BEFORE THE SECRETARY OF COMMERCE

PETITION TO LIST THREE SEAL SPECIES UNDER THE ENDANGERED SPECIES ACT: RINGED SEAL (*PUSA HISPIDA*), BEARDED SEAL (*ERIGNATHUS BARBATUS*), AND SPOTTED SEAL (*PHOCA LARGHA*)

CENTER FOR BIOLOGICAL DIVERSITY

MAY 28, 2008

Notice of Petition

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U.S. Department of Commerce
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Washington, D.C. 20230

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PETITIONER

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Date: this 28 day of May, 2008

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Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. §1533(b), Section 553(3) of the Administrative Procedures Act, 5 U.S.C. § 553(e), and 50 C.F.R. §424.14(a), the Center for Biological Diversity ("Petitioner") hereby petitions the Secretary of Commerce, through the National Marine Fisheries Service ("NMFS"), to list the ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), and spotted seal (*Phoca largha*) as threatened or endangered species and to designate critical habitat to ensure their survival and recovery.

The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center has over 40,000 members in Alaska and throughout the United States. The Center and its members are concerned with the conservation of endangered species, including the bearded seal, spotted seal, and ringed seal, and the effective implementation of the ESA.

NMFS has jurisdiction over this petition. This petition sets in motion a specific process, placing definite response requirements on NMFS. Specifically, NMFS must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. §1533(b)(3)(A). NMFS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." *Id.* Petitioner needs not demonstrate that the petitioned action *is* warranted, rather, Petitioner must only present information demonstrating that such action *may* be warranted. While Petitioner believes that the best available science demonstrates that listing the bearded seal, spotted seal, and ringed seal as endangered *is* in fact warranted, there can be no reasonable dispute that the available information indicates that listing these species as either threatened or endangered *may* be warranted. As such, NMFS must promptly make a positive initial finding on the petition and commence a status review as required by 16 U.S.C. § 1533(b)(3)(B).

The term "species" is defined broadly under the ESA to include "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." 16 U.S.C. § 1532 (16). A Distinct Population Segment ("DPS") of a vertebrate species can be protected as a "species" under the ESA even though it has not formally been described as a separate "species" or "subspecies" in the scientific literature. A species may be composed of several DPSs, some or all of which warrant listing under the ESA. Petitioners ask that the Secretary of Commerce list the ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), and spotted seal (*Phoca largha*) as threatened or endangered species because the continued existence of each of these species is threatened by one or more of the five listing factors. As described in this petition, the spotted seal is monotypic. The bearded seal contains two currently recognized subspecies: Pacific bearded seal *Erignathus barbatus nauticus* and Atlantic bearded seal *Erignathus barbatus barbatus*. The ringed seal contains five currently recognized subspecies: *Pusa hispida hispida, Pusa hispida botnica, Pusa hispida ochotensis, Pusa hispida ladogensis,* and *Pusa hispida saimensis*. Each of these subspecies meets the definition of a "species" eligible for listing under the ESA. In the event that NMFS does not find that the entire species of ringed seal or bearded seal meets the requirements for listing, we request that NMFS evaluate whether each subspecies of bearded and ringed seals is eligible for listing. In the event that NMFS does not recognize the taxonomic validity of the bearded and ringed seal subspecies or the spotted seal species as described in this petition, we request that NMFS evaluate whether the spotted, ringed and bearded seals of the Bering, Chukchi, and Beaufort Seas that are the subject of this petition constitute a DPS of the full species and/or represent a significant portion of the range of the full species and are therefore eligible for listing on such basis.

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Executive Summary

The rapid melt of Arctic sea ice as a result of global warming threatens all Arctic marine mammals with extinction. All five ice-associated pinnipeds that inhabit Alaskan waters are particularly vulnerable. Through this Petition, the Center for Biological Diversity seeks Endangered Species Act ("ESA") protection for the ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), and spotted seal (*Phoca largha*). The Center filed petitions seeking protection of the ribbon seal (*Histriophoca fasciata*) and Pacific walrus (*Odobenus rosmarus divergens*) in December 2007 and February 2008 respectively. Those petitions are undergoing agency review. Another Arctic marine mammal, the polar bear (*Ursus maritimus*) was listed as "threatened" under the ESA on May 15, 2008 as a result of a Center petition filed in February 2005.

The ringed seal is the most widespread marine mammal in the ice-covered regions of the Northern Hemisphere and the smallest and most ice-adapted of all northern pinnipeds. Five distinct subspecies of the ringed seal are recognized: the Arctic ringed seal (*P. h. hispida*) that inhabits the seasonally and permanently ice-covered waters of the Arctic Ocean and contiguous subarctic seas; the Okhotsk ringed seal (*P. h. ochotensis*) restricted to the Okhotsk Sea; the Lake Saimaa ringed seal (*P. h. saimensis*) confined to Lake Saimaa, Finland; the Lake Ladoga ringed seal (*P. h. ladogensis*) confined to Lake Ladoga, Russia; and the Baltic ringed seal (*P. h. botnica*) restricted to the Baltic Sea. Unlike other northern phocids, the ringed seal is able to inhabit and reproduce in landfast ice during the winter and spring breeding season due to its ability to make and maintain breathing holes in thick ice and to excavate subnivian lairs in snowdrifts over breathing holes, which it uses for resting, giving birth, and nursing pups during March-May.

The bearded seal is, after the walrus, the largest of the ice-associated pinnipeds that inhabit Alaskan waters. The bearded seal occurs in a patchy circumpolar distribution around the perimeter of the Arctic Ocean and the contiguous subarctic seas. Two subspecies of the bearded seal are recognized: the Atlantic bearded seal (*E. b. barbatus*) and Pacific bearded seal (*E. b. nauticus*). Bearded seals reproduce and haulout primarily on drifting pack ice over shallow water where the ice is in constant motion producing leads, polynyas and other openings. Because the bearded seal feeds predominantly on benthic prey, its distribution is generally restricted to relatively shallow shelf waters of less than 150-200 m where such prey are more abundant. Both bearded and ringed seals perform seasonal migrations in conjunction with the seasonal advance and retreat of sea ice.

The spotted seal or larga seal is characterized by its vivid markings of brownish to black irregularly shaped spots scattered over a lighter base coat. Spotted seals primarily breed and haulout on the sea-ice front of the Bering and Okhotsk Seas, although southern breeding populations occur in the seasonally ice-covered regions of the northern Sea of Japan and northern Yellow Sea. The spotted seal moves between breeding areas on the sea-ice front in winter and spring to coastal habitats during the ice-free season in summer and fall.

Accurate abundance estimates for all three species are lacking, but previous estimates are of over a million ringed seals worldwide, and perhaps 750,000 bearded seals and 250,000 spotted seals.

The sea-ice habitat of the ringed, bearded, and spotted seal is threatened by rapid Arctic climate change that is occurring at a pace that is exceeding the predictions of the most advanced climate models. Arctic surface temperatures increased twice as much as the global average during the 20th century. Winter sea-ice extent in 2006 and 2007 declined to a minimum which most climate models forecast would not be reached until 2070, and summer sea-ice extent in 2007 plummeted to a record minimum which most climate models forecast would not be reached until 2050.

In the range of the ringed and bearded seals, sea-ice extent has declined significantly during the March through July breeding and molting season in recent decades throughout most of the range, including the seasonally ice-covered Okhotsk and Bering Seas, Hudson Bay, Baffin Bay, Greenland Sea, Canadian Archipelago, Barents Sea, Kara Sea, Laptev Sea, Chukchi Sea, and Arctic Ocean. In the range of the spotted seal, sea-ice extent in the Bering and Okhotsk Seas has already experienced large declines throughout the March-June spotted seal reproductive and molting periods in recent decades.

Of foremost concern for these three seal species, global warming will accelerate in this century. Arctic air temperatures are projected to increase by an average of 8°C during winter by the end of the century. Climate scientists are warning that the Arctic may have already passed a tipping point beyond which an ice-free Arctic summer is inevitable, and that a seasonally ice-free Arctic Ocean might be realized as early as 2012. Winter and spring sea ice will also continue to decline with the accelerating loss of summer sea ice that creates large open-water areas that increase the ice-albedo feedback. The Bering, Okhotsk, and Barents Seas are projected to lose at least 40% of winter sea-ice area by 2050. Any remaining sea-ice habitat will likely be of low quality because the sea ice will be thinner and the ice will melt sooner, leading to breakup of the sea ice during the reproductive and molting periods.

Global warming will impact ringed, bearded, and spotted seals directly by degrading and eliminating critical sea-ice habitat, which will have devastating consequences by reducing adult reproductive success and the survival of pups and impairing their ability to molt. Growing threats from climate change include depletion of prey resources due to changing ocean conditions and ocean acidification; increasing exposure to predators, competitors, disease, and human disturbance; and increasing shipping activity and oil and gas development, with associated risks of oil spills and noise pollution as sea-ice loss increases the accessibility of previously ice-covered regions. The ringed, bearded, and spotted seal also face threats from current or potential overexploitation from hunting, current oil and gas development in many parts of their range, rising contaminant levels in the Arctic, and bycatch mortality from commercial fisheries. Although the ringed, bearded, and spotted seal face multiple threats, each of these species merits listing under the ESA due to the threats from global warming alone.

Existing regulatory mechanisms have been ineffective in mitigating the principal threats to the ringed, bearded, and spotted seal, the most important of which is global warming. There are currently no legal mechanisms regulating greenhouse gases on a national level in the United States. The immediate reduction of greenhouse gas pollution is essential to slow global warming and ultimately stabilize the climate system while there is still suitable sea-ice habitat remaining. Unless greenhouse gas emissions are cut dramatically in the immediate future, the disappearance of the sea ice and the decline and likely extinction of the ringed, bearded, and spotted seal, as well as the loss of the entire Arctic ecosystem, are essentially assured.

PART ONE: SPECIES ACCOUNTS

RINGED SEAL (*Pusa hispida*)

I. Species Description

The ringed seal (*Pusa hispida*) is the most widespread marine mammal in the ice-covered regions of the Northern Hemisphere and the most ice-adapted of all northern pinnipeds (Frost 1984). The ringed seal is distinguished by its prominent gray-white rings, either separate or fused, scattered across a light or dark base coast (Figure 1) (Kelly 1988b). Ringed seals are polymorphic in coloration. The light phase has a dark gray saddle with light rings and lightly colored lateral and ventral surfaces with or without darker spots, while the dark phase has a dark base coat with lighter rings (Kelly 1988b). Ringed seal pups are born with a white, wooly natal lanugo which insulates the pup until it has acquired a blubber layer (Frost 1984). At six to eight weeks after birth, pups completely shed their lanugo which is replaced by a fine-textured coat that is silver on the belly and dark gray on the back, occasionally with traces of the adult ringed pattern (Frost 1984). The ringed seal is also distinguished by its short muzzle, catlike face, and rotund body shape, with its girth at the foreflippers often exceeding 80% of its length during winter (Frost 1984).

The ringed seal is the smallest of all northern phocids (Frost 1984), and its body size varies considerably by geographic location and on an individual basis, with a large range of lengths and weights observed in all age classes (Frost 1984). On average, males tend to be slightly larger than females (Kelly 1988b). In Alaska, ringed seals average 116.3 cm in length for males and 112.1 cm for females (Lowry et al. 1982). Average body length of males is 123.0 cm in the Chukchi Sea, 129.7 cm in the Bering Sea, and 118.0 cm in the Okhotsk Sea (Kelly 1988b). Adult males in eastern Canadian Arctic averaged about 135 cm and females slightly less (Kelly 1988b). In Alaska, the average weight of adult ringed seals is 50 kg while pregnant females may exceed 100 kg (Frost 1984). Weight varies seasonally with changes in the thickness of the blubber layer (Kelly 1988b). Males are heaviest in winter from freeze-up through February and reach a low during June and July following a prolonged period of reduced feeding associated with breeding and molting (Frost and Lowry 1981). Johnson et al. (1966) reported weight gains in winter of 31-34% and weight losses in spring and summer of 18-39% among ringed seals in the southern Chukchi Sea. Pregnant females follow a similar pattern but without a pronounced loss of weight until parturition in March and April (Kelly 1988b). Pups at birth average 4.5 kg in weight and 65 cm in length (Frost and Lowry 1981).

Figure 1. Ringed seal in Svalbard, Norway.
Photo courtesy © Pete Spruance.

II. Taxonomy

The ringed seal belongs to the order Carnivora, suborder Pinnipedia, family Phocidae, subfamily Phocinae, tribe Phocini, and genus *Pusa* (Rice 1998). The genus *Pusa* includes three allopatric species—the ringed seal, Caspian seal *Pusa caspica*, and Baikal seal *Pusa sibirica* seal, the latter two of which inhabit landlocked lakes in central Asia (Rice 1998). These three *Pusa* species share similarities in their small size, delicate skull, and affinity for ice, but are differentiated by cranial morphology, pelage color, and reproductive behavior (Frost and Lowry 1981, Rice 1998). The specialization in the three *Pusa* species for occupying seasonally ice-covered waters is thought to have arisen in the mid Pliocene (~3 million years ago), when the first evidence of radiation of *Pusa* in high latitudes has been discovered (Kelly 1988b). Radiation into high latitudes may have occurred from Caspian seals that expanded into southward extensions of the Arctic Ocean (Kelly 1988b).

The ringed seal was first described as *Phoca hispida* by Schreber in 1775 based on specimens from Greenland and Labrador (Frost and Lowry 1981). The genus name derives from the Greek word for seal while the species name comes from the Latin *hispidus* which means barbed or bristly and refers to the coat of the ringed seal adult (Frost and Lowry 1981). Numerous populations and subspecies of the ringed seal have been reported (Rice 1998). Currently five distinct subspecies are usually recognized: the Arctic ringed seal *Pusa hispida hispida* from the Arctic Ocean and Bering Sea; the Okhotsk ringed seal *P. h. ochotensis* (Pallas, 1811) from the Okhotsk Sea; the Lake Saimaa ringed seal *P. h. saimensis* (Nordquist, 1899) from Lake Saimaa, Finland; the Lake Ladoga ringed seal *P. h. ladogensis* (Nordquist, 1899) from

Lake Ladoga, Russia; and the Baltic ringed seal *P. h. botnica* (Gmelin, 1788) from the Baltic Sea (Rice 1998).

Separation of ringed seals of Lake Ladoga and Lake Saimaa into distinct subspecies is well supported. Seals of these freshwater subspecies differ significantly from each other and from the nearby marine population of Baltic ringed seals in skull morphology, pelage color and behavior (Palo et al. 2001), and are separable in discriminant analyses based on cranial measurements (Amano et al. 2002).

Rice (1998) cites evidence that seals of the geographically isolated Okhotsk Sea and Baltic Sea subspecies are fairly well-differentiated morphologically from populations of *P. h. hispida* further north. However, a study of genetic variability and population structure of Baltic ringed seals and *P. h. hispida* from Svalbard using microsatellite loci detected weak differentiation between these subspecies (Palo et al. 2001). Palo et al. (2001) state that Arctic ringed seals first gained access to the Baltic Basin ~11,500 years ago through a strait across central Sweden, were isolated ~10,900 years ago when marine access was closed by land uplift, and are thought to have remained isolated when the Baltic Sea was reconnected to the North Sea ~9,500 years ago because intervening ice-free habitat prohibited population exchange. These researchers suggest that limited gene flow has occurred between the Arctic and Baltic ringed seal based on the low level of detected genetic differentiation (Palo et al. 2001).

An assessment of subspecies-level taxonomy based on differences in skull morphology of the five recognized ringed seal subspecies also found low differentiation between the Arctic ringed seal, Baltic ringed seal, and Okhotsk ringed seal but high differentiation among seals from Lake Saimaa and Lake Ladoga (Amano et al. 2002). However, the researchers note that the analysis for the Okhotsk ringed seal were based on small sample size and the study should be repeated with a larger sample size. Further, although the Baltic ringed seal was not fully discriminated, the researchers argue for retention of its subspecies status based on its geographic separation and unique dark pelage. The study also failed to detect differences among ringed seals of *P. h. hispida* from Alaska, eastern Canadian Arctic, and Russian Arctic. Overall, Amano et al. (2002) uphold recognition of the five ringed seal subspecies: "In conclusion, we consider it reasonable to recognize 5 subspecies in *P. hispida: P. h. hispida, P. h. botnica, P. h. ladogensis, P. h. ochotensis,* and *P. h. saimensis*" (Amano et al. 2002: 377).

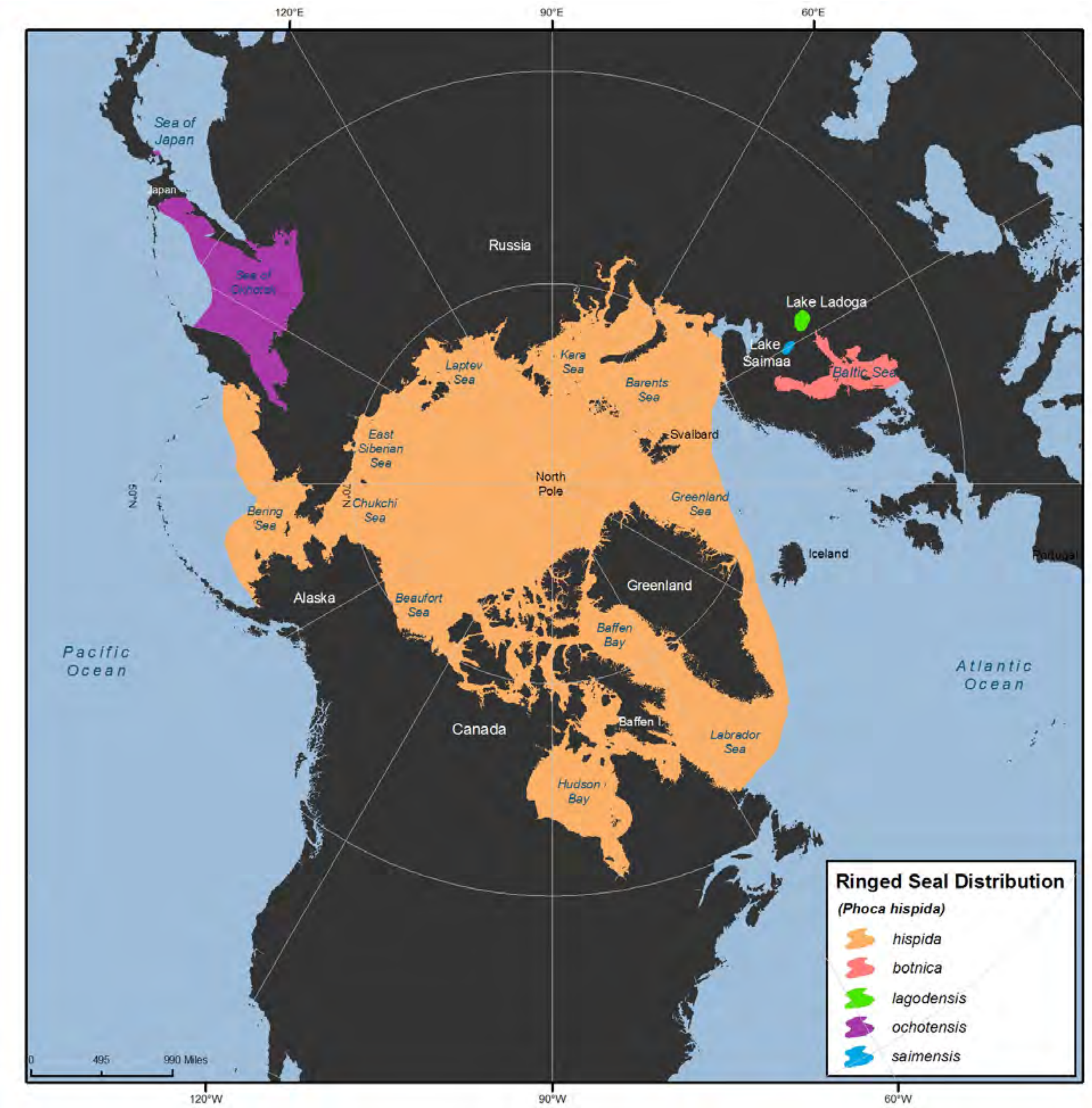
Finally, within *P. h. hispida*, polymorphisms in pelage pattern, body size, and craniology have been documented, but the relationships of polymorphism to population discreteness are unclear (Kelly 1988b). Although ringed seals in pack ice tend to be smaller than those on landfast ice, differences in body size may result from poorer growth in pack ice rather than from genetic isolation among populations (Kelly 1988b). Clearly, genetic work is needed to further elucidate relationships among subspecies and populations of the ringed seal.

III. Distribution

Ringed seals have a wide circumpolar distribution in the seasonally and permanently ice-covered waters of the Northern Hemisphere, northward to the North Pole (Figure 2) (Frost and Lowry 1981, Kelly 1988b). In the North Pacific, they extend southward to the southern Bering

Sea and southern Okhotsk Sea (Kelly 1988b). In the North Atlantic, they extend southward to Newfoundland to the west and the Baltic Sea to the east (Kelly 1988b). As discussed in detail below, the ringed seal distribution extends further north than that of all other Arctic pinnipeds because they are the only seal species that can create and maintain holes in thick sea ice (Kelly 1988b). The ranges of the five subspecies are further described below.

Figure 2. Distribution of the ringed seal.
Source: Based on Frost and Lowry (1981) and Miyazaki (2002).



The Arctic ringed seal *P. h. hispida* is found throughout the Arctic basin along the Arctic coasts of North America and Eurasia including Greenland, Baffin Island, Novaya Zemlya, Spitsbergen, and Labrador (Frost 1984). Ringed seals range seasonally in to the North Atlantic, Hudson and

James Bays, the White Sea, the coast of the Barents Sea in northern Norway, and the Bering Sea including Karaginskiy Bay and northern Bristol Bay (Frost and Lowry 1981, Rice 1998).

The Okhotsk ringed seal *P. h. ochotensis* inhabits the western, northern, and northeastern Okhotsk Sea, ranging south to the northern coast of Hokkaido to the west and Mys Lopatka, Kamchatka to the east (Rice 1998).

The Baltic ringed seal *P. h. botnica* inhabits the northern Baltic Sea including the gulfs of Bothnia and Finland, southward to Stockholm, Sweden, and Riga, Latvia (Rice 1998).

The Ladoga ringed seal *P. h. ladogensis* inhabits freshwater Lake Ladoga in Russia and may occasionally transit the Neva Reka between Lake Ladoga and the Gulf of Finland (Rice 1998).

The Saimaa ringed seal *P. h. saimensis* inhabits a series of interconnected lakes in Finland, including Lakes Saimaa, Haukivesi, Orivesi, Puruvesi, and Pyhäselkä, that are connected by a river to the adjacent sea (Rice 1998).

Seasonal changes in distribution and migration

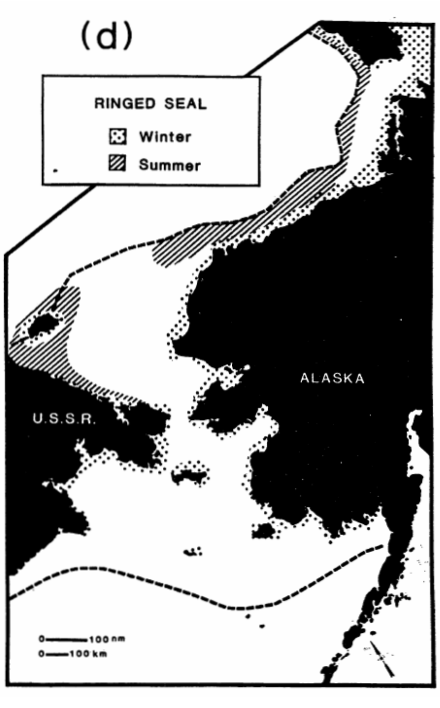
Sea ice is the major factor affecting the distribution of the ringed seal, which changes seasonally in association with the quantity and characteristics of sea ice (Frost and Lowry 1981, Frost 1984). In winter to early summer, adult ringed seals occupy breeding areas primarily in stable landfast ice over the continental shelf along Arctic coasts, bays, and inter-island channels, where they occur in the highest densities (Frost and Lowry 1981). Adults also use nearshore and offshore drifting pack ice where they occur in lower densities (Frost and Lowry 1981, Finley et al. 1983, Kelly 1988b, Wiig et al. 1999). Younger, smaller non-breeders are typically excluded from the inner landfast ice by breeding adults and occupy the outer, less stable landfast ice areas, flaw zones adjacent to the landfast ice, and drifting pack ice in winter and spring (Frost and Lowry 1981). During the molt period in May and June when territoriality breaks down, ringed seals haul out on the disintegrating landfast and pack ice above collapsed lairs, at enlarged breathing holes, near natural openings in the ice, and on ice remnants as warmer temperatures and long days of solar radiation melt the snow cover (Kelly 1988b, Burns 2002a). As the sea ice retreats in late spring and summer, ringed seals in many regions move northward with the sea-ice edge (Kelly 1988b). During summer and fall when the sea-ice extent is at a minimum and has disappeared from many regions, ringed seals of all ages occur along the edge of the permanent pack ice, on nearshore ice remnants, or in open water (Frost and Lowry 1981, Burns 2002a). Thus, ringed seals remain in contact with sea ice most of the year (Frost 1984, Kelly 1988b). The ringed seal distribution is generally smaller in winter and spring when they are constrained by access to breathing holes within territories in the landfast ice, and larger in summer when they occupy the reduced pack ice and open water. For example in Baffin Bay, the total area visited by ringed seals ranged between 10,300-18,500 km^2 in the summer open-water season, 2,500-7,000 km^2 in winter, and 800-2100 km^2 in spring (Born et al. 2004).

Ringed seals appear to be migratory in some regions, moving significant distances to maintain a year-round association with ice, while other populations are relatively sedentary and make only local movements in response to ice conditions (Burns 2002a). The movements of populations of each of the five subspecies are described in detail below.

Arctic ringed seal seasonal distribution: Bering, Chukchi, and Beaufort Seas

In winter and early spring, ringed seals are abundant in the northern Bering Sea and throughout the Chukchi and Beaufort Seas (Figure 3) (Frost 1984). In the Bering Sea in heavy ice years, ringed seals occur south to Nunivak Island and Bristol Bay, but are generally not abundant south of Norton Sound except in nearshore areas (Frost 1984). Ringed seals in the Bering Sea and Chukchi Seas occur in the highest densities in the extensive, largely unbroken landfast ice, although they are found throughout the Bering Sea pack ice (Burns et al. 1981). For example, aerial surveys in the eastern Chukchi Sea in late May-early June 1999-2000 found that ringed seals were four to ten times more abundant in nearshore fast and pack ice environments than in offshore pack ice (Bengtson et al. 2005). Most ringed seals that winter in the Bering Sea and southern Chukchi Sea migrate northward in late spring and early summer as the landfast ice melts and pack ice retreats (Frost 1984). Seals of the Bering Sea move through the Bering Strait in May and June, hauling out on remnant ice floes to molt and bask during this time (Frost 1984, Lowry 2000). Ringed seals of the Bering and Chukchi Seas spend the summer in the pack ice of the northern Chukchi and Beaufort Seas, although some juveniles may remain in ice-free open water in summer (Frost 1984, Lowry 2000). When sea ice begins to form again in autumn, many ringed seals migrate southward into the northern Bering and southern Chukchi Seas (Frost 1984). Ringed seals in Alaskan waters rarely haul out on land (Kelly 1988b).

Figure 3. Areas where the greatest densities of adult ringed seals in the Bering, Chukchi, and Beaufort Seas are thought to occur in winter and summer.
Source: Ray and Hufford (1989): Figure 1d.



In the Beaufort Sea where ice moves a relatively short distance offshore during the summer (at least until recently), ringed seals are thought to be much less migratory, making smaller seasonal movements from the winter and spring landfast ice to summer drifting pack ice and nearshore ice remnants (Lowry 2000). However, tagging studies indicate that some sub-adult ringed seals make long-distance movements westward from the Beaufort Sea during the summer. Of 300 ringed seals marked in fall in the eastern Beaufort Sea and Amundsen Gulf, four recoveries were made. Two seals were sighted near the tagging site while two other seals were sighted in the Chukchi Sea at Point Barrow, Alaska, and East Cape, Siberia, but it unknown if these seals returned to the eastern Beaufort Sea in the following spring or following years (Frost and Lowry 1981). Similarly, sub-adult ringed seals instrumented in the Canadian Beaufort Sea in the fall of 2001 and 2002 moved westward to the Chukchi and East Siberian Seas, traveling up to 2,500 km in six weeks (Harwood and Smith (2003) cited in Bengtson et al. 2005)).

Arctic ringed seal seasonal distribution: Svalbard and Baffin Bay

In Svalbard and Greenland, the Arctic ringed seal appears to exhibit a mixture of year-round site fidelity (i.e. remaining in same area year-round) and seasonal site fidelity (i.e. making long-distance movements from the breeding area in summer but returning to the breeding area in winter). In Svalbard, two studies of post-molting movements found that adult seals that used coastal fast-ice in winter and spring either (1) remained in coastal and fjord areas in summer, making only local movements, or (2) made long-distance feeding excursions north to the drifting pack ice up to 583 km from the tagging site but returned to the same breeding areas (Gjertz et al. 2000a, Freitas et al. 2008). Similarly, satellite telemetry studies of adult and sub-adult ringed seals tagged off northwest Greenland in northern Baffin Bay found that most seals remained in the area, making short-distance movements in coastal waters, while some seals emigrated from the area, including one sub-adult that made a long-distance 2000 km movement to southern Baffin Bay (Teilmann et al. 1999, Born et al. 2004). Another tagging study of sub-adults in Greenland found that 31 of 38 seals were caught within 120 km of the tagging site up to 14 years after tagging, while 3 of 38 seals made long-distance movements across Baffin Bay (Kappel et al. (1998) cited in Teilmann et al. (1999) and Gjertz et al. (2000a)).

Okhotsk ringed seal seasonal distribution

During winter and spring, Okhotsk ringed seals inhabit breeding areas in the landfast ice and drifting pack ice in the western and northwestern Okhotsk Sea and in the southern Okhotsk Sea near the Shantarsk Islands, Sakhalin Gulf, and eastern Sakhalin Island (Popov 1982, Fedoseev 2000). Although summer distribution has not been well-studied, ringed seals are thought to occupy coastal waters of the Okhotsk Sea during the summer and fall ice-free period (Fedoseev 2000).

Baltic ringed seal seasonal distribution

The winter distribution of the Baltic ringed seal is concentrated in areas of landfast and pack ice with good snow cover (Meier et al. 2004). The Baltic ringed seal has three distinct breeding areas: the Gulf of Riga, the eastern part of the Gulf of Finland, and the Bay of Bothnia, and breeding is also known to occur in the southwestern archipelago of Finland (Meier et al.

2004). Pupping occurs in February or early March in subnivian birth lairs on the landfast and pack ice, and the nursing period lasts another 4-6 weeks (Meier et al. 2004). Ringed seals haul out on sea ice to molt during April and May, when the Baltic sea ice is retreating (Meier et al. 2004).

Ladoga and Saimaa ringed seal seasonal distribution

The seasonal distribution of the Ladoga and Saimaa ringed seals are limited to the confines of inland lakes they inhabit.

IV. Adaptations to the Arctic Environment

The ringed seal is the most ice-adapted all northern pinnipeds (Frost 1984). Because of its unique adaptations, the ringed seal's range extends farther north and encompasses areas of heavier ice than any other marine mammal except the polar bear (Burns 2002a). Notably, the ringed seal is the only seal in the Northern Hemisphere that regularly inhabits the fast ice (Frost 1984). Two adaptations that allow ringed seals to inhabit stable, coastal landfast ice during the winter and spring are its ability to make and maintain breathing holes as the ice thickens by scraping the ice with the strong claws on their front flippers (Burns 2002a). Secondly, the ringed seal is able to excavate subnivian lairs in snowdrifts over its breathing holes, where it can conceal itself due to its small body size, and which it depends on for resting, giving birth, and nursing its pup during March-May (Stirling and Smith 2004, Burns 2002a). Each of these adaptations is described in more detail below.

Ringed seals surface to breathe in the open water of cracks and leads as the sea-ice extent increases in fall and early winter (Kelly 1988b). Wind and ice pressure also create pressure ridges and ice hummocks which have cracks that seals use as breathing holes (Smith and Stirling 1975). As openings begin to freeze over, ringed seals maintain breathing holes by breaking thin ice with their heads or scratching through with their stout claws (Kelly 1988b). Seals also scratch at the sides of breathing holes with their claws as the ice thickens and can maintain holes through 2 m or more of ice (Kelly 1988b). Breathing holes are approximately 30 cm in diameter at the surface and are surrounded by an ice dome at the surface created by the displacement of water by surfacing seals (Kelly 1988b). When snow accumulates and buries the breathing hole, the seal must breathe through the snow layer, although there is sometimes a small hole at the top of the dome (Smith and Stirling 1975, Kelly 1988b).

Ringed seals dig snow lairs on top of their breathing holes to create haulout lairs and birth lairs (Smith and Stirling 1975). To create snow lairs, seals enlarge the opening of the breathing hole to 40 cm and excavate chambers into the snow drift with their foreflippers (Kelly 1988b). Snow depths required for lair construction have been reported at 65-79 cm (Furgal et al. 1996). Due to the need for adequate snow cover, lairs are typically excavated next to pressure ridges, ice hummocks, or other ice deformities that accumulate deeper snowdrifts (Kelly 2001). Haulout lairs are typically single-chambered and round or elongate in shape while birth lairs are larger often with an extensive system of tunnels created by pups (Smith and Stirling 1975). Lairs of all types typically average 32 cm high (10-65 cm range), and birth lairs can be 30-900 cm long (Kelly 1988b). Less commonly, the ringed seal uses lairs formed in pressure ridges where ice buckles and rafts under pressure to create a natural cavity, but these are less stable (Kelly 1988b). Adult ringed seals maintain multiple breathing holes and lairs simultaneously, typically within a distance of 1-2 km (Bengtson et al. 2005). As described further below, the hidden complex of snow lairs provides concealment from predators and thermal protection for altricial pups and adults in winter and spring (Stirling and Smith 2004).

V. Habitat Requirements

The ringed seal depends on the sea ice for survival since sea ice represents the only substrate where ringed seals give birth, nurse their pups, and haul out to complete their annual molt (Frost 1984). In addition to providing a stable platform for critical life history activities (reproduction, molting, resting), sea ice and snow cover also afford protection from predators, insulate seals from exposure to extreme weather conditions, and influence the distribution and availability of prey species (Frost 1984). The sea-ice types that the ringed seal selects for its life history activities and the importance of sea ice for these activities are described below.

A. Sea-Ice Types Utilized for Critical Life History Activities

Landfast ice. Adult ringed seal preferentially use landfast ice in winter in spring where they maintain breathing holes and excavate subnivian layers in which to rest, give birth, and nurse their pups, and haul out to molt following the breeding season (Frost 1984). The fast ice is attached to land and forms ice sheets in coastal areas over shelves where it grows annually or for several years (Bluhm and Gradinger 2008). Landfast ice is likely preferred by ringed seals for reproduction because it provides the most stable platform for pupping, and nursing pups are less liable to be separated from their mothers in stable landfast ice than in offshore pack ice (Gjertz et al. 2000a, Lowry 2000). Habitat factors such as ice stability, snow accumulation, and degree of ice deformation influence the local abundance of ringed seals within areas of landfast ice (Smith and Stirling 1975).

The stability of the landfast ice is an important habitat factor for the ringed seal because it determines the length of time available for rearing pups before sea-ice breakup. Landfast ice stability is influenced by the topography of the coastline, ocean currents, and bathymetry. For example, in the Canadian Arctic, large expanses of relatively stable annual landfast ice are anchored between large islands or by complex coastlines indented with bays and fjords that protect the ice from early breakup (Smith and Lydersen 1991). In contrast, landfast ice in the northern Bering, Chukchi, and western Beaufort Sea occurs in an unprotected linear band that is more heavily influenced by storms and ocean currents at the time of freeze-up and throughout the winter (Frost et al. 2004). Multiple studies have found that highest proportion of ringed seal adults occurs in the more stable areas of the landfast ice to the interior and in deep bays and fjords, while subadults are more numerous in the unstable flaw zone adjacent to the pack ice edge (Frost 1984). For example, in Svalbard adults are found in prime breeding habitat in stable landfast ice areas sheltered from strong currents and anchored by nearby small islets or shoals, while subadults are found on the periphery of the landfast ice (Smith and Lydersen 1991).

The amount of snow accumulation is another critical habitat factor for the ringed seal because sufficient snow depth over breathing holes is essential for the construction of subnivian lairs for resting and rearing pups (Smith and Lydersen 1991). Snow accumulation is influenced by the degree of ice deformation, date of ice consolidation, snowfall, and ice stability (Smith and Lydersen 1991). Of particular importance, ice deformations like pressure ridges and ice hummocks facilitate thicker snow accumulation and provide more suitable habitat for lairs (Smith and Stirling 1975). In the eastern Canadian Arctic, ringed seal subnivian structures occur primarily in deep snow associated with large, thick ice ridges or deformations (Furgal et al. 1996). In western Svalbard, higher densities of subnivian structures occur near glacial fronts where ice debris frozen into the annual ice provides for sites of deep snow accumulation rather than in flat fjord and bayfast ice which have little snow accumulation (Smith and Lydersen 1991).

During the molting period following the breeding season, ringed seals utilize the flatter landfast ice and the ice edge (Frost et al. 2004). During the period of ice breakup, ringed seals that were widely distributed at holes on the landfast ice during the breeding season move to areas with less than 40% deformation of the ice surface and towards the landfast ice edge (Kelly 1988b, Frost et al. 2004). Ringed seals likely prefer smooth ice for basking because they are better able to detect approaching predators in open areas of smooth ice than in rougher ice (Frost et al. 2004).

Pack ice. Breeding adults and subadults are present in low densities in the moving pack ice where cracks, leads, and polynyas provide breathing holes (Frost 1984). Ringed seals appear to select areas with heavy pack ice coverage. Aerial surveys conducted over the pack ice south of St. Lawrence Island in March 2001, found that ringed seals prefer large, flat ice floes (>48 m in diameter) common in the interior ice pack in areas with greater than 90% sea-ice coverage (Simpkins et al. 2003). Ringed seals commonly use and maintain breathing holes in the middle of these large floes, although they also haul out along the edge of floes of various sizes (Simpkins et al. 2003). Flat floes devoid of ice ridges likely allow ringed seals hauled out at holes in the middle of these floes to detect and avoid predatory polar bears approaching over the ice (Simpkins et al. 2003). In the Barents Sea, breeding ringed seals use pack ice habitat of near compact (7/10-10/10) first year pack ice ranging from 50-100 cm thick with new-frozen ice in between, where snow depth above subnivian lairs was 50 to 100 cm thick (Wiig et al. 1999).

Ringed seal distribution does not appear to be constrained by water depth since they prey on pelagic organisms and are found over abyssal depths of the Arctic basin as well as in shallow waters of the continental shelf (Frost 1984).

B. Importance of Sea Ice and Snow Cover to Reproduction

Ringed seals give birth and nurse their pups exclusively in subnivian lairs in landfast ice and pack ice. Ringed seal pups are born in snow lairs in late winter to early spring, nursed for six weeks or more, and weaned prior to ice breakup (Kelly 1988b). Birthing and nursing pups occurs when the ice is most stable and snow cover is at a maximum but not yet affected by thawing temperatures (Kelly 1988b). During the reproductive period, sea ice and snow cover provide several advantages that influence reproductive success and pup survival.

First, sufficient snow cover over subnivian lairs is essential to pup survival by providing physical concealment from predators during the long nursing period (Kelly 2001). While snow lairs are intact, pups are safe from visual predators like gulls and ravens (Kelly 2001). However, polar bears and Arctic foxes, which are olfactory predators, collapse or excavate lairs to hunt ringed seal pups and adults (Ferguson et al. 2005). One common hunting method used by polar bears is to locate a seal lair by smell, collapse the top of the den, and seize an unwary seal (Stirling 1998). Several studies have found that polar bear success in killing seals in lairs decreases as snow depth and thickness of the roof covering lairs increases (Hammill and Smith 1991, Furgal et al. 1996), and additionally that predation attempts decrease with increasing snow depth (Hammill and Smith 1991). The deep snow of the birth lair also acts as a barrier to fox entry and gives the female seal time to move her pup to an alternate structure (Smith and Lydersen 1991). Thus, pups in subnivian birth or haulout lairs with thin snow roofs are more vulnerable to predators than those in lairs with thick roofs.

Secondly, sufficient snow roofs on subnivian lairs are crucial for providing thermal insulation for the ringed seal pup, especially for the prevention of hypothermia. Ringed seal pups are the smallest neonates of any polar seal, averaging 4-4.5 kg, are born without an insulating blubber layer, and have a high surface area to volume ratio that makes it difficult to conserve heat (Smith and Stirling 1975). The insulating white lanugo of the ringed seal pup is largely sufficient to keep the pup thermoneutral without the shelter of the lair if the lanugo stays dry (Smith et al. 1991). However, lanugo loses its insulative properties when wet (Stirling and Smith 2004). Ringed seal pups are forced to enter icy waters if the subnivian lair is attacked by polar bears or Arctic foxes in order to escape and move to an alternate lair (Smith and Lydersen 1991). Female ringed seals will move a young pup between lairs within her complex if the lair is attacked, while older pups are able to shift between lairs independently to escape predators (Smith et al. 1991). As pups get older, they also begin to enter the water to practice diving while still in the lanugal phase (Lydersen and Kovacs 1999). The insulation of the subnivian birth lair is critical to pup survival since wet pups require the shelter of lairs in order to regain thermoneutrality, especially when temperatures fall below freezing (Smith et al. 1991, Stirling and Smith 2004).

Subnivian lairs provide a significantly warmer environment compared to outside temperatures because the snow cover traps heat from the seawater below the lairs and from the body heat of seals (Kelly 2001). Ringed seal pups are born primarily in April when winds and temperatures as cold as -30°C result in extremely low wind chill temperatures (Kelly 2001). In a study of the thermal environment of subnivian lairs in the Alaskan Beaufort Sea from early in the birthing season to late spring of 1998-2001, researchers found that temperatures inside lairs in April were above -9°C (mean = -5°C, sd=1.6) while outside air temperatures were as low as -29°C (mean = -15°C, sd = 5.3). Internal lair temperature increased by an average of 7°C when occupied by a seal and increased primarily in the first hour of hauling out (Kelly 1988b).

