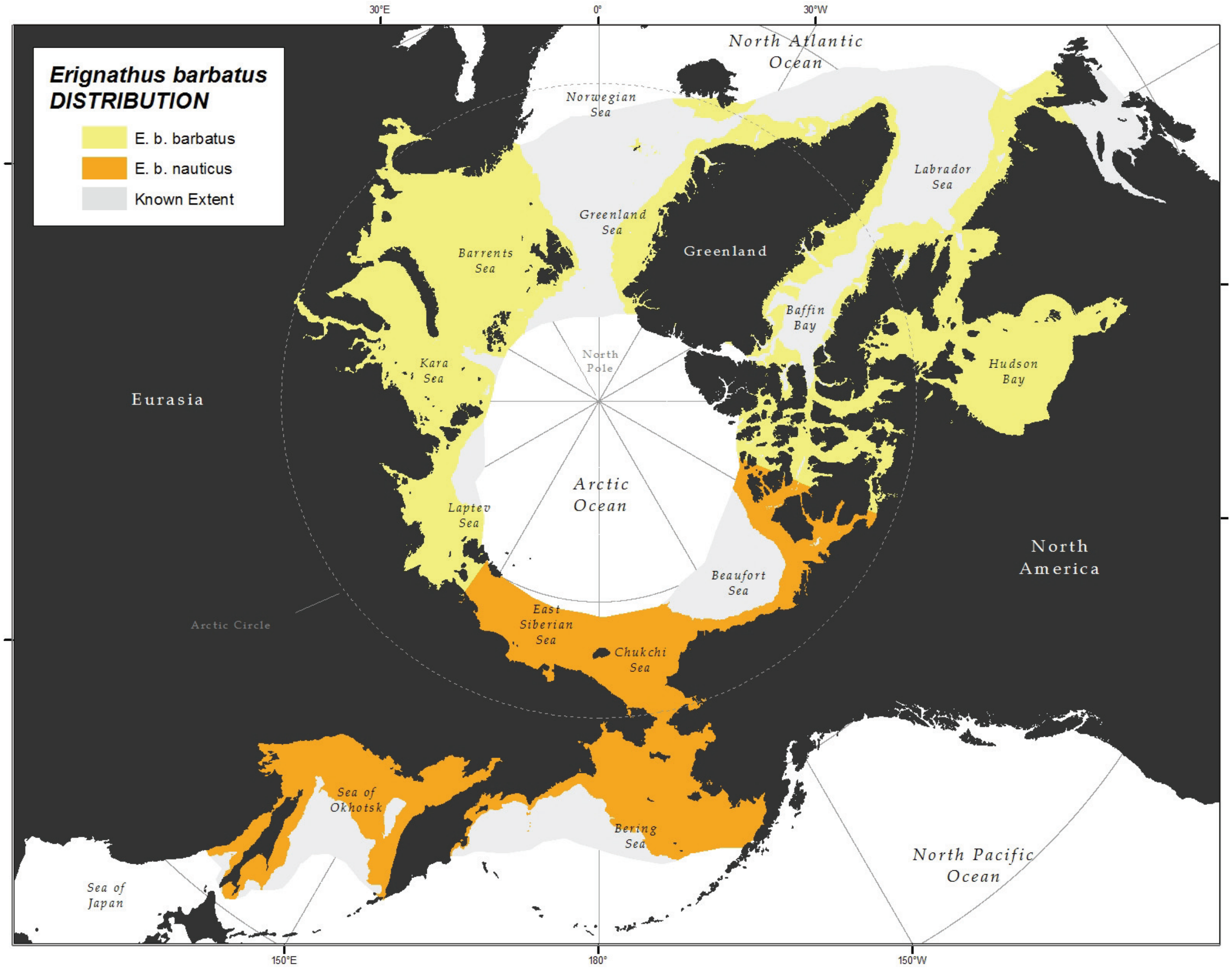


Figure 3. -- The global distribution of bearded seals as adapted from maps of known extent in Burns (1981) and Kovacs (2002). The colored areas of core distribution are those areas of known extent that are in waters <500 m deep. The subspecies range boundaries were approximated from the literature.

2.5 Reproduction and Molting

During the winter and spring, as sea ice begins to break up, perinatal females find broken pack ice over shallow areas on which to whelp, nurse young, and molt (Burns 1981). Although parturition has been reported by Eskimo hunters to occur occasionally in the water (Vibe 1950, Burns 1967), bearded seals are considered to use ice as their birthing platform (Reeves et al. 1992, Kovacs et al. 1996). A suitable ice platform is likely a prerequisite to whelping, nursing and rearing young (Heptner et al. 1976, Burns 1981, Reeves et al. 1992, Lydersen and Kovacs 1999, Kovacs 2002). Despite descriptions of pups occurring throughout the species' range, the timing and relative importance of specific areas for whelping (and subsequent nursing, breeding, and molting) is poorly known because quantitative surveys are lacking.

2.5.1 Whelping

2.5.1.1 Spatial distribution

2.5.1.1.1 Canadian Arctic Archipelago, Baffin Bay, Hudson Bay and Beaufort Sea

In the eastern Canadian Arctic, the winter and pre-whelping distribution of bearded seals is largely associated with the location of polynas and shore leads (Stirling et al. 1981). These wintering grounds are presumed to represent staging areas for females prior to whelping because these locations host mothers with dependent pups in the spring. Western and central Baffin Bay are unique among whelping areas as mothers with dependent pups have been observed on pack ice over deep water (>500 m)(Koski 1980). In the Canadian High Arctic, years of earlier spring melt have been correlated with higher abundances of bearded seals around the time of whelping, suggesting an ice-mediated migration of pregnant females from southern wintering areas (Kingsley et al. 1985). In the eastern Beaufort Sea, where the breakup of sea ice occurs relatively late in the spring and in some years not at all, mother-pup pairs concentrate in shore leads associated with the Cape Bathurst polynya (Stirling and Archibald 1977, Smith 1980, Stirling et al. 1982). Bearded seals also winter along the shore lead system of western Hudson Bay and in polynyas of the eastern Bay near the Belcher Islands; their high abundance throughout the Bay during summer suggests that whelping and breeding may also take place there in the spring (McLaren 1958a, Mansfield 1967, Stirling et al. 1981). Moreover, young of the year have been collected at sites throughout the Hudson Bay area, which, along with Foxe Basin and Hudson Strait (including Ungava Bay), are considered to host the highest numbers of bearded seals in the Canadian Arctic (Smith 1981, Stirling et al. 1981).

2.5.1.1.2 Barents Sea, Kara Sea, Greenland Sea, Laptev Sea and East Siberian Sea

In the northeast Atlantic Ocean, at the Svalbard Archipelago, females rear young on floes in open pack ice nearshore and in close-packed ice within the fjords. Adult bearded seals have been observed in these coastal waters through the winter, which become suitable whelping and breeding areas in the spring (Hop et al. 2002, Lydersen et al. 2002b). The number of pregnant females that migrate from other areas is unknown. Concentrations of mothers with pups have also been observed in loose pack ice along several hundred kilometers of the seasonal ice edge from southern Svalbard to the north-central

Barents Sea (Wiig and Isaksen 1995). Whelping is believed to occur in the drifting pack ice throughout the Barents Sea (Heptner et al. 1976, Kovacs and Lydersen 2008b). Overwintering bearded seals in the polynya of northeast Greenland, and their continued presence there during summer, suggest this also is a whelping and breeding area (Ugland and Ree 1983, Dietz et al. 1985, Stirling 1997).

In the southern Barents Sea, historical accounts of sealers suggested whelping areas were at the edge of ice receding from the mouth of the White Sea, including Mezensky Bay, to the coast of Novaya Zemlya (Heptner et al. 1976, Popov 1976). More recently, mating calls by male bearded seals have been recorded within the White Sea near the Onega Peninsula indicating the likely presence of nursing females (Belkovich and Agafonov 2006). Sealing ships also encountered whelping seals on drifting ice in Pechora Bay and between Kanin Peninsula and Kolguev Island and on landfast ice off the west coast of Novaya Zemlya (Chapskii 1938). Lower densities of pups were reported in the central and southern White Sea and in the western Kara Sea (Heptner et al. 1976, Popov 1976).

Few details are known about the incidence of bearded seal whelping in the Laptev and East Siberian Seas. Breeding grounds have been reported at Cape Chelyuskin where large numbers of individuals were presumed to have migrated from the Laptev Sea (Tyulin 1938, Rutilevskii 1939, Heptner et al. 1976). Sporadic sightings of bearded seals eastward into the East Siberian Sea in the late spring and summer suggest a limited distribution there but do not confirm whether these areas are used for whelping (Heptner et al. 1976). Despite a gap in research in eastern Russian waters, the infrequent observations of bearded seals – even historically among sealing ships – indicate a small population and a corresponding low incidence of whelping.

2.5.1.1.3 Bering Sea and Chukchi Sea

In the Bering Sea, the highest densities of seals in early spring have been observed between St. Lawrence and St. Matthew Islands, with lower densities southeast of St. Matthew and in the southern Gulf of Anadyr (Krylov et al. 1964, Kosygin 1966b, Braham et al. 1981, Cameron et al. 2008). In some years, high densities of seals occur north and west of St. Lawrence Island in early spring (Braham et al. 1977, Fedoseev et al. 1988, Cameron et al. 2008). However, the age and sex composition of these aggregations has not been documented, so it is not known if these are whelping areas. The spring pulse in the harvest of bearded seals at St. Lawrence Island, Little Diomede Island, and Pt. Hope occurs in early June, a few weeks after the main whelping period (Kenyon 1962, Johnson et al. 1966, Burns 1967). This suggests that pregnant females spend the winter on drifting ice in the Bering Sea, whelp and wean pups in about the same area, and then migrate northbound with the receding ice prior to molting.

Wintering and whelping bearded seals are also known to occupy coastal leads of the Bering and Chukchi Sea, such as in Bristol and Kuskokwim Bays, Norton and Kotzebue Sounds, the Gulfs of Karaginskiy and Anadyr, and near Point Hope (Johnson et al. 1966, Kosygin 1966b, Burns and Frost 1979, Burns 1981, Fedoseev et al. 1988, Coffing et al. 1998, Georgette et al. 1998). Compared to hunting areas at St. Lawrence Island and Point Hope, a relatively brief pulse in the harvest of bearded seals in Norton Sound and Kuskokwim Bay occurs two months earlier (April) during whelping, with pups being taken (Kenyon 1962, Johnson et al. 1966, Burns and Frost 1979, Georgette et al. 1998, Coffing et al. 1999). Thus, some portion of pregnant females inhabiting coastal waters in the Bering Sea apparently winter and whelp in the same area (Burns and Frost 1979). Intermittent shore leads deep in the winter ice pack of the eastern Chukchi and Beaufort Seas provide at least marginal habitat for low densities of females to whelp in the spring (Burns and Frost 1979). In the western Chukchi Sea, bearded seals arrive at Wrangel Island in the spring as shore leads develop but whelping has not been documented (Cline 2001).

2.5.1.1.4 Sea of Okhotsk

As in other areas, the spatial distribution of whelping in the Sea of Okhotsk is influenced by the location of the marginal ice zone in the spring. Following a winter of maximum ice cover, bearded seals were generally dispersed at the time of whelping with the highest densities occurring in pack ice greater than 200 km from open water in 3 areas of coastal, shallow water: 1) just off the east coast of Sakhalin Island to within and south of Terpeniya Bay; 2) south and southeast of P'yagina Peninsula to inside Tauyskaya Bay; and 3) southern and central Gulf of Shelikhov (Fedoseev 1971, Heptner et al. 1976, Fedoseev 2000). When ice cover was below average, seals were more concentrated but in similar areas. Coastal leads and polynas in the Shantarsk Archipelago provide overwintering and likely whelping habitat for some females, though in lower numbers (Heptner et al. 1976). Mothers and pups have not been quantified during surveys so actual whelping areas can only be inferred from the presence of seals at the time of whelping (Fedoseev 2000).

2.5.1.2 Annual timing

Similar to the spatial distribution, estimates of the annual timing of whelping are based largely on inconsistent or sparse data. Because bearded seals whelp on ice, populations have likely adapted their phenology to the ice regimes of the regions that they inhabit (Tikhomirov 1966, Burns 1967). In some areas, whelping is believed to be centered around the period of maximum ice extent (Tikhomirov 1966, Fedoseev 2000). Earlier researchers proposed a latitudinal gradient in the timing of whelping (1952, McLaren 1958b, Burns 1981), and though there are examples of earlier whelping at lower latitudes there is little systematic data to support latitude as consistent factor. Regional patterns of ice suitable as as a haul-out substrate, and proximity to shallow water may be more significant factors for whelping. Wide-ranging observations of pups generally indicate whelping occurs from March to May with a peak in April (Figure 4), but there are considerable geographical differences in reported timing, which may reflect real variation but may also result from inconsistent sighting efforts across years and locations.

In the Sea of Okhotsk, the beginning of whelping has been noted as late February (Naumov 1941, Tikhomirov 1966), though other researchers consider early or late March the typical onset (Krylov et al. 1964, Heptner et al. 1976). Based on opportunistic sightings, most births reportedly occur from late March through April (Krylov et al. 1964, Heptner et al. 1976), with a pronounced peak in mid-April (Tikhomirov 1966); and the last pups are born in early to mid-May (Krylov et al. 1964, Tikhomirov 1966, Heptner et al. 1976, Fedoseev 2000). These dates correspond approximately with whelping in the southern and central Bering Sea where newborn pups have been observed from mid-March to early May. A peak in births in the Bering Strait and central Chukchi Sea was estimated to occur in late April (Johnson et al. 1966, Tikhomirov 1966, Heptner et al. 1976, Burns 1981). Similarly, in the Gulf of Anadyr, the peak of whelping occurs in mid-April (Tikhomirov 1966). Although whelping reportedly occurs in polynas and coastal leads in the western Laptev Sea (Tyulin 1938, Rutilevskii 1939, Heptner et al. 1976), there are no accounts of the actual timing. Near the boundary of the Kara and Barents Seas, around Pechora Bay, hunter accounts and specimens suggest that whelping begins in mid-March and peaks in late April or early May (Chapskii 1938). The latest newborn pups there were sighted in early June (Potelov 1975b, Heptner et al. 1976). In the western Barents and White Seas, newborn pups have been encountered from mid-March to early June, with an apparent pulse of births in April (Potelov 1975b, Heptner et al. 1976, Popov 1976). Early accounts suggest that whelping may occur as early as mid-February in the White Sea (Chapskii 1938). Within the fjords and adjacent seasonal ice pack of the Svalbard Archipelago, newborn pups are typically present in April and May with a peak in whelping during the first half of May (Lydersen et al. 1994b, Wiig and Isaksen 1995, Lydersen et al. 1996, Lydersen and Kovacs 1999, Lydersen et al. 2002a). The timing of whelping in the eastern Canadian and High Arctic is essentially unknown, though it has been predicted using extrapolated birth size and fetus collections to occur in April and May with a peak in mid-April (Vibe 1950, McLaren 1958b). This whelping period is consistent with advertisement calls by breeding males in the High Arctic, which occur from mid-April to late June (Stirling et al. 1983). Throughout the species' range the main period of whelping is most consistently reported to occur during the second half of April.

2.5.2 Nursing and rearing

Shortly after giving birth, bearded seal mothers mother lead their pup away from the birth floe (Lydersen and Kovacs 1999). Females with pups are generally solitary, tending not to aggregate (Heptner et al. 1976, Kovacs et al. 1996). Pups enter the water immediately after or within hours of birth, gradually spend more time in the water developing aquatic skills (Tikhomirov 1966, Burns 1967, Kovacs et al. 1996, Holsvik 1998, Gjertz et al. 2000). Pups nurse on the ice, (Lydersen and Kovacs 1999), and by the time they are a few days old they spend half their time in the water, splitting it almost equally between surface swimming and diving (Lydersen et al. 1994b, Gjertz et al. 2000, Watanabe et al. 2009). Earlier studies estimated that lactation was as short as 12-18 days and that weaning was abrupt (Burns 1967), or that it lasted a month or longer (Chapskii 1938). More recent studies using recorders and telemetry on pups have revealed greater detail suggesting extended lactation of about 24 days, a transition to diving and more efficient swimming, mother-guided movements of greater than 10 km, and foraging while still under maternal care (Hammill et al. 1994, Lydersen et al. 1994b, Lydersen and Kovacs 1999, Gjertz et al. 2000, Watanabe et al. 2009). Significant shifts in the daily locations of mothers and pups were related to the availability of ice in the whelping area (Van Parijs et al. 2001).

Detailed studies on bearded seal mothers show they forage extensively, diving shallowly (< 10 m), and spending only about 10% of their time hauled out with pups and the remainder nearby at the surface or diving (Holsvik 1998, Krafft et al. 2000). Although their condition and mass decline abruptly during lactation, losing about 4.5 kg per day, bearded seal mothers sustain a lower proportional loss of mass compared to those of other ice-breeding seals that feed little or not at all (Krylov et al. 1964, Heptner et al. 1976, Andersen et al. 1999, Lydersen and Kovacs 1999, Krafft et al. 2000). Despite the relative independence of mothers and pups, their bond is described as strong, with females being unusually tolerant of threats in order to remain or reunite with pups (Krylov et al. 1964, Burns and Frost 1979, Hammill et al. 1994, Lydersen et al. 1994b). Mothers apparently cue on olfactory and auditory signals, as demonstrated by mutual nosing upon reuniting with pups, and responsiveness to pup calls (Hammill et al. 1994). Similarities in diving between mothers and pups have led to speculation that pups are imitating the foraging behavior of mothers (Lydersen et al. 1996, Watanabe et al. 2009). A mixture of crustaceans and milk in the stomachs of pups indicates that independent foraging occurs prior to weaning, at least in some areas (Chapskii 1938, Burns 1981). Weaned bearded seal pups average 85 to 117 kg, for the Bering Strait and Svalbard Archipelago, respectively. The latter is based on telemetry findings that point to a longer lactation period (three rather than two weeks) and larger weaning mass of pups than previously estimated (Burns 1967, Holsvik 1998, Gjertz et al. 2000). Newly weaned pups have about 25% body fat, the leanest of the Arctic phocids and similar to that of adults (Ryg et al. 1990a, Lydersen et al. 1996, Lydersen and Kovacs 1999). It is believed their lean body mass is a reflection of a more energetically demanding rearing period, which may be an adaptation allowing pups to rapidly develop skills to forage for benthic prey before the winter ice covers foraging grounds (Lydersen and Kovacs 1999). Studies around the Svalbard Archipelago, show that a month after weaning, pups dispersed 40 – 550 km (mean = 167 km) from their natal area, diving predominantly over the shallow shelf and in fjords (Gjertz et al. 2000). Post-lactating mothers traveled less, staying in shallow areas near Svalbard with access to fast or drifting ice (Gjertz et al. 2000).

2.5.3 Breeding

Adult female bearded seals ovulate after lactation (McLaren 1958b, Potelov 1975b, Atkinson 1997), and are presumably then receptive to males. Copulation is believed to usually take place at the surface of the water (Stirling 1983), but it is unknown if it also occurs underwater or on land or ice, as observed in some other phocids (Merdsoy et al. 1978, Beier and Wartzok 1979). Early accounts suggest that copulation may occur at the surface with animals oriented vertically and in contact, only heads visible, one seal a head length higher than the other (Chapskii 1938, Sleptsov 1943), which is similar to that documented in harp seals (Merdsoy et al. 1978). Because there are few actual accounts of copulation, the extent to which mothers may still be nursing when pairing with males is unknown. Adult males are reported to haul out with perinatal females (Finley and Renaud 1980), as well as with nursing females at the end of lactation (Krylov et al. 1964, Burns 1967, Fedoseev 1971).

Due to the rarity of these accounts, the estimated timing of breeding (Figure 4) has been based largely on less definitive physiological metrics. Ovarian dissections indicate reproductive females ovulate from March to June with a peak from mid-April to mid-May (McLaren 1958b, Tikhomirov 1966, Burns 1967, Potelov 1975b). In the Barents Sea, spermatozoa indicative of mating were found in females from late March to mid-May suggesting a peak in late April (Potelov 1975b). Similarly, testicular analysis suggested that males in the North Pacific and Sea of Okhotsk were in breeding condition from March to June with a peak in late April (Tikhomirov 1966, Burns 1967). In the Canadian Arctic, a decline in testicle size in June and July was believed to indicate a peak in breeding condition somewhat later in mid-May (McLaren 1958b). Given the paucity of data, it is unclear what factors may affect the timing and peak period of copulations, or even more so actual fertilization, though it would be expected that initial pairing of males and females would correspond closely to when mothers wean their pups (Atkinson 1997). In the northern Bering Sea, the earliest impregnated female (in the pre-implantation stage) was collected on 13 April and the latest on 23 May (Burns 1967).

After a female is fertilized, the blastocyst stays dormant for approximately 2 to 2.5 months until June to mid-August when implantation occurs (Chapskii 1938, McLaren 1958b, Burns 1967, Burns 1981). In phocids, blastocyst implantation occurs during molting. A female's nutritional and molting status may affect the levels of hormones (e.g., estrogen) required to reactivate the embryo (Ling 1970, Reijnders 1990, Atkinson 1997). Gestation lasts 9 months, during which average fetal growth is an estimated 123 g/day (Burns 1967). At parturition, female bearded seals have expended about a third of the anticipated total investment in a weaned pup, which is average for ice-associated species of the North Atlantic (Lydersen and Kovacs 1999).

2.5.4 Molting

2.5.4.1 Newborns

Bearded seal pups begin shedding their dark lanugo coat in utero, some finishing prior to birth, and they are born with a layer of subcutaneous fat that is not characteristic of other Arctic phocid seals (Burns 1970, Lydersen et al. 1994b, Kovacs et al. 1996, Lydersen and Kovacs 1999, Kovacs 2002). These characteristics are thought to be adaptations to entering the water soon after birth as a means of avoiding predation (Stirling 1977, Kovacs et al. 1996, Lydersen and Kovacs 1999). It was previously assumed that most bearded seal pups were born with lanugo largely intact and that they molted into a shorter, stiffer pelage at weaning (King 1983). Recent studies in the Svalbard Archipelago, however, showed that greater than 90% of pups had already completed molting upon reaching about half their expected weaned size (Kovacs et al. 1996). Bearded seals may also exhibit geographical variation in molting patterns. Earlier observers in the Barents Sea noted prenatal molting in bearded seal pups, in contrast to pups of the Bering Sea, which were believed to complete molt closer to weaning (Heptner et al. 1976).

2.5.4.2 Adults

Adult and juvenile bearded seals molt annually, a process of new hair growth, regenerating epidermis, and shedding pelage that in mature phocid seals typically begins shortly after mating (Chapskii 1938, Ling 1970, Ling 1972, King 1983, Yochem and Stewart 2002). In phocids, which do not have a well-developed underfur or insulating hair, pelage is believed to function more in streamlining, mechanical protection, and traction than in thermoregulation (Scholander et al. 1950, Murray 1964, Scheffer 1964, Murray and Nicholis 1965, Ling 1970, Ling 1984). Molting in bearded seals reportedly involves "intensive peeling" of the epidermis (Chapskii 1938). The actual shedding of hair and skin marks the end of the epidermal cycle and in phocids may start before or after new hair has emerged (Ling 1970). Bearded seals haul out of the water more frequently during molting (Burns 1981, Fedoseev 2000), a behavior that facilitates higher skin temperatures and may accelerate shedding and regrowth of hair and epidermis (Héroux 1960, Feltz and Fay 1966, Fay 1982).

2.5.4.2.1 Annual timing

Though not studied in bearded seals, molting has been described as diffuse, with individuals potentially shedding hair throughout the year but with a pulse in the spring and summer (Burns 1981, Kovacs 2002). This may be reflected in the wide range of estimates for the timing of molting, though these estimates are also based on irregular observations (Figure 4). Accounts in the Kara and Barents Seas suggest an onset of molting as early as April and as late as June, with a peak in late July, and an end from June to August (Chapskii 1938). In the northern Barents Sea, at the Svalbard Archipelago, researchers estimated peak molting to occur in June and July (Gjertz et al. 2000, Kovacs 2002). Though not specifically studied, the molting period of bearded seals in the Bering and Chukchi Seas is also reportedly protracted, occurring between April and August with a peak in May and June (Tikhomirov 1964, Kosygin 1966a, Burns 1981). Air temperature may explain the apparent differences in molt timing from southern (earlier) to northern (later) areas of the Sea of Okhotsk, which is similar to a trend reported for the White Sea (earlier) compared to the northern Barents Sea (later) (Heptner et al. 1976). In the southern Sea of Okhotsk, the onset of molting generally has been reported to occur in early May, though some reports indicate molting begins as early as late March (Naumov 1941, Sleptsov 1943, Bychkov 1960, Shmakova 1978). Peak molting in the southern Sea of Okhotsk takes place in June with most animals completing the molt by the end of June (Tikhomirov 1961).

Adult females typically initiate molting before adult males, a pattern that possibly reflects different strategies and demands during the breeding season (Thompson and Rothery 1987, Beck et al. 2003, Daniel et al. 2003). Male bearded seals, exhibit an extended period of mating displays and longer attendance in the breeding grounds than females, thus seemingly supporting this pattern (McLaren 1958b, Tikhomirov 1966, Burns 1967, Stirling et al. 1983, Cleator et al. 1989, Daniel et al. 2003). In addition, hair growth is inhibited by testosterone which is elevated in male phocids during the breeding season (Mohn 1958, Noonan et al. 1991, Atkinson and Gilmartin 1992, Bartsh et al. 1992, Atkinson 1997, Coltman et al. 1999). Similarly, in post-lactating female seals, declining levels of estrogen, which inhibits hair growth, are thought to influence the onset of molting (Mohn 1958, Ling 1970, Ling 1984, Daniel et al. 2003). Though molting cycles have been studied in only a few species of phocids, researchers have found that the interval between breeding and molting seasons is about equal to the interval between the onset of follicular activity and first emergence of new hair (Ling 1970, Ling 1984). Moreover, in female phocids, the onset of hair growth (or possibly the completion of molting), may be a prerequisite for blastocyst implantation (Laws 1956, Ling 1970, Ling 1984, Daniel et al. 2003). Immature bearded seals are reported to molt before sexually mature animals (Krylov et al. 1964, Heptner et al. 1976, Fedoseev 2000), similar to findings for other phocid species (Ling 1970, Ashwell-Erickson et al. 1986, Thompson and Rothery 1987, Burns 2002b, Daniel et al. 2003). Nutritional status also affects the pelage cycle in phocids; malnutrition suppresses thyroid (follicle-stimulating) function, which delays the onset of molt or causes a diffuse molt (Hickling 1962, Ling 1965, Ling 1970, Walker and Bowen 1993, Coltman et al. 1997).

2.5.4.2.2 Spatial distribution

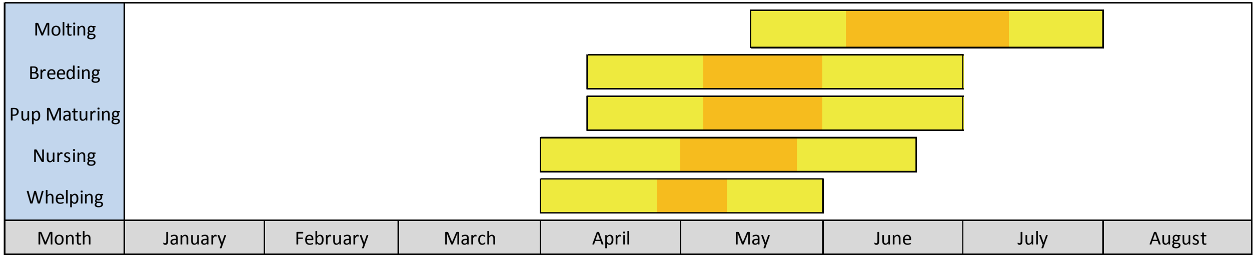
The need for a platform on which to haul out and molt from late spring to mid-summer, when sea ice is rapidly melting and retreating, may necessitate movement for bearded seals between habitats for breeding and molting. In the Sea of Okhotsk, spatial distribution of bearded seals is similar between whelping and molting seasons so only short movements occur (Fedoseev 1971, Heptner et al. 1976, Fedoseev 2000). In contrast, bearded seals that whelp and mate in the Bering Sea migrate long distances to summering grounds at the ice edge in the Chukchi Sea, a period of movement that coincides with the observed timing of molt (Heptner et al. 1976, Burns 1981). Similar migrations prior to and during the molting period have been presumed from the White Sea and southeastern Barents Sea to more easterly and northern areas of the Barents Sea where ice persists through the summer (Heptner et al. 1976). Also during the interval between breeding and molting, passive movements on ice over large distances have been postulated between the White and Barents Sea, and from there further east to the Kara Sea (Popov 1976). Molting bearded seals are considered “most numerous” in the shallows between Kolguev and Kanin Peninsulas in the southern Barents Sea, and are found in modest concentrations along both shores of Novaya Zemlya to Franz Josef land Archipelago, and into the Kara Sea as far east as the Yamal Peninsula and the mouths of the Ob, Yennisey, and P’yasina Bays (Heptner et al. 1976, Popov 1976). A post-breeding migration to molting grounds has also been postulated to occur from the southern Laptev Sea, encompassing the Gulf of Yana, westward to Cape Chulyuskin and Vil’kitsk Strait into the eastern Kara Sea (Heptner et al. 1976). Bearded seals have been regularly reported to haul out on shore in the Sea of Okhotsk during ice-free periods of the summer and fall, and in the southern Laptev Sea at the Gulf of Yana and in the White Sea, areas that are also ice-free and some distance from ice in the summer (Heptner et al. 1976). Although the period when bearded seals are known to use haul-out sites ashore overlaps with their molting season, the molting phenology of bearded seals on shore is unknown.

2.5.4.2.3 Metabolic costs

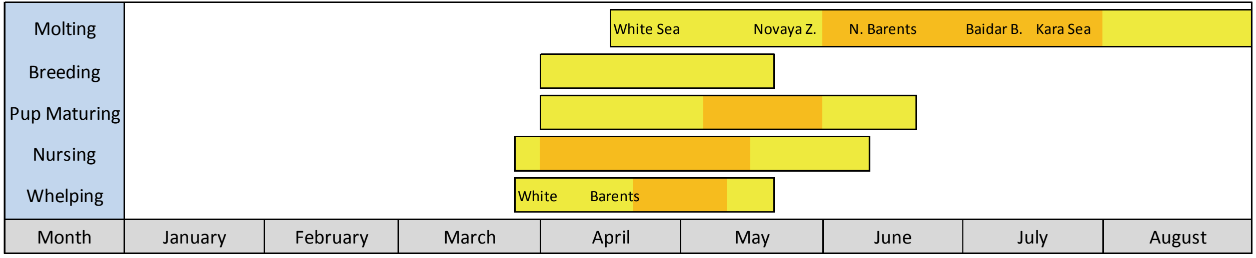
Phocids perfuse their epidermis with blood during molt to promote growth of new hair (Boily 1995). This greater blood supply increases heat loss which, combined with the cost of pelage replacement, may lead to greater energy demands; this hypothesis has been confirmed by studies showing elevated metabolic rates in molting phocid seals (Boyd et al. 1993, Boily 1995, Boily and Lavigne 1997, Chabot and Stenson 2002, Routti et al. 2010). Hence, molting seals haul out of the water to accrue the energetic savings of lower heat flux in air (Feltz and Fay 1966, Ling 1970, Boily 1995). Heat flux models for large phocids that theoretically stay in the water to molt, predict that water temperature must exceed 8°-13 °C for skin mitosis to occur in animals that are thermally neutral (i.e., not expending an additional overhead to maintain body core temperature)(Boily 1995).

To date, there have been no studies on metabolism and the molting energetics of live bearded seals. However, studies on collected bearded seals support a negative energy balance during molting. Measures of body condition and blubber thickness reach their annual minimums after molting (July/August)(Smith 1981, Andersen et al. 1999), similar to findings from three sympatric seals: harp, hooded, and ringed seals (Ryg et al. 1990b, Chabot and Stenson 2002, Thordarson et al. 2007).

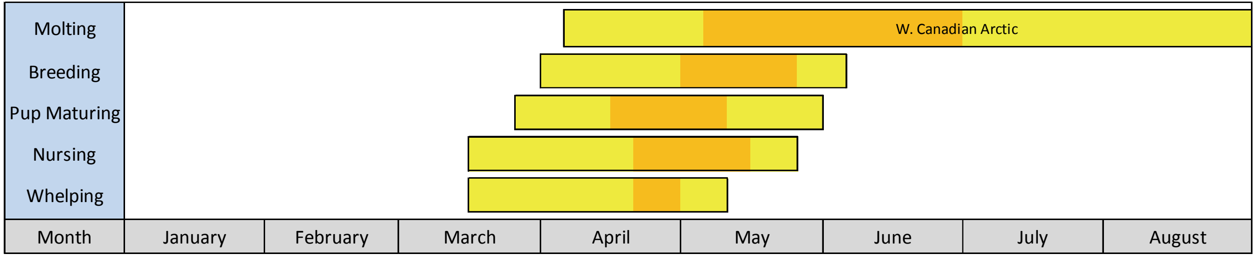
A. NW Atlantic, E. Canadian Arctic [60-83°N]



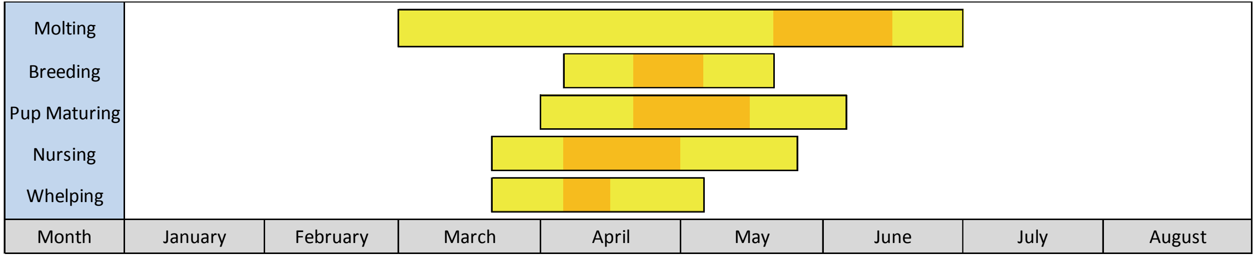
B. White Sea, Barents Sea, Svalbard Archipelago, Kara Sea [65-80°N]



C. Bering Strait , Central Chukchi, W. Canadian Arctic [65-75°N]



D. Southern Bering [55-65°N]



E. Sea of Okhotsk [44-65°N]

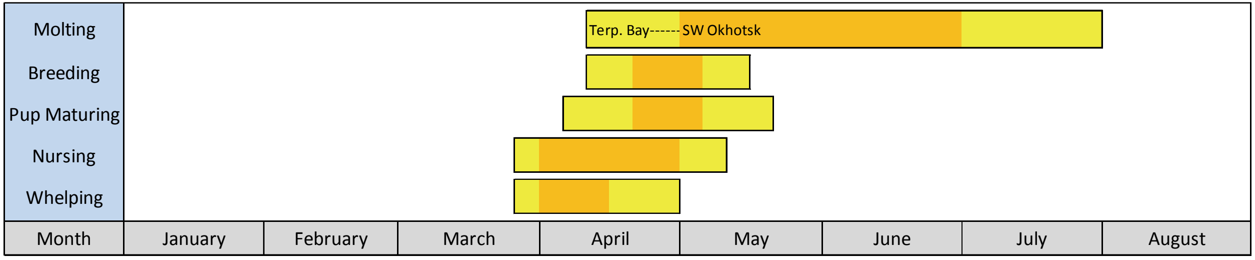


Figure 4. -- Approximate annual timing of the bearded seal's reproduction and molting in five regions of its range. Yellow bars indicate the range over which each event is reported to occur and orange bars indicate the peak timing of each event. For molting, reports for juveniles and adults were combined. "Pup Maturing" refers to the period when weaned pups may remain at least partially dependent on sea ice while they develop proficiency at diving and foraging for themselves. Locations are noted where differences within regions occur.

2.6 Vital Parameters

Information on the biological characteristics of bearded seals is available for all populations, but at various levels of detail and time scales. Data are often difficult to interpret due to possible age- and sex-biased sampling or the effects of exploitation or other anthropogenic impacts on density-dependent parameters, such as productivity and mortality, which may vary during the depletion and subsequent recovery of the sampled populations.

The sex ratio is reported to be 1:1 at birth, but in older age classes it shifts slightly towards females (Johnson et al. 1966). Burns and Frost (1979) suggested that the shift was related to higher mortality for males. Johnson et al. (1966) suggested that the higher proportion of females in the harvest sample they examined may be related to the fact that females were more likely to float than males. Smith (1981) suggested that seasonally increased vulnerability of females or segregation of the sexes could contribute to the prevalence of females in harvests. Burns and Frost (1979) derived mortality estimates based on life tables from 1975-1978 harvest data in the Bering, Chukchi, and Beaufort Seas. Pup mortality approached 60%, decreasing to 19% by age 1 (Burns and Frost 1979, Nelson et al. 1984). Mortality for ages 6 to 20 was about 8% per annum, and increased gradually for older ages (Burns and Frost 1979, Nelson et al. 1984). Based on life tables, about 20% of pups survive to sexual maturity. Quakenbush et al. (2010) determined age distributions and developed survivorship curves for bearded seals harvested during the periods 1962-1978 and 1998-2008 in the Bering and Chukchi Seas. Based on discrete age groups (0 (pup), 1-5, 6-10, 11-15, 16-20, and > 20 years of age) they found fewer age 0 seals in the 1960s versus the 1970s or 2000s. However, a larger proportion of seals aged 6-10 and 11-15 years were observed in the 1960s. In the 1970s and 2000s, the proportion of the older age groups (i.e., ages 6 and older) declined. The survivorship curves supported these trends, as fewer pups and more adults were present in the 1960s than in the latter two periods. Sex ratios were generally female biased, however the pattern was not consistent over time or by age groups. When age classes were pooled, the proportion of males was higher in the 1970s and 2000s.

In general, bearded seals attain sexual maturity at ages 5-6 and 6-7, respectively for females and males (McLaren 1958b, Tikhomirov 1966, Burns 1967, Burns and Frost 1979, Smith 1981, Andersen et al. 1999). While some females may first ovulate at ages 3 or 4 (Tikhomirov 1966, Potelov 1975b, Heptner et al. 1976, Smith 1981, Nelson et al. 1984, Cleator 1996, Fedoseev 2000, Quakenbush et al. 2010), most do not become pregnant until age 5 (Cleator 1996, Fedoseev 2000). Cleator (1996) summarized published ovulation and pregnancy rates and stated “Ovulation ranged from 0.46 and 1.0 (Stirling et al. 1977, Smith 1981), while pregnancy rates range between 0.33 and 0.85 (Burns 1967, Stirling et al. 1977, Smith 1981, Burns and Frost 1983). Typical pregnancy rates (six years and older) were 0.80 to 0.85.”

Quakenbush et al. (2010) examined reproductive tracts collected in the 1960s, 1970s, and 2000s from Alaska Native subsistence harvests. During the three time periods, pregnancy rates (ages 4 years and older) were 88.3%, 91.2% and 93.9%, respectively. Similarly, the majority of female bearded seals in Canadian Arctic (64-86%), and the Barents, Kara, and White Seas (75-85%) become pregnant annually (Tikhomirov 1966, Burns 1967, Potelov 1975b, Popov 1976, Burns and Eley 1978, Burns 1981, Smith

1981). Earlier collections in Canadian Arctic and Bering, Okhotsk and Kara Seas, have suggested only a 50% pregnancy rate (Chapskii 1938, Sleptsov 1943, McLaren 1958b). Some authors have since speculated that such variation could result from differences in carrying capacity between habitats (Burns 1981, Smith 1981), where condition of post-lactating females is constrained by how they balanced the demands of nursing their pups and maintaining their own nutritional reserves. Reproductive senescence has not been reported in this species (Burns and Frost 1979, Cleator 1996)

The normal life span of a bearded seal is about 20-25 years (Kovacs 2002), with a maximum to around 30 years (Benjaminsen 1973, Andersen et al. 1999). McLaren (1958b) used claw annuli to determine ages of seals in the Canadian Arctic. However, due to wearing of the claw tip the maximum ages he assigned to females and males, respectively, were 15+ and 16+ years. Benjaminsen (1973) demonstrated a strong linear relationship between canine tooth length and number of cementum bands, and annuli laid down in claws and cementum in the upper canine from seals collected at Svalbard. Based on both claw annuli and cementum bands in teeth, Smith (1981) reported that the maximum ages for male and females seals in Arctic Canada were 23 and 25 years, respectively, which are similar to what Burns and Frost (1979) reported for males (26) and females (23) in the Bering and Chukchi Seas. In Svalbard, the oldest male and female, respectively, were 27 and 18 years old (Andersen et al. 1999). The latter two studies relied on tooth ages.

2.7 Feeding Habits

Bearded seals feed primarily on benthic organisms, which include epifaunal and infaunal invertebrates, and demersal fishes. They are also able to switch their diet to include schooling pelagic fishes, when advantageous (Finley and Evans 1983, Antonelis et al. 1994). Bearded seals are euryphagous and considered to be foraging generalists because they have a diverse diet with a large variety of prey items throughout their circumpolar range (Table 2) (Vibe 1950, Kenyon 1962, Finley and Evans 1983, Antonelis et al. 1994, Dehn et al. 2007). The stomach contents of individual bearded seals can be either homogeneous or diverse in species composition (Kosygin 1971, Dehn et al. 2007). The bulk of the diet appears to consist of relatively few prey types, primarily bivalve mollusks and crustaceans like crab and shrimps, but fishes like sculpins, Arctic cod (*Boreogadus saida*), polar cod (*Arctogadus glacialis*)[2], or saffron cod (*Eleginus gracilis*) can also be a significant component (Allen 1880, Ognev 1935, Chapskii 1938, Dunbar 1941, Pikharev 1941, Vibe 1950, Wilke 1954, Kenyon 1962, Johnson et al. 1966, Burns 1967, Chugunkov 1970, Fedoseev and Bukhtiyarov 1972, Nikolaev and Skalkin 1975, Heptner et al. 1976, Frost et al. 1977, Burns and Frost 1979, Lowry et al. 1979, Lowry et al. 1980, Finley and Evans 1983, Nelson et al. 1984, Bukhtiyarov 1990, Antonelis et al. 1994, Hjelset et al. 1999, Dehn et al. 2007).

There is conflicting evidence regarding the importance of fish in the bearded seal diet throughout their range. Several studies have found that bearded seals in the Bering and Chukchi Seas mainly consume

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[2] The common names for Arctic cod and polar cod are not internationally consistent. In the United States and in this document, Arctic cod refers to *Boreogadus saida* and polar cod refers to *Arctogadus glacialis*, but in Europe and in some Russian literature, these common names are reversed.

crustaceans and mollusks and that fishes are much less important or even nonexistent in the diet. In these studies the most common species were usually tanner and spider crabs, crangonid shrimps, and clams (Pikharev 1941, Kenyon 1962, Johnson et al. 1966, Lowry et al. 1980, Fedoseev 2000). But other research in the Bering and Chukchi Seas has reported that fishes are an important component in the diet, even a primary prey item in some instances. In these studies, Arctic cod, sculpins, eelpouts, and capelin (*Mallotus villosus*) were the most common fishes observed (Kosygin 1971, Heptner et al. 1976, Lowry et al. 1979, Antonelis et al. 1994, Dehn et al. 2007). The high frequency of benthic fishes in stomachs indicates that seals are intentionally foraging for fish and not just opportunistically ingesting them (Nikolaev and Skalkin 1975). Although most studies found that clams were one of the most important prey items for bearded seals, Kosygin (1971) found that crustaceans occurred most frequently in the diet of seals sampled in the Bering Sea, fish were also important, but he did not find any evidence of clams. Quakenbush et al. (2010) examined stomach contents from bearded seals collected from the 1960s to 2000s in the Bering and Chukchi Seas. They determined that the consumption of fishes increased while fewer invertebrates were consumed in the 2000s compared to the 1960 and 1970s (Quakenbush et al. 2010). In the Sea of Okhotsk, some researchers found that crustaceans and mollusks were the primary prey types and that fishes were unimportant (Pikharev 1941, Fedoseev and Bukhtiyarov 1972), while others determined that fishes were a significant part of the diet (Wilke 1954, Nikolaev and Skalkin 1975, Bukhtiyarov 1990). In the Kara and Barents Seas, Chapskii (1938) concluded that crustaceans and mollusks were the main prey items, but fish, particularly Arctic cod, were also frequently consumed by bearded seals. In the Canadian High Arctic and Svalbard, fishes were much more prevalent in the diet of bearded seals' than invertebrates (Finley and Evans 1983, Hjelset et al. 1999). Fishes composed 85% of the organisms consumed and by weight were a major component of the diet. In contrast, crustaceans composed only 3% of organisms consumed (Finley and Evans 1983). Clams were infrequently found in the stomachs of seals from this area, and almost all of the clams were from one seal that had consumed more than 600 g of *Serripes groenlandicus*. In the Svalbard area, fish composed 70% of all prey organisms found in the stomachs of seals. Crustaceans were the second most important prey group, but in low numbers compared to fishes (Hjelset et al. 1999). Several studies have found high frequencies of fishes in the diet, but it is not known whether major consumption of fish is related to the availability of prey resources or to the preferential selection of prey (Antonelis et al. 1994). For example, Antonelis et al. (1994) determined that seals in the central Bering Sea foraged extensively on capelin, a schooling fish. It is possible that if capelin were not available in dense, nearshore schools in the spring, seals may have consumed crabs or gadids most frequently because they are abundant around St. Matthew Island at that time of year (Antonelis et al. 1994).

Seasonal changes in diet composition have been observed (Johnson et al. 1966, Burns 1967, Lowry et al. 1980, Finley and Evans 1983). Clams and fishes were more important in spring/summer months than in fall/winter; when shrimps (e.g., *Sabinea septemcarinata*) and brachyuran crabs (e.g., *Hyas coarctatus*) made up a greater proportion of the diet (Johnson et al. 1966, Burns 1967, Lowry et al. 1980, Nelson et al. 1984). Clams appear to be the most variable of the major prey types consumed by bearded seals; with changes in the proportion of clams in the diet depending on age class, time of year, and location (Lowry et al. 1980). Clams are known to be a major part of the diet but only in the summer months (Johnson et al. 1966, Burns 1967, Burns and Frost 1979, Lowry et al. 1980). Possible explanations for this seasonality are that clams may become more palatable to seals in the summer, other prey types may not be as available during summer months, and clams may be less active when water temperature is lower in the winter (Burns 1967, Burns 1981, Nelson et al. 1984). Johnson et al. (1966) also suggested that clams may be consumed more frequently in spring/summer because clam beds that were ice-covered during winter become accessible as the ice retreats. Other prey types also showed some seasonal variation. Shrimp were very important in the diet, from November to June and crabs were a major part of the diet from April through June (Johnson et al. 1966). The prey composition of bearded seals also showed interannual variation. In a multi-year study, not all prey species were seen every year, and even species that occurred most frequently in one year were not seen in other years (Kosygin 1971). Fish migrations may change from year to year, or ice conditions could prevent seals from reaching particular foraging grounds in some years, both of which could explain this interannual variation (Kosygin 1971).

Except in very young animals, bearded seals generally have weak dentition, (Kenyon 1962, Johnson et al. 1966, Burns 1967). Older animals have extremely worn teeth, and so they are often limited to consuming prey that can be swallowed whole (Burns 1967). Indeed, many prey items found in stomachs have been mostly intact, including shrimps, amphipods, octopus, nemerteans, and fish (Kenyon 1962, Nikolaev and Skalkin 1975, Finley and Evans 1983). Even smaller crabs have been found eaten whole (Burns 1967, Nikolaev and Skalkin 1975). Finley and Evans (1983) determined that seals were selectively feeding on smaller sculpins. The most common species (*Myoxocephalus scorpius*) is highly sexually dimorphic and the authors assumed that the seals were probably not physically able to swallow the larger, spiny females and so were focusing on males which are half as large (Finley and Evans 1983). Crabs and cephalopods collected from stomachs were also generally small; the largest crustacean found (*Sclerocrangon boreas*) weighed 30 g and the largest cephalopod weighed 50 g (Finley and Evans 1983). Usually only legs and abdomens of mollusks and crabs were found in stomach contents (Johnson et al. 1966, Burns 1967). Crab carapaces rarely occurred in stomachs, indicating that they are discarded before being eaten (Kenyon 1962). Bearded seals also appear to remove the shells from clams and snails before eating them. The remains of clams usually only consist of the feet, which are often undamaged with parts of the visceral mass attached, siphons, and typically only a few tiny shell fragments are present (Kenyon 1962, Johnson et al. 1966, Nikolaev and Skalkin 1975, Lowry et al. 1980, Finley and Evans 1983).

The major prey types of bearded seals are the same in different geographical locations, but the species differ slightly (Burns and Frost 1979, Nelson et al. 1984). This variability in diet is likely a result of differences in prey assemblages in each location (Lowry et al. 1980). Crabs, shrimps, and clams are major prey types for bearded seals in the Bering, Chukchi, and Beaufort Seas, but tanner crabs (*Chionoecetes* spp.) are more important in the southern Bering Sea, and spider crabs (*Hyas* spp.) are most important in the northern Bering, Chukchi, and Beaufort Seas (Burns and Frost 1979, Nelson et al. 1984). The feeding habits of bearded seals in the Bering and Okhotsk Seas are also similar (Kosygin 1971). The main prey types in both regions were crustaceans, mollusks, fishes, and worms, but the most commonly consumed prey species differed slightly between areas (Kenyon 1962, Burns 1967, Kosygin 1971, Frost et al. 1977, Lowry et al. 1979, Lowry et al. 1980, Antonelis et al. 1994). The same crab species (tanner and spider crabs) that were most frequent in the Bering Sea were also found regularly in bearded seals collected off the eastern coast of Sakhalin Island (Nikolaev and Skalkin 1975). However, the fish species found mainly in seals from the Sea of Okhotsk included sea-poachers, flounders, and sand lances, rather than the sculpins, Arctic cod, and eelpout, which are more commonly the prey of seals in the Bering Sea (Burns 1967, Nikolaev and Skalkin 1975, Lowry et al. 1980). Fedoseev and Bukhtiyarov (1972) found that prey composition varied between the northern and southern regions of the Sea of Okhotsk. In the northern area, decapod crustaceans made up 87% of the prey items found, which were followed by mollusks (bivalves, gastropods, cephalopods), and then fishes which only made up 3.7% of prey items (Fedoseev and Bukhtiyarov 1972). In the southern area, bivalves made up the highest proportion of the diet, followed by gastropods, crustaceans, and worms (Fedoseev and Bukhtiyarov 1972, Bukhtiyarov 1990). Seals in the southern Sea of Okhotsk also consumed significantly more fish than in other areas of the Okhotsk (Bukhtiyarov 1990). Lowry et al. (1980) examined geographical variation in the diets of seals collected at seven villages in the Bering and Chukchi Seas. They found that clams, shrimps, and brachyuran crabs were the major prey items at villages in both Bering and Chukchi Seas, except Diomede (in Bering Strait), where fish were more important (Lowry et al. 1980). The primary prey items of bearded seals from the Canadian High Arctic were fishes rather than crustaceans or clams (Finley and Evans 1983). Demersal fishes such as sculpins and schooling fishes such as Arctic cod occurred most frequently and contributed the largest proportion of prey by wet weight. In Greenland waters, bearded seals primarily consumed the gastropod, *Buccinum sp.*, but in areas with depths greater than 100 m, Arctic cod was the primary and sometimes only prey found in stomachs (Vibe 1950).

Changes in bearded seal diet over a 20 year period (1958-1979) were observed at locations in the Bering and Chukchi Seas (Lowry et al. 1980). Lowry et al. (1980) indicated that the frequency of clams in the diet had declined by the end of the study period in the late 1970s. They suggested that the decline may have been due to the expansion of walrus in areas between the Bering Strait and St. Lawrence Island. However, the lower availability of clams in the area may not have had a major effect on the bearded seal population because bearded seals have a variable diet and consume many other benthic prey items. For example, as the number of clams in the diet decreased, the proportion of shrimps increased (Lowry et al. 1980).

Although no differences have been shown between the feeding habits of males and females (Kelly 1988), prey composition showed some variation with age in bearded seals (Lowry et al. 1980). In Hudson Bay, differences in mercury concentrations in the liver of pups (n = 9), juveniles (n = 4) and adults (n = 3) foraging in the same area suggest that these three age classes feed on markedly different prey with juveniles feeding at higher trophic levels than adults (Young et al. 2010). In the Bering Sea, clams, crabs, and shrimps were major foods for all age classes, but their relative importance changed with age (Burns and Frost 1979, Lowry et al. 1980). Based on both frequency of occurrence and volume, clams were more important to older seals and the importance of brachyuran crabs, sculpins, and flatfish also increased with age (Burns and Frost 1979, Lowry et al. 1980, Nelson et al. 1984). Isopods and saffron cod however, were more important to younger animals (Lowry et al. 1980, Nelson et al. 1984), and based on volume, shrimps were also more important to young seals (Burns and Frost 1979, Nelson et al. 1984).

Yet the frequency of occurrence of shrimps in the diet did not change with age and ranged from 92-100% (Lowry et al. 1980). The volumetric importance of shrimps from the Hippolytidae family decreased with age, and the significance of shrimps from the Pandalidae family increased with age (Lowry et al. 1980).

Bearded seals of different ages may forage at different times of day. Kosygin (1971) stated that young seals foraged mostly during the first part of the day and mature adults foraged later in the afternoon. He also concluded that seals often fed at night because stomachs from animals hunted early in the morning contained digested food (Kosygin 1971). This observation is supported by Frost et al. (2008) who found that instrumented young-of-year bearded seals foraged mostly in the morning between 06:00 and 12:00.

Estimating the amount of a particular prey species consumed by bearded seals would require data on the density of bearded seals, their rate of food consumption, and the proportion of their diet consisting of that prey. The precision with which these variables are known will influence greatly the resulting estimate (McAlister 1981, Lowry et al. 1982). Current estimates of bearded seal population levels are considered unavailable as are quantitative estimates of their food requirements. Captive pinnipeds consume 4-10% of their body weight per day, and there is considerable variation with age as well as reproductive and physiological condition (Keyes 1968, Geraci 1975, Gehnrich 1984, Kelly 1988). Variations in bearded seal diet relating to age, season, and geographical location make it difficult to estimate the proportion of particular prey consumed by bearded seal populations.

Table 2. -- Prey species eaten by bearded seals

Species	Common Name	Sources*
FISHES		
Rajidae		
Raja sp.	skate	12, 19
Clupeidae		
Clupea harengus	Atlantic herring	3, 12
Clupea pallasii	Pacific herring	22
Osmeridae		
Mallotus villosus	capelin	6, 9, 18
Hypomesus olidus	pond smelt	9
Osmerus mordax	rainbow smelt	6, 21, 22
unidentified spp.	unknown smelt	3
Salmonidae		
Salmo trutta	brown trout	12
Stenodus leucichthys	inconnu	12
Oncorhynchus gorbuscha	pink salmon	3
unidentified sp.	unknown salmon	3
Macrouridae		
Coryphaenoides cinereus	popeye grenadier	9
Gadidae		

Species	Common Name	Sources*
Boreogadus saida	Arctic cod	2, 7, 8, 12, 15, 16, 18, 20, 22, 23
Eleginus gracilis	saffron cod	6, 8, 9, 15, 17, 22
Eleginus nawaga	Atlantic navaga	12
Gadus macrocephalus	Pacific cod	19
Gadus morhua	Atlantic cod	21
Theragra chalcogramma	walleye pollock	3, 10, 15, 18, 19, 23
Arctogadus glacialis	polar cod	17, 21
Trisopterus esmarkii	Norway pout	20
unidentified spp.	unknown cod	3, 13, 19, 21, 22
Scorpaenidae		
unidentified spp.	rockfish	10, 5
Cottidae		
Gymnocanthus tricuspis	Arctic staghorn sculpin	7, 23
Myoxocephalus quadricornis	fourhorn sculpin	8
Myoxocephalus scorpius	shorthorn sculpin	21
Gymnocanthus sp.	sculpin	8, 23
Myoxocephalus sp.	sculpin	3, 7, 8, 9, 19, 23
Enophrys spp.	Sculpin	23
unidentified spp.	sculpin	6, 8, 15, 16, 17, 19, 21, 22
Agonidae		
Leptagonus decagonus	Atlantic poacher	17
Podothecus accipenserinus	sturgeon poacher	18
Podothecus sp.	poacher	12
unidentified sp.	unknown poacher	3, 23
Cyclopteridae		
Eumicrotremus orbis	Pacific spiny lumpsucker	10
Eumicrotremus spinosus	Atlantic spiny lumpsucker	21
unidentified sp.	unknown lumpsucker	17
Liparidae		
Liparis spp.	snailfish	23
unidentified spp.	unknown snailfish	19
Zoarcidae		
Lycodes palearis	wattled eelpout	10
Lycodes polaris	Canadian eelpout	17
Lycodes mucosus	saddled eelpout	17
Lycodes spp.	eelpout	16, 19, 21, 22, 23, 5
Gymnelus sp.	eelpout	17
unidentified spp.	unknown eelpout	3, 15
Stichaeidae		
Leptoclinus maculatus	daubed shanny	10
Stichaeus nozawae		
Lumpenella longirostris	longsnout prickleback	19
Anisarchus medius	stout eelblenny	21

Species	Common Name	Sources*
Acantholumpenus machayi	blackline prickleback	23
Lumpenus fabricii	slender eelblenny	23
Lumpenus sp.	prickleback	13, 18, 23
unidentified spp.	prickleback	8
Trichodontidae		
Arctoscopus japonicas	sailfin sandfish	18
Ammodytidae		
Ammodytes hexapterus	Pacific sand lance	8, 10, 12, 13, 16, 18, 23
Ammodytes sp.	sand lance	3
Percidae		
unidentified sp.	unknown perch	18
Pleuronectidae		
Lepidopsetta bilineata	rock sole	10
Hippoglossoides elassodon	flathead sole	12, 18
Hippoglossoides platessoides	American dab	20, 21
Limanda aspera	yellowfin sole	18, 23
Limanda proboscidea	longhead dab	23
Pleuronectes platessa	European plaice	13
Pleuronectes glacialis	Arctic flounder	23
Pleuronectes quadrituberculatus	Alaska plaice	23
Hippoglossoides sp.	flounder	19
unidentified spp.	flatfish	3, 6, 8, 10, 15, 16, 18, 22
Unknown family		
unidentified spp.	unknown fish	11, 12, 17, 18, 21
CRUSTACEANS		
Mysida		
Mysidae		
Neomysis rayii	mysid	8, 19, 23
Neomysis spp.	mysid	19, 23
Mysis spp.	mysid	23
Acanthomysis spp.	mysid	23
unidentified spp.	mysid	10, 19
Euphausiacea		
Thysanoessa raschii	Arctic euphausiid	12
Thysanoessa longipes	euphausiid	8
Euphausia pacifica	euphausiid	8
Thysanopoda sp.	euphausiid	8
Amphipoda		
Hyperiidae		
unidentified sp.	unknown hyperiid	19
Dexaminidae		
Atylus carinatus	gammarid amphipod	21
Atylus spp.	gammarid amphipod	23

Species	Common Name	Sources*
Nototropis sp.	gammarid amphipod	10
Uristidae		
Anonyx nugax	gammarid amphipod	13, 23, 5
Anonyx multiarticulatus	gammarid amphipod	10
Anonyx spp.	gammarid amphipod	23
Ampeliscidae		
Ampelisca spp.	gammarid amphipod	8, 23
Gammaridae		
Gammarus locusta	gammarid amphipod	2
Gammarus setosus	gammarid amphipod	21
Gammarus spp.	gammarid amphipod	23
Stegocephalidae		
Stegocephalus inflatus	gammarid amphipod	2
Stegocephalus sp.	gammarid amphipod	10
Gammarellidae		
Gammarellus homari	gammarid amphipod	2
Gammaracanthidae		
Gammaracanthus loricatus	gammarid amphipod	21
Eusiridae		
Rhachotropis aculeata	gammarid amphipod	10, 23
Lysianassidae		
Socarnes bidenticulatus	gammarid amphipod	10
unidentified sp.	gammarid amphipod	21
Melitidae		
Maera sp.	gammarid amphipod	19
unidentified sp.	gammarid amphipod	23
Oedicerotidae		
Acanthostepheia behringiensis	gammarid amphipod	23
Unknown family		
unidentified spp.	unknown amphipod	3, 9, 12, 19, 22
Isopoda		
Chaetiliidae		
Saduria entomon		2, 13, 16, 23
Saduria sp.		8, 22
Idoteidae		
Synidotea bicuspida	isopod	10
Synidotea sp.	isopod	10
Tecticipitidae		
Tecticeps sp.	isopod	3
Arcturidae		
Arcturus baffini	isopod	5
Unknown family		
unidentified spp.	unknown isopod	9, 15

Species	Common Name	Sources*
Decapoda		
Pandalidae		
Pandalus borealis	northern shrimp	8, 21
Pandalus goniurus	humpy shrimp	3, 7, 8, 9, 10, 12, 18, 23
Pandalus hypsinotus	coonstriped shrimp	3, 9, 12
Pandalus jordani	ocean shrimp	10
Pandalopsis aleutica	Aleutian bigeye	8
Pandalus spp.	pandalid shrimp	3, 7, 10, 16, 17, 19, 22, 23
Hippolytidae		
Eualus gaimardii	circumpolar eualid	2, 10, 13, 21, 23
Eualus gaimardii belcherii		8
Eualus fabricii	Arctic eualid	8, 17, 23
Eualus macropthalmus	bigeye eualid	8
Eualus macilentus	Greenland shrimp	10
Lebbeus groenlandicus	spiny lebbeid	3, 8, 9, 10, 23
Lebbeus polaris	polar lebbeid	8, 17, 21
Heptacarpus tridens	threespine coastal shrimp	8
Spirontocaris arcuata	Rathbun blade shrimp	10
Spirontocaris murdochi	Murdoch blade shrimp	12, 18
Spirontocaris spinus	parrot shrimp	4, 17, 21, 5
Spirontocaris phippsii	punctate blade shrimp	21
Spirontocaris polaris	shrimp	5
Spirontocaris furgida	shrimp	5
Hetairus polaris	shrimp	13
Eualus spp.	eualid	9, 10, 12, 16, 19, 23
Lebbeus spp.	shrimp	10, 12, 23
Spirontocaris spp.	hippolytid shrimp	12, 18, 23, 5
Heptacarpus sp.	shrimp	12
unidentified spp.	hippolytid shrimp	2, 7, 18, 21
Crangonidae		
Crangon dalli	ridged crangon	8, 10, 12, 23
Crangon septemspinosa	sand shrimp	3, 8, 18
Crangon alaskensis	northern crangon shrimp	23
Sclerocrangon boreas	sculptured shrimp	2, 3, 4, 7, 8, 9, 10, 1315, 16, 17, 21, 22
Sclerocrangon ferox		2, 13, 17
Sclerocrangon salebrosa	Bering shrimp	3, 18
Argis lar	kuro shrimp	3, 8, 18, 23
Argis crassa	rough argid	8, 23
Argis dentata	Arctic argid	8, 17
Argis levior	Nelson argid	8
Sabinea septemcarinata	sevenline shrimp	1, 2, 17, 21, 5
Neocrangon communis	gray shrimp	3
Argis spp.	argid	7, 9, 14, 15, 16, 19, 23

Species	Common Name	Sources*
Crangon spp.		7, 10, 12, 14, 15, 16, 19, 23
Sclerocrangon spp.		3, 7, 10, 18, 23
Sabinea spp.		13, 23
unidentified spp.	unknown crangonid shrimp	3
Paguridae		
Pagurus pubescens	right-handed hermit crab	2, 3, 13, 21
Pagurus capillatus	right-handed hermit crab	8
Pagurus brandti	sponge hermit	8
Pagurus rathbuni	longfinger hermit	10
Pagurus undosus	Pribilof hermit	10
Pagurus middendorfii	hermit crab	3
Labidochirus splendescens	splendid hermit	8, 10
Pagurus spp.	right-handed hermit crab	3, 7, 9, 10, 23
unidentified spp.	hermit crab	15, 19, 22
Oregoniidae		
Hyas coarctatus	Arctic lyre crab	10, 16, 18, 22
Hyas coarctatus alutaceus	Arctic lyre crab	3, 7, 8, 9, 12
Hyas araneus	Atlantic lyre crab	2, 13, 21
Hyas lyratus	Pacific lyre crab	8, 23
Chionoecetes opilio	snow crab	3, 8, 12, 14, 15, 16, 19, 23
Chionoecetes opilio opilio	snow crab	10
Chionoecetes bairdi	southern tanner crab	8
Chionoecetes spp.	tanner crab	10, 19, 23
Hyas spp.	spider crab	13, 15, 23
Lithodidae		
Paralithodes brevipes	king crab	6, 10
Paralithodes platypus	blue king crab	3
Hapalogaster grebnitzkii	soft crab	3, 23
Dermaturus mandtii	wrinkled crab	3
Paralithodes spp.	crab	10, 23
Hapalogaster sp.	crab	8
Placetron sp.	crab	8
Cheiragonidae		
Telmessus cheiragonus	helmet crab	3, 8, 16, 23
Erimacrus isenbeckii	hair crab	3, 8, 10, 18
Telmessus spp.	helmet crab	23
Oplophoridae		
Hymenodora sp.	ambereye	17
Majidae		
unidentified spp.	unknown spider crab	23
Unknown family		
unidentified spp.	unknown decapod	6, 8, 11, 18
unidentified spp.	unknown crustacean	8, 22

Species	Common Name	Sources*
Sessilia		
Balanidae		
unidentified sp.	unknown barnacle	3
PYCNOGONIDA		
unidentified sp.	unknown sea spider	8
MOLLUSKS		
Cephalopoda		
Gonatidae		
Gonatus sp.	gonatid squid	17
Octopodidae		
Enteroctopus dofleini	Pacific giant octopus	6
Bathypolypus arcticus	spoonarm octopus	17, 21
Octopus spp.	unknown octopus	6, 18, 19, 22, 23
Bathypolypus spp.	unknown octopus	3
unidentified spp.	unknown octopus	10, 12
Ommastrephidae		
Todarodes sagittatus	squid	20
Sepiolidae		
Rossia sp.	squid	21, 5
Octopoda		
unidentified sp.	unknown octopus	8
Unknown family		
unidentified spp.	unknown cephalopod	11
Gastropoda		
Acmaeidae		
Acmaea sp.	limpet	17
Naticidae		
Cryptonatica affinis	Arctic moonsnail	1, 2, 8
Cryptonatica aleutica	moonsnail	9
Euspira pallida	pale moonsnail	10
Natica plausa		5
Natica sp.	moonsnail	3, 16, 19, 23
Polinices sp.	moonsnail	8, 10, 16, 19, 23
Buccinidae		
Buccinum angulosum	angular whelk	7
Buccinum undatum	waved whelk	2
Buccinum ciliatum	whelk	2
Buccinum hydrophanum	whelk	2
Buccinum spp.	whelk	1, 3, 8, 9, 13, 16, 17, 1819, 21, 22, 23, 5
Neptunea spp.	whelk	2, 16, 19, 22
Plicifusus sp.	whelk	7
Colus spp.	whelk	17
Capulidae		

Species	Common Name	Sources*
Trichotropis borealis	boreal hairysnail	9
Conidae		
Oenopota sp.		8
Lamellariidae		
Lamellaria sp.	lamellaria	1
Muricidae		
Boreotrophon sp.	trophon	8
Ranellidae		
Fusitriton oregonensis	Oregon triton	8
Trochidae		
Margarites sp.	margarite	21
Solariella sp.		3
unidentified sp.	unknown trochidae	23
Turritellidae		
Tachyrhynchus sp.	turretsnail	9
Velutinidae		
Velutina velutina	smooth lamellaria	8
Velutina plicatilis	oblique lamellaria	7
Velutina spp.	lamellaria	3, 9, 23
Opisthobranchia		
unidentified sp.	unknown opisthobranch	8
Unknown family		
unidentified spp.	unknown gastropod	3, 10, 11, 12, 15, 18, 20, 21
Bivalvia		
Tellinidae		
Macoma calcarea	chalky macoma	2
Macoma sp.	macoma	17, 23
Tellina spp.	unknown tellin	23
Astartidae		
Astarte borealis	boreal astarte	17
Astarte montagui	narrow-hinge astarte	17
Astarte sp.	astarte	2, 3, 8, 9, 21
Cardiidae		
Serripes groenlandicus	Greenland cockle	7, 9, 16, 17, 18, 21, 22
Clinocardium ciliatum	hairy cockle	9, 13, 16, 17
Clinocardium spp.	unknown cockle	23
Cardium sp.		3
Serripes spp.	unknown cockle	23
Ciliatocardium ciliatum		21
Hiatellidae		
Hiatella arctica	Arctic hiatella	9, 5
Hiatella sp.	unknown hiatella	8
Panomya norvegica	Arctic roughmya	3

Species	Common Name	Sources*
Mactridae		
Mactromeris polynyma	Arctic surfclam	16
Mactromeris spp.	unknown surfclam	23
Spisula sp.	surfclam	9
Myidae		
Mya truncata	truncate softshell	17
Mya arenaria	softshell clam	3
Mya spp.	softshell clam	22, 23
Mytilidae		
Musculus niger	black mussel	17
Musculus spp.	unknown mussel	23
Mytilus sp.	mussel	17
Nuculanidae		
Nuculana pernula	northern nutclam	10
Nuculana sp.		19, 21
Nuculidae		
Ennucula tenuis	smooth nutclam	21
Nucula sp.	nutclam	10
Pholadidae		
Zirfaea pilsbryi	Pilsbry piddock	9
Polyplacophora		
unidentified sp.	unknown chiton	8
Pharidae		
Siliqua spp.	unknown razor	23
Unknown family		
unidentified spp.	unknown bivalve	3, 7, 11, 12, 18, 20
WORMS		
Urechidae		
unidentified spp.	unknown echiuran worm	6
Sipunculidae		
unidentified sp.	unknown sipunculan worm	8
Echiuridae		
Echiurus echiurus	echiuran worm	3, 8, 10, 16
Echiurus sp.	echiuran worm	19
unidentified spp.	echiuran worm	21, 22, 23
Polychaeta		
Pectinariidae		
Cistenides hyperborea	annelid worm	10
Pectinaria sp.	annelid worm	21
Polynoidae		
Eunoe sp.	polynoid worm	16
Harmothoe sp.	polynoid worm	17
unidentified sp.	unknown polynoid worm	21

Species	Common Name	Sources*
Nephytyidae		
Nephtys sp.	nephthyd worm	16
Nereididae		
Neanthes virens	nereid worm	3
Nereis sp.	nereid worm	16
unidentified spp.	unknown nereid worm	23
Chaetopteridae		
unidentified sp.	chaetopterid worm	19
Sabellariidae		
Sabellaria cementarium	worm	3
Unknown family		
unidentified spp.	unknown annelid worm	4, 7, 8, 9, 10, 11, 15, 2223, 5
Hirudinea		
unidentified sp.	unknown leech	8
Pogonophora		
unidentified sp.	unknown pogonophore	10
Enopla		
unidentified sp.	unknown nemertea	12
PORIFERA		
Spongiidae		
Spongia sp.	sponge	3, 10
Unknown family		
unidentified spp.	unknown sponge	7, 8, 23
CNIDARIA		
Hydractiniidae		
Hydractinia sp.	unknown hydractinia	8
Sertulariidae		
Sertularia sp.	unknown hydroid	3
Oculinidae		
Neohelia maxima		5
Actiniaria		
unidentified spp.	unknown anemone	3, 17
PRIAPULA		
Priapulidae		
Priapulus caudatus	priapulid	3, 10, 13
unidentified spp.	priapulid	23, 5
Unknown family		
unidentified sp.	unknown priapulid	8, 19, 22
ECHINODERMATA		
Holothuroidea		
unidentified spp.	unknown sea cucumber	22, 23
Echinoidea		
unidentified spp.	unknown urchin	23

Species	Common Name	Sources*
Cucumariidae		
Cucumaria frondosa	sea cucumber	13, 5
Cucumaria calcigera	sea cucumber	3
Thyonidium sp.	sea cucumber	17
Synaptidae		
unidentified sp.	sea cucumber	3
Molpadiidae		
Molpadia sp.	sea cucumber	3
Echinarachniidae		
Echinarachnius parma	sand dollar	3
TUNICATA		
Styelidae		
Cnemidocarpa rhizopus	ascidian	21
Pyuridae		
Boltenia echinata		3
Boltenia sp.		8
Ascidiacea		
unidentified sp.	unknown tunicate	3, 13
Ascidiidae		
unidentified spp.	unknown tunicate	23
Unknown family		
unidentified spp.	unknown tunicate	23
BRYOZOA		
Unknown family		
unidentified spp.	unknown bryozoan	23
PLANTS		
Zosteraceae		
Zostera marina	eel grass	6
Phyllospadix sp.	surfgrass	3

*Sources: (1) Allen 1880, (2) Chapskii 1938, (3) Pikharev 1941, (4) Dunbar 1941, (5) Vibe 1950, (6) Wilke 1954, (7) Kenyon 1962, (8) Johnson et al. 1966, (9) Burns 1967, (10) Kosygin 1971, (11) Fedoseev and Bukhtiyarov 1972, (12) Nikolaev and Skalkin 1975, (13) Heptner et al. 1976, (14) Frost et al. 1977, (15) Lowry et al. 1979, (16) Lowry et al. 1980, (17) Finley and Evans 1983, (18) Bukhtiyarov 1990, (19) Antonelis et al. 1994, (20) Hauksson and Bogason 1995, (21) Hjelset et al. 1999, (22) Dehn et al. 2007, (23) Quakenbush et al. 2010

2.8 Historic and Current Abundance and Trends

No accurate worldwide abundance estimates exist for bearded seals. Bychkov (1971) citing Chapskii (1966) reported a species-wide estimate of 750,000 seals; 300,000 in the area roughly equivalent to the range of *E. b. barbatus* and 450,000 in the range of *E. b. nauticus.* A decade later, Burns (1981) cited these numbers while referencing an estimate of 300,000 bearded seals from his own unpublished work in the Bering and Chukchi Seas. Stirling and Archibald (1979) estimated a world population in excess of 500,000, and more recently Kovacs (2002), based on reviews of catch history from the second half of the 20th century, reasoned that the global population was likely in the hundreds of thousands, while Blix (2005) suggested that the total population is in the order of 1 million. Aerial and shipboard surveys of abundance have been conducted sporadically in various areas over the past six decades (Table 3) (McLaren 1958a, Shustov 1972, Stirling et al. 1982, Braham et al. 1984, Burkanov et al. 1988, Fedoseev et al. 1988, Lunn et al. 1997, Fedoseev 2000, Bondarev 2004, Ognetov 2008).