Because of the importance of subnivian lairs to pup survival, it is critical that the landfast and pack ice used for pupping and the snow cover over subnivian lairs remain stable throughout the long six-week nursing period that typically lasts through June. Because they have the longest lactation (36-41 days) and slowest growth of pagophilic pinnipeds (Lydersen and Kovacs 1999), ringed seal pups are vulnerable to circumstances forcing them to abandon their stable ice platform prior to the end of nursing period (Smith and Harwood 2001). Since pups attain 93% of their first-year growth during the nursing period, premature weaning would most certainly compromise pup growth and result in wasting, stunting, and increased mortality (Smith and Harwood 2001). Young seal pups forced into the water at an early age would also be exposed to increased risks of predation and thermal stress (Smith and Harwood 2001). Even after molting and weaning, pups require access to ice for resting since swimming is energetically costly (Smith 1987). Pups lose weight immediately after weaning in June and July during the period of independence when they are learning foraging skills (Kelly 1988b), and the persistence of sea ice during this energetically stressful transition period undoubtedly influences pup fitness. Thus, stable ice is essential for the survival and fitness of pups throughout the nursing period and post-weaning (Frost 1984).

Snow cover must also be of sufficient depth for building lairs. When ringed seals are forced to birth in the open due to lack of snow cover, nearly 100% of pups succumb to predation (Kelly 2001). For example, in Svalbard where low snow cover causes ringed seals to birth their pups in the open in some years, pups born outside of snow lairs are heavily depredated by Arctic foxes and avian predators:

> During a period from 5 to 9 April one of us (TGS) … witnessed several pups being born in the open. We were able to observe up to four foxes waiting in the nearshore pressure ice for females to drop their pups. In one instance a fox appeared beside the newly born seal within one minute of birth and frightened the mother who dived down her hole into the water. The pup was dragged away and killed (Smith and Lydersen 1991: 591).

C. Importance of Sea Ice to Molting

Ringed seals molt annually on the sea ice from late March through July (Frost and Lowry 1981, Burns 2002a). Young, reproductively immature individuals molt earlier than breeding adults who undergo peak molt in May to June (Frost and Lowry 1981). During the molt, ringed seals emerge from their snow lairs to haul out for long periods of time on fast ice near collapsed lairs, enlarged breathing holes, and flat floes of pack ice near cracks, leads, or holes where they have rapid access to water (Frost 1984, Burns 2002a).

During molt the growth of new hair depends on high skin temperatures and these temperatures are only reached when the seals are out of the water (Feltz and Fay 1966). The requirement for elevated epidermal temperatures to grow new hair likely underlies the increasing amount of time that ringed seals spend hauled out in spring even when still using subnivian lairs (Kelly 1988b). During molt, feeding reflexes are inhibited and overall activity decreases, meaning that ringed seals need to spend most of their time sleeping on ice during this physiologically demanding period (Fedoseev 2000). Therefore, persistence of the sea ice through June is critical to allowing ringed seals adequate time to complete their molt.

D. Importance of Sea Ice to Resting

Ringed seals use the sea ice for resting throughout the period of sea-ice cover, from within subnivian lairs in winter and early spring and later on the ice surface in late spring and summer. Resting periods on sea ice may be particularly critical for adult female ringed seals. Carlens et al. (2006) found that ringed seal adult females haulout for the longest periods (up to 141 hours of continuous haulout), likely due to an increased need for rest after a demanding nursing period.

VI. Reproduction and Reproductive Behavior

The breeding system of the ringed seal is thought to be monogamous or polygynous (Kelly and Wartzok 1996). Males are in breeding condition from late March through mid-May and show evidence of territorial defense behaviors during the breeding season that include the following: (1) males bear wounds during the breeding season and the flippers of old males show heavy scarring; (2) males emit a strong odor during the breeding season by secreting an oily substance from the facial sebaceous glands that they likely use to mark breathing holes; and (3) vocalization rates are higher during the breeding season (Kelly 1988b, Krafft et al. 2007). Male seals appear to defend underwater territories during the mating season that encompass the activity areas of several females or may defend access to breathing holes of females (Kelly and Wartzok 1996). In Svalbard, adult females occupy the inner, stable fast-ice area, subadults occupy less stable outer fast-ice, and males occupy both areas, suggesting that males compete for territories in the prime breeding areas and attempt to exclude subordinate males from these areas (Krafft et al. 2007). The sex ratio in prime breeding areas in Svalbard is 1 male to 2.4 females which also indicates a slightly polygynous mating system (Krafft et al. 2007).

Mating occurs under the ice primarily in late April and early May within one month of parturition while females are still lactating, although females breeding for the first time may mate earlier in the season (Kelly 1988b). Typically 85-95% of mature females are thought to be pregnant in each year (Kelly 1988b). Gestation lasts ~11-12 months including a period of delayed implantation of the blastocyst lasting 2.5 to 3.5 months after mating (Kelly 1988b).

Females give birth to a single pup in a subnivian lair on the landfast ice or pack ice from mid-March to mid-April depending on the region (Kelly 1988b). Ringed seal pups are typically 60-65 cm in length and 4.5-5.0 kg in weight at birth, although regional variation exists (Kelly 1988b). Pups are born in white, wooly lanugo which provides insulation while they develop a blubber layer (Kelly 1988b). Pups begin to shed the lanugo at two to three weeks old and are fully molted at six to eight weeks old, when the lanugo is replaced by a shorter, less-insulating adult pelage (Frost and Lowry 1981). Ringed seals have the longest nursing period of the ice-breeding northern phocids which lasts approximately five to seven weeks (Kelly 1988b, Krafft et al. 2007).

Ringed seal pups survive immersion as newborns by burning brown adipose tissue, but pups begin entering the water voluntarily after they accumulate a subcutaneous blubber layer (Lydersen and Kovacs 1999). A study of three seal pups in Svalbard that were tagged during the nursing period at 25-39 days old indicated that they spent ~50% of their time in the water and ~50% of their time hauled out on ice (Lydersen and Hammill 1993). Pups spent 80% of their time in the water at the surface and 20% making shallow, short duration dives averaging 59 seconds and less than 10 m (Lydersen and Hammill 1993). Maximum dive duration and depth were 12 minutes and 89 m for the oldest pup (39-49 days old) (Lydersen and Hammill 1993). Pups used an average of 8.7 ± 3.5 breathing holes. The large proportion of time spent in the water, development of diving skills, use of multiple breathing holes, and prolonged lanugo stage are likely adaptations to avoiding predation from polar bears (Lydersen and Hammill 1993).

Ringed seal pups are weaned abruptly when the female abandons the pup in the subnivian lair (Frost and Lowry 1981). Weaning typically occurs when pups have gained a maximum deposition of blubber, have shed their lanugo, and sea ice begins to break up (Kelly 1988b). Weaned pups typically stay in the proximity of the collapsed subnivian lair and bask on top of the ice (Frost and Lowry 1981). Newly weaned pups in the Bering and Okhotsk Seas average 82 cm in length and 9-12 kg in weight which is two to three times their birth weight (Frost and Lowry 1981, Kelly 1988b). Pups lose weight immediately after weaning in June and July during the period of independence when they are learning foraging skills (Kelly 1988b).

VII. Diet and Foraging Behavior

Ringed seals exhibit seasonal, geographic, and age-related differences in diet (Frost 1984). During late summer, fall, winter, and early spring, ringed seals spend much of their time in the water foraging, while feeding intensity is greatly reduced in the late spring and early summer when ringed seals bask on the sea ice during molt (Frost 1984). Ringed seals in any one area rarely prey upon more than 10-15 species and not more than 2-4 species are considered as important prey (Weslawski et al. 1994). This indicates that ringed seals depend strongly on a few key prey species in any area (Weslawski et al. 1994). The ringed seal diet consists primarily of fishes of the cod family (especially Arctic and saffron cod), pelagic amphipods, euphausiids, shrimps, and other small crustaceans (Frost and Lowry 1981). The Arctic cod (*Boreogadus saida*) is the dominant prey in most localities.

An analysis of stomach contents from 973 ringed seals from seven locations in the Alaskan waters of the Bering, Chukchi, and Beaufort Seas in 1976-1977 showed significant seasonal and regional differences in diet (Lowry et al. 1980b). In winter, Arctic cod comprised 90% of the diet in most study regions (Lowry et al. 1980b). In late spring to early summer, epibenthic crustaceans such as shrimps, mysids, and gammarid amphipods were predominant in the diet and the total volume of food consumed decreased (Lowry et al. 1980b). In late summer and early fall, pelagic crustaceans such as euphausiids and hyperiid amphipods and saffron cod (*Eleginus gracilis*) comprised the major prey (Lowry et al. 1980b). Age related diet differences were evident in the northeastern Bering Sea and southeastern Chukchi Sea during spring and early summer where younger seals consumed a lower proportion of fish and higher proportion of crustaceans (Lowry et al. 1980b), although diet studies in the Beaufort Sea indicated that both pups and adults eat large quantities of Arctic cod (Frost 1984). Stomach analysis of 1893 ringed seals collected at Point Hope in the southern Chukchi Sea from November 1960 to mid-June 1961 found that more than 90% of volume of stomach contents consisted of fish, primarily Arctic cod, during November to February (Johnson et al. 1966). Saffron cod replaced Arctic cod in importance in April-June, and invertebrates became more important than fish in March through June particularly hyperiid amphipods, shrimp, and mysids (Johnson et al. 1966). Ringed seal stomach contents had the highest average volumes during December to February (116 cm^3, 264 cm^3, and 149 cm^3 respectively) when Arctic cod was the predominant food species, highlighting the importance of this prey species, and the average volume of stomach contents was lowest in June (35 cm^3) (Johnson et al. 1966).

Diet studies in Baffin Bay, the Barents Sea, and Svalbard also indicate that Arctic cod is predominant in the ringed seal diet. A study of ringed seal diet using stomach content analysis and stable isotope analysis from seals collected in northern Baffin Bay on the west versus east sides of the North Water Polynya in May-July 1998 found that Arctic cod was the dominant prey items for adult seals throughout the polynya (Holst et al. 2001). This study also found some evidence for age-related diet shifts since the amphipod *Themisto libellula* was the dominant prey type in the diet of immature ringed seals from the western polynya, although Arctic cod predominated in the diet of immature seals in the eastern polynya, similar to adults (Holst et al. 2001). In the Barents Sea, a stomach content analysis from ringed seals sampled along the ice edge in October 1995 indicated that diet was dominated by Arctic cod (Wathne et al. 2000). Ringed seal diet studies from Svalbard showed that Arctic cod, shrimp *(Pandalus borealis)*, krill *(Thysanoessa inermis)* and the amphipod *Themisto libellula* were the most important prey, and that prey changed seasonally (Weslawski et al. 1994). Ringed seals consumed more benthic prey in winter and more pelagic prey during ice breakup and the open water period in summer (Weslawski et al. 1994).

Ringed seals are primarily shallow divers, although they are capable of deep diving. A study of male and female ringed seal diving in the Northwest Territories during the breeding season found that modal dive depths were between 10-45 m for breeding-age males and 100-145 m for subadult males and post-parturient females (Kelly and Wartzok 1996). The maximum observed dive depth of 222 m in this study was limited by water depth in the study area (Kelly and Wartzok 1996). Median dive durations were less than 10 minutes with a maximal duration of 26.4 minutes (Kelly and Wartzok 1996). The shorter and shallower dives for males suggested that males might be spending much of their time guarding territories or mates near the ice undersurface (Kelly and Wartzok 1996). A study of diving by post-molting ringed seals in Svalbard from July through winter found that half of all dives were shallower than 20 m and 90% were shallower than 100 m (Gjertz et al. 2000a). Most dives (95%) were shorter than 10 minutes and 99.5% were shorter than 15 minutes (Gjertz et al. 2000a). Ringed seals in North Water Polynya of northern Baffin Bay foraged primarily in the upper 100 m, and mostly in the upper 50 m, where their main prey of Arctic cod and *T. libellula* occurred (Born et al. 2004). However, some adults dove deeper, especially in winter and early spring, to maximum depths over 500m, probably to forage on benthic prey such as older Arctic cod and cephalopods (Born et al. 2004). Blood characteristics indicate that ringed seals are adapted for deep or sustained diving, given their high total erythrocyte and hemoglobin concentrations that confer high oxygen storage capacity (Frost and Lowry 1981).

VIII. Sources of Natural Mortality

Predators of ringed seals include killer whales (*Orcinus orca*), Greenland sharks (*Somniosus* microcephalus), walruses (*Odobenus rosmarus*), polar bears (*Ursus maritimus*), wolves (*Canis lupis*), Arctic foxes (*Alopex lagopus*), red foxes (*Vulpes vulpes*), wolverines (*Gulo

gulo), ravens (*Corvus corax*), and gulls (*Larus* spp.), but polar bears and Arctic foxes are the most significant predators (Kelly 1988b).

Polar bears prey on all age classes of ringed seals, although studies in Canada indicate that they prey more heavily on ringed seals less than two years of age, particularly from March until ice breakup (Kelly 1988b). Polar bears hunt seals on moving, offshore ice along floe edges and also on stable landfast ice by catching animals when they surface to breathe and by pouncing on lairs and pinning seals (Kelly 1988b). In the Canadian Arctic, polar bear depredation on seal lairs in the landfast ice varied regionally from 1.6% to 20.3% where 17% to 33% of the incidents were confirmed as kills (Kelly 1988b). In the Canadian High Arctic, polar bears are reported to kill a ringed seal every 2-4 days in spring and every 5 days in summer (Kingsley and Stirling 1991). Thus polar bear predation is a major source of mortality for ringed seals. Behaviors of ringed seals at haulout sites that are likely adaptation for reducing polar bear predation include lying facing both their breathing holes and downwind and maintaining a high level of vigilance (Kingsley and Stirling 1991).

Arctic foxes depredate ringed seal pups after excavating birth lairs (Kelly 1988b). In the eastern Beaufort Sea in Amundsen Gulf, a four-year study from 1971-1975 found significant depredation by Arctic foxes, estimated at 26.1% of ringed seal pup production (range 4.4 to 57.7%) (Kelly 1988b). Fox depredation may be less frequent in the western Beaufort Sea where foxes and birthing lairs occur at lower densities (Kelly 1988b). A study between Point Barrow and Flaxman Island from 1982-1985 found that 12.8% of lairs had been entered by foxes, and 25% of examined lairs showed evidence of a kill (Kelly 1988b).

Walruses occasionally feed on phocid seals including ringed seals, and most seal-eaters appear to be males (Kelly 1988b). Lowry and Fay (1984) found that Pacific walruses may have increased their consumption of seals, including ringed, spotted, and bearded seals, in the late 1970s compared with the 1950s and 1960s. They suggested that seal consumption may increase in years when Bering Sea sea-ice extent is lower than average, leading to a greater overlap in the distributions of walruses and seals (Lowry and Fay 1984).

In Svalbard, pups are killed by glaucous gulls (*Larus hyperboreus*) when pups are exposed in years with insufficient snow cover or during periods of mild temperatures and rain which melt snow lairs (Lydersen and Smith 1989). Lydersen and Smith (1989) note that the ringed seal pup’s small body size and long nursing period make it especially vulnerable to avian predators when it doesn’t have the protection of the snow lair and that avian predation may even be a factor limiting the southern range of breeding ringed seals.

IX. Demographic Rates

Demographically, ringed seals exhibit delayed maturity, low reproductive rates, high adult survival, and high longevity which are associated with a ‘slow’ life history strategy. Accordingly, their population growth rates are sensitive to changes in adult survival and they are slow to recover from population declines.

Age at maturity. Male ringed seals reach sexual maturity at 5-7 years while females reach sexual maturity at 4-8 years (Kelly 1988b).

Fecundity. The reproductive rate for ringed seals is 16-18% (Frost 1984). Reproductive rates appear to remain constant from age ten to maximum life expectancy (Frost 1984).

Survivorship. Survival rates are lowest in the first year of life. Survival is estimated at 59-70% in pups and increases to 90% by sexual maturity, decreasing slowly after 15 years of age (Kelly 1988b).

Longevity. Average life expectancy is 15-20 years, although ringed seals can live to at least 43 years (Frost and Lowry 1981, Kelly 1988b).

X. Abundance and Population Trends

Current Abundance

Ringed seals are thought to be the most abundant phocid in the northern hemisphere (Kelly 2001). Estimates of the global population of ringed seals range from 2.3 to 7 million, but surveys have not been comprehensive across the range and abundance estimates are generally unreliable (Kelly 1988b). Perhaps the most comprehensive population estimates are available for the geographically constrained Baltic, Lake Saimaa, and Lake Ladoga ringed seal that are more accessible for censusing than the more widespread and inaccessible Arctic and Okhotsk ringed seals.

Estimates of population sizes for ringed seals are derived primarily from aerial surveys conducted during late spring and early summer during the molt period when high numbers of ringed seals of all ages bask on the ice surface (Frost and Lowry 1981). Densities of seals from aerial surveys are used to approximate total population size using conversion factors for the proportion of seals visible on the ice surface relative to the total number (Frost and Lowry 1981). Correction factors are typically extrapolated from the haulout behavior of a small sample of tagged seals during the survey to the entire population. However, the multitude of studies that have examined haulout behavior in order to develop correction factors have generally found a high degree of variance in haulout patterns across individuals and years, making it difficult to develop reliable correction factors. Thus, a problematic underlying assumption of this methodology is that the proportion of seals visible during the surveys is sufficiently constant among individuals and years to permit inter- and intra-annual comparisons of estimated densities.

Kelly (1988b) provided an estimate of 1 to 1.5 million ringed seals in Alaskan waters based on Littlefield (1977), but noted that this estimate is crude because of inadequate methodology for estimating population size (Kelly 1988b), and indeed the methods used to generate this estimate are not specified. In its most recent stock assessment, NMFS states that a reliable abundance estimate for the entire Alaska stock of ringed seals is currently not available (Angliss and Outlaw 2008). Some partial estimates for ringed seal abundance in Alaskan waters were provided by Bengtson et al. (2005) and Frost et al. (2002). Based on aerial surveys in May-

June of 1999 and 2000 along the eastern Chukchi Sea coast from Shishmaref to Barrow, Bengtson et al. (2005) estimated 252,488 (SE = 47,204) and 208,857 (SE = 25,502) ringed seals in 1999 and 2000, respectively, after correcting for seals not hauled out. Aerial surveys conducted in May-June 1985-1987 in the Alaskan Beaufort Sea estimated ringed seal densities ranging from 0.81 to 1.17/km^2 (Frost et al. 2002). Based on a survey area of 18,000 km^2 and an average seal density of 0.98/km^2, NMFS estimated ~18,000 seals for the Beaufort Sea without correcting for seals not hauled out (Angliss and Outlaw 2008). Combining the estimate of 18,000 ringed seals for the Beaufort Sea with an average estimate of 230,673 ringed seals for the eastern Chukchi Sea results in a total of approximately 249,000 ringed seals (Angliss and Outlaw 2008). However, this is an under-estimate since it does not include ringed seals throughout their range in Alaskan waters.

The most recent population estimate for the Okhotsk ringed seal is 650,000-700,000 individuals based on aerial surveys between 1968-1990 (Fedoseev 2000). Estimated population sizes for the remaining subspecies are 5,000-6,000 Baltic ringed seals in 1996 (Ministry of Agriculture and Forestry 2007), 220-250 Saimaa ringed seals in the late 1990s (Kokko et al. 1999, Palo et al. 2003), and ~5,000 Ladoga ringed seals in the mid 1990s (Sipilä et al. 1996).

Population trends

Population trends for ringed seals are difficult to detect because there are few repeated or reliable abundance estimates. However, population declines have occurred in all populations for which trend analysis is possible.

For the Arctic ringed seal, Frost et al. (2002) reported that trend analysis based on a comparison of observed seal densities in the central Beaufort Sea in the 1980s and 1990s suggested a marginally significant but substantial decline of 31% in the ringed seal population from 1980-87 to 1996-99. A Poisson regression model indicated highly significant density declines of 72% on fast ice and 43% on pack ice over the 15-year period (Frost et al. 2002). However, Frost et al. (2002) noted that the apparent decline between the 1980s and the 1990s may have been due to a difference in the timing of surveys rather than an actual decline in abundance.

For the Okhotsk ringed seal, censuses conducted between 1968-1990 (Fedoseev 2000) indicate a slightly declining population trend over this time period. The Baltic ringed seal population decreased dramatically from ~190,000-200,000 individuals at the beginning of the 1900s to ~4000 in the late 1970s, primarily due to excessive hunting but also due in part to sterility caused by organochlorine contaminants (Meier et al. 2004). The total population was estimated at 5,000 in the mid-1980s (Kokko et al. 1999) and 5,600-6,000 in 1996, of which 4,000 were estimated in the Bothnian Bay, 1,000 in the Gulf of Riga, a few hundred in the Gulf of Riga, and ~150 in the Archipelago Sea (Ministry of Agriculture and Forestry 2007). The Baltic ringed seal population in the Bothnian Bay is reported to have increased by 5% per year according to population estimates between 1988-2002, but the remaining populations do not appear to be growing (Ministry of Agriculture and Forestry 2007).

The Saimaa ringed seal population declined drastically during the 20th century from 1,000 seals to 130-150 in the 1980s due to overhunting and then due to fisheries bycatch, human disturbance, and regulation of water levels (Palo et al. 2003). The population increased slightly to 220-250 seals in the late 1990s (Palo et al. 2003). Similarly the Ladoga ringed seal population declined dramatically from 20,000 seals at the beginning of the 20th century to ~5,000 in the mid-1990s due to overhunting, fisheries bycatch, and human disturbance (Sipilä et al. 1996).

BEARDED SEAL (*Erignathus barbatus)*

I. Species Description

The bearded seal (*Erignathus barbatus*) is the largest of the four ice-associated phocids that inhabit Alaskan waters (Kelly 1988a). Its species name *barbatus* (bearded) refers to its distinctive long mustachial vibrissae that curl inward when dry (Burns 1981). Adult bearded seals range in color from gray to brown with a slightly darker dorsal surface, the hair is short and straight, and sexes are similarly colored (Figure 4) (Burns 1981). In some regions, bearded seals have a reddish or rust-colored face and foreflippers that likely comes from contact with ferrous compounds in bottom sediments that adhere to surface of hair and oxidize when brought to the surface (Kovacs 2002). Bearded seal pups are born mostly molted with a dense coat of brown or gray, slightly wavy hair that can be interspersed with fuzzy gray-blue lanugo (Burns 1981, Kovacs 2002). Pups also have white patches and white eyebrow spots on their faces and one to four broad, transverse light bands on the crown and back (Burns 1981, Kovacs 2002).Yearlings look similar to pups but their facial pattern is less distinct and they have small dark spots on their bellies (Kovacs 2002).

The bearded seal is also distinguished by its robust, rectangular-shaped body with a relatively small head, square-shaped foreflippers with strong claws, and the presence of four mammary glands where other northern phocid seals have two (Burns 1981, Kovacs 2002). Its robust body form comes from its wide girth that measures 71-83% of its standard length behind the foreflippers (Burns 1981). Compared with other ice-associated phocids of North Pacific, the bearded seal’s skull is wide, comparatively short, and massive, which likely assists in breaking through the ice with its head (Burns 1981). The bearded seal has an arched palate and large buccal cavity that is presumed to be an adaptation for a modified type of suction feeding (Burns 1981). The foreflippers have a blunt, squared appearance because the third digit slightly longer than the others, which contrasts with other northern phocids in which the first digit is the longest (Burns 1981). While resting on ice floes, bearded seals can be distinguished by their large size and behavior of resting singly at the edge of floes oriented towards the water (Kelly 1988a).

Male and female bearded seals are similar in appearance. Sexual size dimorphism is manifest in the body dimensions of some populations including those in the southern Okhotsk Sea and Bering and Chukchi Seas where females are 3%-4% longer than males on average (Johnson et al. 1966, Burns 1981). In the Bering and Chukchi Seas, the average length and weight of adult bearded seals of both sexes ages 10 and older is 223 cm and 229 kg, respectively (Burns 1981). On a sex-specific basis, the maximum length and weight for females is 243 cm and 360.5 kg while that of males is 233 cm and 262 kg (Burns 1981). In the southern Okhotsk Sea females aged 10 years and older average 223 cm in length and 225 kg in weight while males average 216 cm in length and 209 kg in weight (Fedoseev 2000). In Svalbard, average masses are 247.3 kg for adult males and 245.0 kg for adult females (Gjertz et al. 2000b). Bearded seals of both sexes undergo seasonal changes in thickness of their blubber layer which varies from high values averaging 7.2 cm in late fall through early spring to low values averaging 4.4 cm in summer when lactation and reduced feeding association with molt contribute to blubber loss (Burns 1981). Newborn pups in the Bering and Chukchi Seas average 131.3 cm in length and 33.6 kg in weight (Burns 1981).

Figure 4. Bearded seal resting on ice.
Photo courtesy © David S. Isenberg.

II. Taxonomy

The bearded seal *Erignathus barbatus* (Erxleben, 1777) belongs to the order Carnivora, suborder Pinnipedia, family Phocidae, subfamily Phocinae, and is the only member of genus *Erignathus* (Rice 1998). Two intergrading subspecies of the bearded seal are recognized: the Atlantic bearded seal *E. b. barbatus* (Erxleben, 1777) and Pacific bearded seal *E. b. nauticus* (Pallas, 1811) (Rice 1998). The Pacific bearded seal is confined principally to the Arctic and subarctic waters of the Laptev Sea eastward to the central Canadian Arctic, while the Atlantic bearded seal occurs in the Arctic and subarctic waters from the eastern Canadian Arctic (Hudson Bay) eastward to the Laptev Sea (Burns 1981, Rice 1998).These subspecies have been distinguished based on differences in skull morphology by three studies (Kosygin (1969), Manning (1974), and Chapskiy (1975)) although one study has disputed this division (Kosygin and Potelov (1971)). Heptner et al. (1976) described differences in the condylobasal length of the skull, dimensions of the nasal bones, and body size (e.g. Pacific bearded seal are slightly larger in size) that differentiate the subspecies. As noted by Naumov and Smirnov (1936), morphological differences between the subspecies overlap and require a large sample size to distinguish: “The distinctive features of *E. b. nauticus* are generally not quite distinct as they overlap with each other, and many of them can be recognized only when comparing in a large series” (Naumov and Smirnov 1936 cited in Heptner et al. 1976).

Researchers have noted differences in the morphology and vocalization structure among bearded seal populations that indicate the presence of population structure. For example, populations in the Bering and Okhotsk Seas differ in the number of lip vibrissae, in the shape of the nasal bones and occipital foramera, in body dimensions (length and weight), and in helminth parasite species (Fedoseev 2000). Differences in repertoire size and structure of bearded seal vocalizations measured at widely spaced sites in the Arctic (eastern Chukchi/western Beaufort Seas, western Canadian Arctic, Hudson Bay, Baffin Bay, and the Canadian High Arctic) also suggest that bearded seals in these regions are geographically isolated by physical distance and may represent different breeding populations (Cleator et al. 1989, Risch et al. 2007). Clearly, genetic studies will be important in clarifying the taxonomic relationships between bearded seal subspecies and populations.

III. Distribution

A. General Distribution

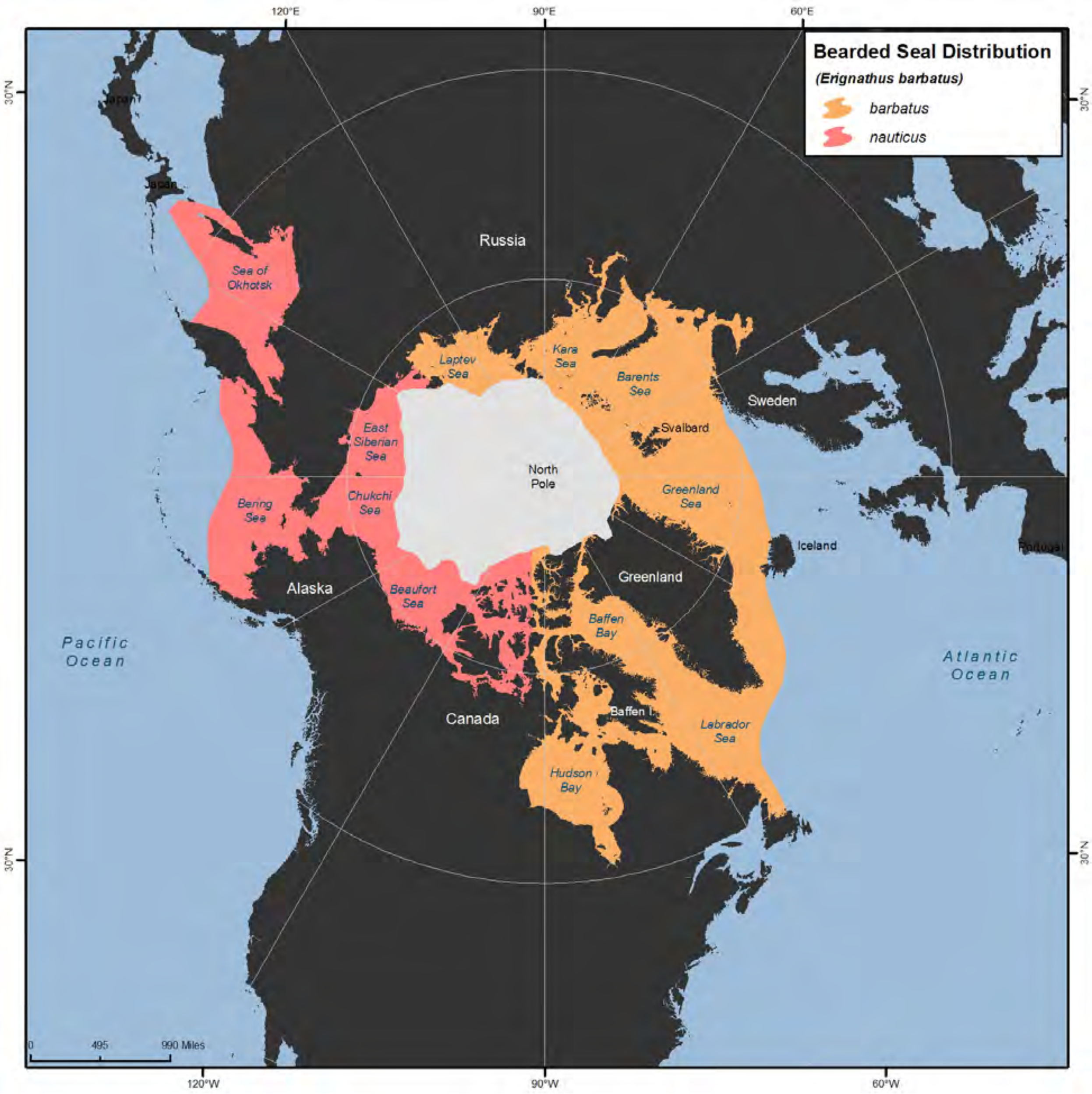
The bearded seal *Erignathus barbatus* occurs in a patchy circumpolar distribution around the perimeter of the Arctic Ocean and the contiguous subarctic seas, with a northern limit of 85°N in the Arctic Ocean and southern limits of 45°N in Hokkaido and 55°N in Hudson Bay (Figure 5) (Kelly 1988a).

The Atlantic bearded seal *E. b. barbatus* is found in the eastern Canadian Arctic eastward to the Laptev Sea, including Baffin Bay, the Barents Sea, and the Kara Sea (Burns 1981, Kelly 1988a). Its northern range extent includes Jones Sound in the Canadian Arctic Archipelago, Kap York in western Greenland, Nordostrundingen in eastern Greenland, Svalbard, Franz Josef Land, and Novaya Zemlya, and its southern range extent includes James Bay, northern Newfoundland, Kap Farvel in Greenland, Iceland, Jan Mayen, Bjørnøya, and Vesterålen in northern Norway (Rice 1998).

The Pacific bearded seal *E. b. nauticus* occurs in Arctic and subarctic seas from the Laptev Sea eastward to the central Canadian Arctic, including the East Siberian, Chukchi, and Beaufort Seas southward to the Bering and Okhotsk Seas (Burns 1981, Kelly 1988a). In the East Siberian Sea, bearded seals occur in the region near Chaunsk Bay, the coastal areas east of Cape Shelagsk, and the region directly adjoining Wrangell Island, but are apparently absent in western parts of the sea, including the Kolyma region (Heptner et al. 1976). Based on the absence of bearded seals from the western region of the East Siberian Sea, Heptner et al. (1976) suggested that the boundary between the ranges of *E. b. barbatus* and *E. b. nauticus* occurs in the East Siberian Sea rather than in the Laptev Sea. Noting the low numbers of bearded seals in the Laptev and East Siberian Seas, Tavrovskii (1971) also suggested that the boundary of two subspecies may be in the East Siberian Sea (Heptner et al. 1976, Burns 1981). In the Beaufort

Sea, the Pacific bearded seal occurs eastward to Amundsen Gulf and Banks and Victoria Islands (Rice 1998, Smith 2001, Stirling 2002). In the Chukchi Sea, bearded seals occur as far west as Wrangell and Herald Islands and are distributed in the zone between the Chukchi coast and the pack ice edge (Heptner et al. 1976). In the Bering Sea, the bearded seal occurs from the Bering Strait southward to Bristol Bay to the southeast and the Karaginsky Gulf to the southwest (Heptner et al. 1976). The bearded seal also inhabits the Okhotsk Sea south to Hokkaido and the Kuril Islands of northern Japan (Fedoseev 2000).

Figure 5. Distribution of the bearded seal. Note that the range boundaries between the two subspecies were approximated from the literature.
Source: Based on Burns (1981) and Kovas (2002).



B. Seasonal Breeding and Foraging Range

In winter and spring, bearded seals typically occur in breeding areas in broken pack ice generally over shallow waters, although some populations overwinter in landfast ice adjacent to polynyas (Smith 1981, Kovacs 2002). In summer, some populations move significant distances following the seasonal retreat of sea-ice cover, while other populations make more local movements in response to ice conditions (Kovacs 2002). Among Pacific bearded seals, seals of the Bering-Chukchi Sea population move between the Bering Sea in the winter and the Chukchi Sea in the summer to follow the pack ice year-round while those in the Okhotsk Sea appear to be resident throughout the year (Burns 1981, Fedoseev 2000). Among Atlantic bearded seals, many populations in the Barents, Kara, and White Seas appear to follow the sea-ice year-round. The distribution and movements of populations of the Pacific and Atlantic bearded seal are described in detail below.

Pacific bearded seal: Bering and Chukchi Seas

The Bering-Chukchi shelf comprises one of the largest areas of continuous habitat for bearded seals in the world (Nelson et al. 1984). The Bering-Chukchi bearded seal population undertakes a seasonal migration between the Bering and Chukchi Seas that is directly related to the seasonal advance and retreat of sea-ice cover to maintain access to the sea ice (Burns 1981). During winter and spring including the reproductive period from mid-March through early May, most of the Bering-Chukchi bearded seal population is widely and patchily distributed in the drifting pack ice over a broad area of the northern and central Bering Sea shelf (Burns 1981). Based on extensive observational records and surveys, bearded seals occur in the highest densities in the northern Bering Sea shelf southwest of St. Lawrence Island (Figures 6 and 7) (Burns 1981, Kelly 1988a, Ray and Hufford 1989). Aerial surveys in March 2001 and shipboard surveys in mid-April through mid-June 2007 in the northern Bering Sea detected the highest abundance of bearded seals in the shallow waters near the St. Lawrence Island polynya and farther west into the Gulf of Anadyr, which contains some of the highest benthic biomass in the Bering Sea (Simpkins et al. 2003, Cameron and Boveng 2007). Lower densities of bearded seals occur in the southeastern Bering Sea from St. Matthew Island to western Bristol Bay (Ray and Hufford 1989, Fedoseev 2000). Relatively few bearded seals remain in the Chukchi Sea during winter and spring because favorable sea-ice habitat is limited, occurring only in flaw zones where heavy drifting ice influenced by winds and currents interacts with coastal features (Burns 1981).

As the Bering Sea ice disintegrates and moves northward from April-June, most of the population that wintered in the Bering Sea migrates north through the Bering Strait to follow the sea-ice edge (Burns 1981, Kelly 1988a). The northward spring migration through the Bering Strait occurs from May through July, although the timing of male and female movements differs (Burns 1981). Male bearded seals begin migrating to the Chukchi Sea in the last third of May, while females and young begin migrating later in the second half of June to early July usually after the disappearance of ice in the Gulf of Anadyr (Burns 1981). Most of the bearded seal population spends the summer concentrated along the wide fragmented margin of multi-year ice in the Chukchi Sea where it overlaps the shallow shelf (Burns 1981, Kingsley et al. 1985). Some juveniles wander more broadly and use open water regions of the Bering-Chukchi Seas during

Figure 6. Areas where the greatest adult densities of bearded seals in the Bering and Chukchi Seas are thought to occur in winter and summer.
Source: Ray and Hufford (1989): Figure 1f.

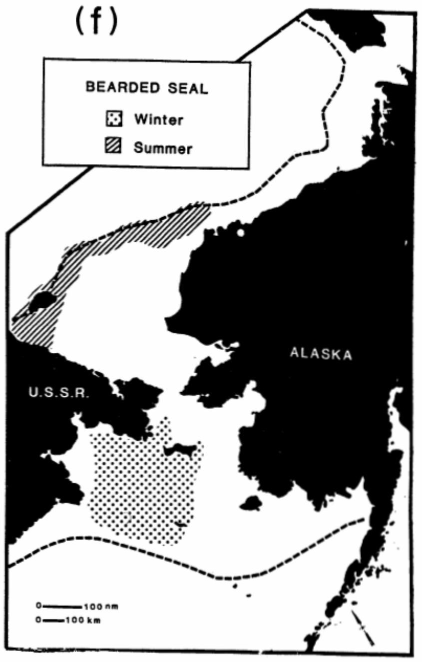
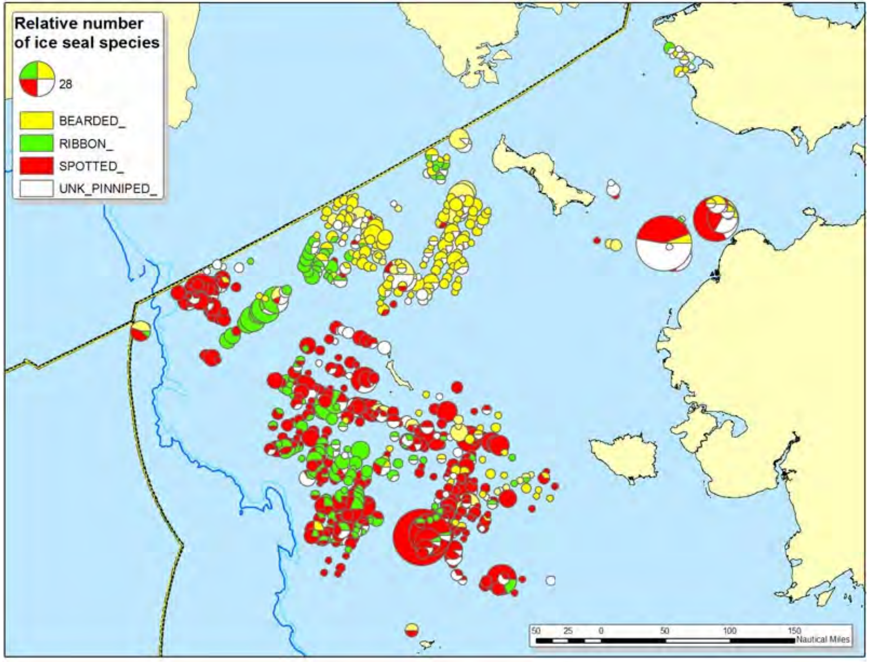


Figure 7. Map showing the abundance and distribution of seals observed during the *Healy* cruises (10 April–12 May and 16 May–18 June 2007). Counts of animals were summed over 5 nmi of survey trackline and are represented by a pie chart. The diameter of the pie chart represents the total number of animals in the 5 nmi of trackline.
Source: Cameron and Boveng (2007).



summer, occasionally entering small bays and rivers (Burns 1981, Kovacs 2002). During fall to early winter (October-December), bearded seals that summered in the Chukchi Sea move southward ahead of the newly forming pack ice that advances rapidly southward and winter in the Bering Sea (Burns 1981). Bearded seals do not use coastal hauling areas in the Bering-Chukchi Sea region because they are able to maintain an association with sea ice year-round in water depths suitable for benthic feeding (Burns 1981).

Pacific bearded seal: Beaufort Sea

In the Beaufort Sea, suitable habitat for bearded seals is more limited because the continental shelf is narrow and the ice edge can occur off the shelf over water too deep for feeding (Nelson et al. 1984). Bearded seals in the western Beaufort Sea occur in landfast and pack ice during the winter and move to the pack ice front where it overlaps with the Beaufort Sea shelf in the summer (Kingsley et al. 1985).

Pacific bearded seal: Okhotsk Sea

During winter and spring, the bearded seal population in the Okhotsk Sea is concentrated on the broken pack ice in the coastal shallow-water zones over the shelf in the northern and southwestern regions (Fedoseev 2000). During the breeding season from mid-March through May, the primary breeding areas are located in the Shelikov Gulf and near the eastern coast of Sakhalin Island and the Shantarsk Islands (Fedoseev 2000). In late spring and early summer as the sea ice begins to melt, the population becomes more dispersed on drifting ice floes in shallow areas (Burns 1981). When the sea ice melts completely in late August to October or recedes beyond the shallow shelf, bearded seals haul out in beach rookeries (Burns 1981, Fedoseev 2000). As soon as the sea ice begins to form again in the winter, bearded seals leave the coast to inhabit the outer edge of coastal ice and open water pools among mobile broken ice floes (Fedoseev 2000).

Atlantic bearded seal

In winter and spring the primary breeding areas for *E. b. barbatus* occur in the entrance to the White Sea and Mezensky Bay, southeastern Barents Sea and its adjacent gulf, the coast of Novaya Zemlya, and waters near Svalbard, while lower numbers occur in the southern White Sea, western Kara Sea, and near Medvezhy Island in the Barents Sea (Popov 1982). A large portion of the bearded seal population in the Barents, White, and Kara Seas migrates to the northern Barents and Kara Seas during summer and autumn as the sea ice recedes northward (Potelev 1975 cited in Wiig and Isaksen 1995). In the northern Barents Sea, bearded seals follow the drifting pack ice from October to July, with high concentrations on the sea-ice edge, and are found in summer and autumn in the open drift ice in the Barents Sea (Wiig and Isaksen 1995). Bearded seals in coastal areas near Svalbard are thought to remain in near-shore fjords most of the year but may also migrate northward as far as 84°N with the sea ice (Gjertz et al. 2000b). In the Fram Strait and Greenland Sea, bearded seals are most abundant north of 79°N and west of 5°W (Gjertz et al. 2000b).

IV. Adaptations to the Arctic Environment

The bearded seal is adapted to the Arctic environment in several key ways: its large body mass and thick blubber help insulate it from cold Arctic temperatures; it can create and maintain of breathing holes in thin sea ice which it breaks through with its head; it has a relatively large buccal cavity for suction feeding which allows it to forage on the rich benthic biomass of Arctic sea shelf bottoms; and it can move great distances to follow sea-ice cover as it seasonally advances and retreats (Burns 1981).