Several factors make it difficult to accurately assess bearded seals' abundance and trends. The remoteness and dynamic nature of their sea-ice habitat along with their broad distribution and seasonal movements makes surveying bearded seals expensive and logistically challenging. Additionally, the species' range crosses political boundaries and there has been limited international cooperation to conduct range-wide surveys. Details of survey methods and data are often limited or have not been published, making it difficult to judge the reliability of the reported numbers, especially some produced by Soviet-era, Russian government institutions. Logistical challenges also make it difficult to collect the necessary behavioral data to make proper adjustments to seal counts. Until very recently, no suitable behavioral data have been available to correct for the proportion of seals in the water at the time of surveys. Research is just beginning to address these limitations and so current and accurate abundance estimates are considered unavailable.

Table 3. -- Bearded seal survey results and abundance estimates (in thousands). Several of the reported estimates were based on surveys with incomplete coverage, and researchers used various survey and analysis techniques which may not be directly comparable; therefore, caution is advised when interpreting these data.

Year	Sea of Okhotsk	Bering Sea	E. Beaufort Sea	Hudson Bay and Canadian Arctic Archipelago	Barents, Kara and White Seas	Source
1951				186		McLaren 1958a
1968	233					Fedoseev 2000
1969	253					Fedoseev 2000
1970	180	90				Shustov 1972
1971					2.8^{WS}	Bondarev 2004
1972		221*				Kenyon 1972
1974	110	87^{W}				Fedoseev 2000
1974			3.1			Stirling et al. 1982
1975			1.4			Stirling et al. 1982
1976	125	57^{W}				Fedoseev 2000
1976		1.9^{N}				Braham et al. 1984
1976		2.9^{SE}				Braham et al. 1984
1976			1.7			Stirling et al. 1982
1977			1.3			Stirling et al. 1982
1978			3.1			Stirling et al. 1982
1979	187	83^{W}				Fedoseev 2000
1979			2.1			Stirling et al. 1982

1979			7.4-9.5		Koski 1980
1981	104				Fedoseev 2000
1984		2^{K}			Burkanov et al. 1988
1986		1.1^{K}			Burkanov et al. 1988
1986	143				Fedoseev 2000
1987		1.1^{K}			Burkanov et al. 1988
1987		52-65			Fedoseev et al. 1988
1987		84^{W}			Fedoseev 2000
1988	143				Fedoseev 2000
1989	105				Fedoseev 2000
1990	95				Fedoseev 2000
1993				4^{WS}	Bondarev 2004
1994			12^{WH}		Lunn et al. 1997
1995			1.9^{WH}		Lunn et al. 1997
2003		3-65^{C*}			Simpkins et al. 2003
2003				5.8-6.2^{WS}	Bondarev 2004
2007		38-139^{C}			Footnote 1
"Current"				15^{NB}	Lydersen and Wiig
"Current"				25-30	Ognetov 2008

^{W} western Bering Sea
^{N} northern Bering Sea
^{SE} southeastern Bering Sea
^{B} Baffin Bay
^{K} Karaginski Gulf
^{WS} White Sea
^{WH} western Hudson Bay
^{C} central Bering Sea
^{NB} northern Barents Sea including Svalbard
* Actual count, not an abundance estimate in thousands

2.8.1 Erignathus barbatus nauticus

2.8.1.1 Sea of Okhotsk

Aerial surveys conducted in the Sea of Okhotsk during 1968-1969 provided a population estimate of 233,000-253,000 bearded seals, with the majority in the northern part of the sea and fewer in the south around Sakhalin Island (Fedoseev 1970, Fedoseev 1971). Fedoseev (1971) did not make adjustments for seals in the water because the estimated survey error (20%) was greater than the assumed correction coefficient (16-17%). Shustov (1972) and Popov (1976) reported identical estimates but did not cite Fedoseev's (1970, 1971) work. Shustov (1972) suggested that bearded seal numbers had stabilized at very low levels after years of intensive harvesting and Popov (1976) considered seals in the north and south to be separate populations. Coastal aerial surveys were conducted in 1986 and over 2,000 bearded seals were counted (Lagarev 1988). Fedsoseev (2000) presented multiple years of unpublished data from 1968 to 1990 and estimated bearded seal abundance in the Sea of Okhotsk between 200,000 and 250,000 seals with 60,000-75,000 around eastern Sakhalin Island. Most surveys were designed primarily for ringed and ribbon seals, as they were more abundant and of higher commercial value. Although adjustments were made for seals in the water, this was assumed to be 30% for all species at all times of day based on ship observations partially published by Shustov (1969). Fedoseev (2000) did not provide specific methodology for any of the surveys or analyses, though he stated that his highest confidence was in the bearded seal estimates from 1968 and 1969. Recognizing the sparse documentation of the survey methods and data, as well as the 20 years or more that have elapsed since the last survey, the BRT recommends considering the 1990 estimate of 95,000 individuals to be the current bearded seal population in the Sea of Okhotsk.

2.8.1.2 Bering Sea

The earliest aerial survey of the entire Bering Sea took place in 1972 and was focused on estimating the abundance and distribution of walrus (Kenyon 1972). Over 200 bearded seals were seen on the survey but no reliable abundance estimate could be calculated. In 1976, surveys of the Bering Sea ice front were conducted by Alaska Department of Fish and Game (ADFG). Unstratified density estimates from these data were calculated to be 0.083 bearded seals/nmi^2 in the southeastern Bering Sea and 0.141 bearded seals/nmi^2 in the north (Braham et al. 1984). This research was a joint U.S.-Soviet effort and is the most thorough survey of the Bering Sea to date. Abundance estimates from these surveys were reported at 2,452 (stratified) and 2,948 (unstratified) in the southeast in an area >35,000 nmi^2, and 1,732 (stratified) and 1,917 (unstratified) bearded seals in the north in an area between 13,000 – 14,000 nmi^2. Only seals on the ice were counted, and no adjustment was made for seals in the water. Kibal'chich et al. (1979) estimated as many as 64,588 bearded seals on the ice in the Karaginski, Kamchatka, and Anadyr Bays and the Ozernoy Gulf in spring of 1979. Without citing methods, Fedoseev (2000) corrected this estimate for haulout to 87,000. Burkanov (1988) estimated 2,000 bearded seals in the Karaginski Gulf in 1984, and 1,100 in both 1986 and 1987. From sightings in the western Bering Sea of 223 bearded seals in April 1987 and 244 bearded seals in May 1987, Fedoseev (1988) estimated populations of 52,063 and 64,709 bearded seals, respectively. Curiously, when reporting an estimate from these same areas and years in a later publication Fedoseev (2000) reported a number of 84,000 but provided no explanation for the difference.

Aerial surveys were conducted by the National Marine Mammal Laboratory (NMML) in the central Bering Sea pack ice in 2003 (Simpkins et al. 2003), 2007 (Cameron and Boveng 2007, Moreland et al. 2008), and 2008 (Cameron et al. 2008). Data from 2007 have recently been analyzed for abundance in an area of 81,600 km^2 in the eastern Bering Sea in April and May (Footnote 1). The study used sightings from 2,748 km^2 of aerial line transect surveys and accounted for seals in the water using a generalized linear mixed model for seal haul-out probability (Ver Hoef et al. 2010) and for incomplete detection through standard distance-sampling methods (Buckland et al. 2001) along with a double-observer model (Borchers et al. 2006). The availability and detection models were combined in a Horvitz-Thompson-like sampling model for local abundance in space and time. Remotely sensed ice images were used as part of a hierarchical spatially-autocorrelated regression model to predict abundance at each survey date, and Bayesian estimation methods provided an estimate of 63,200 bearded seals with a 95% credible region estimate of 38,400 to 138,600. This is a partial estimate for bearded seals in the U.S. waters of the

Bering Sea because the survey area did not include known bearded seal habitat in the eastern Bering Sea and north of St. Lawrence Island. The estimate is similar in magnitude to the western Bering Sea estimates reported by Fedoseev (2000) from surveys in 1974-1987, ranging from 57,000 to 87,000. The BRT recommends considering the current total Bering Sea bearded seal population to be about double the estimate reported by Ver Hoef et al. (2010), or approximately 125,000 individuals.

2.8.1.3 Chukchi Sea

Aerial surveys flown along the coast from Shishmaref to Barrow during May-June 1999 and 2000 resulted in an average density of 0.07 seals/km^2, and 0.14 seals/km^2 respectively, with consistently high densities along the coast to the south of Kivalina (Bengtson et al. 2005). These densities were not converted to an abundance estimate due to the lack of appropriate correction factors. Without any correction for seals in the water, a crude estimate based on the areas surveyed in the two years and the calculated densities yields about 13,600 bearded seals. These surveys covered only a portion (U.S. coastal) of the Chukchi Sea. Assuming that the waters along the Chukchi Peninsula on the Russian side of the Chukchi Sea contain similar numbers of bearded seals, the combined total would be about 27,000 individuals.

2.8.1.4 Beaufort Sea

Aerial surveys of the eastern Beaufort Sea conducted in June during 1974 – 1979, provided estimates that averaged 2,100 bearded seals (Stirling et al. 1982), uncorrected for seals in the water. Annual variations in abundance (range = 1,300-3,100) may have been due to differences in sea ice conditions. It should be noted that because the surveys were designed chiefly for examining the distribution and density of ringed seals, their coverage of strata with the highest densities of bearded seals may not have been adequate. Bearded seals were much less abundant than ringed seals, and accurate estimates of their densities would have required greater coverage of survey areas (Kelly 1988). The ice-covered continental shelf of the western Beaufort Sea is roughly half the area surveyed by Stirling et al. (1982), suggesting a crude estimate for the entire Beaufort Sea in June of about 2,100 X 1.5 = 3,150, uncorrected for seals in the water. For such a large area in which the subsistence use of bearded seals is important to Alaska Native and Inuvialuit communities, this number is likely to be a substantial underestimate. A possible explanation is that many of the subsistence harvests of bearded seals in this region may occur after a rapid seasonal influx of seals from the Bering and Chukchi Seas in the early summer, but slightly later than the June period in which Stirling et al (1982) conducted their surveys.

2.8.1.5 East Siberian Sea

Obukhov (1974) described bearded seals as rare, but present during July-September, based on year-round observations (1959-1965) of a region extending about 350 km east from the mouth of the Kolyma River. Typically, one bearded seal was seen during 200-250 km of travel. Geller (1957) described the zone between the Kola Peninsula and Chukotka as comparatively poor in marine mammals relative to the more western and eastern portions of the northern Russian coasts. The BRT is not aware of any other information about bearded seal abundance in the East Siberian Sea.

2.8.2 Erignathus barbatus barbatus

2.8.2.1 Hudson Bay, the Canadian Arctic Archipelago and western Baffin Bay

In 1958 McLaren (1958a) calculated a population estimate of 186,000 bearded seals in the waters of Foxe Basin, Hudson Bay, Hudson Strait, Ungava Bay, Cumberland Sound, Frobishier Bay, and off of northern and eastern Baffin Island. The estimate was based on the relative numbers of bearded seals to ringed seals sighted during shipboard surveys, assumptions of suitable habitat and catch statistics. By the author's own admission, "not much confidence can be attached to these figures."

Aerial surveys of Baffin Bay in 1978 from early-May through mid-July reported densities of bearded seals ranging from 0.003/km^2 to 0.0442/km^2 (Koski 1979). Similar surveys in 1979 reported densities of bearded seals in early- and late-June of 0.0382/km^2 and 0.0338/km^2, respectively, which were then scaled up for the area surveyed to produce estimates of 9,500 and 7,400 seals respectively, though they were not corrected for seals in the water at the time of survey. Lunn et al. (1997) provided "visual" population estimates of 12,290 and 1,980 for western Hudson Bay in June for the years 1994 and 1995 respectively. Although the study attempted to adjust for various environmental variables (e.g., ice concentration, wind speed and duration and cloud cover), the researchers were unable to correct for seals in the water. Differences between the two estimates were thought to be the result of ice conditions or observer bias.

After summing these different indices (and others for the Beaufort Sea) for bearded seal abundance, Cleator (1996) suggested that a minimum of 190,00 bearded seals inhabit Canadian waters. This minimum estimate was produced for a status review of the bearded seal for the the Canadian Department of Fisheries and Oceans (DFO). The BRT recommends considering the current bearded seal population in Hudson Bay, the Canadian Archipeligo and western Baffin Bay to be about 188,000 individuals. This value was chosen simply as the DFO estimate for all of Canada (190,000) minus 2,000 to account approximately for the average number estimated by Stirling et al. (1982) to occur in the Canadian portion of the Beaufort Sea, which we have assumed are part of the *E. b. nauticus* subspecies (see Section 3).

2.8.2.2 Greenland

The conservation status of bearded seals in Greenland is cited as "Favorable" but they are listed as "Data Deficient" on the Greenland Red List (Boertmann 2008, Boertmann et al. 2009b). Bearded seals are often noted as widespread and common around the island, but occur mostly in low densities (Boertmann et al. 2009b). The species is an important subsistence resource in Greenland and though local populations are surveyed somewhat regularly, the BRT was unable to find survey results that included specific estimates of abundance which would allow us to derive an island-wide estimate for the number of bearded seals. Indeed, the population size is regularly cited as "unknown" and the population trend as "probably stable" or "unknown" (Boertmann et al. 1998, Mosbech et al. 2000, Boertmann et al. 2009a, Nielsen 2010). Most recently the North Atlantic Marine Mammal Commission remarked that "There is no abundance estimate nor information on stock status despite a continued exploitation of the species" (NAMMCO 2010).

2.8.2.3 Barents, Kara and White Seas and Svalbard

Bondarev (2004) briefly described the results of three shipboard surveys for bearded seals in 1971, 1993 and 2003 providing estimates of 2,800, 4,000 and 5,800-6,200 seals, respectively. The survey methods were only briefly described and appeared to be similar to aerial line transect surveys except, owing to the lack of sea ice in the study area, the observers were primarily focused on seals in the water. The surveys covered different areas, in different months and the calculations used to estimate abundance (though not provided in detail) were different for each survey. Considerations for sea state were applied to the 2003 estimates, although without further information it is impossible to determine the reliability of even these recent estimates.

Similarly, Ognetov (2008) provided an estimate of "no more than" 25,000-30,000 bearded seals in the Barents, White and Kara Seas without describing any methods. These numbers were contrasted with an earlier estimate of 50,000 seals in the same area by Timoskenko and Potelov (1974).

Lydersen and Wiig (1995) presented two rough estimates for bearded seals inhabiting the Barents Sea including Svalbard. The first was a range of 10,000 to 100,000 seals and was based on an estimate of 300,000 seals in the Barents, White Kara and Laptev Seas, and the knowledge that many animals that winter in the White and Kara Seas migrate into the Barents Sea during summer and fall (Potelov 1975a). The base estimate of 300,000 is from an English translation of Bychkov (1971) citing Chapskii (1966). There is confusion about this number in the literature and the BRT feels that Chapskii's (1966) estimate of 300,000 likely also included bearded seals in eastern Canada, including Hudson Bay. If true, Lydersen and Wiig's (1995) first estimate range would be high. Their second estimate of 15,000 seals was calculated using a northern Barents Sea and Svalbard estimate of 200,000 ringed seals and a ringed seal/bearded seal ratio of 13:1 for Baffin Island (Smith, T.G. cited in King 1983). None of these estimates appear to be based upon any direct surveys of bearded seals in the Barents Sea.

An aerial survey designed to estimate the abundance of ringed seals in Van Mijenfjorden and Van Keulenfjorden—representing about 30% of the fast-ice covered fjords in Spitsbergen, Svalbard—in June 2003 also recorded the numbers of bearded seals observed (Krafft et al. 2004). The survey was conducted almost entirely over fast ice, a habitat not preferred by bearded seals, and only 27 bearded seals were estimated to be present on the ice in the study area.

2.8.2.4 Laptev Sea

The BRT is not aware of any information about bearded seal abundance in the Laptev Sea. Although present, bearded seals are reported to be somewhat rare in this area which led Heptner et al. (1976) to suggest that the boundary between *E. b. barbatus* and *E. b. nauticus* in Russia lies in the eastern Laptev Sea.

2.8.3 Trends

Although the estimates of bearded seals in the Sea of Okhotsk appear to reflect a decrease in population size over time (Table 3), Fedoseev (2000) stated that recognizing even large scale fluctuations in the abundance of bearded seals in Russian waters after 1970 is not possible due to differences in aerial surveys, study designs and funding. Burkanov (1988) also reported a decline in bearded seal numbers in Karaginski Gulf from 1984-1986 but noted that absolute counts were higher than the lower bounds he presented as population estimates. Similar to Stirling et al. (1977), Bengtson et al. (2005) suggested that the different densities of seals reported along the Chukchi Sea coastline in 1999 and 2000 were the result of inter-annual variation in ice conditions or prey distribution and abundance.

Because of the imprecision and incompleteness of abundance estimates for bearded seals, there are no reliable quantitative estimates of population trends for the species as a whole or for the major breeding concentrations (Taylor et al. 2007). Although it is sometimes possible to monitor trends by indexes of population size rather than complete abundance estimates (e.g., Small et al. 2003), this method has not been applied to bearded seals, likely because of the remoteness of their seasonal concentrations and high costs of repetitive monitoring.

In some cases, qualitative assessments of trends may be more useful than imprecise quantitative estimates. An Alaska Native hunter from Saint Lawrence Island reported that bearded seals were in better condition and that hunters were having greater success than in the past (Pungowiyi 2000). He suspected that the greater numbers observed were due to changes in ice and weather but did not speculate on whether the population had actually increased or there was simply a shift in distribution toward Saint Lawrence Island. In contrast, Alaska Native hunters from Hooper Bay, one of five Bering and Chukchi Sea communties surveyed by ADFG, noted a perceived decline in the availability of bearded seals (Quakenbush and Sheffield 2007, Quakenbush et al. 2010) in their region. The hunters in the remaining four communities reported that bearded seals are present in similar numbers and found in the same areas as in the past. Hooper Bay is the southernmost of the villages surveyed, on the margin of the bearded seal range in the Bering Sea, and was also the only community to report that the bearded seal is not the most important species they hunt. This custom may also reflect historical overall lower abundance in this area. All villages in the report have noticed longer ice-free periods, which shorten the hunting season. Given bearded seals' affinity for sea ice, it is likely that they do not range as far south during periods of reduced ice extent. Because the hunters in these communities have a regular presence in bearded seal habitat and a keen interest in the well-being of the seal populations, they may currently be one of the best hopes for detecting any substantial declines in the near future. Comprehensive surveys of the major zones of bearded seal habitat should be made a high priority for research and monitoring so that quantifying medium- to long-term trends will be possible.

3 SPECIES DELINEATION

To be considered for listing under the ESA, a group of organisms must constitute a “species”, which according to the ESA includes “any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature”.

Two subspecies of bearded seals are widely recognized: *E. b. barbatus* often described as inhabiting the Atlantic sector, and *E. b. nauticus* inhabiting the Pacific sector (Rice 1998). The geographic distributions of these subspecies are not separated by conspicuous gaps. There are regions of intergrading generally described as somewhere along the northern Russian and central Canadian coasts (Burns 1981, Rice 1998). Scheffer (1958) accepted the division largely as a matter of convenience while noting that Bobrinskii et al. (1944) believed the division, at least along the Russian coast, was unjustified. Manning (1974) asserted that efforts by Allen (1902), Anderson (1930, 1946), Osgood (1904) and Ognev (1935) to address the question using skulls from the two sectors were largely based on appearance rather than on detailed measurements. Kosygin and Potelov (1971) conducted a more systematic study of craniometric and morphological differences between bearded seals in the White, Barents, and Kara Seas (collectively named the “Barents Sea population”), and bearded seals in the Bering Sea and Sea of Okhotsk. They reported differences in measurements between the three regions, but suggested that the differences were not significant enough to justify dividing the population into two or more subspecies. Manning (1974), tested the differences in skull measurements between two groups: an Atlantic group composed of skulls collected from Norway, Svalbard, Greenland, and the central and northeastern Canadian coast, and a Pacific group composed of skulls collected from the Bering, Chukchi and East Siberian Seas, Japan, and the northwest coast of Canada (six of the skulls collected along the Canadian coastline between the Amundsen Gulf and Pelly Bay were considered likely to be intermediate forms between the two subspecies and so omitted from analyses). He recommended the continued recognition of the two subspecies but was unwilling to define their exact boundaries without additional samples.

It should be noted that the phenotypic characters used in these studies do not necessarily reflect genetic structure. Fedoseev (2000) indicated that much of the variation in cranial characteristics is likely to reflect regional variation in diet, ice conditions, and ecological communities. Thus, two populations differing substantially in characteristics that reflect residence in or development under local conditions will still be relatively homogeneous genetically if there is sufficient breeding dispersal. In summary, the morphological studies of differences between putative breeding areas may reflect some actual structure in the population, but the strength of the discreteness, and the details of which areas were reported to differ from other areas may not be reliable on their own for justifying a division into subspecies.

Genetic information is likely to be a more direct reflection of taxonomic structure, and for that reason has become a common and important tool for supplementing or replacing morphometrics in studies of both phylogeny and population structure. Davis et al. (2008) examined micro-satellite DNA at 13 loci from 119 bearded seals sampled at locations in the Bering Sea (Saint Lawrence Island and the Gulf of Anadyr); the Beaufort Sea; Qaanaaq, Greenland; the Labrador Sea; and Svalbard, Norway. Their analysis indicated that the most likely number of populations was two. One cluster included all of the seals sampled in the Bering Sea and one of the seals sampled in the Beaufort Sea. The second cluster included the remaining 15 seals sampled in the Beaufort Sea and all seals sampled in Greenland and Svalbard. These groupings support the continued recognition of two subspecies; *E. b. barbatus* in the Atlantic sector and *E. b. nauticus* in the Pacific sector.

In this case, the morphometric and genetic results are qualitatively similar, though the number and distribution of samples are insufficient for precise specification of the best placement of boundaries within zones of likely intergradation of the two subspecies. Despite doubts expressed by some about the veracity of dividing *E. barbatus* into two subspecies the BRT concluded that the evidence for retaining the subspecies is stronger than any evidence for combining them.

3.1 Consideration of Distinct Population Segments

Under the ESA, a species division smaller than a subspecies may be afforded protection if it is a "distinct population segment." The term "distinct population segment" (DPS) is not commonly used in scientific discourse, so the USFWS and NMFS developed the *Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act* (partially quoted below) to provide a consistent interpretation of this term for the purposes of listing, delisting, and reclassifying vertebrates under the ESA:

> *"Three elements are considered in a decision regarding the status of a possible DPS as endangered or threatened under the Act. These are applied similarly for addition to the lists of endangered and threatened wildlife and plants, reclassification, and removal from the lists:*
>
> 1. *Discreteness of the population segment in relation to the remainder of the species to which it belongs,*
> 2. *The significance of the population segment to the species to which it belongs, and*
> 3. *The population segment's conservation status in relation to the Act's standards for listing (i.e., is the population segment, when treated as if it were a species, endangered or threatened?).*
>
> *Discreteness: A population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:*
>
> 1. *It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.*
> 2. *It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the Act.*
>
> *Significance: If a population segment is considered discrete under one or more of the above conditions, its biological and ecological significance will then be considered in light of Congressional guidance (see Senate*

> *Report 151, 96th Congress, 1st Session) that the authority to list DPSs be used ''… sparingly'' while encouraging the conservation of genetic diversity. In carrying out this examination, the Services will consider available scientific evidence of the discrete population segment's importance to the taxon to which it belongs. This consideration may include, but is not limited to, the following:*
>
> 1. *Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon,*
> 2. *Evidence that loss of the discrete population segment would result in a significant gap in the range of a taxon,*
> 3. *Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or*
> 4. *Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.*
>
> *Because precise circumstances are likely to vary considerably from case to case, it is not possible to describe prospectively all the classes of information that might bear on the biological and ecological importance of a discrete population segment.*
>
> *Status: If a population segment is discrete and significant (i.e., it is a distinct population segment) its evaluation for endangered or threatened status will be based on the Act's definitions of those terms and a review of the factors enumerated in section 4(a). It may be appropriate to assign different classifications to different DPSs of the same vertebrate taxon"* (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1996).

The BRT applied this policy to determine whether either of the bearded seal subspecies merited delineation into DPSs. This analysis is described in the following sections.

3.1.1 Evaluation of Discreteness

3.1.1.1 Separation by Physical, Physiological, Ecological, or Behavioral Factors

The range of the species occurs in cold, seasonally or annually ice-covered Arctic and sub-Arctic waters, without persistent intrusions of warm water or other conditions that would pose potential physiological barriers. Furthermore, the seasonal timings of reproduction and molting vary little throughout the bearded seal's distribution suggesting that there are no obvious ecological separation factors.

The underwater vocalizations of males during the breeding season recorded in U.S., Canadian and Norwegian waters are often more similar between adjacent geographical regions than between more distant sites, suggesting that bearded seals may have strong fidelity to specific breeding sites (Cleator et al. 1989, Van Parijs et al. 2003, Risch et al. 2007). However, these same researchers stated that observed differences in vocalizations may be due to other factors such as ecological influences or sexual selection, and not to distance or geographic barriers. Bearded seals are known to make seasonal movements of greater than 1,000 km (Gjertz et al. 2000, Frost et al. 2005, Cameron 2007, Frost et al. 2008, Cameron and Boveng 2009), and so only very large geographical barriers would have the potential by themselves to maintain discreteness between breeding concentrations. As primarily benthic feeders, bearded seals may be constrained to relatively shallow waters and so expanses of deep water may also pose barriers.

3.1.1.1.1 Erignathus barbatus nauticus

Given the bearded seals' circumpolar distribution and their ability to travel long distances, it is difficult to imagine that land masses pose a significant barrier to their movement except perhaps for the great southerly extent of the Kamchatka Peninsula. The seasonal ice does not extend south to the tip of that peninsula, and the continental shelf is very narrow along its eastern, Bering Sea coast. The seals' affinity for ice and shallow waters may help to confine bearded seals to their respective sea basins in the Bering or Okhotsk Seas. Heptner et al. (1976) and Krylov et al. (1964), described a typical annual pattern of bearded seals in the Sea of Okhotsk to be one of staying near the ice edge when ice is present and then moving north and closer to shore as the ice recedes in summer. Unlike other researchers describing tendencies of the species as a whole, Krylov et al. (1964) described the bearded seal as more or less sedentary, based primarily on observations of seals in the Sea of Okhotsk. Indeed, published maps indicate that the southeastern coast of the Kamchatka Peninsula is the only location where the distribution of the bearded seal is not contiguous (Burns 1981, Kovacs 2002, Blix 2005), and there are no known records of bearded seals moving between the Sea of Okhotsk and Bering Sea. Fedoseev (1973, 2000) suggested that differences in the numbers of lip vibrissae as well as length and weight indicate population structure between the Bering and Okhotsk Seas.

3.1.1.1.2 Erignathus barbatus barbatus

The Greenland and Norwegian Seas, which separate northern Europe and Russia from Greenland form a very deep basin and could potentially act as a type of physical barrier to a primarily benthic feeder. The *a priori* groupings in Manning's (1974) craniometric study precluded him from studying the differentiation of additional subpopulations. Risch et al. (2007) described distinct differences in male vocalizations at breeding sites in Svalbard and Canada, however they also suggested that ecological influences or sexual selection, and not a geographical feature restricting gene flow, could be the cause of these difference. Gjertz (2000) described at least one pup known to travel from Svalbard nearly to the Greenland coast across Fram Strait, and Davis et al. (2008) failed to find a significant difference between populations on either side of the Greenland Sea. Both studies suggest that the expanse of deep water is apparently not a geographic barrier to bearded seals. However, it should be noted that not all of the DNA samples used in the study by Davis et al. (2008) were collected during the time of breeding and so might not reflect the potential for additional genetic discreteness if discrete breeding groups disperse and mix during the non-breeding period.

3.1.1.2 Delimitation by International Differences in Management and Regulatory Mechanisms

The core range of bearded seals includes the waters of five countries (Russia, United States, Canada, Greenland, and Norway) with management regimes sufficiently similar that considerations of cross-boundary management and regulatory mechanisms do not outweigh or contradict the divisions proposed above on biological grounds. All countries allow some level of harvesting for subsistence purposes. Except for Greenland, this subsistence harvest is restricted to specific ethnic groups. Greenland and Norway allow sport hunting, while Russia and Greenland allow commercial harvests, though (except for Greenland) they are highly regulated and limited. In all countries annual harvest rates are considered small relative to the local populations and harvesting is assumed to have little impact on abundance. Furthermore, bearded seals of both subspecies have been shown to cross international marine boundaries (Gjertz et al. 2000, Frost et al. 2005, Cameron 2006, Frost et al. 2008, Cameron and Boveng 2009). Therefore, bearded seals occupying the waters of any particular country may do so only seasonally or intermittently, and cannot be considered to be subject solely to the management and regulatory mechanisms of that country; a division of the population along international boundaries would not be logical. A possible exception occurs in the Sea of Okhotsk where, if the Kamchatka Peninsula serves as a geographic barrier, the entire population of bearded seals may lie within one national jurisdiction.

3.1.1.3 Distinct Population Segments under consideration

3.1.1.3.1 Segments within *E. b. nauticus*

The studies by Manning (1974) and Davis et al. (2008) were not designed to test for population structure between the Bering Sea and the Sea of Okhotsk. However, the BRT considered the morphological evidence for discreteness presented by Kosygin and Potelov (1971) and the argument given above for the Kamchatka Peninsula functioning as a potential barrier between breeding populations behaviorally confined to their respective seas, to indicate that the population inhabiting the Sea of Okhotsk and the remainder of the range of *E. b. nauticus* should be evaluated for significance and possible designation as separate DPSs.

3.1.1.3.2 Segments within *E. b. barbatus*

Although the vocalizations of breeding males were different between populations at Svalbard and Canada, the movement data presented by Gjertz et al. (2000), and Davis et al.'s (2008) analysis of microsatellite DNA suggested that the deep water basin, comprised of the Greenland, Norwegian, and Barents Seas, is not a significant dispersal barrier to bearded seals. When considered altogether, the BRT judged that subdividing *E. b. barbatus* into two or more DPSs was not warranted on grounds of discreteness.

3.1.2 Evaluation of Significance

Having determined that *E. b. nauticus* is likely composed of discrete segments, the BRT evaluated the significance of these segments to the subspecies.

3.1.2.1 Persistence in an Unusual or Unique Ecological Setting?

Throughout most of their range, adult bearded seals are rarely found on land (Kovacs 2002). However, some adults in the Sea of Okhotsk, and more rarely in Hudson Bay (COSEWIC 2007), in the White and Laptev Seas (Heptner et al. 1976), Bering, Chukchi and Beaufort Seas, (Burns 1981, Nelson 1981, Smith

1981) and Svalbard (Kovacs and Lydersen 2008a) use haul-out sites ashore in late summer and early autumn. In these locations, sea ice either melts completely or recedes beyond the limits of shallow waters where seals are able to feed (Burns and Frost 1979, Burns 1981). By far the largest and most numerous and predictable of these terrestrial haul-out sites are in the Sea Of Okhotsk where they are distributed continuously throughout the bearded seal range and may comprise tens, to hundreds, or even more than a thousand individuals (Scheffer 1958, Tikhomirov 1961, Krylov et al. 1964, Chugunkov 1970, Tavrovskii 1971, Heptner et al. 1976, Burns 1981). Indeed, the Sea of Okhotsk is the only portion of the range of *E. b. nauticus* reported to have any such aggregation of adult haul-out sites (Fay 1974, Burns and Frost 1979, Burns 1981, Nelson 1981). Although it is not clear for how long bearded seals have exhibited this behavior, its commonness is unique to the Sea of Okhotsk, possibly reflecting responses or adaptations to changing conditions at the range extremes. This difference in haul-out behavior may also provide insights about the resilience of the species to the effects of climate warming in other regions.

3.1.2.2 Would Loss of a Segment Result in a Significant Gap in the Range?

The Sea of Okhotsk and the remainder of the range of *E. b. nauticus* are very large geographic areas, large portions of the range of the subspecies (Figure 3), and home to many thousands of individuals (Table 3). Loss of either segment of the subspecies' range would result in a substantially large gap in the overall range.

3.1.2.3 Population Segment is the Only Surviving Natural Occurrence?

Because bearded seals are not known to have been eliminated from any part of their historical range, and there are substantial populations in both the Sea of Okhotsk and the remainder of the *E. b. nauticus* range, neither of these two segments could be considered to be the sole surviving naturally occurring unit of the population.

3.1.2.4 Segment Differs Markedly in Genetic Composition?

Currently, the study by Davis et al. (2008) is the only analysis of the genetic population structure of bearded seals. Unfortunately, the samples available to them did not provide the ability to test for genetic differences of bearded seals anywhere in Russia including the Sea of Okhotsk. Therefore, there are no genetics results available to assess whether bearded seals in the Sea of Okhotsk are distinct from those in the remainder of the range of *E. b. nauticus*.

3.1.3 Determination of Distinct Population Segments

Considering arguments for the discreteness of seals occupying the Sea of Okhotsk as well as their significance and importance to the overall species range, the BRT recommends that, for the purposes of assessing extinction risk, *E. b. nauticus* be subdivided into an Okhotsk DPS and a DPS consisting of the remainder of that subspecies' range. Because bearded seals seem largely confined in their distribution and movements to the continental shelf region, this remaining segment of the *E. b. nauticus* range is bounded to the north by the shelf-slopes in the Chukchi, Beaufort, and East Siberian Seas, and to the south by the shelf-slope in the Bering Sea. The region between these bounds has been referred to as "Beringia". It is the region that formed a land bridge between Asia and North America when the continental shelves were exposed by the drop in sea level that occurred during the last glacial period, about 12-15 thousand years ago. The name Beringia was coined in recognition of Vitus Bering's 18th-century explorations of the region (West 1996). Because of the close correspondence of the *E. b. nauticus* range–minus the Okhotsk DPS–with the present-day marine portion of Beringia, the BRT designated this segment as the Beringia DPS.

3.1.3.1 Definition of Segment Ranges

For the purposes of this assessment the BRT defined geographic boundaries for the divisions between these two subspecies and DPSs, subject to the strong caveat that distinct boundaries do not appear to exist in the actual populations and there is considerable uncertainty about the best locations for the boundaries. Therefore, the BRT defined longitude 112°W, (i.e., the midpoint between the Beaufort Sea and Pelly Bay), as the North American delineation between the two subspecies. Following Heptner et al. (1976), who suggested an east-west dividing line at Novosibirskiye, the BRT defined 145° E as the Eurasian delineation between the two subspecies in the Arctic. Further, we have defined the Kamchatka Peninsula and 157° E as the division between the Okhotsk DPS and the Beringia DPS. Distribution maps published by Burns (1981) and Kovacs (2002) provide the known northern and southern extents. However, in order to feed on the seafloor bearded seals are known to nearly always occupy shallow waters (Fedoseev 2000, Kovacs 2002). The preferred depth range is often described as < 200 m (Kosygin 1971, Heptner et al. 1976, Burns and Frost 1979, Burns 1981, Fedoseev 1984, Nelson et al. 1984, Kingsley et al. 1985, Fedoseev 2000, Kovacs 2002), though adults have been known to dive to around 300 m (Kovacs 2002, Cameron and Boveng 2009), and six of seven pups instrumented near Svalbard have been recorded at depths greater than 488 m (Kovacs 2002). Therefore, the BRT has defined the core distribution (e.g., pupping, breeding,molting and most feeding) as those areas of known extent that are in water <500 m deep (see Figure 5).

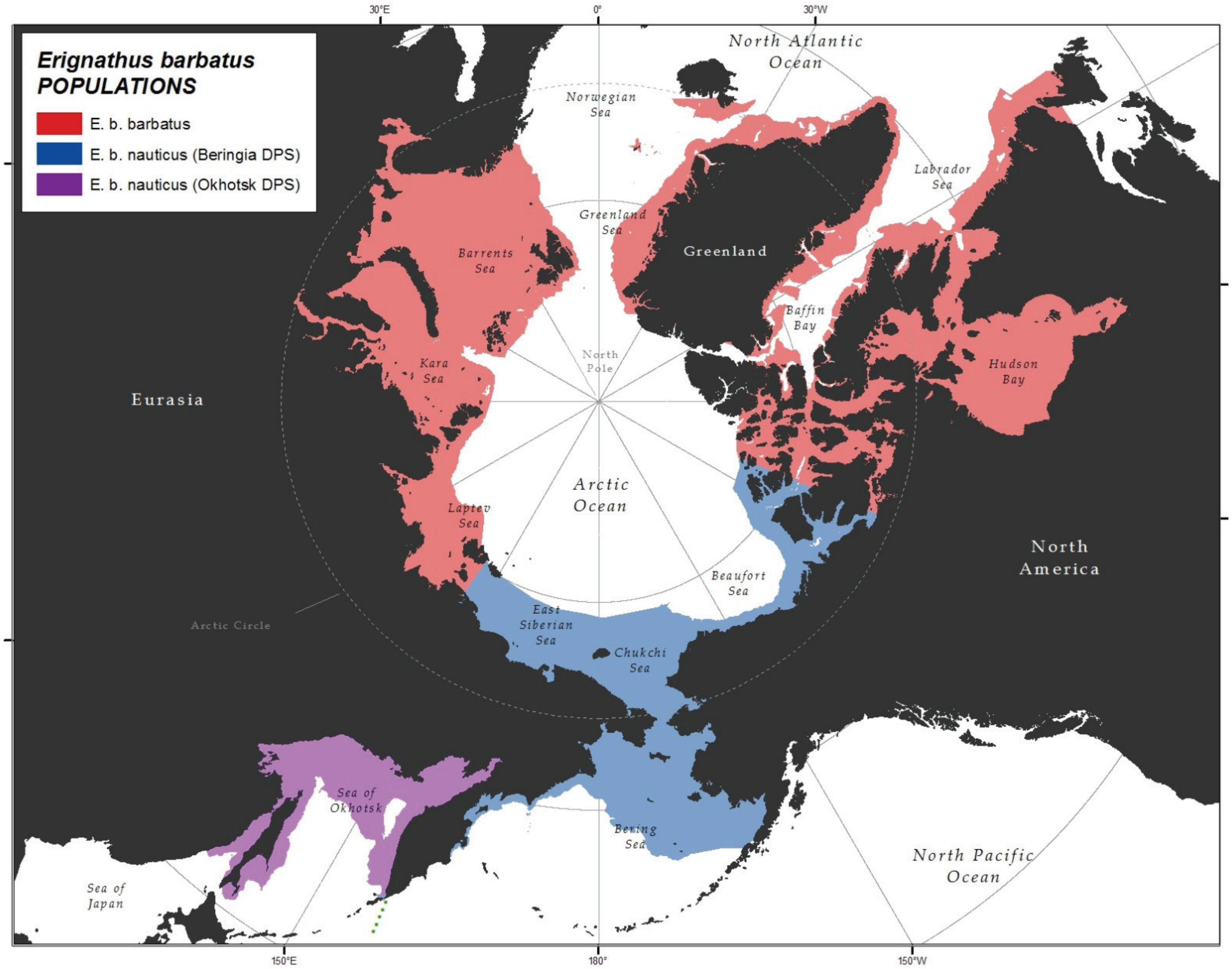

Figure 5. -- The three bearded seal populations considered by the BRT. *E. b. barbatus* is considered separately from *E. b. nauticus* which is subdivided into two distinct population segments (DPSs): The Beringia DPS (co-incident with the range of *E. b. nauticus* except for the Sea of Okhotsk) and the Okhotsk DPS. The dotted green line is drawn along 157° E longitude, which is considered to be the boundary between the Okhotsk DPS and Beringia DPS.

4 EXTINCTION RISK ASSESSMENT

4.1 Time Frame: The Foreseeable Future

The purpose of this status review is to conduct an extinction risk assessment for support of decisions about whether bearded seals should be listed under the ESA and, if so, whether they should be listed as *threatened* or *endangered*. The ESA defines the term *endangered species* as "any species which is in danger of extinction throughout all or a significant portion of its range". The term *threatened species* is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range". Making a determination of whether a species is threatened, therefore, requires consideration of the time frame over which the population status can be said to be "foreseeable", in the sense of a credible prediction of the likely outcome. To be credible, a prediction must have a substantial element of rigor that derives from factors such as relevant data, consideration of uncertainty (to assess whether an outcome is more likely than not to occur), and concurrence of relevant subject-matter experts. Speculation alone does not constitute credible prediction or foreseeability.

The foreseeability of a species' future status depends upon the foreseeability of both the threats to the species and its response to those threats. When a species is exposed to a variety of threats, each threat may be foreseeable on a different time frame. For example, a threat stemming from well-established, observed trends in a global physical process may be foreseeable on a much longer time horizon than a threat stemming from a potential episodic process such as an outbreak of disease that may never have been observed to occur in the species.

4.1.1 Factors in the Foreseeability of Threats to Bearded Seals

The petition by the CBD to list bearded seals cited global warming as the foremost concern, and others have speculated similarly that bearded seals and other ice-associated marine mammals are at risk from loss of sea-ice habitat in a warming climate (Tynan and DeMaster 1997, Lowry 2000, Learmonth et al. 2006, Simmonds and Isaac 2007, Kovacs and Lydersen 2008b, Laidre et al. 2008, Moore and Huntington 2008). Other potential threats, such as modification of bearded seals' prey community by ocean acidification may be related to warming by the common driver of greenhouse gas (GHG) emissions, the root cause of the largest portion of observed and projected climate change. Therefore, the predictability of GHG emissions is of primary consideration in the foreseeability of climate-related threats to bearded seals.

The analysis and synthesis of information presented by the Intergovernmental Panel on Climate Change (IPCC) in its *Fourth Assessment Report* (AR4) (IPCC 2007a) represents the scientific consensus view on the causes and future of climate change (but see Oppenheimer et al. (2007) for a reminder that achieving consensus may preclude consideration of the full range of uncertainty and plausible outcomes). The IPCC AR4 is the most recent comprehensive summary of observations, analyses, and models that collectively have been found to be compelling by all major scientific bodies in the United States with directly relevant expertise (Oreskes 2004). The IPCC AR4 used a range of future GHG emissions produced under six "marker" scenarios from the Special Report on Emissions Scenarios (SRES; IPCC 2000) to project plausible outcomes under clearly stated assumptions about socio-economic factors that will influence the emissions. Conditional on each scenario, the best estimate and *likely* range of emissions were projected through the end of the 21st century.

The factors that distinguish the SRES marker scenarios include economic and population growth rates, technological development, and the mix of energy sources used to meet global needs. The policy of the IPCC is to consider all six SRES marker scenarios equally likely. The differences in emissions under these scenarios, however, reflect an important source of uncertainty that must be recognized in association with any particular projection or prediction of future conditions, especially in the latter half of the 21st century.

Conditions such as surface air temperature and sea-ice area are linked in the IPCC climate models to GHG emissions by the physics of radiation processes. When anthropogenic carbon dioxide (CO_2) is added to the atmosphere, it has a long residence time and is only slowly removed by ocean absorption and other processes. Based on IPCC AR4 climate models, expected global warming, defined as the change in global mean surface air temperature (SAT), by the year 2100 depends strongly on the assumed emissions scenario of CO_2 and other greenhouse gasses. By contrast, warming out to about 2040-2050 will be primarily due to emissions that have already occurred and those that will occur over the next decade. Thus, conditions projected to mid-century are less sensitive to assumed future emission scenarios (Figure SPM.5 in IPCC 2007b). Though low-frequency (i.e., decadal and multidecadal) natural variability is a factor, uncertainty in the amount of warming out to mid-century is primarily a function of model-to-model differences in the way that the physical processes are incorporated, and this uncertainty can be addressed by incorporating the range in projections from different models.

The IPCC AR4 emphasized the importance of this consideration for evaluating its 21st-century projections (Meehl et al. 2007):

> *"There is close agreement of globally averaged SAT multi-model mean warming for the early 21st century for concentrations derived from the three non-mitigated IPCC Special Report on Emission Scenarios (SRES: B1, A1B and A2) scenarios (including only anthropogenic forcing). . . this warming rate is affected little by different scenario assumptions or different model sensitivities, and is consistent with that observed for the past few decades. . . Possible future variations in natural forcings (e.g., a large volcanic eruption) could change those values somewhat, but about half of the early 21st-century warming is committed in the sense that it would occur even if atmospheric concentrations were held fixed at year 2000 values. By mid-century (2046–2065), the choice of scenario becomes more important for the magnitude of multi-model globally averaged SAT warming. . . About a third of that warming is projected to be due to climate change that is already committed. By late century (2090–2099), differences between scenarios are large, and only about 20% of that warming arises from climate change that is already committed."*

The USFWS used this guidance from the IPCC AR4 to define the horizon of the foreseeable future as the year 2050 in its decision to list the polar bear (*Ursus maritimus*) as threatened (U.S. Fish and Wildlife Service 2008). The NMFS used the same guidance and time horizon in its decision not to propose any listing for the ribbon seal (National Marine Fisheries Service 2008a).

In its review of the spotted seal, the NMFS recognized that the physical basis for some of the primary threats faced by the species had been projected, under certain assumptions, through the end of the 21st century, and that these projections currently form the most widely accepted version of the best available information about future conditions. Therefore, the NMFS used the end of the 21st century as the time horizon when deciding to list the Southern DPS (i.e., Chinese and Korean populations) of spotted seals at threatened (National Marine Fisheries Service 2009b). In the risk assessment for bearded seals that follows, the BRT similarly used the full 21st-century projections as the basis for the foreseeability of threats stemming from climate change.

Because the current consensus is to treat all SRES scenarios as equally likely, one option for representing the full range of variability in potential outcomes would be to project from any model under all six scenarios. This may be impractical in many situations, so the typical procedure for projecting impacts is to use an intermediate scenario, such as A1B or B2 to predict trends, or one intermediate and one extreme scenario (e.g., A1B and A2) to represent a significant range of variability or uncertainty.

It is important to note that the SRES scenarios are non-mitigated; that is, while a few may make assumptions of reduced future emissions levels (e.g., resulting from a transition to cleaner fuels) they do not contain explicit assumptions about implementation of agreements or protocols on emission limits beyond current mitigation policies and related sustainable development practices. Recent studies have begun to explore the projected outcomes of emissions mitigation scenarios (Van Vuuren et al. 2008, Strassmann et al. 2009). The mitigated scenarios produce substantially less 21st century warming than the SRES scenarios, though even the most stringent mitigation scenarios result in an average of about 1.4°C warming (range of 0.5-2.8°C) above 1990 levels (Van Vuuren et al. 2008). However, incorporating the likelihood of further mitigation policies being adopted and implemented, and the likely effectiveness of the mitigation, into an assessment of risks to bearded seals is beyond the purview and capabilities of the BRT. It is left as a policy choice as to whether anticipation of climate mitigation measures should be a factor in the decision of whether to list bearded seals under the ESA.

Not all potential threats to bearded seals are climate related, and therefore not all can be regarded as foreseeable through the 21st century. Evidence of morbillivirus (phocine distemper) exposure in sea otters has recently been reported from Alaska (Goldstein et al. 2009). Thus, distemper may be considered a threat to bearded seals, but the time frame of forseeability of an inherently episodic and novel threat is difficult or impossible to establish.

4.1.2 Factors in the Foreseeability of Bearded Seal Responses to Threats

A threat to a species, and the species' response to that threat are not, in general, equally predictable or foreseeable. The demographic, ecological, and evolutionary responses of bearded seals to threats from a warming climate are in most cases very difficult to predict, even though future warming is highly likely to occur. The difficulty stems both from uncertainty about the species' current status (i.e., abundance, trends, vital rates) and uncertainty about the species' habitat requirements and resilience to the effects of climate change. As discussed in more detail in Sections 4.2 and 4.3, the data on size and trends of the populations are very imprecise, and there is very little information available to quantitatively link projected environmental conditions to bearded seal vital rates of survival and reproduction. In our limited understanding of bearded seal biology, there is no analog to the relatively well understood processes that link GHG emissions to warming. Projecting bearded seal populations forward from an uncertain beginning state is subject to further uncertainty that increases with time into the future. The range of uncertainty in forward projections of bearded seal population size is bounded above by the maximum growth rate that is feasible for the species' life history. Of course, there is no theoretical lower bound on the rate of population change, as any population could conceivably go extinct instantly from a sufficiently severe perturbation. These extreme scenarios of hypothetical population responses, however, are not very helpful in the practical matter of judging whether bearded seals are likely to reach some threshold conservation status within a particular period of time. We must therefore rely upon the judgment of experts familiar with the natural history of the species and its evolutionary origins.

4.1.3 Lack of a Single Time Frame for the Foreseeable Future

Many of the anticipated effects of GHGs have been projected through the end of the 21st century, and a broad consensus has formed around various outcomes in those projections, subject to certain inputs and assumptions. These nearly century-long projections should be considered in the assessment of the outlook for bearded seals, yet there is no single period of time that is appropriate for consideration of the risks from all the apparent threats faced by the species, and the species' responses to the threats. The foreseeability of each threat should be considered separately, and the foreseeability of the species' response to each threat should be included in the assessment of what time frame is reasonably foreseeable with respect to whether bearded seals are more likely than not to become endangered (i.e., they should be considered currently threatened if they are likely to become in danger of extinction within the foreseeable future). Finally, for a species like the bearded seal, composed of multiple subspecies and DPSs, these assessments should be made separately for each unit.

4.2 Analysis of Factors Listed Under Section 4(a)(1) of the Endangered Species Act

Section 4(a) of the ESA requires the determination of whether a species is endangered or threatened because of any of the following factors:

(A) the present or threatened destruction, modification, or curtailment of its habitat or range;

(B) overutilization for commercial, recreational, scientific, or educational purposes;

(C) disease or predation;

(D) the inadequacy of existing regulatory mechanisms; or

(E) other natural or manmade factors affecting its continued existence.

4.2.1 Present or Threatened Destruction, Modification, or Curtailment of the Species' Habitat or Range

4.2.1.1 Global climate change

4.2.1.1.1 Overview

Research, monitoring, and modeling of global climate change have progressed rapidly during the past several decades, yielding a vast body of information on the causes of climate change, effects, and ways to mitigate the problems. In 1988, the World Meteorological Organization and the United Nations Environmental Programme established the Intergovernmental Panel on Climate Change (IPCC) to provide an objective source of information about this complex issue (IPCC 2008). The IPCC has produced four assessment reports that represent syntheses of the best available and most comprehensive scientific information on climate change to date. The following two excerpts from the IPCC's "Climate Change 2007: Synthesis Report, Summary for Policymakers" (IPCC 2007c), highlight some of the observed and projected changes in climate and their anticipated effects/impacts:

> *"Observed changes in climate and their effects:*
>
> - *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.*
> - *Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.*
> - *There is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers*".

> *"Projected climate change and its impacts:*
>
> - *There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, GHG emissions will continue to grow over the next few decades.*
> - *Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.*
> - *There is now higher confidence than in the TAR* [Third Assessment Report] *in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice.*
> - *Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change.*

- *Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilized*
- *Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change*".

Both the observed and the projected effects of a warming global climate are most extreme in northern high latitude regions (ACIA 2005, Meehl et al. 2007), in large part due to the ice-albedo feedback mechanism in which melting of snow and sea ice lowers reflectivity and thereby further increases surface warming by absorption of solar radiation (e.g., Weatherly et al. 1991). A vast and rapidly growing body of information documenting this and other Arctic climate processes, and projecting future changes, has been comprehensively reviewed and assessed in widely available formats (ACIA 2005, IPCC 2007b, Walsh 2008), notwithstanding the very recent findings, which seem to be published on an almost weekly basis (e.g., Stroeve et al. 2008, Kwok and Rothrock 2009, Wang and Overland 2009, Zhang 2010).

Our focus in this section is to assess the observed and projected changes with significant potential to impact the bearded seal's range and habitat, including both the physical and biological components of habitat. We address changes in sea ice, ocean temperature, ocean pH (acidity), and associated changes in bearded seal prey species.

4.2.1.1.2 Effects of climate change on the annual formation of bearded seal's sea-ice habitat

Sea ice in the Northern Hemisphere can be divided into first-year sea ice , that formed in the most recent autumn-winter period, and multi-year sea ice that has survived at least one summer melt season. Multi-year sea ice is generally confined to the Arctic Ocean. More southerly regions, such as the Bering Sea, Barents Sea, Baffin Bay, the Sea of Okhotsk, and Hudson Bay, are known as seasonal ice zones where first year sea ice is renewed every winter. Sea-ice extent at the end of summer (September) 2007 in the Arctic Ocean was a record low (4.3 million km^2), nearly 40% below the long-term average and 23% below the previous record set in 2005 (5.6 million km^2) (Stroeve et al. 2008). Sea-ice extent in September 2008 and 2009 was greater than in 2007, but was still more than two standard deviations below the 1979-2000 climatology. Most of the loss of sea ice was on the Pacific side of the Arctic. Of even greater long-term significance was the loss of over 40% of Arctic multi-year sea ice over the last 5 years (Figure 6)(Kwok et al. 2009). While the annual minimum of sea-ice extent is often taken as an index of the state of Arctic sea ice, the recent reductions of the area of multi-year sea ice and the reduction of sea ice thickness is of greater physical importance. It would take many years to restore the ice thickness through annual growth, and the loss of multi-year sea ice makes it is much less likely for the Arctic to return to previous climatological conditions. Continued loss of sea ice will be a major driver of changes across the Arctic over the next decades, especially in late summer and autumn.

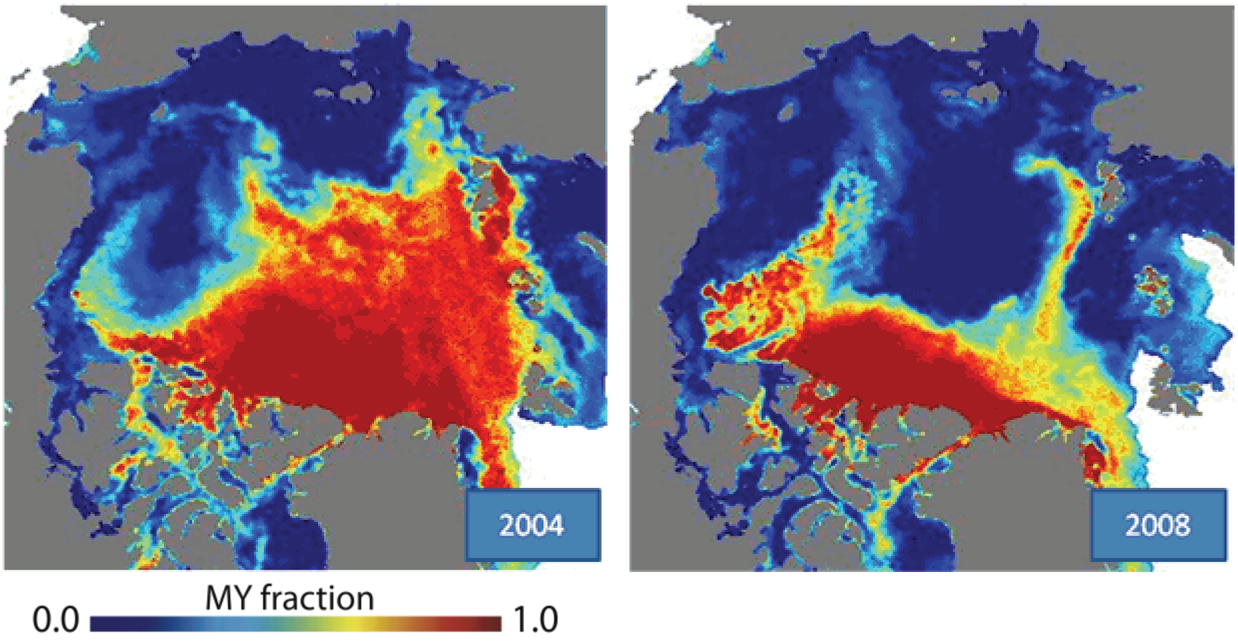

Figure 6. -- QuickSCAT satellite derived maps of the Arctic showing the percent concentration of multi-year (MY) ice. Note the 42% loss of MY ice from January 2004 to 2008. Data provided by Ron Kwok (JPL).

Sea ice and other climatic conditions that influence bearded seal habitats are quite different between Arctic and the seasonal ice zones. In the Arctic, sea ice loss is a summer feature with a delay in freeze up occurring into the following fall. Sea ice will always persist from late fall through mid-summer due to cold and dark winter conditions. Sea ice variability is primarily determined by radiation and melting processes during the summer season. The seasonal ice zones are free of sea ice during summer. The variability in extent, thickness, and other sea ice characteristics important to marine mammals are determined primarily by changes in the number, intensity and track of winter and spring storms in the sub-Arctic. Although there are connections between sea ice conditions in the Arctic and the seasonal ice zones, the early loss of summer sea ice in the Arctic cannot be extrapolated to the seasonal ice zones which are behaving differently than the Arctic. For example, the Bering Sea has had 4 years of colder than normal winter and spring conditions from 2007-2010, with near record sea-ice extents, rivaling the sea ice maximum in the mid-1970s (Figure 7), despite record retreats during summer in the Arctic.

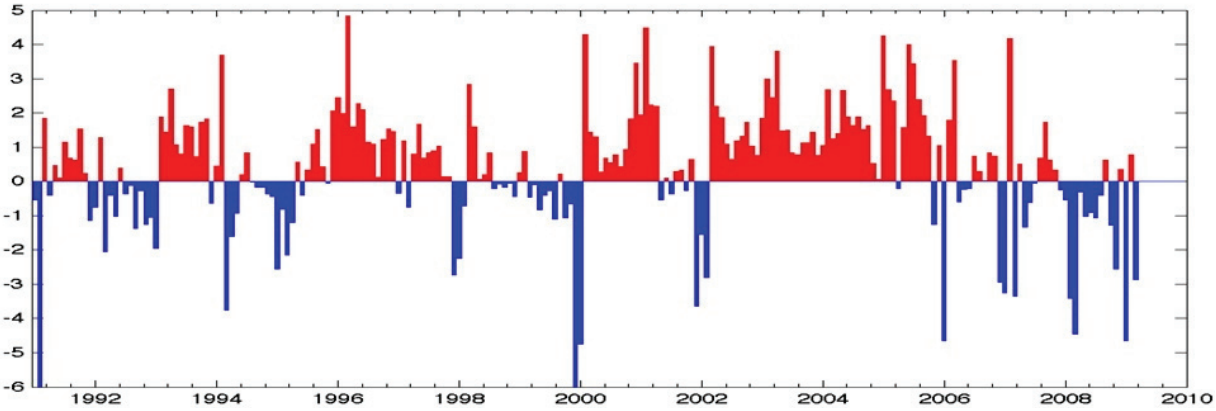

Figure 7. -- Mean monthly surface air temperatures anomalies (relative to the mean from 1961-1990) at St. Paul, Pribilof Islands, Alaska.

4.2.1.1.2.1 IPCC model projections

Comprehensive Atmosphere-Ocean General Circulation Models (AOGCMs) are the major objective tools that scientists use to understand the complex interaction of processes that determine future climate change. The IPCC used the simulations from about two dozen AOGCMs developed by 17 international modeling centers as the basis for the Fourth Assessment Report (AR4) (IPCC 2007a). Regional projections from these models are also being used by management agencies to assess and plan for future ecological and societal impacts (e.g., Scenarios Network for Alaska Planning: http://www.snap.uaf.edu/home). The AOGCM results are archived as part of the Coupled Model Intercomparison Project-Phase 3 (CMIP3) at the Program for Climate Model Diagnosis and Intercomparison.

The IPCC's AR4 emphasizes that current generation AOGCMs provide credible quantitative estimates of future climate change at continental scales and above (IPCC 2007a). The CMIP3 models are improved over the models used for the 3rd Assessment Report (Randall et al. 2007, Reichler and Kim 2008). Climate researchers are also making use of the AR4 AOGCM simulations on regional scales (e.g., Walsh et al. 2008). The Program for Climate Model Diagnosis and Intercomparison shows over 1,100 projects and over 500 publications using CMIP3, most based on regional studies. The CMIP3 AOGCMs provide reliable projections, because they are built on well-known dynamical and physical principles, and they simulate quite well many large scale aspects of present-day climate (Randall et al. 2007, Knutti et al. 2008). Further, some biases in simulated climate by different models can be unsystematic (Räisänen 2007, Jun et al. 2008). The coarse resolution of most current climate models certainly dictates careful application on small scales in heterogeneous regions such as along coastlines or rugged orography. Our experience and that of other groups conducting model evaluations indicates the importance of multiple, complementary approaches.

There are three main contributors to the divergence in AOGCM climate projections: large natural variations, the range in emissions scenarios, and across-model differences (Hawkins and Sutton 2009).

First, it is known that if climate models are run several times with slightly different initial conditions, the trajectory of day-to-day and indeed year-to-year evolution will have different timing of events, even though the underlying statistical-spectral character of the model climate tends to be similar for each run. This variability is a feature of the real climate system, and consumers of climate projections must recognize its importance. Natural variability is a source of ambiguity in the comparison of models with each other and with observational data. This variability can affect decadal or even longer means, so it is relevant to the use of model-derived climate projections. The variability can be incorporated by averaging the projections over decades or, preferably, by forming ensemble averages from several runs of the same model.