V. Habitat Requirements: Sea Ice and Water Depth

Two principal factors that influence bearded seal distribution and movements are sea-ice characteristics and water depth (Burns 1981). Because the bearded seal relies on the sea ice for reproduction, resting, and molting, the timing of advance and retreat of pack ice, the areal extent of pack ice, and the relative concentration of pack ice (i.e., percent of open water within the pack ice) have strong impacts on bearded seal distribution (Bengtson et al. 2005). Secondly, because the bearded seal depends on the benthic ecosystem for foraging, the bearded seal is generally restricted to shallow continental slope waters within its circumpolar range (Burns 1981). The bearded seal's habitat requirements and the importance of sea ice to its essential life history behaviors are described in depth below.

Bearded seals prefer drifting pack ice in areas over shallow water where the ice is in constant motion producing leads, polynyas and other openings (Burns 1981). They typically avoid regions of continuous thick, landfast ice and unbroken heavy drifting ice since there are few opening in these ice types, and bearded seals can only make and maintain breathing holes in relatively thin ice (Burns 1981), although some populations overwinter in landfast ice adjacent to polynyas (Smith 1981, Kovacs 2002). In the Bering Sea, aerial surveys of bearded seals south of St. Lawrence Island in March 2001 confirmed that bearded seals avoid heavy-coverage sea ice and large-floes habitat, and prefer transitional habitat between small and large floes (Simpkins et al. 2003). Bearded seals appear to select areas with 70–90% sea-ice coverage while avoiding areas with greater than 90% coverage (Simpkins et al. 2003). Surveys of bearded seal densities in the eastern Chukchi Sea during late May-early June 1999 found the highest concentrations of bearded seals in the offshore pack ice of the southeastern Chukchi Sea where benthic productivity was highest (Bengtson et al. 2005). The lowest densities occurred in nearshore fast ice which is not preferred ice habitat and where benthic productivity was lower (Bengtson et al. 2005). In the Okhotsk Sea, bearded seals also avoid consolidated fields of thick white ice and prefer thinner ice (less than 60 cm) in shallow waters over the shelf less than 200 m deep (Fedoseev 2000). Bearded seals in the Okhotsk Sea occur mostly in the coastal areas where the sea ice is highly mobile and rich in polynyas and leads, preventing the formation of extensive fields of solid white ice (Fedoseev 2000). In the Canadian High Arctic, bearded seals prefer broken ice, particularly in large floes with ice cover of 6/8 to 7/8, and occur in low densities in landfast ice (Kingsley et al. 1985).

Because the bearded seal feeds predominantly on benthic prey, its distribution is generally restricted to relatively shallow shelf waters of less than 150-200 m where its benthic prey are more abundant (Burns 1981, Kelly 1988a, Simpkins et al. 2003). Although foraging dives of 130-200 m have been reported (Kosygin 1971 cited in Burns 1981, Kelly 1988a), bearded seals appear to prefer shallower depths less than 100 m and especially 25-50 m (Stirling et al. 1977, Kingsley et al. 1985, Gjertz et al. 2000b). Illustrating the bearded seal's preference for shallow water, Burns and Frost (1979) reported that bearded seals in the Bering and Chukchi Seas occur on the pack ice front over the Chukchi Sea shelf in summer, but were not associated with the ice front when it receded over deep water (Kingsley et al. 1985). In the Bering Sea characterized by a shallow shelf and deep basin, the bearded seal's benthic invertebrate prey are particularly abundant from 10-100 m because benthic production is higher at these shallower depths (Fay and Burns 1988). The production of the middle shelf (10-100m) is an order of magnitude higher than on the outer shelf (100-200 m) due to the partitioning of primary production to the benthos in shallower waters and to the pelagic food web seaward of the 100 m isobath (Fay and Burns 1988).

A. Importance of Sea Ice to Reproduction

Sea ice provides an essential platform for bearded seal reproductive activities of birthing and nursing. Bearded seals give birth to a single pup on the sea ice in March through May, followed by a three week period when the pup is nursed on the sea ice. The ice provides several advantages that influence subsequent pup survival. First, the sea ice allows bearded seals to avoid excessive predation on their dependent young by terrestrial predators (Burns 2002a). The sea ice also provides an important resting platform for pups during the three week nursing period (Lydersen and Kovacs 1999). Although bearded seal pups actively dive throughout the nursing period, pups spend 50% of their time resting on the ice, half of which is spent sleeping (Lydersen et al. 1994, Lydersen and Kovacs 1999).

B. Importance of Sea Ice to Molting

Bearded seals require the sea-ice platform for the annual molt of their fur since they do not haul out on land to molt. Bearded seals undergo a diffuse molting period from April through August and may shed hair year-round (Burns 1981, Kovacs 2002). However, during May through July bearded seals haul out on the sea ice during a concentrated molting period (Burns 1981, Gjertz et al. 2000b) when they depend on increased summer temperatures and day length to raise their skin temperature to facilitate epidermal growth (Feltz and Fay 1966). Therefore, persistence of the sea ice through July is critical to allowing bearded seals adequate time to complete their molt.

C. Importance of Sea Ice to Resting

Bearded seals use the sea ice for resting throughout the year, although peak haulout occurs during the concentrated molting period in May-June (Burns 1981). Breeding and molting activities are physiologically demanding and the sea ice provides an important resting platform which may also serve in thermoregulation.

D. Importance of Sea Ice for Transportation

Bearded seals follow the seasonal sea-ice advance and retreat of sea ice over the shallow continental shelf in many regions. In the Bering and southern Chukchi Seas the seasonal movement of sea ice is more extensive than in any other Arctic region (Ray and McCormick-Ray 2004). The ice edge moves freely in response to dynamic and thermodynamic forces, resulting in high variability in sea-ice cover and distribution (Francis et al. 2005). As bearded seals rest on sea ice or actively follow sea-ice floes while foraging, they are transported over great distances. A primary advantage of passive transportation by sea ice is that new feeding areas (leads) are constantly being opened up as sea ice moves (Ray and McCormick-Ray 2004). Associating with sea ice allows Pacific bearded seals to continually move to new unexploited foraging areas after depleting local resources, vastly broadening their foraging range and opportunities.

VI. Reproduction and Reproductive Behavior

Bearded seals mate at the end of the lactation period after pups are weaned, typically during May, although some females may breed while lactating (Burns 1981). Male bearded seals are in breeding condition longer than females from mid-March through mid-June (Burns 1981). During the breeding season and peaking in April and May, males produce distinct, elaborate underwater vocalizations to advertise their breeding condition and maintain aquatic territories (Risch et al. 2007). Their songs consist of complex, long oscillating frequency-modulated warbles that may be longer than a minute followed by a short unmodulated low-frequency moan, which are repeated (Burns 1981). A study of bearded seal vocalizations over 16 years off Point Barrow, Alaska, found that male vocalizations were individually distinct, vocal characteristics generally did not change over time, and male bearded seals showed high site fidelity during the breeding season across years (van Parijs and Clark 2006). Mating takes place in the water (Kovacs 2002, Risch et al. 2007). Implantation of the blastocyst occurs approximately two months after fertilization during mid-July through early August and gestation lasts an additional nine months (Burns 1981, Kelly 1988a). Bearded seals are capable of breeding annually, although seals may breed every other year when habitat quality is poor (Burns 1981).

The pupping period of the bearded seal lasts from mid-March through the first week of May, with the peak birthing period varying by region (Burns 1981). Peak birthing occurs during late April in the Chukchi Sea and Bering Strait, in early-to-mid-April in the southern Bering Sea and Okhotsk Sea, and during mid-April to mid-May in Svalbard (Burns 1981, Gjertz et al. 2000b). Females give birth to a single pup in a solitary fashion on small drifting ice floes with ready access to water (Kovacs et al. 1996, Kovacs 2002). Bearded seal pups are precocious relative to other ice-breeding phocids (Kelly 1988a). They are born with a thick layer of subcutaneous blubber layer and short fur instead of lanugo, which they molt in utero (Kovacs et al. 1996). These characteristics allow bearded seal pups to enter the water and swim with their mothers within hours of birth, likely adaptations to avoid polar bear predation (Kovacs 2002).

Bearded seal pups grow quickly and develop their swimming skills rapidly during the nursing period which is estimated to last 12-18 days (Burns 1981) or somewhat longer at 18-24 days (Gjertz et al. 2000b). Most of what is known about pup and female behavior during the lactation period comes from studies of the Atlantic bearded seal in Svalbard, Norway, and is summarized below. Bearded seal pups are nursed by their mothers on the ice and gain an average of 3.3 kg per day while drinking more than 7.3 liters of milk per day, with a high, stable fat content of 50% (Lydersen et al. 1996). Despite this high energy intake, bearded seal pups do not get as fat as do other nursing phocids due to their larger body size, the lower fat content of the milk compared to other phocids, and their very active aquatic behavior (Lydersen et al. 1996). During the first few days of life, bearded seal pups spend most of their time on the ice surface (Lydersen and Kovacs 1999). When bearded seal pups are less than one week old, they spend about 50% of their time in the water swimming and diving while being attended by their mothers, and 50% of their time on the ice, half of which is spent sleeping (Lydersen et al. 1994, Lydersen and Kovacs 1999). When just a few weeks old, bearded seal pups are able to dive to 84 m for maximum intervals of about 5.5 minutes, although most dives are shallow (10 m average) and of short duration (1 minute average) (Lydersen et al. 1994). As pups spend more time in the water, they increase the number of long dives and the mean dive duration throughout the lactation period (Lydersen et al. 1994). Unlike most other phocids, bearded seal pups appear to learn to forage for themselves while they are still attended by their mothers as evident from the mixture of milk and crustaceans found in the stomachs of pups (Burns 1981, Lydersen et al. 1996).

During the lactation period, bearded seal mothers divide their time among nursing, tending the pup on the ice, tending the pup from the water, and actively foraging. A study of the activity patterns and diving behavior of four bearded seal mothers during the lactation period found that females spent 8 ± 3% of their time hauled out on the ice tending the pup and 92 ± 3% in the water, where approximately half of their time in the water was spent diving and half spent tending the pup from the water surface (Krafft et al. 2000). Bearded seal mothers actively forage during lactation and may also teach their pups to feed independently (Lydersen 1996). Bearded seal moms in Svalbard made limited movements and exhibited high site fidelity during the nursing period (Gjertz et al. 2000b). However, other studies indicate that bearded seal mom-pup pairs can move tens of kilometers from one day to the next (Kovacs 2002). Mothers and pups have a strong bond during the early nursing period and engage in mutual nosing and scratching when reunited on the ice (Burns 1981).

Bearded seals are weaned less abruptly and in leaner body condition than most other phocids, although they still have a body composition of one-third fat and weigh 85 kg at independence which is more than double their birth weight (Burns 1981, Kovacs 2002). As described above, bearded seal pups are weaned as skilled divers capable of independent feeding and also exhibit some degree of predator avoidance. A study of pup movements after weaning in Svalbard, Norway, found that pups dispersed widely and were able to dive deeper than 448 m by the time they were two months old (Gjertz et al. 2000b).

VII. Diet and Foraging Behavior

Bearded seals are benthic foragers that feed primarily on epibenthic fauna and infauna as well as some schooling demersal fish (Burns 1981). Although bearded seals consume a wide array of prey species, relatively few species compose the bulk of the diet (Burns 1981). Decapod crustaceans and molluscs appear to comprise the bulk of the bearded seal diet across its range, although species composition varies geographically (Kelly 1988a). The proportions of prey species in the diet reflect seasonal and regional differences in prey availability, vary with age, and may be influenced by interspecific competition with Pacific walruses (Lowry et al. 1980a).

Four studies in the Bering and Chukchi Seas indicate that crabs, clams and shrimp are particularly important prey species in this region. A stomach contents analysis of 397 bearded seal stomachs collected from the Bering Sea (n=121), Bering Strait (n=42) and Chukchi Sea (n=234) from 1975-1979 found that clams, crabs, and shrimp comprised the bulk of prey species in both the Bering and Chukchi Seas, while fish (sculpins, cod, flatfish), snails, isopods, echiuriod worms, polycheates, and sponges were of minor volumetric importance (Lowry et al. 1980a). Specifically, major prey included three clam species (cockle *Cliniocardium ciliatum*, Greenland cockle *Serripes groenlandicus*, and surf clam *Spisula polynyma*), three crab species (tanner crab *Chionocetes opilio*, spider crab *Hyas coarctatus*, and hairy crab *Telmessus chieragonus*) and several shrimp species (crangonid *Argis* spp., *Crangon* spp, *Sclerocrangon boreas*, hippolytid shrimp *Eualus* spp., and pandalid shrimp *Pandulus* spp.). Consumption of clams changed seasonally and with age, with most clams consumed in May through September by older individuals (Lowry et al. 1980a). Johnson et al. (1966), studying stomach contents of 164 seals near Point Hope during November to June 1961, found that shrimp were important in winter, crabs became more important in spring, and clams became important beginning in June. A stomach contents analysis of 565 stomachs collected from the eastern Bering Sea near Nunivak, St. Matthew Island, St. Lawrence Island, and Gulf of Anadyr during March-July 1963-1965 found that three species comprised the bulk of diet by frequency of occurrence and biomass: snow crab *Chionocetes opilio,* shrimp *Nectocrangon lar lar,* and the annelid *Priapulus caudatus* (Fedoseev 2000). Finally, a stomach contents analysis of bearded seals collected in the Bering Sea near St. Matthew Island from mid-March through mid-April 1981 reported a high frequency of occurrence of schooling fish (86% of stomachs) such as capelin, codfish, eelpouts and longsnout pricklebacks, followed by crabs (73%), clams (55%), snails (47%), and amphipods (32%) (Antonelis et al. 1994).

In the Beaufort Sea, crabs (*Hyas coarctatus*), shrimp (*Sabinea septemcarinata*), and Arctic cod (*Boreogadus saida*) were the most important prey, and more cod were eaten in winter (Burns 1981, Nelson et al. 1984). In the Okhotsk Sea, diet was dominated by crabs (*Hyas coarctatus*), echuriods (*Echiurus echiurus*), shrimps (*Sclerocrangon boreas, S. salebrosa, Pandalus hipsinotus*), cephalopods, gastropods, and bivalves (Heptner et al. 1976). Burns (1981) reported that crabs and shrimp accounted for 87% of diet in northern Okhotsk Sea while clams (40%), gastropods (12%) and worms (23%) comprised the diet in southern Okhotsk Sea near Sakhalin Island.

In the coastal waters of the Canadian Arctic, a stomach content analysis of 34 bearded seals collected off northeastern Baffin Island and southern Ellesmere Island during summer 1978-1980 found that bearded seals fed heavily on benthic fishes (primarily sculpins) and schooling fish (primarily Arctic cod) while whelks (*Buccinum*) and shrimp (*Sclerocrangon boreas*) were of secondary importance (Finley and Evans 1983). In Hudson Bay, important prey included decapod crustaceans, pelecypod molluscs, and Arctic cod, and were primarily benthic (Smith 1981). In the Kara and Barents Seas, shrimp and molluscs are the primary prey of the bearded seal with Arctic cod of secondary importance (Finley and Evans 1983). In northwest Greenland, bearded seals feed on benthic fishes, benthic invertebrates, and Arctic cod (Finley and Evans 1983).

Bearded seals appear to actively select regions of high benthic biomass for foraging (Simpkins et al. 2003, Bengtson et al. 2005). Bearded seals are shallow divers with most dives less than 100 m deep in trips less than 10 minutes (Gjertz et al. 2000b). A study of diving behavior of adult female bearded seals in May and June near Svalbard found that seals displayed a bi-modal dive behavior with dives divided between those less than 10 m or between 50 to 70 m (Gjertz et al. 2000b). The presence of sand and pebbles in bearded seal stomachs and wear on their claws and foreflippers indicate that bearded seals excavate some prey from the bottom, such as buried bivalves and worms; however, most food is not buried (epibenthic) and is sensed with the whiskers (Kovacs 2002).

VIII. Sources of Natural Mortality

The primary predators of bearded seals are polar bears (Burns 1981). In Alaskan waters, polar bear predation peaks during late summer and fall when bearded seals and polar bears are concentrated together along the margin of multi-year ice in the Chukchi Sea, and decreases in winter when most bearded seals are located in the Bering Sea south of the polar bear distribution (Burns 1981). Bearded seals exhibit behaviors that are presumed adaptations to polar bear predation over a significant portion of the range. The bearded seal rests on the edges of wide leads or large holes in the ice or on the points of small ice floes, facing toward the water and downwind (Kingsley and Stirling 1991). When alarmed, they bolt into water by raising and propelling bodies with simultaneous movements of both foreflippers (Burns 1981). In addition, pups are able to swim shortly after birth (Burns 1981). Killer whales and walruses are also known predators (Kelly 1988a). In the Okhotsk Sea, brown bears (*Ursus arctos*) are known to attack bearded seals hauled out at beach rookeries (Fedoseev 2000).

IX. Demographic Rates

Age at maturity. Burns (1981) reported that females attain sexual maturity at ages five and six, with first ovulation beginning at age three for some females. Similarly, Fedoseev (2000) reported that females in the Bering and Chukchi Seas reach sexual maturity between ages three to six: 8% of females reach sexual maturity by age three, 21% by age four, 83% by age five, and 100% by age six. Males reach sexual maturity slightly later than females between ages four to eight (Fedoseev 2000). Heptner et al. (1976) reported that males reach sexual maturity between ages five to seven: 50% at age five, 66% by age six, 100% by age seven.

Fecundity. The annual reproductive rate of bearded seals is estimated at 19% (Popov 1982). The net reproductive rate (i.e. the average number of pups a female leaves during her lifetime) has been estimated at 1.14 for the Bering Sea and 1.06 for the Okhotsk Sea (Fedoseev 2000).

Survivorship. Bearded seal survival is lowest during the first year of life, with survival rates estimated at 42% in the Bering Sea and 60% in the Okhotsk Sea (Fedoseev 2000: Table 52). Survival increases with age and averages ~90% for ages three and older in the Bering and Okhotsk Seas (Fedoseev 2000: Table 52).

Longevity. Bearded seals are thought to live 20-25 years of age (Kovacs 2002), although the oldest reported individual was 31 years old (Kelly 1988a).

X. Abundance and Population Trends

Current abundance

The global population size of the bearded seal is difficult to estimate since they inhabit a remote and difficult-to-access environment, have a patchy distribution, and spend part of their time underwater. The current size of the bearded seal population is unknown since recent population census data are not available. Most recently, Kovacs (2002) estimated that the global population "likely numbers in hundreds of thousands throughout the Arctic," but cites no data for this estimate. In the early 1980s, Burns (1981) estimated 750,000 individuals worldwide, excluding the Canadian Arctic, but also cites no data for this estimate. The Burns (1981) estimate included 300,000 individuals in the North Atlantic, corresponding to the range of *E. b. barbatus* encompassing the North, White, Barents, Kara, and Laptev Seas, as well as 450,000 individuals in the North Pacific corresponding to the range of *E. b. nautiucs*.

Regional population estimates are available for some portions of the bearded seal range. Burns (1981) estimated that the Bering and Chukchi Sea population numbered 300,000 seals. More recently, Fedoseev (2000) estimated that the Bering-Chukchi Sea population numbered 250,000 seals and the Okhotsk Sea population numbered 200,000-250,000 seals based on surveys in the western Bering Sea and Okhotsk Sea during the 1970s and 1980s. In its most recent 2007 draft stock assessment for the bearded seal, NMFS reported a population size of 250,000-300,000 individuals for the Bering and Chukchi Seas based on Popov (1976) and Burns (1981) (Angliss and Outlaw 2008). Because no recent census data are available, NMFS stated that "there is no reliable population abundance estimate for the Alaska stock of bearded seals" (Angliss and Outlaw 2008).

For the southeastern Beaufort Sea, surveys conducted from the Alaskan border to the west coast of Banks Island and north to Gore Island in June 1974 and 1975 estimated 2757 ± 728 bearded seals hauled out on the sea ice in 1974 and 1197 ± 239 in 1975 in an area of 143,040 km^2, although the proportion of seals not hauled out was not accounted for (Stirling et al. 1977). For western Hudson Bay, aerial surveys conducted in early June 1994 and 1995 estimated densities of 0.122 $seals/km^2$ ice in 1994 and 0.024 $seals/km^2$ ice in 1995 with an estimated population size of 12,290 seals in 1994 and 1,980 seals in 1995 (Lunn et al. 1997). For the eastern Chukchi Sea from Shismaref to Barrow, aerial surveys conducted in May-June 1999 and 2000 estimated average bearded seal densities of 0.07 seals km^2 in 1999 (range 0.011–0.393) and 0.14 seals km^2 in 2000 (range 0.009–0.652) (Bengtson et al. 2005). Since these densities were not adjusted for seals not hauled out, abundance estimates cannot be calculated without this correction factor (Bengtson et al. 2005).

Population trends

Population trends for bearded seals are generally unknown because there are few repeated or reliable abundance estimates. As detailed on pages 94-96, bearded seal populations in the

Bering and Okhotsk Seas experienced significant declines in the 1950s and 1960s due to overexploitation by commercial sealing. Population surveys in the Bering Sea from 1974-1987 and in the Okhotsk Sea from 1968-1990 do not indicate that bearded seal populations have rebounded (Fedoseev 2000) after vessel-based commercial harvest in these regions decreased in 1970. Specifically, bearded seal population numbers in the Bering Sea remained relatively constant during the 1974-1987 census period. In the Okhotsk Sea where censuses were more frequent, population numbers appear to have declined during the 1968-1990 census period. As noted by Kovacs (2002) regional populations that are subjected to harvests can be easily depleted because densities are naturally low and most populations are sedentary.

SPOTTED SEAL (*Phoca largha*)

I. Species Description

The spotted seal (*Phoca largha*) or larga seal is characterized by its vivid markings of brownish to black irregularly shaped spots, sometimes encircled by a faint ring, scattered over a lighter base coat (Figure 8) (Heptner et al. 1976, Bigg 1981). The color of the base coat varies from whitish to silver-gray on the underside and from gray-white to yellowish-gray to blue on the upper body (Heptner et al. 1976, Lowry 1984). Overall, spotted seal sub-adults and adults resemble harbor seals (*Phoca vitulina*) but are lighter and more uniform in color and pattern (Bigg 1981). Pups are born with a dense coat of white to smoky gray-colored lanugo which provides insulation until the pup accumulates a sufficient blubber layer for thermoregulation (Lowry 1984).The adult-patterned spotted coat becomes evident when the lanugo is shed at weaning (Popov 1982, Lowry 1984).

The spotted seal is distinguished by its relatively large head with a short body and short limbs (Heptner et al. 1976). Its skull is thick with a broad facial area and a short lower jaw (Bigg 1981, Lowry 1984). The sexes are similar in size and appearance (Bigg 1981, Lowry 1984). The spotted seal is intermediate in size compared to other ice-dependent phocid seals in its range. It is similar in size to the ribbon seal, smaller than the bearded seal, and larger than the ringed seal (Lowry 1984). Adult males from Bering Sea range from 161-176 cm in length and 85-110 kg in weight, while adult females range from 151-169 cm in length and 65-115 kg in weight (Bigg 1981). Popov (1982) reported the maximum length and weight of adult spotted seals as 214 cm and 150 kg, respectively. Newborn pups from the Okhotsk Sea ranged 78-92 cm in length and 7-12 kg in weight (Burns 2002b).

Figure 8. Young spotted seal on Bering Sea ice.
Photo by Josh M London, National Marine Mammal Laboratory, NOAA.

II. Taxonomy

The spotted seal belongs to the order Carnivora, suborder Pinnipedia, family Phocidae, subfamily Phocinae, tribe Phocini, genus *Phoca*, and species *largha* Pallas 1811 (Rice 1998). The species name *largha* comes from the name for the spotted seal in the Tungus language of eastern Siberia (Rice 1998). The genus *Phoca* also includes the spotted seal's sibling species, the harbor seal (*Phoca vitulina*), and these two species are the most closely related members of the subfamily Phocinae (Rice 1998, Burns 2002b). Although the spotted seal and Pacific harbor seal were historically thought to be closely related subspecies (*Phoca vitulina largha* and *Phoca vitulina richardsi*, respectively), they have been distinguished as sister species based on genetic, ecological, behavioral, and morphological differences (Rice 1998, Burns 2002b).

The genetic isolation of the spotted and harbor seals was confirmed by two mtDNA studies (O'Corry-Crowe and Westlake 1997 cited in Rice 1998, Mizuno et al. 2003). In terms of ecological separation, the spotted seal inhabits pack ice from autumn through late spring and is adapted to breeding on ice, whereas the harbor seal is generally pagophobic and inhabits ice-free coasts and islands year-round, giving birth on beaches, sandbars, and rocky reefs and occasionally on iceberg fragments from tidewater glaciers in protected fjords (Rice 1998, Burns 2002b). Where the spotted and harbor seal are sympatric in the southern Bering and Okhotsk Seas, the harbor seal mates and gives birth two months later than the spotted seal (Rice 1998, Burns 2002b), providing a behavioral mechanism for their reproductive isolation. In addition, while the harbor seal congregates in herds during the breeding season, the spotted seal occurs in widely spaced pairs (Burns 2002b).

Based on appearance, the spotted seal is monomorphic in pelage color (i.e. always exhibits a light-colored base coat) while the harbor seal exhibits both a light and dark phase of its base coat (Quakenbush 1988, Rice 1998). As newborns, spotted seals are born with lanugo while most harbor seals shed this in utero and are born with an adult-type pelage (Quakenbush 1988, Rice 1998). Although the body size and skull measurements of the spotted seal fall within range of those of the harbor seal, the ratios of some cranial measurements differ significantly between the two species, including the jugal length/condylobasal length ratio, the maxillo-frontal suture/condylobasal length ratio, and the interorbital width/mastoid width ratio (Burns 1981). In addition, several non-metric morphological characteristics differ between the species. Compared to the harbor seal, the spotted seal has a less massive skull, the bullae are less flattened and angular, the premolar teeth of adults are straight, the posterior margin of jugal bone is rounded, the glenoid fossa are less flattened and angular, the bony process of external auditory meatus is mostly blunt and rounded, the shape of posterior edge of bony palate is mostly rounded, and the hyoid arch is complete (Burns 1981).

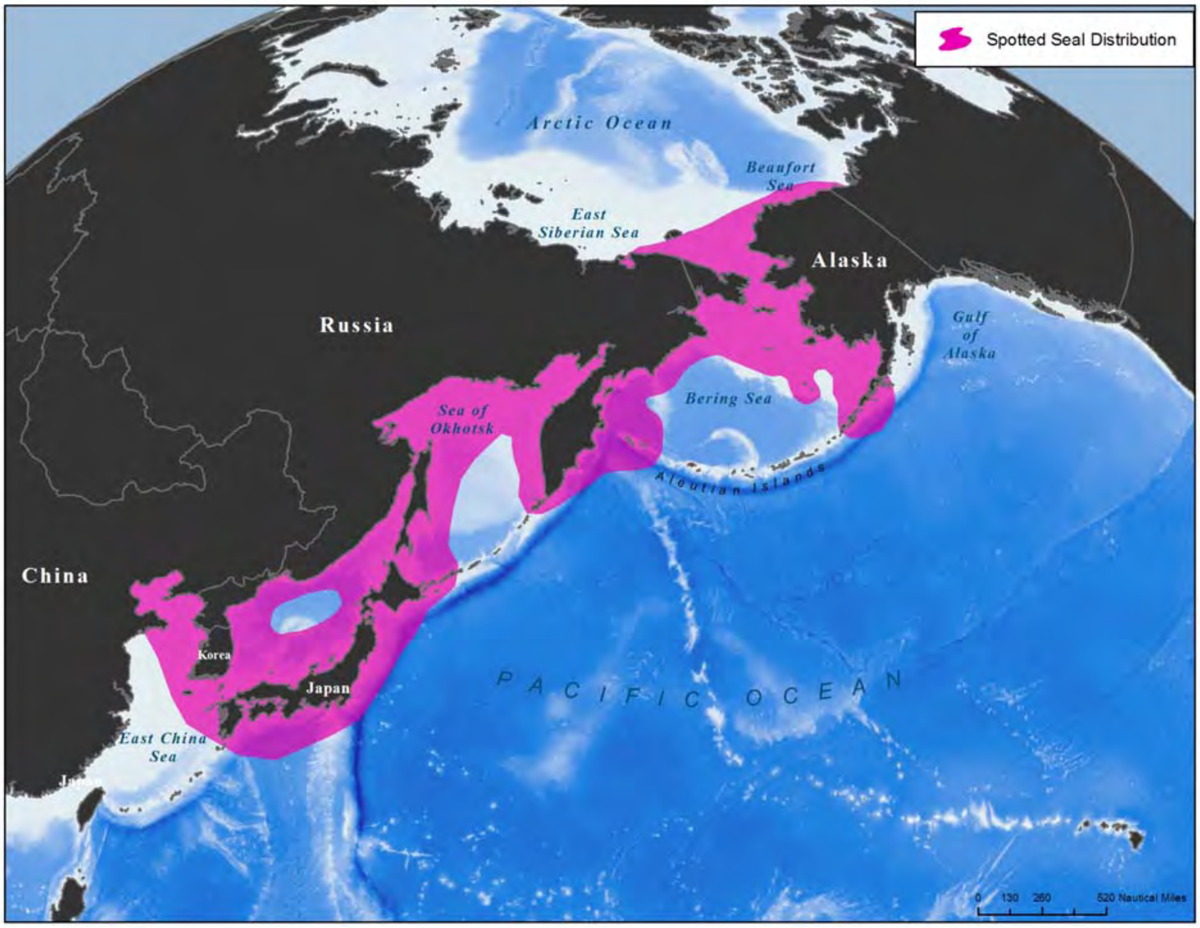
III. Distribution

The spotted seal occurs in the seasonally ice-covered subarctic and marginal seas adjacent to the North Pacific Ocean (Figure 9) (Quakenbush 1988). Spotted seals are found principally in the Chukchi, Bering, and Okhotsk Seas but range into the Beaufort Sea and East Siberian Sea (Shaughnessy and Fay 1977, Lowry 1984). Small southern breeding populations occur in the northern Sea of Japan and northern Yellow Sea where the cold winter climate produced by the Siberian high pressure system results in sea-ice cover in winter (Burns 2002b). The spotted seal distribution overlaps with that of the Pacific harbor seal in the southeastern and southwestern Bering Sea, Kamchatka peninsula, Kuril Islands, and northern Japan (Burns 2002).

Migration Between Breeding and Foraging Areas

The spotted seal moves between breeding areas on the sea-ice front in winter and spring to coastal habitats during the ice-free season in summer and fall (Quakenbush 1988). Spotted seal breeding aggregations in winter and spring are found in eight, relatively distinct offshore regions (Shaughnessy and Fay 1977). Three breeding areas occur in the Bering Sea: the northwestern Bering Sea between the Koryak coast of Russia and the Pribilof Islands, the southeastern Bering Sea from the Pribilof Islands to Bristol Bay, and Karaginskiy and Ozernovskiy Bays off the Kamchatka peninsula (Fedoseev 2000). Two breeding areas occur in the Okhotsk Sea: the northern Okhotsk Sea in the Shelikov Gulf region and the east side of Sakhalin Island to northern Hokkaido. The three remaining breeding aggregations occur in the Tatar Strait in the northern Sea of Japan, Peter the Great Bay in the northern Sea of Japan, and the Bo Hai Sea in the Northern Yellow Sea, specifically in Liaodong Bay (Shaughnessy and Fay 1977).

Figure 9. Distribution of the spotted seal.
Sources: Based on Heptner et al. (1976), Bigg (1981), and Burns (2002b).



When the sea ice retreats and disintegrates in spring and early summer, spotted seals begin to disperse shoreward to coastal habitats where they use haulouts on coastal barrier islands, nearshore rocks, reefs, sandbars, tidal flats, and isolated mud, sand or gravel beaches until the sea ice returns (Quakenbush 1988, Lowry et al. 1998). Spotted seals start hauling out on sea ice again as soon as it forms in fall, especially on the early ice that forms near river mouths and estuaries (Burns 2002b). As sea ice thickens and becomes attached to land and extends farther from shore, spotted seals move seaward and associate with drifting ice, especially with the highly labile sea-ice margin (Burns 2002b). Thus, the spotted seal undergoes large seasonal shifts in range with the annual cycle of sea-ice advance and retreat (Burns 2002b).

The direction and timing of movements of spotted seals from breeding areas on the sea ice in winter and spring to nearshore environments in summer and fall vary regionally (Quakenbush 1988) and are described below for each region.

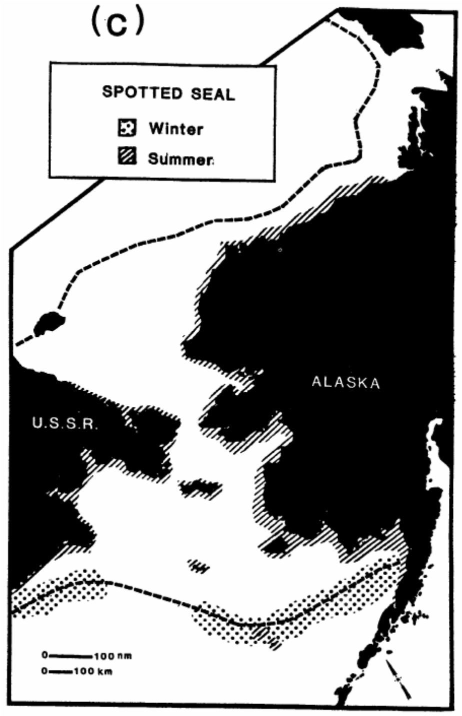
Bering-Chukchi Sea

Detailed information on spotted seal seasonal distribution, movements, and habitat use in the Bering and Chukchi Seas is available from satellite telemetry studies of seals tagged during 1991-1993 and from surveys and observational studies (Figure 10). Spotted seals of the Bering and Chukchi Seas associate with the sea-ice front of the Bering Sea from November to June (Lowry et al. 2000). As described above, they use three regions of the Bering Sea ice front for giving birth, nursing, and molting during March to June (Lowry et al. 1998). Satellite telemetry studies indicate that spotted seals in the Chukchi Sea generally begin moving southward to their breeding grounds in the Bering Sea beginning in October, and most seals pass through the Bering Strait in November (Lowry et al. 1998). Seals first haul out on sea ice when it forms in October (Chukchi Sea) and November (Bering Sea) (Lowry et al. 1998). Tagged seals spend December to June in the Bering Sea between Kuskokwim Bay and Anadyr Gulf in a region that corresponds to the location of the sea-ice front (Lowry et al. 1998). In January to June, seals are located in the broad sea-ice front zone mostly 0–200 km north of the sea-ice edge, commonly in areas with extensive ice coverage (7/10–9/10) (Lowry et al. 2000). They avoid heavier pack ice and open water (Lowry et al. 2000). Seals appear to make short east-west movements during February-May likely to stay within their preferred habitat of the sea-ice front and fringe (Lowry et al. 1998).

As the sea-ice cover diminishes and coastal areas become ice-free, some spotted seals move to nearshore areas of the Bering Sea while others migrate northward into the Chukchi and Beaufort Seas, where they alternate between resting at coastal haulouts and making long offshore foraging trips (Lowry et al. 1998, Burns 2002b). Spotted seal haulouts in the Bering Sea occur in northern Bristol Bay and the Yukon-Kuskokwin Delta on sandbars near herring and capelin spawning areas; St. Matthew Island and nearby Hall Island; St. Lawrence Island; Besboro Island in Norton Sound; and further north at Cape Woolley and Port Clarence (Quakenbush 1988). In the Chukchi Sea, important haulouts occur near Cape Espenberg in Kotzebue Sound and most importantly in Kasegaluk Lagoon near Utukok Pass, Akoliakatat Pass and Avak Inlet where 1,000 or more spotted seals commonly haul out inside barrier islands (Frost et al. 1993). Overall, the summer spotted seal distribution extends as far west as Chaun Bay (70°N, 170°E) in the Chukchi Sea and at least as far east as Herschel Island (69°N, 139°W) in the Beaufort Sea (Quakenbush 1988). To the south, spotted seals occur near the Pribilof Islands, Bristol Bay, and the eastern Aleutian Islands (Quakenbush 1988). Thus, the total range of the Bering Sea population extends over 15° latitude or 1665 km (Burns 2002b). Spotted seals also travel up rivers to catch spawning salmon in Kamchatka, Anadyr, and Tauyskaya Bay and haul out on spits (Fedoseev 2000).

Movement of spotted seals tagged in Kasegaluk Lagoon in the eastern Chukchi Sea during August 1991-1993 found that seals alternated between resting at coastal haulouts for an average of 2 days (range 1 hour -13 days) and making long foraging trips lasting an average of 9 days (range 0.5-38 days) (Lowry et al. 1998). This study suggests that spotted seals spent ~16% of their time at coastal haulouts and ~84% at sea (Lowry et al. 1998). Foraging trips ranged westward to coast of Russia, south almost to the Bering Strait, and north and east in to the Beaufort Sea, and many trips covered distances of more than 1,000 km (Lowry et al. 1998).

Figure 10. Areas where the greatest adult densities of spotted seals in the Bering and Chukchi Seas are thought to occur in winter and summer.
Source: Ray and Hufford (1989): Figure 1c.



Okhotsk Sea

In the Okhotsk Sea, spotted seals occur in breeding areas to the north in the Shelikov Gulf region and along the east side of Sakhalin Island to northern Hokkaido in winter and spring (Shaughnessy and Fay 1977). Mizuno et al. (2002) identified the pack ice off northern Hokkaido as an important breeding area for spotted seals based on the high numbers of spotted seal pups detected in aerial surveys in March-April 2000. Mizuno et al. (2002) noted that females and pups were detected more frequently in the center of larger, rougher floes in stable pack ice areas. Fedoseev (2000) noted that breeding areas occurred in areas where currents and water circulation prevent the formation of consolidated ice and favors broken ice fields. Spotted seals in the Okhotsk Sea move to coastal rookeries after the sea ice melts in July (Fedoseev 2000). Fedoseev (2000) reported rookeries of 10,000 individuals along the Sakhalin Island coast, 30,000 individuals along the continental coast of Sea of Okhotsk, and 20,000 individuals on the western Kamchatka coast (Fedoseev 2000).

Peter the Great Bay

In Peter the Great Bay, most of the spotted seal population hauls out on the sea ice in Amur Bay beginning in December as soon as ice floes form and follows the sea-ice edge as it expands southward through March (Trukhin and Mizuno 2002). Spotted seals give birth on sea ice and on the Rimskii-Korsakov Islands from mid-January to early April and molt on sea ice and the Rimskii-Korsakov Islands in February-April (Trukhin and Mizuno 2002). When the sea ice disappears in April, spotted seals haul out at island and coastal rookery sites in Peter the Great Bay and along the east coast of the Primorye region to the northeast and may also migrate to the Okhotsk Sea (Trukhin and Mizuno 2002). Juvenile seals tagged in winter in Peter the Great Bay have been resighted off Hokkaido and eastern Sakhalin Island in fall, indicating that yearlings are capable of moving 1,000-1,400 km between winter and summer habitats (Trukhin and Mizuno 2002).

Bo Hai Sea

In the Bo Hai Sea, spotted seals arrive at their breeding grounds on the ice floes of Liaodong Bay from October-December (Won and Yoo 2004). Spotted seals give birth on ice floes from January to mid-February and remain on the sea ice to molt after the breeding season (Won and Yoo 2004). When the sea ice disappears in spring, spotted seals of this population spend the spring, summer, and autumn at foraging grounds along the coast of western South Korea on the Bak-ryoung Islands, Chil-San Islands, and the Tae-An peninsula (Won and Yoo 2004).

IV. Habitat Requirements

Spotted seals rely on the dispersed floes of the sea-ice front and fringe during winter and spring as a platform for birthing and nursing pups as well as for molting and resting (Rugh and Shelden 1997, Burns 2002b). In all spotted seal breeding areas, sea ice forms seasonally over the continental shelf in winter through spring, generally in water depths less than 200 m (Rugh and Shelden 1997). Aerial surveys in the Bering Sea south of St. Lawrence in March found that spotted seals preferred smaller ice floes (< 20 m in diameter) near the sea-ice edge (Simpkins et al. 2003). Floes selected for pupping tend to be less than ten meters across, separated from adjacent floes by slush or water, and prevented from consolidating by winds and currents (Lowry 1984). Thus ice characteristics in breeding areas balance reliable access to water with physical instability caused by the proximity to the open ocean and associated turbulence (Lowry 1984). Spotted seals avoid stationary shore ice or highly compacted masses of broken ice floes (Lowry 1984).

A. Importance of Sea Ice to Reproduction

The use of sea ice as a platform on which to give birth and nurse pups is central to the ecology of the spotted seal (Burns 2002b). Timing of birthing in spotted seal populations evolved to coincide with the period of greatest extent and stability of sea-ice cover (Burns 2002b). Sea ice provides several advantages that influence reproductive success and pup survival. First, spotted seals use the offshore sea-ice edge that allows them to avoid excessive predation of their dependent, non-aquatic young (Burns 2002a). Spotted seal pups are born exposed on ice floes and do not begin to swim until after weaning. In the Bering Sea, spotted seal pups are isolated from significant predation by polar bears or Arctic foxes because these predators can not reach the labile marginal ice zone that occurs south of their range (Burns 2002b). In the Okhotsk Sea, pups born on the sea ice are isolated from depredation by land-based predators like brown bears and wolves that are thought to take significant numbers of spotted seals in summer at coastal haulouts (Popov 1982).

The sea ice also provides a dry platform necessary for pup survival during the lactation period and a necessary resting platform as pups learn aquatic proficiency after weaning (Burns 2002b). Spotted seal pups can only survive periods of submersion in the icy waters after they have formed their subcutaneous blubber layer that provides protective thermoinsulation (Fedeseev 2000). Unseasonably early disintegration of sea ice that forces pups into the water prematurely and truncates the nursing period is thought to result in a high mortality of nursing pups (Burns 2002b). Spotted seal pups are also dependent on the sea ice during the transition period after weaning when they must learn to swim and feed on their own (Burns 2002b). Weaned pups have poor swimming and diving skills because their hefty blubber stores make them buoyant, and spend substantial time on the sea ice resting while they eventually achieve aquatic proficiency. This is an energetically stressful transition period for pups during which time they lose 18-30% of their body weight (Burns 2002b). Therefore, the persistence of sea ice during this period undoubtedly influences pup fitness. Overall, the persistence of ice floes used for pupping throughout the three-to-six-week period of pup-rearing and afterward during the period when pups are learning independence is critical to pup fitness and survival.

B. Importance of Sea Ice to Molting

Spotted seals rely on sea ice as a safe platform to complete their annual molt in spring. In the Bering and Chukchi Seas, spotted seals molt mainly in late spring with intensive molt occurring in May and June when sea ice is retreating rapidly (Burns 1981). Following breeding, spotted seals of all ages congregate in loose groups of up to 200+ animals on ice remnants to molt before the sea ice melts and seals move to the coast (Bigg 1981, Lowry 1984). In the Bering Sea, molting herds occur in Karaginskiy and Ozernovskiy Bays and to the north along the ice margin near the Gulf of Anadyr, St. Lawrence and St. Matthew Islands (Fedoseev 2000). Molting herds in the Okhotsk Sea occur in northern part of sea and in Terpeniya Gulf of eastern Sakhalin (Fedoseev 2000). As the sea ice breaks up, spotted seals move northward with the ice remnants of the retreating sea-ice edge (Fedoseev 2000). Subadults, which complete the molt earlier than adults, do not remain on ice remnants but move to the Bering Sea coast (Lowry 1984). Only in regions where sea ice disappears early (Peter the Great Bay) and in minimal ice years do spotted seals complete their molt on island or shore haul outs (Burns 1981). Overall, the persistence of sea ice through June is important to allow spotted seals adequate time to complete their molt on the safe platform of the sea ice.

V. Reproduction and Reproductive Behavior

The mating system of the spotted seal is annually monogamous (Burns 2002b). Females and males in the Bering and Okhotsk Seas form a pair bond approximately ten days before the female gives birth (Quakenbush 1988). Triads (female, male, and pup) and pairs (male and a female that didn’t bear a pup) are separated from other family groups by at least 0.25 km and may actively defend their territory (Bigg 1981). Males and females stay together until mating which occurs when the female ovulates just after the pup is weaned (Quakenbush 1988). Mating is thought to take place in the water (Quakenbush 1988). Gestation lasts ~10.5 months including a period of delayed implantation of the blastocyst lasting 1.5 to 4 months after mating (Quakenbush 1988).

Timing of birthing appears to be synchronized with the maximum extent and stability of the sea ice (Quakenbush 1988). Pups are born earlier in the southern parts of the range where the sea ice melts earlier (Burns 2002b). Peak pupping occurs in late January in the northern Yellow Sea, in February and March in the Sea of Japan, and in the first half of April in the Bering and Okhotsk Seas (Quakenbush 1988). The female gives birth to a single pup on exposed sea ice. The pup is covered in a dense coat of lanugo that provides insulation and camouflage and is retained until weaning when the pup has acquired a blubber layer (Burns 2002b). The pup remains on the sea ice during the three to six-week nursing period and does not begin to swim until after weaning (Bigg 1981). During the nursing period, the pup is frequently attended by its mother, although females leave pups unattended while on foraging trips (Quakenbush 1988, Burns 2002b). Healthy pups double and sometimes triple their weight during the lactation period (Burns 2002b).

Weaning occurs abruptly when the female abandons her pup on the ice floe (Burns 2002b). At weaning, most pups weigh more than at any other time during their first year of life due to their large fat stores which provide critical sustenance during early stages of learning independence (Burns 2002b). Weaned pups have poor swimming and diving skills because their hefty blubber stores make them buoyant (Burns 2002b). During the early period of independent life when pups are learning to swim and feed on their own, pups depend on their fat reserves and may lose between 18-30% of their body weight (Burns 2002b). Pups are thought to begin independent feeding 10-15 days after weaning (Burns 2002b) and can dive to depths up to 80 m after one month (Quakenbush 1988).

VI. Diet and Foraging Behavior

The spotted seal is a generalist feeder that forages opportunistically on abundant schooling fishes, crustaceans, and cephalopods (Bigg 1981, Burns 2002b). Spotted seal diet varies with age, region, and season since the spotted seal has an ice-associated offshore pelagic distribution in winter and spring versus a coastal-pelagic distribution during summer and fall (Burns 2002b). Spotted seals consume about 5-6% of their body weight per day (Bigg 1981).

Newly weaned spotted seal pups depend heavily on zooplankton associated with ice floes and begin feeding on larger fish at 2-3 months of age (Popov 1982). Diet studies found that pup diet in the Okhotsk Sea consisted primarily of euphausiids, while pups in the Karaginskiy Bay and Gulf of Anadyr in the Bering Sea consumed amphipods, algae, shrimp, and shoaling fish (Quakenbush 1988, Burns 2002b). Immature spotted seal diet consisted of shrimps and isopods in the Bering Sea and euphausiids in the Sea of Okhotsk (Fedoseev 2000), although Popov (1982) noted that immature animals (ages 1-4) also feed on pelagic fish (flounders, pollock), cod, halibut, and gobies. Overall, the occurrence of crustaceans and algae in the diet is thought to decrease with age, while the occurrence of benthic fishes such as flounders, sculpins, and halibut increases with age (Quakenbush 1988).

Adult spotted seals forage primarily on schooling fish such as Alaska pollock, Arctic cod, capelin and sandlance in winter and spring and on salmon in the summer. In the Bering Sea, diet studies of adult spotted seals collected in the winter and spring (March-June) indicate that seals preyed primarily on Arctic cod, capelin, and saffron cod in the northern Bering Sea; capelin, pollock, and herring in the southeast Bering Sea; walleye pollock and eelpout in the central Bering Sea; Arctic cod, pollock, sand lance, and octopus in the Gulf of Anadyr; and sand lance, herring, and octopus in Karaginsky Bay (Bukhtiyarov et al. (1984) in Lowry et al. 2000). A more recent study of stomach contents from adult spotted seals collected from the northern Bering Sea in summer and fall 2000-2003 also found that fish dominated the diet, with herring first in importance followed by gadids (Dehn et al. 2007). In the Okhotsk Sea, diet studies in late spring and early summer indicated that schooling fish, specifically walleye pollock and herring, were the most important, followed by cephalopods and then decapods (Quakenbush 1988, Burns 2002b, Dehn et al. 2007).

The spotted seal's diet in summer when it inhabits the coastal zone has not been well-sampled (Burns 2002b). Diet studies in September-October indicate that spotted seals rely heavily on anadromous and coastal spawning fishes such as salmon, saffron cod, and herring (Lowry et al. 2000). Herring and salmon spawn near shore and are abundant along the coast during the summer, moving offshore to overwinter, while saffron cod live permanently in the coastal zone (Lowry et al. 2000). No data are available on the spotted seal's diet during November–February (Lowry et al. 2000).

Diet studies in Peter the Great Bay found that primary prey were fishes including saffron cod, flounders, and rockfish (Burns 2002b). In Tarter Strait saffron cod, flounders, and salmon were dominant followed by crustaceans and cephalopods (Burns 2002b).

Studies of foraging behavior of spotted seals are limited. However, adults may dive to 300 m and may travel up to 400 m underwater (Bigg 1981). Pups are thought to begin independent feeding 10-15 days after weaning (Burns 2002b) and dive to depths up to 80 m one month after weaning (Quakenbush 1988).

VII. Sources of Natural Mortality

Predators of spotted seals include killer whales (*Orcinus orca*), Pacific sleeper sharks (*Somniosus pacificus*), Steller sea lions (*Eumeopias jubatus*), walruses (*Odobenus rosmarus*), polar bears (*Ursus maritimus*), brown bears (*Ursus arctos*), wolves (*Canis lupis*), Arctic foxes (*Alopex lagopus*), eagles (*Haliaeetus* spp.), ravens (*Corvus corax*), and gulls (*Larus* spp.) (Quakenbush 1988). Brown bears and wolves may be significant predators of spotted seals at coastal rookeries in the Okhotsk Sea where the mortality rate may reach 10% (Popov 1982). Spotted seals host numerous helminth species which can infest the heart and lungs, and endoparasitism may be a significant factor in juvenile mortality (Quakenbush 1988).

VIII. Demographic Rates

Age at maturity. Most females attain sexual maturity at 3-6 years of age and males at 5-6 years of age (Fedoseev 2000).

Fecundity. The annual reproductive rate of spotted seals is estimated at 20% (Popov 1982). The net reproductive rate (i.e. the average number of pups a female produces during her lifetime) was estimated at 1.36 for the Bering Sea and 1.25 for the Okhotsk Sea (Fedoseev 2000).

Survivorship. Survival in the first year of life is much lower than in subsequent years. The survival rate for the first year was reported at 57% for the Okhotsk Sea and 58% for the Bering Sea (Fedoseev 2000) and similarly at 55% by Popov (1982). The survival rate for animals aged one and older was reported as 86% for the Okhotsk Sea (Quakenbush 1988) and 92% by Popov (1982).

Longevity. The maximum lifespan of the spotted seal is at least 35 years (Quakenbush 1988, Burns 2002b).

IX. Abundance and Population Trends

Current abundance

The current size of the spotted seal population is unknown since recent, accurate population census data are not available (Angliss and Outlaw 2008). Estimates of spotted seal abundance from recent decades provide conflicting information and are reviewed below.

Burns (1973) estimated the global spotted seal population in the early 1970s at 335,000-450,000 individuals. This estimate included 200,000-250,000 individuals in the Bering Sea based on Alaska Department of Fish and Game studies in 1968, 1971, and 1972, and 168,000 individuals in the Okhotsk Sea based on aerial surveys by Fedoseev (1971) (Quakenbush 1988, Angliss and Outlaw 2008). However, the Bering Sea estimate of 200,000-250,000 seals is considered unreliable (“educated guess” according to Burns (2002)) since it was based on indirect survey methods and projections from relative abundances of other animals (Rugh and Shelden 1997). More recently, Burns (2002) reported a global spotted seal population in the 1980s of ~248,000 individuals based on estimates of 100,000-135,000 seals in the Bering Sea and 130,000 seals in the Okhotsk Sea.

Additional, widely varying estimates are available for the eastern and western Bering Sea. For the eastern Bering Sea, Braham et al. (1984) estimated an abundance of 10,876-13,125 spotted seals from aerial surveys conducted in 1976, although seals in the water were not included in this calculation (Rugh and Shelden 1997). Aerial surveys in the eastern Bering Sea conducted by the National Marine Mammal Lab in 1992 and 1993 estimated a much lower number of 3,356 (2,988-3,724) seals hauled out, which also did not correct for seals in the water or an unknown portion of harbor seals (Rugh and Shelden 1997). Using a correction factor for seals in the water and the maximum count of 4,145 seals from 1992 yields a rough estimate of 59,214 seals (Angliss and Outlaw 2008). For the western Bering Sea, Fedoseev (1988) estimated 28,000 seals in Karaginskiy Bay and 60,000 seals in the Gulf of Anadyr based on a small number of sightings (431) from aerial surveys (Rugh and Shelden 1988). In contrast, Burkanov et al. (1988) estimated a much lower number of 10,700 seals in Karaginskiy Bay in 1986-1987 based on vessel-supported aerial surveys, and argued that Fedoseev (1988) used faulty sampling methods (Rugh and Shelden 1988).

Population estimates for the Okhotsk Sea are equally variable. Popov (1982) estimated the spotted seal population at 13,000 seals in 1969 based on aerial surveys, Shustov (1972) estimated 130,000 seals, and Lagerev (1988) estimated 50,000 seals using helicopter surveys in 1986 and 1987 (Quakenbush 1988, Rugh and Shelden 1997). More recently, Mizuno et al. (2002) estimated 13,653 spotted seals in March 2000 and 6,545 in April 2000 in the southern Okhotsk Sea off Hokkaido. Finally, based on aerial surveys in the Okhotsk Sea conducted between 1968 and 1990, Fedoseev (2000) reported an average multi-year estimate of 176,800 spotted seals (range: 67,000 - 268,000) with a peak in 1976 and generally declining thereafter. The most recent estimates for the entire Okhotsk Sea are 96,000 in 1989 and 178,000 in 1990 (Fedoseev 2000).

The remaining populations in the Tatar Straight, Peter the Great Bay, and the Bo Hai Sea are thought to be small. The most recent estimates are 8,000-10,000 individuals in the Tatar Strait (Heptner et al. 1976), 1,000 individuals in Peter the Great Bay in 1996 (Trukhin and Mizuno 2002), and 4,500 individuals in the Bo Hai Sea in 1990 (Burns 2002b).

Population Trends

Population trends for spotted seals over recent decades are difficult to assess since reliable populations estimates are not available for most populations. Burns (2002b) states that indirect and anecdotal information suggests that the Bering-Chukchi Sea spotted seal population has declined since the early 1980s, likely due to changing climate conditions, unfavorable sea-ice conditions, and altered food web dynamics, in accordance with trends in harbor seals in northern part of Pacific range. In reviewing observations of Alaska Natives from the northern Bering and Chukchi Seas, Pungowiyi (2000) states that spotted seals appeared to have declined from the late 1960s and early 1970s to the present. Aerial surveys conducted by Fedoseev (2000) in the Okhotsk Sea between 1968 and 1990 suggest that there was a population peak for spotted seals in 1976 with a general decline in numbers thereafter.

The spotted seal population in Peter the Great Bay declined precipitously in the 20th century due to over-hunting and has not rebounded in recent decades despite the prohibition on hunting (Trukhin and Mizuno 2002). The spotted seal population in Peter the Great Bay was estimated at several thousand individuals at end of 19th century. The population decreased considerably through the early and mid 20th century when spotted seals disappeared from haulout sites due to high hunting pressure along the coast that killed up to 80 seals per day, and reached a low of several hundred individuals in 1968 (Trukhin and Mizuno 2002). Aerial surveys in 1985-1986 estimated the population at 1,000 individuals, and the population likely rebounded somewhat due to protection of island and coastal haulout sites by the establishment of the Far Eastern Marine Reserve in Peter the Great Bay in 1978 (Trukhin and Mizuno 2002). However, the population in 1996 was again estimated at 1,000 individuals, reflecting no population growth over a ten year period despite the prohibitions on hunting, protection of breeding areas, and favorable environmental conditions (Trukhin and Mizuno 2002). Trukhin and Mizuno (2002) attributed the lack of population growth to high mortality rates (10%) of spotted seals from bycatch in the saffron cod trap net fishery in Peter the Great Bay.

In Liaodong Bay in the Bo Hai Sea, the spotted seal population in the 20th century also declined in numbers and range due to over-hunting and destruction of coastal habitat, which remain ongoing (Won and Yoo 2004). The spotted seal population in the Bo Hai Sea was estimated at 7,000-8,100 individuals in the 1930s to 1940, and declined markedly after 1940 due to high hunting pressure that killed more than 1,000 seals per year in the 1950s and 400-500 per year in the 1960s and 1970s (Won and Yoo 2004). The spotted seal population fell to a low of 2,267-2,300 seals in 1979-1982 (Rugh and Shelden 1997, Won and Yoo 2004). The population increased to 4,500 seals in 1990 likely due to the ban on hunting in the 1980s (Burns 2002b). However, killing of spotted seals in this region continues from bycatch in fisheries, direct killing of seals by commercial fishers, and poaching for fur, meat, oil, and genitalia for use in traditional medicine (Won and Yoo 2004). Fishermen and residents of Bak-ryoung Island off western South Korea (an important haulout site for spotted seals in Yellow Sea) have repeatedly stated that seal numbers in the region have declined since the 1970s due to habitat disturbance and persecution by humans (Won and Yoo 2004).

PART TWO: ANALYSIS OF ENDANGERED SPECIES ACT LISTING FACTORS

I. Criteria for Listing Species as Endangered or Threatened

Under the ESA, 16 U.S.C. § 1533(a)(1), NMFS is required to list a species for protection if it is in danger of extinction or threatened by possible extinction in all or a significant portion of its range. In making such a determination, NMFS must analyze the species' status in light of five statutory listing 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;
> (E) other natural or manmade factors affecting its continued existence.

16 U.S.C. § 1533(a)(1)(A)-(E); 50 C.F.R. § 424.11(c)(1) - (5).

A species is "endangered" if it is "in danger of extinction throughout all or a significant portion of its range" due to one or more of the five listing factors. 16 U.S.C. § 1531(6). A species is "threatened" if it is "likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." 16 U.S.C. § 1531(20). While the ESA does not define the "foreseeable future," NMFS must use a definition that is reasonable, that ensures protection of the petitioned species, and that gives the benefit of the doubt regarding any scientific uncertainty to the species.

Because global warming is one of the foremost threats to the ringed, beared, and spotted seal, NMFS should consider the timeframes used in climate modeling. The minimum time period that meets these criteria is 100 years. Predictions of impacts in the next 100 years or more are routine in the climate literature, demonstrating that impacts within this timeframe are inherently "foreseeable." The IUCN threatened species classification system, described below, also uses a timeframe of 100 years. Moreover, in planning for species recovery, NMFS and the US Fish and Wildlife Service (USFWS) routinely considers a 75-200 year foreseeable future threshold (Suckling 2006). For example, the Alaska Region of the USFWS stated in the Steller's Eider Recovery Plan:

> The Alaska-breeding population will be considered for delisting from threatened status when: The Alaska-breeding populations has <1% <u>probability of extinction in the next 100 years</u>; AND Subpopulations in each of the northern and western subpopulations have <10% probability of extinction in 100 years and are stable or increasing. The Alaska-breeding population will be considered for reclassification from Threatened to Endangered when: The populations has > 20% <u>probability of extinction in the next 100 years</u> for 3 consecutive years; OR The population has > 20% probability of extinction in the next 100 years and is decreasing in abundance (USFWS 2002 (emphasis added)).

With regard to the Mount Graham red squirrel, the USFWS stated "At least 10 years will be needed to stabilize the Mt. Graham red squirrel population and <u>at least 100 to 300 years will be needed to restore Mt. Graham red squirrel habitat</u>" (Suckling 2006 (emphasis added)). With regard to the Utah prairie dog, the Service defined the delisting criteria as "[t]o establish and maintain the species as a self-sustaining, viable unit with retention of 90 percent of its genetic diversity <u>for 200 years</u>" (Suckling 2006 (emphasis added)). NMFS stated of the Northern right whale: "[g]iven the small size of the North Atlantic population, downlisting to threatened <u>may take 150 years</u> even in good conditions" (Suckling 2006 (emphasis added)).

Perhaps most importantly, the time period that NMFS uses in its listing decision must be long enough so that actions can be taken to ameliorate the threats to the petitioned species and prevent extinction. Slowing and reversing impacts from anthropogenic greenhouse gas emissions, a primary threat to the ringed, bearded, and spotted seal, will be a long-term process for a number of reasons, including the long lived nature of carbon dioxide and other greenhouse gases and the lag time between emissions and climate changes. For all these reasons, Petitioner suggests a minimum of <u>100 years</u> as the "foreseeable future" for analyzing the threats to the continued survival of the ringed, bearded, and spotted seal. The use of less than 100 years as the "foreseeable future" in this rulemaking would be clearly be unreasonable, frustrate the intent of Congress to have imperiled species protected promptly and proactively, and fail to give the benefit of the doubt to the species as required by law. NMFS must include these considerations in its listing decision.

II. The Survival of Each of the Petitioned Seal Species is Threatened by the Five Endangered Species Act Listing Factors

Petitioner believes that all five listing factors threaten the future existence of the ringed, bearded, and spotted seal. Global warming poses the most immediate and grave threat to these ice-dependent seal species since they are likely to suffer dramatic population declines, if not extinction, with the rapid degradation and loss of sea-ice habitat in this century which they rely on for the critical life-history behaviors of reproduction and molting. Declining snow cover and early sea-ice breakup are already having significant impacts on ringed seal populations. Growing threats from climate change include depletion of prey resources due to changing ocean conditions and ocean acidification, increasing exposure to predators, competitors, disease, and human disturbance; and increasing shipping activity and oil and gas development, with associated risks of oil spills and noise pollution, as sea-ice loss increases the accessibility of previously ice-covered regions. The ringed, bearded, and spotted seal also face threats from current or potential overexploitation from hunting, current oil and gas development throughout their range, rising contaminant levels in the Arctic, and bycatch mortality from commercial fisheries. Existing regulatory mechanisms have proven ineffective in mitigating these threats to these seal species. Although the ringed, bearded, and spotted seal face multiple threats, each of these species merits listing under the Endangered Species Act based on the threats from global warming alone. Clearly, the ringed, bearded, and spotted seal are in dire need of the additional protections that only listing under the ESA can provide.

A. The Present or Threatened Destruction, Modification or Curtailment of Their Habitat or Range

1. Global Climate Change

Global warming represents the gravest threat to the long-term survival of the ringed, bearded, and spotted seal. All three seal species depend on sea ice as a platform for resting, birthing, nursing, and molting, making the disappearance and degradation of their sea-ice habitat due to global warming the primary threat to their continued existence. These species' Arctic habitat has already warmed more than twice as fast as the global average, and a number of climate feedbacks will continue to accelerate future levels of warming in the Arctic. Observed changes to date include accelerating, unprecedented declines in winter and summer sea-ice extent, progressively earlier breakup dates of sea ice, decreasing sea-ice thickness, and declines in snow cover.

The effect of global warming will worsen in this century. Of importance for the ringed, bearded, and spotted seal, the best available science indicates the near-complete disappearance of Arctic summer sea ice by 2030 (Stroeve et al. 2008) or even as early as 2012 (Amos 2007, Borenstein 2007). Winter sea-ice loss is also accelerating and is predicted to decline in the Barents, Okhotsk and Bering Seas by 40% by mid-century (Meier et al. 2007). Without sea ice, these seals will experience widespread breeding failures and pup mortality, compromised body condition, and impairment in molting, and without question would qualify as endangered species. Unless greenhouse gas emissions are cut dramatically in the immediate future, the disappearance of sea ice is essentially assured. As discussed under "The Inadequacy of Existing Regulatory Mechanisms," below, such emission cuts are not likely to happen absent significant changes in domestic and global energy policies.

This section reviews the best available scientific information regarding (a) the greenhouse effect and current levels of greenhouse gases; (b) climate feedbacks that result in accelerated global warming in the Arctic; (c) environmental changes observed to date in the Arctic due to global warming and specifically in the ice-covered seas inhabited by the ringed, bearded, and spotted seal; (d) projected climate change in the Arctic; (e) impacts to these three seal species from global warming observed to date; and (f) future impacts to these three seal species from global warming within this century.

a. The Climate System, Greenhouse Gas Concentrations, the Greenhouse Effect, and Global Warming

In its most recent 2007 report, the Intergovernmental Panel on Climate Change (IPCC) [1] expressed in the strongest language possible its finding that global warming is occurring: "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" (IPCC 2007: 5). The international scientific consensus of the IPCC is that most of the recent warming observed has been caused by human activities and that it is "very likely" due to increased concentrations in anthropogenic greenhouse gases (IPCC 2007). One of the most troubling recent findings is that the concentration of atmospheric carbon dioxide, the biggest contributor to global warming, has been rapidly increasing throughout the 2000s and is generating stronger-than-expected and sooner-than-predicted climate forcing (Canadell et al. 2007, Raupach et al. 2007). Studies that have used climate projections to examine the ecological consequences of global warming have forecast catastrophic species extinctions. Using a mid-range climate scenario, Thomas et al. predicted that 15-37% of species will be committed to extinction by 2050. Malcolm et al. (2006) estimated that 11-43% of endemic species in biodiversity hotspots will go extinct by the end of the century under a scenario of doubled carbon dioxide concentrations, which includes an average of 56,000 endemic plants and 3,700 endemic vertebrate species.

The IPCC's *Fourth Assessment Report – Climate Change 2007* and the Arctic Climate Impact Assessment's[2] ("ACIA's") *Impacts of a Warming Arctic* (ACIA 2005) have synthesized

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[1] The IPCC was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 (IPCC 2001a). The IPCC's mission is to assess available scientific and socio-economic information on climate change and its impacts and the options for mitigating climate change and to provide, on request, scientific and technical advice to the Conference of the Parties to the United Nations Framework Convention on Climate Change (IPCC 2001b). Since 1990, the IPCC has produced a series of reports, papers, methodologies, and other products that have become the standard works of reference on climate change (IPCC 2001). The 2007 *Fourth Assessment Report* is the most current comprehensive IPCC reference and has built and expanded upon the IPCC's past products.

[2] The Arctic Council is a high-level intergovernmental forum that addresses the common concerns and challenges faced by the Arctic people and governments of the eight Arctic nations – Canada, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, and the United States, as well as six Indigenous Peoples organizations – Aleut International Association, Arctic Athabaskan Council, Gwich'in Council International, Inuit Circumpolar Conference, Russian Association of Indigenous Peoples of the North, and Saami Council, as well as official observers (ACIA 2005). The Arctic Council commissioned the ACIA project and charged its working groups – Arctic Monitoring and Assessment Programme ("AMAP"), Conservation of Arctic Flora and Fauna ("CAFF"), and the International Arctic Science Committee ("IASC") - with its implementation.

the best available science on global warming in the Arctic, including a detailed analysis of observed climate trends and future climate projections for the Arctic. An ever-growing body of newer climate studies provides continuous updates to the IPCC findings. Based on these synthesis reports and the latest research, this section briefly reviews global warming, the greenhouse effect, and the contributions of greenhouse gases to global warming.

The basic physics underlying global warming are as well established as any phenomena in the planetary sciences. The earth absorbs heat in the form of radiation from the sun, which is then redistributed by atmospheric and oceanic circulations and also radiated back to space (Le Treut et al. 2007). The earth's climate is the result of a state in which the amount of incoming and outgoing radiation is approximately in balance. Changes in the earth's climate can be caused by any factor that alters the amount of radiation that reaches the earth or the amount that is lost back into space, or that alters the redistribution of energy within the atmosphere and between the atmosphere, land, and ocean (Le Treut et al. 2007). A change in the net radiative energy available to the global earth-atmosphere system is called "radiative forcing" (Le Treut et al. 2007). Positive radiative forcings tend to warm the earth's surface while negative radiative forcings tend to cool it (Albritton et al. 2001).

Radiative forcings are caused by both natural and anthropogenic factors (Albritton et al. 2001, ACIA 2005, Le Treut et al. 2007). The level of scientific understanding of these different forcings varies, and the forcings themselves and interactions between them are complex (Le Treut et al. 2007). The primary cause of global warming, however, is society's production of massive amounts of "greenhouse gases" such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons that cause positive radiative forcings (Forster et al. 2007, Le Treut et al. 2007).

The Enhanced Greenhouse Effect is caused by increasing concentrations of these greenhouse gases in the earth's atmosphere. As greenhouse gas concentrations increase, more heat reflected from the earth's surface is absorbed by these greenhouse gases and radiated back into the atmosphere and to the earth's surface. Increases in the concentrations of greenhouse gases slow the rate of heat loss back into space and warm the climate, much like the effect of a common garden greenhouse (Forster et al. 2007, Le Treut et al. 2007). The higher the level of greenhouse gas concentrations, the larger the degree of warming experienced.

By the time of the Fourth Assessment Report of the IPCC in 2007, the atmospheric concentration of carbon dioxide had increased by 36% since 1750 to a level that has not been exceeded during the past 650,000 years and likely not during the past 20 million years (Denman et al. 2007). About three fourths of anthropogenic carbon dioxide emissions come from fossil fuel burning, and most of the remaining emissions are due to land-use changes, primarily deforestation (Denman et al. 2007). Carbon dioxide is considered the most important greenhouse gas overall because the volume emitted is greater that of all the other greenhouse gases combined.

The efforts of hundreds of scientists over four years, as well as the special knowledge of indigenous peoples, contributed to the ACIA report. In sum, the ACIA (2005) is a comprehensively researched, fully referenced, and independently reviewed evaluation of Arctic climate change and its impacts (ACIA 2005).

Of great concern, the rate of increase of total atmospheric carbon dioxide concentrations is accelerating, with especially rapid increases observed in the 2000s (Canadell et al. 2007). Carbon dioxide emissions increased from 3.2 ± 0.1 GtC yr^{-1} during the 1990s to 4.1 ± 0.1 GtC yr^{-1} during 2000-2005 (Denman et al. 2007). These increased emissions have been attributed to rises in fossil fuel burning and cement production (average proportional growth increased from 1.3% yr^{-1} to 3.3% yr^{-1}) rather than emissions from land-use change which remained approximately constant (Canadell et al. 2007). During the past 50 years, carbon dioxide sinks on land and oceans have become less efficient in absorbing atmospheric carbon dioxide, which is also contributing to the observed rapid rise (Canadell et al. 2007). As of March 2006, the atmospheric carbon dioxide concentration was 381 ppm, and rising at over 2 ppm per year (Shukman 2006).

The atmospheric concentration of methane, another important greenhouse gas, has increased by about 150% since 1750, continues to increase, and has not been exceeded during the past 650,000 years (Forster et al. 2007). About 60% of current methane emissions come from human activities, and there is also evidence that current carbon monoxide (CO) emissions are a cause of increasing methane concentrations (Denman et al. 2007). Over a 100-year period, methane will trap about 23 times more heat than an equal amount of carbon dioxide (Albritton et al. 2001).

The atmospheric concentration of nitrous oxide (N_2O) has increased by about 18% since 1750, continues to increase, and has not been exceeded during at least the last 2000 years (Forster et al. 2007). About half of the nitrous oxide emissions to the atmosphere come from human activities (Denman et al. 2007). Over a 100-year period, nitrous oxide will trap about 296 times more heat than an equal amount of carbon dioxide (Albritton et al. 2001).

Halocarbons are carbon compounds that contain fluorine, chlorine, bromine, or iodine (Forster et al. 2007). Most types of halocarbons are produced exclusively by human activities (Forster et al. 2007). Halocarbons that contain chlorine, like chlorofluorocarbons, ("CFCs") also cause depletion of the stratospheric ozone layer and are regulated under the Montreal Protocol (Forster et al. 2007). The combined tropospheric abundance of ozone-depleting gases peaked in 1994 and is now declining slowly (Forster et al. 2007). However, some compounds which have been promoted as substitutes for now-regulated CFCs are themselves greenhouse gases, and concentrations of these gases, such as hydrochloroflurocarbons ("HCFCs") and hydroflurocarbons ("HFCs") are now increasing (Forster et al. 2007). There are many different types of halocarbons, which have global warming potentials that vary between 12 and 12,000 times that of carbon dioxide (Forster et al. 2007).

Ozone is another important greenhouse gas found in both the troposphere, the portion of the atmosphere that begins at the earth's surface and extends from 8 to 14.5 kilometers (5 to 9 miles) high, and the stratosphere, the portion of the atmosphere that starts just above the troposphere and extends to 50 kilometers (31 miles) high (Albritton et al. 2001). Ozone is not directly emitted, but rather is formed from photochemical processes involving both natural gases and manmade emissions (Albritton et al. 2001). Because ozone persists in the atmosphere for only a short period of time varying from weeks to months, its role in radiative forcing is more complex and less certain than for more persistent greenhouse gases (Albritton et al. 2001).

The loss of ozone from the stratosphere (a phenomenon popularly termed a “hole in the ozone layer”) has resulted in negative radiative forcing that has offset some portion of the warming caused by other greenhouse gases (Albritton et al. 2001). However, the ozone layer is expected to rebound as a result of the Montreal Protocol, and the negative forcing caused by the current depressed levels of ozone in the stratosphere is expected to reverse (Albritton et al. 2001). The most recent findings of the Fourth Assessment Report indicate that global stratospheric ozone decreased between the late 1970s to early 1990s but has increased slightly since the early 1990s (Forster et al. 2007).

Increasing concentrations of ozone in the troposphere also cause positive radiative forcing (Albritton et al. 2001). Ozone in the troposphere is in fact the third most important greenhouse gas after carbon dioxide and methane (Albritton et al. 2001). Tropospheric ozone is estimated to have increased by approximately 35% since the Industrial Revolution, though increases have varied by region (Albritton et al. 2001). Ozone concentrations respond relatively quickly to changes in the emissions of ozone precursors such as NO and NO_2 (the sum of which is denoted NO_x) and volatile organic compounds (“VOCs”) (Albritton et al. 2001).

Black carbon, or soot, consists of particles or aerosols released through the inefficient burning of fossil fuels, biofuels, and biomass (Quinn et al. 2007). Black carbon warms the atmosphere as a solid, not a gas. Unlike greenhouse gases, which warm the atmosphere by absorbing longwave infrared radiation, soot has a warming impact because it absorbs shortwave radiation, or visible light (Chameides and Bergin 2002). Black carbon is an extremely powerful greenhouse pollutant. Scientists have described the average global warming potential of black carbon as about 500 times that of carbon dioxide over a 100 year period (Hansen et al. 2007, *see also* Reddy and Boucher 2007). This powerful warming impact is remarkable given that black carbon remains in the atmosphere for only a few days to a few weeks, with a mean residence time of 5.3 days (Reddy and Boucher 2007).

Black carbon contributes to Arctic warming through the formation of “Arctic haze” and through deposition on snow and ice which increases heat absorption (Quinn et al. 2007, Reddy and Boucher 2007). Arctic haze results from a number of aerosols in addition to black carbon, including sulfate and nitrate (Quinn et al. 2007). The effects of Arctic haze may be to either increase or decrease warming, but when the haze contains high amounts of soot, it absorbs incoming solar radiation and leads to heating (Quinn et al. 2007). Soot also contributes to heating when it is deposited on snow because it reduces reflectivity of the white snow and instead tends to absorb radiation. A recent study indicates that the direct warming effect of black carbon on snow can be three times as strong as that due to carbon dioxide during springtime in the Arctic (Flanner et al. 2007). Black carbon emissions that occur in or near the Arctic contribute the most to the melting of the far north (Quinn et al. 2007, Reddy and Boucher 2007).

Other gases, such as NO_x, volatile organic compounds, and carbon monoxide are called indirect greenhouse gases because of their impact on the abundance of tropospheric ozone and other greenhouse gases such as methane (Forster et al. 2007). These compounds interact and contribute to global warming in complex ways. For example, increases in NO_x concentrations decrease methane concentrations but increase tropospheric ozone (Forster et al. 2007).

Many other natural and human caused factors contribute to positive or negative radiative forcing, including aerosol emissions, land-use changes, and changes in solar and volcanic activity, water vapor, and cloud cover (Le Treut et al. 2007). Nevertheless, scientists now know that greenhouse gases are the most important force driving global warming, and that carbon dioxide is in turn the most important of the greenhouse gases (Forster et al. 2007, Solomon et al. 2007). Carbon dioxide emissions from fossil fuel burning are virtually certain to remain the dominant control over trends in atmospheric carbon dioxide concentrations during this century (Forster et al. 2007).

b. The Arctic is Warming Much Faster than Other Regions

Due to its unique characteristics, the Arctic has warmed and is projected to warm more rapidly than any other region on earth (ACIA 2005, Anisimov et al. 2007). 'Arctic amplification' is the phenomenon of greater and more rapid warming over the Arctic compared with other regions as a result of several interactions and feedbacks. The following section reviews the most important feedbacks that contribute to rapid Arctic warming.

The first major feedback relating to Arctic climate change involves surface reflectivity, referred to as the ice-albedo feedback (ACIA 2005). As the Arctic warms, rising temperatures melt snow and ice, which begin to form later in the autumn and melt earlier in the spring (ACIA 2005). Less snow and ice cover results in lower reflectivity of solar radiation (i.e. lower "albedo") because the land and water surfaces beneath the snow and ice are much darker and absorb more of the sun's energy than the snow or ice (ACIA 2005). While sea ice reflects 85-90% of solar radiation, ocean water reflects only 10% (ACIA 2005). Greater heat absorption leads to more warming. This increased warming creates a self-reinforcing cycle by which global warming is amplified and the warming trend is accelerated (ACIA 2005). The ice-albedo feedback process is already underway in the Arctic (ACIA 2005).

An important aspect of the ice-albedo feedback that influences the melting of sea ice is that the extra heat absorbed by the ocean in the summer is carried through winter to the following year (Serreze and Francis 2006). As described above, as more sea ice melts during the summer due to rising temperatures, the ocean absorbs more heat. The growth of the autumn and winter sea ice is delayed and the resulting ice is thinner. Due to this decrease in thickness, the autumn-to-spring sea ice, which is typically 1 to 4 meters thick, is not as effective in insulating the Arctic ocean from the colder autumn-to-spring air temperatures, and more of the heat absorbed by the ocean in the summer escapes to the atmosphere, explaining why surface temperatures are expected to rise most in autumn and winter over the ocean. However, some of the extra ocean heat will be retained through the ice season and will promote the earlier melting of sea ice in spring, exposing more of the ocean surface which will absorb more solar energy. As a result of this positive feedback loop, the heat content of the ocean continues to rise, and the cycle continues until none of the sea ice survives the melt season, resulting in an ice-free Arctic summer (Serreze and Francis 2006).

The ice-albedo positive feedback loop is enhanced by three physical processes. First, as sea ice melts, meltwater pools forming on the surface of the sea ice have lower reflectivity and thus lead to increased melting of the surface (Serreze and Francis 2006). Secondly, as more gaps (i.e. leads and polynyas) open in the sea ice, more radiation is absorbed by the exposed ocean surface which triggers further melting of the edges and undersides of the ice floes (Serreze and Francis 2006). Finally, as snow melts, the snow grains increase in size which reduces the reflectivity and increases the melt rate (Serreze and Francis 2006).

Another factor that enhances the ice-albedo feedback is the deposition of black carbon in the Arctic. Black carbon, or soot, consists of particles or aerosols released from the burning of fossil fuels, in particular from fossil fuels and biomass, which are carried by winds and deposited in the Arctic (ACIA 2005). The soot deposition slightly darkens the surface of the otherwise white snow and ice, further reducing surface reflectivity, increasing heat absorption, and therefore increasing warming (ACIA 2005). Arctic warming will also be further accelerated by reflectivity changes that occur as boreal forests expand further northward and replace existing tundra (ACIA 2005). Forests are taller, darker, and more textured than the relatively smooth tundra, and therefore absorb more radiation (ACIA 2005). While the greater carbon intake of forests versus tundra may moderate this impact, scientists believe that the impacts from decreases in surface reflectivity are likely to outweigh the impacts from greater carbon uptake (Chapin et al. 2005).

A second positive feedback that enhances Arctic warming is the interaction between rising temperatures and release of greenhouse gases from permafrost (ACIA 2005). Large amounts of carbon are currently trapped as organic matter in the permafrost that underlies much of the Arctic (ACIA 2005). During the summer when the surface layer of permafrost thaws, organic matter in this layer decomposes, releasing carbon dioxide and methane into the atmosphere (ACIA 2005). Global warming accelerates the decomposition rate of organic matter in the permafrost, increasing the release of greenhouse gases and further increasing their atmospheric concentrations (ACIA 2005). A positive feedback loop is created which amplifies the rate of warming (ACIA 2005). A long-term concern is the release from the permafrost of large amounts of methane, a potent greenhouse gas that traps about 23 times more than the same amount of carbon dioxide over a 100-year period. Large amounts of methane are currently stored in permafrost and at shallow depths in cold ocean sediments (ACIA 2005). Even a relatively small rise in temperature of the permafrost or water at the seabed could initiate the release of this methane and greatly increase global warming.

c. Climate and Environmental Changes Observed to Date

Climate change in the Arctic is occurring at a rapid pace that is exceeding the predictions of the most advanced climate models. The mean model forecast from the IPCC’s Fourth Assessment Report significantly under-estimates the declining trend in both summer and winter Arctic sea-ice extent (Stroeve et al. 2007). Winter sea-ice extent in 2006 and 2007 declined to a minimum which most climate models forecast would not be reached until 2070 (Stroeve et al. 2007), and summer sea-ice extent in 2007 plummeted to a record minimum (NSIDC 2007b) which most climate models forecast would not be reached until 2050 (Stroeve et al. 2007). Conditions in 2007 shattered records for Arctic climate in other ways. Greenland ice sheet melt has been accelerating, and in 2007, an unprecedented 552 billion tons of ice melted from the ice sheet, which is ~12% more than in the previous worst year of 2005 (Borenstein 2007). The northern Bering, Chukchi, and Beaufort Seas experienced sea surface temperatures in 2007 that were 3-3.5°C warmer than historical averages during the past century and 1.5°C warmer than the historical maximum (Hines 2007). Climate scientists are warning that the Arctic may have already passed a tipping point beyond which an ice-free Arctic summer is inevitable, and that a seasonally ice-free Arctic Ocean might be realized as early as 2012 (Amos 2007, Borenstein 2007). Clearly, rapid degradation of the ringed, bearded, and spotted seal habitat poses a grave threat to the persistence of these species.

This section reviews the best available science on observed changes in Arctic climate conditions that are most relevant to the ringed, bearded, and spotted seal. The most recent scientific information on Arctic-wide climate change is presented, followed by information on regional climate change in the range of these species.

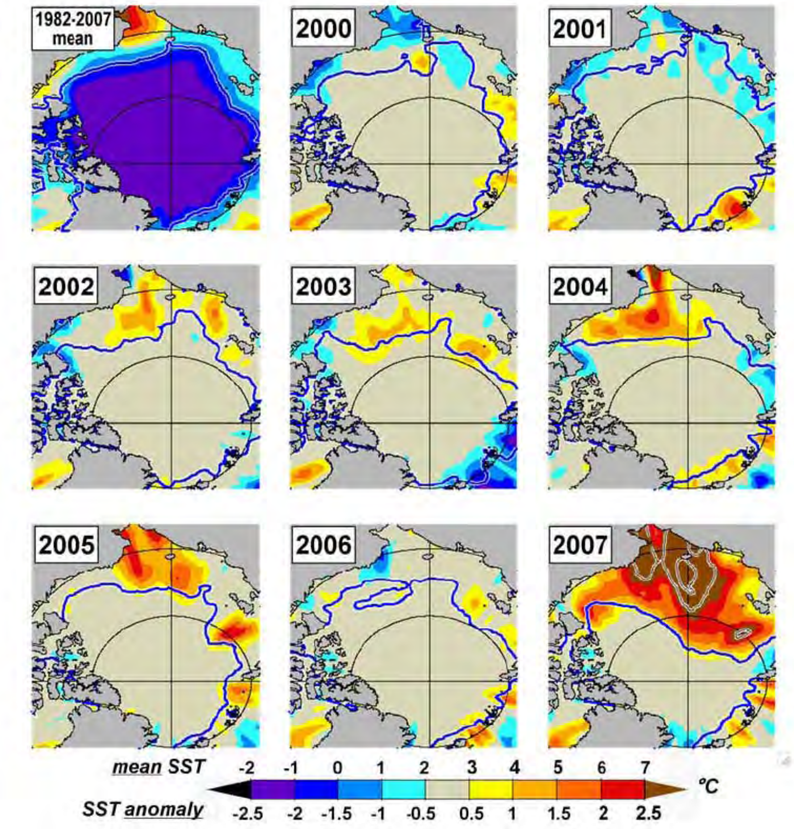
Increases in surface temperature

Arctic surface temperatures increased twice as much as the global average during the 20th century (Trenberth et al. 2007), and warming trends have accelerated in recent decades. The Arctic Climate Impact Assessment (ACIA) evaluated the spatial and temporal variations in temperature over all land areas in the Arctic for the 20th century (1900-2003) using the Climatic Research Unit and GHCN databases (ACIA 2005). Temperature trends in the Arctic were similar to the global trends: the Arctic was cooler than average from 1890-1920, warmer from 1920s-1940s, cooler from the 1940s to the mid-1960s, and warmer from the mid-1960s onward, with warming especially strong from 1990 to present (ACIA 2005). One of the most important findings was that the rate of temperature increase in the Arctic was much larger than the global average increase during the 20th century and has been particularly rapid since the mid-1960s. The average rate of temperature increase during 1966-2003 over the Arctic was 0.4 ºC/decade, approximately four times greater than the average for 20th century (ACIA 2005). The land-surface annual air temperature trends in northwestern Alaska and northeastern Russia in coastal areas surrounding the Bering and Chukchi Seas inhabited by ringed, bearded, and spotted seals increased by 1 to 2ºC per decade during 1966-2003 (ACIA 2005: Figure 2.7(d)). In some areas of western Alaska and eastern Russia, winter and spring (December-May) temperatures over land have increased by as much as 4-8°C over the last 40 years (1966-2003) (ACIA 2005: Figure 2.8(d)).