A second source of variation in projections arises from the range in plausible emissions scenarios. Emissions scenarios have been developed based on assumptions for future development of humankind (Nakicenovic and Swart 2000); they are converted into greenhouse gases and aerosol concentrations, which are then used to drive the AOGCMs in the form of radiative forcing specified in the CMIP3 models, and summarized in the IPCC AR4. For this study, we used emission scenario A1B, a middle range case, which is also the closest to the CO_2 concentrations observed in the last decade, and A2 a high emissions scenario (IPCC 2000). Because of the residence time of carbon in the atmosphere and the thermal inertia of the climate system, climate projections are often relatively insensitive to the precise details of which future emissions scenarios are used over the next few decades. The impacts of the scenarios are rather similar before mid-21st century (Hawkins and Sutton 2009). For the second half of the 21st century, however, and especially by 2100, the choice of the emission scenario becomes the major source of variability among climate projections and dominates over natural variability and model-to-model differences (IPCC 2007a). If 2030-2050 is a timescale of interest, we will often use the A1B scenario—or A1B and A2 together —to increase the number of potential ensemble members as their CO2 trajectories are similar before 2050.

The third source of variability is termed across-model uncertainty[3] (Knutti et al. 2008). Different numerical approximations of the model equations, spatial resolution, and other model development factors introduce structural uncertainty between different models. The potential for model bias introduces uncertainty. Because this bias is rarely systemic however, this uncertainty can be addressed and mitigated in part by using the ensemble means from multiple models (Overland et al. *In review*).

There is no universal method for combining AOGCMs for climate projections (Gleckler et al. 2008, Räisänen et al. 2010), and there is no one best model. Our objective was to reduce the impact of models with large hindcast error. We culled the poor performing models—rather than selecting the best models—and retained several models as a measure of model variability).

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[3] Note that here we use “uncertainty” to refer to statistical measures of variation that should not be confused with the more general use of the term to refer to something that is unreliable or untrustworthy.

4.2.1.1.2.2 Northern Hemisphere

4.2.1.1.2.2.1 Data and analytical methods

The CMIP3 model simulations used in our analyses were obtained from the Program for Climate Model Diagnosis and Intercomparison online (PCMDI 2010). There are several sources of sea-ice data available; we chose to use the gridded sea-ice concentration analysis from the Hadley Center (MET Office Hadley Data Centre 2008) as the observed values in this study. Conventionally, sea-ice extent was then defined as the area where the ice concentration is more than 15% in a grid box.

Confidence that climate models provide credible quantitative projections of future climate is built upon their demonstrated ability to reproduce observed features of recent climate (Gerdes and Köberle 2007). It is therefore important to apply an observational constraint on the CMIP3 models, and cull poor performing models from further consideration. Inspired by Knutti et al. (2006), Wang and Overland (2009) required that models simulate the seasonal cycle and the mean of September sea-ice extent to within ± 20 % of the Hadley Centre sea ice and sea surface temperature data set (HadISST) analysis for the period of 1980-1999. Wang and Overland (2009) provided the basic model for sea ice projection analysis used in this report. Reproducing the correct magnitude of the seasonal cycle of sea-ice extent is one way of demonstrating the models' sensitivity to changes in external forcing (e.g., solar insolation). The September mean sea-ice extent is an efficient constraint to eliminate models with systematic biases. Our constraints are based on comparisons to the HadISST sea-ice concentration analysis, which was made more homogeneous by compensating satellite microwave-based sea-ice concentrations for the impact of surface melt effects in the Arctic (Rayner et al. 2003). The combination of the seasonal cycle and mean conditions is an improved constraint relative to previous studies (Overland and Wang 2007, Stroeve et al. 2007). The culling process not only reduces the range of variability in the future model projections, but it also shows that models with a reasonable seasonal cycle relative to observations project a faster decline of future September sea-ice extent (Figure 8).

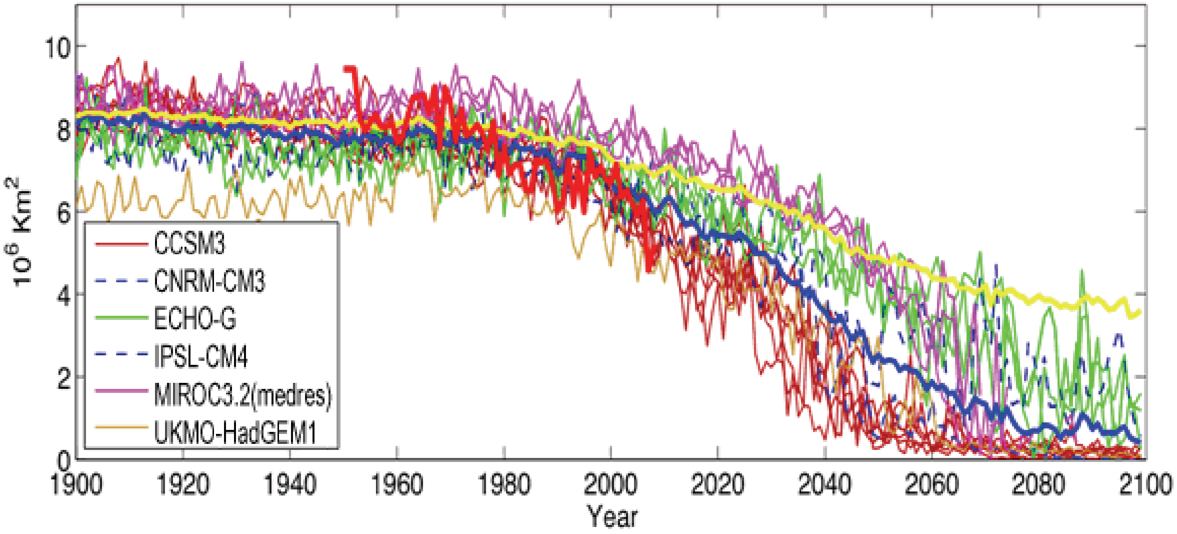


Figure 8. -- Future summer sea-ice extent in September from individual runs of the six models used in this study, under the A1B emissions scenario. In the model runs with the fastest summer sea ice loss, the Arctic is nearly sea ice free before 2050. The heavy red line represents the observed record. The yellow line is the mean over all 23 IPCC models, showing an overestimation of ice extent in recent years. The blue line is the mean future trajectory of the selected six models that adequately reproduced the observed record, indicating increased climate sensitivity to greenhouse gases. Figure from Wang and Overland (2009).

Applying these observational constraints we eliminated 17 of the 23 CMIP3 models. We retained six models: CCSM3, CNRM-CN3, ECHO-G, IPSL-CM4, MIROC3.2(medres) and UKMO-HadGEM1. Although an evaluation of why some models perform better than others is difficult (Gleckler et al. 2008), we note that three (CCSM3, CNRM-CM3 and UKMO-HadGEM1) of the six models include a multiple sea ice thickness distribution as part of a sophisticated consideration of sea ice physics and dynamics, a feature only present in five of the current generation of the CMIP3 models (Zhang and Walsh 2006).

4.2.1.1.2.2.2 Northern Hemisphere predictions

Figures 9-14 show the new and primary predictions of the future for sea ice used in this report. For each geographic image pixel, each model concentration was averaged for 11 years centered on the nominal forecast time (e.g., a prediction reported for 2050 encompasses the years 2045 to 2055). Averaging reduced the large influence of year-to-year natural variability in forming estimates of sea-ice concentration in a particular decade. Contrasting the minimal and maximal concentrations provides a measure of the monthly model-to-model projections.

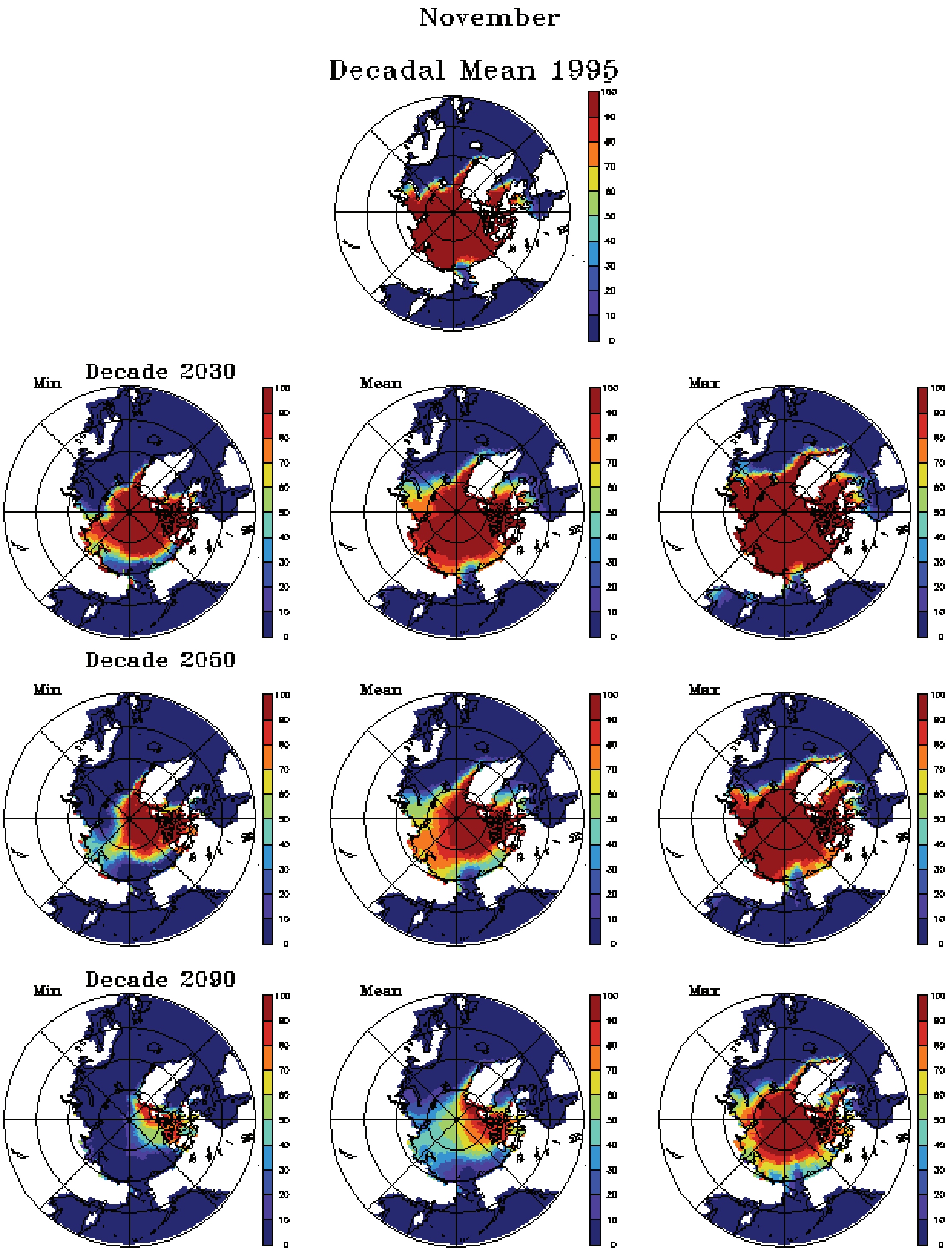
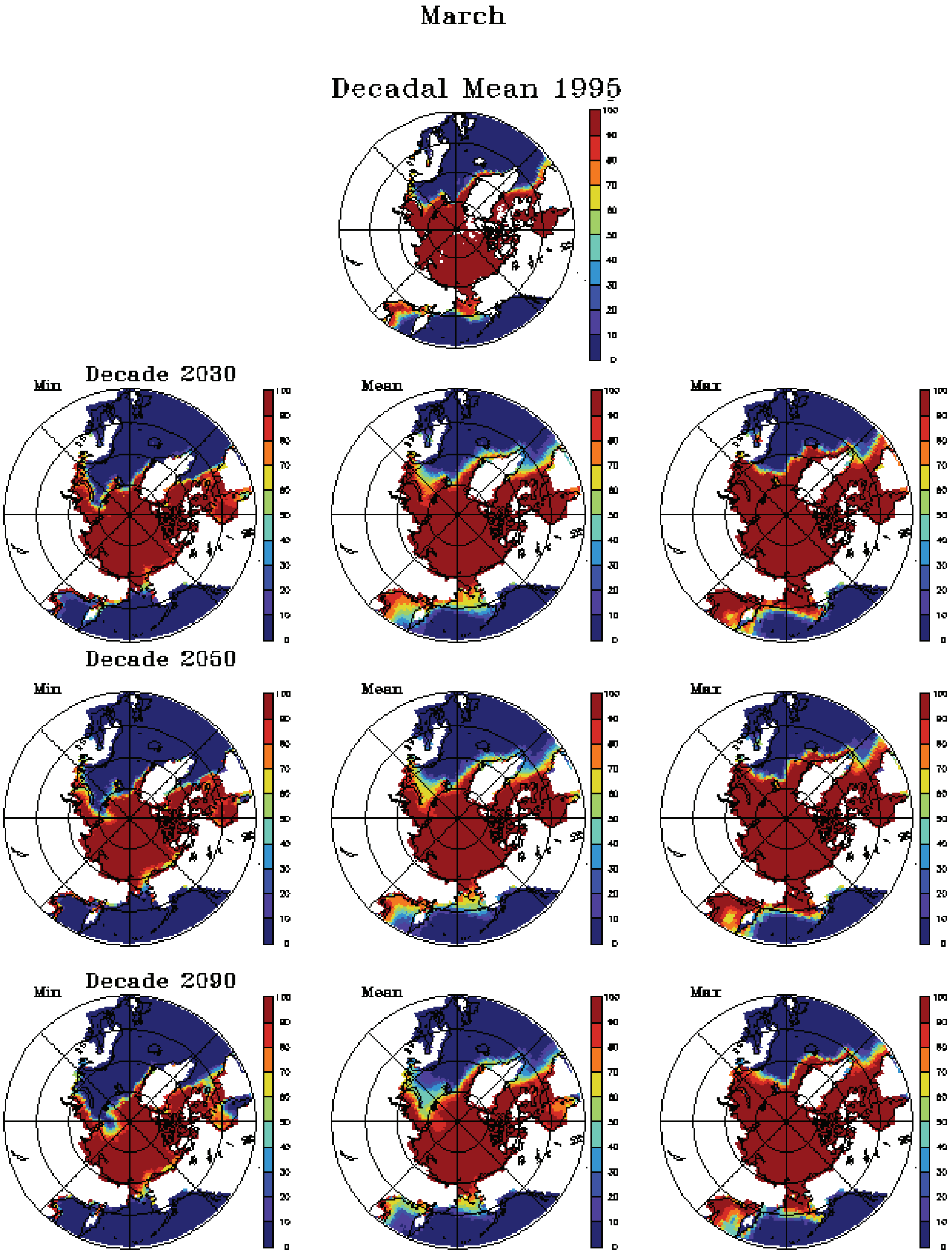


Figure 9. -- Mean sea-ice concentration observed for November in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).



March

Decadal Mean 1995

Decade 2030

Decade 2050

Decade 2090

Figure 10. -- Mean sea-ice concentration observed for March in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

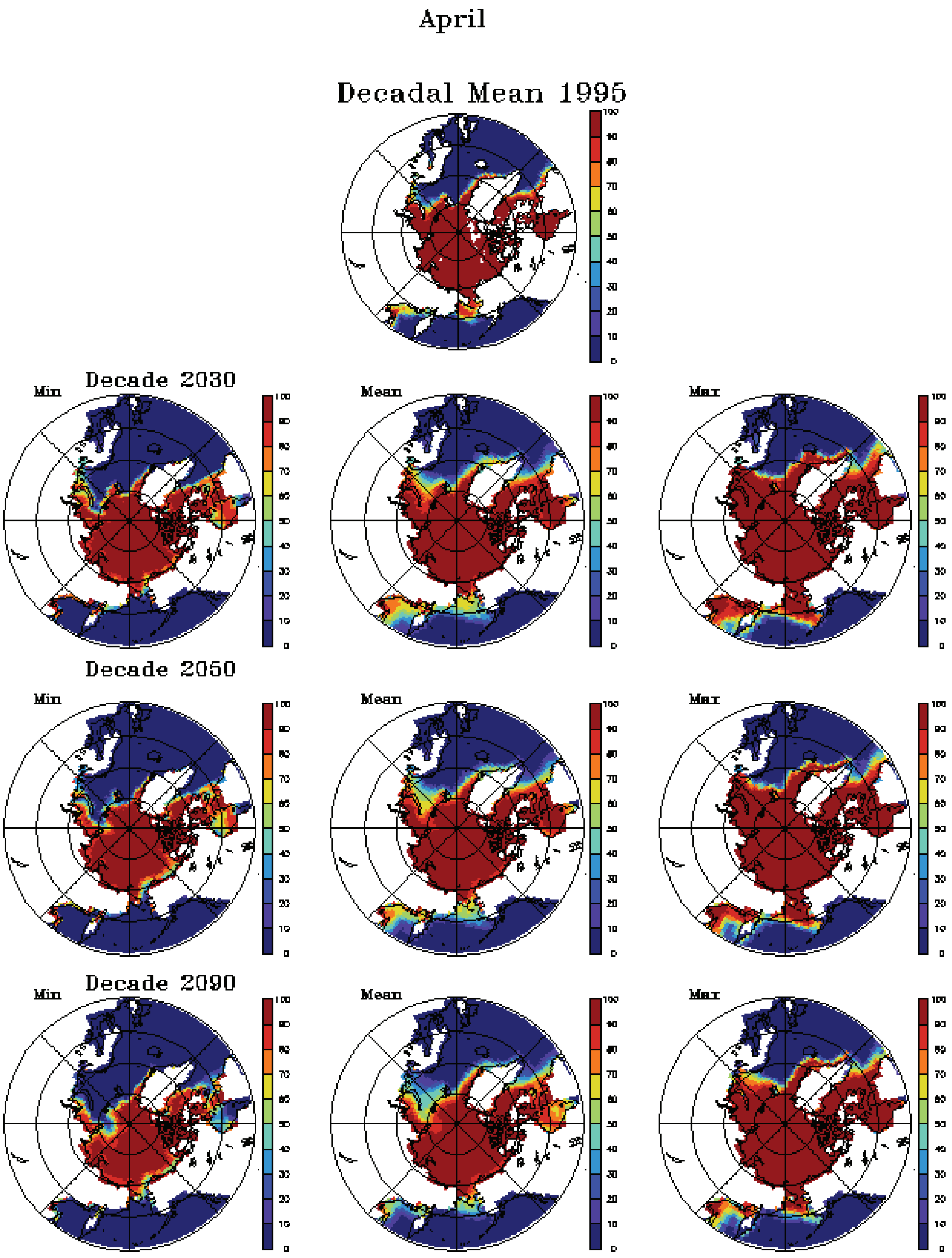


Figure 11. -- Mean sea-ice concentration observed for April in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

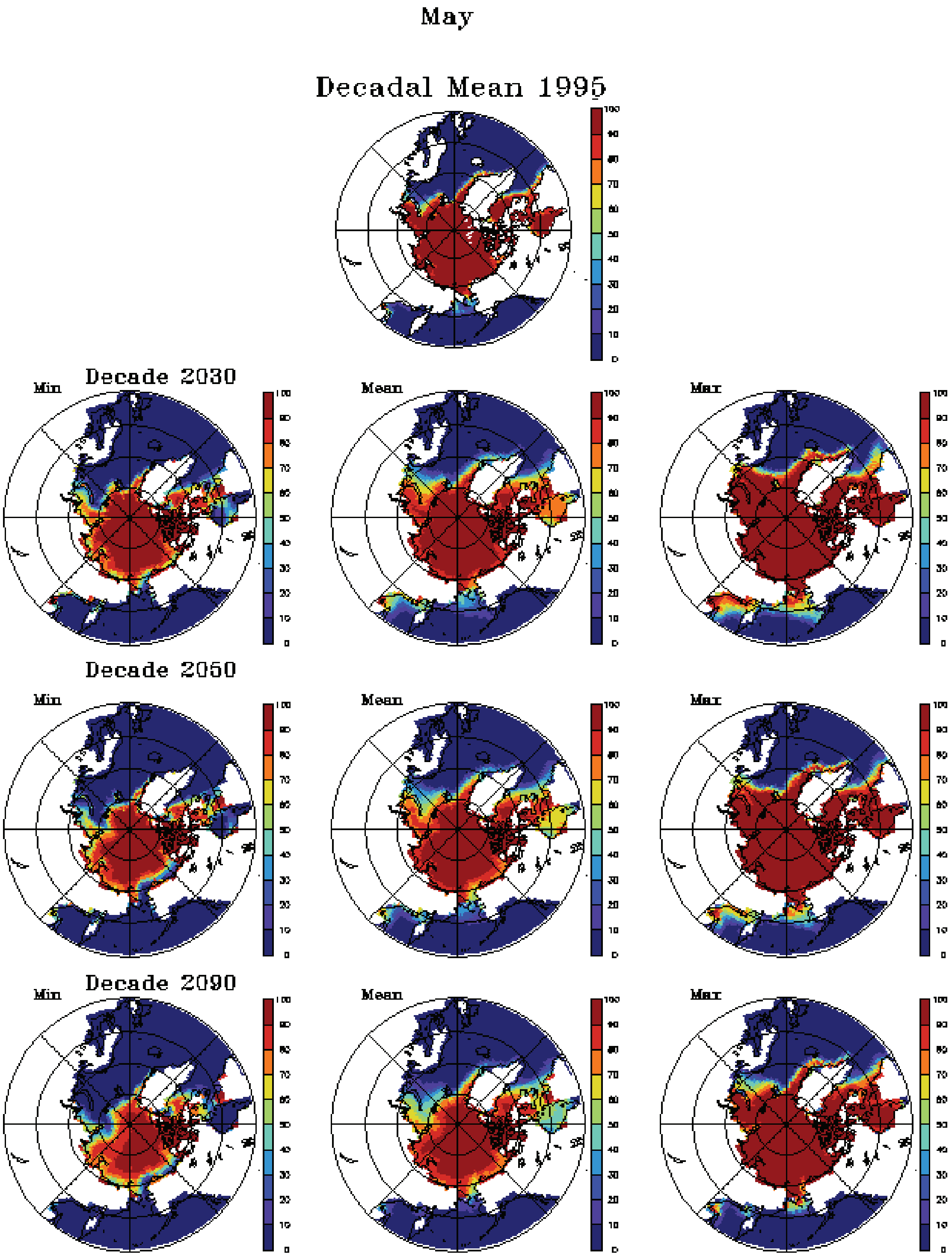


Figure 12. -- Mean sea-ice concentration observed for May in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

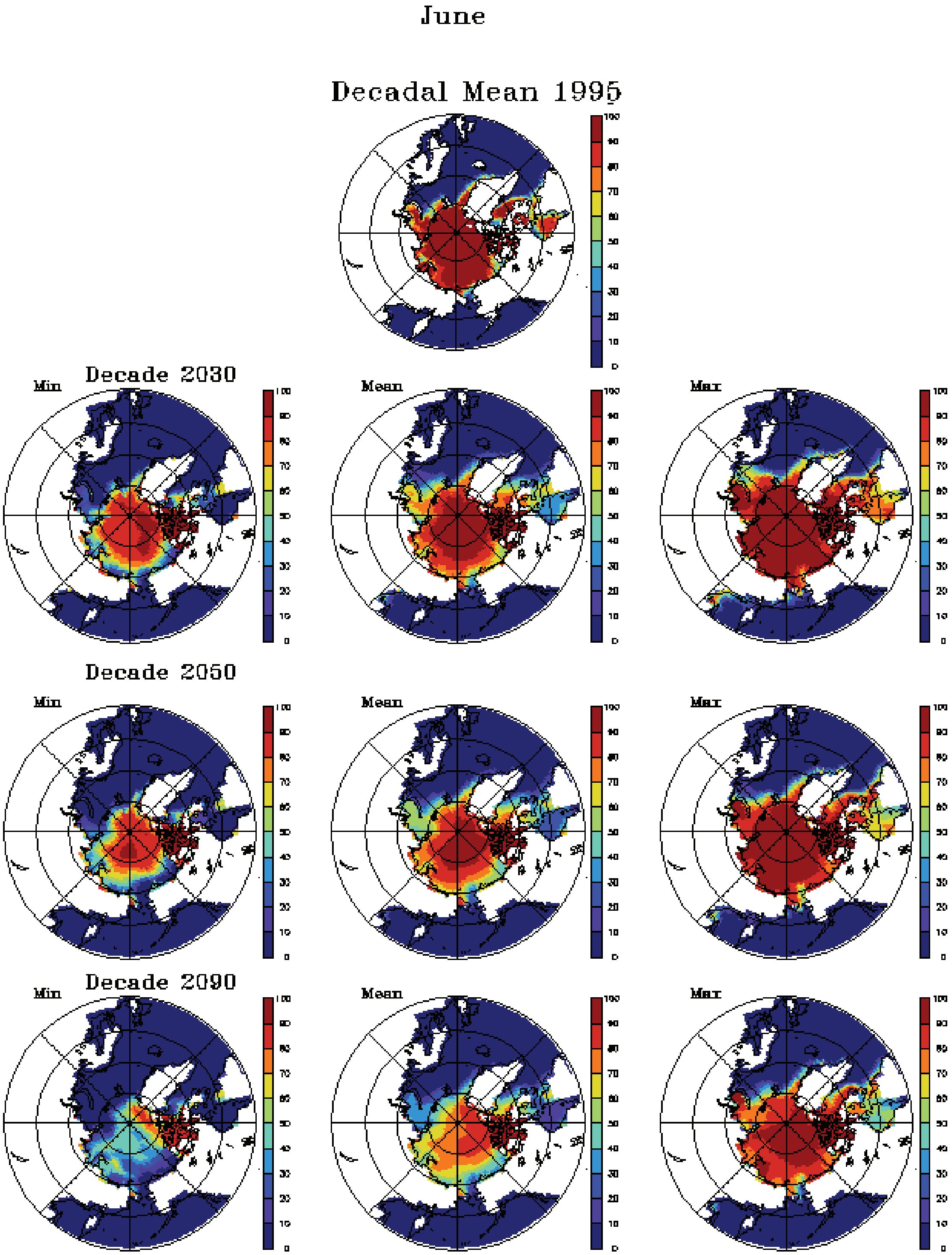


Figure 13. -- Mean sea-ice concentration observed for June in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

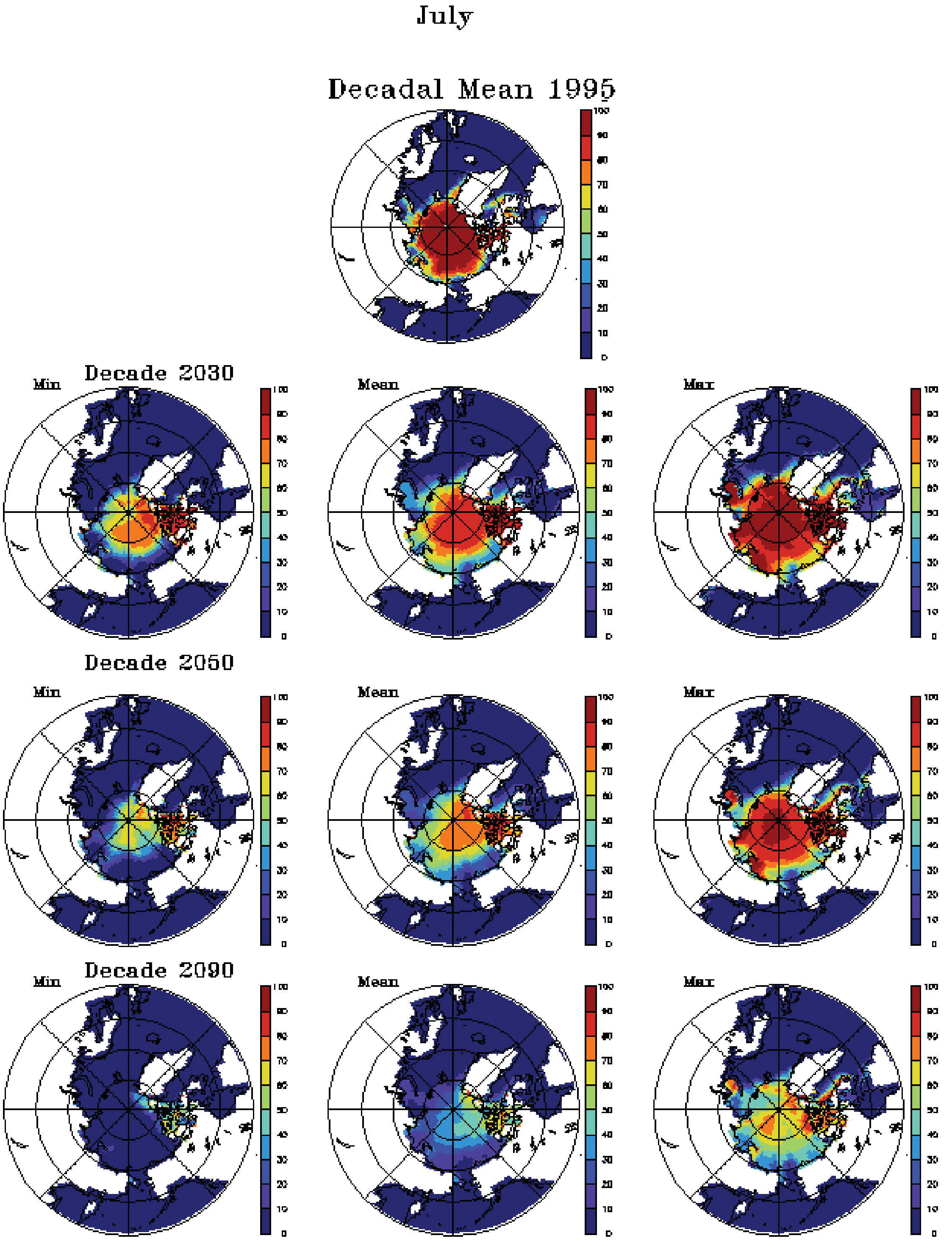


Figure 14. -- Mean sea-ice concentration observed for July in the 1990s (top) based on Hadley Centre sea ice analysis. Rows 2-4 show minimal (left), mean (center), and maximal (right) projected ice concentrations for each of three future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

The projections for November (Figure 9) indicate a major delay in fall freeze up by 2050 north of Alaska and in the Barents Sea. By 2090, the average sea-ice concentration is below 50% in the Russian Arctic and some models show a nearly ice free Arctic, except for the region of the Canadian Arctic Archipelago. In March and April (Figures 10 and 11), generally winter type conditions persist even out to 2090. There is some reduction of sea ice by 2050 in the outer portions of the seasonal ice zones, but the sea ice south of Bering Strait, eastern Barents Sea, Baffin Bay and the Kara and Laptev Seas remains substantial. May (Figure 12), is similar to April but with diminishing sea-ice cover at 2050 and 2090 in the Barents Sea and Sea of Okhotsk. The month of June (Figure 13), begins to show substantial changes as the century progresses. Current conditions occasionally exhibit a lack of sea ice near the Bering Strait by mid-June. By 2050 however, this sea ice loss becomes a major feature with open water continuing along the northern Alaskan coast in most models. Open water in June spreads to the East Siberian Shelf by 2090. The eastern Barents Sea experiences a reduction in sea ice between 2030 and 2050. The models indicate that sea ice in Baffin Bay will be affected very little until the end of the century. In July (Figure 14), the Arctic Ocean shows a marked effect of global warming, with the sea ice retreating to a central core as the century progresses. The loss of multi-year sea ice over the last 5 years has provided independent evidence for this conclusion. By 2050, the continental shelves of the Beaufort, Chukchi and East Siberian Seas are approaching an ice free state in July with ice concentrations less than 20% in the ensemble mean projections. The Kara and Laptev Seas also show a reduction of sea ice in coastal regions by mid-century in most but not all models. The Canadian Arctic Archipelago and the adjacent Arctic Ocean north of Canada and Greenland however, are predicted to become a refuge for sea ice through the end of the century. This conclusion is supported by typical Arctic wind patterns which tend to blow onshore in this region. Indeed, this refuge region is why sea ice scientists use the phrase: a *nearly* sea ice free summer Arctic by mid-century.

4.2.1.1.2.3 Sub-regions

4.2.1.1.2.3.1 Regional boundaries and overview of methodology

Based on the six models identified by Wang and Overland (2009), the decadal mean sea-ice concentration shown in Figures 9-14 clearly indicate that sea ice declines at a faster rate in the fall (November) and early summer (July) than in winter (March and April) or spring (May and June). Climate models generally perform better on continental or larger scales, but because habitat changes are not uniform throughout the hemisphere, we further evaluated these six models independently on their performance at 12 different sub-regions throughout the bearded seals' range: Baffin Bay (50-80°N, 70-45°W), Barents Sea (65-80°N, 12-60°E), Beaufort Sea (70-80°N, 157-112°W), eastern Bering Sea (54-66°N, 175-157°W), western Bering Sea (54-66°N, 165°E-175°W), Canadian Arctic Archipelago (62-84°N, 112-70°W), Chukchi Sea (66-80°N, 180-157°W), Greenland Sea (60-84°N, 45°W-12°E), East Siberian Sea (70-80°N, 145-180°E), Hudson Bay (50-62°N, 95-70°W), Kara-Laptev Seas (70-80°N, 60-145°E), and the Sea of Okhotsk (44-62°N, and 137 -162°E). The boundaries of each selected region are shown in Figure 15.

All six of the models met the performance criteria for predicting sea ice in the Chukchi Sea, and in the East Siberian Sea. To forecast sea-ice extent and concentration in the other regions, we used a subset of models, results from previous analyses or other analytical methods appropriate for the region.

- Beaufort Sea – Four of the six models (CCSM3, ECHO-G, IPSL, and UKhadGEM1) simulated both the mean and seasonal cycle of Beaufort Sea ice extent with reasonable agreement with observations, so the projections are based on these four models.
- eastern Bering Sea - Four of the six models (CCSM3,CNRM, ECHO-G, and MIROC3.2(medres)) met the criteria, which still allowed projections to be made from a basis that includes model-to-model variation and sufficient numbers of available model runs.
- western Bering and the Barents Seas – Only one of the six models (CCSM3) met the performance criteria in these regions and most of the other models tended to overestimate the observed ice extent year-round. We used the single model as the basis for projecting sea ice with caveats about the reliability described below.
- None of the models performed satisfactorily in the remaining regions and so we employed other methods to predict sea ice.
    - Existing analyses for Hudson Bay (Joly et al. 2010) were used to infer ice conditions in those areas.
    - For the Sea of Okhotsk, we investigated the use of SAT for projecting future ocean and ice conditions.
    - For Baffin Bay, the Canadian Arctic Archipelago, and the Greenland, Kara and Laptev Seas we performed a qualitative analysis of seasonal and decadal changes using results of the central Arctic (70-90°N) with caveats about the reliability described below.

Below we present details of these analyses for each region. Whenever the relevant model outputs were available, we analyzed the conditions projected under the “medium” A1B and “high” A2 emissions scenarios (IPCC 2000). By including both the A1B and A2 emissions scenario, we doubled the number of ensemble members and represented much of the range of variability contained in the SRES scenarios. For regions where ice projections could not be obtained, we present results of the other regionally appropriate analyses.

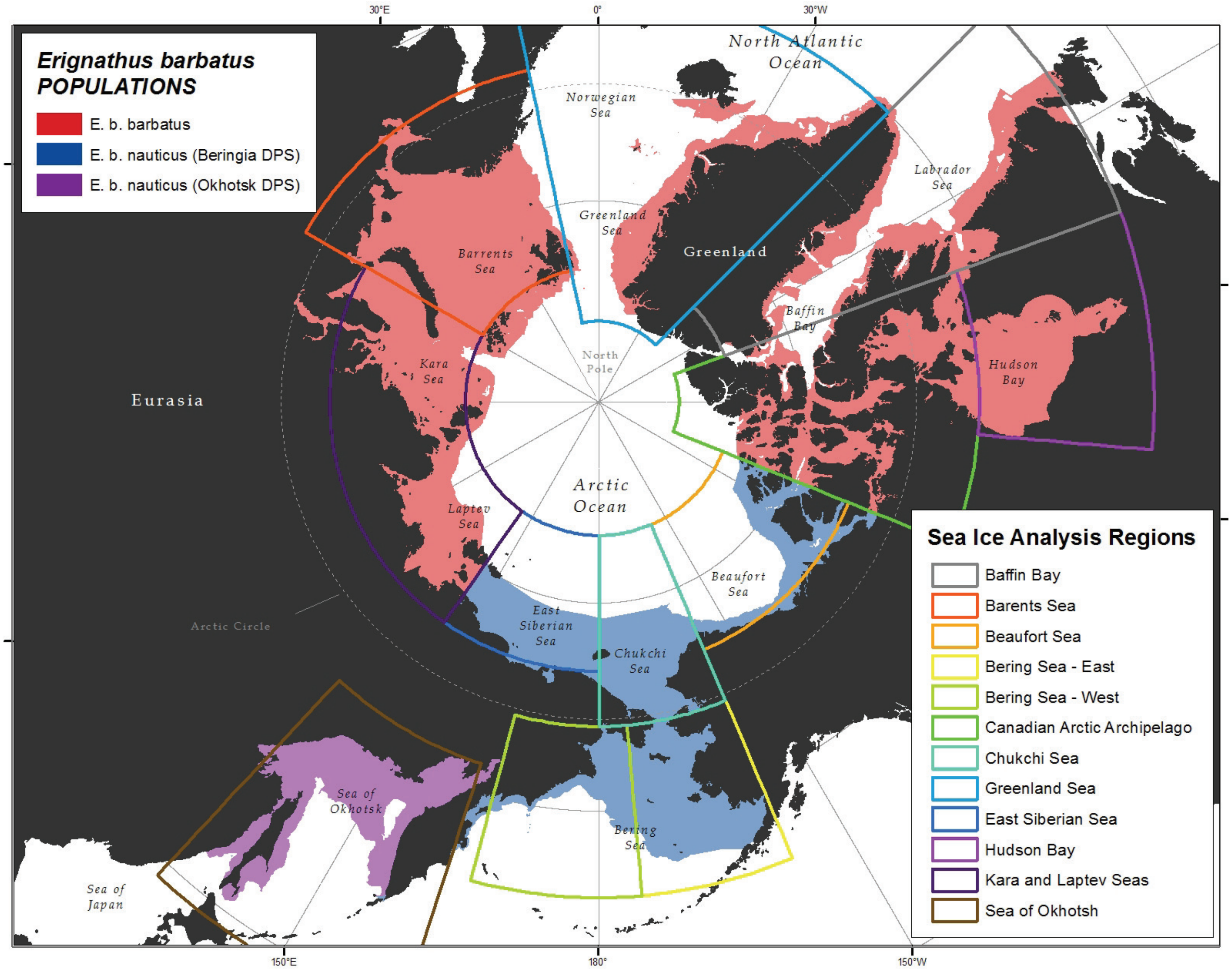


Figure 15. -- Boundaries of regions used to predict sea ice, superimposed over the three bearded seal population units considered by the BRT.

4.2.1.1.2.3.2 Regional predictions

4.2.1.1.2.3.2.1 Chukchi Sea

The Chukchi Sea is located well north of the Arctic Circle, with its northern boundary adjoining the Arctic Ocean. Sea ice typically starts to retreat in late May or later, and predictions suggest that at least part of the region will be covered by ice during summer in most years out to the end of the 21st century. We found no significant ice reduction projected for winter and early spring (January to May). This is in contrast to a sharp declining trend near the end of the 21st century for the late autumn and summer (e.g., November) and July (Figure 16). The downward trend is especially apparent after 2070 in the projection for November and only significant by the end of the century for June, but by then the difference between the emissions scenarios (blue for A1B, and magenta for A2; Figure 16) becomes a major contributor to the trends. It is also obvious from the figures that the model projections are more variable after the mid-century, which is shown by a wider spread of the area covered by the grey lines.

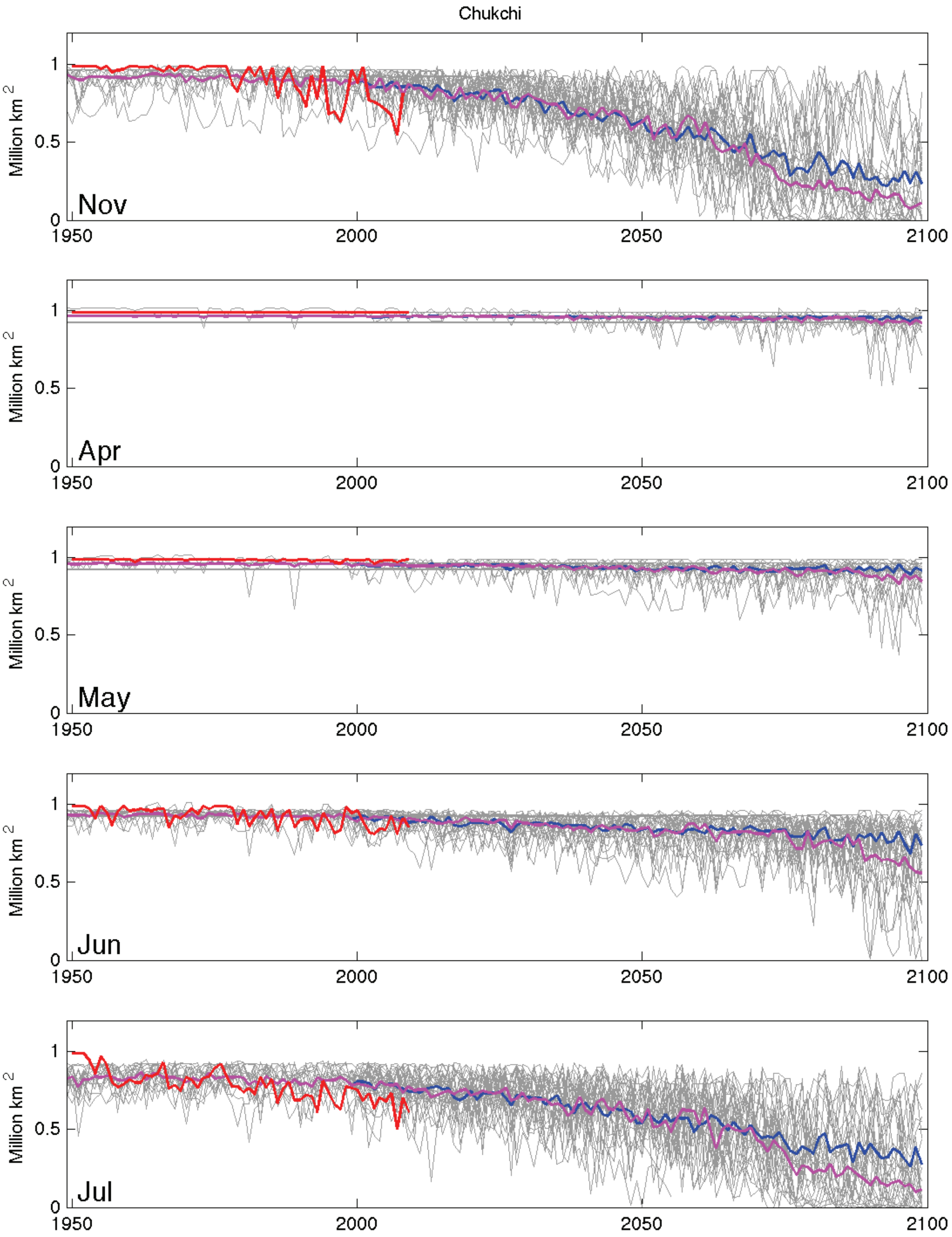


Figure 16. -- Model simulated sea-ice extent over the Chukchi Sea for November and April-July. The red lines (observations) are based on HadISST analysis and the other colored lines are the ensemble means of the six models (CCSM3, CNRM, ECHO-G, IPSL, MIROC(medres), and UKMO-Hadgem1) under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by one of these models.

4.2.1.1.2.3.2.2 East Siberian Sea

All six models simulated the seasonal cycle of the sea-ice extent over the East Siberian Sea in reasonable agreement with observations. The projection from these six models shows that the decline of sea ice will be obvious only after 2050 for November and July (Figure 17). The change in winter and spring ice condition is minimal.

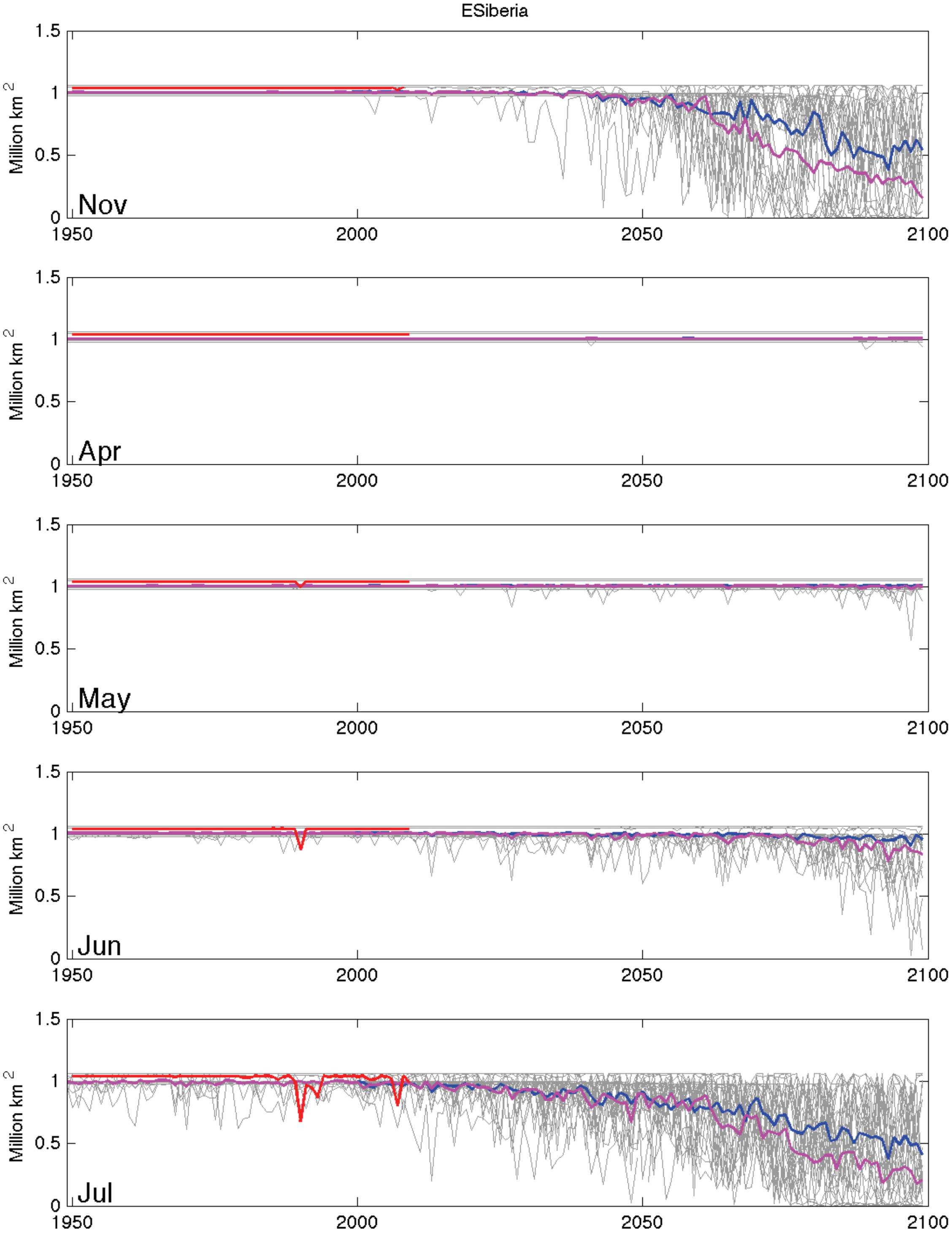


Figure 17. -- Model simulated sea-ice extent over the East Siberian Sea for November and April-July. The red lines (observations) are based on HadISST analysis and the other colored lines are the ensemble means of the six models (CCSM3, CNRM, ECHO-G, IPSL, MIROC(medres), and UKMO-Hadgem1) under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by one of these models.

4.2.1.1.2.3.2.3 Beaufort Sea

All six models simulated the seasonal cycle of sea-ice extent over the Beaufort Sea in reasonable agreement with observations, although two of them underestimated the summer sea-ice extent. The projections for the future are therefore made from four models (CCSM3, ECHO-G, IPSL and UKHadgem1). Apparently sea ice will be present in the Beaufort Sea in the winter and spring, even until the end of 21st century. In early summer (July) and fall (November) we see an accelerated decline after 2050 (Figure 18). The shortened period of sea-ice cover in the Beaufort Sea, suggests that coastal areas might be impacted the most.

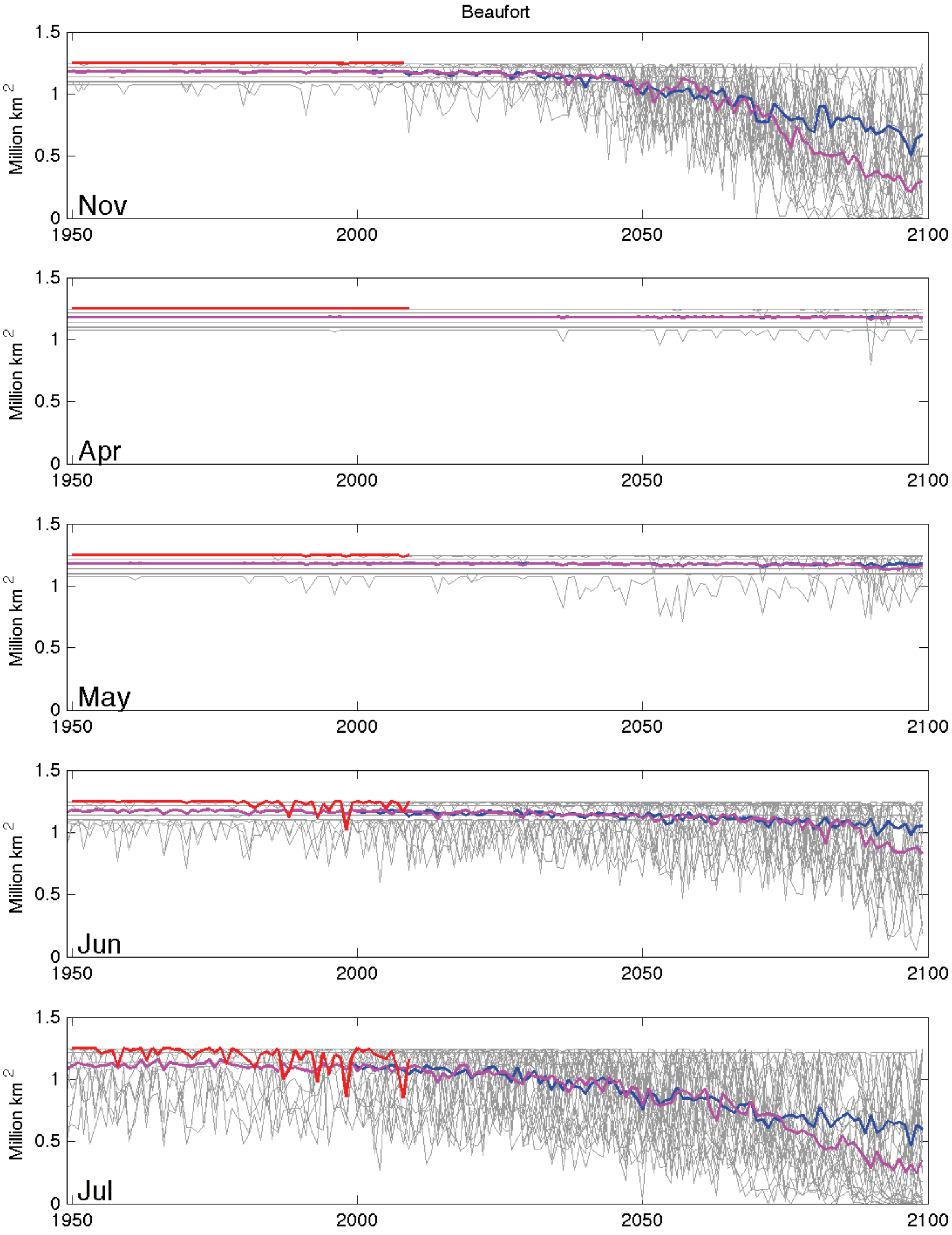


Figure 18. -- Model simulated sea-ice extent over the Beaufort Sea for November and April to July. The red lines (observations) are based on HadISST analysis and the other colored lines are the ensemble means of the four models (CCSM3, ECHO-G, IPSL and UKHadGEM1) under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by one of these models.

4.2.1.1.2.3.2.4 Eastern Bering Sea

Sea ice begins to cover the eastern Bering Sea in November, and gradually advances south to reach its maximum in March. Figure 19 shows the projections of sea-ice extent over the eastern Bering Sea for March, April, May, and June. From March to May, the interannual variability of sea-ice extent is large, and the overall downward trend is small, but visually obvious. Very little ice has remained in the eastern Bering in June since the mid-1970s. At the scale of these models, very little change in extent is predicted to the end of the century. The largest decline in sea-ice extent is projected to occur in the late autumn months of November and December (not shown). By 2050, the averaged sea-ice extent in late autumn would be 28% of the 1980-99 period mean, whereas the average spring sea-ice extent (average of March to May) would be at 58% of the present value. By 2075, the average spring sea-ice extent would decline to 37% of present day value, and the autumn average extent (not shown) would be at only 12% of present day value.

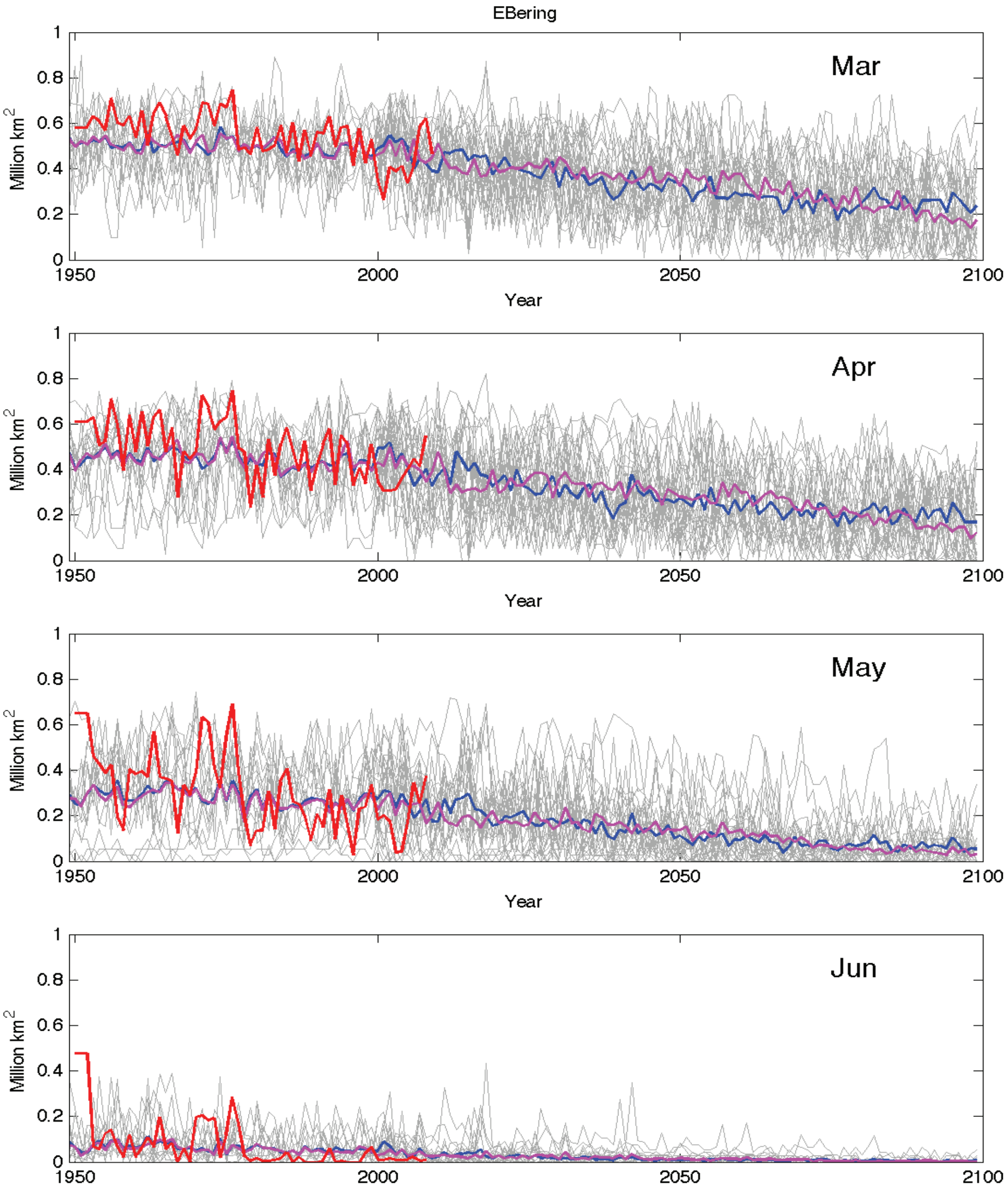


Figure 19. -- Model simulated sea-ice extent over the eastern Bering Sea for March - June. The red lines (observations) are based on HadISST analysis and the other colored lines are the ensemble means of the four models (CCSM3, CNRM, ECHO-G, and MIROC(medres)) under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by one of these models.

4.2.1.1.2.3.2.5 Western Bering Sea

As noted above, we discovered that the majority of models tend to overestimate the sea-ice coverage for the western Bering Sea in winter, with one model underestimating the ice conditions, and only one model (CCSM3) passing the selection criteria. For reference, we provide this single model's output, and we caution that the results must be interpreted in the context of possible bias and lack of model-to-model variation. Projections from a single model may fail to represent the full range of variability or may be subject to biases of a particular model formulation, perhaps reducing confidence in the output for this region. The western Bering Sea projections are shown in Figure 20 for spring. Compared with historical observations, this model overestimated sea-ice extent in both March and April, but performed reasonably well for May and June. It projected a rapid decline in sea-ice extent over the first half of the 21st century, then a slower decline to the end of the century (top 3 panels of Figure 20). The mean linear trends estimated from the CCSM3 model were 28×10^3 km^2/decade (8%/decade) and 17×10^3 km^2/decade (9%/decade) for April and May, respectively during the 21st century. Under these scenarios, the western Bering Sea is projected always to have ice in March and April through nearly the end of the 21st century, though the average extent in the latter half-century would be approximately 25% of the present-day extent. The projection for May indicates that there will commonly be years with little or no ice beyond mid-century.

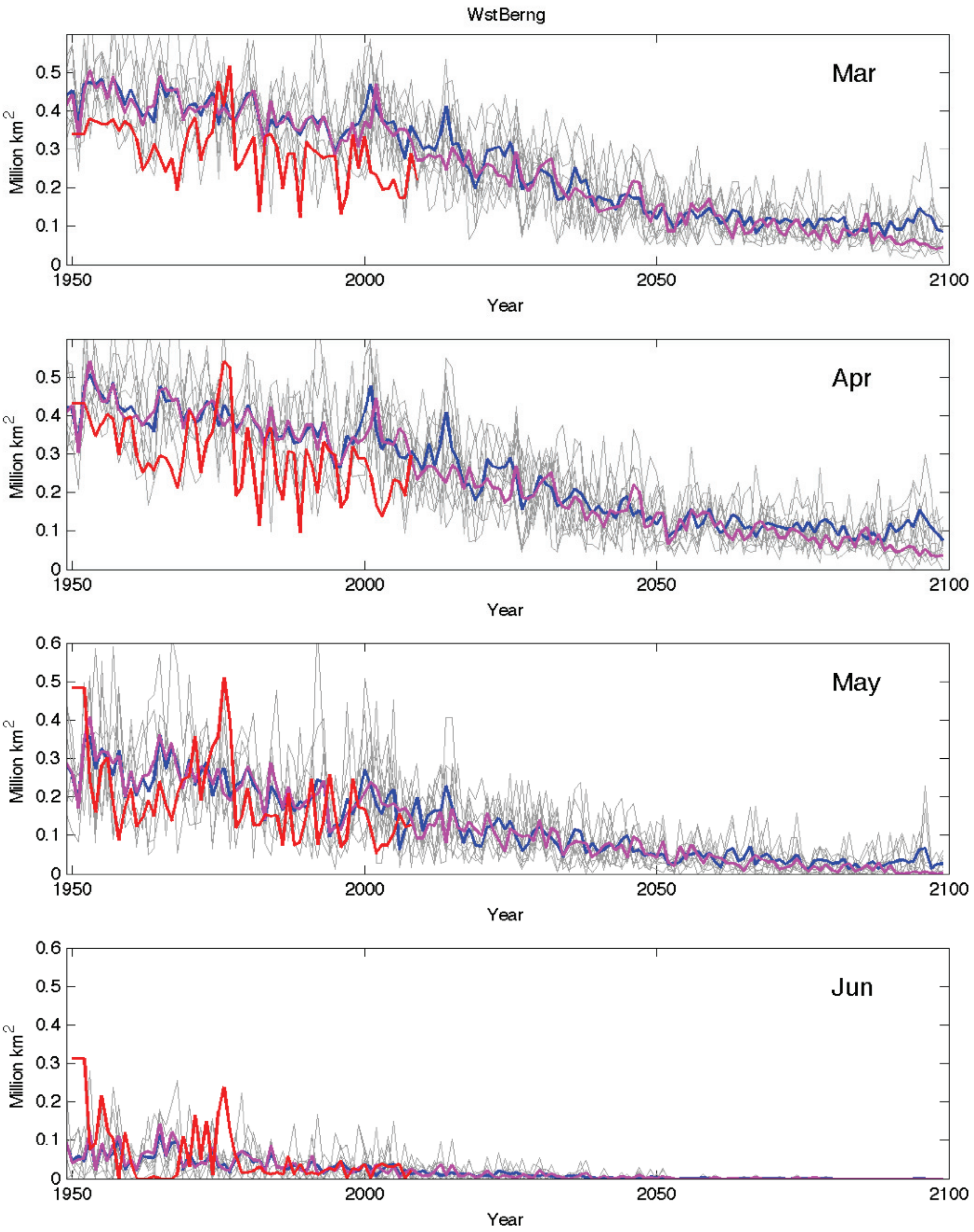


Figure 20. -- Model simulated sea-ice extent over the western Bering Sea for spring (April-June). The red lines (observations) are based on HadISST analysis and the colored lines are the ensemble means of the CCSM3 model under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by this model.

Figure 21 shows an example of the projected ice concentration for May and November by one of the models (CCSM3), in the coming decades. Colored contour lines outline the 15% ice concentration position. This clearly shows that the average November ice extent is projected to decrease faster than the average May ice extent.

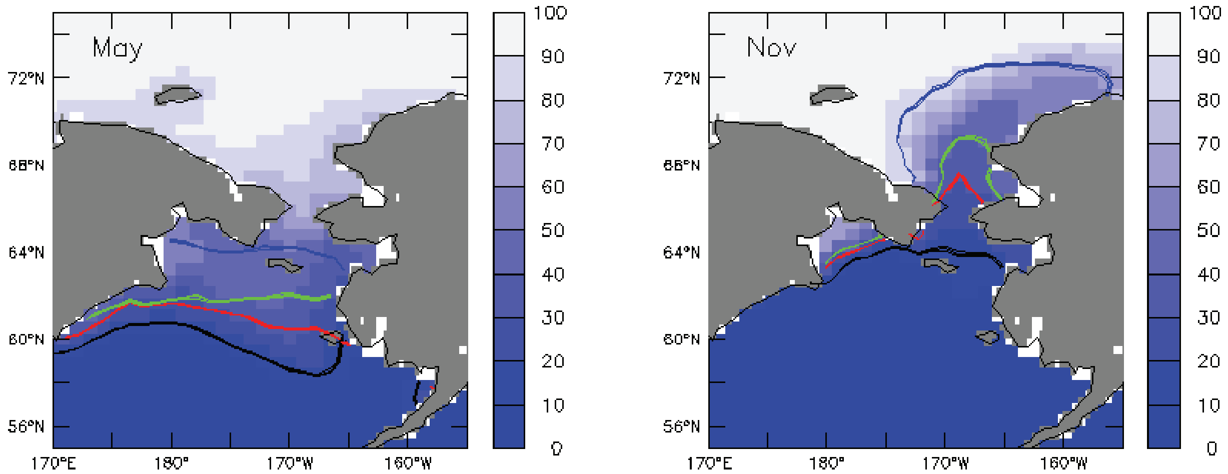


Figure 21. -- The shaded area shows an example of projected sea-ice concentration under the A1B emission scenario from one run of the CCSM3 model for May (left) and November (right). The colored lines indicate the average position of the ice edge, which is defined as 15% ice concentration in a grid box, in the recent past (1980-99, black), in 2011-2019 (red), in 2031-2039 (green), and in 2051-2059 (blue).

4.2.1.1.2.3.2.6 Barents Sea

Previous studies have shown that most models tend to have a cold bias in their SAT simulations and excessive sea-ice cover over the Barents Sea region (Overland et al. *In review*). Indeed only one of the six models (CCSM3) simulates the seasonal cycles of the sea-ice extent over the Barents Sea region satisfactorily. Figure 22 shows the sea-ice extent projected by CCSM3 for November, and from April through July. As this projection is from only one model, caution must be used when considering the future state of the Barents Sea sea-ice extent. The model simulates the April and May ice conditions in reasonable agreement with observations, and projects that ice will continue to decline in the region at relatively constant linear rate throughout the 21st century. The model underestimates the ice conditions in the fall (November) however and, in the months of June and July, it predicts that ice will disappear rapidly in the coming decades.

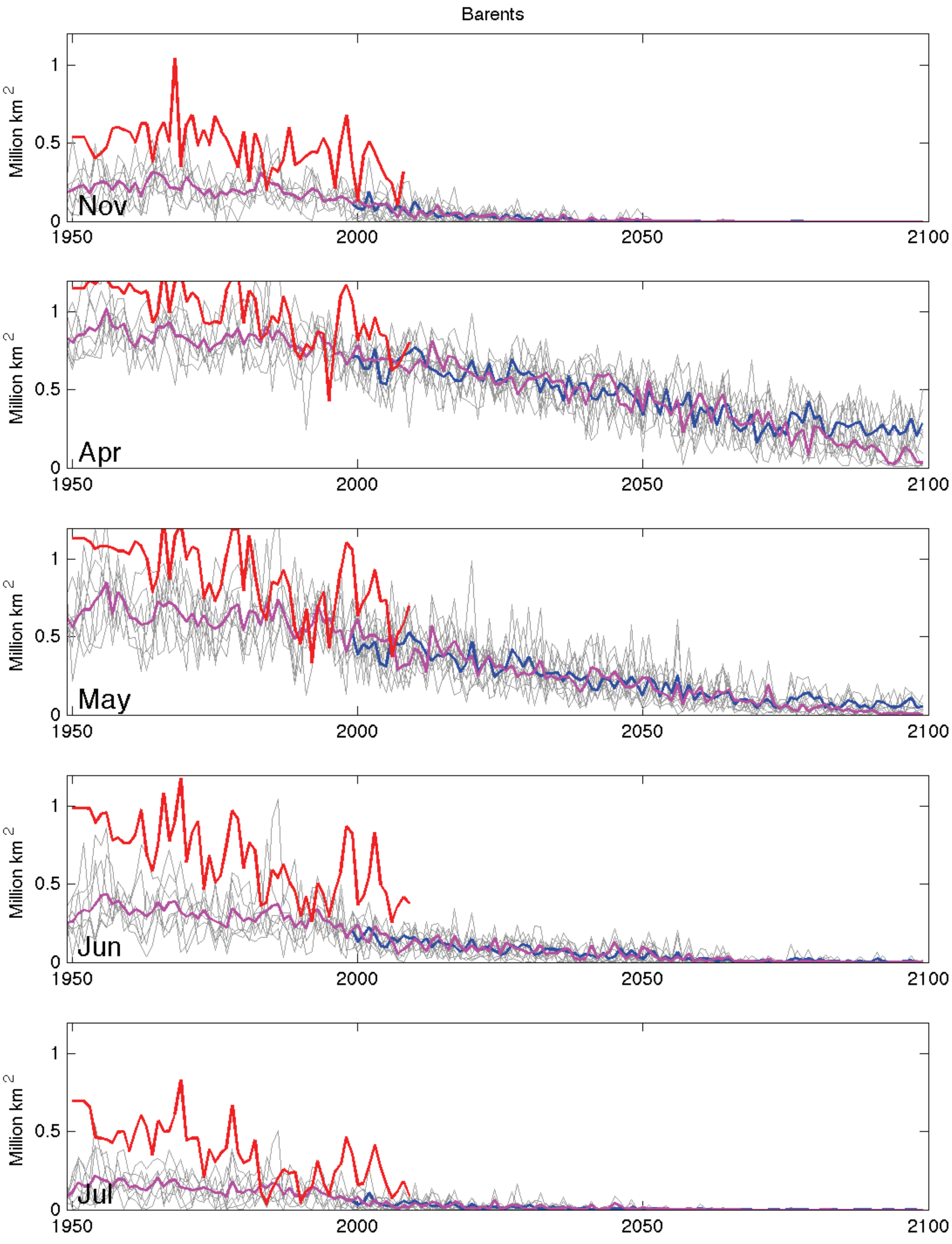


Figure 22. -- Model simulated sea-ice extent over the Barents Sea for the months of November and April to July. The red lines (observations) are based on HadISST analysis and the other colored lines are the ensemble means of the runs from CCSM3 model under A1B (blue) and A2 (magenta) emission scenarios. Each grey line represents one realization by one of these models.