Satellite-derived temperature data for both land and sea surfaces, providing full coverage of the Arctic for the past 25 years, indicate that warming trends are accelerating. From 1981-2005, the Arctic region has been warming at a rate of 0.72 ± 0.10 °C per decade (Comiso 2006b). Regionally, the trends are 0.54 ± 0.11 °C per decade over sea-ice, 1.19 ± 0.20 °C per decade over Greenland, 0.84 ± 0.18 °C per decade over North America and 0.13 ± 0.16 °C per decade over Northern Eurasia (Comiso 2006b). High temperature anomalies were much more prevalent in the 2000s compared to the 1980s (Comiso 2006b).

In a study of Arctic ocean summertime surface warming trends over the past 100 years, Steele et al. (2008) detected pronounced warming across Arctic seas (60-90°N) since 1995 and especially after 2000. Steele et al. (2008) calculated that the increase in upper ocean summertime warming between 1965-1995 alone would be sufficient to reduce the following winter's ice growth by 0.75 m or alternately to delay winter ice growth by two weeks to two months. The northern Bering, Chukchi, Beaufort, and East Siberian Seas experienced the greatest summer warming since the late 1990s, where surface temperatures during summer of 2007 were 3 to 3.5°C warmer than historical averages and 1.5°C warmer than the historical maximum (Figure 11) (Hines 2007, Stroeve et al. 2008). The region just north of the Chukchi Sea experienced sea surface temperatures 5°C above average in 2007, a record high never before observed (Hines 2007, Steele et al. 2008).

Figure 11. Mean satellite-derived summer sea surface temperature from 1982-2007 and anomalies from this mean during 2000-2007. The dark blue contour represents the September mean sea-ice edge.
Source: Steele et al. 2008: Figure 3.



Regional analyses in the Bering Sea have also found that surface air and ocean temperatures are rising. Temperature data from 1950-2002 at St. Paul Island on the southeastern Bering Sea shelf show a transition from cold to warm anomalies in 1976, consistently earlier springs beginning in 1996, and longer warm periods extending from February through November beginning in 2000 (Overland and Stabeno 2004). At St. Lawrence Island in the northern Bering Sea, air temperatures have increased from 1997-2004 (Grebmeier et al. 2006b). Depth-averaged summer ocean temperatures measured at a mooring at 70 m depth on the southeastern Bering Sea shelf were 2°C warmer in 2001-2003 compared to the mid-1990s (Overland and Stabeno 2004). In the Northern Bering Sea, bottom water temperatures have been increasing from 1988-2005 (Grebmeier et al. 2006b).

Decreases in snow cover

Snow cover is a climate variable of high significance for the ringed seal since ringed seals require adequate snow accumulation for constructing subnivian lairs that it depends on for birthing and nursing pups during the long lactation period. Precipitation has increased in the Arctic (Anisimov et al. 2007, Min et al. 2008), perhaps by as much as 8% in the past 100 years (ACIA 2005). However, snow-cover extent appears to be decreasing (ACIA 2005) as more precipitation falls as rain instead of snow. Rain-on-snow events have increased significantly across much of the Arctic, with increases of 50% recorded over the past 50 years in western Russia (ACIA 2005). Snow depth on multi-year Arctic sea ice declined in all months between 1954-1991, with the largest decrease in May (the month of maximum snow depth) of 8 cm over 37 years (Warren et al. 1999). Similarly, the fraction of solid precipitation diminished at all stations in the Norwegian Arctic between 1975 and 2001 (ACIA 2005). There is also evidence of a general decrease in snow depth in Canada since 1946, especially in the spring, and of decreases in winter snow depths over European Russia since the beginning of the last century (Serreze et al. 2000). Snow cover has decreased by about 10% over the Northern Hemisphere as a whole since 1972, and snow cover in North America has decreased in spring extent since the 1950s (ACIA 2005). Overall, decreasing snow cover over land and sea ice will lower its surface albedo and accelerate ice melt.

Changes in permafrost

Changes in the temperature and extent of permafrost in the Arctic have been recorded as temperatures warm, providing another indicator of global warming (Lemke et al. 2007). Permafrost warming is occurring in the North American and Russian Arctic. Permafrost temperature has increased by up to 2-3°C in northern Alaska since the 1980s, by 0.3-0.8°C in the Canadian High Arctic since the 1990s, and by 0.3-0.7°C in the 1980s in western Siberia in parallel with increasing air temperature and decreasing insulating snow cover (Lemke et al. 2007). Permafrost degradation, where the thickness and areal cover of permafrost are reduced by thawing, is especially severe along Arctic coasts with ice-bearing permafrost. Over the Alaskan Beaufort Sea coast, mean annual erosion rates range from 0.7 to 3.2 m/year with maximum observed rates of 16.7 m/year (Lemke et al. 2007). Along the Russian Arctic coast, erosion rates range from 2.5-3.0 m/year for ice-rich coasts to 1.0 m/year for ice-poor permafrost coasts (Lemke et al. 2007). Overall, warming permafrost is releasing greenhouse gases that will further increase warming.

Changes in the Greenland ice sheet

Melting of the Greenland ice sheet has accelerated far beyond what scientists predicted even just a few years ago. Using satellite observations, Rignot and Kangaratnam (2006) found that mass loss from the Greenland ice sheet more than doubled between 1996 and 2005, increasing from 91 to 224 km^3 per year, due to the acceleration of ice discharge in western and eastern Greenland. Using a longer study period, Steffen et al. (2007) reported a 30% increase in the ice sheet melt area in western Greenland between 1979 and 2006, with record melt years in 1987, 1991, 1998, 2002, 2005, and the most extreme melt year in 2007. In 2007, 552 billion tons of ice melted from the Greenland ice sheet, which is ~12% more than the previous worst year of

2005 (Borenstein 2007). These losses have been linked to extended, warm air temperatures over the Greenland ice sheet, which have increased by 4°C since 1991 (Steffen et al. 2007).

The rate of ice loss from the Greenland ice sheet has been consistently under-estimated by climate models because they do not include important physical processes that influence the magnitude of glacier response to changes in air and ocean temperature (Rignot and Kangaratnam 2006). Such physical processes include reduced surface albedo, loss of buttressing ice shelves, lowered ice surface altitude, and the formation of rivers of melt water, called "moulins," that flow down several miles to the base of the ice sheet, where they lubricate the area between the ice sheet and the rock, speeding the movement of the ice towards the ocean (Hansen et al. 2006, Rignot and Kangaratnam 2006). In addition, the floating ice shelves that front Greenland glaciers, such as the large Petermann Glacier in northwestern Greenland, are interlaced with numerous, wide sub-ice-shelf channels which created by bottom melting of ice from warm ocean water underneath (Rignot and Steffen 2008). Rignot and Steffen (2008) warn that the presence of these deep channel incisions makes the ice shelves more vulnerable to breakup by warmer ocean waters much sooner than predicted. The accelerating melt of the Greenland ice sheet is relevant to ringed, bearded, and spotted seal population persistence because it further reduces surface albedo in the Arctic, thus enhancing warming, and provides another warning that Arctic ice is melting much faster than climate models predict.

Changes in sea ice: Declining extent, declining length of the ice season, declining thickness

Key climate indicators of critical importance to ringed, bearded, and spotted seals are sea-ice extent, timing of formation and breakup, and thickness. These species are dependent on sea ice as a substrate for birthing, nursing, molting, and resting. Reductions in sea-ice extent, duration, and quality will increase stress and mortality by disrupting these essential life history behaviors.

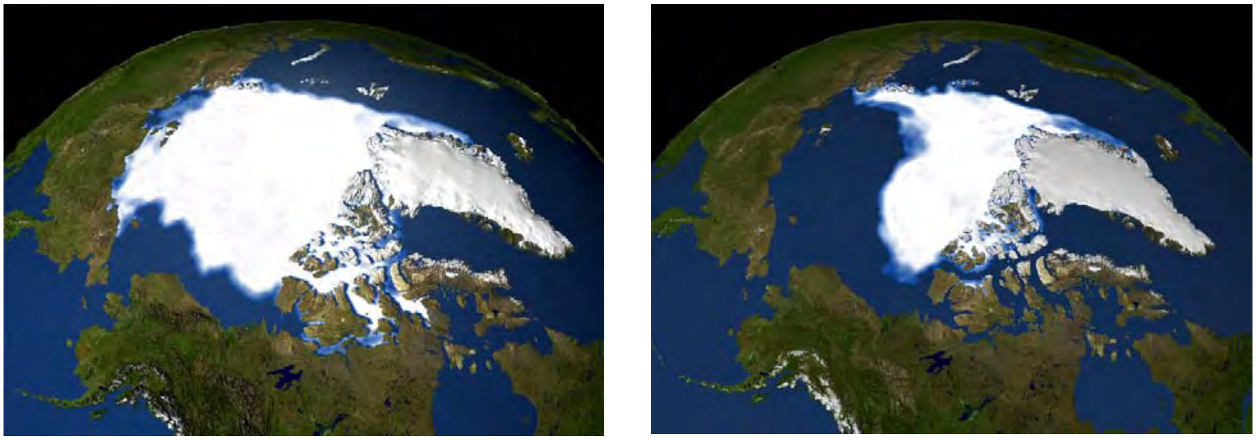
Sea-ice extent

The extent of sea ice is a key indicator of climate change (ACIA 2005). It significantly influences climate by affecting surface reflectivity, cloudiness, humidity, exchanges of heat and moisture at the ocean surface, and ocean currents, and thus likely exerts a substantial influence on climate change related to global warming (ACIA 2005). Within each year, the Arctic sea-ice cover reaches its maximum extent in March and its minimum extent in September at the end of the melt season (ACIA 2005). The perennial ice is the sea ice that survives the summer melt season which consists mainly of the thick multi-year ice floes that are the mainstay of the Arctic sea-ice cover (Comiso 2005). Studies of changes in sea-ice extent throughout the Arctic and on a regional basis are summarized below.

A. Arctic-wide declines in sea-ice extent

September Arctic sea-ice extent declined by 10.7% per decade from 1979-2007, equivalent to a loss of 72,000 km^2 per year (NSIDC 2007b, Stroeve et al. 2008). This rate of loss has accelerated in recent decades as evident from the lower rate of decline when a longer time period is considered: -7.8% per decade from 1953–2006 (Stroeve et al. 2007). Record losses of summer sea ice occurred in 2002 and 2005, and summer sea-ice extent reached an utterly stunning new record minimum in 2007 (NSIDC 2007b, Comiso et al. 2008). At 4.13 million km^2 (1.59 million square miles), the five-day minimum sea-ice extent in September 2007 (Figure 12) was about 39% (one million square miles[3]) below the average minimum sea-ice extent between 1979 and 2000 (NSIDC 2007b) and 23% less than the previous low in 2005 (NSIDC 2007b). Using an extended time series from the Met Office Hadley Center, Stroeve et al. (2008) calculated that September sea-ice extent in 2007 was 50% lower than conditions in the 1950s to 1970s.

Figure 12. Sea-ice extent on September 21, 1979 and September 14, 2007.
Source: Images courtesy NASA/Goddard Space Flight Center Scientific Visualization Studio.



Sea-Ice Extent in September 1979 Sea-Ice Extent in September 2007

In response to this unprecedented loss of summer sea ice, NSIDC senior scientist Mark Serreze warmed that the positive feedback loop of Arctic amplification may have reached a tipping point:

> The sea-ice cover is in a downward spiral and may have passed the point of no return. As the years go by, we are losing more and more ice in summer, and growing back less and less ice in winter. We may well see an ice-free Arctic Ocean in summer within our lifetimes....The implications for global climate, as well as Arctic animals and people, are disturbing (NSIDC 2007b).

As noted above, Arctic summer sea ice is melting more rapidly than recent climate models predict. Stroeve et al. (2007) evaluated how well the IPCC Fourth Assessment Report multi-model ensemble simulated observed Arctic sea-ice loss over the 1953-2006 study period, and found that the mean model forecast significantly underestimated the declining trend in September sea-ice extent. The most striking finding was that recent summer sea-ice minima are approximately 30 years ahead of the IPCC ensemble mean model predictions (Stroeve et al. 2007; Figure 5). The 2007 minimum was lower than the sea-ice extent most climate models predict would not be reached until 2050 (Figure 13).

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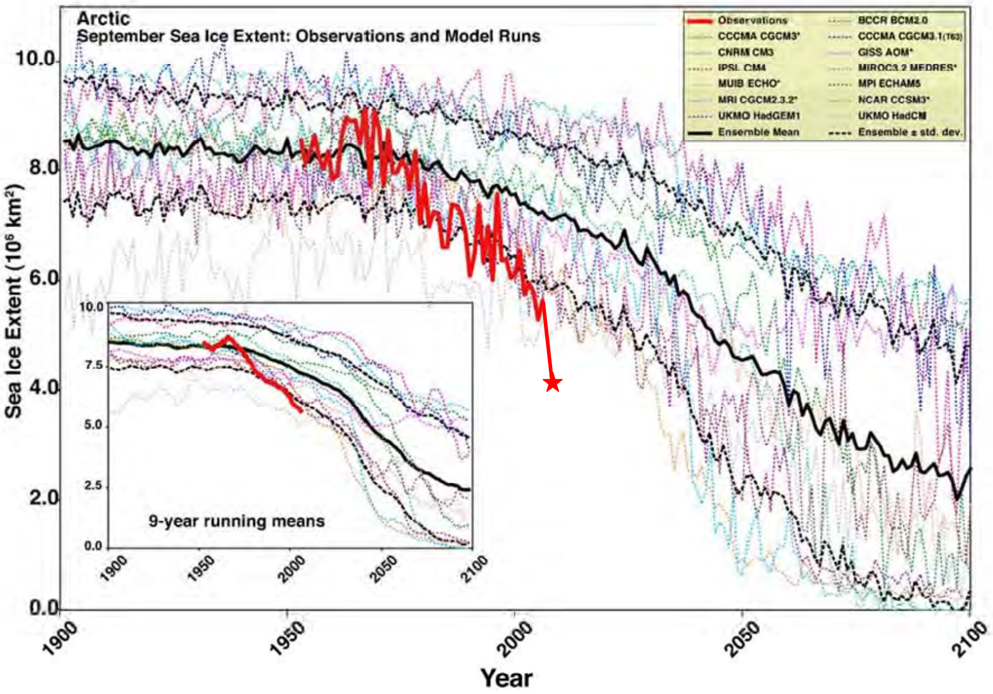
[3] One million square miles is equal to about the area of Alaska and Texas combined.

Figure 13. Arctic September sea-ice extent (x 10^6 km^2) from observations (thick red line) and 13 IPCC-AR4 climate models, shown with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). Inset shows 9-year running means. Red asterisk shows 2007 observed sea-ice extent (asterisk and connecting line added by Petitioner).
Source: Based on Stroeve et al. (2007): Figure 1.

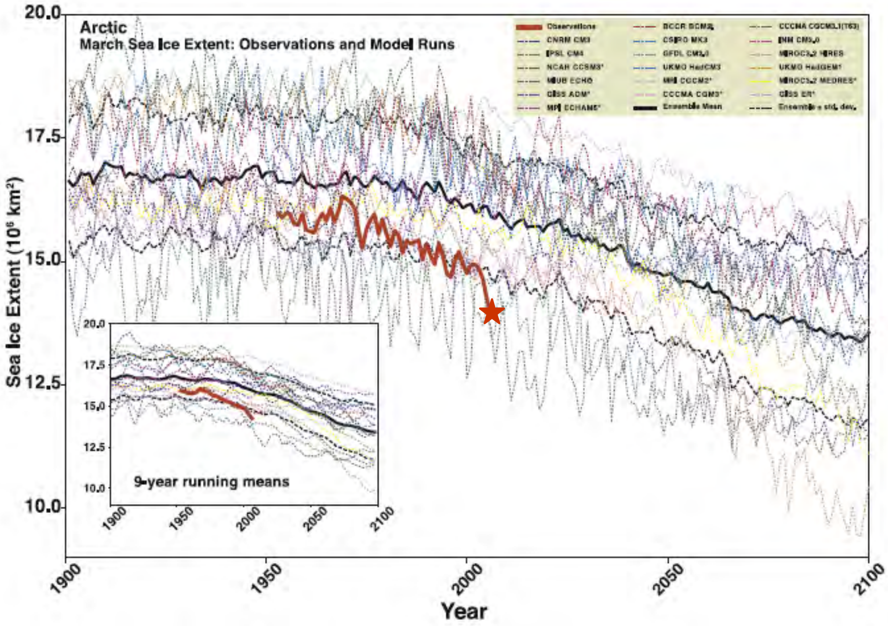


Another troubling trend is the increasing loss of winter sea-ice (Meier et al. 2005, Comiso 2006a). Until recently, sea ice has largely been able to rebound during the dark winter season despite decreasing summer sea-ice extent (Meier et al. 2007). The downward trend in March sea-ice extent (the climatological sea-ice maximum) was -1.8% per decade from 1953-2006, but has accelerated over recent decades: -2.9% per decade from 1979-2006 (Stroeve et al. 2007). Meier et al. (2005) reported that sea-ice extent was anomalously low during winter 2004 and spring 2005 (December 2004-May 2005) when every month except May 2005 experienced record-low sea-ice extent. Declines in winter sea-ice extent in 2004-2005 occurred in all regions of the Arctic, including the north Atlantic and north Pacific, indicating that the onset of freeze-up was delayed throughout the Arctic (Meier et al. 2005). In 2006, March sea-ice extent fell to the lowest value in the satellite record (14.5 million km^2), and March sea-ice extent in 2007 (14.7 million km^2) narrowly missed the 2006 low (NSIDC 2007a). March sea-ice extent in 2008 rebounded slightly to 15.2 million km^2, but was still 0.54 million km^2 lower than the 1979-2000 mean (NSIDC 2008). Including 2008, the linear trend for March indicates that the Arctic is losing an average of 44,000 km^2 of ice per year in March (NSIDC 2008). Comiso et al. (2008) highlighted that declines in both summer and winter sea ice have accelerated markedly in the past decade. Sea ice extent trends for the entire ice cover (seasonal and perennial ice) shifted from -2.2% per decade in 1979–1996 to -10.1% per decade in 1997-2007 (Comiso et al. 2008).

Of foremost concern, Stroeve et al. (2007) found that winter sea ice is melting more rapidly than the IPCC Fourth Assessment Report multi-model ensemble predicts (Figure 14). March sea-ice extent in 2006 reached a minimum that most climate models forecast would not be reached until 2070 (Stroeve et al. 2007).

Figure 14. Arctic March sea-ice extent (x 10^6 km^2) from observations (thick red line) and 18 IPCC-AR4 climate models, shown with the multi-model ensemble mean (solid black line) and standard deviation (dotted black line). Inset shows 9-year running means. Red asterisk shows 2007 observed sea-ice extent (added by Petitioner).

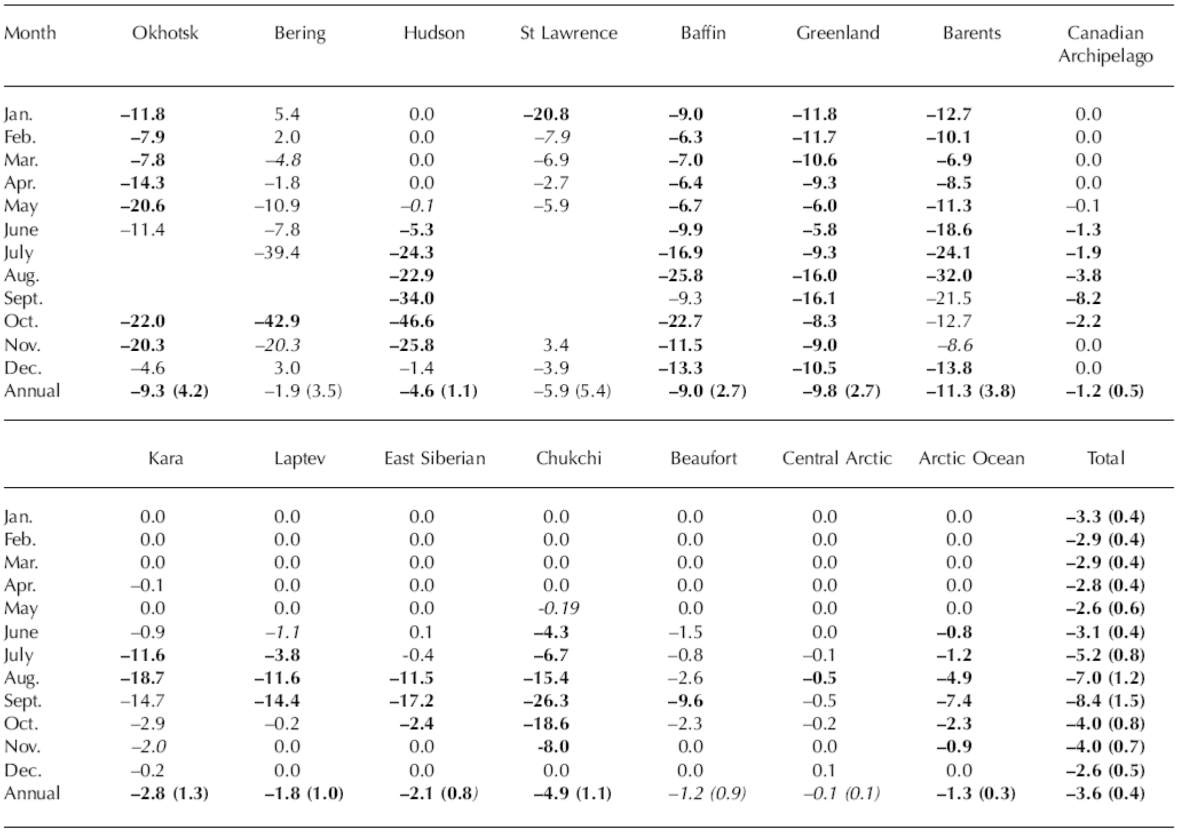
Source: Based on Stroeve et al. (2007): Figure 2.



B. Regional declines in sea-ice extent in Arctic and subarctic seas inhabited by the ringed, bearded, and spotted seal

A study of regional and monthly trends in sea-ice extent from 1979-2006 using pan-Arctic satellite data indicates that sea-ice extent is declining significantly throughout the Arctic in all regions (Table 1) (Meier et al. 2007). The highest rates of mean annual sea-ice loss (≥ -9.0% per decade) occurred in the Barents Sea, Greenland Sea, Okhotsk Sea, and Baffin Bay where significant sea-ice loss occurred in most or all months, reaching -32.0% per decade in August in the Barents Sea (Meier et al. 2007). Significant mean annual sea-ice loss also occurred during late spring through fall in the Chukchi Sea, Hudson Bay, Kara Sea, East Siberian Sea, Laptev Sea, Canadian Archipelago, and Arctic Ocean (Meier et al. 2007). In the remaining regions, sea-ice loss was significant in the Bering and Beaufort Seas during late summer and early fall (-42.9% per decade in October and -9.6% per decade in September, respectively), in St. Lawrence Bay in winter (-20.8% per decade in January), and in the central Arctic in summer (-0.5% per decade in August) (Table 1) (Meier et al. 2007).

Table 1. Regional trends in sea-ice extent in Arctic seas given as % per decade for each month for 1979-2006. Standard deviation values are provided in parentheses for the annual trends. Trends in bold are statistically significant at the 99% level and in italics at the 95% level. Blank fields indicate months where little or no ice is found in the region. A trend of zero generally reflects 100% ice cover in a region throughout the time series.
Source: Based on Meier et al. (2007): Table 2.



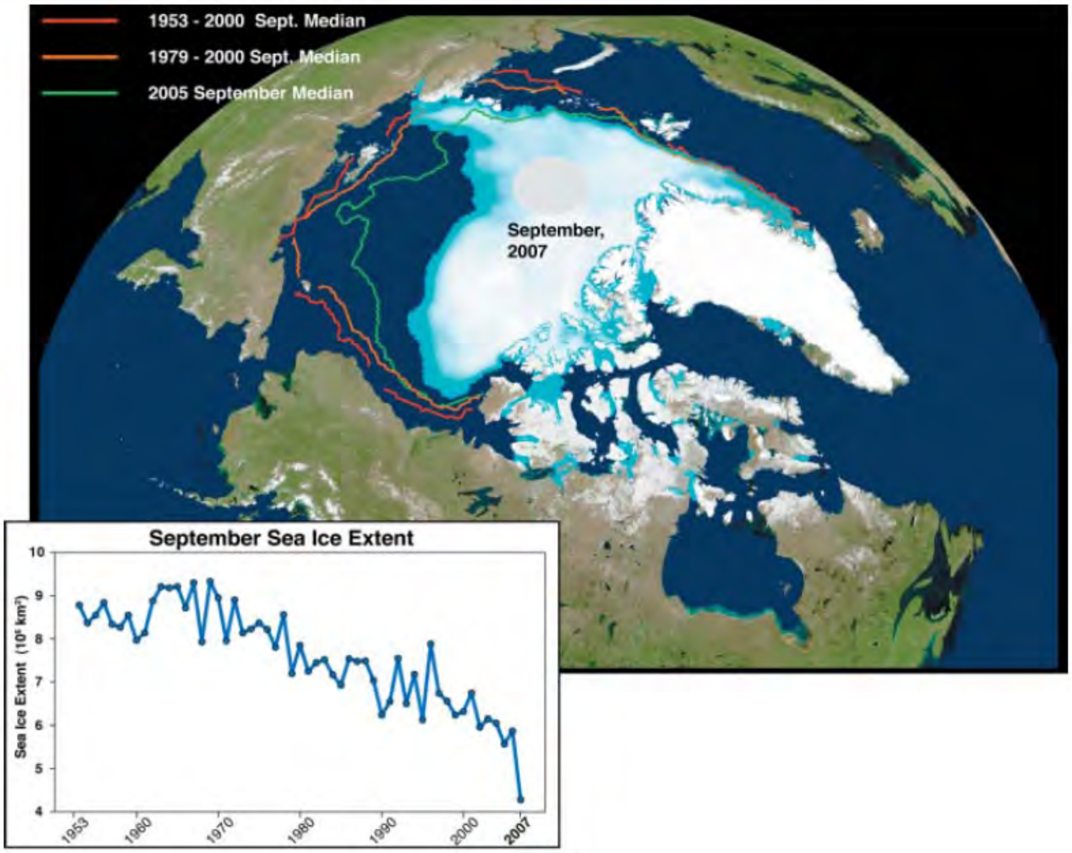
Month	Okhotsk	Bering	Hudson	St Lawrence	Baffin	Greenland	Barents	Canadian Archipelago
Jan.	**–11.8**	5.4	0.0	**–20.8**	**–9.0**	**–11.8**	**–12.7**	0.0
Feb.	**–7.9**	2.0	0.0	*–7.9*	**–6.3**	**–11.7**	**–10.1**	0.0
Mar.	**–7.8**	*–4.8*	0.0	–6.9	**–7.0**	**–10.6**	**–6.9**	0.0
Apr.	**–14.3**	–1.8	0.0	*–2.7*	**–6.4**	**–9.3**	**–8.5**	0.0
May	**–20.6**	–10.9	*–0.1*	–5.9	**–6.7**	**–6.0**	**–11.3**	–0.1
June	–11.4	–7.8	**–5.3**		**–9.9**	**–5.8**	**–18.6**	**–1.3**
July		–39.4	**–24.3**		**–16.9**	**–9.3**	**–24.1**	**–1.9**
Aug.			**–22.9**		**–25.8**	**–16.0**	**–32.0**	**–3.8**
Sept.			**–34.0**		–9.3	**–16.1**	–21.5	**–8.2**
Oct.	**–22.0**	**–42.9**	**–46.6**		**–22.7**	**–8.3**	–12.7	**–2.2**
Nov.	**–20.3**	*–20.3*	**–25.8**	3.4	**–11.5**	**–9.0**	*–8.6*	0.0
Dec.	–4.6	3.0	–1.4	–3.9	**–13.3**	**–10.5**	**–13.8**	0.0
Annual	**–9.3 (4.2)**	–1.9 (3.5)	**–4.6 (1.1)**	–5.9 (5.4)	**–9.0 (2.7)**	**–9.8 (2.7)**	**–11.3 (3.8)**	**–1.2 (0.5)**

	Kara	Laptev	East Siberian	Chukchi	Beaufort	Central Arctic	Arctic Ocean	Total
Jan.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**–3.3 (0.4)**
Feb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**–2.9 (0.4)**
Mar.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**–2.9 (0.4)**
Apr.	–0.1	0.0	0.0	0.0	0.0	0.0	0.0	**–2.8 (0.4)**
May	0.0	0.0	0.0	*-0.19*	0.0	0.0	0.0	**–2.6 (0.6)**
June	–0.9	*–1.1*	0.1	**–4.3**	–1.5	0.0	**–0.8**	**–3.1 (0.4)**
July	**–11.6**	**–3.8**	-0.4	**–6.7**	–0.8	–0.1	**–1.2**	**–5.2 (0.8)**
Aug.	**–18.7**	**–11.6**	**–11.5**	**–15.4**	–2.6	**–0.5**	**–4.9**	**–7.0 (1.2)**
Sept.	–14.7	**–14.4**	**–17.2**	**–26.3**	**–9.6**	–0.5	**–7.4**	**–8.4 (1.5)**
Oct.	–2.9	–0.2	**–2.4**	**–18.6**	–2.3	–0.2	**–2.3**	**–4.0 (0.8)**
Nov.	*–2.0*	0.0	0.0	**-8.0**	0.0	0.0	**–0.9**	**–4.0 (0.7)**
Dec.	–0.2	0.0	0.0	0.0	0.0	0.1	0.0	**–2.6 (0.5)**
Annual	**–2.8 (1.3)**	**–1.8 (1.0)**	**–2.1 (0.8)**	**–4.9 (1.1)**	*–1.2 (0.9)*	*–0.1 (0.1)*	**–1.3 (0.3)**	**–3.6 (0.4)**

Consistent with Meier et al. (2007), a regional study of changes in sea-ice concentration near southern Baffin Island, including southern Baffin Bay, Davis Strait, the northern Labrador Sea, northeastern Hudson Bay, and Hudson Strait, found that sea-ice concentration has decreased by 10-20% per decade from 1979-2004, with the largest reductions occurring in early summer and early winter (Moore 2006). These high sea-ice losses coincided with statistically significant surface warming in the region during the fall and early winter over the study period (Moore 2006).

Multiple studies have also identified dramatic losses of summer sea-ice cover in the Chukchi and Beaufort Seas inhabited by the ringed, bearded, and spotted seal, and East Siberian Sea inhabited by the ringed and bearded seal. Based on sea-ice extent data from 1953-2007, the estimated position of the September sea-ice edge in the Chukchi, Beaufort, and East Siberian Seas has retreated northward dramatically over this period (Figure 15) (Stroeve et al. 2008).

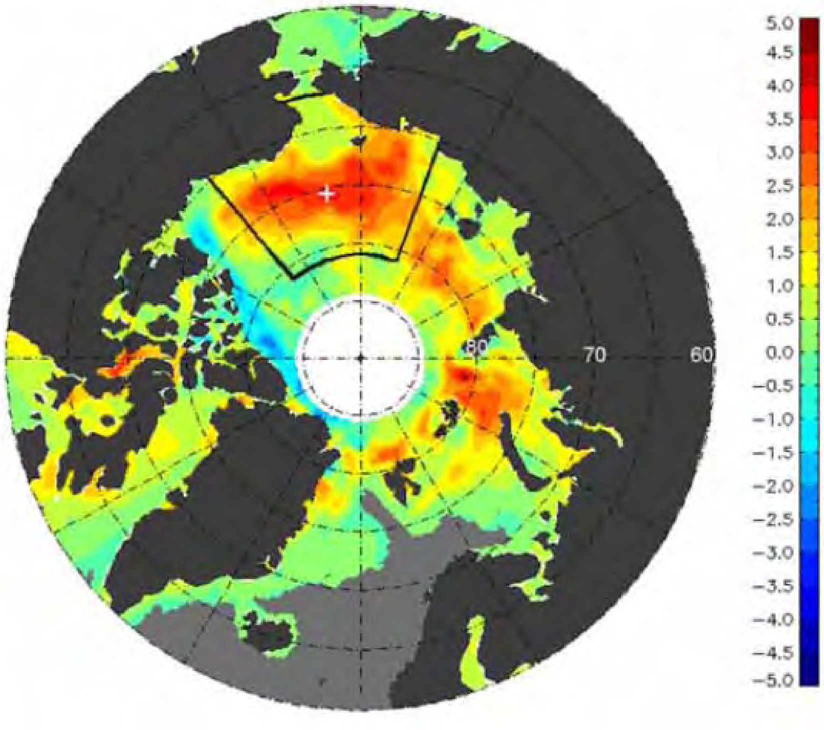
Figure 15. Sea-ice concentration for September 2007, along with Arctic Ocean median extent from 1953 to 2000 (red curve), from 1979 to 2000 (orange curve), and for September 2005 (green curve). September ice extent time series from 1953 to 2007 is shown in the insert. Source: Stroeve et al. (2008): Figure 1.



Francis and Hunter (2006) examined changes in the position of the summer southern sea-ice edge (defined as the maximum ice retreat anomaly) in six peripheral seas of the Arctic Ocean during 1979-2004 using passive microwave satellite imagery. These researchers detected significant downward trends (>99% confidence) in the Chukchi and Beaufort Seas, where the summer sea-ice edge retreated northward at an average of 168 km per decade and 113 km per decade, respectively, during the study period (Francis and Hunter 2006). In a study of the distribution of the Pacific walrus in the Chukchi Sea during the summer, Jay et al. (2008) analyzed the number of ice-free days on the Chukchi continental shelf during 1979-2007, where the shelf was defined as the 200 m isobath or shallower. The shelf was effectively ice-free during the summer in 5 of the last 6 years (2002-2007), but only once (1999) in the previous 23 years (1979-2001) (Jay et al. 2008).

Due to declines in sea-ice cover, abnormally large open water areas have formed in summer in the Chukchi, Beaufort, and East Siberian Seas (Figure 15) (Comiso 2005, Comiso 2006b). The rise in summer open-water area has resulted in large decreases in the albedo of the Chukchi and Beaufort Seas in recent decades (Comiso 2006b). This decrease in albedo would be expected to increase the absorption of solar radiation in the surface ocean. Indeed, a study examining changes in the amount of solar energy absorbed in open water areas Arctic-wide during 1979-2005 found that the largest increases in heat content occurred in the Chukchi Sea (Perovich et al. 2007). Overall, Perovich et al. (2007) detected increases in the amount of solar energy entering the upper ocean in 89% of the study region, and found that the increase in absorbed solar energy was significantly related to the increase in open water area rather than to a change in the total incident solar radiation in the Arctic, which remained constant. The increases in annual solar heat absorption in the Chukchi Sea and adjacent Beaufort and East Siberian Seas occurred at rates up to 4% per year during the study period (Figure 16) (Perovich et al. 2007).

Figure 16. Map of the linear trend of annual solar heat input to the ocean from 1979-2005 with units of percent per year.
Source: Perovich et al. (2007): Figure 2.



Regional studies in the Bering Sea using satellite, field, and Yupik traditional ecological observations also indicate that seasonal sea-ice concentrations are undergoing significant declines (Grebmeier et al. 2006b). In the southeastern Bering Sea, sea ice monitored in a 1° rectangle of latitude (57-58°N) exhibited two downward shifts. First, during 1971-1989, sea ice decreased in the mean number of days for which there was more than 5% ice cover after January 1, declining from 130 days during 1971-1976 to 67 days during 1977-1989 (Overland and Stabeno 2004). Next, beginning in 2000, sea ice has been almost completely absent from this study region (Overland and Stabeno 2004). In the northern Bering Sea, sea-ice concentrations in April from 2000-2004 were below 70% in the region between the Alaska coastline and St. Lawrence Island (Grebmeier et al. 2006b).

Declining length of the ice season

The length of the sea-ice season, including the timing of sea-ice freeze-up and breakup, is another critical variable of immediate concern for the ringed, bearded, and spotted seal. Several studies have found that the length of the ice season is shrinking throughout the Arctic. Using satellite passive microwave data from 1979 to 2005, Stroeve et al. (2006) detected a trend to an earlier onset of spring melt and a longer melt season, particularly in the region north of Alaska and Siberia, corresponding to large retreats of sea ice observed in these regions. Overall, the Arctic is experiencing a lengthening of the melt season by 2 weeks per decade (Stroeve et al. 2006). On a regional basis, all regions of the Arctic showed a statistically significant (99% confidence level or higher) lengthening of the melt seasons by at least 1 week per decade, except for the central Arctic which showed a statistically significant increase of 5.4 days per decade (Stroeve et al. 2006).

Similarly, Comiso (2006b) reported a shift to a delayed onset of Arctic ice growth between 1979 and 2005, which is resulting in a shorter ice season and longer melt season. Using pan-Arctic satellite data, Comiso (2006b) found that the length of the melt season has increased by 15.2 days per decade over sea ice, 1.5 days per decade over the Greenland ice sheet, 2.0 days per decade over northern Eurasia, and 5.5 days per decade over northern North America. Of importance for the ice seals, the duration of the melt season over sea-ice has increased by more than 5 weeks between 1979 and 2005. This equates to a shorter ice season and thinner sea ice.

Several regional studies also indicate earlier sea-ice breakup and later freeze-up. In the western Hudson Bay in Canada inhabited by the ringed and bearded seal, breakup of the annual ice is occurring approximately 2.5 weeks earlier than it did 30 years ago (Stirling et al. 1999, Derocher et al. 2004). Gagnon and Gough (2005) also found a trend towards earlier breakup in southern and western Hudson Bay and towards later freeze-up in the northern and northeastern regions of Hudson Bay that coincided with increasing regional temperatures. In the western Canadian Arctic on southern Banks Island bordering the Amundsen Gulf, Inuvialuit community experts on sea ice reported that breakup in the region in the 1990s was occurring several weeks earlier than in past decades while freeze-up was occurring later (Nichols et al. 2004). Most recently, in fall 2007, researchers were surprised to witness sea ice in the southern Beaufort Sea forming more than one month late (Struznik 2008).

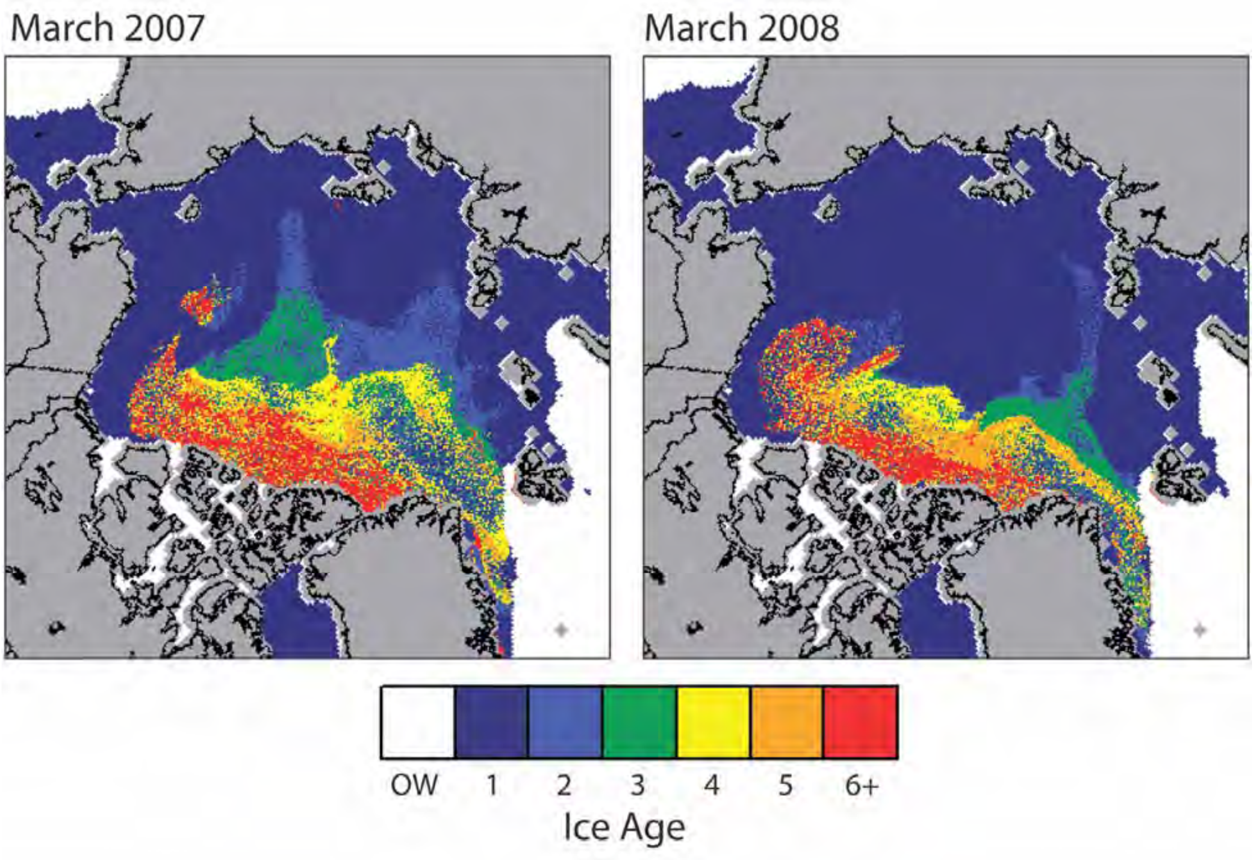
Declining sea-ice thickness

The thickness of sea ice is an important factor for ringed, bearded, and spotted seals since sea ice must be thick enough to provide a stable platform throughout the winter and spring reproductive and molting periods (Tynan and DeMaster 1997). Several studies indicate that sea-ice thickness is decreasing. Rothrock et al. (1999) detected a mean decrease in sea-ice thickness of 1.3 m in most of the deep water portion of the Arctic Ocean, from 3.1 m in 1958-1976 to 1.8 m in the 1990s. The greatest decrease occurred in the central and eastern Arctic in a band from the Chukchi Sea to the Fram Strait (Rothrock et al. 1999, ACIA 2005).

A more recent study assessed Arctic-wide changes in sea-ice thickness from 1982-2007 using satellite-derived estimates of sea-ice age and thickness (Maslanik et al. 2007b). Pack ice contains a mixture of first-year ice and multi-year ice. Multi-year ice has survived for one or more melt seasons and is typically thicker than first-year ice. This study found that the mean age and thickness of ice within the remaining multi-year ice pack has decreased due to the loss of the oldest ice types, and the remaining older, thicker ice is confined to a much smaller portion of the Arctic Ocean. Specifically, the area of ice greater than 5-years-old decreased by 56% between 1982 and 2007 (Maslanik et al. 2007). The most striking changes occurred in the central Arctic Ocean where coverage of ice greater than 5-years-old declined by 88% and ice older than 8 years essentially disappeared (Maslanik et al. 2007). The loss of older, thicker ice has resulted in a decrease in mean thickness of ice over Arctic Ocean from 2.6 m to 2.0 m between March 1987 and March 2007 (Stroeve et al. 2008).

In addition, the most recent data from March 2008 indicate that the trend toward thinner sea ice is continuing. In March 2008, relatively thin, first-year ice covered 72% of the Arctic Basin including the region around the North Pole, and considerably exceeded the first-year ice cover of March 2007 (Figure 17) (NSIDC 2008). Since very little first year ice survives the summer melt season (e.g. in 2007 only 13% of first-year ice survived), more first-year winter ice results in lower sea-ice cover in summer (NSIDC 2008). As such, the September minimum sea-ice extent in 2008 is predicted to be extremely low (NSIDC 2008).

Figure 17. Map of estimated ice age for the third week of March for 2007 (left) and 2008 (right). Dark blue indicates first-year ice; red indicates ice that is 6 years old or more; gray is land and white indicates areas where ice age is not tracked.
Source: Image from National Snow and Ice Data Center courtesy of James Maslanik, Chuck Fowler, and Sheldon Drobot at the University of Colorado at Boulder.



Finally, a regional study of trends in seasonal fast ice thickness in the northwestern Barents Sea off southeastern Svalbard over 40 years (1966-2007) found a significant decline of -0.11 m per decade that coincided with increasing local summer surface air temperatures (+0.85°C per decade in 1966–2007) and fall surface water temperatures (+0.36°C per decade in 1972–2007) (Gerland et al. 2008).

Attribution of sea-ice loss to greenhouse gas forcing and natural variability

The observed losses of Arctic sea ice have been attributed to positive radiative forcing due to rising concentrations of greenhouse gases (greenhouse gas forcing) and to natural climate variability favoring sea-ice loss (Serreze et al. 2007). The most recent scientific consensus is that greenhouse gas forcing has contributed to and continues to contribute significantly to sea-ice loss; that rising temperatures from greenhouse gas forcing have acted synergistically with natural climate variability to accelerate sea-ice loss in recent decades; and that the impacts of greenhouse gas forcing on sea-ice loss are growing. Studies examining attribution of sea-ice loss to greenhouse gas forcing and natural climate variability are briefly reviewed below.

The loss of sea ice is influenced by the natural variability in large-scale atmospheric circulation regimes which drive winds and sea-ice circulation patterns. The Arctic Oscillation (AO) and closely related North Atlantic Oscillation (NAO) have been widely considered as the most dominant atmospheric circulation patterns affecting Arctic climate (Maslanik et al. 2007a). The AO and NAO refer to cyclical shifts in sea level pressure between the high latitudes and mid latitudes (ACIA 2005, Serezze et al. 2007). The AO enters a positive mode when sea level pressure over the Arctic is low and sea level pressure over mid-latitudes is high. Similarly, the NAO enters a positive mode when sea level pressure of the Icelandic Low pressure system is low and pressure of the mid-latitude Azores High is high. When the AO-NAO is in a positive phase, surface winds produce a counterclockwise motion of sea ice and a greater net transport of sea ice away from the Siberian coast. Sea ice is transported from Siberia, across the pole, and through the Fram Straight into the North Atlantic (i.e. an enhanced Transpolar Drift Stream). In short, a positive AO-NAO mode results in thinning of ice along the coast and the enhanced movement of ice out of the Arctic basin.

The AO-NAO was in a positive mode from 1970 to the mid-1990s and was particularly strong during 1989-1995 (Stroeve et al. 2007). The positive AO-NAO mode is thought to have acted synergistically with increasing temperatures from global warming to accelerate declines sea-ice thickness and volume from the late 1980s to mid-1990s (Lindsay and Zhang 2005, Rothrock and Zhang 2005). Lindsay and Zhang (2005) propose a three-part mechanism by which this occurred: (1) air temperatures (fall, winter, spring) over the Arctic Ocean increased due to greenhouse gas forcing, resulting in the thinning of the first-year ice at the start of summer (pre-conditioning); (2) a positive AO-NAO mode triggered the accelerated decline of sea ice by flushing some ice out of the Arctic basin, thereby reducing sea-ice thickness and increasing summer open water, (3) and subsequent increasing greenhouse gas forcing combined with the ice-albedo feedback prevented sea-ice recovery (i.e. increased absorption of solar radiation further melts ice and warms water, creating thinner first year ice; thinner ice provides less insulation and more heat loss to the atmosphere, leading to higher spring temperatures and earlier melt season). The most important aspects of this cycle are that increased warming preconditioned the sea ice for declines and that warmer temperatures contributed to the ice-albedo feedback after the AO-NAO cycle returned to more favorable conditions for ice growth.

While the positive mode of the AO-NAO is thought to have contributed to sea-ice decline until the mid-1990s, another unusual Arctic atmospheric circulation pattern appears to have influenced Arctic Basin winds and sea-ice transport since 2000 (Maslanik et al. 2007a, Stroeve et al. 2008). This circulation pattern, called the dipole pattern, is characterized by high sea level pressure over the Canadian Arctic and low pressure over the Siberian Arctic that leads to persistent southerly winds over the western Beaufort, Chukchi, and East Siberian Seas, and favors northward ice drift and warmer temperatures (Maslanik et al. 2007b). The net result is the transport of sea ice from the Pacific side to the Atlantic side of the Arctic basin (Maslanik et al. 2007a). The strengthening of the dipole pattern since 2000 is thought to have contributed to the loss of sea ice in the Chukchi, Beaufort, and East Siberian Sea, and was particularly persistent in the summer of 2007 (Maslanik et al. 2007b).

Although variability in atmospheric circulation patterns contributed to the loss of sea ice, there is strong scientific consensus that sea-ice extent would have declined due to greenhouse gas forcing even without the influence of natural climate variability (Francis et al. 2005, Lindsay and Zhang 2005, Rothrock and Zhang 2005). Three main lines of evidence support this consensus. First, Rothrock and Zhang (2005) simulated sea-ice thickness and volume changes during 1948-1999 and found a steadily downward trend in sea ice (-4% per decade) that occurred during both negative and positive phases of the AO-NAO cycle and which was best explained by rising Arctic surface temperatures. Similarly, Meier et al. (2007) examined Arctic sea-ice extent during 1979-2005 and detected a strong relationship between sea-ice extent and air temperatures (correlation of -0.74) throughout this period, while the AO did not seem to have a prevailing effect, especially after the late 1990s.

Secondly, Stroeve et al. (2007) partitioned out the variance in the observed sea-ice loss in summer and winter from greenhouse gas forcing and natural variability and found that greenhouse gas forcing contributed significantly to sea-ice declines. Stroeve et al. (2007) estimated that 33–38% of the observed September trend from 1953–2006 was forced by greenhouse gas warming, which grew to 47–57% from 1979–2006 despite the strong influence of the AO-NAO and the dipole pattern during that period. The trend in winter (March) sea-ice decline also showed a large and rising contribution from greenhouse gas forcing: 34-39% from 1953-2006 and 45-52% from 1979–2006. In a second study, Francis et al. (2005) found that greenhouse gas forcing explained most of the variability in the northern ice edge position in six marginal Arctic seas (East Siberian, Chukchi, Beaufort, Barents, Kara, and Laptev)–approximately 40%--and more than other thermal or dynamic explanatory factors.

Third, the observed declines in sea-ice extent are simulated by climate models only when greenhouse gas forcing is incorporated into the models. Specifically, Zhang and Walsh (2006) found that the models used in the IPCC Fourth Assessment Report, which incorporate a range of greenhouse gas emissions levels, produced a multi-model mean annual trend in sea-ice extent within 20% of the observed climatology from 1979–1999, with a good simulation of the seasonal cycle of more sea-ice loss in the summer than in the winter (Zhang and Walsh 2006).

A final important finding of these attribution studies is that the influence of greenhouse gas forcing on sea-ice extent has been consistently under-predicted by climate models. Stroeve et al. (2007) extended the above-cited analysis of Zhang and Walsh (2006) to a longer time period (1953-2006 versus 1979-1999) to evaluate how well the IPCC Fourth Assessment Report multi-model ensemble simulated observed sea-ice loss. Stroeve et al. (2007) found that the mean model forecast significantly underestimated the declining trend in September Arctic sea-ice extent. The most striking finding was that recent summer sea-ice minima are approximately 30 years ahead of the IPCC ensemble mean model predictions. Stroeve et al. (2007) hypothesized that the models used in this analysis appeared to under-represent the greenhouse gas response most likely due to short-comings of the models in representing important feedback processes in the Arctic. In support, the two models that best matched observations over the satellite record incorporated more sophisticated sea-ice models. Stroeve et al. (2007) concluded that "it appears that impacts of GHG loading on Arctic sea ice in September are strong, and growing, and have also impacted March ice extent."

d. Projected Climate and Environmental Changes

There is no credible scientific dispute that global warming will continue and may accelerate if greenhouse gas emissions are not reduced. All climate models in the IPCC and ACIA assessments predict significant warming in this century, with variation only as to the rate and magnitude of the projected warming (ACIA 2005). For its Fourth Assessment Report ("AR4"), the IPCC performed an unprecedented, internationally coordinated climate change experiment using 23 models by 14 modeling groups from 10 countries to project future climate conditions. This large number of models that range from simple to complex, running the same experiments, provides more accurate quantification of future climate conditions, the importance of different model parameters, and the uncertainty in the results. For projecting future climate change, the model experiments used an array of different emission scenarios. These include three of the six Special Report on Emissions Scenarios ("SRES'), B1, A1B, and A2 that represent low, medium and high greenhouse gas growth scenarios during this century, respectively. In addition, experiments included scenarios with CO_2 doubling and quadrupling and scenarios with different levels of greenhouse gas mitigation, including (1) constant composition commitment scenarios in which greenhouse gas concentrations are fixed at year 2000 levels, (2) zero emission commitment scenarios in which emissions are set to zero in the year 2100 and (3) overshoot scenarios in which greenhouse gas concentrations are reduced after year 2150 (Meehl et al. 2007). The ACIA utilized the climate models used in the IPCC's Third Assessment Report and is a comprehensively researched, fully referenced, and independently reviewed evaluation of Arctic climate change and its impacts for the region and for the world. It involved an international effort by hundreds of scientists over four years, and also included the special knowledge of indigenous people (ACIA 2005). This section reviews changes in climate condition in the Arctic that are projected by the IPCC and ACIA multi-model ensembles.

Surface air temperature, precipitation, and permafrost melt

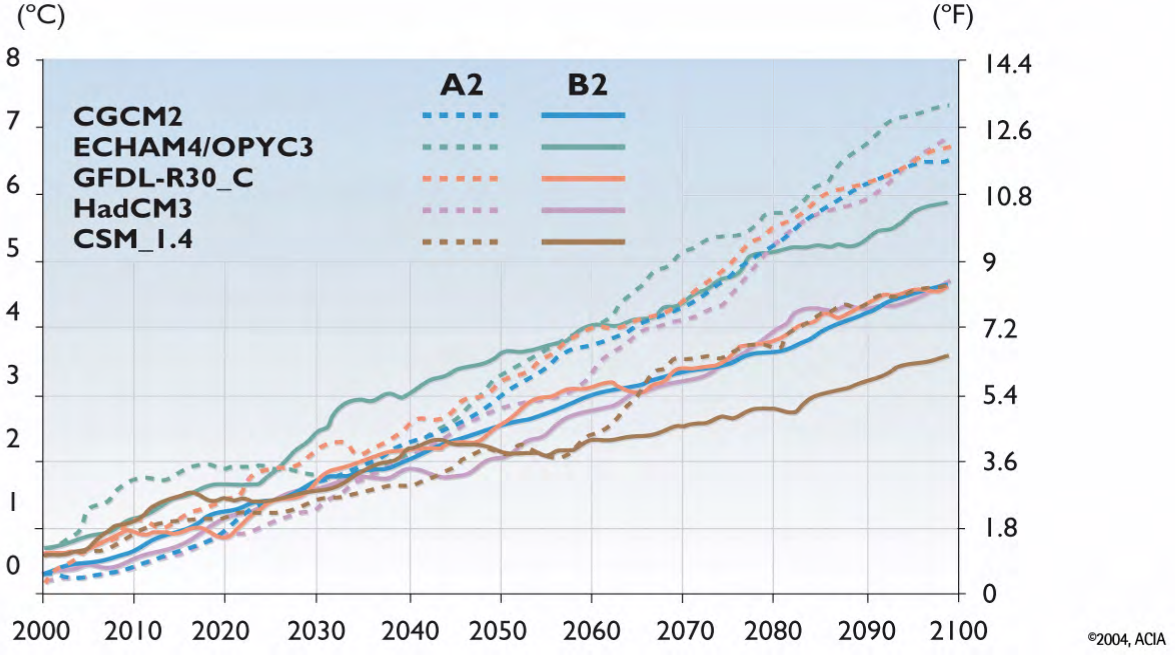
Climate model projections are unanimous that temperatures will continue to rise throughout the 21st century and that warming will be the largest in the high northern latitudes of the Arctic (Serreze and Francis 2006, Christensen et al. 2007). According to the IPCC Fourth

Assessment Report (IPCC-AR4), annual mean warming in the Arctic in this century will be more than twice the level of global annual mean warming, while Arctic winter warming will be four times the level of global mean warming (Christensen et al. 2007). By the end of the 21st century, annual Arctic temperatures are projected to rise by an average of 4.9°C under the A1B mid-level emissions scenario (also known as the "business-as-usual" scenario), based on the average from 21 models (range: 2.8-7.8°C) (Christensen et al. 2007: Table 11.1). Mean warming will be larger under the A2 higher-emissions scenario (5.9°C) and smaller under the B1 lower-emissions scenario (3.4°C). Notably, winter temperatures will rise more significantly (4.3-11.4°C) than in summer (1.2-5.3°C) (A1B scenario) (Christensen et al. 2007). In the marine realm, temperatures will rise by 5-7°C over the central Arctic Ocean, and warming in winter and autumn will be especially extreme due to reduced sea-ice cover (Christensen et al. 2007).

The ACIA (2005) projected that annual average temperatures will increase across the entire Arctic, with increases of approximately 3-5° C over land areas and up to 7° C over the oceans within this century under the B2 emissions scenario (Figure 18). Consistent with IPCC projections, winter temperatures will rise even more significantly, with increases of approximately 4-7° C over land areas and approximately 7-10° C over oceans (ACIA 2005). Patterns of temperature change predicted by regional climate models (RCMs) are quite similar to those simulated by the ACIA general circulation models. However, regional climate models project more warming along the sea-ice margins possibly because they better capture mesoscale weather systems and air-sea fluxes associated with the ice edge (ACIA 2005).

Figure 18. ACIA projected Arctic surface air temperature during 2000-2100 from 60°-90°N under the B2 and A2 emissions scenarios, expressed as the change from the 1981-2000 average.

Source: ACIA (2005: 27).



New (2005) projected that the average global temperature will have risen 2° C above pre-industrial levels sometime between 2026 and 2060, a result that is consistent with the results of the ACIA (2005) discussed above. A 2°C rise in average global temperature will translate into an average Arctic temperature increase of 3.2-6.6°C by mid-century, which will be greater in winter (4-10°C) and lower in summer (1.5-3.5°C) (New 2005).

Despite some variation among climate models and some remaining uncertainty regarding climate sensitivity, the salient point is that all models predict a warming climate in the relatively near future. The differences in the models are primarily only in the rate of change and occasionally geographic variation in the strength and timing of effects (ACIA 2005). Even using the lowest emissions scenario and the model that generates the least warming in response to atmospheric composition leads to a projection of warming in this century more than double that experienced in the last (ACIA 2005). All models project that the world will warm significantly as a result of human activities and that the Arctic is likely to experience this warming particularly early and intensely (ACIA 2005, Christensen et al. 2007).

Precipitation is projected to increase by ~18% (range 10-28%) over the Arctic by the year 2100 under the A1B scenario, with most of the increase falling as rain (Christensen et al. 2007). Projected precipitation increases are larger (22%) under the A2 scenario and smaller (13%) under the B1 scenario, but overall precipitation increases are robust among models (Christensen et al. 2007). The increase is projected to be largest in the winter and smallest in the summer, consistent with higher projected warming in the winter (Christensen et al. 2007). Regionally, precipitation is expected to increase over all land areas except southern Greenland (ACIA 2005). During the summer, precipitation will increase over northern North America and Chukotka, Russia (ACIA 2005).

Of importance for the ringed seal, Arctic snow cover will undergo widespread reductions during the 21st century under the IPCC model simulations, due to the strong association between higher air temperature and reduced snow cover (Meehl et al. 2007). Under the B2 emissions scenario, mean Arctic snow cover over land will decrease by 9-18% by the end of this century, in addition to the approximately 10% decline already observed over the past three decades (ACIA 2005). The decreases are projected to be greatest in spring and late autumn/early winter, suggesting a further shortening of the snow cover season (ACIA 2005, Meehl et al. 2007). Snow cover will decrease since the beginning of the snow accumulation season will start later and the beginning of the snow melt season will shift earlier (ACIA 2005, Meehl et al. 2007). Snow quality is also expected to change, including an increase in thawing and freezing in winter that leads to ice layer formation (ACIA 2005). Overall, projected decrease in snow cover over land and sea ice will continue to lower its surface albedo and accelerate ice melt (ACIA 2005).

Declining sea-ice extent

Summer and winter sea-ice has been declining significantly faster than the IPCC-AR4 multi-mean ensemble predicts (Stroeve et al. 2007). Summer sea-ice extent in 2007 plummeted to a record minimum (NSIDC 2007b) which most climate models forecast would not be reached until 2050 while winter sea-ice extent in 2006 and 2007 declined to a minimum which most climate models forecast would not be reached until 2070 (Stroeve et al. 2007). Based on observed sea-ice trends, leading climate scientists have proposed that summer Arctic sea ice could disappear by 2030 (Stroeve et al. 2008) or even as early as 2012 (Amos 2007, Borenstein 2007).

Arctic-wide sea-ice declines

Using the IPCC-AR4 multi-model ensemble, Zhang and Walsh (2006) projected that <u>mean</u> summer (September) Arctic sea-ice area will decrease by 65.0% under the A2 scenario, 59.7% under the A1B scenario, and 45.8% under the B1 scenario by the end of this century. In a similar assessment of the IPCC-AR4 model ensemble, Arzel et al. (2006) found that September Arctic sea-ice extent will decrease by an <u>average</u> of 62% between 1981-2000 and 2081-2100, with a smaller 15% decrease in winter (March) sea ice under the A1B scenario. Half of the models exhibited an ice-free summer Arctic by 2100 (Arzel et al. 2006). One of the important implications of retreating perennial sea ice is that the average thickness of the ice cover becomes thinner and more vulnerable to future summer melt as the fraction of multi-year ice floes decreases and the fraction of seasonal ice floes increases (Comiso 2005).

Another series of IPCC-AR4 modeling efforts demonstrated that sea-ice extent is unlikely to decline linearly but may instead experience periods of abrupt and rapid declines. Holland et al. (2006) examined the potential for future abrupt transitions in Arctic summer sea-ice extent using a subset of models employed in the IPCC-AR4 analysis (seven ensemble members from Community Climate System Model, version 3) under an A1B scenario. Abrupt transitions, defined as periods of rapid sea-ice loss, commonly occurred in all of these 21st century model simulations, as early as 2015 (Holland et al. 2006). Abrupt reductions in sea ice were associated with thinning of the spring sea ice which increased the formation of open water and accelerated summer ice loss due to an enhanced ice-albedo feedback. An important result of this work was that lower greenhouse gas emissions decreased the severity and likelihood of abrupt transition events. Under the lower emission B1 scenario, 3 of 15 models show abrupt transitions lasting 3-5 years, whereas 7 of 11 models using a higher emissions A2 scenario showed abrupt transition lasting 3-10 years with larger rates of change (Holland et al. 2006).

Another study has projected the average Arctic perennial ice cover based on 25 years of continuous, spatially detailed satellite data (Comiso 2005) and the projection that a 2° C global warming will occur between the years 2026 to 2060 (New 2005). The results show "ever increasing open ocean areas in the Beaufort, Siberian, Laptev and Kara Seas. The impact of such a largely increasing open water area could be profound. It could mean changes in the ocean circulation, marine productivity, ecology, ocean circulation and the climate of the region" (Comiso 2005:53). This study also revealed that for each 1° C increase in surface temperature (global average), the area of the average perennial ice cover decreased by about 1.48 million km^2, an area over three times the size of the state of California (Comiso 2005).

However, the IPCC-AR4 models used in the above-cited studies have significantly under-represented observed trends in summer sea ice, which suggests that summer sea-ice will decline more rapidly than predicted. Recent summer sea-ice minima are approximately 30 years ahead of the IPCC-AR4 ensemble mean model predictions (Stroeve et al. 2007), while summer sea-ice extent in 2007 plummeted to a minimum that most climate models forecast would not be reached until 2050. Given the conservative climate model results and the record minimum sea-ice extent of 2007, Stroeve et al. (2008) proposed that a seasonally ice-free Arctic Ocean might occur as early as 2030. Other leading climate scientists believe that current climate models markedly underestimate important melting processes and that the Arctic Ocean could be mostly ice free by the late summer of 2012 (Amos 2007, Borenstein 2007).

Regional sea-ice declines

Regional projections of changes in sea-ice extent were recently forecast by Overland and Wang (2007), who used the IPCC-AR4 models to better understand how declining sea-ice extent will affect Arctic ecosystems on a regional scale. Overland and Wang (2007) used a subset of IPCC-AR4 models that best simulated observed sea-ice concentrations from 1979-1999 to predict sea-ice extent in the Arctic basin during summer (August–September) and in the more southerly seasonal ice zones during winter (March–April) by 2050 under an A1B emissions scenario. The models projected a consistent loss of summer sea-ice area greater than 40% by mid-century for the entire Arctic basin, including the Chukchi, Beaufort, East Siberian, Kara, and Laptev Seas and the central Arctic north of 80°N (Overland and Wang 2007). The Bering, Okhotsk, and Barents Seas were also projected to lose at least 40% of winter sea-ice area by 2050 (Overland and Wang 2007). However, as discussed above, the IPCC-AR4 multi-model ensemble on which Overland and Wang (2007) based their work has significantly under-estimated observed losses in summer and winter sea-ice extent (Strove et al. 2007), and the disappearance of summer sea ice Arctic-wide could occur as early as 2012 (Amos 2007, Borenstein 2007) or 2030 (Stroeve et al. 2008). Any remaining sea-ice habitat in 2050 will be also be thinner and will likely not persist throughout the winter because the period of sea-ice melt will be longer (later fall sea-ice formation and earlier spring melt).

Feedbacks of sea-ice loss on the Arctic and global environment

The loss of sea ice will have important consequences for the Arctic and global climate. First, rising greenhouse gas concentrations may favor the positive mode of AO-NAO that promotes sea-ice loss (Serreze et al. 2007). If this occurs, the ice-albedo feedback would favor continued Arctic sea-ice loss until greenhouse gas concentrations in the atmosphere are reduced. Additionally, delayed autumn and winter sea-ice growth will promote large increases in surface air temperature over the Arctic by allowing a non-insulated ocean (low sea-ice cover) to lose heat to the atmosphere (Serreze and Francis 2006). Finally, sea-ice loss will affect regions outside the Arctic by influencing mid-atmospheric patterns of atmospheric circulation and precipitation (Sewall and Sloan 2004).

Dangerous Anthropogenic Climate Change and the Climate Commitment

Climate scientists are warning that we are rapidly approaching an emissions threshold beyond which “dangerous climate change” will be unavoidable. Warming of more than 1° C (1.8°F) above year 2000 levels has been defined as “dangerous climate change,” with particular reference to species extinction and sea level rise (Hansen et al. 2006, Hansen et al. 2007). Beyond this point, climate feedbacks will greatly amplify the warming from anthropogenic emissions, leading to rapid additional temperature increases and catastrophic climate impacts[4]. Leading scientists have previously reported that the atmospheric greenhouse gas level "ceiling" that must not be exceeded in order to prevent additional warming of more than 1°C (1.8° F) above year 2000 levels (or 1.7°C relative to pre-industrial time) is 450 ppm of carbon dioxide, and have warned that this threshold may need to be revised downward (Hansen et al. 2006).

Most recently, Hansen et al. (2008) present evidence that the safe upper limit for atmospheric CO_2 is actually 350 ppm (Hansen et al. 2008). Interactions between variables including greenhouse gas emissions, temperature change, ocean heat transport, and melting of ice sheets create time lags in the response of the climate system to greenhouse gas emissions, including short lags resulting from fast climate feedback processes and longer lags from slow feedback processes (IPCC 2001a). Thus, the world is already committed to some level of continued warming and climate change for centuries to come even if greenhouse gas emissions were stabilized immediately (Figure 19) (IPCC 2001a). Using paleoclimatic data from two time periods, Hansen et al. (2008) measured the sensitivity of the global climate system to increasing CO_2 (specifically, the change in global mean surface temperature following a doubling at atmospheric CO_2) when only fast climate feedback processes are considered compared to when both fast and slow feedback processes are considered. Climate sensitivity is ~3°C considering only fast feedback processes such as changes in water vapor, clouds, aerosols, and sea ice, but doubles to ~6°C when slow surface albedo feedbacks are also considered (Hansen et al. 2008). Most climate models do not include important slow climate feedback processes that dramatically increase climate sensitivity such as ice sheet disintegration, vegetation migration, and greenhouse gas release from soils, tundra, and ocean sediments (Hansen et al. 2008). However, Hansen et al. (2008) present evidence that these slow feedbacks may begin to be realized within time scale as short as centuries or less, adding urgency to rapidly reducing our emissions trajectory before the climate system is forced beyond a tipping point (Hansen et al. 2008). At current greenhouse gas emissions levels, warming 'in the pipeline' of 0.6°C is attributable to fast feedback processes and an additional 1.4°C is attributable to slow feedback processes (Hansen et al. 2008). With the current 'climate commitment' of ~2°C, no additional greenhouse gas forcing is required to raise global temperature to at least the levels of the Pleistocene, 2-3 million years ago, which is a degree of warming that would definitively produce dangerous climate impacts (Hansen et al. 2008). Thus, Hansen et al. (2008) conclude that a 350 ppm CO_2 target is urgently needed, is achievable, and must be pursued on a timescale of decades in order to avoid catastrophic consequences:

> If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimatic evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm (Hansen et al. 2008: 1).

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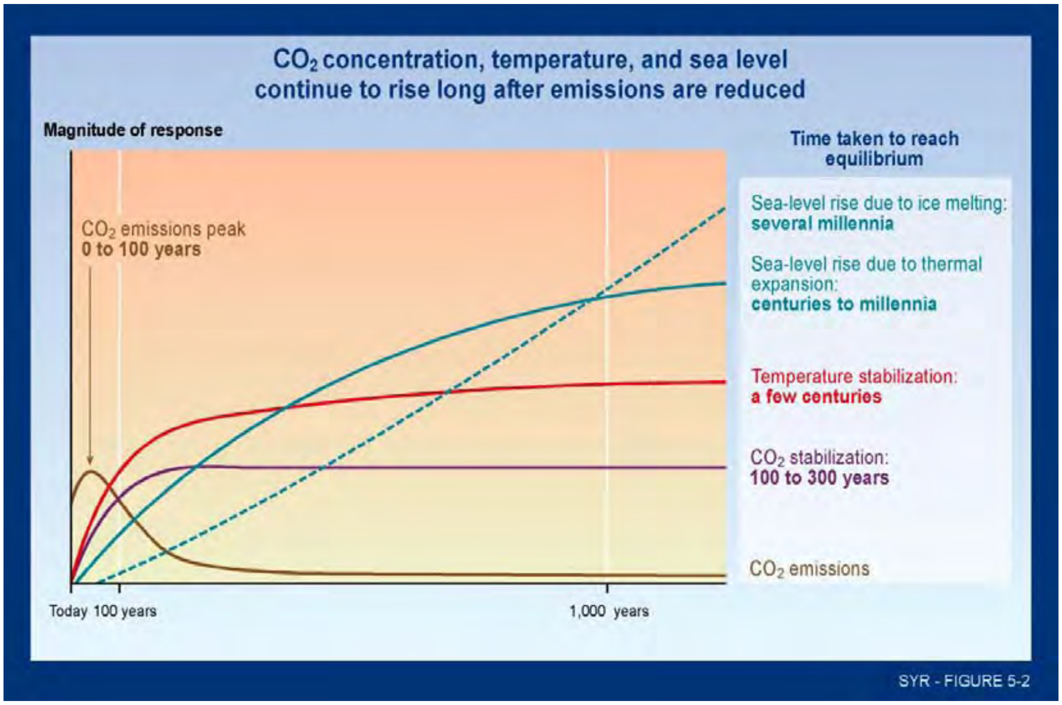
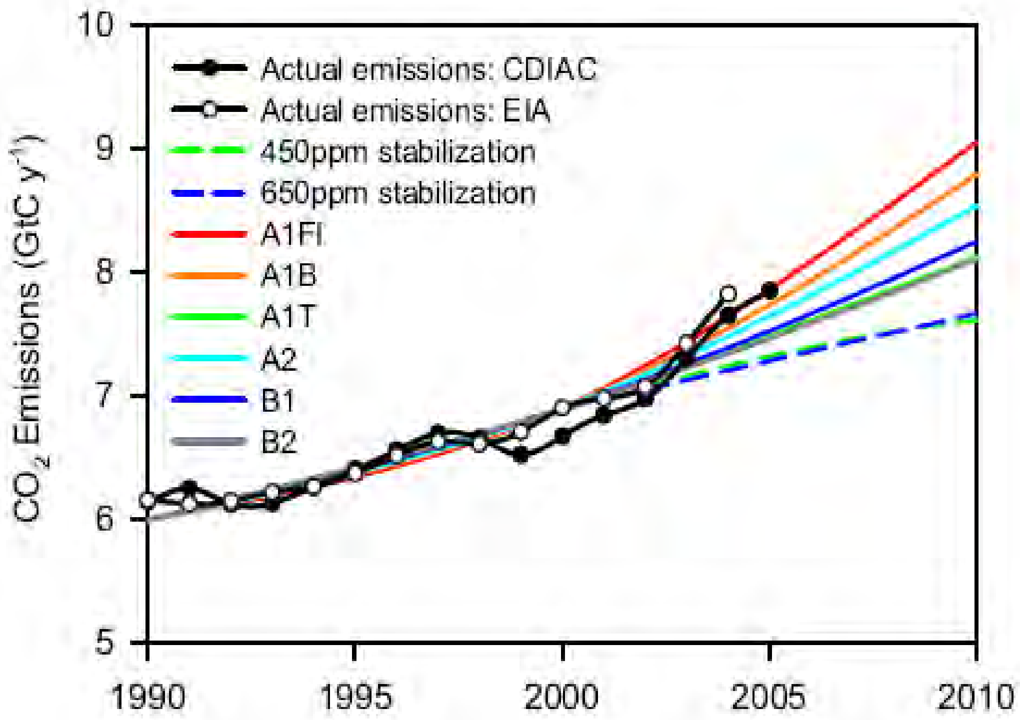
[4] The "tripwire" between keeping global warming to less than 1°C, as opposed to having a warming that approaches the range of 2-3° C, may depend upon a relatively small difference in anthropogenic greenhouse gas emissions (Hansen et al. 2006, Hansen et al. 2007). This is because warming of greater than 1 °C would likely induce positive climate feedbacks, such as the release of large amounts of methane from thawing Arctic permafrost, that will further amplify the warming (Hansen et al. 2006, Hansen et al. 2007).

Figure 19. Relationships between carbon dioxide concentrations, temperature, and sea level rise. After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more.
Source: IPCC (2001(a)): Figure SPM-5.



With atmospheric carbon dioxide at 385 ppm and worldwide emissions continuing to increase by more than 2 ppm each year, rapid and substantial reductions are clearly needed immediately. Since the year 2000, however, society has not followed a path of emissions reductions. Instead, the emissions growth rate has accelerated since 2000, rising from 1.1% per year from 1990-1999 to ~3.25 % per year from 2000-2004 (Raupach et al. 2007). The emissions growth rate since 2000 has even exceeded that of the most-fossil fuel intensive IPCC SRES emissions scenario, A1F1 (Figure 20) (Raupach et al. 2007). As a result, emissions since 2000 were also far above the mean stabilization trajectories needed in order to reach a 450 ppm stabilization target of the alternative scenario, and even well above a 650 ppm stabilization target (Raupach et al. 2007), both of which are now considered inadequate to prevent dangerous climate change (Hansen et al. 2008). If this growth continues for just ten more years, the 49% increase in CO_2 emissions between 2000 and 2015 will make it difficult if not impossible to achieve reductions in emissions needed to avert catastrophic consequences (Hansen et al. 2006, Hansen et al. 2007). For this reason, it is essential that strong greenhouse gas limitations be enacted immediately.

Figure 20. Observed CO_2 emissions from U.S. Department of Energy Energy Information Administration (EIA) data (1980-2004) and U.S. Department of Energy Carbon Dioxide Information and Analysis (CDIAC) data (1751-2005), compared with six IPCC emissions scenarios and with stabilization trajectories describing emissions pathways for stabilization of atmospheric CO_2 at 450 and 650 ppm.
Source: Raupach (2007): Figure 1.



Overall, the sooner greenhouse gas emissions are stabilized, and the lower the level at which they are stabilized, the smaller the overall temperature increase will be (IPCC 2001a). An important point is that stabilization of carbon dioxide emissions at current or near-current levels will not lead to stabilization of carbon dioxide atmospheric concentrations (IPCC 2001a). Stabilization of carbon dioxide concentrations requires reduction of global carbon dioxide net emissions to a small fraction of the current emission level (IPCC 2001a). As discussed in depth in the section on the “Inadequacy of Existing Regulatory Mechanisms,” it is essential that strong greenhouse gas limitations be enacted immediately in order to give ice-dependent seals a chance for survival.

e. Observed Impacts to the Ringed, Bearded, Spotted Seal from Global Warming

Researchers and native peoples have long noted the importance of sea-ice cover and climate conditions to the distribution and abundance of the ice-dependent Arctic seals, as well as the vulnerability of these seals to changes in the extent and character of Arctic sea ice (Vibe 1967, Tynan and DeMaster 1997, ACIA 2005). Ringed, bearded, and spotted seals all depend on sea ice for reproductive activities of birthing and nursing as well as molting that are essential to the survival of these species. Multiple studies have documented how the loss and early breakup of sea ice and decreasing snowfall are negatively impacting the ringed seal throughout many regions in its range. Studies of the ways that changing climate conditions are affecting bearded and spotted seals have not yet been completed. However, research and observations particularly on how sea-ice loss and early breakup are impacting the ringed seal provide insights into the ways global warming is likely affecting bearded and spotted seals.

Anomalies in seasonal cycles of sea ice and snow cover have long been documented to significantly impact ringed seal reproductive success, pup survival, and body condition. Unusually light sea-ice and snow cover has been observed to result in low densities of pupping lairs and the abandonment of lairs in the Alaskan Arctic (Kelly et al. 1986 cited in Kelly 1988), freezing deaths of newborn pups in the White Sea (Lutkin 1980 cited in Kelly 1988), and higher predation rates of pups by polar bears in the Canadian Arctic due to insufficient snow cover on lairs (Hammill and Smith 1991). Alternately, unusually early and heavy sea ice in the Canadian Beaufort in the 1970s reduced the reproductive success and body condition of ringed seals and bearded seals by increasing the difficulty of maintaining breathing holes and reducing primary productivity (Kelly 2001). Due to its sensitivity to snow and ice conditions, the ringed seal has been highlighted as an indicator species for global warming in the Arctic: "The ringed seal (*Phoca hispida*), a key species that depends on sea ice, will likely be among the first marine mammals to show the negative effects of climate warming" (Ferguson et al. 2005:121).

As predicted, changing climate conditions due to global warming, including early sea-ice breakup, diminishing sea-ice extent, reduced winter and spring snowfall, and warmer temperatures, are already having significant impacts on ringed seal populations in many regions across its range, with most studies focused on the Arctic ringed seal *P. h. hispida*. The impacts of changing climate conditions include the following: (1) Decreasing snow cover, earlier snow melt, and increased rain during the late winter cause higher pup mortality because pupping lairs are damaged or destroyed, increasing the risk of hypothermia and facilitating predation by polar bears and Arctic foxes; (2) Earlier sea-ice breakup causes premature weaning of pups before they are fully developed, leading to lower pup body condition and high pup mortality. (3) Early sea-ice breakup and lower sea-ice extent are associated with lower pregnancy rates and body condition of female ringed seals, likely due to reduced prey availability and increased competition by other species. Each of these impacts is described in more detail below.

Ferguson et al. (2005) found that decreasing snow depth is strongly linked to lower ringed seal recruitment in Western Hudson Bay. These researchers examined trends in ringed seal recruitment in Western Hudson Bay relative to environmental factors that might affect pup survival within the birth year, including snow depth, snowfall, rainfall, temperature in April and May, North Atlantic Oscillation ("NAO") from the previous winter, and timing of spring breakup. Samples from 639 ringed seals killed by Inuit hunters between 1991-1992 and 1999-2001 were used to determine the age of all seals killed and generate a survivorship curve representing the number of seals born in any year that survived to be included in the hunt (Ferguson et al. 2005). The percentage deviation from the expected number of survivors for each birth year, including years 1962-2000, was then used as the dependent variable in correlation and regression analyses with environmental factors (Ferguson et al. 2005).

Ferguson et al. (2005) found that environmental conditions changed significantly in western Hudson Bay during 1962-2002. Mean April-May snow depth decreased from 45 cm to 17 cm, temperature increased by 0.7°C per decade, timing of spring sea-ice breakup shifted earlier by 0.8 days per year, and snowfall followed a non-linear pattern of decrease followed by increase followed by decrease (Ferguson et al. 2005). Ferguson et al. (2005) found that ringed seal recruitment and snowfall showed matching temporal trends, both varying from lower than average in the 1970s, to higher in the 1980s, to lower in the 1990s, indicating that recruitment and snowfall are linked (Ferguson et al. 2005). Importantly, snow depth in April and May when pups are born and nursed was a significant explanatory factor for ringed seal recruitment in western Hudson Bay (Ferguson et al. 2005). Decreasing snow depth in April and May, particularly below 32 cm, corresponded with a significant decrease in ringed seal recruitment, and these lower snow depth conditions were more prevalent during the recent study period from 1991-2000 (Ferguson et al. 2005). Ferguson et al. (2005) explained that reduced snowfall results in less snow accumulation over ringed seal birth lairs and consequently less protection for pups from predators (Ferguson et al. 2005). Warming temperatures may also be melting the snow that covers ringed seal birth lairs, making pups more vulnerable to predation and thermal stress at an early age (Ferguson et al. 2005). Ferguson et al. (2005:121) concluded: "Earlier spring breakup of sea ice together with snow trends suggest continued low pup survival in western Hudson Bay."

Mirroring recent declines in recruitment found by Ferguson et al. (2005), two studies of ringed seals in northwestern Hudson Bay detected downward trends in female reproductive success and pup survival that were linked to warming climate conditions (Holst 1999, Stirling 2005). Stirling (2005) and Holst (1999) determined ovulation rates, pregnancy rates, and the proportion of young-of-the-year from ringed seals collected by Inuit hunters during their annual open water harvest in Arviat, Nunavut, in 1991-1992 and 1998-2000. Although ovulation rates were similar to females from other regions, pregnancy rates which averaged 55% and proportions of young-of-the-year were unexpectedly low (Stirling 2005). The proportions of young-of-the-year were 4.8%, 4.2%, 7.5%, 4.1%, and 22.7% for 1991,1992, 1998, 1999, and 2000 respectively, which were significantly lower than expected values (>30%) reported in the literature for ringed seals other parts of the Arctic (Stirling 2005). Thus, some factor or combination of factors caused significant mortality of pups after birth and before the fall open water sampling period (Stirling 2005).

Based on the consistency of the findings across the 1991-2000 study period, Stirling (2005) argued that reproductive parameters of ringed seals and survival of their young are likely experiencing long-term downward shifts rather than short-term fluctuations. Stirling (2005) suggested that the most likely explanation for these downward trends is a combination of ecological factors tied to warming climate trends. (1) Breakup of the annual ice in Western Hudson Bay is occurring approximately 2.5 weeks earlier than it did 30 years ago. Earlier sea-ice breakup in Hudson Bay may be causing premature weaning of pups before they are fully developed, leading to lower pup survival. (2) The trend toward earlier ice breakup and more open water may be changing the availability of prey species in the Hudson Bay in ways that may be negatively affecting the post-weaning survival of ringed seal pups. For example, a study of thick-billed murre (*Uria lomvia*) diet in northern Hudson Bay from 1981-2002 found that the proportion of Arctic cod delivered to chicks declined from 43% in the mid-1980s to 15% by the late 1990s. Thus the availability of Arctic cod, a key prey species for the ringed seal, may be declining. (3) More open water and leads in winter may be leading to an increase in seal species that prefer these conditions, such as bearded and harbor seals. In support, the proportion of harbor seals taken in non-selective open-water harvests at Arviat doubled from 1.8% to 3.7% between 1991-1992 and 1998-2000 (Stirling et al. 2005). In addition, a preliminary study of the diet of polar bears in western Hudson Bay using fatty acid signature analysis reported a decline in the proportion of ringed seals and a significant increase in the proportion of harbor seals between 1994 and 1998 (Stirling et al. 2005). Stirling (2005) concluded:

> Taken together, the decline over several years in the proportion of YOY in the open water and the pregnancy rates of ringed seals sampled at Arviat demonstrated in this study, the lower than expected recruitment in western Hudson Bay through the 1990s (Ferguson et al. 2005), the increasing mean temperatures in spring and the earlier breakup of the sea ice (Stirling et al. 1999, 2004, Gough et al. 2004), the apparent changes in relative importance of different species of seals in the diet of polar bears (Iverson et al. 2005), and the documented changes in the diet of thick-billed murres in northern Hudson Bay over the same period (Gaston et al. 2003) suggest that a comprehensive study of the marine ecosystem of Hudson Bay in relation to climate warming should be a high-priority area for future scientific investigation (Stirling 2005: 386).