4.2.1.1.2.3.2.7 Hudson Bay

For the Hudson Bay, we refer to the analysis of Joly et al. (2010). They used a regional sea-ice–ocean model to investigate the response of sea ice and oceanic heat storage in the Hudson Bay system to a climate-warming scenario. Projections of air temperature for the years 2041–2070, with effective CO_2 concentration of 707–950 ppmv, were obtained from the Canadian Regional Climate Model (CRCM 4.2.3), driven by the third-generation coupled global climate model (CGCM 3) for lateral atmospheric and land and ocean surface boundaries. The projected change in air temperature varied from 0.8°C (summer) to 10°C (winter), with a mean warming of 3.9°C. Figure 23 shows the contrast of present day sea-ice cover (a) to the warmer climate scenario. Under this warmer climate scenario, the sea-ice season is reduced by 7–9 weeks. The shallow coastal regions demonstrate a high capacity of heat storage. The maximal volume of sea ice is reduced by 31%. Overall, the depletion of sea-ice thickness in Hudson Bay follows a southeast–northwest gradient. Sea ice in Hudson Strait and Ungava Bay is predicted to be 50% thinner than present climate conditions during wintertime.

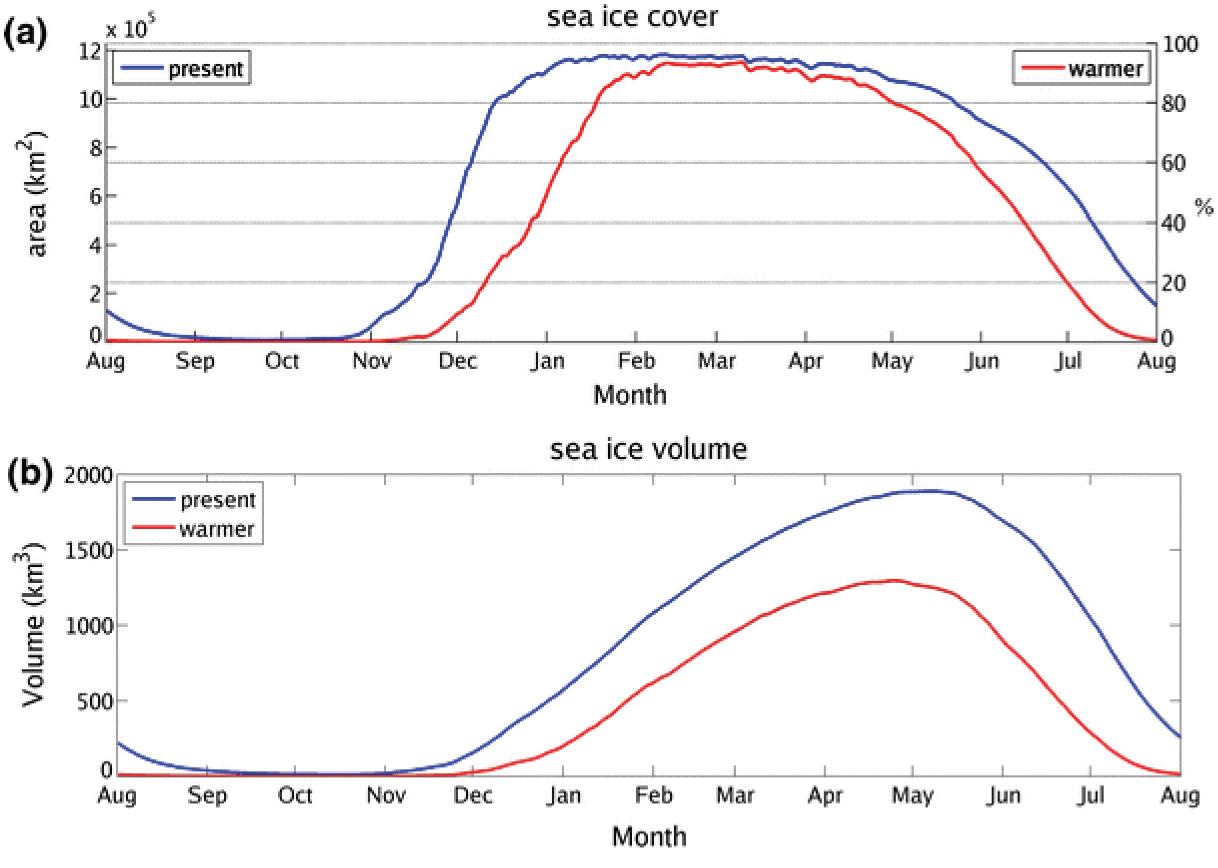


Figure 23. -- Twelve-hour averaged (a) sea-ice cover area (in km2) and (b) sea-ice volume (in km3) for the present climate simulation (blue) and the warmer climate scenario (red) in Hudson Bay; reproduced from Jolly et al. (2010).

4.2.1.1.2.3.2.8 Sea of Okhotsk

The sea-ice forecasts for the Sea of Okhotsk are not sufficiently reliable for the bearded seal assessment due to model deficiencies and the small size of the region compared to the spatial resolution of the climate models. Instead, we examined the model forecasts of air temperature from the IPCC-CMIP3 models relative to the current climate conditions. If future monthly mean temperatures during spring approach the melting point of sea ice, ~0°C, sea ice presumably will not persist.

The Sea of Okhotsk lies to the southwest of the Bering Sea and thus can be expected to have earlier radiative heating in spring. The region is dominated in winter and spring however, by cold continental air masses and offshore flow (Wang et al. 2007). During winter and spring, typical air temperatures in the northern Sea of Okhotsk are colder than in the northern Bering Sea (Wang et al. 2007). Sea ice is formed rapidly and is generally advected southward (Sasaki et al. 2007). As the region is dominated by cold air masses for much of the winter and spring, we would expect the present seasonal cycle of first year sea ice to continue to dominate the future habitat of the Sea of Okhotsk, similar to the Bering Sea. The Sea of Okhotsk in winter and spring lies between the extreme cold region of Siberia to the west and a storm track that brings warm air northward from Japan to the east. Figure 24 shows the surface temperature climatology for the months of March, April, and May. March is dominated by the cold continental air mass with temperatures below -6°C for most of the Sea of Okhotsk. During April there is a large gradient in surface temperatures between the northern and southern portions of the Sea of Okhotsk. There are -4°C temperatures to the north and 0°C to the south. During May there are relatively warm air temperatures to the west and the Sea of Okhotsk region has warmed to the melting point of sea ice throughout the region.

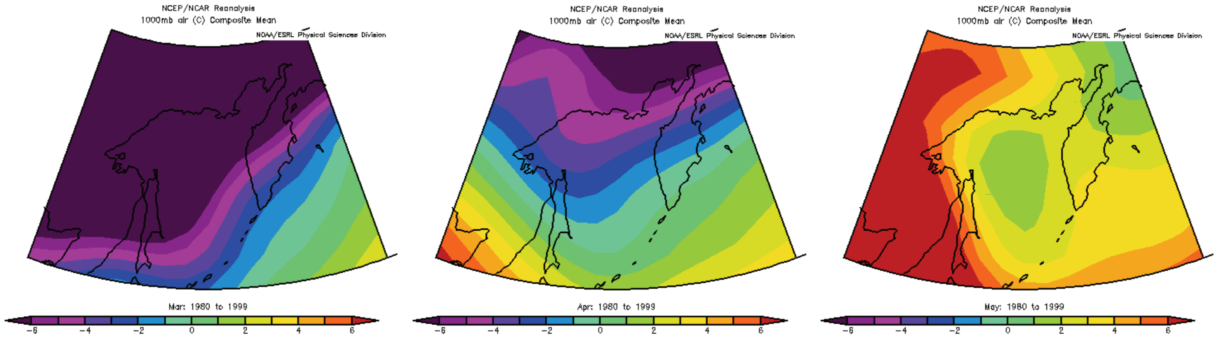


Figure 24. -- Average sea surface air temperature (SAT) in March (left), April (middle) and May (right) over the Sea of Okhotsk from 1980 to 1999. These data fields are from the NCEP-NCAR reanalysis project which combines observational data with model interpolation to create the data fields (Earth System Research Laboratory 2010).

We projected future air temperatures using 13 of the 23 available IPCC-CMIP3 models —selected for their ability to represent the climate of the North Pacific (Overland and Wang 2007)—and two scenarios for increases in anthropogenic gas increases, A1B and A2. The major scenario difference is that A1B slows the rate of CO_2 increase in the second half of the 21st century. Over the Sea of Okhotsk region for the period of 2045-2054, temperatures increases for March, April and May relative to 1980-1999, are projected to be 2.9°, 2.0°, and 1.5°C for the A1B scenario, and 2.6°, 1.9°, and 1.3°C for the A2 scenario. For the 2090-2099 period, the temperature increases for March, April and May relative to 1980-1999, are projected to be 4.9°, 3.4°, and 2.7°C for the A1B scenario, and 5.6°, 3.9°, and 3.2°C for the A2 scenario. Sea water freezes at about -1.8°C and sea ice melts at about 0°C. Thus, we predict a continuation of sea-ice formation or presence in the Sea of Okhotsk for March through the end of this century because 4.9-5.6°C of warming (A1B and A2, respectively) on top of the -7°C recent average would still result in ice-forming or preserving conditions, though the ice may be limited to the northern region in most years after mid-century. Conditions for sea ice in April are likely to be limited to the far northern reaches of the Sea of Okhotsk or non-existent if a 3.4°-3.9°C warming occurs by 2100.

4.2.1.1.2.3.2.9 Baffin Bay, the Canadian Arctic Archipelago, and the Greenland, Kara and Laptev Seas

As noted above, none of the six models performed satisfactorily for the individual regions of Baffin Bay, the Canadian Arctic Archipelago, the Greenland Sea or the Kara and Laptev Seas. For reference, we performed a qualitative analysis of seasonal and decadal changes using results of the central Arctic (70-90°N) predictions (Figures 9-14; shown in greater detail in Figures 25-26). Confidence in these analyses must be tempered by the knowledge that the predictions may fail to accurately represent the variability of the regions and (or) or may be subject to biases.

Baffin Bay, adjacent to the Canadian Arctic Archipelago, shows almost ice free conditions in July by mid-century in the six-model averaged projections (middle panel of the 1st row in Figure 26). Yet for the other months this region should be covered by sea ice as shown in Figures 9-14. Near the end of the century only a small part of Baffin Bay is predicted to have ice in July, and then only occasionally (right panel of 2nd row of Figure 26).

As mentioned earlier, even once the Arctic reaches near ice-free conditions, sea ice will continue to persist in the Canadian Arctic Archipelago region, the ice “refuge”. According to the models (Figure 13) reduction in ice concentration appears possible near the end of 21st century in June along the eastern portion of the archipelago, but the channels in the archipelago would still contain sea ice. Even in July, the eastern archipelago may contain ice in concentrations of more than 20% by 2090. These areas are covered with ice in winter, a situation that does not change much throughout the century (Figures 25-26). In the northern latitudes of the western archipelago, ice concentrations of over 60% are predicted. Around 2050, the archipelago will be covered with ice in the fall, and to a lesser extent, in the early summer as well. Ice grows very fast in the fall, and an average ice concentration of more than 80% is predicted over most of the archipelago in November, even by 2090 (Figure 26, last row).

Most of the ice covering the Greenland Sea is near the east coast of Greenland. This spatial pattern is consistent throughout the year (Figures 9-14) and continues in the future. The one obvious change is in the early summer (July) when, by the end of the 21st century, ice will only cover the northern tip of the Greenland Sea, leaving most of the east coast of Greenland ice free.

Although sea ice has covered most of the Kara and Laptev Seas throughout most of year in the past, models show that this may change in early summer (July) by the middle of 21st century (Figure 25). The delayed freeze-up in the Kara-Laptev Sea region becomes prominent around 2090 with a majority of areas having ice concentrations less than 40% which is about half of present day's value (Figures 9, 13 and 26). The change in winter and early spring ice condition however, is less significant (Figures 10-12).

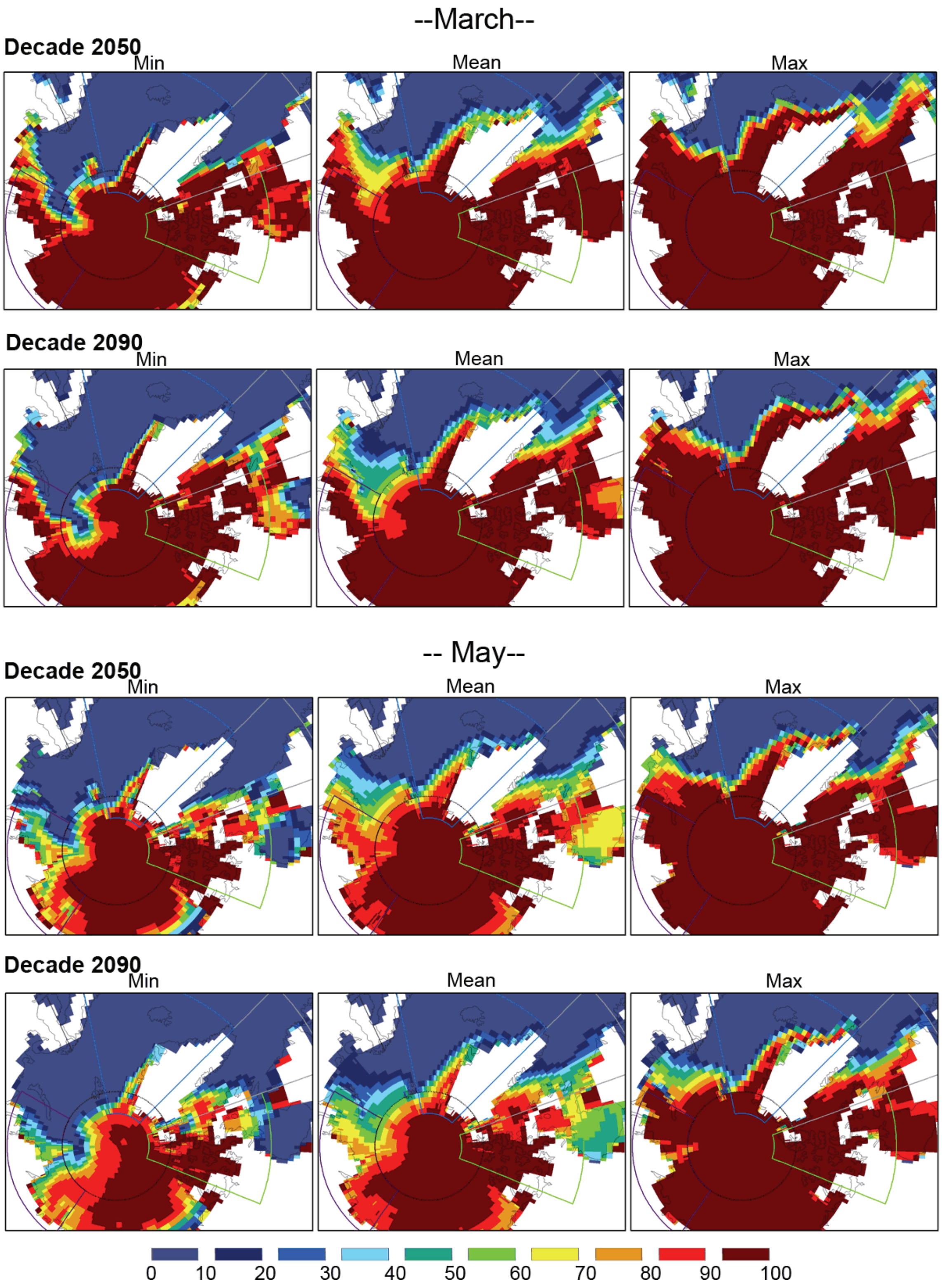


Figure 25. -- Future decadal mean sea-ice concentrations of the central Arctic and its vicinities for March and May in two future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

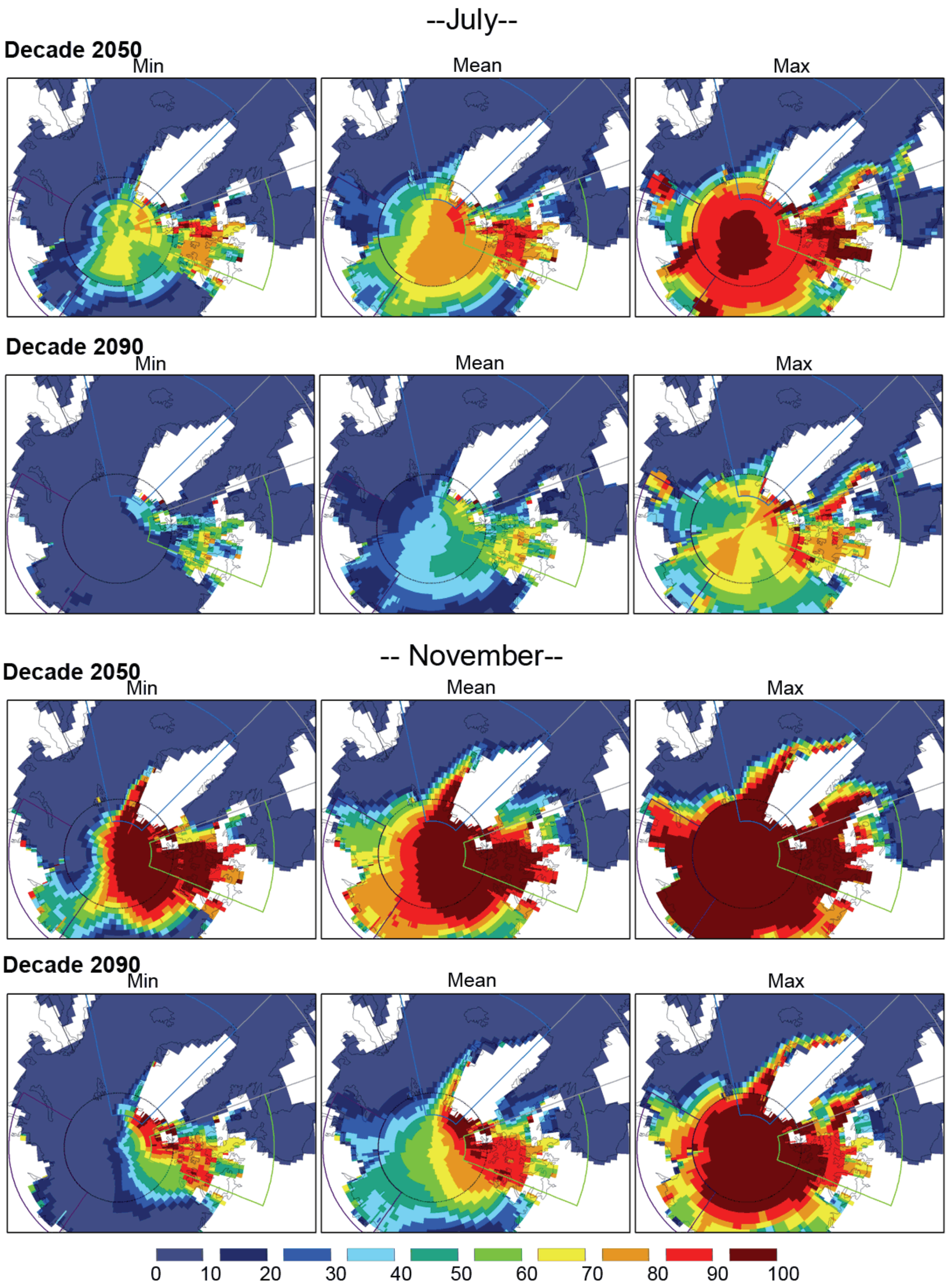


Figure 26. -- Future decadal mean sea-ice concentrations of the central Arctic and its vicinities for July and November in two future periods. The nominal year indicated is the mid-point of an 11-year period over which the forecasts are projected using the six best performing models identified by Wang and Overland (2009).

4.2.1.1.3 Effects of climate change on the quality of bearded seals' sea-ice habitat

The petition to list bearded seals as threatened or endangered cited declining sea-ice thickness as a threat to bearded seals (Center for Biological Diversity 2008). Regional sea-ice thickness is difficult to quantify with current sensing methods, though there is evidence for thinning ice in the Northern Hemisphere. Rothrock et al. (1999) and Kwok and Rothrock (2009) analyzed ice thickness estimates taken from 42 years of submarine records (1958-2000). Unfortunately, most measurements were taken in the central Arctic and no measurements were taken in the shallow waters preferred by bearded seals. Maslanik et al. (2007), used satellite data for March from 1982 to 2007 across the entire Arctic Ocean. All three studies indicated that sea ice in the Arctic Ocean has thinned during the past several decades. This thinning is believed to be the result of a loss in both thick ridged (older) ice and (younger) undeformed ice (Rothrock and Zhang 2005, Maslanik et al. 2007, Kwok and Rothrock 2009). Multiyear ice pack has declined significantly over the recent past with the oldest and thickest ice declining the fastest. Indeed, the oldest ice types have essentially disappeared, and 58% of the multiyear ice now consists of relatively young 2- and 3-year-old ice compared to 35% in the mid-1980s (Maslanik et al. 2007). The western and Siberian Arctic seem affected the most, though ice thickness has increased slightly in a few locations adjacent to the Canadian Arctic Archipelago and in the eastern Beaufort Sea. Overall, Kwok and Rothrock (2009), report an "astonishing" decrease of 1.75 m in mean winter ice thickness from 1980 (3.64 m) to 2008 (1.89 m). There are no reliable time series of ice thickness for the sub-Arctic regions (Bering and Okhotsk Seas or Hudson Bay) that form only annual ice. Shorter ice-forming seasons in all areas in the future may produce thinner ice *in situ* than in the past, but a broad range of floe thicknesses would still be expected due to rafting and ridging processes (Parmerter 1975). Much of the sea ice in the eastern and northern Bering Sea, the Chukchi Sea, and the Laptev Sea during spring is very densely compacted and heavily ridged, such that bearded seals are not found there in significant numbers during the breeding season. A decline in ice concentration and thickness in such areas could conceivably result in new breeding habitat in the future, perhaps mitigating losses of previously-used habitat, though we are not aware of specific examples in which similar mitigative shifts in habitat have occurred during rapid climatic changes. The ability of bearded seals to effectively use thinner annual ice for their life history needs, and their apparent lack of preference about the type and quality of ice in which they are observed (Fay 1974), suggest that it is mostly the presence of ice that may be of consequence and that a decline in ice thickness alone may not be a significant concern to bearded seals throughout their range.

4.2.1.1.4 Effects of climate change on ocean conditions

4.2.1.1.4.1 Ocean warming

The western Beaufort Sea, the Chukchi Sea, and northern Bering Sea surface waters have warmed by as much as 3.5 °C since 1990 (Steele et al. 2008). Summer temperatures of the southeastern Bering Sea warmed 2° C from 1995-2003 (Overland and Stabeno 2004). Ocean temperatures warmed in summer 2007 and 2008 by as much as 4 °C in the East Siberian Sea, 3 °C in the Chukchi Sea, 2 °C in the Kara Sea, and 1.5 °C in parts of the Laptev Sea (Richter-Menge and Overland 2009). In contrast, the Barents, Greenland and parts of the Laptev Seas experienced occasional years of mild (≤1.5 °C) cooling over the same period, and from 2006 through 2009 the temperature of the eastern Bering Sea cooled by as much as 2 °C since 2000 (Napp 2010).

The warming of sea surface temperatures would likely not have much direct impact on bearded seals, except slight benefits to the efficiency of molting and thermoregulation in water (Boily 1995, Harding et al. 2005), perhaps even somewhat mitigating the potential impacts from reduced quantity or quality of sea ice. Indirect effects of ocean warming, however, could be substantial, particularly through altered distributions of prey (Grebmeier et al. 2006b), predators, and pathogenic vectors. These effects are considered in Sections 4.2.1.1.4.3, 4.2.3.3 and 4.2.3.2 respectively.

4.2.1.1.4.2 Ocean acidification

Since the beginning of the industrial revolution in the mid-18th century, the release of greenhouse gases including carbon dioxide (CO_2) from human activities, commonly referred to as "anthropogenic CO_2", has resulted in an increase in atmospheric CO_2 concentrations from approximately 280 to nearly 390 parts per million (ppm), with 30% of the increase occurring in the last three decades. The atmospheric concentration of CO_2 is now higher than experienced on Earth for more than 800,000 years (Lüthi et al. 2008). Over the industrial era, the ocean has absorbed about one-third of anthropogenic carbon emissions (Canadell et al. 2007). When anthropogenic CO_2 is absorbed by seawater, chemical reactions occur that reduce both seawater pH and the concentration of carbonate ions in a process known as "ocean acidification".

Results from global ocean CO_2 surveys over the past two decades have shown that ocean acidification is a predictable consequence of rising atmospheric CO_2 levels. Seawater carbonate chemistry is governed by a series of abiotic chemical reactions (CO_2 dissolution, acid/base chemistry, and calcium carbonate dissolution) and biologically mediated reactions (photosynthesis, respiration, and calcium carbonate precipitation). The pH of ocean surface waters has already decreased (i.e., become less alkaline) by about 0.1 units since the beginning of the industrial revolution (Caldeira and Wickett 2003, Caldeira and Wickett 2005), with a decrease of ~0.0018 yr^{-1} observed over the last quarter century at several open ocean sites (Bates 2007, Bates and Peters 2007, Santana-Casiano et al. 2007). By the middle of this century atmospheric CO_2 levels could reach more than 500 ppm, and over 800 ppm by the end of the century (Orr et al. 2005). This would result in an additional decrease in surface water pH of approximately 0.3 pH units by 2100. Acidity in the ocean would increase by about 150% relative to the beginning of the industrial era.

As the pH of the ocean decreases, the equilibrium between calcium carbonate ($CaCO_3$) and its dissolution products (Ca^{2+} and CO_3^{2-}) favors dissolution. Ocean acidification reduces the calcium carbonate saturation levels, which stresses calcifying organisms by making calcification more difficult. Significant reductions in calcium carbonate saturation have been observed in the ocean since the industrial revolution (Feely et al. 2004). The carbonate saturation horizon is shoaling (becoming shallower), shrinking the layer of carbonate-saturated surface waters in which calcification of organisms can occur. The observed and expected future shoaling of the saturation depth in the North Pacific are greater than in most of the other oceans due to respiration processes as ocean water circulates along the deep conveyor belt from the Atlantic to the Indian and Pacific Oceans (Feely et al. 2004). Shoaling of undersaturated waters has been observed in the high latitude North Pacific (Feely et al. 1988) and the Chukchi Sea in the Arctic (Bates and Mathis 2009) where the biological pump enhances the seasonal undersaturation of carbonate minerals in subsurface waters. Local upwelling can exacerbate the ocean acidification impacts by bringing deep, CO_2 rich waters to the surface exposing organisms to strongly corrosive conditions (Feely et al. 2008). Two recent studies have suggested that undersaturation of aragonite (the naturally occurring crystal form of $CaCO_3$), due to ocean acidification, will develop in Arctic surface waters by or before mid-century under the B1 and A2 IPCC emissions scenarios (Orr et al. 2009, Steinacher et al. 2009).

The process of ocean acidification has long been recognized (Broecker and Takahashi 1966, Broecker et al. 1971, Bacastow and Keeling 1973, Feely and Chen 1982, Feely et al. 1988) but the ecological implications of such chemical changes have only recently begun to be appreciated. Although initial concerns about the effects of acidification focused on the negative effect that decreased $CaCO_3$ saturation state has on the ability of organisms (e.g., pteropod mollusks, shellfish and some benthic invertebrates) to produce calcium carbonate shells and skeletons (Fabry et al. 2008), it is becoming increasingly clear that changes in CO_2 and pH *per se* can affect the growth, survival and behavior for a range of marine organisms (Pörtner 2008). Many non-calcareous species are affected by acidification, and the ability of calcareous species to produce shells can be affected by acidification factors other than just saturation state (Pörtner 2008). In addition to the effects of changes in CO_2, pH, and saturation state, secondary chemical reactions can change other components of seawater, such as the concentration of various forms of trace elements and nutrients, which in turn can affect species growth and survival (The Royal Society 2005, Doney et al. 2009). Ocean acidification also affects sound absorption in the ocean. Brewer and Hester (2009), for example, suggest that changes in borate and carbonate ion concentrations associated with ocean acidification is reducing the absorption of low frequency sound (~ 300 Hz–10 kHz) important to some marine mammals. Potential direct effects of ocean acidification include:

- Reduced calcification rates – The reduced saturation state affects the ability to produce calcium carbonate shell, makes the process more physiologically costly, or leads to dissolution of existing calcium carbonate structures.
- Altered survival and reproduction from reduced pH – Organisms generally require energy to maintain appropriate inter-cellular pH balance. Altering the external pH of seawater can overwhelm pH control mechanisms, affecting survival or reproduction.
- Reduced olfaction in fish – Increased CO_2 in seawater can affect the ability of fishes to detect critical olfactory cues.
- Increased photosynthesis – Because CO_2 is required for photosynthesis, some photosynthetic organisms, especially those without effective carbon concentrating mechanisms, may have increased photosynthetic rates with increased CO_2.
- Hypercapnia – Increased CO_2 in internal fluids, especially in highly energetic species like squid, can affect survival or reproduction. The ability of organisms to decrease CO_2 titers in internal

fluids by transferring CO_2 across membranes to seawater is reduced when seawater CO_2 concentrations are high.

- Acoustic disruption from noisier ocean – Changes in ocean pH will alter the acoustic properties of the ocean, increasing transmission of low frequency sounds, which may affect species relying on acoustic information.
- Response to altered metals, nutrient or toxics speciation – Acidification will alter speciation (ionic from) of various metals, nutrients and toxics in a way that might affect species survival and reproduction.

The numerous pathways for effects (both direct and indirect) imply that ocean acidification will impact many marine species.

The waters of the Arctic Ocean and surrounding seas are among the most vulnerable to ocean acidification (Orr et al. 2005, Gehlen et al. 2007, Cao and Caldeira 2008). Modeling studies have suggested that the high latitude oceans (Arctic and Southern Oceans) will experience aragonite undersaturation by the middle of the century. Recent modeling studies (Feely et al. 2009, Steinacher et al. 2009) argue that the surface waters of the Arctic Ocean will start experiencing localized aragonite undersaturation within the next decade.

Seasonal undersaturation has already been documented (Bates et al. 2009, Yamamoto-Kawai et al. 2009). Bates et al. (2009) measured saturation states for aragonite and calcite for the Chukchi Sea shelf and Canada Basin from 2002 to 2004, and found that aragonite undersaturation is occurring in the subsurface waters over the Chukchi Sea shelf and Canada Basin due to ocean acidification combined with subsurface remineralization of particulate organic carbon. Patches of surface water undersaturated in aragonite were also found in the Canada Basin, which resulted from significant sea ice melt contributions. In a separate study, Yamamoto-Kawai et al. (2009) also found that the synergistic effects of increasing CO_2 and ice melt resulted in surface waters in the Canada Basin that were undersaturated with respect to aragonite.

The Bering Sea/Aleutian Islands and Gulf of Alaska have already experienced documented regime or phase shifts in community organization and productivity related to changing climate (Anderson and Piatt 1999, Ciannelli et al. 2005, Grebmeier et al. 2006b, Litzow et al. 2006, Litzow and Ciannelli 2007, Mueter and Litzow 2008). Ocean acidification is likely to have increasingly profound impacts on the ecosystem structure in the bearded seal habitats, but the exact nature of these impacts cannot be predicted at this time.

For example, the development (calcification, growth, maturation) of juvenile bivalves is negatively affected by elevated CO_2 (e.g., Greene and Pershing 2004, Talmage and Gobler 2009, Tunnicliffe et al. 2009). Adults also show decreased calcification, growth and overall health. Upper trophic level pelagic species' abundance may decline if their early life stages consume prey items (e.g., pteropods (Comeau et al. 2009) that cannot survive the added stress of ocean acidification. Pteropods are important food sources for larval and juvenile walleye pollock, Pacific herring, and cod which are important prey of bearded seals. Therefore, the loss of calcifying species like pteropods from the ecosystem could have a cascading effect on the bearded seals. Lower trophic levels may also be modified because of changes nutrient availability (Zeebe et al. 2008), including the ratio of ammonia to ammonium and availability of iron (Andreev et al. 2009, Shi et al. 2010), speciation of trace metals (Mouvet and Bourg 1983) and the potency of pH-sensitive marine toxins.

4.2.1.1.4.3 Bearded seal prey communities

4.2.1.1.4.3.1 Current status and trends of bearded seal prey

4.2.1.1.4.3.1.1 Beringia DPS: Abundance and distribution of prey

Invertebrates important in the diet of bearded seals in the Beringia DPS primarily include bivalve mollusks and decapod crustaceans. In the Bering and Chukchi Seas, tanner crabs (*Chionoecetes* spp.) and lyre crabs (*Hyas* spp.) are commonly consumed by bearded seals. This region is inhabited by four species of tanner crabs (*Chionoecetes bairdi*, *C. opilio*, *C. angulatus*, and *C. tanneri*), though only two of these (*C. bairdi* and *C. opilio*) are common in shallow water. *Chionoecetes opilio* has a very broad distribution, ranging from Japanese waters through the Sea of Okhotsk, Bering Sea, and Beaufort Sea, as well as the western North Atlantic (Jadamec et al. 1999), and is the most abundant epifaunal invertebrate in the southern Chukchi Sea (Feder et al. 2005). The range of *C. bairdi* is restricted to the North Pacific, southern Sea of Okhotsk, and Bering Sea (Jadamec et al. 1999). Two species of lyre crabs (*Hyas lyratus* and *H. coarctatus*) inhabit the Bering and Chukchi Seas. The Pacific lyre crab (*H. lyratus*) ranges from the southern Chukchi Sea south through the Bering Sea and eastern North Pacific (Sparks and Pereyra 1966, Hart 1982), while the Arctic lyre crab (*H. coarctatus*) is found in the northern Bering Sea and throughout the Arctic. Bearded seals in the Bering and Chukchi Seas also eat shrimp, particularly crangonids. A multitude of crangonid shrimp are known to inhabit the region, and virtually all of these have been found in the diets of bearded seals. Most crangonid shrimp species are broadly distributed throughout the Chukchi, Bering, and Okhotsk Seas, and some, such as *Sclerocrangon boreas*, extend throughout the Arctic and into the north Atlantic as well (Butler 1980). *Argis lar* and *Sclerocrangon boreas* are among the most abundant epifaunal invertebrates in the southern Chukchi Sea (Feder et al. 2005).

Bearded seals in the Bering and Chukchi Seas also consume a variety of bivalves (Pikharev 1941, Kenyon 1962, Johnson et al. 1966, Lowry et al. 1980). Most prominent among these are the cockles, *Serripes groenlandicus* and *Clinocardium ciliatum*, as well as the Arctic surfclam (*Mactromeris polynyma*). Both cockles are distributed throughout the Arctic (MacGinitie 1959), and the Arctic surfclam is found in both the North Pacific and North Pacific Arctic basins (Chamberlin and Stearns 1963). Although these species are widespread, none of them appear to be particularly abundant in the Bering and Chukchi Seas (Feder et al. 1994, Feder et al. 2005, Bluhm et al. 2009).

Over the past decade, there has been a change in the northern Bering Sea ecosystem from Arctic to sub-Arctic conditions due to ocean warming and decreases in ice cover. The result has been a decrease in the standing stock of benthic organisms (Grebmeier et al. 2006a, Grebmeier et al. 2006b). Accompanying this change has been a northward movement of the cold-water barrier that apparently limits the distribution of benthic crabs and fishes (Grebmeier et al. 2006a). In contrast, in Norton Sound the density of benthic species (particularly sea stars, crabs and flatfish) has increased since the mid-

1970s (Hamazaki et al. 2005). Similar increases in sea stars, crabs and shrimp from the 1970s to the late 1990s were observed in the southeast Chukchi Sea and Kotzebue Sound (Feder et al. 2005).

Bering Sea or opilio snow crab (*Chionoecetes opilio*) biomass has declined since the mid-1970s and the stock is considered overfished (Low 2008). Low crab recruitment could be due to fishing, climate, or groundfish predation (Low 2008, Mueter and Litzow 2008). Orensanz et al. (2004) propose an "environmental ratchet hypothesis" to explain the decline in the snow crab stock and the significant long-term shift of the population to the north. Northward shifts in the distribution of crab cohorts associated with ocean warming and decreases in ice cover are because: 1) appropriate conditions for larval growth and survival are associated with spring blooms that develop in association with the ice in cold years, and 2) early juvenile stages require near bottom temperatures below 2 °C (a.k.a. the "cold pool"). After contraction of the stock to the north it is difficult for crab distributions to recover towards the south during warm years because of northerly current patterns and northward expansion of cod and subsequent increased predation. Bering Sea tanner crab (*Chionoecetes bairdi*) have shown extreme variability in abundance, as reflected in recruitment estimates and commercial catches. The population declined from the mid-1970s to the mid-1980s, so much that commercial fishing was closed in 1986 and 1987. Abundances increased until the early 1990s and decreased subsequently (Rosenkranz et al. 1998). Correlations between recruitment estimates and spring wind speed suggest that the variability in recruitment is influenced by upwelling (and thus food availability) and advection of larval stages into favorable habitat (Rosenkranz et al. 1998). Bering Sea shrimp (*Pandalus* and *Pandalopsis*) were prominent commercially harvested species in the 1960s, with catches peaking in 1963 and gradually declining until the fishery ended in 1973. Shrimp abundance in the Bering Sea is currently too low to support a commercial fishery (National Marine Fisheries Service 1999, Low 2008).

During August 2008, the first survey of marine fishes in offshore waters of the Beaufort Sea since 1977 was conducted (Logerwell et al. 2010). Benthic fish and invertebrate species composition, distribution and abundance were assessed with Alaska Fisheries Science Center standard bottom trawl gear and methods. Fish made up 6% of the bottom trawl catch by weight, and invertebrates made up the remaining 94% of the catch. The most abundant invertebrates were brittle stars (*Ophiura sarsi*), opilio snow crab, a mollusk (*Musculus niger*) and a seastar (*Ctenodiscus crispatus*). Snow crab have been observed in previous Beaufort Sea and Chukchi Sea surveys in 1977 and 1990-91 respectively (Frost and Lowry 1983, Paul et al. 1997), but the 2008 Beaufort survey was the first to document the occurrence of snow crab of commercially viable size in the North American Arctic. The presence of female crabs with eggs during the 2008 Beaufort Sea Survey suggests that this population is reproductive.

Although the diets of bearded seals generally consist mostly of invertebrates, there is evidence that fishes are important at least in certain regions and seasons (Kosygin 1971, Heptner et al. 1976, Lowry et al. 1979, Antonelis et al. 1994). Arctic and saffron cod, smelts and herring, sculpins, and eelpouts are the most common groups of fishes found in the diets of bearded seals in this DPS. The Arctic cod is distributed throughout the Arctic, and extends south into the northern Bering Sea, but is not present in the Sea of Okhotsk (Shmidt 1950, Cohen et al. 1990). It is primarily a coastal species, and is usually found either in nearshore waters or offshore associated with sea ice. Arctic cod may be among the most abundant fish species in some Arctic areas (Barber et al. 1997, Mecklenburg et al. 2007). The saffron cod is also prominent in bearded seal diets (Kosygin 1971, Lowry et al. 1980, Bukhtiyarov 1990). It is found throughout the North Pacific, Sea of Okhotsk, and Bering Sea, and extends into the Arctic in the East Siberian, Chukchi, and Beaufort Seas (Cohen et al. 1990). The saffron cod is primarily a demersal species found in shallow coastal waters.

Bearded seals are generally benthic feeders, but they also regularly consume several species of pelagic forage fishes, such as smelts and herring. The smelt species most commonly found in bearded seal diets is capelin, which is found throughout the Arctic, extending south into the Bering and Okhotsk Seas as well as the North Pacific and North Atlantic (Mecklenberg et al. 2002). This pelagic species migrates onshore in large schools to spawn, and therefore large numbers are accessible to bearded seals (Eschmeyer and Herald 1983, Mecklenberg et al. 2002) in shallow water during some times of the year, and at least in the Bering Sea the seals clearly take advantage of this (Antonelis et al. 1994). Other species of smelts consumed by bearded seals (e.g., *Osmerus mordax*) occupy large portions of the Arctic, and are anadromous species generally found in shallow coastal waters. Similarly, the Pacific herring (*Clupea pallasii*) is an abundant, pelagic, schooling species found primarily in coastal waters throughout the North Pacific and Bering Sea, as well as the Sea of Okhotsk, Chukchi, and Beaufort Sea (Whitehead 1985). Herring stocks have been depleted by decades of fishing efforts, but those efforts have been concentrated in the sub-Arctic portions of the species range. Arctic populations of herring are relatively unfished compared to their sub-Arctic counterparts, but are also not as well known (Hay et al. 2001).

In addition to gadids, several other species of bathypelagic and demersal fishes are also found in bearded seal diets, including sculpins, eelpouts, pricklebacks, and flatfishes. The species found in the diets of bearded seals generally reflect the most abundant and diverse groups in the region. Sculpins (Cottidae) are represented throughout the Arctic, Bering Sea, and the Sea of Okhotsk by several genera, including *Artediellus*, *Icelus*, *Gymnocanthus*, *Myoxocephalus*, and *Triglops* (Walters 1955, Mecklenberg et al. 2002, Mecklenburg et al. 2007). The two most abundant species reported by Mecklenburg et al. (2007) from the southern Chukchi Sea were the sculpins *Gymnocanthus tricuspis* and *Myoxocephalus scorpius*, both of which have been found in the diets of bearded seals. Eelpouts (Zoarcidae) are also particularly diverse in Arctic waters, especially the genus *Lycodes*. Although not generally abundant, eelpouts represent a large proportion of the fish biomass, as the family includes some of the largest fishes known from the Arctic (e.g., *Lycodes raridens* and *L. reticulatus* are both robust heavy-bodied species that reach over 70 cm in length) (Mecklenberg et al. 2002). Pricklebacks (Stichaeidae) are another family represented by a number of species in the Arctic. Three of the 10 most abundant species reported by Mecklenburg et al. (2007) from the southern Chukchi Sea were pricklebacks, though none of those species has been reported in the diet of bearded seals in the region. Flatfishes (Pleuronectidae) dominate the shallow demersal fish communities of the eastern Bering Sea, accounting for over 60% of the estimated fish biomass (Lauth and Acuna 2009). The most common flatfishes in the eastern Bering Sea are yellowfin sole (*Limanda aspera*), northern rock sole (*Lepidopsetta polyxystra*), and flathead sole (*Hippoglossoides elassodon*), all of which have been reported from the stomachs of bearded seals. However, in the far northern Bering Sea and the Chukchi and Beaufort Seas, the fish fauna transitions from a community dominated by flatfishes to one dominated by sculpins and cods. Barber et al. (1997)

estimated that 69% of the demersal fish biomass in the northeastern Chukchi Sea was comprised of two species of gadids, and of the 10 most abundant species reported by Mecklenburg et al. (2007) from the Chukchi Sea, only one species was a flatfish (*Hippoglossoides robustus*). Frost and Lowry (1983) reported that 65% of the fish biomass in the eastern Chukchi and western Beaufort Seas was accounted for by three species: Arctic cod, Canadian eelpout (*Lycodes polaris*), and twohorn sculpin (*Icelus bicornis*).

A suite of environmental variables from the North Pacific changed abruptly in 1976-1977 (Ebbesmeyer et al. 1991, Trenberth and Hurrell 1995, Hare and Mantua 2000), what has now become known as a major ocean climate “regime shift”. The regime shift was associated with warmer ocean temperatures and decreased winter ice cover in the Bering Sea (Niebauer 1988, Hollowed and Wooster 1995). This reduction in the extent of winter ice reduced the southerly extent of very cold (<2° C) bottom water on the Bering Sea shelf during summer (a.k.a. the “cold pool”) with subsequent expansion of walleye pollock and contraction of Arctic cod to the north (Wyllie-Echeverria and Wooster 1998). Further research has shown that the northward shift of the summer cold pool has apparently resulted in the northward shift in the center of distribution of multiple taxa of demersal fishes and invertebrates (Mueter and Litzow 2008). Sub-Arctic taxa increasingly occupy the area formerly covered by the cold pool resulting in a shift from a less species-diverse Arctic community devoid of groundfish to a more diverse sub-Arctic community rich in groundfish. Continued reductions in winter sea-ice cover appear to be causing a change from Arctic to sub-Arctic conditions in the northern Bering Sea and a northward shift of the pelagic-dominated marine ecosystem that was previously limited to the southeastern Bering Sea (Grebmeier et al. 2006b). The regime shift had mixed impacts on production of groundfish. Recruits per spawner decreased after the regime shift for flatfish (e.g., yellowfin sole) and increased for rockfish (e.g., Pacific ocean perch (*Sebastes alutus*)). Although production of groundfish (e.g., walleye pollock and Pacific cod) was not impacted by the regime shift (Low 2008), there was a shift in the importance of pollock to the ecosystem, from near 10% of the energy flow in the 1950s to 1960s to over 50% in the 1980s (PICES 2005). Biomass trends in the southeast Bering Sea do show trends coherent with the regime shift. The density of demersal fish and non-crab benthic invertebrates increased from the late 1970s to the early 1990s and then decreased somewhat in the late 1990s (Conners et al. 2002).

The warm period occurring after the 1976-1977 regime shift was followed by a relatively weak cold period from 1989-1998 with a subtle but evident increase in winter ice extent in the Bering Sea (Schumacher et al. 2003). The Bering Sea then experienced another suite of unusual physical and biological conditions in the late 1990s associated with unusually warm sea surface temperatures: the first recorded major coccolithophore blooms, a large die-off of shearwaters, Pacific salmon returns far below predictions and reduced onshore transport of slope water (Schumacher et al. 2003). Production (recruits-per-spawner) decreased for several species of flatfish after 1988-89 (e.g., arrowtooth flounder *Reinhardtius stomias*, rock sole and flathead sole), and increased for rockfish (e.g., Pacific ocean perch) (Low 2008). Cold water species such as Greenland turbot (*Reinhardtius hippoglossoides*), Arctic cod, and snow crab are no longer found in abundance in the southeast Bering Sea (PICES 2005). Adult walleye pollock biomass in the eastern Bering Sea has ranged from 3.2 to 12.6 million metric tons since 1979 and is currently relatively low due to the lack of strong recruitment in recent years (Ianelli et al. 2009). The abundance of smaller, juvenile pollock in the eastern Bering Sea is highly variable due to high interannual variation in year-class strength (Ianelli 2005).

4.2.1.1.4.3.1.2 Okhotsk DPS: Abundance and distribution of prey

Invertebrates important in the diet of bearded seals in the Ohkotsk DPS primarily include bivalve mollusks and decapod crustaceans. In the Sea of Okhotsk, bearded seals eat many of the same crustacean and bivalve species as those in the Bering and Chukchi Seas. Snow crabs, tanner crabs, and Arctic lyre crabs are all found in at least parts of the Sea of Okhotsk, and snow crabs may be very abundant there (Kobvakova 1955). The diversity of pandalid, crangonid, and hippolytid shrimps in the Sea of Okhotsk is also comparable with that of the Bering and Chukchi Seas, and many species are found in both regions (Kobvakova 1955). Likewise, the cockles and surfclams preferred by bearded seals in the Bering and Chukchi Seas are also found in the Sea of Okhotsk (Scarlato 1955), though they have not generally been reported in the diets of the bearded seals in this region (Pikharev 1941, Bukhtiyarov 1990).

Although the diets of bearded seals generally consist mostly of invertebrates, there is evidence that fishes are important at least in certain regions and seasons (Kosygin 1971, Heptner et al. 1976, Lowry et al. 1979, Antonelis et al. 1994). Saffron cod, smelts, herring, sculpins, and flatfishes are the most common groups of fishes found in the diets of bearded seals in the Sea of Okhotsk. The saffron cod (*Eleginus gracilis*) is prominent in bearded seal diets (Kosygin 1971, Lowry et al. 1980, Bukhtiyarov 1990). It is primarily a demersal species found in shallow coastal waters. In addition to gadids, several other species of bathypelagic and demersal fishes are also found in bearded seal diets, including sculpins and flatfishes. Sculpins (Cottidae) are represented throughout the Arctic, Bering Sea, and the Sea of Okhotsk by several genera, including *Artediellus*, *Icelus*, *Gymnocanthus*, *Myoxocephalus*, and *Triglops* (Walters 1955, Mecklenberg et al. 2002, Mecklenburg et al. 2007). Flatfishes account for about 50% of the demersal fish biomass in the Sea of Okhotsk (Il'inskii et al. 2004). Although bearded seals are generally benthic feeders, they also regularly consume several species of pelagic forage fishes, such as smelts and herring. In the Sea of Okhotsk, capelin and Pacific herring are commonly found in bearded seal diets (Mecklenberg et al. 2002).

Biomass of benthic invertebrates overall in the Sea of Okhotsk has declined since the late 1990s to approximately one-third previous levels, due mostly to declines in crabs, shrimps and gastropods (PICES 2005). Red king crab (*Paralithoides camtschaticus*) were harvested intensely in the Sea of Okhotsk from 1924 to 1983. In the last decade the catches have decreased to half the historical maximum catch. In the early 1990s, two high-yielding cohorts recruited to the population and supported commercial harvests until 2000. A decline in crab abundance is expected due to the current lack of high recruitment (Dulepova and Klyashtorin 2008).

Pacific herring stocks in the Sea of Okhotsk declined severely in the latter part of the 20th century due to intense fishing pressure, and commercial herring fishing in the region has been prohibited (Hay et al. 2001). A recent cooling trend in the Sea of Okhotsk, beginning in 1997, has resulted in a decrease in walleye pollock, cod, flatfish and sardine and an increase in herring, capelin, anchovy and squid

(Dulepova and Klyashtorin 2008). Despite dramatic declines, pollock remain the most abundant epipelagic fish in the Sea of Okhotsk (PICES 2005). Total biomass of epipelagic fish is currently below levels of the 1970s-1990s (PICES 2005). In addition, there has been a significant decline in the biomass of all major demersal fish species in the Sea of Okhotsk since 1997, excluding sculpins (PICES 2005).

4.2.1.1.4.3.1.3 E. b. barbatus: Abundance and distribution of prey

E. b. barbatus generally feed more heavily on fishes than those of the Beringia DPS. Gadids are the primary fish prey for bearded seals in this region. Arctic cod are preferred by bearded seals in the Canadian High Arctic, as well as the Greenland, Kara, and Barents Seas, commonly accounting for a greater proportion of the diet than all other fish species combined (Chapskii 1938, Finley and Evans 1983, Hjelset et al. 1999). Arctic cod are found throughout the Arctic, and may be quite abundant in some areas. This species has been fished heavily in the Barents Sea and northwest Atlantic, but its short life span and relatively high fecundity have protected the species from notable depletion (Cohen et al. 1990). The polar cod was also found in the diet of bearded seals in the Canadian High Arctic (Finley and Evans 1983) and Svalbard (Hjelset et al. 1999). It has a disjunct but broad distribution in the Arctic, and has been reported from both sides of Greenland as well as the Canadian High Arctic and the Laptev Sea (Cohen et al. 1990). It is a pelagic species primarily found in offshore waters and associated with sea ice, and its biology is poorly known. Atlantic cod (*Gadus morhua*) have been reported from the stomachs of bearded seals in the Svalbard region (Hjelset et al. 1999). This species is considerably larger than the other gadids found in the diets of bearded seals, and ranges from Hudson Bay through the North Atlantic, Labrador Sea, Greenland Sea, and Barents Sea. The northern limit of its distribution varies according to climate trends (Cohen et al. 1990). The Atlantic cod is among the world's most important commercial fish species. Its history of commercial exploitation dates back centuries, and current stocks represent a fraction of historical population levels.

In addition to gadids, bearded seals in this region regularly consume eelpouts (Zoarcidae), sculpins (Cottidae), pricklebacks (Stichaeidae), and flatfishes (Pleuronectidae), and less frequently poachers (Agonidae), lumpsuckers (Cyclopteridae), and snailfishes (Liparidae) (Smith 1981, Finley and Evans 1983, Hjelset et al. 1999). These represent some of the most diverse families in Arctic waters. At least 26 species of eelpouts are known from Greenland waters alone (Møller et al. 2010). Two genera of eelpouts, *Lycodes* and *Gymnelus*, have been identified in the diets of bearded seals in the Canadian Arctic and Svalbard region. The species of *Lycodes* (*L. polaris* and *L. mucosus*) reported in bearded seals from this region (Finley and Evans 1983) are large, heavy-bodied benthic species either widespread in the Arctic or circumpolar (Anderson and Fedorov 2004). *Gymnelus* is a genus of diminutive benthic eelpouts distributed throughout the Arctic and boreal seas. The taxonomy of this genus and distribution of its species are currently uncertain (Anderson and Fedorov 2004). Sculpins found in bearded seals have usually not been identified beyond the family level. The diversity of sculpins in the range of *E. b. barbatus* is very similar to that of the Beringia DPS, including the same genera (*Artediellus*, *Icelus*, *Gymnocanthus*, *Myoxocephalus*, *Triglops*) and many of the same species. Hjelset et al. (1999) reported relatively large numbers of the prickleback, stout eelblenny (*Lumpenus medius*), and the flatfish, rough dab (*Hippoglossoides platessoides*), in the diet of bearded seals from Svalbard. The stout eelblenny is found throughout the Arctic, and extends south well into the North Atlantic (Mecklenburg and Sheiko 2004), while the rough dab is found throughout the North Atlantic, extending into the Labrador, Greenland, and Barents Seas (Nielsen 1986).

Like the bearded seals of the Beringia DPS, the invertebrate prey of *E. b. barbatus* primarily includes decapod crustaceans and bivalve mollusks, but unlike the seals of the Beringia DPS, gastropod mollusks are prominent as well. Crustaceans consumed by bearded seals in this area are predominantly shrimp of the families Crangonidae and Hippolytidae, most of which are widespread in Arctic waters and some of which (e.g., *Sclerocrangon boreas*) are essentially circumpolar (Butler 1980). The only crab reported to be prominent in the diet of bearded seals in this region is the Atlantic lyre crab (*Hyas araneus*), which is found from the Kara Sea west through the Barents and Greenland Sea into the North Atlantic and Canadian Arctic, and has recently been reported from the Antarctic Peninsula as well (Tavares and DeMelo 2004). The bivalve most commonly found in the diet of *E. b. barbatus* is the Greenland cockle (*Serripes groenlandicus*), along with the hairy cockle (*Clinocardium ciliatum*), nutclams (Nuculidae and Nuculanidae), and small numbers of various other clams and mussels (Smith 1981, Finley and Evans 1983, Hjelset et al. 1999). Both cockles are distributed throughout the Arctic (MacGinitie 1959), as are at least some of the nutclams (e.g., *Ennucula tenuis*). In addition to crustaceans and bivalves, bearded seals from the Canadian Arctic to the Kara Sea consume a number of gastropods (Chapskii 1938, Finley and Evans 1983, Hjelset et al. 1999). Most prominent among these are several species of the genus *Buccinum*, of which approximately 20 species are known from the Arctic waters adjacent to the North Atlantic (Rosenberg 2009).

Northern shrimp (*Pandalus borealis*) abundance in the northwest Atlantic tends to mirror groundfish predator abundance (Stefánsson and Pálsson 1998). For example, a time series of groundfish survey data shows that shrimp densities on the Newfoundland-Labrador shelf were low in the mid-1980s when groundfish densities were high, and then increased in the late 1980s to late 1990s as groundfish abundance declined (Koeller 2000). Similarly, shrimp recruitment in northern Icelandic waters is negatively correlated with the immature cod stock (Stefánsson et al. 1994).

4.2.1.1.4.3.2 Projected changes in bearded seal prey

Using evidence from recent past warming episodes to forecast climate change effects on ecosystems may not be generally appropriate. Bakun (1990) cautions about performing these types of extrapolations because of the different causal mechanisms at work in controlling marine ecosystem dynamics; however, his caution is most appropriate for very complex oceanographic systems such as upwelling zones.

4.2.1.1.4.3.2.1 Impacts of ocean warming

In general, marine populations exhibit a wide array of distribution patterns, reflecting their relative sensitivities to the seasonal temperature cycle (Taylor et al. 1957, Colton 1972, Scott 1982, Murawski and Finn 1988). Warming of the oceans is predicted to drive species ranges toward higher latitudes (Parmesan and Yohe 2003). Climate change can strongly influence fish distribution and abundance (Wood and McDonald 1997) through changes in growth, survival, reproduction, and spawning distribution (Sundby and Nakken 2008). Rapid warming might exceed the ability of local forage species to adapt, thereby causing a major restructuring of regional ecosystems as was observed in the North and Baltic Sea ecosystems (MacKenzie and Schiedek 2007). What can be predicted with some certainty is that further shifts in spatial distribution and northward range extensions are inevitable and that the species composition of the plankton and fish communities will continue to change under a warming climate (Mueter et al. 2009). The bearded seals of different age classes are thought to feed at different trophic levels (Young et al. 2010), so any ecosystem change could be expected to impact bearded seals in a variety of ways.

The benthic invertebrate prey of bearded seals are likely to be impacted in some way by ocean warming. For example, the northward retreat of snow crab with ocean warming and decreased winter ice cover suggests that continued warming will bring further declines in crab abundance in the Bering Sea (Mueter and Litzow 2008). In fact, community-wide responses involving a number of demersal fish and invertebrate species to warming conditions in the Bering Sea have been observed, for example: northward distribution shifts, and changes in community metrics such as total biomass, species richness and average trophic level. These findings suggest the possibility of highly disruptive responses of the benthic community to continued climate change (Mueter and Litzow 2008). Shrimp may be particularly sensitive to climate change because the environment apparently impacts many phases of shrimp life history, particularly the lengthy embryonic and larval stages (Nilssen and Hopkins 1991, Anderson 2000). Abundance of shrimp in the Gulf of Alaska has been shown to be negatively correlated with water column temperature, in both heavily and lightly fished areas (Anderson 2000). A similar relationship has been observed in other areas, such as the Gulf of Maine (Dow 1964), so it would not be inappropriate to expect that shrimp populations in the Pacific and Atlantic sides of the Arctic also will be negatively impacted by ocean warming.

Ocean warming likely will impact the demersal fish prey of bearded seals, such as Arctic cod. Arctic cod is primarily an Arctic species associated with relatively cold waters. The location and extent of cold bottom water < 2°C in the summer (a.k.a. “the cold pool”) in the Bering Sea is linked to the extent of ice cover during the previous winter such that the cold pool is more extensive and expands to the south and east after high ice years. Arctic cod have been found primarily in these cold pool waters such that their summer distribution is also more extensive and further to the south and east after high ice winters. Conversely, Arctic cod distribution is contracted towards the north and west in summers following low winter ice cover (Wyllie-Echeverria and Wooster 1998). Thus, continued ocean warming and decreased winter ice extent in the future could potentially reduce the southerly and easterly extent of the distribution of Arctic cod in the Bering Sea. Arctic cod in the Beaufort Sea are similarly associated with cold waters. A survey of marine fish of the Beaufort Sea conducted in summer 2008 showed that adult Arctic cod in both benthic and pelagic habitats apparently prefer the very cold winter water that emanates from the Chukchi Sea (Logerwell et al. 2010). This is the region of the cold halocline that characterized Chukchi Sea outflow through Barrow canyon and fish distributions and model results suggest that the fish prefer these low temperatures. The Chukchi Sea outflow of cold, winter-formed waters are also rich in dissolved and particulate organic carbon, with this water carried offshore into the halocline (Pickart et al. 2005, Mathis et al. 2007). Previous studies in the marine coastal habitat of the

Beaufort Sea have similarly shown that Arctic cod prefer waters that are cold (-1° to 3 °C) and of high salinity (27-32 ppt; Craig 1984). Future warming of the Chukchi and Beaufort Seas therefore, could potentially impact the distribution and/or abundance of Arctic cod.

Demersal fish in the Atlantic Arctic have also demonstrated sensitivity to ocean warming. Nearly two-thirds of exploited and non-exploited demersal fish species in the North Sea showed a northward shift (average shift was 172.3 km/°C or 12 km per decade; Perry et al. 2005) in response to recent (post-1980s) rapidly warming water temperatures (Perry et al. 2005). The rapid warming led to the northward migration of southern species and the ecosystem changed from one dominated by cold-water species to the one dominated by warm-water species. In the northwest Atlantic Ocean, centroids of mean catches of fish from bottom trawl surveys also shifted north by 0.5-0.8 degrees of latitude for each 1°C increase in average water temperature (Murawski 1993).

Ocean warming may also impact the distribution of pelagic fish. There have been range extensions of pelagic fish such as pollock and Pacific salmon in the northern Bering Sea associated with increased temperatures and decreased ice cover and the evidence is for a continued trend towards more sub-Arctic conditions in that area (Grebmeier et al. 2006b). In the Barents Sea, higher zooplankton biomass has been observed during recent years with warm ocean temperatures and increased inflow of North Atlantic water (1991-2000) compared to previous cold years (1984-1990) (Dalpadado et al. 2003). Thus, warm years would be expected to be favorable for pelagic zooplanktivorous fish such as capelin and herring. In addition, the distribution of capelin has been shown to be linked to ocean temperatures, being shifted to the north and east during warm ocean years (Loeng 1989). In the Russian North Pacific, model predictions indicate cooling until approximately 2020 with decreases in “warm water” pelagic species such as salmon, pollock and sardine and then increases after 2020. Herring and other “cold water” species will increase until 2020 and then decline (Dulepova and Klyashtorin 2008).

Increased river runoff is another predicted consequence of a warming climate, with associated increases in inorganic nutrients, increased turbidity and decreased salinity in coastal waters (ACIA 2004). Several studies (reviewed in Bluhm and Gradinger 2008), suggest that the diversity and biomass of benthic organisms would decrease with increased river runoff, primarily in response to decreased salinity.

In addition to shifts in the distribution of species ranges within Arctic ocean regions, it is reasonable to expect trans-Arctic invasions of the Atlantic by North Pacific species concurrent with a decrease in sea ice and ocean warming. These invasions last occurred during the warm mid-Pliocene epoch (Vermeij and Roopnarine 2008). Given that marine invasions rarely lead to extinctions, the expectation is that the trans-Arctic invasions will result in an increase in species diversity in the Atlantic. Few Atlantic to Pacific invasions are predicted because Pacific-derived species are larger-bodied than Atlantic and would thus be capable of excluding Atlantic invaders.

4.2.1.1.4.3.2.2 Impacts of changes in distribution and abundance of ice

Ice algae contribute 4-26% of the production in seasonally ice-covered waters and >50% in the permanently covered central Arctic (Gosselin et al. 1997). Spring algal blooms in the bottom layer of sea ice can be substantial, above 70 mg Chl *a* m^{-2} (Smith et al. 1993). The ice community is important to the

Arctic ecosystem not only because it contributes to primary production but also because it extends the grazing season of herbivores (ice algae blooms are available before the open water spring bloom). In addition, high densities of algae on the 2-dimensional undersurface of the ice may increase the grazing efficiency of zooplankton compared to the 3-dimensional open water habitat (Bradstreet and Cross 1982). The association of Arctic cod with sea ice is well documented in coastal and offshore Arctic locations across the globe (reviewed in Bradstreet et al. 1986). Arctic cod appear to use sea ice for both feeding and for protection from predators by hiding in water wedges along the edges of ice floes (Gradinger and Bluhm 2004). For example, several species of gammaridean amphipods are endemic consumers of algal ice production in many different areas of the Arctic and in turn are important prey for Arctic cod (Bradstreet and Cross 1982, Lønne and Gulliksen 1989, Lønne and Gulliksen 1991a, Lønne and Gulliksen 1991b, Carey 1992, Polterman et al. 2000, Werner and Gradinger 2002). It is expected that thinning of Arctic sea ice and the resulting increased meltwater and change in morphology of floes will have a negative effect on these under-ice amphipods (Werner and Gradinger 2002) and thus the Arctic cod that prey on them. Finally, enhanced primary production along the ice edge results in a generally enriched benthic biomass (Grebmeier et al. 2006a).

Loss of summer sea ice due to ocean warming could result in a decrease in the availability of this ice-based food web for foraging seals (Bluhm and Gradinger 2008). On the other hand, increased summer ice melt could result in increased primary productivity as more of the ocean surface is exposed to sunlight (Anderson and Kaltin 2001). Nutrients however, could limit the extent of this increase in production. Scenarios based on contemporary nutrient concentrations suggest a doubling of production in the central Arctic with loss of summer sea ice, but no increase in coastal and shelf regions (Bluhm and Gradinger 2008).

Another potential impact of future ocean warming and loss of winter sea ice on Arctic food webs is an alteration of the coupling between pelagic and benthic production. In the northern Bering Sea late retreat of winter ice cover is thought to result in an ice-associated phytoplankton bloom early in the spring. Herbivorous zooplankton are in an early phase of their annual ontogenetic cycle at this time and would not be able to graze down the phytoplankton bloom such that much of the production sinks to the bottom and fuels a benthic food web (Hunt et al. 2002, Grebmeier et al. 2006a). In contrast, early retreat of winter ice cover associated with warmer ocean waters is hypothesized to result in a later spring phytoplankton bloom in open water. In this situation, herbivorous zooplankton would be further along in their ontogenetic cycle and able to graze the phytoplankton bloom such that less production goes to the benthos. By a similar mechanism, zooplankton in the Barents Sea are able to crop more of the primary production in years when water temperatures are relatively high (Rey et al. 1987, Skjoldal et al. 1987). Thus, warming and decrease in ice extent could increase pelagic productivity at the expense of benthic productivity which could be detrimental to bearded seals depending on how well they could shift to a more pelagic-based diet. In fact, ocean warming has apparently resulted in a decrease in the benthic standing stock in the northern Bering Sea and there is evidence for a continued trend towards more sub-Arctic conditions that are unfavorable to benthic productivity (Grebmeier et al. 2006b).

4.2.1.1.4.3.2.3 Impacts of ocean acidification

Ocean acidification is expected to hamper the ability of phytoplankton such as foraminifera and coccolithophorids to maintain their calcareous structures, with negative consequences for the rest of the marine food web (Feely et al. 2004, Orr et al. 2005). Laboratory experiments on the coccolithophore, *Emiliania huxleyi,* have resulted in inconsistent results however (Riebesell et al. 2000, Iglesias-Rodriguez et al. 2008), and so further research is needed on the species-specific responses of phytoplankton to increased ambient CO_2. Ocean acidification also could have severe consequences for calcifying zooplankton, especially shelled pteropods which are prey for carnivorous zooplankton and fish such as salmon, herring and cod (Lalli and Gilmer 1989, Willette et al. 2001, Boldt and Haldorson 2003, Orr et al. 2005). Experiments and *in vitro* measurements show that pteropods are unable to maintain their shells in waters that are undersaturated with calcium carbonate, a consequence of ocean acidification, with expected negative impacts on their survival (Byrne et al. 1984, Feely et al. 2004, Orr et al. 2005).