Reproduction and body condition of ringed seals were also monitored in Prince Albert Sound in the Canadian Arctic across heavier sea-ice conditions in the 1970s and lighter ice conditions in the 1990s (Harwood et al. 2000, Kelly 2001). During the light sea-ice year of 1998, Harwood et al. (2000) and Smith and Harwood (2001) found that an unusually early breakup of landfast ice negatively impacted the growth, condition, and survivorship of unweaned pups. In 1998, the sea ice in Prince Albert Sound cleared 27 days earlier than the average date of clearing during 1970-1978 and 24 days earlier than during 1990-1998 (Smith and Harwood 2001). The researchers believe that the early breakup in 1998 led to an interruption of nursing and premature weaning of pups at the seaward portion of the core breeding habitat which negatively affected the condition and growth of those unweaned pups (Harwood et al. 2000). Half of the 50 neonate pups sampled in June 1998 still had remains of their lanugo pelage, a phenomenon which had never before been documented as late in the season during 20 years of scientific studies and over 40 years of Inuit seal-hunting observations. Three seal pups washed up dead near the sealing area in June 1998 which was also an unprecedented observation (Smith and Harwood 2001). The 25 lanugal pups collected in June 1998 were in significantly poorer body condition than pups that had molted, and ten were classified as “starvelings” (Harwood et al. 2000, Smith and Harwood 2001). The researchers further point out that this happened at a time when marine food appeared to be abundant and available for the other age classes of ringed seals (Harwood et al. 2000). Thus, although early sea-ice breakup may have enhanced food availability, it had an overall negative impact on the ringed seal population by interrupting nursing and increasing pup mortality.

A subsequent study of ringed seals in the eastern Beaufort Sea by Harwood (2005) found that females exhibited reduced reproductive output and reduced body condition between 2003 and 2005, indicating that downward trends in reproductive success are ongoing in this region. Local fishers in the region have suggested that the downturn in seal body condition is related to decreased marine productivity in the area, as evidenced by recent reductions in fishing opportunities for Arctic cod in the same areas that seals hunt (Harwood 2005).

Observations in the Alaskan Bering, Chukchi, and Beaufort Seas also indicate that low snow accumulation and early sea-ice breakup are negatively impacting ringed seals. In 1998-2001, Kelly (2001) investigated the thermal environment of subnivian lairs from early in the birthing season, including air temperature outside the lairs and snow temperatures on the ice at 5 cm depth increments (Kelly 2001). Snowmelt in 1998 occurred three weeks earlier than in 1999-2001, forcing most ringed seals to emerge from their lairs at the time they were just beginning to emerge in 1999-2001 (Kelly 2001). In a review of observations from Alaska Native communities in the northern Bering and Chukchi Sea, Pungowiyi (2000) reported that in years of early sea-ice breakup, such as 1996 and 1997, more ringed seal pups were stranded on beaches. Pungowiyi (2000) noted that these pups were likely abandoned early by their mothers due to early melt of the landfast ice.

Studies of ringed seals in Baffin Bay also found that increased rain during the late winter impacts ringed seals by damaging or eliminating their pupping dens, increasing exposure and the risk of hypothermia, and facilitating predation by polar bears and Arctic foxes (Stirling and Smith 2004). In a study of ringed seals on Hall Peninsula of southeastern Baffin Island in Nunavut, researchers documented the distribution and density of ringed seal lairs during an unusually warm period in March and April 1979 (Stirling and Smith 2004). Predation on seals by polar bears was also documented both by snow machine and helicopter (Stirling and Smith 2004). Rain fell steadily or sporadically on the study area from April 9-11, 1979 (Stirling and Smith 2004). From April 12 through April 24, the weather was clear with maximum temperatures only slightly above freezing, approximately 10-20° C warmer than normal April temperatures for the area (Stirling and Smith 2004). Before the rain event in April, there were two other periods during late March and early April when daily maximum temperatures were at or close to freezing (Stirling and Smith 2004).

The roofs of 40% (6/15) of the haulout and birth lairs found by the end of March and 50% (15/30) of those located in the first week of April had melted and collapsed, something not seen before at higher latitudes (Stirling and Smith 2004). After the rain event of April 9-11, 1979, 28% of the lairs in one part of the study area had collapsed, but this underestimates the real percentage because an unknown number of already washed-out lairs were not recorded (Stirling and Smith 2004). Researchers noted that the successive periods of warmer air temperatures combined with the body heat radiating from seals caused the snow over the lairs to crystallize, which is thought to make the snow weaker and more prone to collapse (Stirling and Smith 2004). Following the April rain event, the researchers noted many instances of adult seals and pups lying on the bare ice, exposing the pups to predators and hypothermia (Stirling and Smith 2004). Predation of pups by polar bears was also observed, and the researchers “suspect that most of the pups in these areas were eventually killed by polar bears, Arctic foxes, or possibly gulls” (Stirling and Smith 2004:66 (internal citations omitted)). The researchers also noted that the success rate of polar bear attacks on seal lairs was higher in their study region (23.4% on the Hall peninsula and 28% along the Cumberland peninsula) compared to rates in the Western or High Arctic, and “may reflect softer snows in the drifts, as well as slumping and weakening of roofs due to periodic external temperature increases and warming from seals in their lairs" (Stirling and Smith 2004: 65).

Stirling and Smith (2004) conclude that their 1979 observations have direct relevance to the impact of climate change on ringed seals, specifically by increasing pup mortality leading to reduced population size:

> We suggest that if the climate continues to warm, an additional consequence will be increased rainfall earlier in spring, which will results in more frequent and widespread collapses of subnivian birth lairs, such as we observed on southeastern Baffin Island in 1979. Should early season rain become regular and widespread at some future time, we predict that mortality of ringed seal pups will increase, especially in more southerly parts of their range, and that local populations may be significantly reduced (Smith and Stirling 2004: 66).

Although most of the observations on the impacts of changing climate conditions due to global warming relate to the Arctic ringed seal, Meier et al. (2004) noted that during the mild winters of 1989-1995, pup mortality for the Baltic ringed seal was high in the more southern populations in the Gulf of Riga and Gulf of Finland.

These studies demonstrate the severe impacts that low snow and sea-ice cover, increased rainfall in spring, and early sea-ice melt are having on ringed seal reproduction, survival, and body condition. As documented in detail in the prior two sections, early sea-ice breakup and declining sea-ice extent are occurring throughout the ranges of bearded and spotted seals as well. Thus, bearded and spotted seals are likely being similarly affected by early sea-ice breakup and lower sea-ice extent which cause premature separation of mom-pup pairs before pups are fully developed, leading to lower pup body condition and high pup mortality. If persistent, these impacts will have devastating population effects on ice-dependent Arctic seals that will no longer be able to successfully reproduce.

f. Future Threats to the Ringed, Bearded, and Spotted Seal from Global Warming

Researchers have consistently warned that the loss of sea ice will prove devastating to ice-dependent Arctic seals (Tynan and DeMaster 1997, Kelly 2001, ACIA 2005, Moore 2005, Learmonth et al. 2006, Simmonds and Isaac 2007). According to the ACIA, "the reduction in sea ice is very likely to have devastating consequences for polar bears, ice-dependent seals, and local people for whom these animals are a primary food source" (ACIA highlights:1). The ACIA (2005) warned that changes in the timing of formation and disappearance of seasonal sea ice, in the quality of the sea ice, and in the extent of total coverage of both seasonal and multiyear ice will impact ice-dependent species. Based on its projections of sea-ice loss, the ACIA (2005) predicted that "negative consequences are very likely within the next few decades for Arctic animals that depend on sea ice for breeding or foraging" (ACIA 2005: 509). Moreover, "the worst-case scenarios in terms of reduced sea-ice extent, duration, thickness, and concentration by 2080 are very likely to threaten the existence of whole populations and, depending on their ability to adapt to change, are very likely to result in the extinction of some species" (ACIA 2005: 509).

Ringed, bearded, and spotted seals are particularly vulnerable to habitat loss from changes in the extent of Arctic ice and early ice breakup because they depend on the persistence of the sea ice for pupping, foraging, molting, and resting (Tynan and DeMaster 1997). Global warming will impact ringed, bearded, and spotted seals directly by degrading and eliminating critical sea-ice habitat, which will have devastating consequences by reducing adult reproductive success and the survival of pups and impairing their ability to complete the annual molt. Indirect threats from climate change include depletion of prey resources due to changing ocean conditions and ocean acidification; increasing exposure to predators, competitors, disease, and human disturbance; and increasing shipping activity and oil and gas development, with associated risks of oil spills and noise pollution, as sea-ice loss increases the accessibility of previously ice-covered regions. Projected habitat loss and associated breeding failures due to global warming will undoubtedly commit ringed, bearded, and spotted seal populations to an increased risk of extinction. Although the ringed, bearded, and spotted seal face multiple threats, each of these species merits listing under the ESA due to the threats from global warming alone. The following section details the ways by which changing climate conditions in this century will impact ringed, bearded, and spotted seals.

i. Ringed Seals: Future Threats from Global Warming

(1) Loss of critical sea-ice habitat and shift of range northward due to declining sea-ice extent and early sea-ice breakup. The ringed seal will increasingly lose its breeding, resting, and molting habitat as winter and spring sea-ice decline and undergo earlier breakup. The ringed seal depends on the landfast and pack ice for birthing in March and April, for nursing pups in subnivian lairs for five to seven weeks until June, for molting in April through July, and for resting throughout the sea-ice season (Kelly 1988b). The persistence of sea-ice habitat from March through July is particularly critical for the success of ringed seal reproduction and the completion of molt. However, sea-ice extent has declined during March through July in recent decades in most regions inhabited by the ringed seal, including the seasonally ice-covered Okhotsk and Bering Seas, Hudson Bay, Baffin Bay, Greenland Sea, Canadian Archipelago, Barents Sea, Kara Sea, Laptev Sea, Beaufort Sea, Chukchi Sea, and Arctic Ocean (Meier et al. 2007). Multiple studies have also identified dramatic losses of summer sea-ice cover and dramatic increases in surface temperature in the Chukchi, Beaufort Seas, and Bering Seas (Overland and Stabeno 2004, Comiso 2005, Comiso 2006b, Francis and Hunter 2006, Grebmeier et al. 2006b, Perovich et al. 2007, Jay et al. 2008, Steele et al. 2008, Stroeve et al. 2008), which provide critical ringed seal breeding and foraging habitat. Winter and spring sea ice in the ringed seal range will continue to decline with the accelerating loss of summer sea ice that creates large open-water areas that increase the ice-albedo feedback. The Bering, Okhotsk, and Barents Seas inhabited by the ringed seal are projected to lose at least 40% of winter sea-ice area by 2050 (Overland and Wang 2007).

Overall, the southern edge of the ringed seal distribution will shift northward as ringed seal populations are lost from regions where sea ice is of insufficient extent or duration for reproduction and molting. The Ladoga and Saimaa ringed seals confined to inland lakes and the

Okhotsk and Baltic seals restricted to seasonally ice-covered seas are limited in their ability to track the receding ice cover northward and will likely lose functional sea-ice habitats entirely. For example, Meier et al. (2004) projected the impacts that changing Baltic Sea sea-ice cover will have on Baltic ringed seal habitat by 2071-2100 under SRES A2 and B2 emissions scenarios. On average, sea-ice volume is projected to be reduced by 83%, freezing will be delayed by two weeks to one month, and breakup will occur one month earlier (Meier et al. 2004). Assuming that sea-ice cover for two months is the minimum required for breeding activities, Meier et al. (2004) found that successful breeding of the Baltic ringed seal will be possible only in the Bay of Bothnia by the end of the century, with breeding not possible in three formerly core breeding areas. Because current climate models have drastically underpredicted sea-ice loss, this study almost certainly under-represents future impacts on Baltic ringed seal sea-ice habitat.

The quality of remaining sea-ice habitat will also continue to diminish by becoming increasingly thinner (Maslanik et al. 2007b). Ringed seals that use pack ice in winter prefer large, flat ice floes (>48 m in diameter) in areas of high (>90%) sea-ice coverage (Simpkins et al. 2003), and heavy ice cover will become increasingly rare.

(2) Increased pup mortality and lower pup fitness due to lack of sufficient snow cover and early melt of sea ice and snow cover. Ringed seals require sufficient snow cover to construct their subnivian birthing lairs, and snow cover over the lairs and sea ice over which lairs are built must remain sufficiently stable in spring to successfully rear pups (Tynan and DeMaster 1997, Kelly 2001). During this century, Arctic snow cover will continue to decrease, warm rain-on-snow events that lead to the collapse of birthing lairs will become more common, and warmer temperatures and the ice-albedo feedback will continue to cause earlier snowmelt and sea-ice breakup (ACIA 2005), all of which will increase ringed seal pup mortality and reproductive failures. Low snow accumulation in winter will prevent ringed seal females from excavating subnivian lairs, and females will be forced to birth on the open ice as observed in Svalbard in low-snow years (Smith and Lydersen 1991), potentially birth on land (ACIA 2005), or abort the reproductive attempt. When birthing occurs in the open due to lack of snow, nearly 100% of pups succumb to predation (Kelly 2001). Since ringed seals do not normally haul out on land, birthing on land would represent a dramatic change in behavior (ACIA 2005) and would undoubtedly expose defenseless pups to devastating rates of depredation during the long, six-week nursing period (ACIA 2005).

Decreasing snow depths, earlier melt of snow cover over subnivian lairs, and increasing rain-on-snow events that lead to lair collapse will expose pups at increasingly earlier ages to polar bear, Arctic fox, and avian predation and to freeze-thaw cycles that make them vulnerable to hypothermia (Kelly 2001, Stirling and Smith 2004). Earlier breakup of the sea ice will result in premature separation of mother–pup pairs during the nursing period (Smith and Harwood 2001). Pups that are prematurely weaned will be in poor body condition and suffer higher mortality due to lack of sufficient blubber reserves, increased exposure to hypothermia, and increased risk of predation. Thus ringed seals will experience an increased frequency of breeding failures due to changing climate conditions, with resultant population declines.

(3) Impaired molting due to early sea-ice breakup. Ringed seals depend on the sea ice during May through July to molt. With early sea-ice breakup, ringed seals may suffer physiological stress and associated mortality from being forced into the water before molt completion or onto small, low-quality ice remnants with high concentrations of other animals during the molt period. If ringed seals were forced to haul out on land to complete molting, depredation from terrestrial predators could be devastating, especially since the ringed seal is the smallest of the northern phocids.

(4) Higher physiological stress resulting from loss of haulout sites due to declining sea-ice extent and early breakup. Ringed seals will likely experience more physiological stress due to the loss of haulout sites when subnivian lairs collapse and pack ice hauling sites disintegrate earlier. Females may be particularly impacted by loss of haulout sites due to the need to rest after the physiologically demanding pup-rearing period (Carlens et al. 2006).

(5) Interruption of seasonal migration and breeding behavior. The reduction of winter sea ice and shrinking length of the sea-ice season is likely to interrupt the timing of ringed seal breeding activities, including courtship, birthing, and nursing, with consequent negative impacts on fecundity (Tynan and DeMaster 1997). In regions such as the Bering and Chukchi Seas, ringed seal migration southward in fall and northward in early summer are closely linked to the seasonal cycle of sea ice (Frost 1984). The delayed onset of the winter sea-ice season and northward retreat of the winter sea-ice edge may interrupt this seasonal migration and the timing of aggregations of males and females in breeding areas. In addition, during the breeding season ringed seal males defend territories that encompass the lairs and breathing holes of females as a way to gain mating access to females. The early breakup of sea ice in these territories may disrupt the courtship and mating behaviors of ringed seals.

(6) Reduced food availability. A major decline in sea-ice habitat will also likely result in a decline in ringed seal abundance over time due to reduced availability of prey. Changes in climate, sea-ice extent, and the timing of sea-ice formation and breakup will affect the lower trophic levels of the food web upon which the ringed seal depends. The Arctic food web is driven by the complex interactions between ice, light penetration, nutrient supply, and productivity (Tynan and DeMaster 1997, Bluhm and Gradinger 2008). Because of the Arctic Ocean’s relatively low species diversity, it may be particularly vulnerable to trophic-level alterations caused by global warming (Derocher et al. 2004).

As the sea-ice edge moves northward, crustaceans adapted for life under the ice and fish such as Arctic cod which forage on them will decline in abundance (Anisimov et al. 2007). Arctic cod, a key prey species of the ringed seal, is strongly associated with landfast ice and pack ice year-round, and uses the ice for protection from predators and as feeding habitat since it consumes under-ice amphipods and other zooplankton (Bluhm and Gradinger 2008). This northernmost distributed gadid is a critical link between the sea-ice food web and the ringed seal since it concentrates the energy of the sympagic ice algae production into energy packets large enough to be eaten by seals (Bluhm and Gradinger 2008). Declining sea-ice extent will lead to the loss of the ice-based food web and an associated decline in Arctic cod, which will negatively affect ringed seals (Tynan and DeMaster 1997, Bluhm and Gradinger 2008).

Decreases in Arctic cod abundance have already been recorded and correlated with shrinking ice cover. Gaston et al. (2003) inferred changes in Arctic cod abundance in northern Hudson Bay by analyzing the composition of the diet fed to thick-billed murre chicks in northern Hudson Bay since 1981, and compared those trends to ice cover in Hudson Bay over the same period.

Between 1980-82 and 1999, the percentage of cod in the diet of thick-billed murre chicks fell from 51.5% to 18.9%, while the percentage of capelin increased from 6.7% to 41% over the same time period (Gaston et al. 2003). Ice cover, defined as the extent of ice cover greater than 10% on July 15th of each year, also declined significantly between 1981 and 1999 ($F_{(1,17)} = 9.85$, $R^2 = 0.33$, $p = 0.006$) (Gaston et al. 2003). When data from 1992 (the year Mt. Pinatubo erupted and caused temporary regional cooling) were removed, the R^2 value increase to 0.52 ($F_{(1,16)} = 19.06$) (Gaston et al. 2003).

Gaston et al. (2003:231) concluded as follows:

> We conclude that the trends we observed related to real changes in fish populations, rather than simply reflecting changes in the accessibility of the fish to murres….Given the relative ecology of Arctic cod and capelin, the trends that we have identified seem best explained by changes in the oceanography of northern Hudson Bay, perhaps driven by temperature increases over recent decades. Our evidence from the diet of nestling thick-billed murres suggests that a switch from an Arctic to a Subarctic fish community occurred from 1997 onwards.

The Barents Sea pelagic food web has also shifted in the last two decades with the influx of warmer North Atlantic waters into the Barents Sea (Bluhm and Gradinger 2008). The zooplankton community dominated by the large, lipid-rich calanoid copepod species *Calanus glacialis* endemic to polar waters is being replaced by smaller North Atlantic taxa like *Calanus finmarchicus*, which will likely continue with warmer conditions extending northward (Bluhm and Gradinger 2008). A shift to smaller copepods might reduce the nutritional quality of food for pelagic planktivorous fish that are important prey species for the ringed seal (Bluhm and Gradinger 2008).

(7) Increased competition for food from temperate species. Ringed seals may also face ever-increasing competition for food from temperate species whose ranges are expected to expand northward as temperatures continue to rise (ACIA 2005, Simmonds and Isaac 2007). More open water and leads in winter may result in an increase in seal species that prefer these conditions such as harbor seals. Ringed seals overlap with harbor seals in the southern portions of their range, including Hudson Bay and Svalbard, where they also overlap in diet (Krafft et al. 2007). In Hudson Bay, there is evidence of a recent increase in harbor seals. The proportion of harbor seals taken in non-selective open-water harvests at Arviat doubled from 1.8% to 3.7% between 1991-1992 and 1998-2000, and a study of the polar bear diet in western Hudson Bay reported a decline in the proportion of ringed seals and a significant increase in the proportion of harbor seals between 1994 and 1998 (Stirling 2005).

ii. Bearded Seals: Future Threats from Global Warming

(1) Loss of critical sea-ice habitat and shift northward in range due to declining sea-ice extent and early sea-ice breakup. Similar to the ringed seal, the bearded seal will increasingly lose its breeding, resting, and molting habitat as winter and spring sea-ice extent decline and undergo earlier breakup, and the bearded seal range will shift northward. The bearded seal depends on the pack ice for birthing in March through May, for nursing its pups during the three-week lactation period through June, for molting in May through July, and for resting throughout the sea-ice season (Kelly 1988b). Thus the persistence of sea-ice habitat from March through July is particularly critical for the bearded seal. Sea-ice extent has declined significantly during March through July in recent decades in most regions inhabited by the bearded seal, including the seasonally ice-covered Okhotsk and Bering Seas, Hudson Bay, Baffin Bay, Greenland Sea, Canadian Archipelago, Barents Sea, Kara Sea, Laptev Sea, Chukchi Sea, and Arctic Ocean (Meier et al. 2007). Multiple studies have also identified dramatic losses of summer sea-ice cover and dramatic increases in surface temperature in the Chukchi, Beaufort Seas, and Bering Seas (Overland and Stabeno 2004, Comiso 2005, Comiso 2006b, Francis and Hunter 2006, Grebmeier et al. 2006b, Perovich et al. 2007, Jay et al. 2008, Steele et al. 2008, Stroeve et al. 2008), which provide critical bearded seal breeding and foraging habitat. Winter and spring sea ice in the bearded seal range will continue to decline with the accelerating loss of summer sea ice that creates large open-water areas that increase the ice-albedo feedback. The Bering, Okhotsk, and Barents Seas are projected to lose at least 40% of winter sea-ice area by 2050 (Overland and Wang 2007).

(2) Increased pup mortality and lower pup fitness due to thinner sea ice and early sea-ice breakup. Sea ice has thinned and sea-ice breakup is getting significantly earlier throughout the bearded seal range (Comiso 2006b, Maslanik et al. 2007b), making it less likely that sea ice will remain stable throughout the reproductive period. Increasingly earlier sea-ice breakup will result in premature separation of mother–pup pairs during the nursing period. Pups that are prematurely weaned will be in lower body condition and suffer higher mortality due to lack of sufficient blubber reserves. Thus bearded seals will experience an increased frequency of breeding failures due to changing climate conditions, with resultant population declines.

(3) Impaired molting due to early sea-ice breakup. Bearded seals undergo a peak in molting on the sea ice during May through July. Bearded seals may suffer physiological stress and associated mortality from being forced into the water before molt completion or onto small, low-quality ice remnants with high concentrations of other animals during the molt period. If bearded seals were forced to haul out on land to complete molt, they could suffer high depredation from terrestrial predators.

(4) Higher physiological stress resulting from loss of haulout sites due to declining sea-ice extent and early breakup. Bearded seals follow the advance and retreat of the pack ice, and will likely to experience more physiological stress due to the loss of haulout sites as pack ice extent declines and melts earlier.

(5) Interruption of seasonal migration and breeding behavior. The reduction of winter sea ice and shrinking length of the sea-ice season is likely to interrupt the timing of bearded seal breeding activities, especially in regions like the Bering and Chukchi Seas where bearded seal migrations southward in fall and northward in early summer are closely linked to the seasonal cycle of sea ice (Frost 1984). The delayed onset of the winter sea-ice season and northward retreat of the winter sea-ice edge may interrupt this seasonal migration and the timing of aggregation of males and females in breeding areas.

(6) Reduced access to benthic foraging grounds. Because the bearded seal feeds predominantly on benthic prey, its distribution is generally restricted to relatively shallow shelf waters of less than 150-200 m where its benthic prey are more abundant (Burns 1981, Kelly 1988a, Simpkins et al. 2003). During the winter and spring breeding season when bearded seals utilize the sea ice for reproduction and molting, continuing loss of winter sea-ice cover will shift the bearded seal distribution further north and deprive the Pacific bearded seal of proximal access to large portions of its benthic foraging habitat over the continental shelf. Rather than being distributed relatively widely over the shallow shelf in winter and spring, more of the population will be concentrated into smaller areas on remnant ice floes. The increasing retreat of sea ice northward in summer and fall may result in much of the remaining sea ice being located over water that is too deep for these benthic foragers (Tynan and DeMaster 1997). For example, Burns and Frost (1979) reported that bearded seals in the Bering and Chukchi Seas occur on the pack ice front over the Chukchi Sea shelf in summer, but are not associated with the ice front when it receded over deep water (Kingsley et al. 1985).

(7) Reduced prey availability. Sea-ice loss, rising temperatures, and increased fresh-water discharge from rivers will change the abundance and distribution of the benthic prey species that the bearded seal depends on, with decreases in benthic abundance predicted for the Bering Sea and nearshore regions across the Arctic.

In the northern Bering Sea, an ongoing consequence of rising temperatures and sea-ice loss is that the ecosystem is undergoing a shift from a benthic-dominated ecosystem rich in prey for bearded seals to one dominated by pelagic fish (Grebmeier et al. 2006a, Grebmeier et al. 2006b). This ecosystem shift will lower prey availability for the bearded seal if the loss of sea ice continues. The northern Bering Sea represents a transition region between the Arctic ecosystem of the northern Bering and Chukchi Seas, which are influenced by winter sea-ice cover, and the subarctic ecosystem of the southern Bering Sea, which is an open-water region devoid of seasonal sea ice (Overland and Stabeno 2004). The presence or absence of sea-ice cover influences the timing of primary production which in turn plays a primary role in shaping ecosystem structure. The seasonally ice-covered Bering Sea currently experiences two blooms of primary production: an early “ice edge bloom” followed by an “open-water bloom” after the ice has melted. The intense, spring ice-edge bloom follows the melting sea-ice edge, and the melting ice releases nutrients and fresh water that promote phytoplankton growth. Due to cold spring water temperatures, spring zooplankton populations are low and do not consume much of the organic matter before it settles to the benthos. The net result of the high primary production over these shallow shelves and relatively low grazing pressure is that a heavy rain of organic matter settles to the sea floor where it supports a rich benthic community (Grebmeier et al. 2006b). The benthic-feeding bearded seal, Pacific walrus, gray whale, and seaducks are the primary consumers in the northern Bering Sea (Grebmeier et al. 2006b). In contrast, the southern, subarctic Bering Sea experiences only one bloom—the later summer open-water bloom.

Zooplankton and microbes, which are more abundant due to warmer summer ocean temperatures, graze most of the organic matter before it settles to the benthos. Upper-trophic level fish and epifaunal invertebrates are the primary consumers in this pelagic-dominated ecosystem (Grebmeier et al. 2006b).

Due to rising temperatures and associated sea-ice loss, the Arctic–subarctic temperature front separating the northern and southern regions of the Bering Sea is moving northward, and the northern Bering Sea is losing its sea ice and the associated spring ice-edge bloom that supports high benthic production. As a result, the benthic ecosystem in the northern Bering Sea is shifting to a pelagic-dominated marine ecosystem less favorable for the bearded seal (Grebmeier et al. 2006a). As evidence of this shift, studies have detected a decreased carbon supply to benthos, lower benthic biomass, and increases in pelagic fish abundance in the northern Bering Sea (Grebmeier et al. 2006b). The uptake of oxygen in the sediments provides an indicator of carbon supply to the benthos, and sediment oxygen uptake decreased from ~40 mmol O_2 m^{-2} day^{-1} in 1988 to sustained values of ~12 mmol O_2 m^{-2} day^{-1} from 1998 to 2004 in a region southwest of St. Lawrence Island (Grebmeier et al. 2006b). Benthic standing stock also decreased from ~40 g C m^{-2} to 20 g C m^{-2} during 1988 to 2004 in the same region, suggesting that prey for the benthic-feeding bearded seal is declining in the northern Bering Sea (Grebmeier et al. 2006b). Benthic ampeliscid amphipod biomass and production in the Chirikov Basin of the northern Bering Sea declined by 20% in 1986-1988 and a further 50% of the highest value in 1986 by 2002-2003 (Bluhm and Gradinger 2008). Pelagic fish species also appear to be undergoing northern range expansions, including the movement of large numbers of juvenile pollock (*Theragra chalcogramma*) to south of St. Lawrence Island in 2004 and increases in juvenile pink salmon (*Oncorhynchus gorbusha*) in the northern Bering Sea, which feed on pollock (Grebmeier et al. 2006b). Of importance for the bearded seal, an ecosystem shift away from a benthic-dominated community in the northern Bering Sea that lowers benthic prey availability would undoubtedly have negative consequences for reproductive success and survival in this region.

Secondly, increasing freshwater river runoff in the Arctic will increase turbidity and decrease salinity in the nearshore realm, with likely negative effects on nearshore benthic and pelagic (Arctic cod) biodiversity preyed upon by bearded seals (Bluhm and Gradinger 2008). Decreased salinity has been linked to decreased benthic biomass in the nearshore Kara and White Seas (Bluhm and Gradinger 2008). In addition, decreased salinity from increased river freshwater flux in the Hudson Bay appears to limit the growth of phytoplankton at the ice-water interface and to reduce the foraging success of Arctic cod larvae which avoid the freshwater surface layer (Tynan and DeMaster 1997).

iii. Spotted Seals: Future Threats from Global Warming

(1) Loss of critical sea-ice habitat shift northward in range due to declining sea-ice extent and early sea-ice breakup. The spotted seal breeds in eight seasonally ice-covered areas in the Bering Sea, Okhotsk Sea, northern Sea of Japan, and northern Yellow Sea. Sea-ice extent in the Bering and Okhotsk Seas has already experienced large declines throughout the March-June spotted seal reproductive and molting periods in recent decades. For example, during 1979-2006, sea ice in <u>May</u> declined by 20.6% per decade in the Sea of Okhotsk and by 10.9% per decade in the Bering Sea (Meier et al. 2007). Multiple studies have also identified dramatic losses of summer sea-ice cover and dramatic increases in surface temperature in the Chukchi, Beaufort Seas, and Bering Seas (Overland and Stabeno 2004, Comiso 2005, Comiso 2006b, Francis and Hunter 2006, Grebmeier et al. 2006b, Perovich et al. 2007, Jay et al. 2008, Steele et al. 2008, Stroeve et al. 2008), which provide critical spotted seal breeding and foraging habitat. By 2050, the Bering Sea and Sea of Okhotsk are projected to lose 40% of their winter sea ice under a "business-as-usual" A1B emissions scenario (Overland and Wang 2007). Spotted seals in the northern Yellow Sea and northern Sea of Japan are already breeding in extremely seasonally limited sea-ice habitat in the northernmost reaches of these seas and cannot retreat northward. Habitat loss of this magnitude will undoubtedly commit spotted seal populations to an increased risk of extinction.

(2) High pup mortality and reproductive failure due to loss and early breakup of sea ice. The loss and early breakup of seasonal sea ice could lead to breeding failure of the spotted seal within this century. The ice floes of the sea-ice front must remain stable throughout the period of birthing, nursing that lasts three to six weeks, and pup independence that lasts through June. If females are forced to abandon their pups early, pup mortality would be very high because pups would not have gained a sufficient blubber layer and adequate body condition to survive pre-mature weaning. Pup mortality after weaning will also increase with the early melting and breakup of seasonal sea ice. Spotted seal pups depend on sea ice as a resting platform during the post-weaning period when they are learning aquatic proficiency, diving, and foraging skills. Loss of sea ice during this period, which is an energetically stressful time during which pups rapidly deplete their energy stores, would undoubtedly decrease pup fitness and survival.

(3) Higher physiological stress resulting from loss of haulout sites due to declining sea-ice extent and early breakup. Spotted seals are likely to experience more physiological stress due to loss of haulout sites on the sea ice, which they rely on for resting from winter through summer.

(4) Interruption of seasonal migration and breeding behavior. Similar to the ringed and bearded seal, the reduction of winter sea ice and shrinking length of the sea-ice season is likely to interrupt the timing of spotted seal migration and breeding activities (Tynan and DeMaster 1997). In the Bering and Chukchi Seas, spotted seal move southward in fall and northward in early summer in relation to the seasonal cycle of sea ice (Frost 1984). The delayed onset of the winter sea-ice season and northward retreat of the winter sea-ice edge may interrupt this seasonal migration and the timing of aggregation of males and females in breeding areas.

(5) Changing prey availability. Although changes to Arctic food webs from sea-ice loss can be difficult to predict, some evidence from the Bering Sea suggests that increasing ice-free open water could negatively affect production in this region with cascading effects on the spotted seal. As sea-ice cover is reduced, growing regions of the Bering Sea will lose the spring ice edge bloom and the productivity associated with it. Clement et al. (2004) found initial evidence that the ice edge bloom might not be replaced by an open water bloom in spring. Clement et al. (2004) examined water column production during spring in the northern Bering Sea during a heavy-ice year (1999) and a light-ice year (2001) characterized by thinner, lower ice cover.

These researchers found that the open water areas in the light ice year did not experience a spring bloom because seasonal winds produced too much vertical mixing. They concluded that "higher or temporally accelerated seasonal biological production may not be a consequence of expected global change in the northern Bering Sea that would reduce ice cover" (Clement et al. 2004: 13).

Secondly, as the summer open-water bloom becomes the dominant mode of primary production, the strength of this bloom will have a large effect on overall ecosystem productivity. A primary factor influencing the strength of the summer open-water bloom is wind mixing in summer and fall (May-September) which is necessary to bring nutrients to surface waters (Hunt et al. 2002). However, since 1980, summer wind speeds in the Bering Sea have been below average, reflecting the slackening of summer storms. The rising temperature of the upper ocean layer due to global warming combined with a continuing trend of calmer summers would result in reduced production during the summer (Hunt et al. 2002). This could affect the availability of food needed to support late-season growth of copepods and larval fish, which would compromise their over-winter survival (Hunt et al. 2002). In this scenario, the abundance of crustaceans and fish that the spotted seal depends on could decline.

(6) Increased exposure to predators. Changing climate conditions due to global warming are likely to increase the spotted seal's exposure to predators and increase spotted seal mortality. Of foremost concern, the loss and early melt of seasonal sea ice will continue to shift the spotted seal's distribution further northward, which is likely to increase its contact with polar bears in the pack ice of the Chukchi, Beaufort and Bering Seas (Simmonds and Isaac 2007). Spotted seal pups, which are exposed, defenseless, and non-aquatic, would undoubtedly suffer high depredation rates. If spotted seals were forced to haul out on land to nurse their young, they would risk exposure to terrestrial predators including grizzly bears, wolves, and Arctic foxes. Furthermore, as sea-ice declines, spotted seals will be concentrated in increasingly smaller ice areas shared with other ice-dependent marine mammals which could lead to higher predation by walruses, which are known to depredate seal adults and pups especially when other food resources are less available (Lowry and Fay 1984). The breakup of the sea ice may also permit more interactions with killer whales that would be able to further penetrate the ice (Lowry 2000).

(7) Increased competition with temperate species. Spotted seals may also face ever-increasing competition for food from temperate species whose ranges are expected to expand northward as temperatures continue to rise (ACIA 2005, Simmonds and Isaac 2007). The spotted seal replaces the harbor seal in areas of seasonal sea ice within the Bering Sea (Lowry 1984). In areas where both species occur such as coast between Bristol Bay and the Yukon-Kuskokwim Delta, spotted and harbor seals may compete for hauling areas and food (Lowry 1984). Current competition for pupping and nursing areas is thought unlikely due to the vast areas of habitat on the ice front, but would increase as the sea-ice front disappears (Lowry 1984).

iv. Ringed, Bearded, and Spotted Seal: Additional Impacts of Global Warming For All Three Species

(1) Increased exposure to disease

Climate change poses a risk to ringed, bearded, and spotted seals by improving conditions for disease spread (Harvell et al. 1999, ACIA 2005, Burek et al. 2008). Many wildlife pathogens are sensitive to temperature, rainfall, and humidity (Harvell et al. 2002). As the climate has warmed, these pathogens, in many cases, have expanded their ranges northward because warmer temperatures (1) have allowed their survival and development in areas that were previously below their temperature threshold, (2) increased their rates of development, (3) increased rates of reproduction and biting of their vectors, and (4) lowered the resistance of their hosts (Harvell et al. 2002, Parmesan 2006). Of concern for these seal species, warming temperatures may increase the prevalence of diseases and disease vectors, exposing seals to new diseases or increasing the transmission of existing diseases.

(2) Increased human disturbance

The disappearance of seasonal and perennial sea ice in the Arctic will encourage increased development and human traffic in previously inaccessible, ice-covered areas, which will increase impacts to Arctic marine mammals including the ringed, bearded, and spotted seal (ACIA 2005, Hovelsrud et al. 2008). Shipping activity and oil and gas exploration are expected to increase with declines in sea ice, and tourism and commercial fisheries are also likely to expand (AMAP 2003).

Increased shipping activity in the habitat of the ringed, bearded, and spotted seal is almost certain to occur with the opening of two international shipping routes—the Northwest Passage and the trans-polar route—and the expansion of the Northern Sea Route, all of which pass directly through important breeding and foraging habitat for these species. The Northwest Passage is a potential shipping route that has been historically blocked by perennial sea ice and which connects the Pacific and Atlantic Oceans through the Arctic Ocean along the northern coast of North America. The Northern Sea Route refers to the seasonally ice-covered marine shipping routes from Novaya Zemlya in the west, along the coast of northern Eurasia, to the Bering Sea in the east (ACIA 2005). The Northern Sea Route is administered by the Russian Ministry of Transport and has been open to marine traffic from all nations since 1991, although sea ice poses major challenges and requires specially reinforced ships as well as ice-breakers (ACIA 2005). A trans-polar route across the Arctic Ocean would connect the Atlantic and Pacific Oceans.

The navigation season for the Northern Sea Route is expected to increase from the current 20-30 days per year to 90-100 days per year by 2080, and the Northwest Passage was predicted to open sometime in the 21st century (ACIA 2005). However, expanding access to Arctic shipping routes is occurring much faster than predicted. In September 2007, the most direct route of the Northwest Passage was fully navigable due to the extreme loss of perennial sea ice, while the Northern Sea Route remained only partially blocked (ESA 2007).

Marine shipping vessels are already a significant source of oil pollution and greenhouse gas emissions, including carbon dioxide, nitrous oxides, and black soot (Earthjustice 2007). Increased shipping will heighten the risk of oil spills, increase emissions of greenhouse gases that with further accelerate Arctic warming, and increase emissions of black carbon that accelerate local melting of Arctic sea ice by reducing the ice albedo. Russian scientists also cite increasing use of a Northern Sea Route for transit and regional development as a major source of disturbance in the Russian Arctic (Belikov and Boltunov 1998). Ships involved in the expanded use of the Northern Sea Route would likely use leads and polynyas to avoid breaking ice and reduce transit time, and this loose ice with openings is preferred habitat for bearded seals and other ice-dependent seals. Overall, heavy shipping traffic on the Northern Sea Route, Northwest Passage, and trans-polar route is likely to disturb ringed, bearded, and spotted seal reproductive and foraging activities, increase the risk of oil spills in critical ringed, bearded, and spotted seal habitat, and further accelerate global warming.

Oil and gas exploration and commercial fisheries are also expected to expand into Arctic waters as the sea ice diminishes (AMAP 2003). The threats posed to ringed, bearded, and spotted seals by oil and gas exploration and commercial fisheries are discussed beginning on pages 108 and 119, respectively.

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Ringed, bearded, and spotted seals were overexploited by commercial hunting in the 20th century which resulted in significant population declines in several regions. Currently, poaching of spotted seals in the Bo Hai Sea remains a significant threat, and high allowable harvest levels set by the Russian Federation in the 2000s for ringed, bearded, and spotted seals in the Okhotsk and western Bering Sea create the potential for renewed overexploitation of these populations.

Ringed seal

Ringed seals have historically been important to the subsistence of human inhabitants of the Arctic (Kelly 1988b), and are still widely hunted across the Arctic for subsistence purposes. Intensive commercial hunting of each of the five subspecies of ringed seal in the 20th century resulted in overexploitation and severe population declines.

Arctic ringed seal. In the Bering Sea, commercial vessel-based hunting of ringed seals by the Soviet Union began in 1961 (Fedoseev 2000). Vessel-based harvest of ringed seals in the Russian waters of the Bering Sea averaged 5,100 individuals per year between 1961-1969 and 3,300 seals per year or less between 1970-1990, not including losses due to sinking (Fedoseev 2000). Since up to 50% of seals struck can be lost (Kovacs 2002), sinking losses significantly increase estimated mortality from harvesting. Harvest quotas in White Sea were set at 3,500 seals by the early 1980s (Popov 1982) and subsequently reduced to 1,500 seals (Reijinders et al. 1993). In Greenland, 70,000-100,000 ringed seals were harvested annually from 1979-1983 (Reijinders et al. 1993)

In the United States, commercial hunting of ringed seals is prohibited by the Marine Mammal Protection Act (16 U.S.C. § 1361 *et seq*.). In Alaskan waters, ringed seals are harvested exclusively by Alaska native subsistence hunters. The estimated annual subsistence harvest of ringed seals in Alaska decreased from 7,000 to 15,000 in the period from 1962-1972 to an estimated 2,000- 3,000 in 1979 (Angliss and Outlaw 2008). Based on data from two villages on St. Lawrence Island, the annual take in Alaska during the mid-1980s likely exceeded 3,000 seals (Kelly 1988b). Currently, there are no efforts to quantify the harvest level of ringed seals by all

Alaskan communities (Angliss and Outlaw 2008). The Division of Subsistence of the Alaska Department of Fish and Game estimated that the number of ringed seals harvested for subsistence per year is 9,567 as of August 2000, using data gathered in the 1980s from 16 villages and data gathered from 1990 to 1998 (Angliss and Outlaw 2008). As a more recent approximation, the US Fish and Wildlife Service's Walrus Harvest Monitoring Program reported that 47 ringed seals were harvested annually between 1999-2003 by 5 of over 100 villages that participate in seal harvest (Angliss and Outlaw 2008). Because of the small sampling of villages, the total number of ringed seals harvested by subsistence hunting could be considerably larger. Subsistence hunting by native Alaskans is not subject to regulation under the ESA (16 U.S.C § 1539(e)).

In Canada, the government of Nunavut estimates the current rate of harvest of ringed seals at approximately 35,000 seals each year. The ringed seal harvest in Labrador has been in the range of less than 2,000 animals per year in recent years.

Okhotsk ringed seal. In 1932 the Soviet Union began commercial hunting of ringed seals from large-scale pelagic vessels in the Sea of Okhotsk (Kelly 1988b). An average of 78,500 ringed seals were killed each year by vessel-based sealers from 1955 to 1968, which resulted in overexploitation of the population (Popov 1982, Fedoseev 2000). In 1969, an annual quota of 32,000 individuals was imposed on vessel-based sealing, and the quota was later reduced to 25,000 in 1972 and to 18,000 in 1975 (Popov 1982). More recently, Grachev (1960) reported vessel-based commercial harvests in the Okhotsk Sea averaging 14,686 ringed seals per year between 1990-1993, after which sealing reportedly declined during the *Perestroika* transition. In terms of land-based harvest by coastal populations, Popov (1982) reported that the average annual take of ringed seals in the Okhotsk Sea did not exceed 25,000-30,000 individuals from the end of the 1800s to the mid-1900s (Popov 1982). Fedoseev (2000) estimated that native hunting of the ringed seal in the Okhotsk Sea before the 1950s likely killed between 12,500 and 17,550 ringed seals per year (e.g. an estimated 25,000 to 35,000 animals per year were taken of which 50% were ringed seals).