Calcification rates of the shells of bivalves, such as mussels, oysters and clams decrease in response to increasing CO_2 (Bamber 1990, Michaelidis et al. 2005, Gazeau et al. 2007, Ries et al. 2010). Crustaceans may be particularly sensitive to ocean acidification because they require calcium and bicarbonate ions for the mineralization of their exoskeleton after molting. However, the effects of ocean acidification on crabs and shrimps have not been widely documented. One series of experiments showed that crab, shrimp and lobsters increased their rate of calcification with increasing CO_2. Two possible mechanisms were proposed for this unexpected result: the organisms were able to maintain elevated pH at the site of calcification via proton regulation and/or the organisms had an exoskeleton that was covered by a protecting external organic layer (Ries et al. 2010).

Not only can ocean acidification affect calcification of marine invertebrate structures, changes in ocean chemistry can have direct effects on the physiology of marine invertebrates and fish. In general, the expectation is that an increase in CO_2 will cause changes in the mode of metabolism of marine organisms, with possible reductions in growth and reproduction. This hypothesis, however, has not been tested in long-term field experiments (Pörtner et al. 2004). CO_2 impacts animal physiology predominantly through its acidifying effect on acid-base balances. Changes in acid-base balance will impact membrane-bound ion regulation, as has been observed for both fishes and crabs (Pörtner et al. 2004). Compensation for increased acidity causes potentially unfavorable changes in the ionic composition of plasma and other body fluids. These processes are not likely to be life-threatening but are expected to hamper growth, reproduction and survival (Pörtner et al. 2005). For example, studies have demonstrated detrimental effects of low pH on the growth of shrimps and sturgeon (Wickins 1984, Crocker and Cech 1996), and on reproductive success of perch (Vinogradov and Komov 1985). Likewise, Yamada and Ikeda (1999) found that exposure to very high CO_2 concentrations (> 2000 ppm) does reduce survival of six different copepod species - prey for cod and other fish - but levels expected over the next century do not seem to have a significant impact (Kurihara and Ishimatsu 2008). Other effects that ocean acidification may have on fish include behavioral changes and abnormal otolith growth (Checkley et al. 2009, Munday et al. 2009).

Another common adaptive strategy to increased CO_2 is to suppress aerobic energy rates, or “metabolic depression” (reviewed in Guppy and Withers 1999). Comparing patterns seen in fish with those found in invertebrates indicates that the effect of metabolic depression occurs with smaller increases in CO_2 in invertebrates. Vertebrates apparently have an enhanced capacity to avoid metabolic depression in the face of long-term elevated CO_2 levels. However, the processes that control vertebrate metabolism under conditions of increased CO_2 reflect changes in energy use and allocation with potential consequences for long-term survival (Pörtner et al. 2005). A laboratory experiment on a Mediterranean sea bream (*Sparus aurata*) indicated that prolonged exposure to moderate increases in CO_2 caused shifts in metabolic pathways from aerobic to anaerobic metabolism (Michaelidis et al. 2007). Other studies have shown an alteration in protein biosynthesis or patterns of gene expression (Langenbuch and Pörtner 2003). It is not known whether these processes are adaptive to long-term increases in ocean CO_2 concentrations or whether they would contribute to decreased growth and survival (Pörtner et al. 2005).

Additional concerns about ocean acidification are related to the fact that future climate change scenarios will involve not only increases in oceanic CO_2 concentrations but also increased warming and decreased dissolved oxygen due to eutrophication. Because CO_2 affects several physiological mechanisms that are also affected by thermal extremes and oxygen deficiency, it has been suggested that current trends of warming, CO_2 increase and oxygen reduction in marine waters may exert harmful synergistic effects on marine organisms (Pörtner et al. 2005). For example, physiological responses to increased CO_2 will likely result in a narrowing of the thermal tolerance of marine organisms (e.g., for Hyas crabs Walther et al. 2009), which would be most detrimental for animals living at the edges of their distributional range. This interaction could cause shifts in geographical distribution as well as alteration of ecosystem composition and functioning (Pörtner et al. 2005).

The rate of change observed is at least 100 times more rapid than any experienced over the past 100,000 years (Raven et al. 2005). The high rate of increase in CO_2 concentration means that organisms are being exposed to changes that are faster than they have encountered in their recent evolutionary history. The capacity of calcifying marine organisms to adapt to progressively acidified oceans is not known, but may be related to a species generation time. Species with a short generation time may have increased opportunities for micro-evolutionary adaptation (Raven et al. 2005), while long-lived species, such as benthic molluscs, would be less able to adapt quickly. In April 2010, the National Research Council of the National Academies released their report *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*. This report concluded that “the chemistry of the ocean is changing at an unprecedented rate and magnitude due to anthropogenic carbon dioxide emissions; the rate of change exceeds any known to have occurred for at least the past hundreds of thousands of years”(National Research Council 2010). The report also stated that while the ultimate consequences of ocean acidification are still unknown, the magnitude and rate of change present a risk to ecosystems and threaten fisheries, protected species, and other natural resources of value to society. The National Research Council (2010) also acknowledged the possibility that rising CO_2 and ocean acidification could cause catastrophic changes in ecosystems (e.g., massive release of methane from the melting of clatherates from ocean sediments), however such high impact events are considered of low probability.

The most likely impact of ocean acidification on bearded seals therefore, will be through the loss of benthic calcifiers and lower tropic levels on which the seal's prey depend. Unfortunately, our lack of understanding of planktonic and benthic calcifiers in the Arctic (e.g., even their baseline geographical distributions) means that future changes will be difficult to detect and evaluate (Orr et al. 2009). A workgroup of the European Science Foundation composed of 28 internationally recognized experts on ocean acidification recently stated the following about our current ability to forecast ocean acidification impacts (European Science Foundation 2009):

> *"Based on the presently-available data, little is known about the responses of genetically diverse populations, the life-history stages of animals and plants, synergistic effects from other stressors (e.g., temperature, hypoxia, nutrients), and the ability of organisms to undergo physiological and genetic adaptations to decreasing pH. A large gap in our understanding concerns the accumulation of responses from individual organisms to community and ecosystem levels. In view of these uncertainties, it is presently not yet possible to define critical thresholds (tipping points) for tolerable pH decline or to predict the pathways of ecosystem changes where threshold levels have been surpassed. In summary, our present knowledge of the effects of ocean acidification on marine biota is largely based on limited experimental work with single species and strains, maintained in short-term incubations, often exposed to abrupt and extreme changes in carbonate chemistry."*

Thus, at present, it is unclear to what extent ocean acidification will impact bearded seal populations in the foreseeable future.

4.2.1.1.5 Effects of climate change on bearded seals' shore habitat

Throughout most of their range, adult bearded seals are rarely found on land (Kovacs 2002). However, some adults in the Sea of Okhotsk, and more rarely in Hudson Bay (COSEWIC 2007), in the White and Laptev Seas (Heptner et al. 1976), Bering, Chukchi and Beaufort Seas, (Burns 1981, Nelson 1981, Smith 1981) and Svalbard (Kovacs and Lydersen 2008a) use haul-out sites ashore in late summer and early autumn until ice floes reappear at the coast. An increase in the period of open water could lengthen the duration of time seals choose to haul out on shore. A warming climate could affect this coastal habitat by physical alteration of the coastline or by changing the patterns of use by humans and predators. The rate of coastal erosion in the Arctic is increasing, likely due to multiple factors, such as 1) declining sea ice (lengthened ice-free season); 2) increasing sea surface temperature; 3) rising sea-level; 4) thawing permafrost; and 5) increases in storm power (Mars and Houseknecht 2007, Jones et al. 2009). The use of land for hauling out is most common in the Sea of Okhotsk where bearded seals form numerous shore rookeries that can have tens to hundreds of animals each (Tikhomirov 1961, Krylov et al. 1964, Chugunkov 1970, Tavrovskii 1971, Heptner et al. 1976, Burns 1981). The risk of habitat loss from erosion may be less in this area than in more northern parts of their range because increased erosion rates from a warming climate are more likely to occur along permafrost coastlines (Jones et al. 2009). The BRT was unable to locate evidence of impacts to existing bearded seal haul-out sites ashore from erosion or deposition of sediments. The complex coastal processes of erosion, deposition, waves, and currents make it difficult to project the net effect of climate-induced changes to coastal bearded seal habitat. Loss of some habitat might be offset by creation of new habitat, or isolation of parts of existing coastline that might be currently unsuitable because of predation or disturbance.

4.2.1.2 Impacts of global climate change on bearded seals

4.2.1.2.1 Sea ice related impacts

For at least some part of the year, bearded seals rely on the presence of sea ice over the productive and shallow waters of the continental shelves where they have access to food–primarily benthic and epibenthic organisms–and a platform for hauling out of the water. For bearded seals, the presence of sea ice in April and May is considered a requirement for whelping and nursing young (Reeves et al. 1992, Kovacs et al. 1996). Similarly, the molt in phocid seals is believed to be promoted by elevated skin temperatures that, in polar regions, can only be achieved when seals haul out of the water (Feltz and Fay 1966, Boily 1995). Thus, if suitable ice cover is absent from shallow feeding areas during times of peak whelping and nursing (April/May), or molting (May/June and sometimes through August), bearded seals would be forced to seek either sea-ice habitat over deeper waters (perhaps with poor access to food) or coastal regions in the vicinity of haul-out sites on shore (perhaps with increased risks of disturbance, predation, and competition). Both scenarios would require bearded seals to adapt to novel (i.e., suboptimal) conditions, and to exploit habitats to which they may not be well adapted, likely compromising their reproduction and survival rates.

An assessment of the risks to bearded seals posed by climate change must consider the species' life-history functions, how they are linked with sea ice, and how altering that link will affect the vital rates of reproduction and survival. The main functions of sea ice as they relate to the species' life-history are: 1) a dry and stable platform for whelping and nursing of pups; 2) a rearing habitat that allows mothers to feed and replenish energy reserves lost while nursing; 3) a habitat that allows a pup to gain experience diving, swimming and hunting with its mother, and that provides a platform for resting, relatively isolated from most terrestrial and marine predators; 5) a habitat for rutting males to hold territories and attract post-lactating females; and 6) a platform suitable for extended periods of hauling out during molting. These functions are discussed separately and in greater detail below.

Whelping and nursing: Although there are rare observations of water births (Vibe 1950, Burns 1967), pregnant females are considered to require sea ice as a dry birthing platform (Kovacs et al. 1996, Atkinson 1997). Similarly, pups are thought to nurse only while on ice. So a shift to whelping and nursing on land would represent a major behavorial change that would likely compromise bearded seals' ability to escape predators, a highly developed response on ice. Bearded seal mothers feed throughout the lactation period, continuously replenishing fat reserves lost while nursing pups (Holsvik 1998, Krafft et al. 2000). So, the presence of a sufficient food resource near the nursing location is also important. Rearing young in poorer foraging grounds would require mothers to forage for longer periods and (or) compromise their own body condition, both of which could impact the transfer of energy to offspring and affect survival of pups, mothers, or both.

Pup maturation: When not on the ice, there is a close association between mothers and pups, which travel together at the surface and during diving (Lydersen et al. 1994b, Gjertz et al. 2000, Krafft et al. 2000). Pups develop diving, swimming, and foraging skills over the nursing period, and perhaps beyond (Watanabe et al. 2009). Learning to forage in a suboptimal habitat could impair a pup's ability to learn effective foraging skills, potentially impacting its long-term survival. Further, hauling out reduces thermoregulatory demands which, in Arctic climates, may be critical for maintaining energy balance. Hauling out is especially important for growing pups which have a disproportionately large skin surface and rate of heat loss in the water (Harding et al. 2005, Jansen et al. 2010).

Mating: Male bearded seals are believed to establish territories under the sea ice and exhibit complex acoustic and diving displays to attract females (Van Parijs et al. 2003, Van Parijs et al. 2004, Van Parijs and Clark 2006, Risch et al. 2007). Breeding behaviors are exhibited by males up to several weeks in advance of females' arrival at a location to give birth (Stirling et al. 1983). Mating takes place in the water soon after females wean their pups (Chapskii 1938, Sleptsov 1943, Stirling 1983). The stability of the ice cover is believed to have influenced the evolution of this mating system (Van Parijs et al. 2004, Van Parijs and Clark 2006). If females were driven to whelp and nurse on shore it seems unlikely that bearded seals would be able to effectively alter their mating behaviors to adapt to a terrestrial habitat.

Molting: Bearded seals are thought to undergo a protracted, diffuse molt that involves shedding hair during all months of the year, though this has not been studied (Burns 1981, Kelly 1988, Kovacs 2002). There is a peak in the molt during May-June, when most bearded seals (except young of the year) tend to haul out on ice to warm their skin. Molting in the water during this period could incur energetic costs which might reduce survival rates.

For any of these life history events a greater tendency of bearded seals to aggregate while hauled out on land or in reduced ice fields (Fedoseev 2000), could increase intra- and inter-specific competition for resources, the potential for disease transmission, and predation; all of which could affect annual survival rates. In particular, a reduction in suitable sea-ice habitat would likely increase the overlap in the distributions of bearded seals and walrus, another ice-associated benthic feeder with similar habitat preferences and diet (Lowry et al. 1980). The walrus is also a predator of the bearded seal, though seemingly infrequent (Fay 1960, Heptner et al. 1976, Lowry and Fay 1984, Kelly 1988). Interestingly, walrus appear to be using haul-out sites ashore more commonly than in the past (Kochnev 2004, Kavry et al. 2008); a strategy that, if also adopted by bearded seals, might increase inter-specific interactions in coastal areas. Hauling out closer to shore or on land could also increase the risks of predation from polar bears, terrestrial carnivores, and humans.

For a long-lived and abundant animal with a large range the mechanisms of impact identified above (i.e., low ice extent and the absence of sea ice over foraging areas on the shelf) are not likely to be significant to an entire population in any one year. Rather, the overall strength of the impacts is likely a function of the frequency of years in which they occur, and the proportion of the population's range over which they occur. The low ice years, which will occur more frequently than in the past, may have impacts on recruitment via reduced pup survival if, for example, pregnant females are ineffective or slow at adjusting their breeding locales for variability of the position of the sea ice front. Also, the effects on different age classes might be expected to be correlated, though not always in concert because they involve ice characteristics at different times in the breeding-molting period; low ice extent during breeding may not always be accompanied by early melting, and vice versa.

How resilient will bearded seals be to these changes? Potential mechanisms for resilience on relatively short time scales (i.e., behavioral and ecological as contrasted with evolutionary) include adjustments to the timing of breeding in response to shorter periods of ice cover, and adjustments of the breeding range in response to reduced ice extent. The extent to which bearded seals might adapt to more frequent years with early ice melt by shifting the timing of reproduction is uncertain. Jemison and Kelly (2001) documented shifts in whelping dates of harbor seals (*Phoca vitulina*) at Tugidak Island, Alaska. The peak of whelping was 9-14 days earlier in 1964 and in the mid-1990s than it was in the late 1970s. They showed that the changes were unlikely to be caused by shifts in the age structure coupled with age-specific differences in timing of reproduction, and therefore may have been a response to changes in environmental conditions. There are many examples of shifts in timing of reproduction by pinnipeds and terrestrial mammals in response to body condition and food availability (Boyd 1984, Skogland 1984, Stewart et al. 1989, Duck 1990, Bowyer 1991, Rachlow and Bowyer 1991, Lunn and Boyd 1993, Lunn et al. 1994, Ruthven et al. 1994, Boyd 1996, Ben-David 1997). In most of these cases, suboptimal conditions led to reproduction later in the season. Such a phenotypic response to earlier spring ice melt would not likely be beneficial to bearded seals that require sea ice for whelping and nursing. A shift to an earlier mean melt date may however, over the longer term, provide selection pressure for an evolutionary response over many generations toward earlier reproduction.

It is impossible to predict whether bearded seals would be more likely to occupy ice habitats over the polar basin or more terrestrial habitats if sea ice failed to extend over the shelf. Outside the critical life history periods related to reproduction and molting there is evidence that bearded seals might not require the presence of sea ice for hauling out, remaining in the water for weeks or months at a time (Frost et al. 2008)(Footnote 1). Still, even during the spring and summer bearded seals appear to possess some plasticity in their ability to occupy different habitats at the extremes of their range. Throughout most of their range, adult bearded seals are seldom found on land (Kovacs 2002), however in the Sea of Okhotsk, bearded seals are known to use haul-out sites ashore regularly and predictably during the ice free periods in late summer and early autumn (Heptner et al. 1976). Similarly, western and central Baffin Bay are unique among whelping areas as mothers with dependent pups have been observed on pack ice over deep (>500 m) water (Koski 1980). These behaviors are extremely rare in the core distributions of bearded seals however, and so the habitats that necessitate them should be considered suboptimal. Consequently, predicted reductions in sea-ice extent, particularly when such reductions separate ice from shallow water habitats, can reasonably be used as a proxy for predicting years of reduced survival and recruitment (though not the magnitude of the impact). In addition, the frequency of predicted low ice years can serve as a useful tool for assessing the cumulative risks posed by climate change.

In the following sections we provide specific descriptions of the predicted changes of both sea-ice cover and of the frequency of low ice years for April through July (i.e., the peak timing of whelping, nursing of pups, pup maturation, and molting) for the three population units of bearded seals. Assessing the potential impacts of these predicted changes on the conservation status of bearded seals requires knowledge or assumptions about the relationships between sea ice and bearded seal vital rates. Because no quantitative studies of these relationships have yet been conducted, the BRT relied upon two studies in the Bering Sea that estimated bearded seal preference for ice concentrations, based on aerial survey observations of seal densities. Simpkins et al. (2003) found that bearded seals near St. Lawrence Island in March preferred 70-90% ice coverage, compared with 0-70% and 90-100%. Preliminary results from another study in the Bering Sea (Ver Hoef et al. *In review*), found the highest probabilities of occurrence of bearded seals in April-May was in ice of 75-100% coverage, but only the 0-25% ice class had substantially lower probability of bearded seal occurrence (Figure 27). Lacking a more direct measure of the relationship between bearded seal vital rates and ice coverage, the BRT assumed that this preference relationship reflects the species requirements for sea-ice coverage in the important period of April-May. In other words, the BRT defined areas within the current core distribution of bearded seals where the decadal averages and minimums of ice projections in April-May were below 25% concentration, as inadequate for whelping and nursing. The BRT also assumed that the sea ice requirements for molting in May-June are less stringent than those for whelping and rearing pups, and that 15% ice coverage in June would be minimally sufficient for molting.

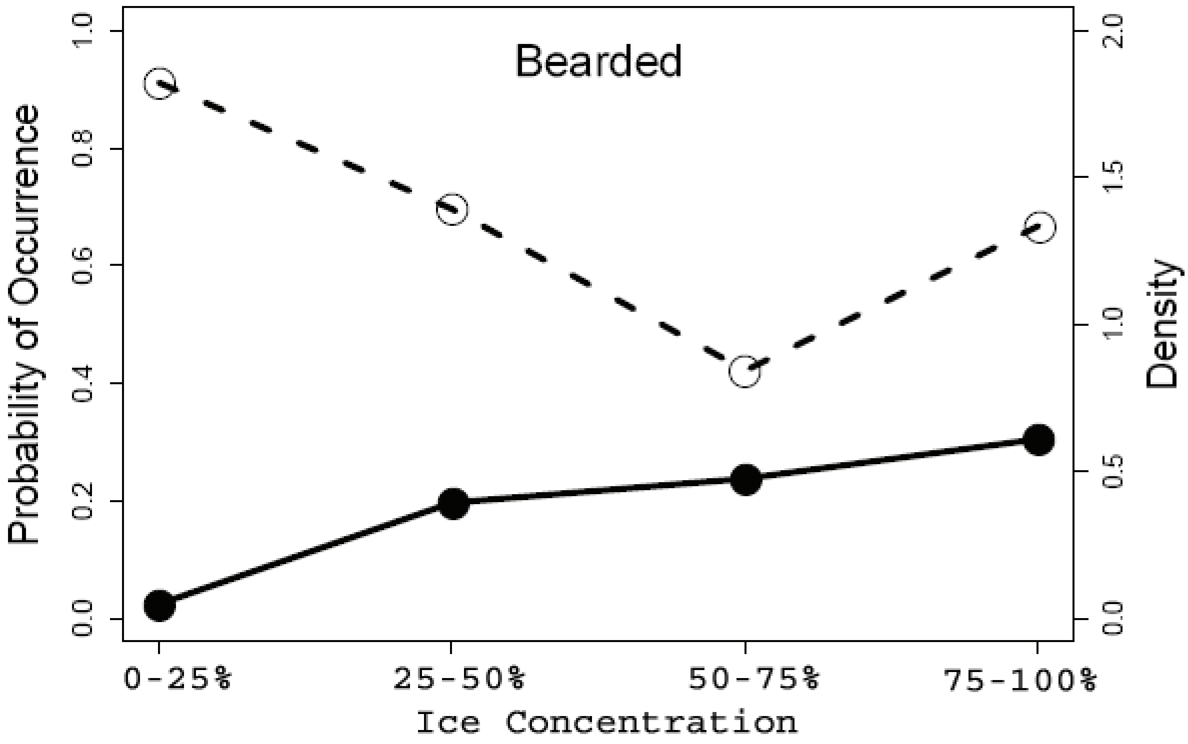


Figure 27. -- Fitted estimates for the probability of at least one bearded seal being in a sampling unit (solid line), and their density (dashed line), given they are present.

It should be noted, however, that judging the timing of onset of potential impacts to bearded seals is complicated by the coarse resolution of the IPCC models. The models available for assessment of future sea-ice conditions are global in scale with a typical spatial resolution (~1° of latitude) that is much coarser than the scale at which bearded seals are likely to interact with fields of sea ice (Boveng et al. 2009). The model scenarios and the remotely-sensed ice data that have been used to fit and tune the models may depict zero ice at times, even in areas where seals would remain capable of finding suitable ice. Indeed, when estimating the area of ice extent the IPCC defines the “edge” to be a concentration of 15%. Thus, the model projections likely understate the availability of suitable ice for bearded seals so that a downward trend in ice extent may appear problematic some years or decades before actually becoming so.

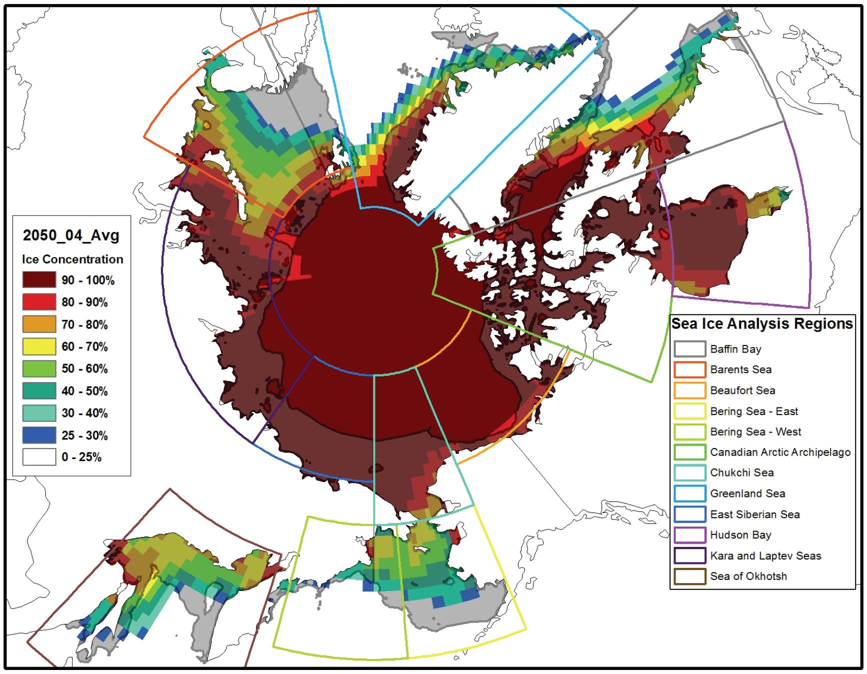


Figure 28. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for April, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

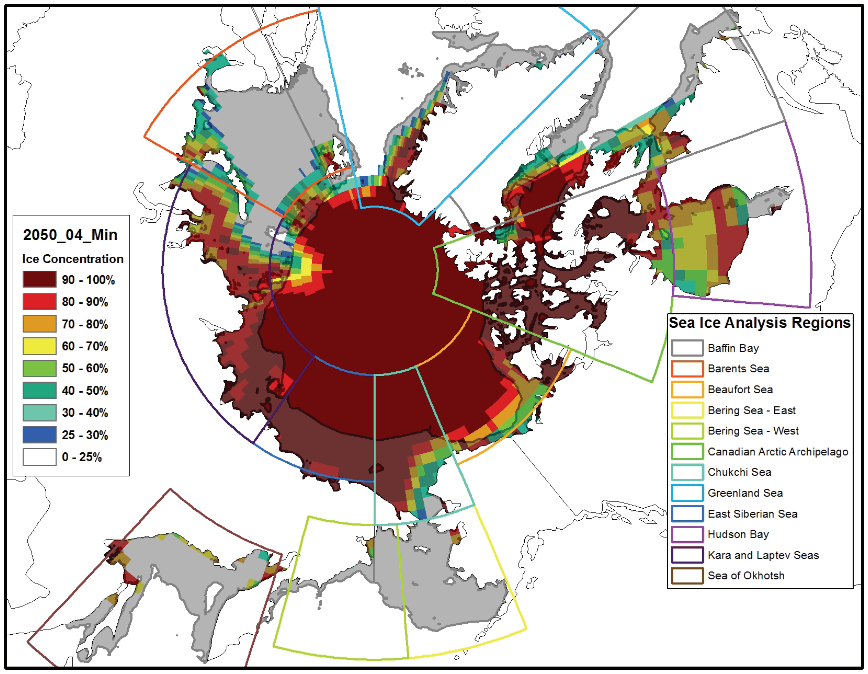


Figure 29. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for April, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

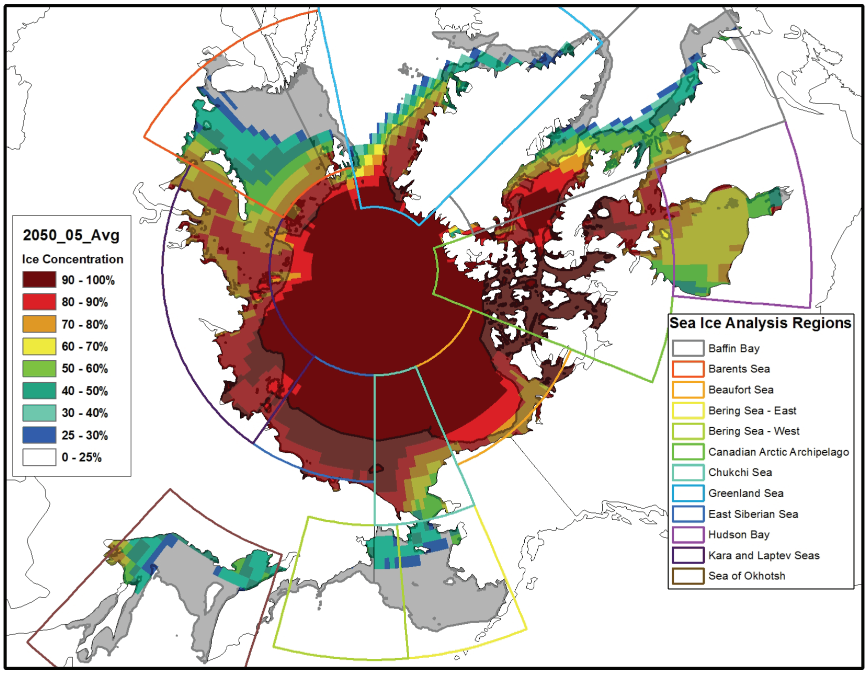


Figure 30. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for May, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

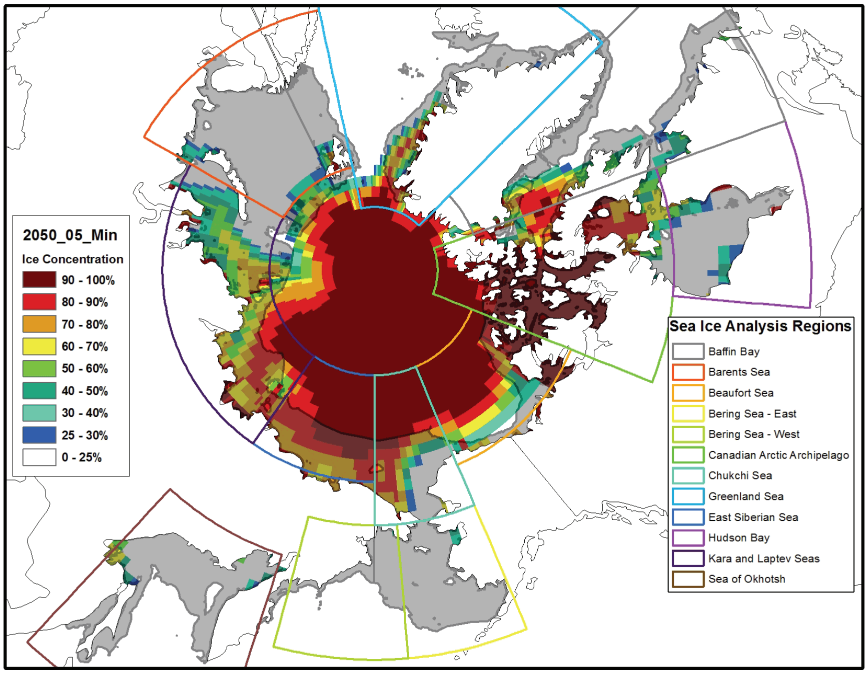


Figure 31. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for May, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

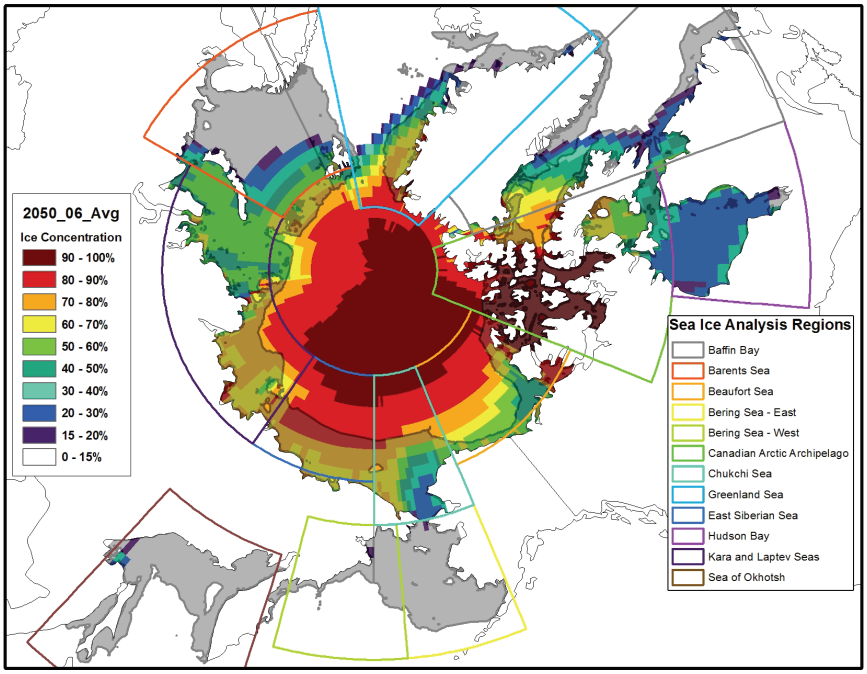


Figure 32. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for June, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 15% are not shown.

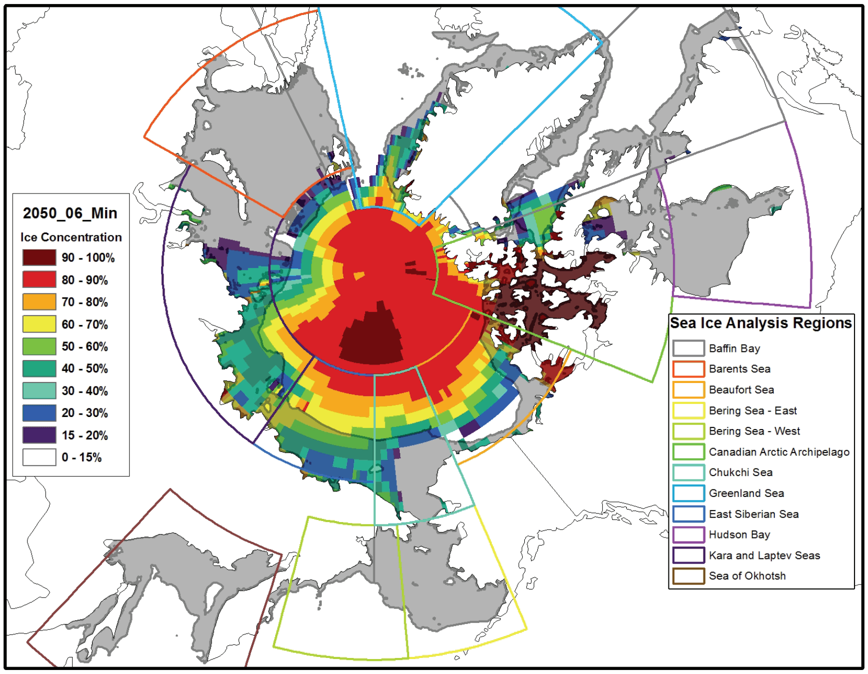


Figure 33. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for June, 2050. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 15% are not shown.

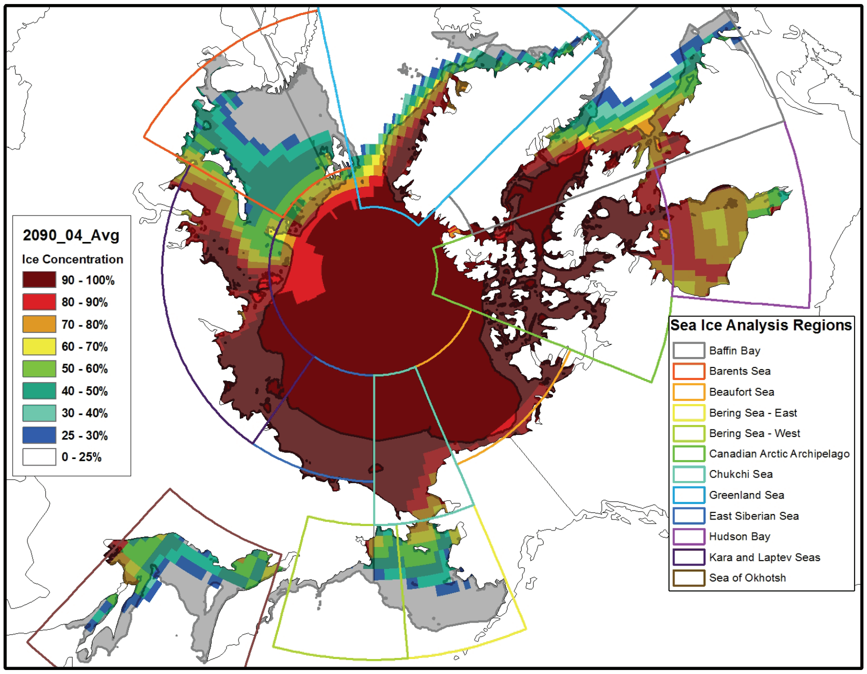


Figure 34. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for April, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

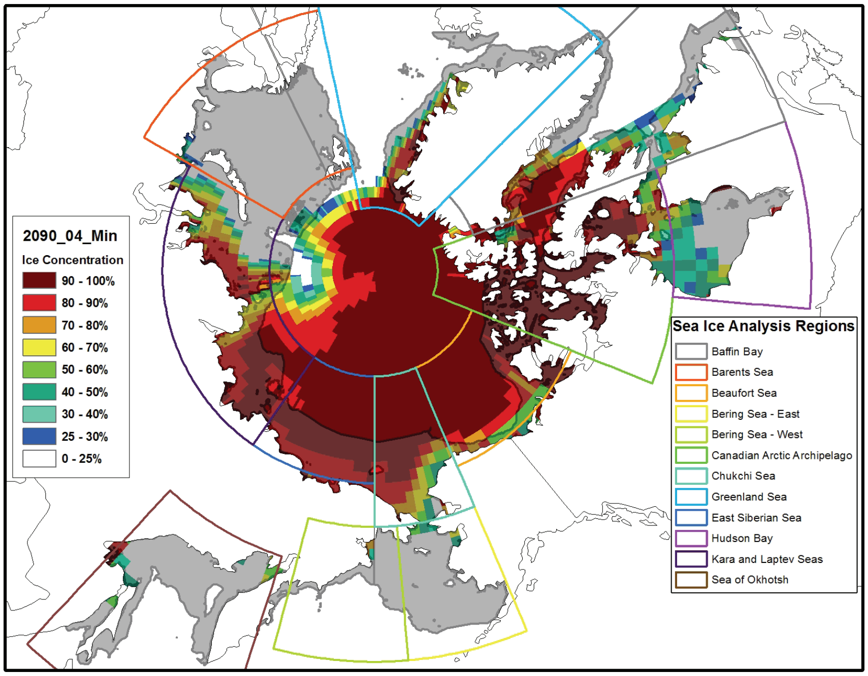


Figure 35. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for April, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

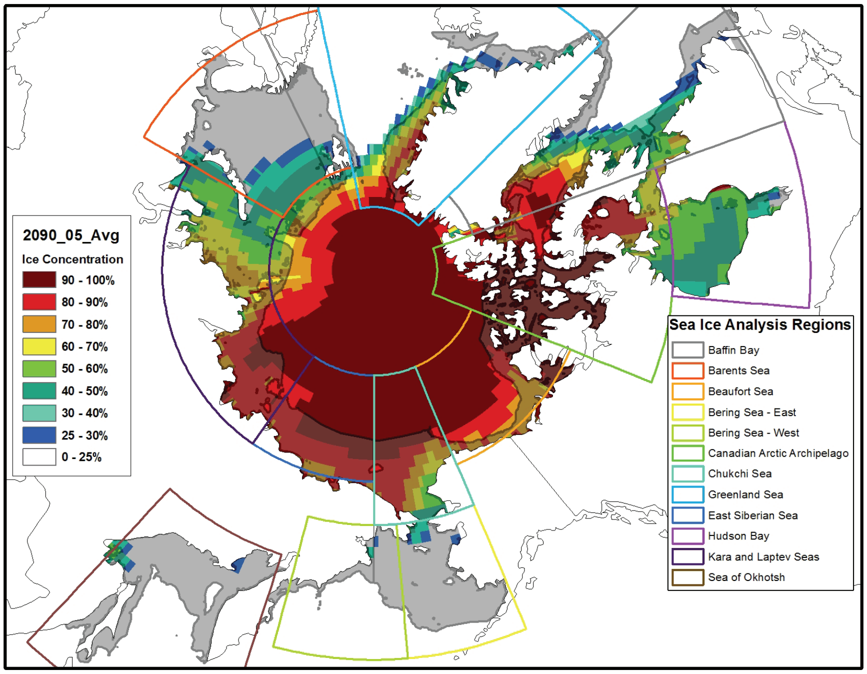


Figure 36. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for May, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

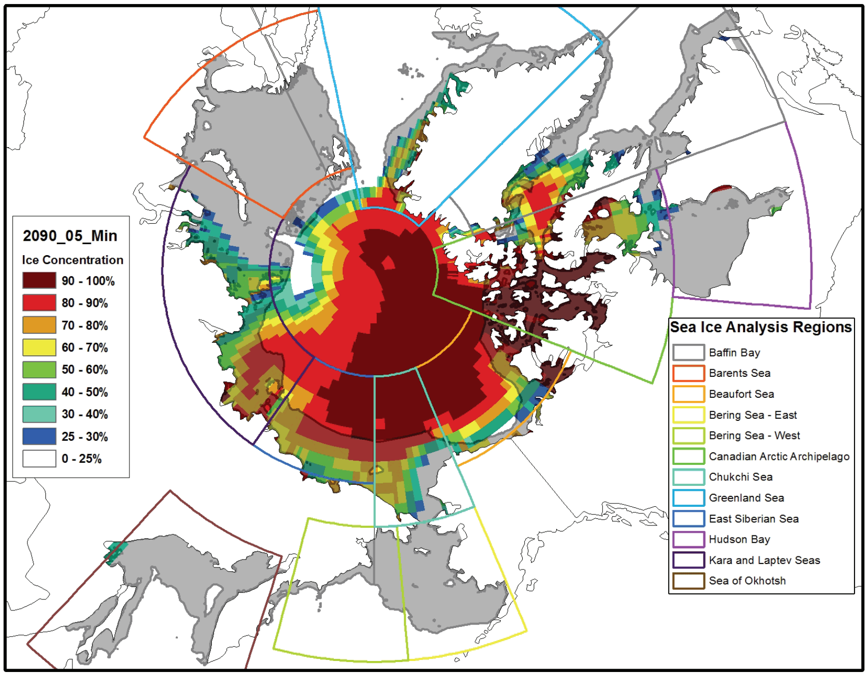


Figure 37. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for May, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 25% are not shown.

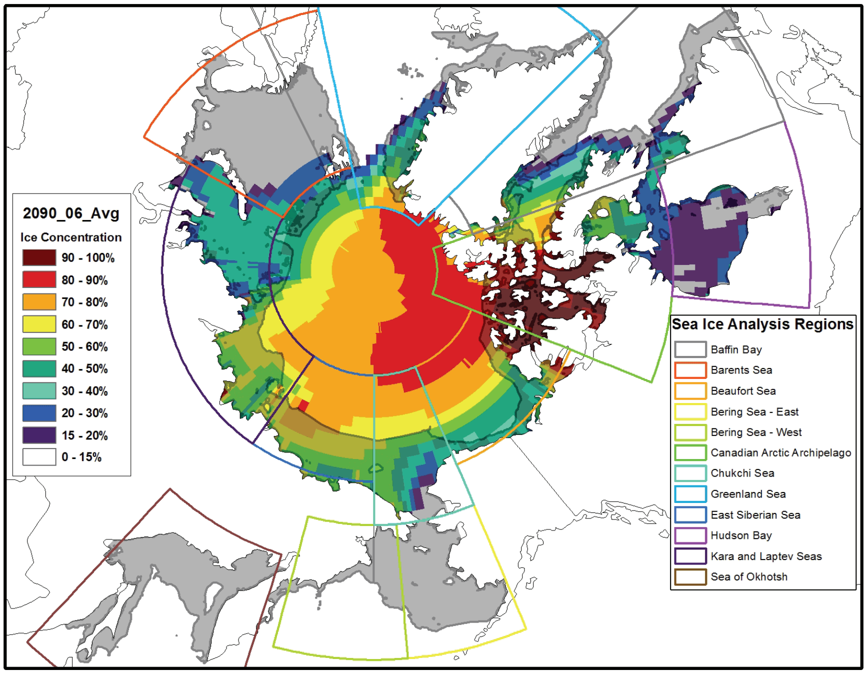


Figure 38. -- Map of the distribution of bearded seals (gray), over the projected decadal mean sea-ice concentrations for June, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 15% are not shown.

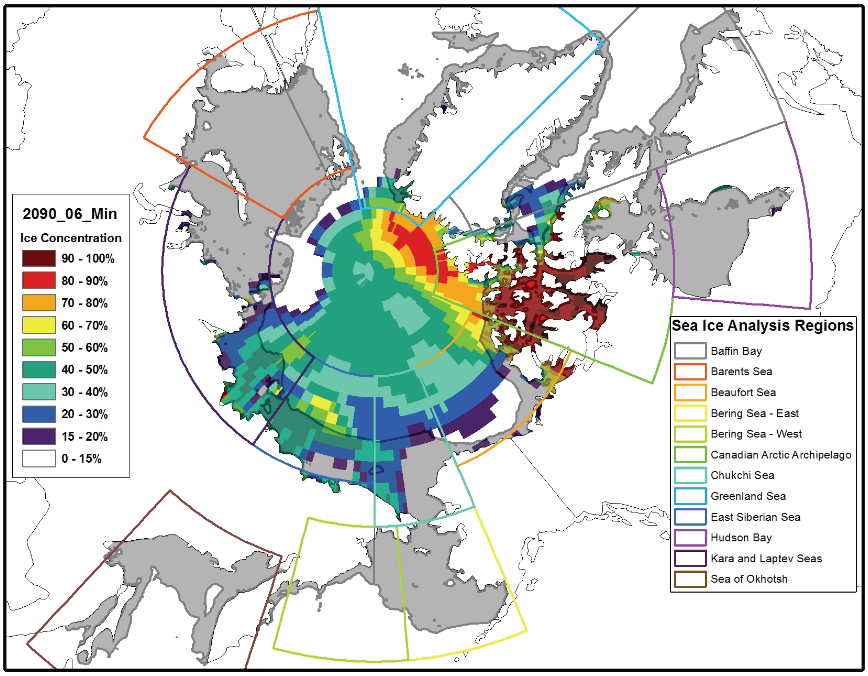


Figure 39. -- Map of the distribution of bearded seals (gray), over the projected decadal minimum sea-ice concentrations for June, 2090. Projection is from the six best performing models identified by Wang and Overland (2009). Predicted concentrations less than 15% are not shown.

4.2.1.2.1.1 Beringia DPS

4.2.1.2.1.1.1 East Siberian Sea, Chukchi Sea and Beaufort Sea

In the East Siberian, Chukchi and Beaufort Seas the average ice extents during April and May (i.e., the period of whelping, nursing, mating and some molting) are all predicted to be very close to historical averages out to the end of the 21st century. The annual variability of this extent will continue to increase (Figures 16-18), and single model runs indicate the possibility of a few years in which April and May sea ice would cover only half (or in the case of the Chukchi Sea, none) of the Arctic shelf in these regions by the end of the century. In June, also a time of molting, the average sea-ice extent is predicted to cover no more than half of the shelf in the Chukchi and Beaufort Seas, and in the A2 emissions scenario, to become ice free (Figures 16 and 18). The East Siberian Sea, however, will not experience losses of these magnitudes until July by the end of the century (Figure 17). Still, the frequency of these low ice years will continue to increase and will become more common after 2050. The spatial projections of ice for selected decades indicate that there will typically be 25% or greater ice concentration in April-June over the entire shelf zones in these regions through the end of the century (Figures 34, 36 and 38). In the minimal ice years there will be 25% or greater ice concentration over the shelf zones in April and May except in the eastern Chukchi and central Beaufort Seas (Figures 35 and 37). By June 2095, ice suitable for molting (i.e., ≥ 15% concentration) is mostly absent in minimal years, except in the western Chukchi Sea and northern East Siberia Sea (Figure 39).

4.2.1.2.1.1.2 Bering Sea

Early springtime sea-ice habitat for bearded seals whelping in the Bering Sea should be sufficient in most years through 2050 and out to the second half of the 21st century, when the average ice extent in April would still be approximately 50% of the present-day extent (Figures 19 and 20). The historical data and range of ensemble projections of future conditions suggest that it is nearly impossible to create a sea-ice-free Bering Sea in April. For example, mean maximum temperatures for Nome Alaska for April are below -2° C, so even with a global warming signal of +2° C later in this century, April will continue to be a month of sea ice growth.

The general trend in the May (nursing, rearing and molting) through June (molting) projections of sea ice for the Bering Sea is toward a longer ice-free period resulting from more rapid spring melt. Until at least the middle of the 21st century, the variability among model runs (Figures 19 and 20) includes nearly all of the historical range, meaning that there will still be some years with near-maximum ice extent. But, there will be less ice on average, manifested as more frequent years in which the spring retreat occurs earlier and peak ice extent is lower. By the end of the 21st century however, projections indicate that there will commonly be years with little or no ice in May and that sea ice in June is expected to be nonexistent in most years (Figures 19 and 20). To adapt to this regime, bearded seals would likely have to shift their nursing, rearing, and molting areas to the ice-covered seas north of the Bering Strait.

Figures 28-39 are based on six IPCC models; however, only four of these models performed satisfactorily for the eastern Bering Sea and only one for the western Bering Sea. As such, projections of the spatial extent and concentration of sea ice in these regions should be used with caution. These projections suggest that there will typically be 25% or greater ice concentration in April-May over a substantial portion of the shelf zone in this region through 2055 (Figures 28 and 30). By 2095 there will be sufficient ice only in small zones of the Gulf of Anadyr and the area between St. Lawrence Island and Bering Strait (Figures 34 and 36). In the minimal ice years there will be little or no ice of 25% or greater ice concentration over the shelf zone in the Bering Sea during April and May, perhaps commencing as early as the next decade (Figures 29-31). Conditions will be particularly poor for the molt in June when typical ice predictions suggest less than 15% ice by mid-century (Figure 32).

4.2.1.2.1.2 Okhotsk DPS

Unfortunately none of the IPCC models performed satisfactorily for the Sea of Okhotsk and so projected average sea surface temperature was used a proxy to predict sea-ice extent and duration. The Sea of Okhotsk is located southwest of the Bering Sea and thus can be expected to have earlier radiative heating in spring. The region is dominated in winter and spring by cold continental air masses and offshore flow (Wang et al. 2007). Sea ice is formed rapidly and is generally advected southward (Sasaki et al. 2007). As this region is dominated by cold air masses for much of the winter and spring, we would expect the present seasonal cycle of first year sea ice to continue to dominate the future habitat of the Sea of Okhotsk. However, unlike the Bering Sea, the winter/spring temperature transition is early, occurring between April and May. During April there is a large gradient in surface temperatures between the northern and southern portions of the Sea of Okhotsk. There are -4°C temperatures to the north and 0°C to the south. During May, projected SSTs indicate that the Sea of Okhotsk region has warmed to the melting point of sea ice throughout the region. Investigation of model results suggests little to no sea ice in May by 2050 and in April by 2090 (Figure 24). The ice-covered area is much smaller in the Sea of Okhotsk than the Bering Sea and, unlike in the Bering Sea, there is no marine connection to the Arctic Ocean. Over the long-term, bearded seals in the Sea of Okhotsk do not have the prospect of following a shift in the average position of the ice front northward as seals in the Bering Sea would. The question of whether a future lack of sea ice will cause the Okhotsk DPS of bearded seals to go extinct depends in part on how successful the populations are at moving their reproductive activities from ice to haul-out sites on shore. Although bearded seals in this area are known to use land for hauling out, this only occurs in late-summer and early autumn. The BRT is not aware of any occurrence of bearded seals whelping or nursing young on land, so this predicted loss of sea ice is expected to be significantly detrimental to the long-term viability of the population.

4.2.1.2.1.3 Erignathus barbatus barbatus

4.2.1.2.1.3.1 Canadian Arctic Archipelago, Hudson Bay, Baffin Bay and the Greenland Sea

Unfortunately none of the IPCC models performed satisfactorily for the Canadian Arctic Archipelago, Baffin Bay, or the Greenland Sea so their spatial predictions of sea-ice concentration (Figures 28–39) should be used with caution. The models predict that ice in April, May and June will continue to persist in the Canadian Arctic Archipelago “ice refuge” in all years out to 2090. Even in the low ice years at the end of the century the many channels throughout the archipelago are still expected to contain ice.

Predictions for Baffin Bay, were similar, showing April-June ice concentrations similar to historical levels out to 2050. Sea-ice cover and extent is predicted to diminish somewhat during the last half of the century but average conditions should still provide sufficient ice for the life history needs of bearded seals. Most of the ice covering the eastern Greenland Sea is near the east coast of Greenland over shallow waters preferred by bearded seals. Sea-ice concentrations and extent will slowly decrease over the next century. In April and May, the ice edge will contract westward, closer to the Greenland coast, but in most years, sea ice is predicted to cover the shallow waters of the entire shelf. In June, the ice edge will retreat further north throughout the century. By mid-century, the average ice extent and distribution will be similar to that of current low ice years. At least until the end of the 21st century, some ice is always predicted along Greenland in April and May. In June however, the low ice concentrations in minimum years will not be sufficient for molting.

Joly, et al. (2010) used a regional sea-ice–ocean model and air temperature projections to predict sea ice conditions in Hudson Bay out to 2070 (Figure 23). Compared to present averages, the extent of sea ice in April is expected to change very little by 2070, though reductions of 20% in June ice and 60% in July ice are expected by 2070. The authors also predicted that sea ice in Hudson Bay would become up to 50% thinner over this time, though this would still probably provide enough buoyancy for bearded seals, which often seem to select ice floes with low freeboard (Heptner et al. 1976).

4.2.1.2.1.3.2 Barents Sea, Kara Sea and Laptev Sea

Projections for the Barents Sea are from a single model, but it simulated the April and May ice conditions in reasonable agreement with observations, and projected that ice in April will continue to decline in a relatively constant linear trend throughout the 21st century (Figure 22). The trend for May declines faster, predicting half as much ice by 2050, and the trend for June declines faster still, predicting that ice will all but disappear in the region in the next few decades. Bearded seals in the Barents Sea are known to conduct seasonal migrations following the ice edge, moving from the southeastern Barents Sea to the east and north in the spring and summer (Potelov 1969, Wiig and Isaksen 1995). Similar to the Bering Sea, the impacts of an ice-free Barents Sea would depend largely on the ability of bearded seals to relocate to more ice-covered waters, and there is little or no basis on which to determine the likelihood of this occurring.

All of the IPCC models performed poorly for the Kara and Laptev Seas and so predictions of sea-ice concentration (Figures 28-39) should be used with caution. Although sea ice has covered the Kara and Laptev Seas throughout most of year in the past, models show that the area will experience a west-to-east reduction in the concentration of springtime sea ice over the next century. By the end of the century in some years, half of the Kara Sea could be ice free in May, and in June by mid-century. In most years however, ice (albeit in low concentrations) will still cover the Kara Sea Shelf. Similarly, out to the end of the century, the Laptev Sea is predicted to always have springtime ice. In July, by century's end, significant portions of both seas are predicted to be ice free in most years. Unlike most regions, the peak of molting in these seas is reportedly well into July (Chapskii 1938, Heptner et al. 1976), so bearded seals in these areas would need to modify the location or timing of their molt to avoid the increased metabolic costs of molting in water. Bearded seals in the White and Laptev Seas are known to occasionally haul out on shore during late-summer and early-autumn (Heptner et al. 1976). This behavior could mitigate the impacts of an ice-free July.

Because only one of the IPCC models (CCSM3) was considered appropriate for the Barents Sea, it would be improper to infer the extent and concentration of ice from the spatial predictions (Figures 28-39) based on all six IPCC models which tended to overestimate the amount of ice in the region.

Simpkins et al. (2003) observed that bearded seals avoided areas with greater than 90% ice coverage. So it is worth noting that bearded seal are considered rare in the Laptev Sea (Heptner et al. 1976), which currently has extremely high concentrations of ice throughout most of the year. One possible effect of global warming may be to increase suitable habitat for bearded seals in the Kara and Laptev Seas, offsetting a decrease of habitat farther west, though we are not aware of past examples in which similar mitigative shifts in habitat have occurred during rapid climatic change.

4.2.1.2.2 Ocean condition related impacts

Ocean acidification may impact bearded seal survival and recruitment through changes in the demography or distribution of prey populations, particularly prey that are calcifying or that feed on calcifying prey. The nature and timing of such impacts are uncertain and the possible ecological pathways and outcomes are complex. These ecosystem responses may have very long lags as they propagate through trophic webs. Because of bearded seals' apparent dietary flexibility, this threat should be of less immediate concern than the direct effects of potential sea-ice degradation.

Ocean acidification may also impact bearded seals by affecting the propagation of sound in the marine environment. Researchers have suggested that effects of ocean acidification will cause low-frequency sounds to propagate more than 1.5X as far (Hester et al. 2008, Brewer and Hester 2009), which, while potentially extending the range bearded seals can communicate under quiet conditions, will increase the potential for masking when man-made noise is present. The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR 2009) recently concluded that because of the "logarithmic nature of sound and what is known about hearing systems in mammals, seemingly small changes in background noise levels may result in large reductions of marine animals' communication ranges". Male bearded seals vocalize during the breeding season to advertise mate quality to females, signal competing males of a claim on a female, and (or) proclaim a territory (Chapskii 1938, Burns 1981, Stirling et al. 1983, Van Parijs et al. 2004). A disruption of mating would have obvious impacts on recruitment and population dynamics. Currently, in most of the Arctic a relatively low incidence of vessels combined with their transitory nature suggests a low risk of impacts to seal communication. Those seals near regular, year-round shipping routes, such as off Sakhalin Island, the south Barents Sea, Pechora Bay, and Kara Straits are at a significantly higher risk, particularly during the breeding season. The range at which ships will interfere with the detection of underwater sounds depends on many factors, including the shape of the seafloor, water structure, and other natural ambient sounds. So, without detailed studies, it is not appropriate to generalize about distances at which seal calls in a particular area will be masked. Studies to date show that bearded seal calls can be detected to 30-45 km (Stirling et al. 1983, Cleator et al. 1989), though more recent modeling in other Arctic species with similar call frequencies suggests long-range communication on the order of 100s of km (Rossong and

Terhune 2009). In the foreseeable future, the Arctic will witness significant increases in vessel traffic which will magnify the potential impacts, especially near increasingly busy shipping routes and new "choke points", such as the Bering Strait which at its narrowest point is 85 km wide. Where these areas of high traffic overlap with bearded seal breeding locations, it is plausible that there will be some level of disruption, but probably at relatively small scales (e.g., 10s of km). However, local impacts may become increasingly important as diminishing ice reduces available habitat.

4.2.2 Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

4.2.2.1 Commercial, subsistence and illegal harvest

Evidence of seal hunting by Native villages in the Arctic goes back at least 5000 years (Riewe 1991). Bearded seals were among those species hunted by the early Arctic inhabitants (Krupnik 1984), and today they remain a central nutritional and cultural resource for many northern communities (Hart and Amos 2004, ACIA 2005, Hovelsrud et al. 2008). By about the late 19th century, bearded seals were harvested commercially in large numbers causing local depletions. Though commercial operations were primarily interested in seal oil and skins, Native hunters have traditionally used all parts of bearded seals: their meat has been used as food for people, sled dogs, and livestock; their durable skins used for foot gear, umiaks (whaling boats), lines, and harnesses, traded for goods, or sold for cash; their blubber rendered into oil for food and fuel; and their flippers, bones, and viscera used for many household, industrial, or medicinal purposes (Krylov et al. 1964, Stewart et al. 1986). The following sections summarize the past and present commercial, subsistence, and illegal harvests of bearded seals in each of their DPSs, and discuss the potential threat of overutilization in the future.

4.2.2.1.1 Beringia DPS

4.2.2.1.1.1 Alaska, Chukotka, and Eastern Siberia (Bering, Chukchi, and East Siberian Seas)

Bearded seals have been an important subsistence resource for Native communities along the coasts of the northern Bering, Chukchi, Eastern Siberian, and Beaufort Seas since the earliest occupation of humans (Park 1999). Hunters mostly take seals during their northward migration in the late spring and early summer, using small boats in open leads among ice floes close to shore (Kelly 1988). Alaskan villages harvested about 1,700 bearded seals annually from 1966 to 1979, with reported takes remaining fairly constant except in 1977 when an estimated range of 4,750-6,308 were taken (Matthews 1978, Burns 1981). About a decade later, in 1986, curtailed monitoring from just five Alaska villages in the Bering Strait area reported 791 bearded seals taken (Kelly 1988). More recently in Alaska, under more comprehensive subsistence monitoring, the estimated harvest peaked from 1990 to 1998 at mean levels of 6,788 bearded seals per year (Coffing et al. 1998, Georgette et al. 1998, Wolfe and Hutchinson-Scarbrough 1999, Allen and Angliss 2010). The most recent harvest estimates (from 2003) cover only villages in the North Slope Borough and suggest that a minimum of 1545 bearded seal are taken from just the eastern Chukchi and western Beaufort Seas (Bacon et al. 2009). The 1990-1998 harvest estimates are the most comprehensive and thus considered the most current for the subsistence hunt in Alaska (Allen and Angliss 2010). It is unclear if variations in the harvest, especially the dramatic shifts, are real or reflect changes in survey methodology, coverage, or reporting. Ice cover in hunting locations can dramatically affect the availability of seals and the success of hunters in retrieving seals that have been shot, which can range from 50-75% success in the ice (Burns and Frost 1979, Reeves et al. 1992) to as low as 30% in open water (Burns 1967, Smith and Taylor 1977, Riewe and Amsden 1979, Davis et al. 1980). Using the mean annual harvest reported from 1990-1998, assuming 25 to 50% of seals struck are lost, the total annual hunt by Alaska Natives would range from 8,485 to 10,182 bearded seals.

Subsistence harvest records dating back to 1941 from the southeastern Chukchi Peninsula, and prior to the Soviet commercial hunts of the 1960s, suggest an average harvest of 629 bearded seals per year (Krupnik 1984). Estimated harvest figures for the entire province of Chukotka (likely including the Chukchi Peninsula), from 1937 to 1954, ranged from 1,700 to 2,700 bearded seal (Geller 1957). In 1961, motivated by signs of depletion of bearded seals in the Sea of Okhotsk, the first ship-based sealing was implemented in the Bering and Chukchi Seas (Krylov et al. 1964, Popov 1976). Peak harvest levels were reached as soon as the late 1960s, exceeding 7,000 bearded seals killed annually, with subsequent catch rates indicating that the population was being depleted (Burns and Frost 1979, Popov 1982). Due to depletion or a shift in commercial interests toward fur, for which bearded seals were not harvested, ship-based sealing in the Bering and Okhotsk Seas was suspended from 1970 to 1975. In 1975, the first annual total allowable catch (TAC) of 3,000 bearded seals was set for the Russian Bering Sea (Mineev 1981). Similar to the commercial harvest, the bearded seal harvest among several Native settlements on the Chukchi Peninsula declined from the 1960s to the 1970s, with average takes dropping from 770 (SD=183) to 427 (SD=159), respectively (Krupnik 1984). Reasons cited for the decline in subsistence harvests were depletions from the growing commercial harvest and reallocation of effort toward walrus hunting (Krupnik 1984). Total harvest of bearded seals by Siberian hunters in the Bering and Chukchi Seas during the 1970s was similar to the harvest by Alaska Natives, averaging about 1,600 taken annually (Burns and Frost 1979), though it may have been as high as 2,300 (Fedoseev 2000).

By 1981-83, the coastal-based harvest of bearded seals in the Russian Bering and Chukchi Seas, presumably by subsistence hunters, averaged 898 seals. Combining this with the contemporaneous commercial ship-based hunt, which averaged 719, suggests a total catch of 1617 (Mineev 1984), similar to the 1700 taken by Alaska Native hunters over nearly the same period (Matthews 1978, Burns 1981). More current estimates for commercial or subsistence hunting in the Russian Bering or Chukchi Seas (i.e., Chukotka and eastern Siberia) are unavailable, so it is unknown if bearded seal hunting has since increased, as was the case in Alaska (Coffing et al. 1998, Georgette et al. 1998, Wolfe and Hutchinson-Scarbrough 1999).

Assuming similar contemporary harvests in eastern Siberia and Alaska, as was the pattern in the 1970s and 1980s, and a comparable struck-loss rate of 25-50%, the total annual take from the entire Bering and Chukchi Seas would range from 16,970 to 20,364 bearded seals. The TACs for 2010, which are set by the Russian Federal Fisheries Agency, of 1,600, 2,000, 2,500, and 150 bearded seals for the western Bering and Chukchi Seas, Chukotka Peninsula, and eastern Siberia, respectively, indicate potential maximum catches (sum of TACs = 6,250) similar to the reported takes from the eastern Bering and Chukchi Seas (6,788; see above). Less than 50% of the total TACs for the Russian Bering and Chukchi Seas is apparently allotted for the subsistence coastal hunt occurring on the Chukotka Peninsula and in eastern Siberia (Russian Federal Fisheries Agency 2009). Commercial harvesting of marine mammals has been prohibited in U.S. waters since 1972 by the MMPA (16 U.S.C. 1361 et seq.), but subsistence hunting by Alaska Native hunters is permitted with some requirements for the utilization of taken seals. See Section 4.2.4.1.2.1.1 for more information about the MMPA.

4.2.2.1.1.2 Western Canadian Arctic (Beaufort Sea)

Bearded seal hunting is culturally and nutritionally important in the western Canadian Arctic, with the Inuvialuit utilizing bearded seals similarly to Alaska Native and Siberian communities (Cleator 1996, Hart and Amos 2004). The importance of the bearded seal harvest to local economies has historically been secondary to the more abundant ringed seal harvest, and its relative importance has fallen even further in recent times (Cleator 1996). Bearded seals are not hunted as frequently because they have a greater tendency to sink after a kill (i.e., they have less blubber), and thus require greater hunting and retrieval skills. Similar to what has been reported elsewhere, sinking losses in the western Canadian Arctic may regularly exceed 50% (Smith and Taylor 1977). Total allowable catches have not been established for bearded seals, nor is there a commercial hunt, with licenses and permits used to control the harvest. There are also no quotas on subsistence hunting (Department of Fisheries and Oceans 2008). From 1988 to 1997, an average of 24 bearded seals (range = 17-33) were taken annually by Native communities in the Inuvialuit Settlement Area, encompassing the western Beaufort Sea and the protected waters off Banks and Victoria Islands, and the western Queen Elizabeth Islands (Inuvialuit Harvest Study Working Group 2003).

4.2.2.1.2 Erignathus barbatus barbatus

4.2.2.1.2.1 Canada

The subsistence hunt of bearded seals in the eastern Canadian Arctic provides essential meat, blubber, and skin, and is a central component of the Inuit culture (Riewe and Amsden 1979, Cleator 1996). From 1996 to 2001, an yearly average of 735 bearded seals was taken by Native communities in the Nunavut Settlement Area, encompassing the east coast of Baffin Island west to Inuvialuit and south to Belcher Islands in Hudson Bay (Priest and Usher 2004). This harvest is similar to the 870 seals taken annually from 1962 to 1971, though this earlier estimate includes many villages that are now part of Inuvialuit (see section 4.2.2.1.1.2)(Smith and Taylor 1977). The most recent estimate of annual harvests from the Quebec coast, including Ungava Bay, Hudson Strait, and the eastern half of Hudson Bay, from the mid-1970s, is 1,800 bearded seals (James Bay Northern Quebec Native Harvesting Research Committee 1976). An estimated 80 seals were taken annually from 1994 to 2002 off the Labrador and Newfoundland coasts (Department of Fisheries and Oceans 2003). Combining the above estimates, even with the overlap in coverage, points to harvest rates similar to the 2,500 to 3,000 seals reported for the entire Canadian Arctic during the late 1970s and 1980s (Reeves et al. 1992). Examining a four-decade time series of harvests from Grise Fjord, an Inuit village on Jones Sound in the High Arctic, revealed a decline in bearded seal numbers from a range of 21 to 50 seals (mean = 28 seals; 1956-1969) to 10 to 31 seals (mean = 20 seals; 1996-2001) despite the Native population growing by at least 50% (Riewe and Amsden 1979). Disproportionate hunting pressure on bearded seals that tend to aggregate in, or migrate through leads associated with Arctic polynas, such as Jones Sound (Grise Fjord), is believed to make local populations more vulnerable to depletion (Stirling et al. 1981). In all cases, takes of bearded seals were secondary to the numerical catch of ringed seals, and do not include losses due to sinking which range from 25-70% (Burns 1967, Smith and Taylor 1977, Riewe and Amsden 1979, Davis et al. 1980, Fedoseev 2000). Applying loss rates of 50% to the range of harvest estimates brings the expected total annual take by Native hunters in the Canadian Eastern High Arctic to 5,000 to 6,000 bearded seals.

4.2.2.1.2.2 Greenland

Seal hunting has declined over the last century in Greenland, a change possibly related to overhunting followed by a warming trend that shifted ice and hunting grounds northward (Hamilton et al. 2000, Hovelsrud et al. 2008, Pike et al. 2008). Still, it remains an important source of nutrition, cultural identity, and income in remote communities in the northern and eastern parts of the island (Pike et al. 2008). The bearded seal harvest is secondary to that of harp and ringed seals, which combined compose about 96% of the catch (Greenland Home Rule 2009). From 2005 to 2007, between 1454 and 1773 bearded seals were taken island-wide (NAMMCO 2009). Records of the bearded seal hunt from specific regions of Greenland are lacking, but a report from small villages in East Greenland, covering the years 1970-1980, suggest that about 200 seals were taken annually (Dietz et al. 1985). Annual take reports are now required though there are no enforced catch limits (Jessen 2007). Hunters use a range of methods depending on the season, with the use of nets becoming increasingly important (Jessen 2007, Pike et al. 2008). Because there are no estimates of abundance, the North Atlantic Marine Mammal Commission (2010) recommends that the status of the species be assessed.

4.2.2.1.2.3 Svalbard and the Russian Federation

Seal hunting has been documented in coastal areas of the White and Barents Seas since the 9th century, and it is likely that indigenous villages relied on seals for food, fuel, and skins for many hundreds, perhaps thousands of years prior (Pike et al. 2008). Commercial harvesting of marine mammals began around the Svalbard Archipelago shortly after its official discovery in 1596, with larger pinnipeds like walrus and bearded seals being favored in the beginning because of a greater yield of blubber and meat (Lydersen 1998). Since the late 1800s, successive technological advances, such as rifles, icebreakers, and plane spotters, magnified the efficiency and scope of hunting in the White and Barents Seas, eventually allowing larger hunting vessels to reach the Svalbard and Franz Josef Land Archipelagos and Novaya Zemlya (Pike et al. 2008). But the emphasis was on species that were more densely aggregated and more efficiently hunted, such as harp and hooded seals rather than bearded seals which were targeted more opportunistically.

Historical records of commercial seal harvests in the Barents and White Seas date back to the 1800’s, with annual takes during 1884-1904 from Norwegian ships ranging from 2400 to 8000 bearded seals. Harp seal landings over the same period climbed from 7000 to >60,000 (Hjort and Knipowitsch 1907). A peak in hunting of bearded seal occurred in 1920 when 12,000 were harvested. From 1925 to 1948, excepting during World War II when there was little to no hunting, annual catches ranged from 2340 to 3269 bearded seals (Hoel 1949). By 1963, harvests in the Barents Sea around the Svalbard Archipelago had seemingly declined as Norwegian ships reportedly took 1563 seals (Heptner et al. 1976). The hunt of harp seals at this time numbered nearly 100,000, down from >300,000 just prior to World War II (Haug 2008). At Svalbard Archipelago, as of 2007, only about 40 bearded seals were taken annually. Licensed hunters can take seals outside of the national parks and nature reserves (Kovacs 2007). Because there are no reliable estimates of abundance, the North Atlantic Marine Mammal Commission (2010) recommends that the status of the species be assessed. It is unknown the extent to which commercial hunting has historically extended into the Kara Sea, where breeding and molting aggregations are reported (Heptner et al. 1976), though Norwegian sealers likely exploited this area (I. Gjertz, Research Council of Norway, pers. comm., June 23, 2010). The remoteness of this area, however, suggests that takes were largely limited to land-based Native populations.

There are no historical or current figures on seals hunted around Franz Josef Land, which has been administered by Russia since 1926, though landings reported for Norwegian sealers as late as the 1940's probably included such seals (Hoel 1949). Given that uncontrolled hunting there depleted walrus and polar bear as late as the 1950s, it seems likely that seal populations were also hunted extensively (Uspenskiy et al. 1986). The walrus was given protection from all hunting in 1956 and the Archipelago was designated a wildlife refuge in 1994. Excepting the commercial hunt of harp seal, a "certain amount of game hunting" reportedly occurs in area (Haug and Svetochev 2004, Schliebe et al. 2006).

Current harvest levels in coastal Russia and controlled waters can only be inferred from TACs issued by the Russian Government, though these are believed to overestimate the actual take by 2-3 times (Karpenko and Balykin 2006). Since 2003, TACs in the White and Barents Seas had been fairly constant at about 200 and 600 bearded seals, respectively, but were reduced in 2010 to 20 and 150. Also in 2010, a new TAC of 150 seals was established for the Kara Sea (Russian Federal Fisheries Agency 2001, 2002, 2003, 2004, 2009). These new TACs may better reflect the actual harvest of bearded seals occurring in Barents, White, and Kara Seas, which combined would number no more than 320 seals (Russian Federal Fisheries Agency 2009). The extent to which harvests are monitored, and TACs enforced, is unknown.

4.2.2.1.1 Sea of Okhotsk DPS

Archaeological evidence from the southern Sea of Okhotsk indicates a gradually increasing reliance by indigenous people on marine mammals, including seals, starting 3000 to 5000 years before present (Niimi 1994, Yamaura 1998). Through many technological advances, this shore-based subsistence harvest has continued to the present day, though with the advent of rifles, ship-based hunting techniques, and commercialization, the scale of the harvest increased dramatically (Krylov et al. 1964, Yamaura 1998).

It is possible that as late as the early 1940s bearded seals were still hunted and utilized largely by Native peoples (Fedoseev 1984). By 1947, the ship-based commercial harvest of bearded seals, which had been growing since the 1930s, had reached 6,000 animals annually, likely eclipsing the traditional hunt that was continuing at unrecorded levels. In 1957, after the hunting grounds off eastern Sakhalin Island had been depleted, the commercial hunting shifted north to Shelikov Bay where the harvest of bearded seals reached its historical peak at 13,229 (Popov 1976). Following further depletions, hunting ships shifted their operations again deeper into Shelikov Bay and westward off Tauyskaya Bay and the village of Okhotsk to find unexploited aggregations of bearded seals, which is reflected in the harvest estimates (Fedoseev 1984). For example, harvest levels declined 60% from the peak to 5,202 seals in the three years after 1957, increased briefly in 1962 (8,969), declined until 1967 (5,541), and again increased the following year (8,825). Numbers then dropped precipitously to a mean of 1334 (SD=918), where they remained for the next 11 years until 1980. Similar to harvest reports elsewhere, these harvest estimates do not include seals that are struck but not retrieved, suggesting that they should be 25-70% higher depending on the hunting method (Burns 1967, Smith and Taylor 1977, Riewe and Amsden 1979, Davis et al. 1980, Fedoseev 2000). Ship-based sealing in both the Sea of Okhotsk and the Bering Sea was suspended from 1970 to 1975, and the first TAC for bearded seals in the Sea of Okhotsk was set at 5,000 (Kelly 1988). More recent harvest estimates are difficult to interpret with conflicting values and different reporting periods and areas (1955-1980: all years; Fedoseev 1984, 1955-2000: every 5 years; Trukhin 2009). The most recent harvest reports suggest hunting levels increased again to 4,639 by 1990 and then dropped again to the lowest harvests on record; 101 and 190 bearded seals taken in 1995 and 2000, respectively (Grachev 2006, Trukhin 2009). Since 2002, the Russian Federal Fisheries Agency (2001, 2002, 2003, 2004) has adjusted the bearded seal TAC for the Sea of Okhotsk between 6,800 and 7,700. In 2010, the TAC is 2,100 which apparently does not include harvesting for subsistence purposes which is unknown (Russian Federal Fisheries Agency 2009).

4.2.2.1.2 Future threat due to commercial, subsistence, or illegal harvest

Climate change may impact bearded seal hunting by modifying habitat quality, local seal densities, the proximity of seals to hunting communities, and the availability of seals to hunters. The quality of the pack-ice habitat favored by bearded seals affects both the tendency for seals to haul out in an area (density effects), and also their accessibility to hunters on foot or by boat or ship (availability effects)(ACIA 2005, Hovelsrud et al. 2008). Indeed, hunting success would likely be higher if seals were denser and closer to shore, potentially increasing the risk of depleting a local population. Inversely, if habitat in traditional hunting areas were degraded or shifted offshore, seal densities would be lower and (or) more distant thus reducing the chance of depletion (Mansfield 1970 cited in Reeves et al. 1998, Teilmann and Kapel 1998). As noted above, the seal hunt in West Greenland declined in the early 1900s as a warming trend pushed the southern limits of the pack ice further north. This also created habitat for Atlantic cod and caused a shift from a hunting-based to fishing-based economy (Vibe 1967, Hamilton et al. 2000).

For shore-based, local hunters, changes to bearded seal habitat seem more likely to negatively impact their ability to find seals, as most communities are located in areas traditionally close to sources of nutrition, toward which seals have and continue to contribute significantly (Inuvialuit Harvest Study Working Group 2003, Priest and Usher 2004). Progressively earlier retreat of ice from the coast in the spring, a prediction of most ice models, will disrupt the spatial and temporal overlap between hunters and seals at a time (breeding) when Native communities – particularly those further south – get a large share if not the majority of their annual supply of seal meat and oil (Kenyon 1962, Johnson et al. 1966, Coffing et al. 1998, Georgette et al. 1998). Moreover, many communities in the Canadian High Arctic, such as Grise Fjord, and other areas of the Arctic exist where they do because of predictable leads in the ice associated with polynas that both provide habitat for seals and give hunters access to them (Riewe and Amsden 1979, Stirling et al. 1981, Riewe 1991). Any disruption to the traditional location, timing, and extent of these leads would likely reduce encounters of hunters with seals that also traditionally use these leads. Hovelsrud et al. (2008) concluded that many of the consequences of climate change are likely to be negative for marine mammals as well as for marine mammal hunters.

Ship-based hunting would not be faced with the same challenges related to altered spatial and temporal overlap. In the short term, diminishing ice cover could concentrate seals and despite possible shifts in distributions, seals would be more vulnerable to mobile, mass hunting methods. However, at longer time scales, less ice would likely increase open water hunting which is inherently less successful due to greater sinking losses. In areas where bearded seals are known to haul out on land in relatively dense aggregations, such as in the Sea of Okhotsk (Heptner et al. 1976, Kosygin et al. 1986), reduced ice may increase the use of terrestrial haul outs putting them at greater risk of being hunted. In the Shantar Archipelago, in the Sea of Okhotsk, there are accounts of commercial hunters using clubs to capitalize on bearded seals hauled out ashore (Heptner et al. 1976). The exploitation of bearded seals in the Sea of Okhotsk and indications of population depletion are cause for concern – particularly considering the lack of current, reliable estimates of bearded seal abundance and annual harvest. Although harvest levels in the Sea of Okhotsk appear to be greatly reduced from historical levels in the absence of reliable information showing that the bearded seal population is recovering from a long period of over-exploitation, the Okhotsk DPS should be considered more sensitive to alterations in habitat, such as caused by climate change or human activities, which may compound other current demographic impacts.

In his qualitative assessment of the threats facing Arctic marine mammals in the coming decades, Huntington (2009) concluded that hunting appears to pose only a modest threat because it “is well understood, is likely to have a low impact, and is amenable to effective conservation through hunting management, which can respond to change relatively quickly”, making it likely “the most readily managed human activity affecting marine mammals in the Arctic.” The author also suggested that co-management regimes, in which hunters and wildlife managers work closely together, taking into account both the population biology of the species and the cultural and economic dimensions of the hunters, are the most effective means of mitigating the risks posed by overutilization (Huntington 2009). However, accurate information on both harvest levels and species’ abundance and trends are needed in order to assess the impacts of hunting as well as to respond appropriately to potential future changes in population levels due to climate change (ACIA 2005, Hovelsrud et al. 2008, Huntington 2009).

4.2.2.2 Scientific and educational utilization

Bearded seals have been occasionally collected for aquariums (i.e., three 7-year old females at the Polaria Aquarium in Tromsø, Norway; and one 10-year old female at Okhotsk Tokkari Center in Japan) or killed for scientific research (e.g., Krafft et al. 2006) in some parts of their range. Total numbers of bearded seals used for scientific or educational purposes are unknown, but are believed to be very small and likely have no impact on any of the populations.

4.2.3 Diseases, Parasites, and Predation

4.2.3.1 Diseases

Relatively little is known about diseases in bearded seals (Burns 1981, Kelly 1988), and generally the natural causes of mortality in bearded seals, other than predation by polar bears, are also largely unknown (Fay et al. 1978). The transmission of many known diseases of pinnipeds is often facilitated by animals crowding together and by the continuous or repeated occupation of a site (Fay 1974, Fay et al. 1979). The pack ice habitat and the more solitary behavior of bearded seals may therefore limit disease transmission (Fay 1974). Other than at shore-based haul-out sites in the Sea of Okhotsk in summer and fall (Heptner et al. 1976), bearded seals do not crowd together and rarely share small ice floes with more than a few other seals, so conditions that would favor disease transmission do not exist for most of the year (Fay 1974, Burns 1981).

Some caliciviruses are known to have a marine origin and are able to spread and cause disease in both marine and terrestrial species, including humans (Barlough et al. 1987, Smith et al. 1998). A couple of well-known examples of these types of caliciviruses are vesicular exanthema of swine (VES) and San Miguel sea lion virus (SMSV), which was the first virus isolated from a pinniped (Smith et al. 1998). Barlough et al. (1987) conducted a study to investigate whether Tillamook calicivirus (TCV), which infects bovines, had a marine origin. Blood samples from several species of marine mammals from Pacific populations, including one bearded seal, were tested for the presence of serum neutralizing antibodies to TCV (Barlough et al. 1987). Spotted, ribbon, ringed, and bearded seals, Pacific walrus, northern fur seals (*Callorhinus ursinus*), some non-ice associated phocids, and a few cetaceans were all negative for antibodies to TCV (Barlough et al. 1987). Only California and Steller sea lions tested positive for antibodies, which was not completely unexpected because most caliciviruses that have been isolated from marine mammals have been from species in the subfamily Otariinae (Barlough et al. 1987). Three bearded seals collected from Alaska also were negative for antibodies to the two caliciviruses, SMSV and VES (Fay et al. 1978). Six bearded seals from the Alaska Native harvest around Gambell, St. Lawrence Island, were tested for 26 calicivirus strains, including SMSV, VES, TCV, and walrus calicivirus. All animals were negative for antibodies to all calicivirus strains (Calle et al. 2008).

Herpesvirus infections have been found in several marine mammal species from the Northern Hemisphere (Kennedy-Stoskopf et al. 1986, Harris et al. 1990, Zarnke et al. 1997). Herpesviruses have been associated with both fatal and nonfatal infections of harbor seals from the North Pacific, central and northern California, and the Netherlands (Borst et al. 1986, Spraker et al. 1994, Gulland et al. 1997). Two types of phocid herpesviruses have been identified. Phocid herpesvirus-1 (PhHV-1) is an alpha herpesvirus, related to both canine herpesvirus (CHV) and felid herpesvirus (FHV), and phocid herpesvirus-2 (PhHV-2), a gamma herpesvirus (Osterhaus et al. 1985, Harder et al. 1996, Zarnke et al.

1997). PhHV-1 caused the death of 11 harbor seal pups in a nursery in the Netherlands and has caused disease in other pinnipeds with clinical signs that included pneumonia, adrenocortical necrosis, and hepatic necrosis (Osterhaus et al. 1985, Borst et al. 1986, Kennedy-Stoskopf et al. 1986, Gulland et al. 1997). PhHV-1 is highly contagious, and natural transmission of the virus occurs through aerosols or direct contact (Zarnke et al. 1997). It is unknown how PhHV-2, the gamma herpesvirus, is transmitted, and there is no evidence that PhHV-2 causes clinical disease in pinnipeds (Zarnke et al. 1997). Zarnke et al. (1997) tested marine mammals from off the coasts of Alaska and Russia for antibodies to PhHV-1 and PhHV-2. They examined walrus, two species of otariids, and five species of phocids, which included 18 bearded seals. In bearded seals, serum antibody prevalence for PhHV-1 and PhHV-2 were 61% and 17%, respectively, and antibody prevalences for neither virus was 33%. Antibody prevalences for PhHV-1 were higher than for PhHV-2 in most of the species examined, and the three highest prevalences of antibodies to PhHV-1 were found in phocid seals. The effects of age, sex, and year of collection on antibody prevalences for both viruses were examined as well. In bearded seals, antibody prevalences of PhHV-1 and PhHV-2 were not related to age, sex, or year of collection (Zarnke et al. 1997). Zarnke et al. (1997) suggested that serum antibody prevalences found in this study indicate that marine mammals off the coasts of Alaska and Russia are regularly exposed to PhHV-1 and PhHV-2 and possibly to other related herpesviruses. PhHV-1 may be an important cause of morbidity in harbor seals; however, the pathogenicity of PhHV-1 is not well understood, and the fact that seals often have concurrent bacterial infections complicates the question (Gulland et al. 1997). Although there have not been any documented herpesvirus epizootics in marine mammals off the coasts of Alaska and Russia, the exposure to herpesviruses allows for the possibility of epizootics (Zarnke et al. 1997).

Quakenbush et al. (2010) collected serum from bearded seals harvested along the coast near Point Hope, Kotzebue, Shishmaref, and Little Diomede Island in 1998 and 2002-2008 and tested for several viruses, including PhHV-1, PhHV-2, phocine distemper virus (PDV), and canine distemper virus (CDV). PDV is a morbillivirus that causes respiratory distress and pneumonia and has been responsible for large die-offs of harbor seals in Europe (Kennedy et al. 1988). PDV has been identified in harbor seals from Alaska as well (Zarnke et al. 1997). Quakenbush et al. (2010) found antibodies for only one of the viruses tested; 29.5% (18 of 61) of bearded seals were positive for PhHV-1 antibodies; however, they did not identify antibodies for PhHV-2, PDV, or CDV in seals they examined. Six bearded seals collected from the native harvest around Gambell onSt. Lawrence Island, Alaska were also negative for antibodies to PDV (Calle et al. 2008). Calle et al. (2008) also tested for influenza A virus, and all seals were negative for antibodies. Bearded seals from the Canadian Arctic have not been examined for morbilliviruses, but serum from 186 polar bears from two areas in the Canadian Arctic was tested for antibodies to CDV and PDV (Cattet et al. 2004). Polar bears from both locations were positive for antibodies to both CDV and PDV, although antibody prevalences were higher for CDV than PDV. Transmission of morbilliviruses between predator and prey may be possible (Cattet et al. 2004), and since polar bears from the Canadian Arctic have tested positive for antibodies to morbilliviruses, bearded seals in these areas may be susceptible to contracting these diseases.

Several bacterial diseases have been identified that are known to affect phocids. Quakenbush et al. (2010) examined bearded seals from the native Alaskan harvest for several bacterial diseases, including *Brucella abortus* and six species of *Leptospira* (*L. bratislava, L. canicola, L. grippotyphosa, L. hardjo, L. icterrohemorrhagiae*, and *L. pomono*). *Brucella* antibodies were found in only 2.2% (1 of 46) of bearded seals tested, and they did not find antibodies for any *Leptospira* species in the 30 seals they examined (Quakenbush et al. 2010). Three bearded seals, also collected from Alaska, were negative for antibodies to *Leptospira pomona,* as well (Fay et al. 1978). Six bearded seals collected from around St. Lawrence Island were tested for antibodies to *Brucella* spp. and five *Leptospira interrogans* serovars (Calle et al. 2008). All seals were negative for *Brucella* antibodies, and one seal had a low titer of 100 to *Leptospira interrogans* serovar *grippotyphosa*. The low *Leptospira* titer could indicate exposure to *Leptospira*, or a cross reaction between serovars of *Leptospira* that were not assayed, or it could be a nonspecific response, suggesting the seal was not exposed to *Leptospira* (Calle et al. 2008). Additionally, serum samples collected from 16 bearded seals from the northern coast of Norway, the pack ice northwest of Jan Mayen, west of Svalbard, west of Iceland, and the Barents Sea were analyzed for *Brucella* antibodies, and all seals were negative for these antibodies (Tryland et al. 1999).

Quakenbush et al. (2010) also examined the stomach and intestinal contents from 19 bearded seals collected from the Bering and Chukchi Seas and tested them for domoic acid and saxitoxin. They found domoic acid or saxitoxin in four bearded seals, but only one seal was positive for both domoic acid and saxitoxin. Levels of both domoic acid and saxitoxin were low in all animals (Quakenbush et al. 2010).

4.2.3.2 Parasites

Neospora caninum and *Toxoplasma gondii* are protozoans that can cause encephalitis and toxoplasmosis, both of which may lead to mortality in several species of domestic and wild animals (Van Pelt and Dieterich 1973, Migaki et al. 1977, Holshuh et al. 1985, Lapointe et al. 1998, Cole et al. 2000, Miller et al. 2001, Dubey et al. 2003). Serum antibody prevalences of *N. caninum* and *T. gondii* have been examined in several species of marine mammals (Dubey et al. 2003, Fujii et al. 2007, Jensen et al. 2010). Dubey et al. (2003) tested serum samples from eight bearded seals that were collected in areas from coastal southeast Alaska to the Bering Strait between 1976 and 1998. Four bearded seals were positive for *T. gondii* antibodies, and only one seal was positive for *N. caninum* antibodies (Dubey et al. 2003). Fujii et al. (2007) analyzed serum from one bearded seal collected near Hokkaido, Japan, but the seal did not test positive for antibodies to either *T. gondii* or *N. caninum*. In this same study, a small percentage of spotted seals tested were positive for antibodies to *N. caninum*, and given that only one bearded seal was examined, it is possible that bearded seals across their range are exposed to both of these protozoans and could become infected (Dubey et al. 2003, Fujii et al. 2007). Jensen et al. (2010) tested for *T gondii* antibodies in a number of marine mammals around Svalbard. Though bearded seal pups were found to be free of antibodies for the protozoan, they were prevalent in 66.7% of the 80 adult bearded seals sampled with females being about twice as likely to have the antibodies. Bearded seals had not been previously tested for the antibodies in Svalbard, but research conducted approximately a decade earlier on polar bears showed a doubling in prevalence levels (Oksanen et al. 2009) and an increase from 0% to 18.7% in ringed seals (1998). Jensen et al. (Jensen et al. 2010) hypothesized that a warming ocean may have contributed to the increased prevalence in these species either by increasing the number, or survivorship of, *T. gondii* oocysts, and/or by contributing to the increased diversity or number of transmission vectors such as of migratory birds or increased ship and other human traffic in the archipelago. Quakenbush et al. (2010) examined 43 bearded seals collected from the Alaska Native harvest in the Chukchi and Bering Seas for antibodies to *Toxoplamsa* spp., and dentified one seal positive for these antibodies. The two main sources of postnatal *T. gondii* infection are ingestion of oocysts in contaminated food or water and ingestion of *T. gondii*-infected tissues (Dubey et al. 2003, Fujii et al. 2007). Felids and dogs are the only known hosts that can excrete environmentally resistant oocysts of *T. gondii* and *N. caninum*, respectively (Dubey et al. 2003, Fujii et al. 2007). Oocysts from both species may be washed into the ocean in runoff contaminated by excrement (Fujii et al. 2007). *T. gondii* oocysts are extremely resistant to environmental influences, and therefore, likely to survive in the ocean (Dubey et al. 2003). Miller et al. (2002) determined that there was a strong association between *T. gondii* seropositivity in sea otters and locations of maximal freshwater outflow along the California coast; therefore, land-based surface runoff was a significant risk for *T. gondii* infection in sea otters in these locations.

Giardia duodenalis and *Cryptosporidium spp*. are also common protozoan parasites that cause intestinal disease in humans and animals worldwide (Hughes-Hanks et al. 2005, Dixon et al. 2008). Fecal samples from 22 bearded seals collected from near Barrow, Alaska, were all negative for both *Giardia spp*. and *Cryptosporidium spp*. (Hughes-Hanks et al. 2005). Intestinal contents from four bearded seals collected from Nunavik, Quebec, were also analyzed for the presence of *Giardia duodenalis* and *Cryptosporidium spp*. *Giardia duodenalis* was present in three of the four seals, but *Cryptosporidium spp*. were not found in any seals (Dixon et al. 2008). Hughes-Hanks et al. (2005) found *Giardia spp*. and *Cryptosporidium spp*. in ringed seals, bowhead whales, and North Atlantic right whales from near Barrow, indicating that these protozoans are present in the marine environment; however, they have only been found in a few bearded seals (Dixon et al. 2008).

Many helminth parasites have been found in bearded seals throughout their circumpolar range, including the Kara and Barents Seas, northwest Atlantic, Gulf of St. Lawrence, Bering, Chukchi, and Okhotsk Seas (Chapskii 1938, Rausch et al. 1956, Yurakhno 1968, Delamure and Popov 1975, Popov 1975, Heptner et al. 1976, Bishop and Wartzok 1977, Fay et al. 1979, Eley 1981, Paggi et al. 1991, Brattey and Stenson 1993, Gosselin et al. 1998, Forbes 2000). Helminth fauna from bearded seals include various species of cestodes, trematodes, nematodes, and acanthocephalan worms (Table 4). Heptner et al. (1976) cited an unpublished study by V.V. Treshchev, wherein only four of 39 “Atlantic” bearded seals (*E. b. barbatus*) examined were without any helminth species, the rest being heavily infected. Similarly, of 100 Pacific bearded seals (*E. b. nauticus*) examined, only seven were without any helminths and the rest had severe infestations (unpublished research by Delyamure and Serdyukov, and M.V. Yurakhno as cited in Heptner et al. 1976). Both subspecies of seals were infected with three to eight species of helminths and all of the seals between ages one and 16 were infected with at least some type of parasitic worm (Heptner et al. 1976).

Table 4. -- Helminth species from bearded seals throughout their range

SPECIES	SOURCE
Cestodes	
Diplogonoporus tetrapterus	3, 5
Diphyllobothrium lanceolatum	1, 2, 3, 5, 7, 9
Diphyllobothrium cordatum	3, 5, 7, 9
Diphyllobothrium hians	3
Diphyllobothrium latum	3
Diphyllobothrium schistochilus	3
Diphyllobothrium macrocephalus	3
Diphyllobothrium sp.	5, 7, 9
Diphyllobothriidae gen. sp.	1, 2
Anophryocephalus ochotensis	5
Pyramicocephalus phocarum	1, 2, 3, 5, 7, 9
Trematodes	
Orthosplanchnus fraterculus	3, 5, 7, 9
Orthosplanchnus arcticus	1, 2, 3
Opisthorchis tenuicollis	3
*Pricetrema erignathi***	1
Phocitrema fusiforme	2, 5
Microphallus orientalis	1, 3
Campulidae gen. sp.	8
Nematodes	
Phocanema decipiens	7, 9
Phocanema sp.	5
Contracaecum osculatum	1, 2, 3, 7
Contracaecum osculatum Species	10
Contracaecum osculatum Species	10
Contracaecum sp.	5
Dipetalonema spirocauda	2, 4, 5, 6
Anisakidae gen. sp.	1, 2
Anisakis simplex	10
Anisakis sp.	2
Phocascaris cystophorae	1, 2
Phocascaris phocae	3
Phocascaris spp.	10
Terranova azarasi	1, 2, 3
Terranova decipiens	1, 2, 3
Terranova sp.	2
Pseudoterranova decipiens	10
Otostrongylus circumlitus	1, 3
Parafilaroides krascheninnikovi	1
Parafilaroides sp.	3, 11
Skrjabinaria spirocauda	3

Acanthocephala	
Bolbosoma sp.	5
Corynosoma hadweni	3, 5
Corynosoma strumosum	1, 2, 3, 5
Corynosoma semerme	2, 3, 5
Corynosoma validum	1, 2, 3, 5, 7, 9
Corynosoma ventronudum	3
Corynosoma villosum	5

Sources: (1) Delamure and Popov 1975, (2) Popov 1975, (3) Heptner et al. 1976, (4) Burns and Eley 1977, (5) Shults 1977, (6) Burns and Eley 1978, (7) Fay et al. 1978, (8) Bishop 1979, (9) Fay et al. 1979, (10) Brattey and Stenson, (11) Gosselin et al. 1998.

In bearded seals, the organs most commonly infected by helminth species include the stomach, duodenum, heart, gall bladder, lungs and all sections of the intestinal tract (Chapskii 1938, Yurakhno 1968, Delamure and Popov 1975, Popov 1975, Heptner et al. 1976). Bearded seals studied by Delamure and Popov (1975) and Bishop and Wartzok (1977) exhibited helminth-induced damage, including subacute stomach ulcers, local inflammation of the stomach wall, and fibrosis in underlying tissues, which was associated with moderate to heavy infestations of nematodes of genera *Contracaecum*, and *Phocanema*. Anisakid nematodes were also found in clumps attached to the stomach wall, where they primarily caused non-perforating ulcers, although small perforating ulcers in the stomach wall were occasionally observed (Delamure and Popov 1975, Bishop and Wartzok 1977, Fay et al. 1979). A necropsy performed on a bearded seal from the Chukchi Sea also revealed trematodes and cestodes present in the lumen and attached to the mucosa of the small intestine (Bishop and Wartzok 1977). Delamure and Popov (1975) also found the nematode, *Parafilaroides krascheninnikovi*, (lungworm) in the lungs of two young bearded seals, which was the first time this nematode was recorded in the Sea of Okhotsk. Lungworm causes endobronchitis and hemorrhagic pulmonary infarction, and the infected seals were extremely emaciated and sluggish. The worms were found in the major bronchus and lung tissue, the surrounding lung tissue was filled with blood, and some parts of the lungs showed areas of collapse (Delamure and Popov 1975). A single bearded seal collected near Quebec, Canada, in the Gulf of St. Lawrence, was also infected with the lungworm, *Filaroides (Parafilaroides) gymnurus* (Gosselin et al. 1998).

Brattey and Stenson (1993) collected seals off Newfoundland and Labrador to investigate host specificity, numbers, and the proportions of ascaridoid nematodes in five species of phocids. All five phocid species were infected with several species of nematodes, but bearded seals had a distinctive nematode fauna. Bearded seals were primarily infected with *Contracaecum osculatum A*, *C. osculatum B*, and *Pseudoterranova decipiens C*, while the other phocid species harbored various compositions of different nematodes. Bearded seals were also the only species with significant numbers of *C. osculatum A* and *C. osculatum B*., and the only seals infected with adults of *P. decipiens C* (Brattey and Stenson 1993). Paggi et al. (1991) also determined that bearded seals are the only definitive host of *P. decipiens C* which occurs in the North Atlantic, Norwegian and Barents Seas.

The cestode *Diphyllobothrium lanceolatum*, was found in all 30 bearded seals collected from Sakhalin Bay and the Sea of Okhotsk, including the youngest animals (Delamure and Popov 1975). A bearded seal from the Chukchi Sea had more than one thousand cestodes in the small intestine when it was necropsied (Bishop 1979). Three bearded seals collected from the Bering Sea had greatly thickened, fibrous bile ducts, which were associated with an abundance of trematodes (Fay et al. 1978, Fay et al. 1979). Trematodes found in the pancreatic ducts were associated with fibrous granulation and enlargement of areas of the pancreas (Fay et al. 1979).

Eley (1981) examined hearts and pulmonary arteries from marine mammals in Alaskan waters to determine the prevalence and distribution of *D. spirocauda*, a filaroid nematode that frequently infects the cardiovascular system. The nematode was only found in the four species of ice-associated seals inhabiting Alaskan water (i.e., spotted, ringed, ribbon and bearded seals), but was most common in harbor seals which are not associated with sea ice (Eley 1981). *D. spirocauda* were not found in walrus, Steller sea lion (*Eumetopias jubatus*), northern fur seal, bowhead whale (*Balaena mysticetus*), beluga whale (*Delphinapterus leucas*), Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*), or the polar bear (Eley 1981).

Trichinella is a nematode that can infect humans through the consumption of raw or undercooked meat. *Trichinella* has a circumpolar Arctic distribution in marine mammals but only a few host species (Forbes 2000). Cases of human trichinellosis have often been associated with the consumption of walrus and beluga whales around Greenland (Forbes 2000). *Trichinella* larvae were found in 1 of 28 bearded seals examined from West Greenland, and the infected seal was believed to be the source of a trichinellosis outbreak in Greenland (Roth 1949, cited in Lukashenko et al. 1971). In 1961, a large study was conducted to assess the presence of *Trichinella* in both terrestrial and marine mammals with circumpolar ranges. *Trichinella* larvae were found in walrus, bearded seals, and ringed seals (Forbes 2000). One bearded seal collected from Point Lay, Alaska, was also found to be infected with *Trichinella* larvae (Rausch et al. 1956). Quakenbush et al. (2010) examined 53 bearded seals for the presence of *Trichinella* larvae, and all seals were negative. A similar study from Chukotka, Russia, examined 190 marine mammals, including one bearded seal, for trichinellosis. *Trichinella* larvae were not found in any of the marine mammals examined (Lukashenko et al. 1971).

Bearded seals can become infected with helminths at a young age, probably when they start foraging independently (Delamure and Popov 1975). Delamure and Popov (1975) collected eight "underyearlings", which were each already infected with two to six species of parasites. Parasites were also found in the stomachs of five- to six-month old seals from the Barents and Kara Seas (Chapskii 1938), and pups collected from the Bering Sea about a month after weaning were already heavily infested with helminths, some of which were a meter long (Fay et al. 1979). The diversity of helminth species infecting bearded seals appear to increase with age; seals greater than 5 years old were infected with four to eight species of worms (Delamure and Popov 1975).

In the Bering Sea, larval stages of several helminth species found in bearded seals have also been found in fishes that are common prey of bearded seals (Shults 1977, Fay et al. 1979). Fay et al. (1979)

examined 195 individuals from 16 fish prey species and found at least one species of a larval helminth also known to infect bearded seals, in 15 of the 16 prey species.

Echinophthirius horridus, a species of anopluran lice, is believed to commonly infect phocids in the Northern Hemisphere. However, different studies of the prevalence of their infection in bearded seals appear inconsistent. In the Sea of Okhotsk, *E. horridus* was widely prevalent in bearded seals (Heptner et al. 1976), and Freund (1933) cited in (Chapskii 1938) observed *E. horridus* in bearded seals from the Kara and Barents Seas. However, in the Bering Sea, Fay et al. (1979) did not find any *E. horridus* on bearded seals and they were only rarely found on spotted, ringed, and ribbon seals (1-10 lice per seal).

Halarachnid mites (Acarina: Halarachnidae) are parasites that inhabit the respiratory tract in mammals, primarily residing in the nasal passages (Fay et al. 1979, Fay and Furman 1982). Nasal mites have been found infrequently in bearded, ringed, ribbon, and spotted seals (Fay et al. 1979, Fay and Furman 1982). Fay and Furman (1982) examined nasal passages from marine mammals, including 43 bearded seals, collected in the eastern Bering, eastern Chukchi, and western Beaufort Seas. Nasal mites were not found in bearded seals; they were only found in spotted and harbor seals, and Steller sea lions, and no lesions were associated with the nasal mites. Although only 6% of spotted seals had nasal mites and no other ice-associated seals were infected, it is still likely that these seals are infected by nasal mites, but rarely (Fay and Furman 1982). In another study of 202 ribbon, bearded, and spotted seals from the Bering Sea, only four spotted seals, and no bearded seals, were infected with nasal mites (Fay et al. 1979).

4.2.3.3 Predation

Direct observations or data on bearded seal predation are limited. Known predators include polar bears, killer whales (*Orcinus orca*), brown bears (*Ursus arctos*), and man, though walruses have also been known to eat bearded seals (Heptner et al. 1976, Lowry and Fay 1984, Kelly 1988). The Greenland shark (*Somniosus microcephalus*) is also a suspected predator (Heptner et al. 1976).

Polar bears are the primary predators of bearded seals (Cleator 1996). They are carnivorous, and a top predator of the Arctic marine ecosystem. Polar bears prey heavily throughout their range on ice-dependent seals; principally ringed seals, though bearded seals are more than twice as large as ringed seals and so are also important (Stirling and Archibald 1977).

Around Svalbard and in the Barents Sea in April and May, bearded seals are the predominant prey of polar bears by biomass (50%) and; about a third of kills were pups (Derocher et al. 2002). Stirling and Archibald (1977) noted that bearded seals were more a more important prey items to polar bears in the active ice of the western Arctic than in the more stable ice of the High Arctic. However, Smith (1980) stated that some bearded seals are also taken in the shorefast ice. Stirling and Archibald (1977) suggest that pups and subadults appear to be most vulnerable to polar bear predation, but their sample sizes were small. Polar bear populations are known to fluctuate with prey abundance (Stirling and Lunn 1997), and local declines in ringed and bearded seal numbers and productivity have resulted in marked declines in polar bear populations (Stirling 1980, Stirling and Øritsland 1995, Stirling 2002).

Thiemann et al. (2008) used quantitative fatty acid signature analysis to examine the diets of 1,738 individual polar bears sampled across the Canadian Arctic over a 30-year span. The sex/age class of polar bears had an important effect on foraging. Large bearded seals and walruses were consumed most often by older male bears, whereas ringed seals and, where available, harbor seals were most important to younger bears. In Western Hudson Bay, bearded seal consumption declined between 1995 and 2001 for both male and female bears and continued to decline among females up to 2004.

Walrus also consume bearded seals, though apparently infrequently (Fay 1960). Lowry and Fay (1984) documented walrus predation on ringed, spotted and bearded seals in the Bering Sea. Stomach contents of walruses from 1952 to 1982 were examined and seal parts were found in 5 of 364 stomachs. The five stomachs contained a total of two bearded seals which appeared to be young animals.

Killer whales are known to be highly capable predators of marine mammals throughout the world (Forney and Wade 2006). They are most abundant in sub-polar and polar latitudes (Jefferson et al. 1991), and the remains of bearded seals have been found in the stomachs of some killer whales (Zenkovich 1938, Lowry et al. 1987). The extent of predation by killer whales on bearded seals is currently unknown.

Bearded seal adaptations that may have evolved because of polar bear predation include large, highly aquatic and mobile pups and female preference for small, drifting ice floes for nursing. These adaptations might afford mothers and pups some protection against polar bear predation (Burns and Frost 1979, Burns 1981, Kovacs and Lavigne 1986, Lydersen and Kovacs 1999, Kovacs 2002). Bearded seal pups are more alert than pups of other ice-breeding species, and even when left alone on ice, rarely venture any distance from the ice floe edge and water where they can escape quickly upon being threatened or surprised (Kingsley and Stirling 1991, Holsvik 1998, Lydersen and Kovacs 1999). Similarly, there is speculation that bearded seals avoid areas used by walruses as a tactic to avoid predation (Cleator and Stirling 1990, Stirling 1997), but evidence that favors predation over competition for food as an explanation for spatial separation of the two species is limited (Chapskii 1938, Lowry and Fay 1984, Cleator 1996).

4.2.3.3.1 Future scenarios

With scarce information on the degree of interaction between bearded seals and potential predators, as well as the distribution and behavior of those predators, it is difficult to project how a changing sea-icescape would impact the vulnerability of bearded seals to predation. A reduction in seasonal sea ice is likely to affect the distribution and perhaps abundance of both polar bears and bearded seals. This may result in more diffuse distribution of sea ice and less favorable conditions for polar bear predation than under present conditions. Polar bears are not expected to maintain their current level of predation on seals with the loss of sea ice and have not proved to be efficient hunters at sea (Derocher et al. 2004). Reduced sea ice may encourage a wider segment of the bearded seal population to breed, whelp, and molt on nearshore, non-ice habitats. Under such a scenario, bearded seal pups may be more vulnerable to predation from wolves, foxes, and bears. The range of plausible scenarios is large, making it impossible to predict the direction or magnitude of the net impact on bearded seal mortality.

Walrus predation on bearded seals may increase as all the pagophilic species are forced to share less ice and their distributions are compressed. Lowry and Fay (1984) noted increased consumption of seals by walrus during a low ice year. Changes in the distribution of sea ice could also increase the potential for predation by walrus. As with polar bear predation, this depends largely on how the sea ice is distributed. If the available sea ice is constrained to the northern region and more coastal areas, then the risk of increased exposure to walrus is higher. A more diffuse distribution of sea ice would likely decrease the potential interaction between walruses and bearded seals.

Reduced availability of sea ice may lead to increased time spent by bearded seals in the water earlier in the spring/summer, especially for molting adults and recently weaned pups; they would then be more susceptible to predation in the water, for example by killer whales or sharks. Killer whales are highly adaptable and mobile, so reduced sea-ice extent might facilitate greater access to bearded seals in the spring and early summer. Killer whales have been seen throughout the Bering and Chukchi Seas, occupying the ice edge, polynyas, and areas of 3-7/eighths ice coverage where they have preyed on bearded seals in the past (Lowry et al. 1987). In Hudson Bay, the typical cycle of ice cover is that freeze-up occurs in late October and November and breakup is usually complete by early August. However, both the extent and duration of sea ice in Hudson Bay has decreased in recent decades (Higdon and Ferguson 2009). Higdon and Ferguson (2009) examined correlations between the frequency and distribution of killer whale sightings in Hudson Bay and sea-ice concentration to determine if declining sea ice is related to changes in observations of killer whales in the area. Declining sea ice in Hudson Bay and specifically Hudson Strait has changed killer whale numbers and distribution; as sea-ice concentration declined in Hudson Strait, killer whales were observed more often and farther west in Hudson Bay (Higdon and Ferguson 2009). Bearded seals are one of five species of seals that are located in this area that has typically been closed to killer whales, so the potential for increased bearded seal predation due to changes in ice cover may exist in Hudson Bay. Another uncertainty is the amount of time that might elapse before killer whales expand their typical foraging range in response to a long-term reduction in ice extent or in response to changing prey availability. The topics of how mammal-eating killer whales switch among favored prey, and the ecological consequences, are currently under active investigation and debate (Springer et al. 2003, DeMaster et al. 2006, Mizroch and Rice 2006, Trites et al. 2007, Wade et al. 2007, Springer et al. 2008).

4.2.4 Inadequacy of Existing Regulatory Mechanisms

A summary of regulatory mechanisms relevant to bearded seal conservation is presented below for perspective on the related threats. The human activities that are the subject of any such efforts, however, are included in the suite of threats considered under the other ESA Section 4(a)(1) factors (4.2.1 - 4.2.3 and 4.2.5).

Bearded seals are currently protected under U.S. law, specifically by the Marine Mammal Protection Act (16 U.S.C. 1361 et seq.)(Marine Mammal Commission 1995). However, at this time, there are no known regulatory mechanisms that effectively address reductions in bearded seals' sea-ice habitat, or other effects of global climate change. Commercial hunting of marine mammals is prohibited in U.S. territorial waters by the MMPA and is not considered a threat to the species in this part of its range. The BRT is not aware of any laws that provide a similar level of protection to marine mammals in Canadian, Greenlandic, Norwegian or Russian waters; however, each of these countries require government issued permits for killing marine mammals for any purpose (Department of Fisheries and Oceans 2007, Governor of Svalbard 2008, Greenland Home Rule 2009) (V. Burkanov, Kamchatka Branch of the Pacific Institute of Geography, May 1, 2009, pers. comm.). A full discussion of commercial and subsistence harvesting of bearded seals can be found in Section 4.2.2.1

4.2.4.1 Existing conservation efforts

4.2.4.1.1 International agreements and oversight

4.2.4.1.1.1 The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

CITES is a treaty aimed at protecting species at risk from unregulated international trade. CITES regulates international trade in animals and plants by listing species in one of its three appendices. The level of monitoring and control to which an animal or plant species is subject depends on which appendix the species is listed in. Appendix I includes species threatened with extinction which are or may be affected by trade. Trade of Appendix I species is only allowed in exceptional circumstances. Appendix II includes species not necessarily threatened with extinction now, but for which trade must be regulated in order to avoid utilization incompatible with their survival. Appendix III includes species that are subject to regulation in at least one country, and for which that country has asked other CITES Party countries for assistance in controlling and monitoring international trade in that species. Bearded seals have no special status under CITES.

4.2.4.1.1.2 The International Union for the Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species

The IUCN Red List of Threatened Species identifies and documents those species most in need of conservation attention if global extinction rates are to be reduced, and is widely recognized as the most comprehensive, apolitical global approach for evaluating the conservation status of plant and animal species. In order to produce Red Lists of threatened species worldwide, the IUCN Species Survival Commission draws on a network of scientists and partner organizations, which use a scientifically standardized approach to determine species’ risks of extinction. The bearded seal is currently classified as a species of “Least Concern” on the IUCN Red List (Kovacs and Lowry 2008). This listing was justified due to its large population size, broad distribution, and variable feeding habits. However, the IUCN also believed it likely that the bearded seal would be negatively impacted by climate change, and so should be monitored.

4.2.4.1.1.3 The Council of Europe’s Bern Convention on the Conservation of European Wildlife and Habitats

The Bern Convention is a regional European treaty on conservation of wild flora and fauna and their natural habitats. Within the range of the bearded seal, Norway is a current party to the convention and the Russian Federation participates as an observer. The agreement calls for signatories to provide special protection for fauna species listed in Appendix II (species to be strictly protected) and Appendix III (species for which any exploitation is to be regulated) to the convention. The bearded seal falls under Appendix III of the convention.

4.2.4.1.1.4 Agreement on Cooperation in Research, Conservation, and Management of Marine Mammals in the North Atlantic (North Atlantic Marine Mammal Commission [NAMMCO])

NAMMCO was established in 1992 by a regional agreement among the governments of Greenland, Iceland, Norway, and the Faroe Islands to cooperatively conserve and manage marine mammals in the North Atlantic. Canada and the Russian Federation participate in NAMMCO as observers.

4.2.4.1.1.5 Regulation of the European Parliament and the Council of the EU on Trade in Seal Products (Regulation 1007/2009)

An EU regulation banning marketing and importation of commercial seal products was adopted in September 2009 by the European Parliament and the Council of the European Union in response to animal welfare concerns. Further measures are to be developed within 9 months to allow limited exceptions for products derived from subsistence harvest by indigenous communities. The governments of Canada and Norway have initiated the World Trade Organization’s dispute resolution process concerning the regulation (Lester 2010), and a lawsuit to overturn the regulation has been filed in the European Union General Court by a number of Inuit organizations (Inuit Tapiriit Kanatami 2010).

4.2.4.1.1.6 Mechanisms to limit sea-ice reduction and ocean acidification by regulation of GHG emissions

There are no known regulatory mechanisms that effectively address changes to bearded seal habitat from reductions in sea ice or from ocean acidification. The primary international regulatory mechanisms addressing GHG emissions and global warming are the United Nations Framework Convention on Climate Change and the Kyoto Protocol. However, the Kyoto Protocol’s first commitment period only sets targets for action through 2012. There is no regulatory mechanism governing GHG emissions in the years beyond 2012. The United States is a signatory to the Kyoto Protocol but has not ratified it; therefore, the Kyoto Protocol is non-binding on the United States.

4.2.4.1.1.7 International agreements on contaminants

The Stockholm Convention on Persistent Organic Pollutants (SCPOP), which went into force in 2004, is a global treaty to protect human health and the environment from POPs. Most of the countries within the range of the bearded seal have signed, but not all have ratified, the agreement. Twelve POPs were identified under the SCPOP to be banned or restricted, and recent amendments to the SCPOP added 9 other POPs. In addition, the Convention on Long-Range Transboundary Air Pollution, which went into force in 1983, has produced internationally legally binding protocols to reduce and control major air pollutants in signatory countries. Most European countries, the Russian Federation, Canada, and the United States have signed, but not all have ratified, the agreement and its related protocols. Levels of many of the 12 POPs originally targeted by the Stockholm Convention have declined in the Arctic (AMAP

2009). However, concentrations of some of these POPs have remained high in some arctic marine mammals and seabirds (AMAP 2009). In addition, there is evidence of Arctic accumulations of a number of compounds with POP characteristics that are currently in commercial use, but are not yet subject to any international agreements.

4.2.4.1.2 National regulatory mechanisms

4.2.4.1.2.1 United States

4.2.4.1.2.1.1 Marine Mammal Protection Act of 1972, as amended (MMPA)

Bearded seals are protected in U.S. waters and on the high seas by the MMPA (16 U.S.C. 1361 et seq.). The MMPA was enacted in response to growing concerns among scientists and the general public that certain species and populations of marine mammals were in danger of extinction or depletion as a result of human activities. The MMPA set forth a national policy to prevent marine mammal species or population stocks from diminishing to the point where they are no longer a significant functioning element of the ecosystems.

The MMPA places an emphasis on habitat and ecosystem protection. The habitat and ecosystem goals set forth include: (1) management of marine mammals to ensure they do not cease to be a significant element of the ecosystem to which they are a part, (2) protection of essential habitats, including rookeries, mating grounds, and areas of similar significance "from the adverse effects of man's action", (3) recognition that marine mammals "affect the balance of marine ecosystems in a manner that is important to other animals and animal products" and that marine mammals and their habitats should therefore be protected and conserved, and (4) directing that the primary objective of marine mammal management is to maintain "the health and stability of the marine ecosystem." Congressional intent to protect marine mammal habitat is also reflected in the definitions section of the MMPA. The terms "conservation" and "management" of marine mammals are specifically defined to include habitat acquisition and improvement.

The MMPA includes a general moratorium on the taking and importing of marine mammals, which is subject to a number of exceptions. Some of these exceptions include take for scientific purposes, for purpose of public display, subsistence use by Alaska Natives, and unintentional incidental take coincident with conducting lawful activities. Take is defined in the MMPA to include the "harassment" of marine mammals. "Harassment" includes any act of pursuit, torment, or annoyance which "has the potential to injure a marine mammal or marine mammal stock in the wild" (Level A harassment), or "has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering" (Level B harassment).

The Secretaries of Commerce and of the Interior have primary responsibility for implementing the MMPA. The Department of Commerce, through the National Oceanic and Atmospheric Administration (NOAA), has authority with respect to whales, porpoises, seals, and sea lions. The remaining marine mammals, including polar bears, walruses, and sea otters, are managed by the Department of the

Interior through the U.S. Fish and Wildlife Service (USFWS). Both agencies are responsible for the promulgation of regulations, the issuance of permits, the conduct of scientific research, and enforcement as necessary to carry out the purposes of the MMPA.

U.S. citizens who engage in a specified activity other than commercial fishing (which is specifically and separately addressed under the MMPA) within a specified geographical region may petition the Secretaries to authorize the incidental, but not intentional, taking of small numbers of marine mammals within that region for a period of not more than five consecutive years (16 U.S.C. 1371(a)(5)(A)). The Secretary "shall allow" the incidental taking if the Secretary finds that "the total of such taking during each 5 year (or less) period concerned will have a negligible impact on such species or stock and will not have an immitigable adverse impact on the availability of such species or stock for taking for subsistence uses." If the Secretary makes the required findings, the Secretary also prescribes regulations that specify (1) permissible methods of taking, (2) means of affecting the least practicable adverse impact on the species and their habitat, and (3) requirements for monitoring and reporting. The regulatory process does not authorize the activities themselves, but authorizes the incidental take of the marine mammals in conjunction with otherwise legal activities described within the regulations.

Similar to promulgation of incidental take regulations, the MMPA also established a process by which citizens of the United States can apply for an authorization to incidentally take small numbers of marine mammals where the take will be limited to harassment (16 U.S.C. 1371(a)(5)(D)). These authorizations are limited to one-year and, as with incidental take regulations, the Secretary must find that the total of such taking during the period will have a negligible impact on such species or stock and will not have an immitigable adverse impact on the availability of such species or stock for taking for subsistence uses. The Service refers to these authorizations as Incidental Harassment Authorizations.

Certain exceptions from the prohibitions on taking are provided. The MMPA exempts Alaska Natives from the prohibitions on the taking of marine mammals, including bearded seals, for subsistence purposes. Sections 101(b)(3) and 103 of the MMPA provide for subsistence harvest regulations for marine mammal stocks designated as depleted under that Act, after notice and administrative hearings as prescribed by the MMPA. Section 119 of the MMPA allows the Secretary of Commerce to enter into cooperative agreements with Alaska Native organizations to conserve marine mammals and provide co-management of subsistence uses. The Alaska Native Ice Seal Committee has an agreement with the NMFS to co-manage bearded seals and other ice-associated seals in Alaskan waters.

4.2.4.1.2.1.2 National Environmental Policy Act (NEPA)

The NEPA requires federal agencies to consider the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies conduct environmental reviews, including Environmental Impact Statement and Environmental Assessments. The NEPA does not itself regulate bearded seals, but it does require full evaluation and disclosure of information regarding the effects of contemplated federal actions on bearded seals and their habitat.

4.2.4.1.2.1.3 Outer Continental Shelf Lands Act (OCSLA)

The OCSLA (43 U.S.C. 331 et seq.) established federal jurisdiction over submerged lands on the outer continental shelf (OCS) seaward of the state boundaries (3-mile limit) in order to expedite exploration and development of oil and gas resources on the OCS. Implementation of OCSLA is delegated to the Minerals Management Service (MMS) of the Department of the Interior. Outer continental shelf projects that could adversely impact the coastal zone are subject to federal consistency requirements under terms of the Coastal Zone Management Act, as noted below. OCSLA also mandates that orderly development of OCS energy resources be balanced with protection of human, marine, and coastal environments. The OCSLA does not itself regulate the take of bearded seals, although through consistency determinations it helps to ensure that OCS projects do not adversely impact bearded seals or their habitats.

4.2.4.1.2.1.4 Coastal Zone Management Act (CZMA)

The CZMA (16 U.S.C. 1451 et seq.) was enacted to “preserve, protect, develop, and where possible, to restore or enhance the resources of the Nation's coastal zone.” The CZMA is a state program subject to federal approval. The CZMA requires that federal actions be conducted in a manner consistent with the state's coastal zone management plan to the maximum extent practicable. Federal agencies planning or authorizing an activity that affects any land or water use or natural resource of the coastal zone must provide a consistency determination to the appropriate state agency. The CZMA applies to bearded seal habitats of Alaska, though the CZMA does not itself regulate the take of bearded seals.

4.2.4.1.2.1.5 Marine Protection, Research and Sanctuaries Act (MPRSA)

The MPRSA (33 U.S.C. 1401 et seq.) was enacted in part to “prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities.” The MPRSA does not itself regulate the take of bearded seals, although it operates to protect the quality of marine habitats that bearded seals rely upon.

4.2.4.1.2.1.6 Mechanisms to limit sea-ice reduction and ocean acidification by regulation of GHG emissions

In 2003, the U.S. Environmental Protection Agency (EPA) rejected a petition urging it to regulate GHG emissions from automobiles under the CAA. In 2007, the U.S. Supreme Court overturned the EPA’s refusal to regulate these emissions and remanded the matter to the agency for further consideration (Supreme Court of the United States 2007). On December 15, 2009, the EPA published a final finding that six GHGs taken in combination endanger the public health and welfare of current and future generations, and that emissions of these GHGs from new vehicles contribute to the total GHG air pollution, and thus to this endangerment (U.S. Environmental Protection Agency 2009). The finding does not impose any emission reduction requirements, but rather allowed EPA to finalize GHG emissions standards for new light-duty vehicles as part of joint rulemaking with the Department of Transportation (U.S. Environmental Protection Agency and U.S. Department of Transportation 2010).

Finalizing these new vehicle emission standards also had implications for regulation of GHGs from stationary sources. EPA's interpretation is that a newly regulated pollutant becomes subject to permit requirements of the Prevention of Significant Deterioration (PSD) and title V programs at the time regulatory requirements to controls emissions of that pollutant take effect (U.S. Environmental Protection Agency 2010b). Thus, GHG emissions from stationary sources become subject to the permitting requirements of these programs when the new vehicle emission standards take effect. On May 13, 2010, EPA issued a final rule that limits the applicability of PSD and title V permitting requirements for GHG emissions to the largest emitters, and excludes smaller stationary emission sources from these permitting requirements until at least April 30, 2016 (U.S. Environmental Protection Agency 2010a).

The BRT did not attempt to separate the risk posed by the lack of a regulatory mechanism for GHG emissions from the risks posed by the effects of those emissions. In Section 4.2.1, the risks posed by increased GHG emissions, via potential destruction or modification of bearded seal habitat, were assessed by evaluating the best available projections of future conditions under scenarios of no regulation of GHGs (the projections were based on "non-mitigated" scenarios for future emissions). Therefore, the implications of the current lack of regulations are already included in the evaluation of risks to bearded seal habitat. In other words, while there are no regulatory mechanisms that effectively address reductions in sea-ice habitat or ocean acidification, we do not expect this shortcoming to result in population-level impacts beyond those already identified in the section on present or threatened destruction of habitat.

4.2.4.1.2.2 Canada

Hunting of seals in Canada is managed at the federal level by the Department of Fisheries and Oceans Canada (DFO) according to the Marine Mammal Regulations established under the Fisheries Act. In regions affected by aboriginal land claims agreements the DFO co-manages seal hunting with regional renewable resource boards in accordance with those agreements (Department of Fisheries and Oceans 2007). Licenses are not required for Canadian aboriginals and land claims beneficiaries to harvest seals for food, social, or ceremonial purposes (Department of Fisheries and Oceans 2007). Licenses are not required for non-aboriginal coastal residents north of 53° N latitude (Sealing Areas 1 to 4) to harvest seals for subsistence purposes. All other uses require a license. Hunting of bearded seals is allowed year-round (Department of Fisheries and Oceans 2008). Bearded seals are not currently harvested commercially in Canada (P. Hall, Department of Fisheries and Oceans, Canada, May 6, 2010, pers. comm.). Bearded seals are included in the Atlantic Seal Management Plan (Department of Fisheries and Oceans 2008), although no total allowable catches or allocations are identified. Bearded seals are classified as "data deficient" under the Canadian Wildlife Species at Risk Act (Committee on the Status of Endangered Wildlife in Canada 2009).

4.2.4.1.2.3 Greenland

Harp and ringed seals are the primary species hunted for subsistence, recreational, and commercial purposes in Greenland. Currently there is no national legislation specifically regulating the harvest of seals or their protection in Greenland, except that hunting of seals is regulated in Melville Bay Nature Reserve and in the national park in North and East Greenland (Greenland Home Rule 2009). Greenlandic citizens can hunt seals year-round provided they have a permit and hunters are responsible for maintaining catch records (Greenland Home Rule 2009). In most municipalities, seal hunting is restricted by area, season, or hunting method through by-laws, although there are currently no harvest quotas (Greenland Home Rule 2009).Bearded seals are identified as a "data deficient" species on the Greenland Red List (Boertmann 2008).

4.2.4.1.2.4 Norway

Bearded seals are relatively rare along the mainland Norwegian coast, and no quotas are issued under the Marine Resources Act for hunting of this species (D. Vongraven, Norwegian Polar Institute, pers. comm., 2 July 2010). In Svalbard territorial waters, harvest of bearded seals is managed under the Svalbard Environmental Protection Act within the framework that "productivity and diversity of species and their habitats are maintained and Svalbard's natural wilderness is protected." Small numbers of bearded seals are harvested annually by licensed hunters outside the major national parks and nature reserves that include about 86% of Svalbard's territorial waters (I. Gjertz, Research Council of Norway, pers. comm., June 23, 2010) (Lier et al. 2010). There are no set harvest quotas throughout the year except for a closed period during the breeding season (K. Kovacs, Norwegian Polar Institute, pers. comm., 22 April 2010; D. Vongraven, Norwegian Polar Institute, pers. comm., 2 July 2010). The bearded seal is not included on the Norwegian Red List (Kålås et al. 2006).

4.2.4.1.2.5 Russia

Although bearded seals are hunted for subsistence uses across much of their range, large-scale commercial harvest has occurred only in Russia (Kovacs 2002). In the late 1950s and 1960s, the annual harvest of bearded seals in the Sea of Okhotsk and later in the Bering and Okhotsk Seas sometimes exceeded 10,000 animals, which likely depleted the population (Popov 1982, Kelly 1988). Large-scale commercial harvest of bearded seals was suspended in 1970 and subsistence harvest limits were also introduced (Popov 1982). Subsistence and small-scale commercial hunting of bearded seals continued to occur after this time, but at much lower levels (Kovacs et al. 2008).

Russian seal hunters are licensed; but, there are few restrictions on time or place of harvest outside of state nature reserves and refuges (Belikov and Boltunov 1998). The Russian Federation government approves total allowable catches (TACs) of marine mammals by species and geographical region (COWI 2008, Marine Mammal Council 2008). TACs are discussed further in Section 4.2.2. Harvest levels are believed to have remained below TACs in recent years (V. Burkanov, Kamchatka Branch of the Pacific Institute of Geography, May 9, 2010, pers. comm.), though it should be noted that harvest reporting and enforcement of catch quotas are difficult to manage in particular in remote areas of Russia (Kovacs et al. 2008). Bearded seals are not listed in the Red Book of the Russian Federation (Danilov-Danilyan 2001).

4.2.5 Other Natural or Human Factors Affecting the Species' Continued Existence

4.2.5.1 Pollution and contaminants

Research on contaminants and bearded seals is limited compared to the extensive information available for ringed seals. Research has only been conducted in a few areas, particularly throughout Arctic environments where bearded seals are an important prey of polar bears and an important diet item in coastal communities (Norheim et al. 1992, Muir et al. 1999, Fisk et al. 2005). However, it is likely that the temporal trend data for contaminants in other Canadian Arctic wildlife (Muir et al. 1999, Fisk et al. 2001, Fisk et al. 2005) also apply to bearded seals.

4.2.5.1.1 Hydrocarbons

The impacts of spilled oil and other hydrocarbons include immediate and long-term effects on individual bearded seals, populations, food webs and habitats. This topic is covered in Section 4.2.5.2.5.2.

4.2.5.1.2 Organochlorine compounds

Pollutants such as organochlorine compounds (OC) and heavy metals have been found in most bearded seal populations (Galster 1971, Galster and Burns 1972, Clausen 1978, Smith and Armstrong 1978, Burrell 1981, Norstrom and Muir 1994, Bang et al. 2001, Hoekstra et al. 2003a, Muir et al. 2003, O'Hara and Becker 2003, Quakenbush and Citta 2008, Quakenbush et al. 2010). Muir et al. (1999) provided an excellent schematic describing the pathways of transport, deposition, redistribution and accumulation of persistent organics and metals in Arctic marine ecosystems (see Figure 40). The variety and sources of the contaminants vary across the bearded seal's range, but these compounds appear to be ubiquitous in the Arctic marine food chain (Wiberg et al. 2000, Kovacs 2007). Statistical analysis of OCs in marine mammals has shown that, for most OCs, the European Arctic is more contaminated than the Canadian and U.S. Arctic (Borgå et al. 2005).

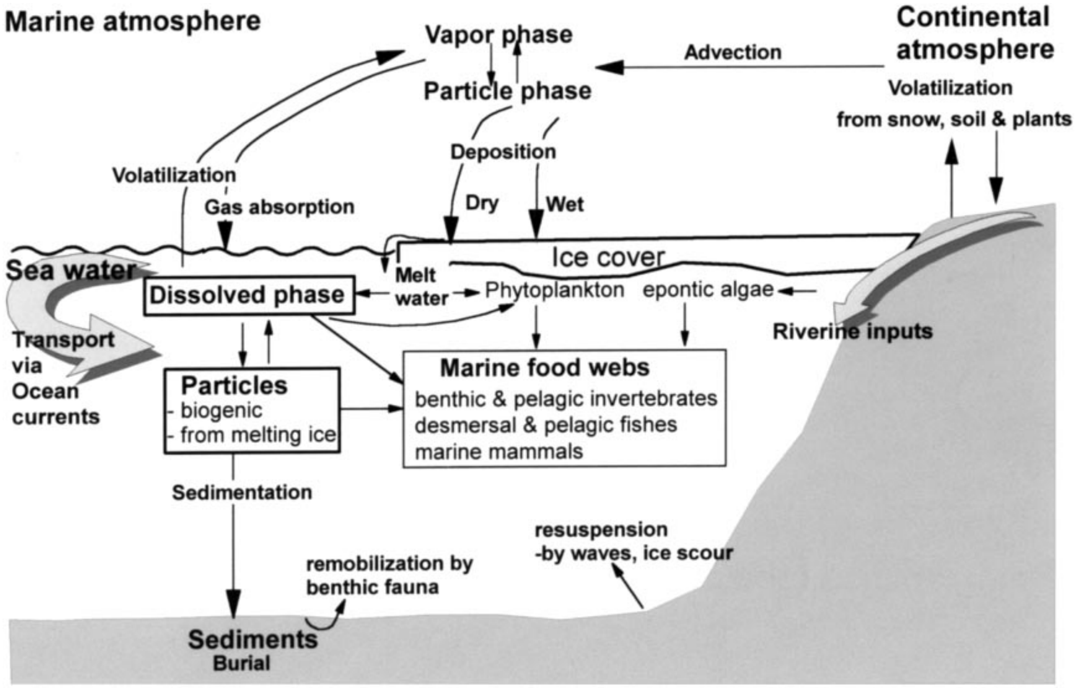


Figure 40. -- Pathways of transport, deposition, redistribution and accumulation of persistent organics and metals to Arctic marine Ecosystems; reproduced from Muir et al. (1999).

A subset of OCs are persistent organchlorine pollutants (POPs), including DDTs (dichloro-diphenyl-trichlorethanes), PCBs (polychlorinated biphenyls), and PCFs (perfluorinated contaminants; (Powley et al. 2008)). In pinnipeds specifically, DDT and PCB exposure have been linked to endocrine disruption, reproductive disorders, and reproductive failure (reviewed by Gregory and Cyr 2003). Kovacs (2007) noted that until late in the 20th century the Arctic was perceived to be one of the last pristine wilderness areas in the world; thus, the presence of persistent organic pollutants (POPs) and other contaminants was a surprise. Concentrations of DDT and related residues generally are much lower among pinnipeds of the Beaufort and Bering Seas than in other regions (Kelly 1988). Bearded seals had the highest concentrations (0.33 ppm) of six marine mammals tested in Alaska. Dieldrin and lindane levels were less than half the concentration of DDT (Galster and Burns 1972). Average PCB concentrations were similar (1.78 ppm) among five species of pinnipeds, including bearded seals, in the Beaufort and Bering Seas (Galster and Burns 1972). Perfluorinated contaminants (PFCs), such as perfluorooctane sulfonate (PFOS) and related synthetic compounds, have been detected in bearded seals in the western Arctic (Powley et al. 2008). These compounds bind to proteins rather than lipids and negatively affect cellular function.

Organochlorine contaminants are of particular concern because they are lipophilic compounds that have potential detrimental effects on health and reproduction (O'Shea 1999, Gregory and Cyr 2003). Cytochrome P450s, a class of hemoproteins induced by exposure to contaminants and pharmaceuticals, are used as biomarkers for exposure to certain contaminants, including organochlorines (Assunção and Ross 2001, Fujita et al. 2001). The accumulation of persistent lipophilic contaminants in marine mammals is generally related to an individual’s size and sex (O'Shea 1999, Aguilar et al. 2002, Hoekstra et al. 2003b), but Hoekstra et al. (2003b) noted that biases associated with sample collections, such as geographical location or the type of tissue examined, may influence these findings. Muir et al. (2003) showed that ΣPCBs and ΣDDTs from the blubber of male bearded seals from the White Sea were approximately 10 times higher than levels reported for male bearded seals from Kongsfjorden in Svalbard (reported in Bang et al. 2001). Male bearded seals from Barrow, Alaska (Chukchi-Beaufort Seas) also had low ΣPCB levels (Hoekstra 2002). Quakenbush et al. (2010), studying bearded seals harvested in Alaska from 2003-2007, indicated that OC concentrations in blubber were an order of magnitude higher than concentrations in the liver.

The spatial distribution of organochlorines in pinnipeds appears to be consistent with levels found in the environment described by de Wit et al. (2006). Organochlorine levels in regions surrounding the Arctic are expected to continue to rise (de Wit et al. 2006). Addison et al. (2005) suggested that the distribution of PCB congeners in the Arctic between the 1980s and the 1990s was consistent with atmospheric transport processes becoming increasingly important. Climate change also has the potential to increase the transport of pollutants into the marine environment through freshwater runoff (Tynan and DeMaster 1997), highlighting the importance of continuing to monitor bearded seal contaminant levels.

4.2.5.1.3 Heavy metals

Mercury, cadmium, lead, selenium, arsenic, and nickel are the most commonly reported heavy metals in Arctic marine mammals (Kovacs 2007, Dietz 2008). Bearded seals bioaccumulate mercury in vital tissues, (e.g., liver, kidney, muscle) and accumulation levels of this metal have been studied in some bearded seal populations (Galster 1971, Freeman and Horne 1973, Holden 1978, Smith and Armstrong 1978, Dietz et al. 2000, Quakenbush and Citta 2009, Quakenbush et al. 2010). There is a strong correlation between mercury and selenium levels and, in the Canadian Arctic, metal levels generally showed a positive correlation with bearded seal age or size (Freeman and Horne 1973, Smith and Armstrong 1978). Smith and Armstrong (1978) also reported that rates of accumulation appear to be somewhat higher in bearded seals as compared to ringed seals and that the input of mercury from natural sources to fresh waters is increasing.

4.2.5.1.4 Butyltin compounds and Polybrominated diphenyl ethers

Butyltin (BT) compounds are used as antifouling agents in ship bottom paints and aquaculture nets (Iwata et al. 1997). They are retained in all tissues, although they are more concentrated in the liver rather than the blubber where polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethane (DDT) also accumulate (Iwata et al. 1997). These compounds have been detected in marine mammal species in North Pacific, Asian and California coastal waters (Iwata et al. 1997, Tanabe et al. 1998, Kannan et al. 2001). Tanabe et al. (1998) reported that "BT accumulation in pinnipeds was lower than in cetaceans, confirming earlier notion that pinnipeds have greater capacity to degrade TBT in the liver and excrete BTs through molting."

Less is known about the toxicity of polybrominated diphenyl ethers (PBDEs), which are flame retardants widely used in plastics, textiles, electronic equipment and other materials (Rigét et al. 2006). PBDEs have not yet been found in bearded seals, but they are ubiquitous in the environment. They are found in air, water, fish, birds, marine mammals and humans and detected levels have increased exponentially over the past 30 years (reviewed in Hites 2004). Studies have shown that they adversely affect thyroid function and neurodevelopment in mammals (Darnerud 2003, Viberg et al. 2004). Sources of PBDEs in the Arctic include Western Europe, eastern North America, highly populated local areas, and southern regions through long-range atmospheric transport (de Wit et al. 2006).

4.2.5.1.5 Radiation

Radiocaesium levels in Arctic seals have been evaluated in the Barents Sea, Svalbard and North Greenland Sea (Carroll et al. 2002, Andersen et al. 2006). The authors note that bearded seals in those regions are continuously exposed to a low level radioactive contamination. This contaminant accumulates in soft tissues, particularly muscle, and it cannot be broken down in the body. Andersen et al. (2006) noted that their findings are consistent with previous studies in the Barents Sea and Svalbard (Carroll et al. 2002) and Alaska (Cooper et al. 2000) indicating low levels of radiocaesium in Arctic seals.

4.2.5.2 Oil and gas exploration, development, and production

4.2.5.2.1 Overview

Commercial oil and gas activities began in the Arctic in the 1920s in Canada's Northwest Territories, and greatly expanded during the 1970s, particularly in Alaska, Russia, and Norway (AMAP 2007). By the 1980s and early 1990s, oil and gas activities had extended farther into the Arctic with several fields being explored and developed offshore. To date, cumulative production from the Arctic is in the billions of cubic meters for both oil and gas, and the Arctic is currently producing about a tenth of the world's oil and a quarter of its gas (AMAP 2007). In 2008, the U.S. Geological Survey (USGS) completed an assessment of undiscovered conventional oil and gas resources in all areas north of the Arctic Circle. Using a geology-based probabilistic methodology, the USGS estimated that 90 billion barrels of oil, 1,669 trillion cubic feet of natural gas, and 44 billion barrels of natural gas liquids may remain to be found in the Arctic, of which approximately 84% is expected to occur in offshore areas (U.S. Geological Survey 2008). These reserves may represent as much as a quarter of the world's undiscovered oil and gas (AMAP 2007). Such extensive reserves coupled with rising global demand make it very likely that oil and gas activity will increase in the Arctic in the future. According to the *Arctic Oil and Gas 2007* assessment (AMAP 2007):

> *"More activity is expected in the next two decades, however projections father into the future become increasingly speculative since the pace of activity is affected by a number of factors including economic conditions, societal considerations, regulatory processes, and technological advances. Global climate change may introduce additional factors that need to be taken into account."*

Climate change is expected to enhance marine access to offshore oil and gas reserves by reducing sea-ice extent, thickness, and seasonal duration, thereby improving ship accessibility to these resources around the margins of the Arctic Basin (ACIA 2004, AMAP 2007). Reduced sea-ice extent and thickness is also likely to allow construction and operation of more economical offshore platforms since the ice forces these structures must withstand may also be reduced (ACIA 2005, AMAP 2007). Conversely, land-based infrastructure such as ice roads, pipelines, artificial islands, and coastal installations will likely be negatively impacted by climate change due to thawing of the permafrost and increased storm surges and coastal erosion (ACIA 2005, AMAP 2007). These effects may make future development on land more complicated and expensive, providing further incentive for the development of marine-based production and transportation infrastructure (AMAP 2007).

4.2.5.2.2 Beringia DPS

4.2.5.2.2.1 United States (Alaska)

The United States schedules oil and gas lease sales on its outer continental shelf (OCS) regions in 5-year programs that indicate the size, timing, and location of proposed leasing activity for each 5-year period. In June 2007, the Secretary of the Interior approved the 2007-2012 OCS Oil and Gas Leasing Program. According to this program, lease sales were planned in the Chukchi Sea in 2008, 2010, and 2012; in the Beaufort Sea in 2009 and 2011; and in the North Aleutian Basin of the southeastern Bering Sea in 2011 (Minerals Management Service 2007b). Two lawsuits were filed against this program in 2007, and in April 2009, the U.S. Court of Appeals for the District of Columbia vacated and remanded the program and required the Department of Interior to "conduct a more complete comparative analysis of the environmental sensitivity of different areas" (Minerals Management Service 2010a). In March 2010, the Minerals Management Service (MMS) announced that the Preliminary Revised 2007-2012 OCS Oil and Gas Leasing Program (Minerals Management Service 2010c) retains the Chukchi Sea lease sale from 2008 and allows proposed exploratory activities on leases in the Chukchi and Beaufort Seas to proceed, but removes the five remaining lease sales in the North Aleutian Basin and Beaufort and Chukchi Seas from the program. A final 2007-2012 leasing program will be approved after the Secretary considers public comments on the revised plan (Minerals Management Service 2010a).

On January 16, 2009, the MMS announced the release of a 5-year Draft Proposed Program (DPP) for offshore oil and gas lease sales for 2010-2015 (Minerals Management Service 2009b), 2 years earlier than the usual schedule. The DPP calls for lease sales in the Chukchi Sea in 2010, 2012, and 2014; in the Beaufort Sea in 2013 and 2015; and in the North Aleutian Basin in 2011 and 2014. On February 10, 2009, the Secretary of the Interior announced that he was extending the comment period on the DPP by 180 days to provide additional time for states, stakeholders, and affected communities to provide input on the plan (Minerals Management Service 2009c). In the meantime, the MMS has initiated the process to develop the new 2012-2017 OCS Oil and Gas Leasing Program, which will supersede the 2010-2015 DPP once it's completed. Currently, this process includes the Chukchi and Beaufort Seas as potential leasing locations for the 2012-2017 program, but does not include the North Aleutian Basin (Minerals Management Service 2010b).

The April 20, 2010 explosion of the *Deepwater Horizon* drilling platform in the Gulf of Mexico, and the catastrophic oil blowout that resulted (estimated to be 4.9 million barrels total, (Deepwater Horizon Response 2010)), will likely impact future oil and gas activities in the United States, including Alaska. For example, on May 27, 2010, the Secretary of the Interior announced that Shell would not be permitted to drill five exploratory wells in their Beaufort and Chukchi Sea leases (scheduled for the summer of 2010) until at least 2011, pending further review by the MMS (U.S. Department of the Interior 2010).

The State of Alaska also conducts lease sales and licensing for the exploration of oil and gas on state lands and in state waters. At least 20 lease sales have been made in state waters of the Beaufort Sea since 1979, and new lease sales are scheduled to occur annually according to the 5-year leasing program for 2010-2014 (Alaska Department of Natural Resources 2010b). The petroleum potential in these coastal waters is considered to be moderate to high.

4.2.5.2.2.1.1 Beaufort and Chukchi Seas

Oil and gas activities have been conducted off the coast of Alaska since the 1970s, with most of the activity occurring in the Beaufort Sea. Between 1976 and 2003, 31 offshore exploratory wells were drilled in the Beaufort Sea, 30 were drilled in the Bering Sea (including 6 deep stratigraphic test wells), and 5 were drilled in the Chukchi Sea (Minerals Management Service 2009a). The MMS has conducted 10 offshore lease sales in federal waters of the Beaufort Sea since 1979, and 7 oil companies had active leases there as of January 2009 (Figure 41). The Alaska DNR has conducted an additional 20 lease sales in state waters of the Beaufort Sea since 1979 (Alaska Department of Natural Resources 2009), and many exploration and development activities are ongoing there (Alaska Department of Natural Resources 2010a). Three oil fields are currently in production in the Beaufort Sea, where drilling is being conducted from artificial islands in state waters: Endicott field has been in production since October 1987, Northstar field since October 2001, and Oooguruk field since June 2008. By 2009, these three fields had produced nearly 600 million barrels of oil (Alaska Department of Natural Resources 2009). Development of the offshore Liberty oil field began in 2008 with production expected to begin in 2011 (Lee 2008). Production at the Nikaitchuq oil field is scheduled to begin from on onshore drilling pad in December 2010 and from an offshore drilling island in 2011 (Anchorage Daily News 2010). Several other oil fields on Alaska's North Slope (e.g., Point Thompson, Badami, Dewline, and Beechey Point) have had development wells drilled near the coast of the Beaufort Sea in recent years (Alaska Department of Natural Resources 2010a).

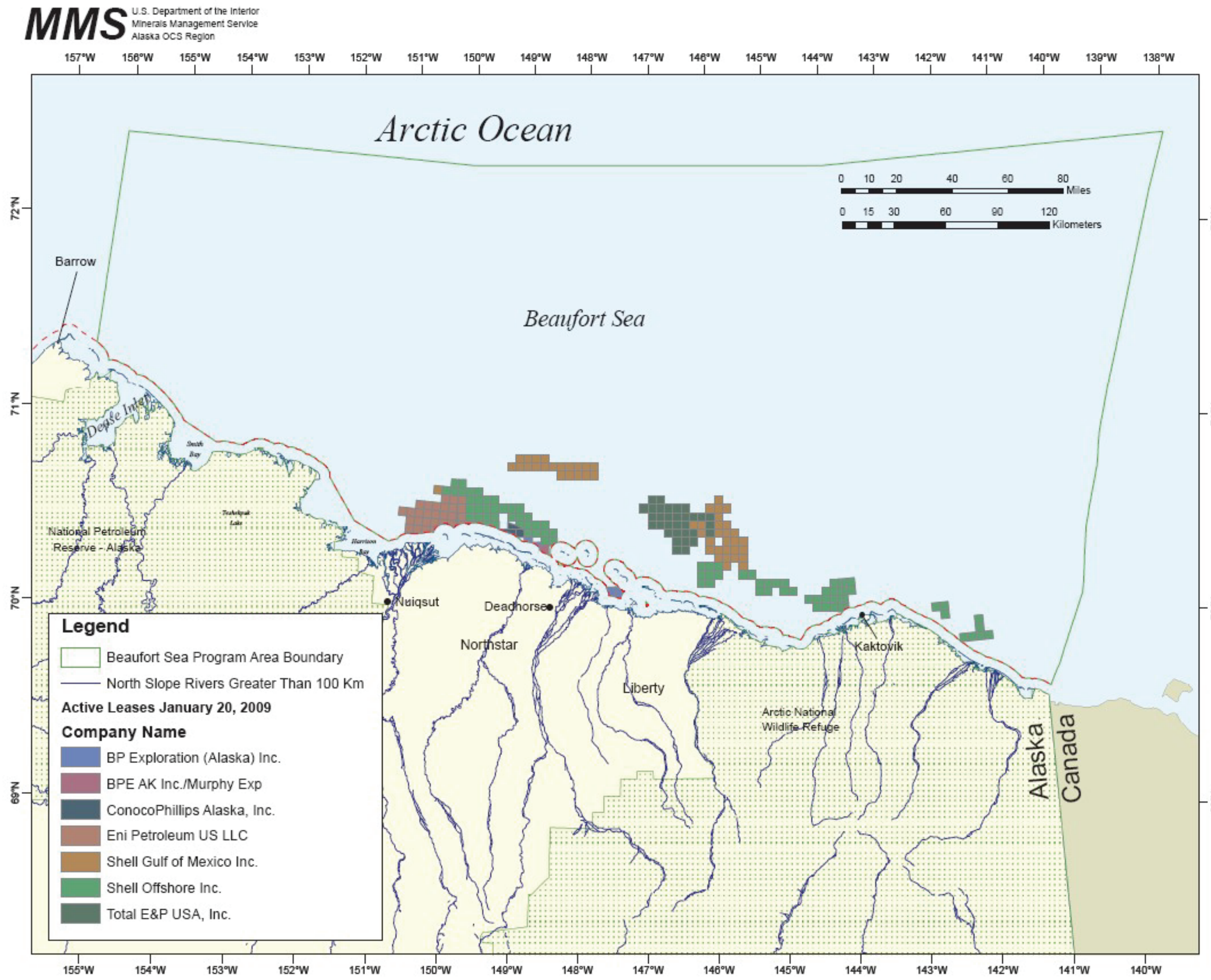


Figure 41. -- Active offshore oil and gas leases in the Beaufort Sea program area (Source: Minerals Management Service 2009a).

Although five exploratory wells have been drilled in the past, no oil fields have been developed or brought into production in the Chukchi Sea to date. The MMS has conducted three offshore lease sales in the Chukchi Sea since 1988, with the latest (sale 193 in 2008) being the most successful in Alaska's history (Minerals Management Service 2008b). In December 2009, the MMS approved Shell Gulf of Mexico Inc.'s (2009) exploration plan for drilling at five potential sites within three prospects known as Burger, Crackerjack, and Southwest Shoebill in the Chukchi Sea during 2010 (Figure 42). Following the Deepwater Horizon blowout in the Gulf of Mexico, these plans have been put on hold until at least 2011, pending further review by the MMS (U.S. Department of the Interior 2010).

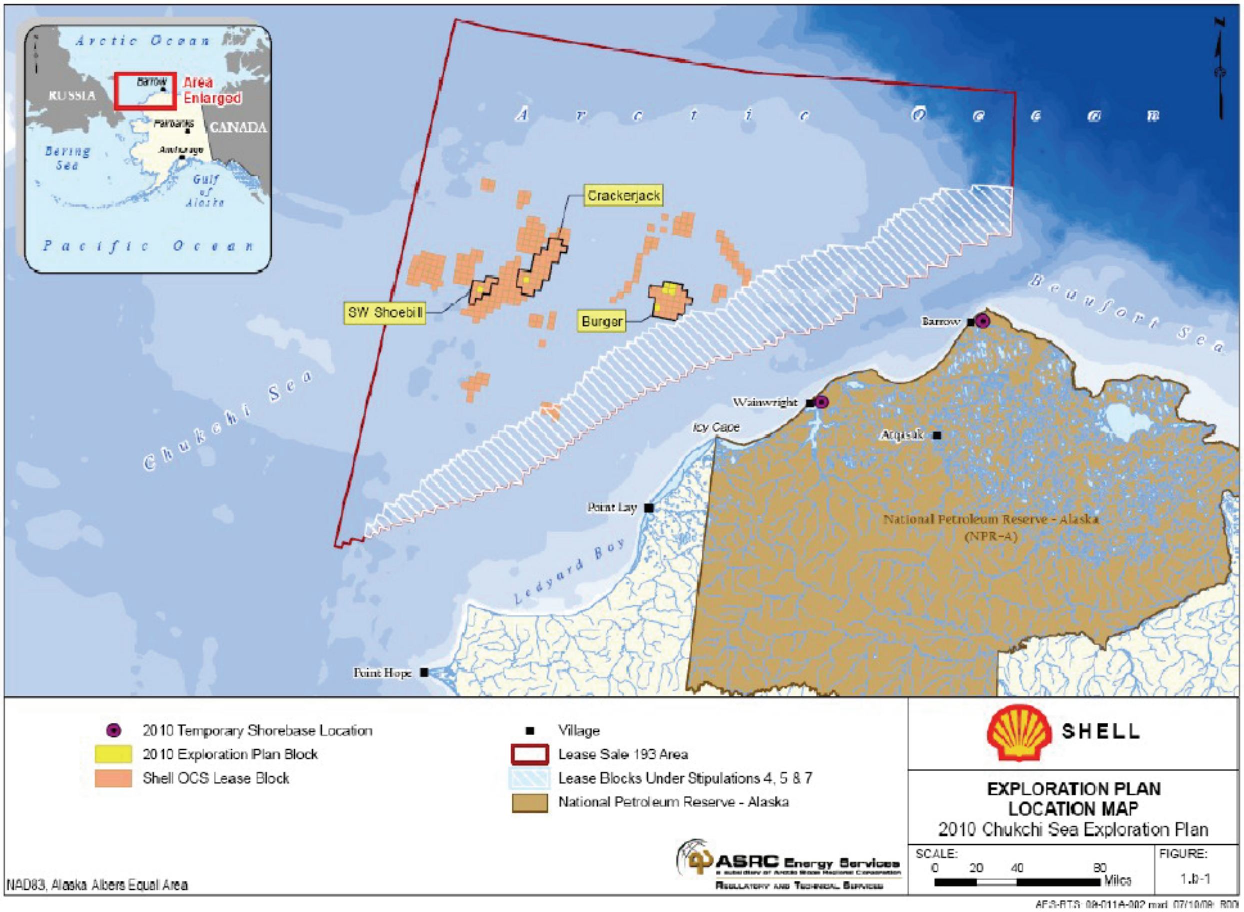


Figure 42. -- Location of three prospects (Burger, Crackerjack, and Southwest Shoebill) identified as potential drilling sites by Shell in their 2010 exploration plan (Source: Shell Gulf of Mexico Inc. 2009).

There are no offshore oil or gas fields in development or production in the Bering Sea, and all previous lease sales have expired (Minerals Management Service 2009a). Lease sales are not expected to resume in this region until 2012 at the earliest (Minerals Management Service 2010b).

4.2.5.2.2.2 Canada (Beaufort Sea)

From 1969 through the late 1980s, more than 400 exploratory wells were drilled in the Canadian Arctic (Popular Geoscience 2007). This activity resulted in the discovery of 47 oil and gas fields in the Mackenzie Delta and Beaufort Sea regions (Popular Geoscience 2007). Estimates of recoverable resources are as much as 1.8 trillion cubic meters of natural gas and 6.7 billion barrels of oil (Cranstone 2002). The level of future oil and gas activities in Canada is likely dependent on factors such as the price of oil or the development of new pipelines. For example, construction of a proposed Mackenzie Valley gas pipeline would likely increase exploration and development activities within the Mackenzie Delta and Beaufort Sea region (AMAP 2007) and may also open the door for a pipeline from the Canadian Arctic Archipelago. However, there has been historical opposition to these pipelines from Native peoples in the region, and even if the economics of pipeline construction were favorable, construction would likely not proceed without support from these communities. There are currently no active drilling operations within the Canadian Beaufort Sea (CAPP 2010).

4.2.5.2.2.3 Russian Federation (East Siberian, Chukchi and Bering Seas)

The continental shelves of Russia's East Siberian, Chukchi, and Bering Seas have excellent prospects for large-scale and long-term developments of offshore oil and gas, with potential recoverable reserves estimated in the billions of tons of conventional fuel (Patin 1999). Arctic waters offshore eastern Russia are thought to contain more than one-third of the Russian Arctic's recoverable offshore oil reserves and more than 10% of its recoverable gas reserves (Frantzen 2007). Recently, there has been renewed interest in the Russian Chukchi Sea as new evidence emerges to support the notion that the region may contain world-class oil and gas reserves. Global oil and gas exploration companies are becoming more interested in the Russian Arctic offshore because it is one of the world's few remaining petroleum frontiers with significant resource potential. In 2006, 3,700 km of seismic surveys were conducted in Russia's North and South Chukchi basins to explore for economically viable oil and gas reserves. Preliminary results were described as "very encouraging" (Frantzen 2007).

4.2.5.2.3 Okhotsk DPS

In the Sea of Okhotsk, oil and natural gas operations are active off the northeastern coast of Sakhalin Island, and future developments are planned in the western Kamchatka region (Figure 43). The project referred to as *Sakhalin-1* consists of three deposits with extraction capability up to 10 billion cubic meters per year, and *Sakhalin-2* is one of the world's largest integrated oil and gas projects with annual production of liquefied gas at nearly 20 billion cubic meters (Chernenko 2007). Oil extraction from these projects has already started, with associated construction of a platform, a terminal for oil shipment, and a floating oil tank with a capacity of one million barrels (Lapko and Radchenko 2000). Initial work and seismic exploration for the projects *Sakhalin-3,4,5* and *6* has also begun (Chernenko 2007). Oil and gas development off Sakhalin Island resulted in an oil spill in 1999 that released about 3.5 tons of oil (Lapko and Radchenko 2000).

An oil and gas project is also planned for development in the northern Sea of Okhotsk in the Magadan region (Chernenko 2007). This project is also proposed for integrated extraction of oil and natural gas (15-20 million tons of oil and 35-50 billion cubic meters of gas). The western side of the Kamchatka shelf is considered a prospective area for oil development as well, with oil and gas extraction planned to begin there by 2015 (Chernenko 2007).

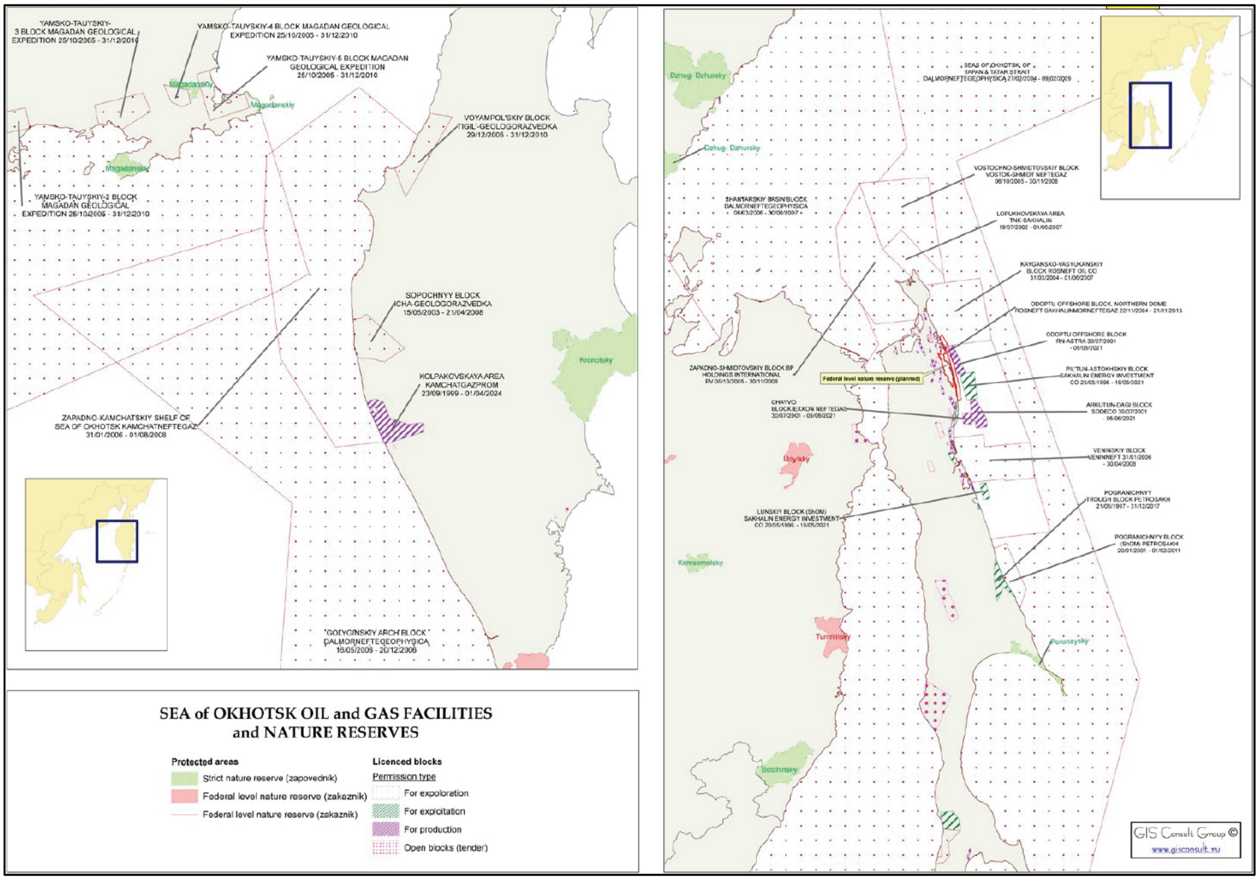


Figure 43. -- Oil and gas fields, areas of exploration, and nature reserves on or around the Kamchatka Peninsula (left panel) and Sakhalin Island (right panel) in the Sea of Okhotsk (Source: Chernenko 2007).

4.2.5.2.4 Erignathus barbatus barbatus

4.2.5.2.4.1 Canada (Canadian Arctic Archipelago)

Two of the gas fields in the Canadian Arctic Archipelago are some of the largest in Canada and total estimates across all fields of "proven, probable, and possible reserves" is 509 billion cubic meters of gas, 9.7 million cubic meters of natural gas liquids, and 200-500 million barrels of oil (Cranstone 2002). In general, the economic costs and logistical challenges of extracting and transporting these petroleum resources south have been too high. One field (Bent Horn) in the Canadian Arctic Archipelago was put into production in the early 1980s and approximately 100-200 thousand barrels of oil were shipped annually to Montreal via an ice-breaking tanker. By the time this practice ended in 1996 (due to a decline in crude prices), 2.8 million barrels of oil had been shipped from Bent Horn (Cranstone 2002). Over the years, construction of natural gas pipelines from the Canadian Arctic Archipelago region have been proposed, but have yet to be proven economically viable.

4.2.5.2.4.2 Greenland

Oil and gas exploration was initiated in areas offshore West Greenland in the early 1970s, with almost 21,000 km of seismic surveys being conducted during this time (GHEXIS 2005). Five exploratory wells were drilled in Davis Strait during 1976-1977, but no oil was found. Exploration activities moved to the East Greenland shelf in 1978, where over 63,000 km of aeromagnetic surveys and nearly 7,800 km of marine seismic surveys were conducted between 1979 and 1982 (GHEXIS 2005). Drilling of exploratory wells was not reported in this area however.

Previous seismic data from West Greenland was re-interpreted in the early 1990s and it was determined that many of the earlier wells had been abandoned prematurely. At least 47,500 km of additional seismic surveys were conducted offshore West Greenland (including the northern regions of Baffin Bay) between 1990 and 2004, and nearly 7,000 km were conducted offshore Northeast and East Greenland between 1990 and 1996 (GHEXIS 2005). While exploration activities have not yet yielded major oil or gas discoveries in these areas, they are being conducted at relatively moderate levels and efforts to date have produced results warranting further evaluation (AMAP 2007). The government of Greenland has recently adopted more favorable policies to increase oil and gas industry interest in Greenland's shelves, and exploration activities are on-going (AMAP 2007).

4.2.5.2.4.3 Norway and Svalbard (Barents Sea)

The Norwegian portion of the Barents Sea holds an estimated 2.2 billion barrels of oil and 30 trillion cubic feet of gas, of which about 90% is yet to be discovered (WWF 2010). Exploration for offshore oil and gas began in the Norwegian portion of the Barents Sea in the 1980s, which resulted in the discovery of a gas field in 1984 and an oil field in 2000 (AMAP 2007). Production began at the gas field in 2007 (AMAP 2007), and the oil field is currently under development (Fouche and Moskwa 2010). Norway is continuing to conduct very high levels of exploratory activity in the Barents Sea and is planning continued oil and gas development activities along with associated offshore pipeline and tanker transport infrastructure in the future (AMAP 2007). In April 2010, Norway and Russia settled a 40-year maritime border dispute in the Barents Sea by dividing the disputed area into two equally significant parts, thereby paving the way for this area to be opened for oil and gas exploration as early as 2012-2013 (Fouche and Moskwa 2010). The entire disputed area holds an estimated 10 billion barrels of petroleum (Fouche and Moskwa 2010).

According to figures in AMAP's (2007) report, oil and gas exploration activities occurred around Svalbard in the period between 1960 and 1979, with at least two exploratory wells being drilled offshore. Recently, several nations and oil companies have expressed interest in exploring for oil and gas around Svalbard (Adam 2007), and in 2009 Russia announced plans to conduct surveys in areas outside of Svalbard's territorial waters (BarentsObserver 2008b). Norway claims the right to establish an economic zone around Svalbard - including some of the areas where Russia proposes to survey - in which all commercial activities would be subject to its regulations, but these claims are being disputed by several nations (BarentsObserver 2008b).

4.2.5.2.4.4 Russian Federation (Barents and Kara Seas)

Of all the oil and gas produced in the Arctic today, about 80% of the oil and 99% of the gas comes from the Russian Arctic (AMAP 2007). And with over 75% of known Arctic oil, over 90% of known Arctic gas, and vast estimates of undiscovered oil and gas reserves, Russia will continue to be the dominant producer of Arctic oil and gas in the future (AMAP 2007). According to Patin (1999), most estimates suggest that oil and gas reserves may be found on about 90% of all Russian shelves, and that 90-100 billion tons of oil equivalent (of which 80% is natural gas) may be potentially recoverable. Two huge oil and gas basins located on the shelves of the Barents and Kara Seas contain numerous oil and gas fields (Figure 44) with potential resources of at least 50-60 billion tons of oil equivalent (Patin 1999). Just two of these fields located in the Kara Sea shelf hold an estimated 5 trillion cubic meters of natural gas, which in 1999 was equivalent to 2.5 times the worldwide gas production (Patin 1999). A gas condensate field located on the Barents Sea shelf is probably the world's largest known offshore gas field, with reserves of about 3 trillion cubic meters of gas and more than 20 million tons of gas condensate (Patin 1999). Another field on the Barents Sea shelf was estimated to hold more than 200 million tons of oil (Patin 1999). Oil and gas developments in the Kara and Barents Seas began in 1992, and large-scale production activities were initiated during 1998-2000 (Patin 1999). Oil and gas production activities are expected to grow in the western Siberian provinces and Kara and Barents Seas in the future, and will likely include the construction of several new pipelines and marine terminals, and subsequent increases in Arctic tanker traffic, for transporting oil and gas to markets around the world (AMAP 2007).

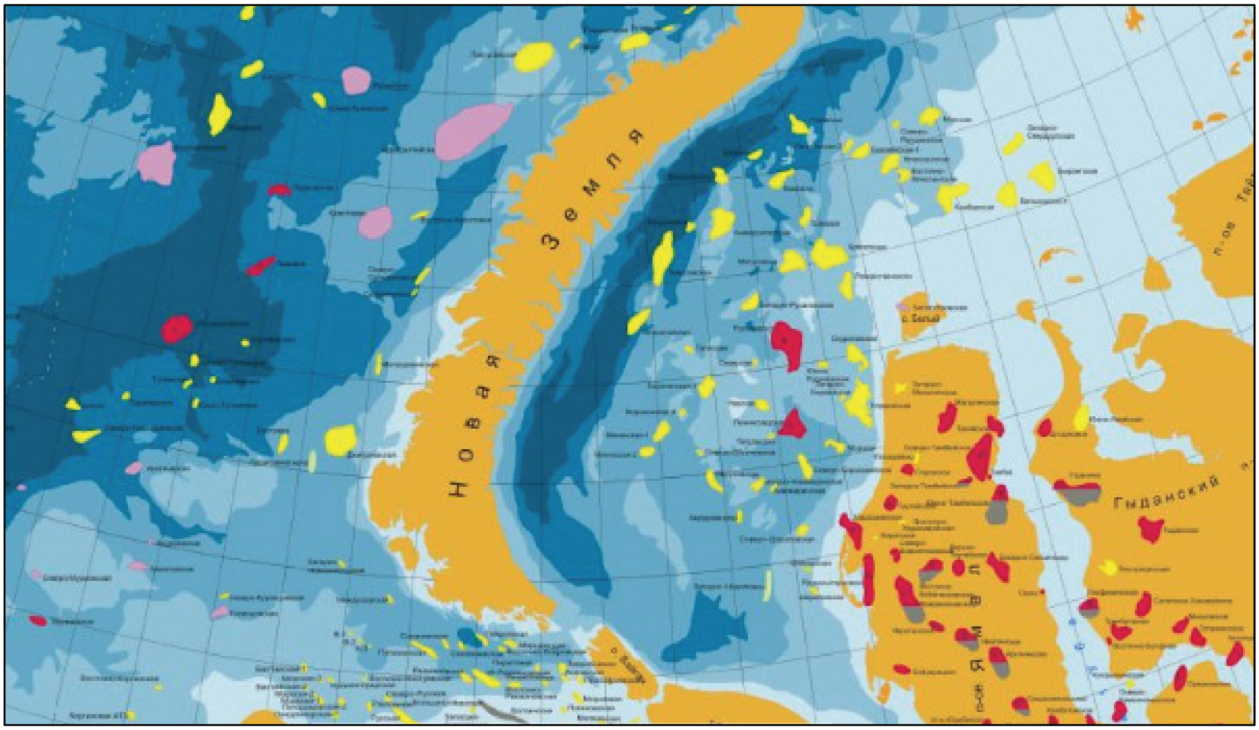


Figure 44. -- Locations of oil (pink) and gas (yellow and red) fields in the Barents and Kara Seas and Yamal region of Russia (Source: BarentsObserver 2008a).

4.2.5.2.5 Potential threats to bearded seals from offshore oil and gas exploration, development, and production

Potentially harmful oil and gas exploration, development, and production activities include, but are not limited to: seismic surveys; exploratory, delineation, and production drilling operations; construction of artificial-islands, causeways, ice roads, shore-based facilities, and pipelines; and vessel and aircraft operations. These activities have the potential to impact bearded seals, primarily through the noise, physical disturbance, and pollution they cause, particularly in the event of a large oil spill or blowout.

4.2.5.2.5.1 Noise and physical disturbance

Noise and physical disturbances associated with oil and gas exploration, drilling, construction, and support activities could potentially interfere with bearded seals' ability to function normally and impact their health. The 'noisiest' and 'busiest' period of offshore oil and gas operations occurs during exploration and site establishment (Richardson et al. 1995). Conversely, production activities are generally quieter and require fewer support operations. To varying degrees, drilling operations produce low-frequency sounds with strong tonal components.

Air and vessel traffic are often needed to support offshore oil and gas exploration and development. Low-flying aircraft could cause ice associated seals that are hauled-out to enter the water, however most of these disturbances will likely be relatively minor, highly variable, and brief in nature. The effects of noise and physical disturbance from ships are discussed in Section 4.2.5.4.1.3.

4.2.5.2.5.1.1 Seismic surveys

Seismic surveys are a particularly intense source of noise, and thus warrant further consideration as a potential threat. Pinnipeds use the acoustic properties of sea water to aid in navigation, social communication, and possibly predator avoidance. There is considerable variability in the vocalizations of seals, and male bearded seals rely on underwater vocalizations to find mates. Phocids have good low-frequency hearing, and so it is expected that they will be more susceptible to masking of biologically significant signals by low frequency sounds, such as those from seismic surveys (Gordon et al. 2003). This masking would be equivalent to a temporary loss of hearing acuity. Brief, small-scale masking episodes might, in themselves, have few long-term consequences for individuals or groups of bearded seals. The consequences might be more serious however, in areas where many acoustic surveys are occurring simultaneously. Underwater audiograms for phocids suggest that they have very low hearing sensitivity below 1 kHz, though they can hear underwater sounds at frequencies up to 60 kHz and make calls between 90 Hz and 16 kHz (Richardson et al. 1995). A more recent review suggests that the auditory bandwidth for pinnipeds in water is 75 Hz to 75 kHz (Southall et al. 2007). While seismic surveys can contain energy up to 1 kHz, most of the emitted energy is less than 200 Hz.

There is no specific evidence that exposure to pulses of airgun sound can cause permanent threshold shifts (PTS) to the hearing of any marine mammal, even with large arrays of airguns. Nevertheless, direct impacts causing injury from seismic surveys would likely occur only if animals entered the zone immediately surrounding the sound source. Southall et al. (2007) proposed that auditory injury would occur to pinnipeds exposed to a single pulse of sound at 218 dB re: 1 micropascal in water and 143 dB re: 20 micropascals in air. Although it is unlikely that airgun operations during most seismic surveys would cause PTS in bearded seals, caution is warranted given the limited knowledge about noise-induced hearing damage in this species.

Reported seal responses to seismic surveys have been variable and often contradictory, although they do suggest that pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays (Brueggeman et al. 1991, Harris et al. 2001, Miller and Davis 2002). Telemetry work by Thompson et al. (1998) indicated that harbor seals and grey seals (*Halichoerus grypus*) exhibit strong avoidance behavior of small seismic airgun arrays, including swimming rapidly away from seismic sources, ceasing feeding activities, and hauling out, possibly to avoid underwater noise. The behavior of most of the seals reportedly returned to normal within 2 hours of the seismic array falling silent. The authors suggested that responses to more powerful commercial arrays might be more dramatic and occur at greater ranges. Based on tagging studies conducted in 2001, Cott et al. (2003) reported that Canadian marine seismic surveys in the Beaufort Sea did not appear to affect the timing or route of the western fall migration of ringed seals, a sympatric ice-associated seal species. A comparison of ringed seal densities in areas of shorefast ice with seismic activity (using explosive charges) vs. undisturbed areas indicated that ringed seals were not appreciably displaced by even intensive seismic activity; however, this analysis was conducted immediately offshore of the Prudhoe Bay oil fields where ringed seals were said to “normally occur at very low densities” over the entire region (Burns and Harbo 1972). Similar studies have not been conducted on bearded seals.

4.2.5.2.5.2 Oil spills

Large oil spills or blowouts are generally considered to be the greatest threat of oil and gas activities in marine environments (AMAP 2007). In contrast to spills on land, large spills at sea are difficult to contain and may spread over hundreds or thousands of kilometers. These threats are magnified by the limited resources for oil spill response in the Arctic (Arctic Council 2009). Current techniques, such as use of dispersants and in-situ burning, may be attempted; however, both techniques have drawbacks that may be made worse in Arctic conditions (AMAP 2007). New techniques, such as the use of ice rather than booms to contain and concentrate oil until it can be recovered by skimmers have shown some promise, but most response techniques require rapid action to be effective, which may not be possible in remote areas without prior staging of equipment and personnel (AMAP 2007). Under the most optimistic scenario, where resources are relatively near a discharge and can mobilize quickly, the extreme conditions in the Arctic will likely reduce – or even negate – the effectiveness of a given response. For example, despite nearby equipment, supplies, and trained personnel, the response to a tanker grounding in Aleutian Islands, Alaska, USA, in December 2004, was significantly compromised by weather conditions that caused a 3 week delay and lead to a substantial amount oil impacting coastal habitats (Nuka Research and Planning Group 2007). A recent analysis of Prince William Sound, Alaska, where there are now advanced spill containment and clean-up capabilities, indicated that a response would not be feasible 38% of the time due to environmental factors (Robertson 2007). Further, the presence of sea ice will delay, limit, or preclude access to areas of contamination. Drifting, broken pack ice was recently identified as the ice type for which there is the greatest need to develop a “credible, effective response” to an oil spill (DF Dickins Associates Ltd. 2004). In ice cover as low as 10%, large-scale recovery systems are inhibited, at 30% containment booms are of little to no use and mechanical recovery of surface oil would be “low” in ice cover above 40% (Minerals Management Service). Clean up efforts themselves are also likely to cause disturbance which, if they occurred during breeding, could interfere with nursing and further impact pup survival (St. Aubin 1988).

Although planning, management, and use of best practices can help reduce risks and impacts the history of oil and gas activities, including recent events, indicates that accidents cannot be eliminated (AMAP 2007). Tanker spills, pipeline leaks, and oil blowouts are likely to occur in the future, even under the most stringent regulatory and safety systems. According to a figure in AMAP’s (2007) report, one oil tanker spill of 35,000 cubic meters or greater is estimated to occur each year, and an oil blowout of 2,000 cubic meters or greater is estimated to occur every 10 years. And according to the MMS (2007a), the probability of one or more large oil spills (≥1,000 barrels) occurring over the production life of a new development in the Chukchi Sea was estimated to be between 35-40%.

Bearded seal behavior will affect their exposure to a released contaminant. Oil tends to concentrate in ice leads and in breathing holes, and will be held closer to the surface against ice edges where seals tend to travel (Engelhardt 1987). Floating sea ice also reduces wave action and surface exchange thus delaying the weathering and dispersion of oil (or other contaminants) and increasing the level and duration of exposure to seals. Low temperatures make oil more viscous and thus increases the hazards associated with fouling of animals. It also reduces evaporation of volatile hydrocarbons, lessening the acute levels of toxins in the air but lengthening the period of exposure (Engelhardt 1987). To date there have been no major oil spills in the Arctic, so real-world data from which to develop a specific response or predict environmental impacts are lacking. Despite this uncertainty, past oil releases, where exposures and effects to phocid seals were documented (Engelhardt 1987, St. Aubin 1990), provide useful scope for the likely physiological and toxicological effects to bearded seals (see Section 4.2.5.1).

Researchers have suggested that ice-associated pups may be particularly vulnerable to fouling because of their dense lanugo coat (Johnson 1983, St. Aubin 1990, Jenssen 1996). Fouled pelage of neonates would have a lower insulative value when hauled out, putting them at greater risk of low-temperature stress (Kooyman et al. 1977, St. Aubin 1990), lower mass at weaning (Davis and Anderson 1976), and lower survival (Harding et al. 2005). Though bearded seal pups exhibit some prenatal molting they are generally not fully molted at birth, and a dry lanugo coat is clearly important for thermoregulation (Davydov and Makarova 1965, Shepeleva 1973, Elsner et al. 1977, Kovacs et al. 1996). Hence, bearded seal pups would be particularly prone to the physical impacts of contacting oil. Energetic costs would be compounded if mothers and pups spend more time in the water by swimming out of the affected area. Adults, juveniles, and weaned young of the year rely on blubber for insulation, so effects on their thermoregulation are expected to be minimal (Jenssen 1996).

Other acute effects of oil exposure, which have been shown to reduce seals' health and possibly survival, include skin irritation, disorientation, lethargy, conjunctivitis, corneal ulcers, and liver legions (Geraci and Smith 1976, St. Aubin 1988). Many of these effects are thought to be largely reversible, but others such as brain lesions and nerve damage may be fatal (Engelhardt 1983, Frost and Lowry 1994, Frost et al. 1994b, Lowry et al. 1994, Spraker et al. 1994, Salazar 2003). Direct ingestion of oil, ingestion of contaminated prey, or inhalation of volatile hydrocarbons transfers toxins to body fluids and tisues causing effects that may lead to death, as suspected in dead grey and harbor seals found with oil in their stomachs (Engelhardt et al. 1977, Engelhardt 1982, St. Aubin 1990, Frost et al. 1994b, Lowry et al. 1994, Spraker et al. 1994, Jenssen 1996). Furthermore, ingestion of hydrocarbons irritates and destroys epithelial cells in the stomach and intestine, affecting motility, digestion, and absorption, which can result in death or reproductive failure (St. Aubin 1990).

Contamination of prey is a particular concern for benthic foragers, such as bearded seals, because of the high potential of sediment toxicity coupled with the propensity of benthic invertebrates (e.g., bivalves) to bioaccumulate oil compounds (Varanasi and Malins 1977, Engelhardt 1987). Spilled oil has caused major disruptions to benthic communities inducing substantial contamination of tissues, failed spawning, significantly lower densities, and transfer of oil through the food web from invertebrates to larger fish (Koyama et al. 2004, Elmgren et al. 1983). Colder regimes may delay recovery of benthic communities for at least 5 years (Elmgren et al. 1983).

Freshly spilled oil contains high levels of toxic aromatic compounds that, if inhaled, could cause serious health effects or death in bearded seals, as occurred with an estimated 300 harbor seals following the *Exxon Valdez* oil spill in Prince William Sound, Alaska (Frost et al. 1994a, Frost et al. 1994b, Lowry et al.

1994, Spraker et al. 1994). Oil that disperses from a spill site may still have high levels of toxic aromatic compounds, depending on the temperature and whether the oil becomes frozen into ice (St. Aubin 1990). Pinnipeds stressed by parasitism or other metabolic disorders may be susceptible to injury or death from even brief exposure to relatively low concentrations of hydrocarbon vapors (St. Aubin 1990). For example, parasitized lungs, relatively common in pinnipeds, can exacerbate the effects of even mild irritation of respiratory tissues (St. Aubin 1990). Toxicity of oil is generally greater in younger animals so exposure to oil contamination during the breeding season would likely cause higher mortality among pups (Jenssen 1996, Jenssen et al. 1996).

4.2.5.2.6 Oil and gas activity threat assessment

Though the probability of an oil spill affecting a significant portion of a bearded seal population is likely low, the potential impacts from such a spill could be significant, particularly if subsequent clean-up efforts were ineffective. Because toxicity varies widely across oil types and with exposure, it is difficult to generalize about the toxicological impacts on bearded seals that come in contact with oil. However, based on the documented exposures of different phocid species to oil, significant effects on health and survival would be expected for any seal that is immersed and (or) coated in oil during the days and weeks following a spill (St. Aubin 1990). The spatial extent, persistence, and proximity of oil to areas with a higher density of bearded seals (e.g., breeding and molting areas) – and the effectiveness of the spill response – are less predictable factors that would greatly modify exposures and thus the biological impacts of a large release of oil into the ocean.

It is important to evaluate the effects of anthropogenic perturbations, such as oil spills, in the context of historical data. Without historical data on distribution and abundance, it is not possible to measure the impacts of an oil spill on bearded seals. Population monitoring studies need to be implemented in areas where significant industrial activities are likely to occur so that it will be possible to compare future impacts with historical patterns and thus determine the magnitude of potential effects (Frost et al. 2004).

In summary, the threats to bearded seals from oil and gas activities are greatest where these activities converge with breeding aggregations or in in migration corridors such as in Bering Strait. In particular, the bearded seals in ice-covered remote regions are most vulnerable to oil and gas activities, primarily due to potential oil spill impacts.

4.2.5.3 Commercial fisheries interactions and bycatch

Commercial fisheries may impact bearded seals through direct interactions (i.e., incidental take or bycatch) and indirectly through competition for prey resources and impacts on size structure, genetics and/or life history of prey populations. Direct interactions between commercial fishing and marine mammals in Alaska federal waters are monitored by shipboard observers (who also monitor the fishery catch). During the 1990s, three commercial fisheries were monitored: the Bering Sea-Aleutian Islands (BSAI) groundfish trawl fishery, longline fisheries and pot fisheries. Observer coverage ranged from 30-74% of tons caught. Incidental mortality of bearded seals was only observed in the BSAI groundfish trawl fishery. There were three mortalities in 1991, four in 1994, one in 1998 and two in 1999 for a mean mortality of 0.6 during this period (Angliss and Lodge 2002). Beginning in 2003 the three fisheries categories were further divided into twelve, reflecting not a change in fishing effort, but an improvement in the information about which components of the fisheries might be responsible for incidental catch of marine mammals (Angliss and Allen 2009). Observer coverage from 2000-2004 ranged from 58.4-64.5%. Incidental mortalities of bearded seals were observed in the BSAI flatfish trawl fishery and the BSAI pollock trawl fishery. There was one mortality in 2000 and one in 2001 for a mean annual mortality rate of 0.68 during this time period (Angliss and Allen 2009). From 2002-2006, observer coverage ranged from 73.0-82.2%. Incidental mortalities of bearded seals were observed in the BSAI pollock trawl fishery: two in 2006 for a mean annual mortality of 1.0 during this period (Allen and Angliss 2010).

For indirect interactions, it is important to note that commercial fisheries target a number of known bearded seal prey species, such as walleye pollock and cod. These fisheries may affect bearded seals indirectly through reductions in prey biomass. The U.S. fisheries in the North Pacific are managed to prevent overfishing of individual stocks. As such, strict limits on catch and bycatch are placed on all groundfish species or species groups. However, even well-managed fisheries will result in reduced levels of biomass relative to theoretical mean unfished levels. The extent that the lower abundance levels of these individual stocks affect the viability of bearded seal populations is unknown. In the U.S. Exclusive Economic Zone (EEZ), overall biomass levels of all groundfish species have remained relatively stable between 15 and 20 million metric tons of biomass after showing substantial increases since the 1970s (Mueter and Megrey 2006). Alaska fisheries targeting groundfish such as pollock and cod can also impact bearded seals through bycatch of their benthic invertebrate prey. Data from Alaska groundfish fisheries observers is used to estimate bycatch of crab, and other “prohibited species” (e.g., halibut, salmon and herring). The bycatch of Bairdi crab was over ten million crab in 1994 but dropped to five million in 1995 and declined steadily to around one million in 2006. In addition to target and prohibited species, non-target species bycatch is also monitored. Non-targets are divided into four categories: 1) forage species, 2) Habitat Areas of Particular Concern (HAPC) (e.g., sponges, anemones, corals), 3) non-specified species (grenadiers, crabs, starfish, jellyfish, benthic invertebrates, shrimp and others), 4) other species (e.g., sculpins, sharks, octopus). In the BSAI non-specified species comprised the majority of non-target catch from 1997-2007 (Gaichas and Boldt 2010). However, jellyfish, grenadiers and sea stars comprised the majority of the non-specified catch so bycatch of non-targets is not relevant to concerns about impacts of bycatch on bearded seal prey, at least in the Bering Sea.

Commercial fishing can also have indirect effects on marine mammals through changes in genetics, reproductive capacity, and life history characteristics of their prey. Fisheries generally select particular individuals (usually larger and older fish) and focus on particular locations (such as spawning or feeding grounds) such that fishing is non-random with respect to fish characteristics (or phenotypes). If there is a genetic component to differences in phenotypes between fish, then fishing will cause evolutionary change. The argument that fishing could cause phenotypic evolution is widely known in general terms. There are numerous examples of changes in life history characteristics of commercially exploited stocks over time, such as weight-at-age, length-at-age, length-at-maturation and age-at-maturation (reviewed in Law 2000). Fisheries can generate selection on life history traits by catching more fish of some ages or sizes than others. In many cases, fisheries remove larger and older fish which means that early-maturing and smaller fish leave more offspring than late-maturing ones and are selected for. This has consequences for yield. For example, the current patterns of fishing are selecting a life history in Northeast Arctic cod in which fish allocate resources to reproduction rather than growth. The sustainable yield associated with this life history could be less than half the yield potentially available (Law and Grey 1989). It is important to note that although changes in life history characteristics of fished populations have been observed, there is uncertainty about what causes these changes. This is due in part to the fact that potential fishery effects on life history characteristics are superimposed on a backdrop of environmental change that can affect the same characteristics (such as the effect of temperature on growth). It is also unclear how fast fishery-induced evolution occurs. It is uncertain whether evolution contributes to the phenotypic changes observed in many fish stocks, or whether it is operating at a much longer time scale (Law 2000).

Fishing can impact reproductive capacity through changes in fish size. Reductions in fish size can result from long-term size-selective fishing (e.g., Zwanenburg 2000). The decrease in the proportion of large fish might have negative impacts on reproductive capacity of the population if smaller, first-time spawners are less successful in producing viable eggs than are larger, more experienced spawners (Trippel et al. 1997). In addition, some temperate demersal fishes, such as cod and other gadids, are thought to rely on the longevity and size of mature individuals to bridge the gaps between years of strong recruitment (Longhurst 1999). A reduction in the average size of prey species also could reduce the per capita energy content and may increase the foraging effort exerted by bearded seals. Conversely, older fish may be more cryptic, harder to catch, and less numerous. Groundfish stocks are known to have a high degree of interannual variability in recruitment and it is likely that such fluctuations occurred prior to fishing. As such, bearded seals dependence on different size composition for groundfish species would seem to be fairly adaptable.

Bottom trawl fisheries also have the potential to indirectly affect bearded seals through destruction or modification of benthic prey and/or their habitat. The predominant direct effects of bottom trawls include “smoothing of sediments, moving and turning of rocks and boulders, resuspension and mixing of sediments, removal of sea grasses, damage to corals, and damage or removal of epibenthic organisms” (National Marine Fisheries Service 2009a). McConnaughey et al. (2000) compared a previously unfished area in the eastern Bering Sea (the Crab and Halibut Protection Zone) to surrounding heavily fished areas and found that in general macrofauna biomass was higher in the fished area. However, 27 of the 42 taxa sampled were more abundant in the unfished area. In addition, structural complexity and diversity were higher in the unfished area. Crustaceans such as crangon shrimp and scavengers such as Hyas crabs were more abundant in the unfished area, whereas infaunal bivalves were more abundant in the heavily fished area. Greig (2010) developed an index of habitat disturbance by trawl gear from observer trawl data collected in the Eastern Bering Sea from 1990-2008. The maximum total area of seafloor potentially disturbed by trawls varied around 120,000 km^2 (10% to 15% of total area) in the 1990s and decreased to approximately 90,000 km^2 in the late 1990s. The area disturbed remained relatively stable in the 2000s (9% to 11% of total area) with a slight increase in 2007-2008. In appendix B of the Final Environmental Impact Statement for Essential Fish Habitat 99 Identification and

Conservation in Alaska, conducted by the NMFS, Alaska Regional Office, results of various bottom trawl studies were analyzed in the context of effects on fish habitat in the Bering Sea (National Marine Fisheries Service 2005). This analysis concluded that bottom trawling has long-term effects on benthic habitat features, but these effects have little impact on fish stock productivity. The analysis also concludes that the reduction of infaunal and epifaunal prey for managed fish species would be 0-3% (National Marine Fisheries Service 2009a). In October, 2009 the North Pacific Fishery Management Council recommended Amendment 94 to the fishery management plan (FMP) for Groundfish of the Bering Sea and Aleutian Islands Management Area. Implementation is scheduled after January 1, 2011. Among other changes to the FMP, this amendment would require the use of modified bottom trawl gear in the Bering Sea subarea for the flatfish fishery and for bottom trawl gear fishing in the Modified Trawl Gear Zone, located in the northern Bering Sea subarea (M. Brown, NMFS Alaska Regional Office, Sustainable Fisheries, April 4, 2010, pers. comm.). The gear will be required to be modified in such a way as to install bobbins, elevating devices on the trawl sweeps to raise most of the gear off of the bottom. It has been shown that these modified sweeps reduce damage and mortality of sessile seafloor animals (e.g., crabs, basket stars and sea whips) on unconsolidated (sand and mud) substrates (National Marine Fisheries Service 2009a). Since the sweeps are elevated off the sea floor, this reduces the amount of gear contact by 90% (National Marine Fisheries Service 2009a, p. 59), and therefore should reduce effects on infauna.

A review of the impacts of bottom trawling on the eastern Canadian continental shelf seabed showed that groundfish trawling occurs over much of the shelf. Since 1985 trawls have covered about 4.3 million km or 785,510 ha (Messieh et al. 1991). Scallop dredging has also been conducted on the shelf since as early as the mid-19th century. Potential impacts of trawls and dredges are: incidental mortality or damage to target and non-target organisms; increased predation resulting from exposure of infaunal organisms; alteration of sediments that may render the seabed less suitable for adult or larval stages of fish; sediment resuspension that reduces the quality of food for filter-feeders; resuspension of toxic material; and increased nutrient flux that stimulates primary production. Most of the studies reviewed by Messieh et al. (1991) indicate that trawling and dredging do have numerous short-term effects. However, there is a lack of historical data from this region to evaluate long-term changes in sediment characteristics and benthic community structure. During an experimental study of the effects of bottom trawling on the Grand Banks of Newfoundland Prena et al. (1999) sampled fished and unfished corridors with an epibenthic sled several hours after trawling. Benthic biomass in the trawled corridors was lower than in the untrawled, by 24%. Species with reduced biomass were relatively large epibenthic forms such as sand dollars, brittle stars, sea urchins and snow crab. The biomass of infaunal molluscs showed no clear evidence of trawling impacts, although there was a general trend of increased damage to mollusc shells in trawled corridors. The results of this experiment were consistent with others (reviewed in Prena et al. 1999) that showed that the organisms most affected by trawling include epibenthic forms of several taxa but that infaunal species are less impacted.

A review of anthropogenic impacts on the Barents Sea (Klungsøyr et al. 1995) showed that the area exploited by bottom trawling for fish, shellfish and shrimps may be quite large. The main effects of trawling are resuspension of sediments and animals in the upper sediment layers, followed by colonization of disturbed areas by opportunistic species which reduce the diversity of benthic species. The authors also found that re-establishment of the original benthic community can take several years (Klungsøyr et al. 1995). An acoustic survey of the impacts of otter trawling on the physical characteristics of the seabed in the Barents Sea showed that trawling resulted in an increase in surface relief or roughness and a decrease in sediment hardness (indicating that sediments were resuspended) (Humborstad et al. 2004). The tracks of trawls were visible as u-shaped depressions about 10 cm deep. The tracks disappeared after 5 months, likely due to shallow water depth and weather- and current-induced sediment transport. Similarly, a video survey of the seabed of the southern Barents Sea showed trawling disturbance (tracks) at up to 90% of the recorded video-lines (Jensen et al. 2009). A study of the immediate effects of experimental bottom trawling on the benthic community of the Barents Sea showed that the most pronounced effect was the increase in dominant infaunal bivalves, due to displacement of animals towards the seabed surface (Kutti et al. 2005). Although retrospective power analysis indicated that the number of post-trawling samples was insufficient to detect many changes. Immigration of scavenging individuals was not observed, perhaps because the benthos was sampled within a few hours of experimental trawling, too soon to detect an increase in slow-moving benthic organisms.

The direct impacts of bottom trawling on the benthic community of the North Sea have been well documented (review in Kaiser and de Groot 2000). It has been estimated that in heavily fished areas, every square meter of seabed is trawled on average seven times a year (Goñi 1998). Direct mortality of various adult macrobenthic species from a single trawl ranged from 5-40%. In addition, potentially substantial amounts of damaged and/or discarded individuals become available to scavengers. Long-term studies show a decrease in the biomass of epifauna and infauna with increased fishing intensity (Jennings et al. 2001). In addition to these direct effects, increased turbidity and altered sediment characteristics caused by trawling and dredging may affect benthic communities (Goñi 1998). Hiddink et al. (2006) developed indicators of the ecological impacts of bottom-trawl disturbance in the North Sea and used a size-based model to predict the recovery time to 90% of pristine benthic biomass or production. Using modeled recovery times and 2003 trawling intensity data, Hiddink et al. (2006) found that 53.3% of the southern North Sea had a trawling intensity that was too high for biomass to reach 90% of pristine. 27.1% had a trawling intensity too high for production to reach 90% of pristine.

Some fisheries may be expected to expand or shift northward in response to an increased length of the ice-free, open-water season in the future. The North Pacific Fishery Management Council has established an Arctic Fisheries Management Plan that would place a moratorium on development of fisheries in federally managed waters in the U.S. EEZ north of Bering Strait (North Pacific Fishery Management Council 2009). Several Russian companies recently sent longline vessels to explore fishing prospects in the Chukchi Sea, with unknown results, and the fishing season in the western Bering Sea has reportedly been increasing due to reduced sea-ice conditions (V. Burkanov, Kamchatka Branch of the Pacific Institute of Geography, September 19, 2008, pers. comm.).

4.2.5.4 Shipping and transportation

4.2.5.4.1 Erignathus barbatus barbatus and Beringia DPS

The extraordinary reduction in Arctic sea ice that has occurred in recent years has renewed interest in broadening the use of the Arctic Ocean as a waterway for coastal, regional, and trans-Arctic marine operations (Brigham and Ellis 2004). Declines in sea-ice extent and thickness have provided greater access to marine navigation routes, especially along the margins of the Arctic Basin, which historically have been ice-covered for most or all of the year (ACIA 2004). Climate models predict that the warming trend in the Arctic will accelerate, causing the sea ice to begin melting earlier in the spring, retreat farther away from most Arctic landmasses and get thinner during the summer, and resume freezing later in the fall, resulting in an expansion of potential shipping routes and lengthening the potential navigation season, on an increasingly frequent basis (ACIA 2004, Howell and Yackel 2004, Howell et al. 2009, Khon et al. 2010). This reduction in sea ice "is very likely to increase marine transport and access to resources" in the Arctic during this century (ACIA 2004). A comprehensive review and analysis of current (2004) and future (2020) marine shipping activities in the Arctic was presented in the *Arctic Marine Shipping Assessment* (AMSA) *2009 Report* (Arctic Council 2009). Much of the following information was incorporated from this report.

According to the AMSA report (Arctic Council 2009), the term "shipping" refers to the various uses of all types of ships (except naval vessels), including tankers, bulk carriers, offshore supply vessels, passenger ships, tug-barge combinations, fishing vessels, ferries, research vessels, and icebreakers. These ships may travel to or from destinations within the Arctic (destinational shipping) or may use the Arctic Ocean as a marine link between the Atlantic and Pacific Oceans (trans-Arctic shipping). At present, the two main navigation routes crossing the Arctic are the Northwest Passage (NWP) and Northern Sea Route (NSR). A proposed new route termed the Central Arctic Ocean Route (CAOR), which would cross a significant portion of the Arctic Basin, could be navigable at least intermittently and be economically feasible by mid-century (Holland et al. 2006, Ellis 2008). Compared to the NSR, the CAOR would reduce the distance between Russian ports by 10-15%.

The NSR, which is actually the central portion of a longer trans-Arctic route called the Northeast Passage, traverses the Russian Arctic along the northern coast of Eurasia from the Barents Sea in the west to the Bering Sea in the east (Figure 45). For ships travelling between northern Europe and Far East Asia or Alaska, the NSR represents a savings of 35-60% in distance when compared to the normal shipping routes through the Suez or Panama Canals (Arctic Council 2009). This shallow, seasonally ice-covered route has been maintained year-round in its western portion by Russian icebreakers since 1979 and has been open to international marine traffic since 1991 (ACIA 2004).

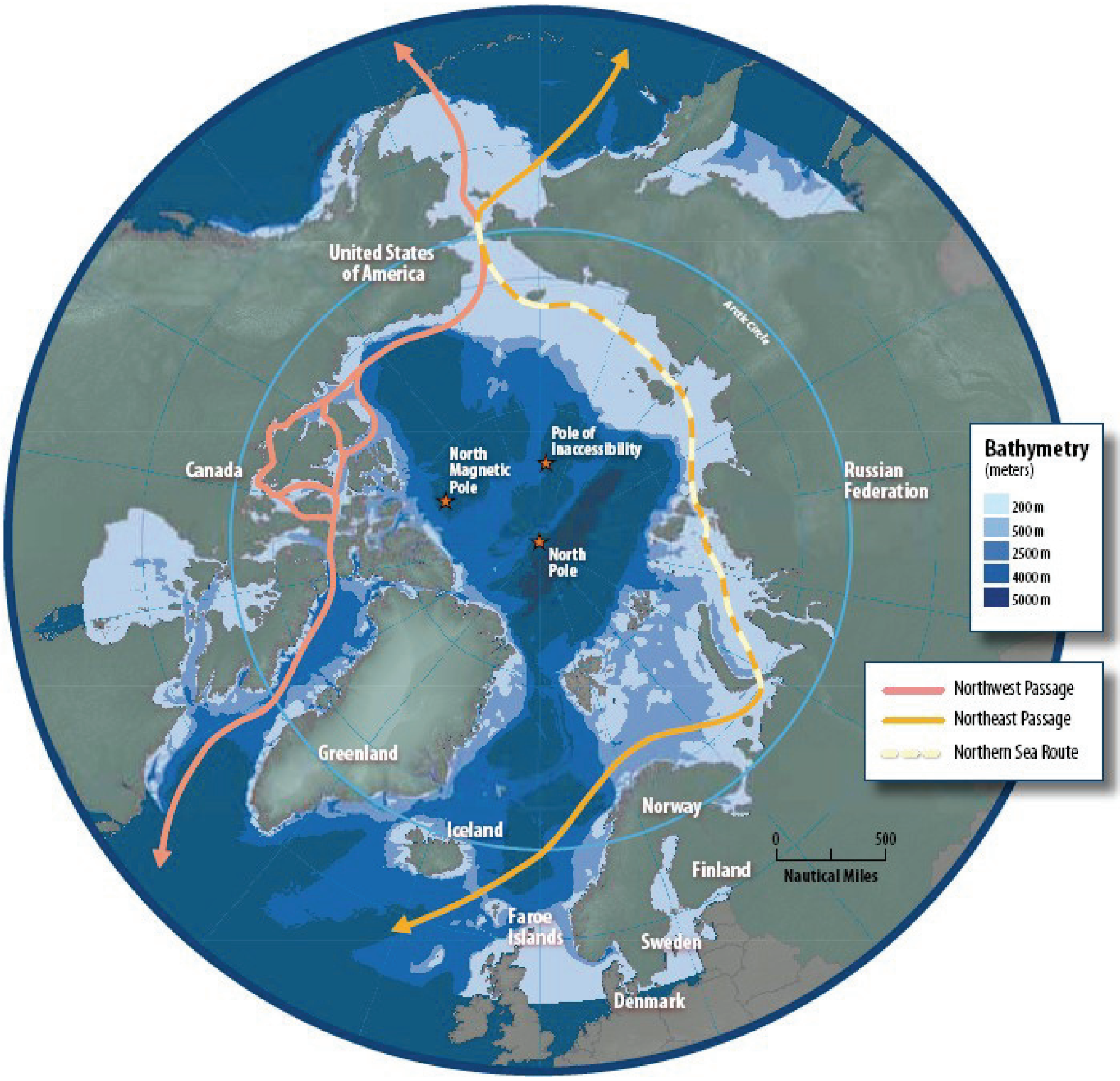


Figure 45. -- Major shipping routes and bathymetry of the Arctic Ocean (Source: Arctic Council 2009; Map 2.1).

The NWP traverses the Arctic along the northern coast of North America from the Labrador Sea in the east, through the Canadian Arctic Archipelago, to the Bering Sea in the west (Figure 45). The current operating season along the NWP is short – generally from late July to mid-October – and depends on the ice conditions in any given year (Arctic Council 2009). This perennially ice-choked passage was ice-free for the first time in recorded history during the summer of 2007 (National Snow and Ice Data Center 2007). Studies by the Canadian Ice Service indicated that sea-ice conditions in this region during the past three decades have been characterized by high interannual variability, making prospects for regular marine transportation less predictable (ACIA 2004, Howell and Yackel 2004). Additional studies by Canada's Institute of Ocean Sciences suggested that increasing amounts of multi-year sea-ice and glacial icebergs could be flushed through the channels and straits of the NWP more frequently as continued melting weakens the perennial blockages or "ice bridges" that have controlled ice movements in the past (ACIA 2004, Howell and Yackel 2004, Howell et al. 2009). These larger, denser ice features could present serious navigational hazards along this route.

4.2.5.4.1.1 Current shipping activity in the Arctic

A comprehensive survey of all shipping activity in the Arctic was conducted as part of the AMSA study, using 2004 as the baseline year (Arctic Council 2009). Responses to the survey varied greatly between Arctic states, with several states unable to provide complete data for 2004; therefore, the AMSA survey likely underestimated the levels of shipping activity during the reporting year. Survey results indicated that approximately 6,000 individual vessels operated in the Arctic during 2004, of which about half were vessels travelling along the Great Circle Route through the Aleutian Islands in the North Pacific Ocean/southern Bering Sea, which the United States defines as being within the Arctic. Excluding vessels using the Great Circle Route, the most vessels by category were fishing vessels at about 1,600 or slightly less than 50% of the remaining total, followed by bulk carriers at about 20%. Shipping activity took place throughout the Arctic in 2004, including eight icebreaker expeditions to the North Pole during the summer; however, most operations occurred along the periphery of the Arctic Ocean in coastal waters that were either ice-free year-round or ice-covered only seasonally (Figure 46). In the seasonally ice-covered areas, nearly all of the vessel activity in 2004 occurred during or after the ice melt, when icebreakers were not required for access (Arctic Council 2009).

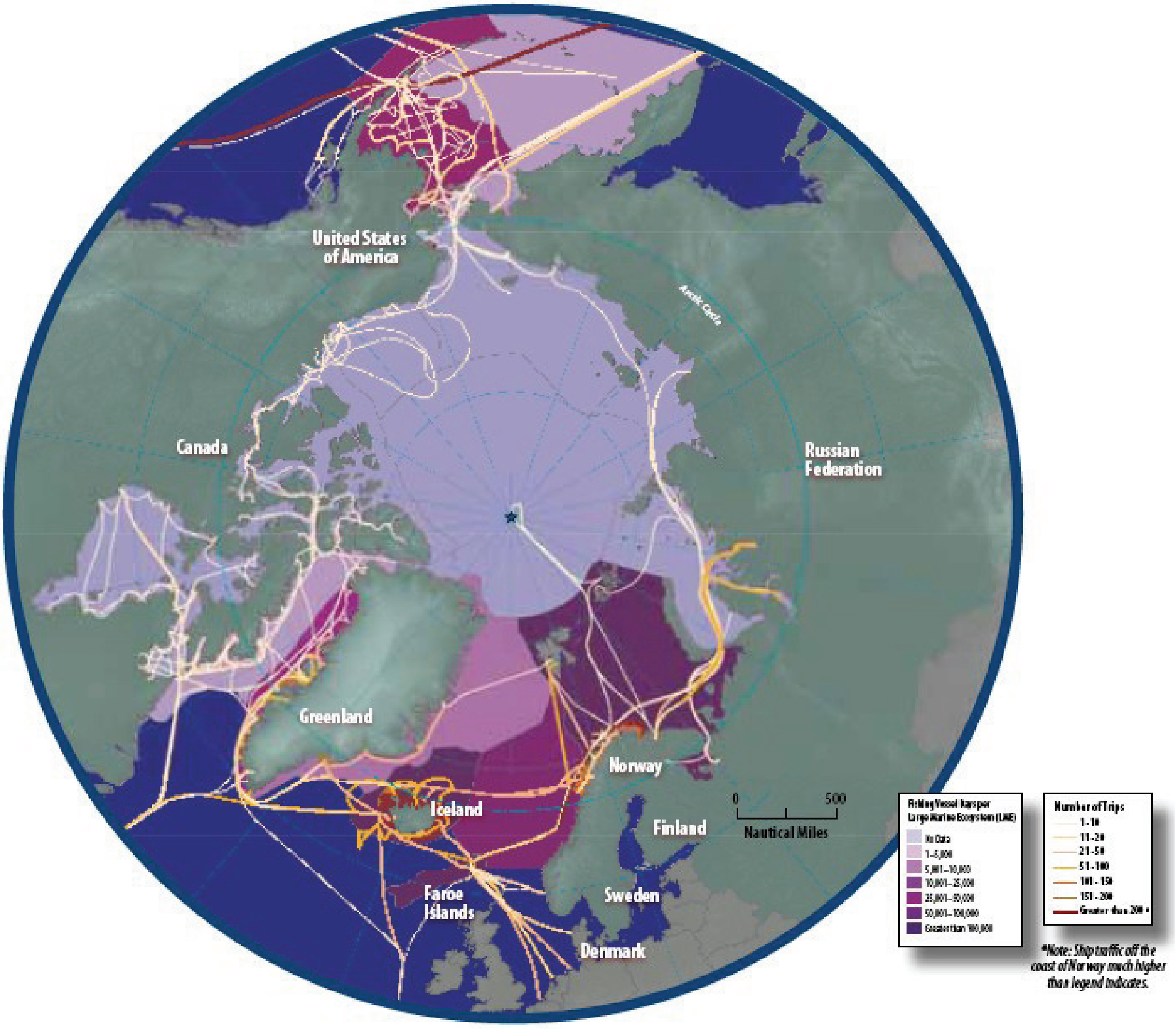


Figure 46. -- Overview of all reported shipping activity in the Arctic in 2004. Purple shading indicates the number of vessel days for fishing activity in different large marine ecosystems, and colored lines indicate the routes and number of trips for all other types of shipping activity. Darker colors indicate increasing levels of activity (Source: Arctic Council 2009; Map 5.1).

Currently, most shipping in the Arctic is destinational (e.g., moving goods into the Arctic for community resupply, transporting natural resources out of the Arctic to world markets, and fishing operations or tourism cruises within Arctic waters). No commercial vessels conducted trans-Arctic voyages on the NSR, NWP, or across the central Arctic in 2004 (Arctic Council 2009). Regions of high concentration of Arctic shipping occurred along the coasts of northwest Russia, where intensive natural resource development drives year-round operations, and in ice-free waters offshore Norway, Greenland, Iceland, and in the Bering Sea. Though shipping in the Canadian Arctic is critical for resupplying remote communities, the level of shipping is relatively low – which is due in large part to the short shipping season. Most Arctic fishing takes place in the Bering and Barents Seas, along the west coast of Greenland, and around Iceland and the Faroe Islands. A summary of shipping incidents and accidents that occurred in the Arctic during 1995-2004 was developed as part of the AMSA survey, and not surprisingly, the areas showing the highest concentrations of incidents and accidents were also the areas with the largest volumes of shipping activity. In the few years since the AMSA survey, shipping activity in the Arctic has increased significantly. For example, cruise ship traffic around Greenland has increased exponentially in recent years, and several new icebreaking tankers are being used to provide a continuous supply of oil and gas for export out of northwest Russia and northern Norway. At the current rate of increase, it will not take long to double or triple the 2004 shipping activity levels in the Arctic (Arctic Council 2009).

4.2.5.4.1.2 Future shipping activity in the Arctic

A set of plausible and diverse future scenarios were developed as part of the AMSA study to identify the major sources of uncertainty that would likely shape the future of Arctic shipping activities to the years 2020 and 2050 (Arctic Council 2009). Table 5 describes the four future scenarios that were chosen as being the most plausible and the most relevant to the Arctic and maritime affairs, while also including an appropriate level of external factors. The uncertainties that were identified as being among the most important included: laws and governance of marine use of the Arctic Ocean, changes in global commodity prices and trade dynamics, degree of Arctic state cooperation, multiple-use conflicts, climate change severity and variability, role of the marine insurance industry, an Arctic maritime disaster, new resource discoveries, and advances in marine technologies. Although climate change and reductions in sea ice were believed to be important in providing improved marine access and potentially longer navigation seasons, economic factors such as natural resource development and regional trade were viewed as being the primary drivers of increased Arctic shipping activity in the future.

In their summary of findings, the AMSA authors noted that the future of Arctic shipping remains largely uncertain and quantitative predictions of future shipping activity are unavailable. Still, their findings indicated that increases in nearly all types of Arctic shipping – including fishing operations, transport of goods into and resources out of the Arctic, commercial icebreaking, scientific explorations, and marine tourism – were either “plausible” or “anticipated” in the future (Arctic Council 2009). Arctic shipping was expected to remain overwhelmingly destinational (for regional trade) through 2020, with trans-Arctic voyages only being plausible on an experimental basis during some summers. The report stated that recent offshore leases in the Beaufort and Chukchi Seas may lead to increased marine traffic in the Bering Strait region, which may require formally established vessel routing measures. The NWP is not expected to become a viable trans-Arctic route through 2020, but destinational shipping is anticipated to increase in the Canadian Arctic during this time. The annual navigation season for light ice-class ships was projected to increase from 2 to 4 months for the NWP and from 3 to 6 months for the NSR by 2100 (Khon et al. 2010). Compared to transit through the Suez Canal, use of the NSR was projected to result in economic savings of 15% per year in shipping costs by the end of the century (Khon et al. 2010). Large investments in resource development and transport made in the Barents Sea may stimulate decadal increases in shipping along the western portion of the NSR. A lack of major ports and other maritime infrastructure were seen as being significant limiting factors to future Arctic marine operations. Finally, it was believed that future socio-economic responses to climate change (e.g., mandatory emission controls) would very likely impact all elements of future Arctic shipping activity (Arctic Council 2009).

Table 5. -- Descriptions of four plausible future Arctic shipping scenarios (Source: Arctic Council 2009; Table 6.2).

	Arctic Race	**Polar Lows**	**Polar Preserve**	**Arctic Saga**
Framing Uncertainties	• More Demand for Resources and Trade • Less Stable Governance	• Less Demand for Resources and Trade • Less Stable Governance	• Less Demand for Resources and Trade • More Stable Governance	• More Demand for Resources and Trade • More Stable Governance
High Concept	• High demand and unstable governance set the stage for an economic rush for Arctic wealth and resources. • This is a world in which many international players anxiously move to outwit competitors and secure tomorrow's resources today. Intense interest in Arctic natural resources.	• Low demand and unstable governance bring a murky and under-developed future for the Arctic. • This is a world in which domestic disturbances divert attention from global issues, and simmering frictions cause prolonged divisiveness. Global financial tensions are prevalent.	• Low demand and stable governance slow Arctic development while introducing an extensive eco-preserve with stringent "no-shipping zones." • This is a world where concern about the environment, coupled with geopolitical and economic interests elsewhere, drives a movement toward a systematic preservation of the Arctic Ocean.	• High demand and stable governance lead to a healthy rate of development that includes concern for the preservation of Arctic ecosystems and cultures. • This is a world largely driven by business pragmatism that balances global collaboration and compromise with successful development of the resources of the Arctic.
Primary Drivers of Change	• Global competition among many nations for future rights to resources intensified by rise of Asia; new oil & gas discoveries • Acute demand for water worldwide; continuing Middle East tensions • Climate warms faster than models predicted; tourism expands	• Global economic downturn and increasing national protectionism • Increased domestic troubles worldwide, including regional outbreaks of new-generation Avian flu • Recession of Arctic ice slower than models projected	• Arctic oil and gas reserves disappointing • Alternative energy emerges as viable source for global growth • Public concern about climate change and conservation, especially impacts to the Arctic	• Expanded global economic prosperity • Systematic development of oil, gas and hard mineral resources • Shared economic and political interests of Arctic states • Climate warms as expected
Implications for Arctic Marine Navigation	• Much activity dominated by destinational traffic supporting resource development • Unilateral governance regimes lead to inconsistent infrastructure with incompatible standards • Seasonal trans-Arctic passage possible, but not economical	• Minimal Arctic marine traffic, consisting of government resupply and research, with periodic disruptions • Market for ice-class ships cools, reducing R&D and shipbuilding • Low attention to regulations, with unenforced and mismatched standards, and no new infrastructure	• Harmonized rules for Arctic ship design and mariner training • Seasonal trans-Arctic shipping possible but proves prohibitively expensive due to environmental restrictions, frequent patrols and aggressive enforcement • Growth of Arctic marine tourism allowed through limited number of "use permits"	• Wide range and variety of marine activity • Navigational infrastructure and aids expanded, making marine transport safer and more efficient • Comprehensive international Arctic ship rules • New technologies make seasonal trans-Arctic shipping a possibility

4.2.5.4.1.3 Shipping threat assessment

Threats to bearded seals stemming from current levels of, and projected increases in, vessel traffic will ultimately hinge on the spatial and temporal overlap of ships, their impacts, and seals. Only icebreakers and certain polar-class vessels are able to transit the typical pack-ice habitat of bearded seals. Currently, through the use of icebreakers on the NSR, only shipping lanes in the Barents and Kara Seas are kept open through pack ice at a time when seals are hauling out in peak numbers to whelp and molt (O'Rourke 2010). In the Canadian Arctic, segments of the NWP are currently used opportunistically as ice conditions permit thus confining most traffic to the late summer when seals are thought to have completed molting and may be largely aquatic. Tourism, in part to view wildlife, is also a specific concern as it occurs disproportionately in areas favored by bearded seals during late whelping and molting. The number of tour ships operating in Greenland has quadrupled to more than 100 between 2004 and 2006 (Brigham 2007) but very little has been reported on the coincidence of cruise ship and bearded seal distributions in this area.

4.2.5.4.1.3.1 Spatial and temporal overlap

At present, and likely for the last 3-4 decades, the highest potential in the Arctic for both spatial and temporal overlap between vessel traffic and bearded seal habitat is in the southern Barents Sea, Pechora Sea, Kara Straits and the southern Kara Sea (Brigham and Ellis 2004). The potential for impacts is likely to increase significantly due to a new “ice-resistant” terminal (22 km offshore in the Pechora Sea) that is expected to increase year-round oil shipments more than ten-fold (ECON 2007, Hurst 2008). Resource production and accessibility will certainly vary over time but their overall positive trends are likely to result in greater spatial and temporal overlap of ships and bearded seals in the Arctic. Of particular concern is where changing conditions result in “choke points”, where the projected increases in vessel traffic are focused spatially and temporally at sensitive places and times for bearded seals.

With diminishing ice cover allowing for longer navigation seasons and increased vessel trips, choke points will magnify shipping threats where they coincide with bearded seals. Although bearded seals usually occur in low densities, reducing overall threats to whole populations, they are roughly aggregated during breeding and molting in areas with ice favorable for hauling out. Recent research suggests that bearded seals may exhibit fidelity to distinct areas and habitats during the breeding season (Van Parijs and Clark 2006). Where choke points concentrate vessel traffic inside these areas threats to bearded seals will be greater, but the number of vessels, their proximity, and overall impact to seals will probably differ across spatial and temporal scales

The Bering Strait area is where routes associated with the NWP and NSR converge in an area used by bearded seals in the early spring for whelping, nursing, and mating (from April to May) and in the late spring for molting and migrating (from May to June). At this choke point there is currently close spatial overlap between ships and seals, but less so temporally. However, this may change as diminishing ice in the spring transforms existing and potential shipping corridors, especially trans-Arctic routes (NWP, NSR, and CAOR), making those less prone to sporadic blockages during seals’ whelping and nursing period. There are presently coastal segments of the NWP and NSR that are preferred pack-ice habitat for molting bearded seals. With increased access to these routes, vessels will occur in closer proximity to bearded seal habitat. If a central Arctic route becomes feasible, there would likely be increasing overlap between ships and seals in the northern Barents Sea, including around the Svalbard Archipelago, but less so in deeper waters. Spatio-temporal overlap may occur in ice-covered waters if icebreakers traverse locations, particularly polynas, where bearded seals are known to aggregate. Four areas of concern are: 1) the southern Barents Sea, including shipping lanes in the White Sea and the Pechora Sea; 2) the western to central Kara Sea; 3) the eastern Canadian Arctic, particularly Baffin Bay, Lancaster Sound, and Hudson Strait and Bay; and 4) the Bering Strait, where all trans-Arctic traffic must funnel and stands to increase dramatically as routes become more navigable under a declining ice regime.

4.2.5.4.1.3.2 Oil Spills

The most significant threat posed by shipping activities to bearded seals in the Arctic is the accidental or illegal discharge of oil or other toxic substances carried by ships. The probability of an oil spill will increase as more vessels and greater volumes of oil are transported as cargo and fuel (Nuka Research and Planning Group 2007). This threat is magnified by the lack of accident response resources in the Arctic, the lack of effective techniques for containing or cleaning up spilled oil under ice or in broken ice, and the challenges of conducting a rapid, effective spill response in a region where weather is often severe, daylight may be limited, and accidents may happen in very remote locations (AMAP 2007). Primary impacts include immediate and long-term effects on individual bearded seals, populations, food webs and habitats. Refer to Section 4.2.5.2.5.2 for a review of this topic.

4.2.5.4.1.3.3 Discharges at sea

The regular discharge of oily sludge, garbage, and other debris also pose risks to bearded seals since these types of pollution are more common and widespread than accidents and can have similar acute and chronic impacts on individuals, populations, and their habitats (Arctic Council 2009). Permissible concentrations of discharges, such as that for solid waste, sewage and oily bilge water, are regulated by MARPOL (International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978). However, a recent study of vessels in the Norwegian and Barents Seas – which has some of the highest vessel traffic in the Arctic – revealed that under established discharge limits (≤15 ppm of oil) the allowable amount released from bilges and tank washings would amount to 2 tons annually, or only about 0.015% of the oily sludge that these ships actually generate in a year (13,000 tons). Any sludge above this small fraction is required to be disposed of in port, requiring facilities that are not available in large stretches of the Arctic (Arctic Council 2009). Of major concern, is that significant and repeated discharges of oil and other contaminants over time can pollute critical ocean systems. Bearded seals may be negatively impacted by this chronic exposure to both high concentrations of toxins that are biomagnified up the food chain and sub-lethal levels of contaminants available in the environment. Once introduced, oil and oily sludge (and associated toxins), are extremely difficult to clean up (Arctic Council 2009).

4.2.5.4.1.3.4 Noise

Increases in international shipping are producing ever-greater levels of underwater noise capable of long-range transmission (Southall 2005, Götz et al. 2009). All vessels produce sound during operation, which when propagated at certain frequencies and intensities can alter the normal behavior of marine mammals, mask their underwater communications and other uses of sound, cause them to avoid noisy areas, and in extreme cases (e.g., high-powered sonar) damage their auditory systems and cause death (Marine Mammal Commission 2007, Arctic Council 2009, Götz et al. 2009). All ice-breeding pinniped species are known to produce underwater vocalizations (reviewed by Richardson et al. 1995, Van Opzeeland et al. 2008). Male bearded seals rely on underwater vocalizations to find mates. As background noise increases, underwater sounds are increasingly masked and uni-directional, deteriorate faster, and are detectable only at shorter ranges. Effects of vessel noise on bearded seal vocalizations have not been studied, though the frequency range of the predominant "trill" and "moan" calls (130-10590 Hz and 130-1280 Hz, respectively) that are broadcast during the mating season, partially overlap the range (20-300 Hz) over which ship noise dominates ambient noise in the oceans (Urick 1983, Cleator et al. 1989, Ross 1993, Risch et al. 2007, Tyack 2009). Vocalizations of the sympatric harp seal were shown to be completely masked by stationary ship noise at a distance of 2 km (Terhune et al. 1979), a finding supported by communication-range models in this species showing call masking and an order of magnitude loss of range in noisy environments (Rossong and Terhune 2009).

Studies show that animals adapt acoustic signals to compensate for environmental modifications to sound (Wilczynski and Ryan 1999). Indeed, background noise has been suggested to account for geographical differences in the range and quality of bearded seal calls (Rogers 2003, Risch et al. 2007). However, compensating for sound degradation – such as by delaying calling, shifting frequencies, moving to a quieter area, or calling louder, longer, and more frequently – incurs a cost (Tyack 2009). The cost of these adaptations, or that of missing signals, is inherently difficult to study in free-ranging seals and to date has not been measured in any phocid seal. Because bearded seals broadcast over distances of at least 30-45 km (Cleator et al. 1989), perhaps over 100s of kilometers (Stirling et al. 1983, Rossong and Terhune 2009), their calls are increasingly susceptible to background interference. Though in some areas male bearded seals may "practice" calling throughout the year, the period of peak vocalization is during the breeding season(April to mid-June) (S. Van Parijs, NMFS Northeast Fisheries Science Center, Protected Species Division, September 1, 2010, pers. comm.) The extent to which vessel traffic is localized near areas where bearded seals are mating, and the acoustic characteristics of the area, will determine the level that communication is disrupted. If vessels largely avoid areas of pack ice, where communication and ultimately mating occurs, or transit these areas outside the breeding season, effects are not expected to be as significant. Ice-breaking vessels have a greater likelihood of disrupting bearded seal communication and thus mating because they produce louder (174-200 dB), higher frequency (> 5000 Hz), and more variable sounds (Arctic Council 2009).

Some masking of bearded seal communication by noise pollution probably already occurs in areas where shipping corridors are nearer to their breeding habitat. Cruise ships could be a more regular source of noise pollution to a variety of species including the bearded seal because they often seek out wildlife habitat for passengers (Arctic Council 2009). Though little research has focused on the effects of anthropogenic noise on Arctic phocid seals, and even less on bearded seals (Southall et al. 2007), current disruption to communication via vessel noise is probably infrequent. As vessels increasingly penetrate the pack-ice environment and bearded seal breeding habitat however, the potential for communication masking and avoidance of noise will increase.

4.2.5.4.1.3.5 Physical Disturbance

The mere presence and movements of ships in the vicinity of seals can also cause disturbance to their normal behaviors (Jansen et al. 2010), and could potentially cause bearded seals to abandon their preferred breeding habitats in areas with high traffic (Smiley and Milne 1979, Mansfield 1983). Due to early visual and acoustic warnings, vessel strikes in the water or on ice are probably not a significant threat to bearded seals. Further, bearded seals are accustomed to a dynamic ice environment so any alterations of the ice habitat by vessels is probably inconsequential, though in the limited areas where they occupy fast ice (e.g., Canadian Arctic Archipelago), impacts to substrate stability are conceivable (Smith 1987). Temporary access to open water leads could have short-term benefits but may also have negative effects, where seals become restricted to unnatural isolated patches where escape is precluded (Smiley and Milne 1979, Stirling et al. 1981, Mansfield 1983). Pups have a greater potential for heat loss, than adults and so would be more prone to incur energetic costs of increased time in the water if vessel disturbance became a more frequent event. The potential for ship traffic to cause a mother to abandon her pup may be lower in bearded seals than in other phocids (Smiley and Milne 1979), as bearded seal mothers appear to exhibit a high degree of tolerance when approach by small boats.

Most ships in the Arctic purposefully avoid areas of ice and thus prefer periods and areas which minimize the chance of encountering ice, though these may be increasingly difficult to predict. This necessarily mitigates many of the risks of shipping to populations of bearded seals that are closely associated with ice throughout the year. However, as noted, icebreakers pose greater risks to bearded seals since they are capable of operating year-round in all but the heaviest ice conditions. These risks will likely increase, as ice-breaking ships are progressively being used more to escort other types of vessels.

Current and future shipping in the Arctic pose varying levels of threat to bearded seals depending on the degree of spatial and temporal overlap, the intensity of shipping, and what is being shipped. The likelihood, timing, location, and overall magnitude of these threats (now or in the future) is inherently difficult to predict. There is no one scenario of global supply and demand that seems most likely (ECON 2007), and knowledge about even present impacts is limited because few are witnessed, documented, or studied. Effective governance and regulations will be necessary to mitigate the threats of shipping to bearded seals and other marine species in the Arctic, especially in sensitive areas and during periods of high risk (Arctic Council 2009). In a preliminary assessment of future threats to Arctic marine mammals, Huntington (2009) considered shipping to be a relatively low level threat with modest impacts that should be amenable to effective regulation. Indeed, shipping impacts alone may pose a lower risk to entire population segments, but when combined with the complex of impacts related to diminishing ice cover, such as increasingly denser aggregations, these impacts will be magnified and may play a critical role in affecting the health of future populations.

4.2.5.4.1.3.6 Indirect effects

Studies have shown that ships contribute significantly to global climate change and air pollution through their emissions of GHGs, aerosols, nitrogen and sulfur oxides, carbon monoxide, and particulate matter. The release and deposition of black carbon in the Arctic is of particular concern because of the effect it has on reducing the albedo of sea ice and snow cover, which in turn increases the rate of melting significantly (ACIA 2005, Arctic Council 2009). The introduction of exotic species into the Arctic by ships could also affect seals, although likely in a more indirect manner, such as through changes in the lower trophic levels of their food webs (Arctic Council 2009).

4.2.5.4.2 Okhotsk DPS

Though few details are available regarding actual shipping levels in the Sea of Okhotsk, resource development over the last decade stands out as a likely significant contributor (Reeves et al. 2005). It is clear that relatively high levels of shipping are needed to support present oil and gas operations, primarily off the northeastern coast of Sakhalin Island, and the western coast of the Kamchatka Peninsula (Lapko and Radchenko 2000, Dulepova and Radchencko 2004), with future developments pointing to an ever-growing shipping industry to support the area’s energy and minerals commerce (United Nations Environment Programme 2006). Large-scale commercial fishing occurs in many parts of the sea, accounting for half of the total Russian fish harvest from the Pacific Ocean (Dulepova and Radchencko 2004). Recent analysis of satellite imagery revealed fairly regular, large offshore oil slicks in the Sea of Okhotsk (Ivanov and Zatyagalova 2008). Sources of the oil could not be identified but many of the largest slicks were linear in form and believed to have been left by passing ships. Fairly regular dumping of engine room and bilge water by fishing and factory processor ships is also believed to be a significant source of pollution (Ivanov and Zatyagalova 2008).

The Russian government and international companies have focused primarily on developing oil and gas fields near Sakhalin and less on developing the resources and technical expertise to respond adequately to large or remote oil spills. For example, many oil tankers operating in the region do not have double hulls (Lawn et al. 1999, United Nations Environment Programme 2006). Though Russian waters are covered by the MARPOL treaty, inadequate port reception facilities, high costs of waste disposal, inaction against violators, and an inability to detect illegal dumping are believed to result in significant waste discharges at sea (Schei and Brubaker 2006, Ivanov and Zatyagalova 2008). An accident at an oil production complex resulted in a 3.5 ton spill in 1999 (Lapko and Radchenko 2000). In winter 2009, an unknown quantity of oil associated with a tanker fouled 3 km of coastline and hundreds of birds in Aniva Bay (Associated Foreign Press 2009). Navigation in this sea is reported to be difficult or impossible during winter due to heavy ice conditions, yet shipping still occurs year-round at the largest ports with the help of icebreakers (Kommersant 2004). Winter shipping activities in the southern Sea of Okhotsk are expected to increase considerably as oil and gas production pushes the development and use of new classes of icebreaking ships, thereby increasing the potential for shipping accidents and spills in the ice-covered regions of this sea (Shumei et al. 2001, Choi 2008).

4.2.5.4.2.1 Shipping threat assessment

The potential threats and general threat assessment in the Sea of Okhotsk are largely the same as they are in the Arctic, though with less detail available regarding the spatial and temporal correspondence of ships and bearded seals; save one notable exception. Though noise and oil pollution from vessels are expected to have the same general relevance in the Sea of Okhotsk, oil and gas activities near Sakhalin Island are currently at high levels and poised for another major expansion of the offshore oil fields that would require an increasing number of tankers (U.S. Energy Information Administration 2008). About 25% of the Okhotsk bearded seal population use this area during whelping and molting, and as a migration corridor (Fedoseev 2000).

Some unknown level of impacts to bearded seals is expected from vessels involved in fishing or fish processing, especially as they are cited as major sources of contaminant discharge (Ivanov and Zatyagalova 2008). Most landing ports for fish are distributed along the Sea's north shore, in the Kuril Islands, and the southern-most areas of western Kamchatka (United Nations Environment Programme 2006). The main aggregations of bearded seals in the northern Sea of Okhotsk are likely within the commercial shipping routes, but vessel frequency and timing relative to the periods when seals are hauled out on ice are presently unknown. Some ports are kept open year-round by icebreakers, largely to support year-round fishing (Kommersant 2004), so there is greater probability here of spatial and temporal overlap of ships with bearded seals hauled out on ice. In a year with reduced ice, bearded seals were more concentrated closer to shore (Fedoseev 2000), suggesting that seals could becoming increasingly prone to shipping impacts as ice diminishes.

As was the case with the Arctic, a quantitative assessment of actual threats and impacts in the Sea of Okhotsk is unrealistic due to a general lack of published information on shipping patterns. Modifications to shipping routes, and possible choke points, due to diminishing ice are likely but there is little data on which to base even qualitative predictions. However, the predictions regarding shipping impacts in the Arctic are generally applicable, and because of significant increases in predicted shipping, it appears that bearded seals inhabiting the Sea of Okhotsk, in particular the shelf area off central and northern Sakhalin Island, are at increased risk of impacts.

4.2.6 Threats Assessment

The BRT members' assessments of the severity of the threats to bearded seals were summarized in numerical scores. The primary threats were grouped by ESA Section 4(a)(1) factors (excluding Inadequacy of Existing Regulatory Mechanisms), and each individual threat was scored—in consideration of its geographic scope and severity—on a scale of 1 (low or zero threat), 2 (moderate threat), 3 (high threat), or 4 (very high threat). For each threat , the level of certainty (i.e., amount and quality of available information) in the threat assessment also was scored. Then, each BRT member assigned an overall score for each factor in recognition that multiple threats may have cumulative effects that sum or magnify the overall threat for the factor. The average score and the range of scores among BRT members are presented for each threat and Section 4(a)(1) factor in Tables 6-8.

Table 6. -- Threats assessment table for *E. b. barbatus*. BRT members judged the significance of each threat and overall ESA Section 4(a)(1) factor to the persistence of the population within the foreseeable future on a scale of 1 (low or zero significance), 2 (moderate significance), 3 (high significance), or 4 (very high significance). BRT members also indicated their level of certainty in each of their threat scores on a scale of 1 (low or no certainty), 2 (moderate certainty), 3 (high certainty), or 4 (very high certainty). The averages and ranges (in parentheses) of these scores are presented.

ESA Section 4(a)(1) Factor	Threats	Level of Certainty	Threat Score	Factor Score
Destruction, modification, or curtailment of habitat or range	Decrease in sea ice habitat suitable for whelping and nursing	2.3 (2-3)	1.9 (1-3)	2.7 (2-4)
	Decrease in sea ice habitat suitable for pup maturation	2.3 (2-3)	1.9 (1-3)	
	Decrease in sea ice habitat suitable for mating	2.2 (2-3)	1.9 (1-3)	
	Decrease in sea ice habitat suitable for molting	2.2 (2-3)	2.4 (2-4)	
	Decoupling of sea ice resting areas from benthic feeding habitat	2.2 (1-4)	2.5 (2-4)	
	Decrease in prey density and/or availability due to changes in ocean temperature and ice cover	2.1 (1-4)	2.3 (2-3)	
	Decrease in prey density and/or availability due to changes in ocean acidification	1.6 (1-2)	2.2 (1-3)	
	Decrease in prey density and/or availability due new competitive relationships and/or other changes in community structure	1.5 (1-3)	1.8 (1-2)	
Overutilization	Excessive subsistence harvest	2.1 (1-3)	1.2 (1-2)	1.0 (1-1)
	Illegal harvest	2.0 (1-3)	1.0 (1-1)	
	Excessive sport and/or commercial harvest	2.2 (1-3)	1.0 (1-1)	
	Excessive scientific take	2.8 (1-4)	1.0 (1-1)	
Disease, parasites, and predation	Increased infection or disease	1.5 (1-3)	1.3 (1-2)	1.4 (1-2)
	Increased predation from polar bears associated with changes in sea-ice cover	1.5 (1-2)	1.6 (1-3)	
	Increased predation from walrus associated with changes in sea-ice cover	1.5 (1-3)	1.2 (1-2)	
Other natural or man-made factors	Increased impairment (e.g., reproductive, metabolic) from contaminants	1.8 (1-3)	1.5 (1-3)	1.7 (1-2)
	Physical disturbance, injury or mortality from oil and gas development, shipping, and/or commercial fisheries	1.9 (1-3)	1.5 (1-2)	
	Noise pollution associated with oil and gas development, shipping, and/or commercial fisheries and ocean acidification	1.9 (1-3)	1.5 (1-2)	
	Disturbance, injury or mortality from oil spills, and/or other discharges	1.8 (1-3)	1.7 (1-2)	

Table 7. -- Threats assessment table for the Beringia DPS. BRT members judged the significance of each threat and overall ESA Section 4(a)(1) factor to the persistence of the population within the foreseeable future on a scale of 1 (low or zero significance), 2 (moderate significance), 3 (high significance), or 4 (very high significance). BRT members also indicated their level of certainty in each of their threat scores on a scale of 1 (low or no certainty), 2 (moderate certainty), 3 (high certainty), or 4 (very high certainty). The averages and ranges (in parentheses) of these scores are presented.

ESA Section 4(a)(1) Factor	Threats	Level of Certainty	Threat Score	Factor Score
Destruction, modification, or curtailment of habitat or range	Decrease in sea ice habitat suitable for whelping and nursing	2.4 (2-3)	2.3 (1-3)	3.1 (2-4)
	Decrease in sea ice habitat suitable for pup maturation	2.5 (2-3)	2.4 (2-3)	
	Decrease in sea ice habitat suitable for mating	2.4 (2-3)	2.2 (2-3)	
	Decrease in sea ice habitat suitable for molting	2.5 (2-4)	2.5 (2-4)	
	Decoupling of sea ice resting areas from benthic feeding habitat	2.5 (1-4)	2.8 (2-4)	
	Decrease in prey density and/or availability due to changes in ocean temperature and ice cover	2.1 (1-4)	2.5 (1-4)	
	Decrease in prey density and/or availability due to changes in ocean acidification	1.6 (1-2)	2.1 (1-3)	
	Decrease in prey density and/or availability due new competitive relationships and/or other changes in community structure	1.8 (1-3)	2.0 (1-3)	
Overutilization	Excessive subsistence harvest	2.1 (1-3)	1.3 (1-2)	1.1 (1-2)
	Illegal harvest	1.9 (1-3)	1.1 (1-2)	
	Excessive sport and/or commercial harvest	2.1 (1-3)	1.1 (1-2)	
	Excessive scientific take	2.7 (1-4)	1.0 (1-1)	
Disease, parasites, and predation	Increased infection or disease	1.5 (1-3)	1.3 (1-2)	1.4 (1-2)
	Increased predation from polar bears associated with changes in sea-ice cover	1.5 (1-2)	1.5 (1-2)	
	Increased predation from walrus associated with changes in sea-ice cover	1.6 (1-3)	1.3 (1-2)	
Other natural or man-made factors	Increased impairment (e.g., reproductive, metabolic) from contaminants	1.8 (1-3)	1.4 (1-2)	1.9 (1-2)
	Physical disturbance, injury or mortality from oil and gas development, shipping, and/or commercial fisheries	1.9 (1-3)	1.5 (1-2)	
	Noise pollution associated with oil and gas development, shipping, and/or commercial fisheries and ocean acidification	1.9 (1-3)	1.5 (1-2)	
	Disturbance, injury or mortality from oil spills, and/or other discharges	2.0 (1-3)	1.8 (1-2)	

Table 8. -- Threats assessment table for the Okhotsk DPS. BRT members judged the significance of each threat and overall ESA Section 4(a)(1) factor to the persistence of the population within the foreseeable future on a scale of 1 (low or zero significance), 2 (moderate significance), 3 (high significance), or 4 (very high significance). BRT members also indicated their level of certainty in each of their threat scores on a scale of 1 (low or no certainty), 2 (moderate certainty), 3 (high certainty), or 4 (very high certainty). The averages and ranges (in parentheses) of these scores are presented.

ESA Section 4(a)(1) Factor	Threats	Level of Certainty	Threat Score	Factor Score
Destruction, modification, or curtailment of habitat or range	Decrease in sea ice habitat suitable for whelping and nursing	2.4 (2-3)	2.9 (1-4)	3.3 (2-4)
	Decrease in sea ice habitat suitable for pup maturation	2.3 (2-4)	3.1 (2-4)	
	Decrease in sea ice habitat suitable for mating	1.9 (1-3)	2.5 (2-3)	
	Decrease in sea ice habitat suitable for molting	2.2 (1-4)	2.8 (2-4)	
	Decoupling of sea ice resting areas from benthic feeding habitat	2.5 (2-4)	2.4 (1-4)	
	Decrease in prey density and/or availability due to changes in ocean temperature and ice cover	1.7 (1-3)	2.2 (1-3)	
	Decrease in prey density and/or availability due to changes in ocean acidification	1.5 (1-2)	1.9 (1-3)	
	Decrease in prey density and/or availability due new competitive relationships and/or other changes in community structure	1.5 (1-2)	1.9 (1-3)	
Overutilization	Excessive subsistence harvest	1.9 (1-3)	1.4 (1-2)	1.5 (1-2)
	Illegal harvest	1.6 (1-3)	1.4 (1-2)	
	Excessive sport and/or commercial harvest	1.9 (1-3)	1.5 (1-3)	
	Excessive scientific take	2.5 (1-4)	1.0 (1-1)	
Disease, parasites, and predation	Increased infection or disease	1.5 (1-3)	1.3 (1-2)	1.3 (1-2)
	Increased predation associated with changes in sea-ice cover	2.0 (1-4)	1.6 (1-2)	
Other natural or man-made factors	Increased impairment (e.g., reproductive, metabolic) from contaminants	1.6 (1-3)	1.8 (1-2)	2.1 (2-3)
	Physical disturbance, injury or mortality from oil and gas development, shipping, and/or commercial fisheries	2.0 (1-3)	1.9 (1-3)	
	Noise pollution associated with oil and gas development, shipping, and/or commercial fisheries and ocean acidification	1.9 (1-3)	1.6 (1-3)	
	Disturbance, injury or mortality from oil spills, and/or other discharges	2.0 (1-3)	1.8 (1-3)	

4.3 Analysis of Demographic Risks

Threats to a species' long-term persistence, such as those evaluated in Section 4.2, are manifested demographically as risks to its abundance; productivity; spatial structure and connectivity; and genetic and ecological diversity. These demographic risks thus provide the most direct indices or proxies of extinction risk. In this section, the current status of each of these risks is assessed in turn by responding to a set of questions adapted from McElhany et al. (2000) and incorporated into a draft NMFS interim protocol for conducting ESA status reviews (Nammack et al. 2007). Although the interim protocol itself has not yet been officially adopted as a whole, these questions are based on general conservation biology principles applicable to a wide variety of species. The BRT used these questions as a guide to the types of considerations that are important to each of the broader demographic risk categories of abundance, productivity, spatial structure, and diversity.

4.3.1 Abundance

Is the species' abundance so low that it is at imminent risk of extinction due to environmental variation or anthropogenic perturbations (of the patterns and magnitudes observed in the past and expected in the foreseeable future)?

Current and accurate abundance estimates are unavailable for each bearded seal sub-species or DPS considered in this review. A few regions have been surveyed by various techniques in the past four decades, supporting crude estimates of about 95,000 individuals in the Okhotsk DPS, 155,000 in the Beringia DPS and 188,000 for *E. b. barbatus*[4]. Many of the assumptions used in obtaining these numbers are conservative (e.g., seals in the water were frequently not included and several regions were simply omitted because there was no obvious basis for constructing any estimate). However, they cannot be said to be strictly minimum or conservative overall, particularly because nearly all are outdated.

With populations of nearly 100,000 to nearly 200,000, *E. b. barbatus,* the Beringia DPS, and the Okhotsk DPS are not at risk from typical year-to-year variation nor to natural episodic perturbations such as oceanographic regime shifts that have no doubt occurred numerous times in the species' past. Thus, leaving aside low-frequency variation such as climate change or sustained removals by hunting, the answer to this question is no, their abundance is not so low that they are at imminent risk of extinction.

The magnitudes and patterns of environmental variation and anthropogenic perturbations that are expected in the foreseeable future were addressed under Section 4.2.1. The anticipated pattern is one of high interannual variability superimposed on a long-term (anthropogenic) trend toward warmer, lower-pH seas with less ice cover. The degree of risk posed by the long-term threats is uncertain due to a complete lack of quantitative information linking environmental conditions to bearded seal vital rates, and a lack of information about how resilient bearded seals will be to these changes. Qualitatively,

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[4] The BRT considered all regional estimates for *E. b. barbatus* to be unreliable except for those in Canadian waters which totaled 188,000. For the purposes of analyzing demographic risks the BRT chose to use 188,000 as the population estimate for *E. b. barbatus*.

though, it seems doubtful that any of these bearded seal populations could avoid becoming at risk of extinction in the face of a long (many decades to centuries) warming trend. The risk would seem to be greater for the Okhotsk DPS than for the Beringia DPS and *E. b. barbatus*. This is primarily because the East Siberian Sea (Beringia DPS) and the Canadian Arctic Archipelago and Laptev Sea (*E. b. barbatus*), are areas in the species' current range that overlap substantially with predicted future ice distributions (Figure 37). In contrast, favorable ice overlying suitable foraging habitat for bearded seal breeding and molting will be essentially absent in the Sea of Okhotsk by the mid- to late-21st century.

Is the species' abundance so low, or variability in abundance so high, that it is at imminent risk of extinction due to depensatory processes?

Depensatory processes, in which per-capita growth rate declines with decreasing abundance (opposite of density dependence), are associated with very low abundance levels and include breakdown of social structures or mating systems, failure to muster foraging groups, and failure of group defenses against predators.

The current abundances of bearded seals in *E. b. barbatus,* the Beringia DPS and the Okhotsk DPS are too high for concern about depensation. The variability in abundance is not well understood, but the life history characteristics of long life and slow reproduction, coupled with a large population, indicate that these seals are not subject to extreme fluctuations leading to imminent risk of depensation.

Is the species' abundance so low that its genetic diversity is at imminent risk due to inbreeding depression, loss of genetic variants, or fixation of deleterious mutations?

An analysis of microsatellite DNA collected from bearded seals in multiple locations throughout their range indicated that the genetic diversity in *E. b. barbatus* and in bearded seals of the Beringia DPS tends to be high (Davis et al. 2008). No data are available on the genetic diversity of bearded seals in the Okhotsk DPS.

Is the species' abundance so low that it is at imminent risk of extinction due to its inability to provide important ecological functions throughout its lifecycle?

This situation would normally be a concern for a species that depends on critical numbers or density for modification of its or another organism's physical or biological environment. No aspect of the bearded seal's life cycle is known to depend on this type of relationship.

Is the species' abundance so low that it is at imminent risk due to demographic stochasticity?

Demographic stochasticity refers to changes in vital rates that arise due to change in the "sampling" that occurs when nature acts on individuals with variable traits. For example, a badly skewed sex ratio, and consequent poor reproduction, could result if most of the remaining females in a small population succumb by chance, even though the overall rate of mortality, averaged over both sexes, is normal. The key factor in risk of demographic stochasticity is small populations. For a large, long-lived mammal such as the bearded seal, demographic stochasticity would be unlikely to be a concern for populations with greater than several tens of individuals. For *E. b. barbatus* and the Beringia and Okhotsk DPSs, demographic stochasticity is therefore highly unlikely to be an imminent risk.

Species status evaluations should take uncertainty regarding abundance into account.

As is evident from the review of information on bearded seal abundance (Section 2.8), nearly all of the abundance estimates are very uncertain. The scoring procedure adopted by the BRT for assessing the threats associated with each ESA Section 4(a)(1) factor includes a component score for "Level of Certainty" in the severity of the threat.

4.3.2 Productivity

Is the species' average productivity below replacement and such that it is at imminent risk of satisfying the abundance conditions described above?

The current net productivity (population trends) of *E. b. barbatus,* the Beringia DPS, and the Okhotsk DPS is unknown due to the imprecision or lack of available abundance estimates or indices. Hypothetically, if the current population size of each of these DPSs is at least 100,000 individuals, they could sustain at least 90 years of a moderately severe decline of, for example, 5% per year before dropping into the realm (less than about 1,000 individuals) in which most of the abundance conditions above become a concern for population persistence. Of course, it would be prudent to try to intervene long before such a dire status was attained. Because of the importance of bearded seals to subsistence communities in broad portions of all three units considered here, any prolonged and large population declines may be evident from observations of hunters before they are detectable or quantifiable by scientific means.

Is the species' average productivity below replacement and such that it is unable to exploit requisite habitats/niches/etc. or at imminent risk due to depensatory processes during any life-history stage?

For *E. b. barbatus* or bearded seals in the Beringia and Okhotsk DPSs, the average productivity is not known to be below replacement, and bearded seals are thought to occupy all of their historically observed ranges and habitats. Depensatory risks were considered in Section 4.3.1.

Does the species exhibit trends or shifts in demographic or reproductive traits that portend declines in per capita growth rate which pose imminent risk of satisfying any of the preceding conditions?

The limited amount of information on the demography or reproductive traits of bearded seals throughout their ranges precludes identification of any shifts or trends in per capita growth rate.

Species status evaluations should take into account uncertainty in estimates of growth rate and productivity-related parameters.

The great uncertainty about bearded seal population trends restricts the overall confidence in assessing the species' long-term risks. Unfortunately, an accurate trend estimate for bearded seals is not likely to be attainable in the near future simply because of the difficulty of surveying and estimating the population with sufficient precision to reveal trends. To account for this uncertainty, the scoring procedure adopted by the BRT for assessing the threats associated with each ESA Section 4(a)(1) factor includes a component score for ""Level of Certainty" in the severity of the threat.

4.3.3 Spatial Structure

Are habitat patches being destroyed faster than they are naturally created such that the species is at imminent risk of extinction due to environmental and anthropogenic perturbations or catastrophic events?

The diminishing quantity, distribution, and seasonal presence of sea ice, as described in Section 4.2.1.1.2, will likely represent significant changes in the habitats available to bearded seals. Changes that are both direct (e.g., sea ice as a platform for whelping, molting, resting) and indirect (e.g., shifts in sea-ice ecosystem food webs) will impact bearded seal habitat. Although there has yet been no documentation of bearded seal habitat destroyed by changes in the sea-ice regime, the model projections indicate that there likely will be substantial habitat loss during this century. It is also possible that changes in the sea-ice regime will create some new habitat for bearded seals, though the most likely times and places where this might occur are very difficult to predict. One possible region where reduced ice coverage may enhance habitat for bearded seals is in the East Siberian Sea (Beringia DPS). This area, which has been said to be relatively low in bearded seal numbers, has historically had very high ice concentrations and long seasonal ice coverage. The average and minimum ice concentrations for April in this region are projected to remain greater than 80% through the end of the century, perhaps higher than optimal for bearded seals (Simpkins et al. 2003). But the average and minimum concentrations for May-June near the end of the century include substantial regions of 20-80% ice, likely suitable for bearded seal reproduction, molting and foraging. Little is known about the biology and productivity of the ecosystem in this region, but it has a broad continental shelf and large river systems that may enhance productivity. This region and perhaps others with similar characteristics in the Canadian Arctic Archipelago and Laptev Sea (*E. b. barbatus*) may be areas of habitat creation or enhancement as the climate warms and sea ice declines, though we are not aware of specific examples in which similar mitigative shifts in habitat have occurred during rapid climatic changes. It may be more likely, and it certainly would be more prudent to assume that the net difference between sea-ice related habitat creation and destruction will be negative, especially because other factors such as ocean acidification are likely to impact habitat. The magnitude of this difference may well be the deciding factor in the long-term fate of the species. However, the current net rate of habitat loss does not seem to rise to the level of placing bearded seals at imminent risk of extinction for *E. b. barbatus* and the Beringia DPS. Ice-related changes and their associated impacts will likely be more severe for the Okhotsk DPS, where no new creation of bearded seal habitat could reasonably be anticipated as ice concentration declines in the future.

Are natural rates of dispersal among populations, metapopulations, or habitat patches so low that the species is at imminent risk of extinction due to insufficient genetic exchange among populations, or an inability to find or exploit available resource patches?

Although dispersal rates are currently unknown, there is no reason to believe that they are low within the ranges of *E. b. barbatus,* the Beringia DPS, or the Okhotsk DPS, given the relative absence of physical barriers within these marine environments (compared with terrestrial or river systems) and bearded seals' proven ability to move long distances. Further sampling and analysis of the genetic population structure within and between the DPSs is a high priority for future research.

Is the species at imminent risk of extinction due to the loss of critical source populations, subpopulations, or habitat patches?

This question is more relevant to species characterized by meta-population dynamics. *E. b. barbatus,* the Beringia DPS and the Okhotsk DPS are relatively large units that are not composed of conspicuous source-sink populations and habitat patches.

Analyses of species' spatial processes should take uncertainty into account.

The BRT has strived to identify and take into account the uncertainty in all aspects of the species' ecology and conservation status, including spatial processes. The scoring procedure adopted by the BRT for assessing the threats associated with each ESA Section 4(a)(1) factor includes a component score for "Level of Certainty" in the severity of the threat.

4.3.4 Diversity

Is the species at risk due to a substantial change or loss of variation in life-history traits, population demography, morphology, behavior, or genetic characteristics?

There are no documented specific risks for *E. b. barbatus* or bearded seals in the Beringia or Okhotsk DPSs related to such changes or losses.

Is the species at risk because natural processes of dispersal and gene flow among populations have been significantly altered?

Rates of dispersal and gene flow are not known to have been altered.

Is the species at risk because natural processes that cause ecological variation have been significantly altered?

***E. b. barbatus* and Beringia DPS:** Bearded seals are wide-ranging inhabitants of sub-Arctic and Arctic ecosystems and thus are continually exposed to ecological variation at a broad range of spatial and temporal scales. For *E. b. barbatus* and bearded seals in the Beringia DPS, the dominant mode of variability is the annual formation and retreat of the sea ice, which will continue to happen throughout much of their ranges for the foreseeable future. The interannual variation in this feature is projected to increase. These modes of variability likely propagate through the marine ecosystem to produce variability in other important factors such as predators and prey of bearded seals. From the standpoint of concern about lack of ecological variation leading to lack of genetic diversity, this should not be a threat for these bearded seals.

Okhotsk DPS: In the Okhotsk DPS, the prospect for complete loss of sea ice in many or most years by the end of this century (and the inability to shift to more ice-covered waters such as exists for *E. b. barbatus* or bearded seals in the Beringia DPS) portends a scenario with significantly reduced ecological variation. In years of low ice, bearded seals are known to concentrate their spatial distribution (Fedoseev 2000). Concentrated populations are more likely to compete for prey and would be more vulnerable to disease transmission, predation, disturbance, stochastic events (e.g., oil spills) and harvests. Bearded seals in the Okhotsk DPS are also known to haul out ashore during the ice-free period in late summer and early fall

(Heptner et al. 1976). A lack of spring ice would conceivably force bearded seals in the Okhotsk DPS to attempt to pup, nurse and mate ashore, which they have not been known to do in the past, and for which they may not be adapted. Such changes could significantly alter the diversity or increase the isolation of the Okhotsk DPS.

Species status evaluations should take uncertainty about requisite levels of diversity into account.

Although there is no standard measure for how much (and what type) of genetic diversity is required for secure conservation status, there are no examples of problems stemming from diversity in other mammal species with similar levels of mtDNA and micro-satellite heterogeneity and similarly large populations to those of *E. b. barbatus,* the Beringia DPS, or the Okhotsk DPS. The BRT has tried to convey throughout this review the importance of uncertainty about diversity, as well as all other factors thought to be important to the species status, so that the uncertainty can be taken into account in the listing decision process. The scoring procedure for assessing the threats associated with each ESA Section 4(a)(1) factor included consideration and scoring of BRT members' level of certainty or confidence in the severity of each threat.

4.3.5 Relevant Modifying or Mitigating Factors

4.3.5.1 Life-history characteristics

Bearded seals are long-lived, with overlapping generations and single offspring produced annually, all traits of a "K-strategist" life history that is suited to an environment with high year-to-year variability. This may be viewed as a mitigating factor for episodic threats or threats that increase environmental variability. On the other hand, these traits also are typically associated with relatively slow population growth rates, possibly a disadvantage for bearded seals if sudden large reductions were to occur.

Ultimately, the question of whether bearded seals as a species can survive a major shift to a warmer climate hinges on their capability to adapt to the altered physical and biological conditions. Short-term adaptations are already a part of bearded seals' normal response to living in the sub-Arctic and Arctic, regions characterized by interannual variability. Yet, their apparent inability to pup or nurse on land is a significant aspect of their biology, and could become a factor critical to their persistence in a future with greatly reduced sea ice.

The now-widespread concern about climate change has prompted numerous attempts to assess the potential effects on marine mammals (e.g., Learmonth et al. 2006, Simmonds and Isaac 2007), and specifically on Arctic marine mammals (e.g., Tynan and DeMaster 1997, Kelly 2001, Schliebe et al. 2006, Boveng et al. 2008, Kovacs and Lydersen 2008b, Laidre et al. 2008, Moore and Huntington 2008, Boveng et al. 2009). Most studies have recognized that factors such as geographic distribution, migratory capabilities, diet diversity, and relation to sea ice during key life history events should play a role in a species' sensitivity to climate change. Still, the task of predicting demographic responses to environmental change is largely impossible because of our lack of understanding of resilience, or the capacity to adjust to the change (Moore and Huntington 2008).

The scope for longer-term, physiological or genetic adaptation is also uncertain. Widely distributed, temperate or high-latitude species may have greater genetic scope for adapting to climate change than narrowly distributed tropical species, at least among ectotherms (Kellermann et al. 2009). Given that the current genetic diversity in bearded seals appears to be high the species likely retains genetic raw materials for adaptation to conditions reflected in its evolutionary history.

Paleoclimate reconstructions indicate that bearded seals have experienced many large deviations from current climatic conditions during the past. Global cycles of glaciation have occurred over the past several million years and are particularly well documented over the past 430 thousand years (kyr) by ice cores. During that period, the cycles consisted of very large climate shifts approximately 100 kyr in duration with only about 10 to 30 kyr spent in each interglacial warm phase (Jansen et al. 2007). During the Last Interglacial, the climate was warmer than present, the Greenland and Antarctic ice sheets were reduced, and there was much less sea ice in the Arctic and surrounding Alaska (CAPE Last Interglacial Project Members 2006, Nørgaard-Pedersen et al. 2007). Thus, bearded seals have survived and adapted to many large climate shifts encompassing periods of both warmer and much colder conditions than the present, indicating that the species has tended to retain the genetic plasticity to adapt to both types of climatic extremes. For many of the shifts in the paleoclimate, however, either the data resolution are too low to adequately judge the rates of change in conditions, or the rates of change are known to have been much slower than the warming now anticipated and already observed in response to anthropogenic increases in GHGs. So, a great deal of uncertainty remains about how quickly bearded seals might be able to adapt to the present warming and predicted changes in sea-ice habitat.

Paleoclimatic records have revealed many abrupt climate changes with hemispheric to global impacts (National Research Council 2002). One of the most well-known examples is the warming shift out of the Younger Dryas interval (YD), about 11.5 kya, when temperatures rose by about 10 °C in 1-2 decades, and snow accumulation rates in Greenland doubled in about 3 years (Alley et al. 1993, Grachev and Severinghaus 2005). Other rapid warming events detected in Greenland ice cores include a rise of 9 °C over several decades about 15 kya (Severinghaus and Brook 1999). More than 20 so-called Dansgaard-Oeschger (D-O) oscillations have been documented in the Greenland ice core record of the past ~110,000 years, each with rapid warming to near inter-glacial temperatures over just a few decades (National Research Council 2002). The onset of the Last Interglacial, the most recent period when Northern Hemisphere climate was warmer than the present, occurred in approximately 100 years (Brauer et al. 2007). Although older Northern Hemisphere paleoclimate records lack the resolution to pinpoint such rapid shifts, they probably occurred in previous ice ages as well (National Research Council 2002).

The rapid and widespread shifts of the D-O oscillations, which are likely associated with changes in the North Atlantic thermohaline circulation regime, have many strongly correlated signals in biological records of the Northern Hemisphere such as terrestrial pollen, fossils, and marine plankton in sediments (National Research Council 2002). These events certainly modified both the physical and biological environments for bearded seals. Although there is, of course, great uncertainty about the nature of the changes, at least some of them must have been very dramatic; no climatic event since the YD has matched its magnitude or rapidity (Alley 2000). Thus, there is ample evidence that bearded seals have adapted successfully many times to both large and rapid ecological changes. This paleoclimatic history is not, on its own, an assurance that bearded seals can adapt to the changes projected for the foreseeable future. However, the present-day life history of the species reflects many of the traits that must have been required to persist through the past 11 million years since the bearded seal ancestor emerged from the other Phocinae.

The present-day life history of bearded seals has several characteristics that others have recognized as providing resilience (Learmonth et al. 2006, Moore and Huntington 2008) to threats that we have considered:

- Bearded seals are highly mobile and migratory, providing the potential for adjusting to changes in conditions by moving to more suitable habitat patches.
- Bearded seals are known to have a diet that is ecologically and trophically diverse, which should enhance resilience to climate-related changes in prey communities, though their apparent preference or requirement for continental shelf foraging grounds may temper this resilience.
- Bearded seals tend to be highly dispersed during periods of both reproduction and molting, and mostly solitary during the ice-free or ice-minimum season, which should reduce the potential for impacts by localized threats.

These factors may provide a hedge against localized threats such as oil spills, concentrations of fishery activity, and interactions with shipping, except where migration corridors coincide with so called shipping “choke points”. The four main areas of concern are: 1) the southern Barents Sea, including shipping lanes in the White Sea and the Pechora Sea; 2) the western to central Kara Sea; 3) the eastern Canadian Arctic, particularly Baffin Bay, Lancaster Sound, and Hudson Strait and Bay; and 4) the Bering Strait, where all traffic between the Arctic and Pacific must pass, and traffic volume and stands to increase dramatically as trans-Arctic routes become more navigable under a declining ice regime.

4.3.5.2 Population characteristics

As noted above, the highly dispersed nature of bearded seals should reduce demographic risks associated with localized threats. An exception to this rule however would be the occurrence of a localized threat in one of the “choke points” through which bearded seals migrate. For example, a large proportion of bearded seals would likely be significantly impacted if an oil spill occurred in the Bering Strait during the time of a seasonal migration.

4.3.5.3 Habitat characteristics

The marine habits of bearded seals and the capability of individuals to undertake large seasonal movements may mitigate some anticipated impacts of anthropogenic climate change. For many species, especially terrestrial ones that have been threatened or endangered by human modification or destruction of habitat, the difficulty for survival is amplified by barriers to migration between remaining suitable, but fragmented habitat patches. This may typically be of less concern for wide-ranging marine mammals. Although many marine mammal populations have been threatened or endangered, the primary cause in nearly every case has been from overharvest or incidental takes in fisheries rather than destruction of habitat (exceptions are manatees, dugongs, and river dolphins, which inhabit easily fragmented or damaged coastal, estuarine, or river habitats). On the other hand, the apparent need for ice coverage that coincides spatially with relatively shallow benthic foraging grounds during whelping, nursing and pup rearing is likely a significant constraint for the species' habitat requirements.

***E. b. barbatus* and Beringia DPS:** If sea-ice habitat for *E. b. barbatus* or for the Beringia DPS is reduced by climate change, it is possible that the populations will adjust by consolidating their range to areas that are anticipated to have spring ice far into the future. Furthermore, in areas with current ice concentrations that may be too high for good bearded seal habitat, the predicted decline in sea ice could conceivably result in new breeding habitat in the future, perhaps mitigating losses of previously-used habitat. However, the BRT is not aware of any specific examples in which similar mitigative shifts in habitat have occurred during rapid climatic changes.

Okhotsk DPS: A similar shift to remain with the springtime sea ice would be limited or unavailable in the Okhotsk DPS which, unlike the Beringia DPS, has a northern boundary of land. If springtime sea ice were to disappear from the Sea of Okhotsk, bearded seals there would be relegated to an ice-free habitat that may not sustain a population or may be sufficient to sustain only a very small population.

4.3.6 Demographic Risks Assessment

The BRT members' assessment of the severity of the demographic risks to the persistence of each bearded seal subspecies or DPS was formalized using a numerical scoring system. Scoring was modeled on similar approaches used in other ESA status reviews (e.g., Atlantic Wolffish Biological Review Team 2009, Butler et al. 2009). The system was designed to elicit expert judgment about the likelihood that the known and potential threats will impact a species' persistence. Specifically, each BRT member considered the risk that the population may be placed in danger of extinction by demographic problems with abundance, productivity, spatial structure, or diversity, and then assigned a score to each of these demographic categories as follows: 1 = very low or zero risk, 2 = low risk, 3 = medium risk, 4 = high risk, and 5 = very high risk. The questions posed in 4.3.1-4.3.4 and used to guide consideration of each demographic category (McElhany et al. 2000) emphasized the present risks of extinction. To assess future risks of extinction, the BRT members also scored the risks that problems associated with those demographic categories will, in the foreseeable future, place the population in danger of extinction. The average score and the range of scores among BRT members are presented in Table 9.

Table 9. -- BRT members judged the risks that threats to the persistence of each bearded seal population unit would be manifested as demographic problems associated with abundance, productivity, spatial structure, or diversity. The severity of the risk that the population may be placed in danger of extinction by these demographic problems—both presently and in the foreseeable future—was given a score of 1 (very low or zero risk), 2 (low risk), 3 (medium risk), 4 (high risk), or 5 (very high risk). The averages and ranges (in parentheses) of these scores are presented.

Demographic Risks	*E. b. barbatus*		*Beringia DPS*		*Okhotsk DPS*	
	Present	Foreseeable Future	Present	Foreseeable Future	Present	Foreseeable Future
Abundance	1.3 (1-2)	3 (2-4)	1.3 (1-2)	3.3 (3-4)	1.7 (1-3)	4.1 (3-5)
Productivity	1.7 (1-3)	3.2 (2-4)	1.8 (1-3)	3.7 (3-4)	2 (1-3)	4.3 (3-5)
Spatial Structure	1.7 (1-3)	3.2 (2-4)	1.8 (1-3)	3.9 (3-5)	2.3 (2-3)	4.4 (4-5)
Diversity	1.3 (1-3)	2.7 (2-4)	1.4 (1-3)	2.9 (2-4)	2.1 (1-4)	3.3 (2-4)

4.4 Conclusions of the Extinction Risk Assessment

Warming—driven by greenhouse gas emissions—is accelerated in the Arctic by positive feedbacks including reduced albedo. Recent reductions in the areal extent of sea ice have contributed strongly to the reduction in albedo, meaning more heat is retained by the ocean and earth's surface. Current atmospheric levels of greenhouse gases are sufficient to continue warming the climate and diminishing ice and snow cover throughout the century. Changes to the ice habitat of bearded seals are forecast to be rapid relative to generation time, challenging the species' ability to respond adaptively. Bearded seal populations may be impacted directly by effects of diminishing ice cover on their rates of survival and reproduction. Indirect effects may result from changes in biological community composition as consequences of ocean warming and acidification.

The BRT considered 18-19 threats to the *E. b. barbatus* subspecies and the Beringia and Okhotsk DPSs of bearded seals, and assessed how those threats are likely to manifest (presently and in the foreseeable future) in the demography as risks to abundance, productivity, spatial structure, and diversity. The geographic scope of each threat was implicit in judgments about the threat's significance. Threats related to the destruction, modification, or curtailment of habitat or range were judged to be the most significant for posing extinction risks. Other categories of threats related to overutilization, diseases, parasites, predation, and other natural or human factors, were judged to be of low to moderate significance. In other words, they were judged to be either insufficiently potent to pose a significant risk anywhere throughout species range, or, for any threats that might be sufficiently potent to pose risks, those threats were judged not to pose a risk to a significant portion of the species range.

4.4.1 Erignathus barbatus barbatus

The BRT judged the decoupling, or spatial separation of sea ice from benthic feeding habitat to be a moderate to high threat to the subspecies *E. b. barbatus*; this, and a decrease in sea ice habitat suitable for molting were judged to be nearly the same strength and the most significant threats to the subspecies. Both threats stem from the anticipated reduction in sea ice area and seasonal persistence, and these combined with other sea-ice, climate, and ocean acidification threats were reflected in a moderate to high score overall for threats associated with habitat modification or loss. Threats within the other ESA Section 4(a)(1) factors were judged to be low or moderate.

The present risks that this subspecies is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low or very low in severity, reflecting the evidence that the population is large and apparently occupying its historic range. Within the foreseeable future, the risks that demographic problems might place the population in danger of extinction were consistently judged to be higher than at present (medium in severity), reflecting the anticipated decline in sea ice habitat over the remainder of the 21st century and consequent impacts on spatial structure (loss of habitat patches) and productivity (changes in vital rates of reproduction and survival).

4.4.2 Beringia DPS

The most significant threats to the persistence of bearded seals in the Beringia DPS were judged to be the same ones as for the *E. b. barbatus* subspecies, plus the threat of a decrease in prey density or availability due to changes in ocean temperature and ice cover. These and other threats related to loss of sea ice habitat and climate-related changes in ocean conditions were scored in the moderate to high range, leading to an overall score of high for threats of habitat modification or loss. Threats within the other ESA Section 4(a)(1) factors were judged to be low or moderate. The threat-specific and overall habitat factor scores were generally higher for the Beringia DPS than for *E. b. barbatus*, likely a measure of greater concern about declines in ice extent that would separate sea ice suitable for pup maturation and molting from benthic feeding areas. The risk of this is likely greater in the range of the Beringia DPS, where the spring and summer ice edge may retreat to deep water of the Arctic Ocean basin, than in much of the range of *E. b. barbatus*, where summer ice refugia are anticipated to occur in the Canadian Arctic Archipelago and northern Greenland.

The present risks that the Beringia DPS is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low or very low in severity, again on the basis of a large population occupying its historic range. Within the foreseeable future, the risks that demographic problems might place the population in danger of extinction were consistently judged to be higher than at present (medium to high in severity), and higher than the corresponding risks to *E. b. barbatus*.

4.4.3 Okhotsk DPS

The greatest threats to the persistence of bearded seals in the Okhotsk DPS were judged to be decreases in sea ice habitat suitable for whelping, nursing, pup maturation, and molting. These threats, which were scored as high, are more severe in the range of the Okhotsk DPS than in the ranges of the Beringia DPS and *E. b. barbatus* because of the likelihood that the Sea of Okhotsk will by the end of this century frequently be ice free or nearly so during April – June, the crucial months for those important life history events. The overall score for habitat-related threats also was greatest for the Okhotsk DPS (high, tending toward very high). Although the scores for the other ESA Section 4(a)(1) factors were in the low to moderate range, they tended to be higher than those for *E. b. barbatus* and the Beringia DPS.

The present risks that the Okhotsk DPS is in danger of extinction due to demographic problems of abundance, productivity, spatial structure, and diversity were all judged to be low in severity but the numerical scores were somewhat higher than for the other species segments. This may be a result not only of stronger threats identified above, but also of the somewhat lower confidence (certainty scores) ascribed to the threats scores for the Okhotsk DPS. Within the foreseeable future, the risks that demographic problems might place the Okhotsk DPS in danger of extinction were consistently judged to be higher than at present (high for abundance, productivity, and spatial structure; medium for severity), and the highest of the three species segments.

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7 APPENDIX: GLOSSARY OF ABBREVIATIONS

Abbreviation	Description
ADFG	Alaska Department of Fish and Game
AMAP	Arctic Monitoring and Assessment Programme
AMSA	Arctic Council's *Arctic Marine Shipping Assessment*
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	IPCC's *Fourth Assessment Report*
BRT	biological review team
BSAI	Bering Sea-Aleutian Islands
BT	butyltin
CAA	Clean Air Act
$CaCO_3$	calcium carbonate
CAOR	Central Arctic Ocean Route
CBD	Center for Biological Diversity
CDV	canine distemper virus
CGCM3	Coupled Global Climate Model version 3
CHV	canine herpes virus
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMIP3	Coupled Model Intercomparison Project Phase 3
CO_2	carbon dioxide
CRCM	Canadian Regional Climate Model
CZMA	U.S. Coastal Zone Management Act
DDE	dichloro-diphenyl-dichloroethylene
DDT	dichloro-diphenyl-trichloroethane
DFO	Canada’s Department of Fisheries and Oceans
DNR	Department of Natural Resources
DPP	Draft Proposed Program
DPS	Distinct Population Segment
EEZ	exclusive economic zone
EPA	U.S. Environmental Protection Agency
ESA	U.S. Endangered Species Act
EU	European Union
FHV	felid herpes virus
FMP	fisheries management plan
GHG	greenhouse gas
HadISST	Hadley Centre sea ice and sea surface temperature data set
HAPC	Habitat Areas of Particular Concern
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation the of Nature and Natural Resources
JPL	Jet Propulsion Laboratory
MARPOL	International Convention for the Prevention of Pollution from Ships
MMPA	U.S. Marine Mammal Protection Act

MMS	U.S. Minerals Management Service, now known as the Bureau of Ocean Energy Management, Regulation, and Enforcement
MPRSA	U.S. Marine Protection, Research, and Sanctuaries Act
mtDNA	mitochondrial DNA
MY	multi-year
NAMMCO	North Atlantic Marine Mammal Commission
NCEP	National Center for Environmental Prediction
NCAR	National Center for Atmospheric Research
NEPA	U.S. National Environmental Policy Act
NMFS	U.S. National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration
NSR	Northern Sea Route
NWP	Northwest Passage
OC	Organochlorine
OCS	outer continental shelf
OCSLA	U.S. Outer Continental Shelf Lands Act
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PDBE	polybrominated diphenyl ether
PDV	phocine distemper virus
PFC	perfluorinated contaminant
PFOS	perfluorooctane sulfonate
PhHV	phocid herpesvirus
POP	persistent organic pollutant
ppm	parts per million
PSD	EPA’s Prevention of Significant Deterioration program
PTS	permanent threshold shift
SAT	surface air temperature
SCPOP	Stockholm Convention on Persistent Organic Pollutants
SD	standard deviation
SMSV	San Miguel sea lion virus
SRES	IPCC's *Special Report on Emission Scenarios*
SST	sea surface temperature
TAC	total allowable catches
TAR	IPCC's *Third Assessment Report*
TBT	tributyltin
TCV	Tillamook calicivirus
TINRO	Russian Federation’s Pacific Research Fisheries Center
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VES	vesicular exanthema of swine
YD	Younger Dryas interval

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