Baltic, Ladoga, and Saimaa ringed seals. Baltic ringed seals were intensively over-hunted during the 20th century, which resulted in a severe population decline (Harding and Harkonen 1999). Hunting of the Baltic ringed seal was gradually limited in several countries and subsequently banned completely throughout the Baltic Sea in 1988, but there is ongoing pressure to permit hunting of ringed seals (Kokko et al. 1997, Ministry of Agriculture and Forestry 2007). Ladoga ringed seals and Saimaa ringed seals were also intensively over-hunted in the 20th century, which led to dramatic population declines (Palo et al. 2003). Hunting of Ladoga ringed seals was banned in 1980, although poaching still occurs, and hunting of Saimaa ringed seals was banned by Finnish Law in 1955 (Palo et al. 2003).

Bearded seal

Historically, bearded seals were harvested by inhabitants of the Arctic coasts for thousands of years (Kelly 1988a). Until the beginning of the 20th century, harvest of bearded seals by native hunters likely did not have significant impacts on the population (Kelly 1988a). However, harvest increased substantially with the use of firearms in the beginning of the 20th century as did the loss rate to sinking (Kelly 1988a). Along the Siberian coast, Fedoseev (2000) estimated that native hunting of the bearded seal in the Okhotsk Sea before the 1950s likely killed between 8,750 and 12,250 bearded seals per year (e.g. an estimated 25,000 to 35,000 animals per year were taken of which 35% were bearded seals). In the Chukotka peninsula, retrieved harvest of bearded seals by native hunting has been estimated at 1,822 (sd=879) from 1915-1937 and 608 (sd=253) from 1940-1980 (Kelly 1988a).

In 1932 the Soviet Union began commercial hunting of bearded seals and other seals from large-scale pelagic vessels in the Sea of Okhotsk, which resulted in over-exploitation (Kelly 1988a). Bearded seals were preferred because of their large size which yielded more blubber and meat (Fedoseev 2000). Commercial hunting vessels killed between 2,000-6,000 individuals per year from 1947-1956, but hunting intensified in the mid-1950s (Kelly 1988). In 1957 commercial sealers killed 15,000 bearded seals and the annual average kill remained around 12,500 for several years (Heptner et al. 1976). The heavy harvest rapidly began depleting the bearded seal population. Populations in the southern Okhotsk Sea from Terpeniya Bay and the east coast of Sakhalin Island decreased so dramatically that they lost commercial importance, and populations of the Shantarsk Island decreased from thousands in the 1930s to a few hundred in the 1960s (Heptner et al. 1976). The average catch per ship in the Okhotsk Sea fell from 1,110 in 1957 to 730 in 1963 (Heptner et al. 1976). The total harvest in the Okhotsk Sea remained constant until the mid-1960s only because commercial sealers extending hunting into the northern regions of the Okhotsk Sea (e.g. Shelikov Gulf) that had not formerly been commercially exploited (Heptner et al. 1976). Overall, an estimated 10,100 bearded seals were killed each year by commercial sealing vessels in the Okhotsk Sea during 1955-1968 before seal harvesting was regulated (Fedoseev 2000). These harvest numbers do not include seals that were killed but not retrieved when bodies sink under water (Fedoseev 2000). Since up to 50% of seals struck can be lost (Kovacs 2002), sinking losses significantly increase estimated mortality from harvesting. These harvest numbers also do not include the local hunt in the coastal zone of the Okhotsk Sea (Heptner et al. 1976). Commercial hunting of bearded seals by the Soviet Union in the Bering Sea began in 1961. An average of 12,000 bearded seals were harvested each year between 1961-1969, not including sinking losses (Fedoseev 2000).

In 1969, the Soviet harvest of bearded seals decreased markedly since the main product of sealing switched from blubber to fur, and bearded seal fur was not valued (Fedoseev 2000). The annual average retrieved harvest from 1969-1990 was estimated at 2,300 in Russian waters and 4,000 in Alaskan waters (Fedoseev 2000). Commercial harvest in the Sea of Okhotsk averaged 2,339 bearded seals killed each year during 1990-1993 (Grachev 2006). In 1970, Soviet quotas for hunting by coastal populations were set at 5,000 in the Okhotsk Sea and 3,000 in the Bering Sea (Popov 1982).

In the United States, commercial hunting of bearded seals is prohibited by the Marine Mammal Protection Act (16 U.S.C. § 1361 *et seq*.). In Alaskan waters, bearded seals are harvested exclusively by Alaska native subsistence hunters (Kelly 1988). From 1966 to 1977, the annual subsistence harvest was estimated to take 1,784 ± 941 bearded seals (Burns 1981). Currently, there are no efforts to quantify the harvest level of bearded seals by all Alaskan communities (Angliss and Outlaw 2008). The Division of Subsistence of the Alaska Department of Fish and Game estimated that the number of bearded seals harvested for subsistence per year is 6,788 as of August 2000, using data gathered in the 1980s from 16 villages and data gathered from 1990 to 1998 (Angliss and Outlaw 2008). As a more recent approximation, the US Fish and Wildlife Service's Walrus Harvest Monitoring Program reported that 273 bearded seals were harvested annually between 1999-2003 by 5 of over 100 villages that participate in seal harvest (Angliss and Outlaw 2008). Because of the small sampling of villages, the total number of bearded seals harvested by subsistence hunting could be considerably larger. Subsistence hunting by native Alaskans is not subject to regulation under the ESA (16 U.S.C § 1539(e)).

In Canada, small numbers of bearded seals are taken each year in the subsistence hunt in northern Atlantic areas.

Spotted seal

Historically, spotted seals were harvested by local hunters in limited numbers along the Alaskan and Siberian coasts (Quakenbush 1988). In the Soviet Union, commercial exploitation of the spotted seal began in the 1930s with the initiation of ship-based seal hunting in 1932 in the Okhotsk Sea and shore-based seal hunting by fur-farming collectives which killed spotted seals as a source of meat and blubber for their fur farms (Quakenbush 1988). Fedoseev (2000) states that native hunting of the spotted seal in the Okhotsk Sea before the 1950s may have taken between 3,750 and 5,250 seals per year (e.g. an estimated 25,000 to 35,000 animals per year were taken of which 15% were spotted seals), which may reflect higher numbers killed for fur farms. An estimated 4,600 spotted seals per year, not including sinking losses, were killed in the Okhotsk Sea during 1955-1968 by vessel-based sealers before seal harvesting was regulated (Fedoseev 2000). Soviet vessel-based seal hunting in the Bering Sea began in 1961, and the average harvest of spotted seals from 1961-1969 was estimated at 2,000 per year, not including sinking losses.

In 1970 the Soviet Union set harvest limits for spotted seals at 7,000 in the Okhotsk Sea (5,000 from vessels and 2,000 from shore) and 8,000 in the Bering Sea (6,000 from vessels and 2,000 from shore) (Popov 1982, Fedoseev 2000). Although Soviet shore-based hunting decreased after 1969 to an average of 347 seals killed during 1969-1983 (Quakenbush 1988), Soviet vessel-based hunting in the Bering Sea increased. Fedoseev (2000) reported that the annual harvest in the Bering Sea increased to an average of 3,000 retrieved spotted seals from 1969-1985 due to the higher demand for fur. Mineev (1981, 1984) reported even higher average annual harvest by Soviet vessels in the Bering Sea during this period of 3,292 retrieved seals during 1969-1983. Kelly (1988) reported an average annual harvest of 3,850 retrieved seals (range 1,800-5,600) during 1966-1976, with 89% taken by commercial vessels and 11% taken by land-based hunting. Commercial harvest in the Sea of Okhotsk had increased substantially in 1990 and averaged 5,149 spotted seals killed each year during 1990-1993 (Grachev 2006).

In the United States, commercial hunting of spotted seals is prohibited by the Marine Mammal Protection Act (16 U.S.C. § 1361 *et seq.*), and spotted seals are only harvested by subsistence hunters. Spotted seals are an important species for Alaskan subsistence hunters, primarily in the Bering Strait and Yukon-Kuskokwim region. From 1966-1976, the annual subsistence harvest was estimated to take an average of 2,400 spotted seals each year, ranging from 850 to 3,600 seals (Lowry 1984). From September 1985 to June 1986 the combined harvest from five Alaska villages was 986 spotted seals (Quakenbush 1988). The Division of Subsistence of the Alaska Department of Fish and Game estimated that 5,265 spotted seals were harvested for subsistence as of August 2000, based on data gathered in the 1980s and 1990s (Angliss and Outlaw 2008). Currently, there are no efforts to quantify the harvest level of spotted seals by all Alaskan communities (Angliss and Outlaw 2008). However, a recent approximation is available from the US Fish and Wildlife Service's Walrus Harvest Monitoring Program which reported that 32 spotted seals were harvested annually between 1999-2003 by 5 of over 100 villages that participate in seal harvest (Angliss and Outlaw 2008). Because of the small sampling of villages, the total number of spotted seals harvested by subsistence hunting is likely larger. Subsistence hunting by native Alaskans is not subject to regulation under the ESA (16 U.S.C § 1539(e)).

Current threats to ringed, bearded, and spotted seals from overexploitation

In the Bo Hai Sea, the spotted seal population decreased significantly during the 20th century, if not before, due to overexploitation from high hunting pressure, and hunting remains a significant ongoing threat. Hunting of spotted seals in the 1950s killed more than 1000 seals per year, which represented a significant portion of the population estimated at 7,000-8,100 in the 1930s and 1940s (Won and Yoo 2004). In the 1960s and 1970s, 400-500 spotted seals were killed annually (Won and Yoo 2004). Spotted seals in Bo Hai Sea were afforded protection from hunting in 1980s (Burns 2002b). However, poaching of spotted seals in the Bo Hai Sea is reportedly occurring at high levels due to demands for meat, fur, oil, and the male genitalia which are used in traditional medicine (Won and Yoo 2004). Fishermen and residents of Bak-ryoung Island off western South Korea (an important haulout site for spotted seals in the Yellow Sea) have repeatedly stated that seal numbers in the region have declined since the 1970s due to habitat disturbance and persecution by humans (Won and Yoo 2004).

In the 2000s, the Russian Federation began setting high total allowable harvest levels for ringed, bearded, and spotted seals in the Okhotsk and Bering Seas (Table 2) (MMC 2007). The actual harvest of seals appears to be less than the allowed harvest. For example, the harvest of bearded seals in the Chukotsky Autonomous Okrug (the administrative division that has access to bearded seals in the Chukchi and northwestern Bering Sea) ranged from 21.6% to 47.4% of the allowed quota during 1997-2005 (Karpenko and Balykin 2006). However, if the allowed harvest were realized, this take of seals in the Okhotsk and western Bering Sea could approach unsustainable harvest levels, especially as seals face increasing threats from global warming. Of particular concern, Grachev (2006) reported that the government of the Magadan region of the Okhotsk Sea invested in the resumption and stimulation of coastal sealing in 2005. Grachev (2006) further reported a growing interest in Russia in resuming the commercial harvest of ringed, bearded, and spotted seals due to the profitability of extracting the internal organs, which are rich in biologically active compounds, for use in the pharmaceutical industry. Overall, the high allowable harvest levels and growing interest in resuming commercial sealing in Russia provide an opportunity for future overexploitation of the ringed, bearded, and spotted seal.

Table 2. Total allowed harvest of ringed, bearded, and spotted seals in the Russian Federation in territorial waters, on the continental shelf, and in the exclusive economic zone during 2002-2005.
Source: MMC (2007).

Ringed seal				
Region	**2002**	**2003**	**2004**	**2005**
Western Bering Sea	6,500	6,300	6,300	5,900
Sea of Okhotsk	27,000	25,500	25,500	25,500
Barents Sea	1,500	2,500	2,500	1,000
White Sea	1,100	1,300	1,000	1,300
Kara Sea				1,500
Total	**36,100**	**35,600**	**35,300**	**35,200**
Bearded Seal				
Region	**2002**	**2003**	**2004**	**2005**
Western Bering Sea	4,000	4,000	4,000	4,000
Sea of Okhotsk	7,400	6,800	6,800	7,700
Barents Sea	250	500	500	600
White Sea	100	100	100	200
Total	**11,750**	**11,400**	**11,400**	**12,500**
Spotted Seal				
Region	**2002**	**2003**	**2004**	**2005**
Western Bering Sea	2,500	2,500	2,500	1,600
Eastern Kamchatka	2,900	2,500	2,800	1,200
Sea of Okhotsk	9,400	8,000	8,000	8,500
Total	**14,800**	**13,300**	**13,300**	**11,300**

C. Disease or Predation

While predation and disease are not currently a threat to the viability of the ringed, bearded, and spotted seal, global warming is likely to markedly increase depredation and disease occurrence in seal populations as discussed in more detail above on page 91-92. Such impacts will likely act synergistically with other threats to the ringed, bearded, and spotted seal to further increase the extinction risk for these species.

D. Inadequacy of Existing Regulatory Mechanisms

1. Regulatory Mechanisms Addressing Greenhouse Gas Pollution and Global Warming Are Inadequate

Greenhouse gas emissions and global warming are the greatest threats to the ringed, bearded, and spotted seal and yet also the least well regulated. The primary international regulatory mechanisms addressing greenhouse gas emissions global warming are the United Nations Framework Convention on Climate Change and the Kyoto Protocol. While the entering into force of the Kyoto Protocol on February 16, 2005 marks a significant partial step towards the regulation of greenhouse gases, it does not and cannot alone adequately address the impacts of global warming that threaten the ringed, bearded, and spotted seal with extinction. There are currently no legal mechanisms regulating greenhouse gases on a national level in the United States. As detailed below, all existing regulatory mechanisms are clearly inadequate to ensure the ringed, bearded, and spotted seals' survival in the wild. The immediate reduction of greenhouse gas pollution is essential to slow global warming and ultimately stabilize the climate system while there is still suitable sea-ice habitat remaining.

a. The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change ("UNFCCC") was adopted in May 1992 at the first Earth Summit held in Rio de Janeiro, Brazil, and entered into force in March 1994 (EIA 2004). The stated objective of the UNFCCC is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (EIA 2004). Due to the complexity of climate issues and the widely divergent political positions of the world's nation states, the UNFCCC itself was unable to set emissions targets or limitations, but instead created a framework that set the stage for a range of subsequent actions (UNFCCC 2004). The UNFCCC covers greenhouse gases not otherwise controlled by the Montreal Protocol on ozone-depleting substances (UNFCCC 2004).

The UNFCCC assigns differing responsibilities to its 189 parties, based on their differing levels of economic development (UNFCCC 2004). Annex I parties include 41 mostly developed countries. Annex I countries set a goal (but not a requirement) of returning their emissions by 2000 to 1990 levels (UNFCCC 2004). They are required to make regular reports on implementation, including reporting on levels of greenhouse gas emissions and policies and measures to reduce them (UNFCCC 2004). Annex II is a subset of Annex I countries which includes the 23 highly developed countries which are required to financially and otherwise support the efforts of the developing countries (UNFCCC 2004). Countries with economies in transition ("EITs") include 14 countries in Eastern and Central Europe and the former Soviet Union which are listed in Annex I but do not have the additional responsibilities of the other Annex I countries. Non-Annex I parties include all parties not included in one of the former categories and are mostly developing countries (UNFCCC 2004). Non-Annex I parties have general commitments to respond to climate change but have fewer obligations and are expected to rely upon external support.

The UNFCCC has not yet effectively controlled greenhouse gas emissions. The year 2000 has come and gone without the UNFCCC's goal of reducing greenhouse gas emissions from Annex I countries to 1990 levels being met. More than thirteen years after the UNFCCC came into force, "dangerous anthropogenic interference with the climate system" remains undefined (International Climate Change Taskforce 2005). There is a growing body of evidence, however, that anthropogenic greenhouse gas emissions have already caused "dangerous" climate change.

b. The Kyoto Protocol

In 1997 the Kyoto Protocol became the first additional agreement added to the UNFCCC to set emissions targets. The Kyoto Protocol set goals for developed countries only to reduce their emissions to at least 5% below their 1990 levels between 2008-2012, the "first commitment period" (UNFCCC 2004). The Kyoto Protocol required ratification by a minimum of 55 countries, encompassing at least 55% of the carbon dioxide emissions of Annex I countries before it would enter into force. Over seven years passed before this occurred. The Kyoto Protocol entered into force on February 16, 2005, 90 days after it was ratified by Russia (UNFCCC 2005).

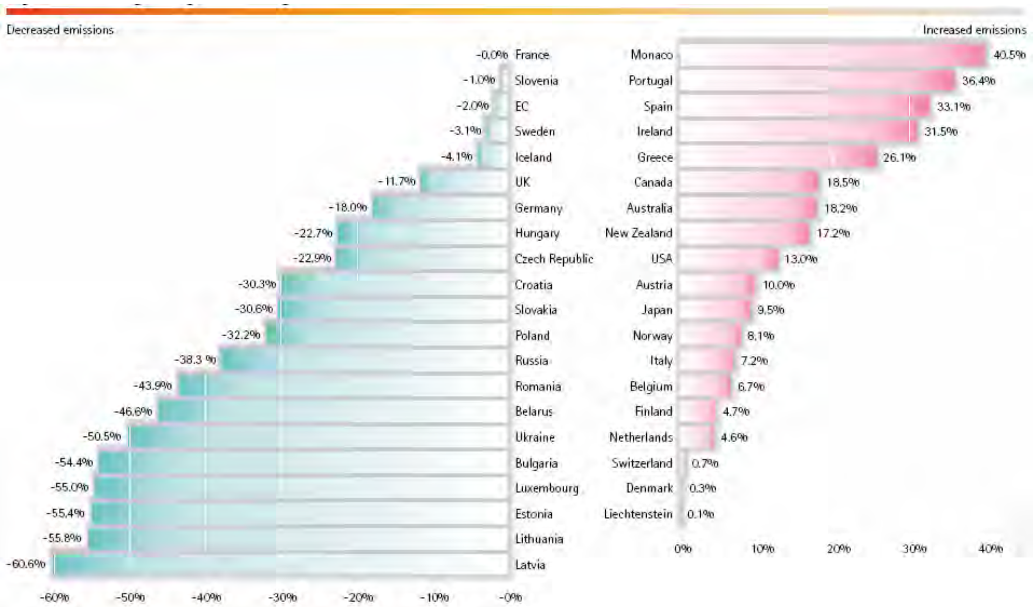
The targets of the Kyoto Protocol's first commitment period are inadequate to prevent significant climate change, and consequently the decline to extinction of the ringed, bearded, and spotted seal. First, the Protocol's overall emissions reduction targets for the first commitment period are highly unlikely to be met, due in large part to the continuing refusal of the United States to ratify the agreement. Second, even if the Kyoto targets were met, they are far too modest to impact greenhouse gas concentrations and global warming sufficiently to ensure the survival of the ringed, bearded, and spotted seal. Third, negotiations for emissions reductions beyond 2012 are just beginning after being blocked for years by the U.S. Each of these issues is addressed in turn below.

The refusal of the United States to ratify the Kyoto Protocol, announced by the Bush Administration in 2001, is a major reason why Kyoto targets are unlikely to be met. Because the United States is responsible for <u>over 20% of worldwide carbon dioxide emissions</u> (EIA 2004), it is highly unlikely that overall targets can be met without U.S. participation. The Kyoto target for the U.S. was a 7% reduction in greenhouse gas emissions levels from 1990 levels by 2012 (EIA 2004). Between 1990 and 2001, United States emissions have in fact <u>increased</u> by 13%. Total United States emissions are projected to grow a staggering additional <u>43.5% through the period 2025</u> (GAO 2003a).

In addition to the outright intransigence of the United States, the overall and many country-specific Kyoto targets are unlikely to be met based on current progress and data. While some Annex I countries have achieved their Kyoto targets or at least some reductions, many other Annex I countries have seen their emissions increase substantially (Figure 21). Emissions also increased in many of the developing nations between 1990 and 2000 (UNFCCC 2004). In addition, although emissions of the EIT countries decreased significantly from 1990-2000 as a result of economic contraction in these countries, they increased from 2000 to 2001 and are projected to continue to do so (EIA 2004). Overall, the EIA estimates that worldwide carbon emissions in 2025 will exceed 1990 levels by 72% (EIA 2004).[5]

Even in the unlikely event that overall Kyoto targets were fully met by the year 2012, the reductions are far too small to substantially reduce global warming and improve the plight of the ringed, bearded, and spotted seal. Implementation of the Kyoto Protocol would only slightly reduce the rate of growth of emissions – it would not stabilize or reduce atmospheric greenhouse gas concentrations (Williams 2002). Carbon dioxide levels currently stand at over 380 ppm, from pre-industrial levels of 280 ppm, and are increasing at more than 2 ppm per year (International Climate Change Taskforce 2005). Stabilizing carbon dioxide concentrations at 440 ppm (23% above current levels, and a level likely to lead to a greater than 2° C average global temperature rise) would require global emissions to drop below 1990 levels within a few decades, with emissions eventually declining to a very small fraction of current levels, despite growing populations and an expanding world economy. These cuts will not be achieved simply by compliance with Kyoto (Williams 2002). The IPCC SRES scenarios predict carbon dioxide concentrations of between 490 and 1260 ppm by 2100 (Albritton et 2001), and these scenarios all assume significant reductions in the rate of greenhouse gas emissions (Nakićenović et al. 2000).

Figure 21. Changes in greenhouse gas emissions by Annex I Countries, 1990-2001.
Source: UNFCCC (2004: 25).



Additionally, the Kyoto Protocol's first commitment period only sets targets for action through 2012. There is no current regulatory mechanism governing greenhouse gas emissions in the years beyond 2012. Discussions for targets for the second compliance period from 2012-

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[5] EIA (2004) projections do not reflect the potential impacts of the Kyoto treaty, because it had not yet come into force when the projections were prepared (EIA 2004). Compliance with Kyoto or other measures to reduce greenhouse gases could cause actual emissions to differ from the projections (EIA 2004), however, as discussed above, compliance with overall Kyoto targets is unlikely.

2016 began at the Bali, Indonesia, UNFCCC conference in 2007. While the European Union delegation attempted to begin discussions at the Conference of the Parties in Milan, Italy in 2003, in Buenos Aires in 2004, in Montreal in 2005, in Nairobi in 2006, not until Bali 2007 did the U.S. agree to a framework for the regulation of post-2012 emissions reductions. No binding or even voluntary agreement yet exists to deal with the cuts needed beyond the Kyoto Protocol.

c. United States Climate Initiatives are Ineffective

Because the United States is responsible for over 20% of global greenhouse gas emissions, regulation of United States emissions is essential to saving the ringed, bearded, and spotted seal from declines to extinction. Unfortunately, despite the nature and magnitude of the risks, and a variety of actions by Congress and the Executive Branch, there is still no regulation of greenhouse gas emissions on the national level in the United States.

Beginning in 1978, Congress established a “national climate program” to improve understanding of global climate change through research, data collection, assessments, information dissemination, and international cooperation. National Climate Program Act of 1978, 15 U.S.C. §§ 2901 *et seq.* Two years later, in the Energy Security Act, Congress directed the Office of Science and Technology Policy to engage the National Academy of Sciences in a study of the “projected impact, on the level of carbon dioxide in the atmosphere, of fossil fuel combustion, coal-conversion and related synthetic fuels activities” authorized by the Energy Security Act. Pub. L. No. 96-294, tit. VII, § 711, 94 Stat. 611, 774-75 (1980). In 1990, Congress enacted the Global Change Research Act, 15 U.S.C. §§ 2931-2938, which established a 10-year research program for global climate issues, directed the President to establish a research program to improve understanding of global change, and provided for scientific assessments every four years that analyze current trends in global change. *Id.* at §§ 2932, 2933, 2936(3). Congress also established a program to research agricultural issues related to global climate change. Pub. L. No. 101-24, tit. XXIV, § 2402, 104 Stat. 4058, 4058-59 (1990). Finally, two years later, in the Energy Policy Act of 1992, Congress directed the Secretary of Energy to conduct several assessments related to greenhouse gases and report to Congress. Pub. L. No. 102-486, § 1604, 106 Stat. 2776, 3002.

The Global Climate Protection Act of 1987 directed the Secretary of State to coordinate U.S. negotiations concerning global climate change. 15 U.S.C. § 2901 note; § 2952(a). Following those negotiations, President George H.W. Bush signed, and the Senate approved, the UNFCCC, which, as discussed above, has yet to effectively control greenhouse gas emissions.

Greenhouse gas emissions have also not yet been effectively regulated under the United States Clean Air Act (“CAA”). Section 103(g) directs the Environmental Protection Agency (“EPA”) to establish a “basic engineering research and technology program to develop, evaluate, and demonstrate nonregulatory strategies and technologies for air pollution prevention” that would address substances including carbon dioxide. 42 U.S.C. § 7403(g). The CAA also states that nothing in Section 103(g) “shall be construed to authorize the imposition on any person of air pollution control requirements.” *Id.*

In 2003, the EPA rejected a petition urging it to regulate greenhouse gas emissions from automobiles under CAA Section 202. In 2007, the Supreme Court overturned the EPA's refusal to regulate these emissions, and remanded the matter to the agency for further consideration. *Massachusetts v. U.S. EPA*, 127 S. Ct. 1438 (2007). The EPA has yet to act following the remand. Moreover, the EPA has denied California's request for a waiver to implement its Clean Vehicle Law, passed in 2002 (AB 1493, Pavley) which requires greenhouse gas reductions from automobiles sold in California, and is thus actively preventing this law from going into effect.

The George W. Bush Administration's climate initiative, revealed after the Administration renounced the Kyoto Protocol, plainly fails to effectively address global warming. This initiative is based entirely on voluntary measures which are incapable of effectively controlling greenhouse gas emissions. This climate plan, termed the Global Climate Change Initiative, also focuses only on reducing the amount of greenhouse gas emissions per unit of energy produced ("emissions intensity"), not the overall level of emissions (GAO 2003a). In the absence of new climate initiatives, United States emissions intensity is expected to decrease by 14% by 2012, while total emissions continue to increase (GAO 2003a). The Bush plan, if fully implemented and successful, would decrease emissions intensity by a mere additional 4%, for an overall reduction of 18%, but total emissions would still continue to increase. Even according to the Bush Administration's own arithmetic, full implementation and success of the plan will result in U.S. greenhouse gas emissions in 2012 that are 30% higher than 1990 emissions, as opposed to the 7% reduction called for by the Kyoto Protocol (Holdren 2003). Cumulative emissions between 2002-2012 will continue to grow and would be only 2% less with the plan than without it (GAO 2003a).

Moreover, the U.S. Government Accounting Office ("GAO") found that the Bush plan does not explain how even the modest 4% claimed reduction in energy intensity will be met. The Bush plan fails to provide any emissions savings estimates at all for 19 of the 30 plan elements (GAO 2003b). Of those 19, at least two seem unlikely to yield any emissions savings at all by 2012 (GAO 2003b). Of 11 initiatives for which savings estimates were provided, at least eight were not clearly attributable to the Bush plan, and there were problems with others as well (GAO 2003b). Overall, the GAO could confirm that emissions savings would be realized from only three of the Bush plan elements (GAO 2003b), an extremely inauspicious finding for the ultimate success of the already modest proposal.

In the absence of federal leadership, state and local governments have taken the lead in measures to reduce greenhouse gas emissions. While certainly a step in the right direction, unfortunately, these measures on their own are insufficient to prevent the extinction of the ringed, bearded, and spotted seal. For example, the strongest law enacted to date is the California Global Warming Solutions Act of 2006. Signed into law in September, 2006, it is the nation's first mandatory cap on a state's overall greenhouse gas emissions. The California Legislature declared:

> Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California. The potential adverse impacts of global warming include the exacerbation of air quality problems, a reduction in the quality and supply of water to the state from the Sierra snowpack,

> a rise in sea levels resulting in the displacement of thousands of coastal businesses and residences, damage to marine ecosystems and the natural environment, and an increase in the incidences of infectious diseases, asthma, and other human health-related problems. (Cal. Health and Safety Code § 38501(a))

The Global Warming Solutions Act requires the reduction of greenhouse gas emissions to 1990 levels by the year 2020. *Id.* at § 38550. The law will be implemented through a series of California Air Resources Board (CARB) rulemakings including establishing emission source monitoring and reporting requirements, discrete early action emission reduction measures, and finally greenhouse gas emission limits and measures to achieve the maximum feasible and cost-effective reductions in furtherance of the greenhouse gas emission cap. *Id.* at § 38550. While the California Global Warming Solutions Act is a promising first step, like the Kyoto Protocol, it is insufficient on its own to slow global warming sufficiently to ensure the survival of the ringed, bearded, and spotted seal.

For all the reasons discussed above, existing regulatory mechanisms relating to global warming are inadequate to ensure the continued survival of the ringed, bearded, and spotted seal. Ensuring the survival of these species requires immediate and dramatic action, particularly in the United States, to reduce greenhouse gas emissions.

2. Regulatory Mechanisms Addressing Other Threats to the Ringed, Bearded, and Spotted Seal Are Inadequate

Oil and Gas Development

The impacts of ongoing and proposed oil and gas development on the ringed, bearded, and spotted seal are described starting on page 108. Existing regulatory mechanisms are inadequate to address these impacts. With the lease sales in the Beaufort, Chukchi, and Bering Seas that occurred under the 2002-2007 U.S. Oil and Gas Leasing Program and those scheduled under the 2007-2012 U.S. Oil and Gas Leasing Program (MMS 2007b), a substantial proportion of ringed, bearded and spotted seal habitat subject to U.S. jurisdiction is now open for oil and gas leasing and development. The Minerals Management Service (MMS) is required to analyze the impacts of oil and gas lease sales and development on the ringed, bearded, and spotted seal and other species while NMFS authorizes “take” of the species from such operations pursuant to the Marine Mammal Protection Act (MMPA). Unfortunately, neither agency is adequately considering the impacts of these activities on the ringed, bearded, and spotted seal. Additionally, nearshore foraging areas for all of three seal species and on-land haulouts for the spotted seal are generally under the jurisdiction of the State of Alaska or other state, local or federal jurisdictions, none of which adequately protect ringed, bearded, and spotted seal habitat from oil and gas activities.

The primary evidence of the inadequacy of MMS mechanisms for protection of the ringed, bearded, and spotted seals (e.g. the Outer Continental Shelf Lands Act (OCSLA) and the National Environmental Policy Act (NEPA)) is the fact that MMS has offered or plans to offer the vast majority of ringed, bearded, and spotted seal habitat in the Chukchi and Beaufort Seas and important habitat in the Bering Sea for oil leasing. If these regulatory mechanisms had been adequate, important seal habitat would have been deleted from MMS lease sales.

The implementation of the MMPA by NMFS also fails to adequately protect the ringed, bearded, and spotted seals from oil and gas activities. In brief, the primary protection the MMPA provides is a prohibition against the unpermitted "take" (i.e. intentional killing or unintentional harassment) of marine mammals. This prohibition is similar to the ESA's Section 9 take prohibition. Authorization to allow take of ringed, bearded, and spotted seals and other marine mammals is provided for in the MMPA pursuant to incidental harassment authorizations ("IHAs") or 5–year incidental take regulations. While the MMPA has a strong take prohibition, permits to allow take are regularly given by NMFS to the oil industry and to date NMFS has never denied a request by the oil industry to take any of these species.

The MMPA also lacks several provisions that the ESA has. The MMPA has no procedural requirement akin to Section 7 that requires agencies to affirmatively look at the impacts of their activities on marine mammals or to avoid jeopardy. The MMPA has no requirement to protect critical habitat. The MMPA has no requirement to develop a recovery plan for a species. Significantly, the MMPA does not have a citizen suit provision, so enforcement is left entirely to NMFS.

Chukchi Lease Sale 193, held on February 6, 2008, resulted in 2.76 million acres of important habitat for ringed, bearded, and spotted seal habitat being bid on by oil companies (MMS 2008), thereby opening the door for oil and gas development in a significant portion of these species' ranges. The Final Environmental Impact Statement ("FEIS") for Chukchi Lease Sale 193 reported that the chance of a large oil spill over the production life of the project is 40% (MMS 2007a):

> We estimate the chance of one or more large pipeline spills is 26%, and the chance of one or more large platform spills is 19% for Alternative I - the Proposed Action over the production life of the project. The total is derived from the sum of the platform, wells and pipeline mean number of spills. The chance of one or more large spills total is 40% for Alternative I - the Proposed Action over the production life of the project. For Alternative I - the Proposed Action, the percent chance of one or more large spills total ranges from 27-54% at the 95% confidence interval over the production life of the project (MMS 2007a: IV-20).

Despite the high risk of a major spill in the Chukchi Sea, the FEIS acknowledged that there is a low success rate in cleaning spills that occur in open water and broken ice conditions: "Spills to open-water and broken-ice conditions result in lower recovery rates of 10-20% of the spilled oil (MMS 2007a: IV-23)."

Additionally, no regulations are in place to protect spotted seals hauled-out on land from disturbance due to oil and gas operations. As diminishing sea ice in the Chukchi Sea forces spotted seals to land for longer periods of time, the lack of such regulation presents a significant threat to the species.

Given the rapidly changing conditions in the Arctic, the precarious status of multiple ice-dependent organisms, and the numerous adverse impacts of oil and gas industry activities on these species, the only adequate regulatory mechanism to protect the ringed, bearded, and spotted seals from oil and gas activities would be a moratorium on new oil and gas leasing and development in the Arctic. Such a moratorium should be implemented immediately and remain in effect until and unless such activity can be demonstrated to not have adverse impacts on the ringed, bearded, and spotted seals and other ice-dependant species, and any greenhouse emissions directly or indirectly associated with such activities are shown to be consistent with a comprehensive national plan to reduce CO_2 and non-CO_2 pollutants to levels determined necessary to avoid the continued loss of sea ice. However, to date the U.S. has not undertaken any of these actions and the impacts of oil and gas development on the ringed, bearded, and spotted seals and their sea-ice habitat continue to accrue.

Shipping

Existing shipping regulations both domestically and internationally are inadequate to protect ringed, bearded, and spotted seals and their habitat from harm. First, the U.S. Environmental Protection Agency (EPA) does not regulate greenhouse gas and black carbon emissions from ships although the Clean Air Act gives it this authority (Earthjustice 2007). The EPA has the authority to regulate emissions from marine shipping vessels, because, consistent with the threshold determinations required under section 213(a)(4) of the Clean Air Act, greenhouse gas and black carbon emissions from marine engines and vessels significantly contribute to global climate change, which may be reasonably anticipated to endanger public health or welfare. 42 U.S.C. § 7547(a)(4).

In addition, the current and projected impacts of shipping on the Arctic are almost wholly unregulated. The U.S. should work in appropriate international forums such as the International Maritime Organization (IMO) and the Arctic Council to prevent the establishment of new shipping routes in the Arctic. Simultaneously, the U.S. should require that any vessel transiting Arctic waters subject to U.S. jurisdiction apply for and operate consistent with take authorizations under the MMPA and ESA so as to minimize direct impacts to the ringed, bearded and spotted seal. However, to date the U.S. has not undertaken any of these actions nor have the IMO or any other relevant international body taken action to protect Arctic resources from shipping.

Ocean acidification

As discussed below, ocean acidification represents a significant threat to the ringed, bearded, and spotted seal and its prey base. Because ocean acidification is driven by anthropogenic carbon dioxide emissions, and, as described above, no adequate mechanisms are in place domestically or internationally to reduce such emissions, regulatory mechanisms to address ocean acidification must also be deemed inadequate.

E. Other Natural and Anthropogenic Factors

1. Ocean Acidification

Ocean acidification poses an ever-increasing risk to ringed, bearded, and spotted seals because of its deleterious effects on the crustacean, fish, mollusc, and squid species that these seals depend on for food. The world's oceans have been absorbing large volumes of carbon dioxide from the atmosphere and cycling it through various chemical, biological, and hydrological processes. In the past few decades, the oceans have absorbed approximately 30% of carbon dioxide released by human activities (Feely et al. 2004). The world's oceans, in fact, store about 50 times more carbon dioxide than the atmosphere (WBGU 2006), and most carbon dioxide released into the atmosphere from the burning of fossil fuels will eventually be absorbed by the ocean (Caldeira and Wickett 2003). As the ocean absorbs carbon dioxide from the atmosphere it changes the chemistry of the sea water by lowering its pH. The oceans' uptake of these excess anthropogenic carbon dioxide emissions, therefore, is causing ocean acidification (WBGU 2006).

Surface ocean pH has already dropped by about 0.1 units on the pH scale from 1750-1994 -- a rise in acidity of about thirty percent (Orr et al. 2005). The pH of the ocean is currently changing rapidly and may drop by another 0.3 or 0.4 (100 – 150% increase in the concentration of H+ ions) by the end of this century (Orr et al. 2005, Meehl et al. 2007). If carbon dioxide emissions continue unabated, resulting changes in ocean acidity could exceed anything experienced in the past 300 million years (Caldeira and Wickett 2003). Even if carbon dioxide emissions stopped immediately, the ocean would continue to absorb the excess carbon dioxide in the atmosphere, resulting in further acidification until the planet's carbon budget returned to equilibrium.

Ocean acidification from unabated anthropogenic carbon dioxide emissions poses a profound threat to marine ecosystems because it affects the physiology of numerous marine organisms, causing detrimental impacts that may ripple up the food chain (Fabry et al. 2008). Changes that have been observed in laboratory experiments include impacts to the photosynthesis of phytoplankton, metabolic rates of zooplankton and fish, oxygen supply of squid, reproduction of clams, nitrification by microorganisms, and the uptake of metals (WBGU 2006). King crab and silver seabream larvae exhibit high mortality rates in CO_2-enriched waters (Ishimatsu et al. 2004, Persselin 2007). Exposure of fish to lower pH levels can cause decreased respiration rates, changes in blood chemistry, and changes in enzymatic activity. Sea urchins raised in lower-pH waters show evidence of inhibited growth due to their inability to maintain internal acid-base balance (Kurihara and Shirayama 2004). Squid are especially vulnerable to ocean acidification because their high energy swimming method and high metabolism require a good supply of oxygen. Increasing ocean CO_2 concentrations lower blood pH and its capacity to carry oxygen (Learmonth et al. 2006, Simmonds and Isaac 2007). Thus, major prey species for ringed, bearded, and spotted seals are likely to be negatively impacted by ocean acidification, including fish species that comprise the bulk of the ringed and spotted seal diet, crabs and clams which are important in bearded seal diet, and squid consumed by ringed seals.

Perhaps most importantly, increasing ocean acidity reduces the availability of carbonate ions that many marine plants and animals rely on to build their shells and skeletons (Feely et al. 2004, Orr et al. 2005, Fabry et al. 2008). Marine organisms including phytoplankton (coccolithophores and foraminifera), coralline algae, corals, echinoderms (sea urchins and starfish), and molluscs (snails, clams, oysters, and squid) are impaired in producing their shells with increasing ocean acidity (Kleypas et al. 2006). Normally, ocean waters are saturated with carbonate ions that marine organisms use to build skeletons (WBGU 2006). However, the acidification of the oceans shifts the water chemistry to favor bicarbonate, thus reducing the availability of carbonate to marine organisms (WBGU 2006). Acidic waters also dissolve existing protective carbonate skeletons and shells (Orr et al. 2005). Because calcifying organisms are at the base of the food web, negative impacts on these organisms will have a cascading effect on other species that rely on these organisms.

Of importance to the bearded seal, the benthic mollusc species which form a large part of their diet will be impaired in calcifying their shells due to rising ocean acidification. Calcification rates of the blue mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) decline linearly with increasing CO_2 sea water concentrations (Gazeau et al. 2007). Gazeau et al. (2007) found that mussel and oyster calcification rates could decrease by 25% and 10%, respectively, by the end of the century, under the IPCC IS92a emissions scenario (740 ppm in 2100). Berge et al. (2005) also found that increased CO_2 sea water concentrations impair shell growth of the blue mussel. In addition, the North Pacific has conditions less favorable for calcification due to the increased solubility of calcium carbonate at lower temperatures and the inflow of CO_2-rich waters from deep ocean basins (Persselin 2007).

Ocean acidification and its impacts on marine biota will worsen in this century due to the continuing rise in atmospheric carbon dioxide concentrations. A large region of the subarctic Pacific bordering the southern edge of the Aleutian Islands is predicted to experience aragonite undersaturation in surface waters within this century under the IPCC IS92a emissions scenario of 788 ppm CO_2 by 2100 (Orr et al. 2005). Under this scenario, the aragonite saturation horizon would shoal from depths of 120 m to the surface, and organisms that use aragonite would no longer be able to survive in this region before the end of the century (Orr et. al 2005). Pteropod marine snails which build their shells from aragonite are important food sources for pollock, herring, and cod, all of which are major components of ringed seal and spotted seal diet. Thus, reductions in pteropods may lead to declines in the fish species that these seal species depend upon. Additionally, continuing carbon dioxide emissions could result in a decrease in calcification rates by up to 60% by the end of this century (Ruttimann 2006). By the close of this century, the acidification of the ocean is likely to have significant negative effects on the principal prey species of the ringed, bearded, and spotted seal.

2. Oil and Gas Exploration and Development

The ringed, bearded, and spotted seal face severe and immediate threats from growing offshore oil and gas development that has the potential to destroy or modify large portions of their foraging and breeding habitat and exert lethal and sub-lethal impacts on populations from oil and noise pollution. Specifically, the adverse impacts of oil industry activities on these three species include (1) contact with and ingestion of oil from acute and chronic spills; (2) industrial noise pollution from ice-breakers, aircraft, and seismic surveys; and (3) harassment from aircraft, ships, and other vehicles that can disrupt breeding, foraging, resting, and breathing activities (Fair and Becker 2000). Additionally, increased oil and gas production translates into higher greenhouse gas production, which furthers global warming’s impact on the ringed, bearded, and spotted seal and their habitat. This section describes the existing and projected oil and gas exploration and development in the range of these species and the effects from resulting oil and noise pollution.

a. Existing and projected oil and gas exploration and development

United States (Alaska)

Both onshore and offshore oil and gas exploration and development activities have been extensive in the U.S. Arctic. Current and growing large-scale offshore leasing for oil and gas development in the Chukchi, Beaufort, and Bering Seas poses a significant threat to the ringed, bearded, and spotted seal. In 2003 the National Research Council noted that "[c]limate warming at predicted rates in the Beaufort Sea region is likely to have serious consequences for ringed seals and polar bears, and those effects will accumulate with the effects of oil and gas activities in the region" (NRC 2003). Since the NRC report, both the impacts of global warming on sea-ice dependent species and the cumulative impacts of oil and gas activities have greatly accelerated.

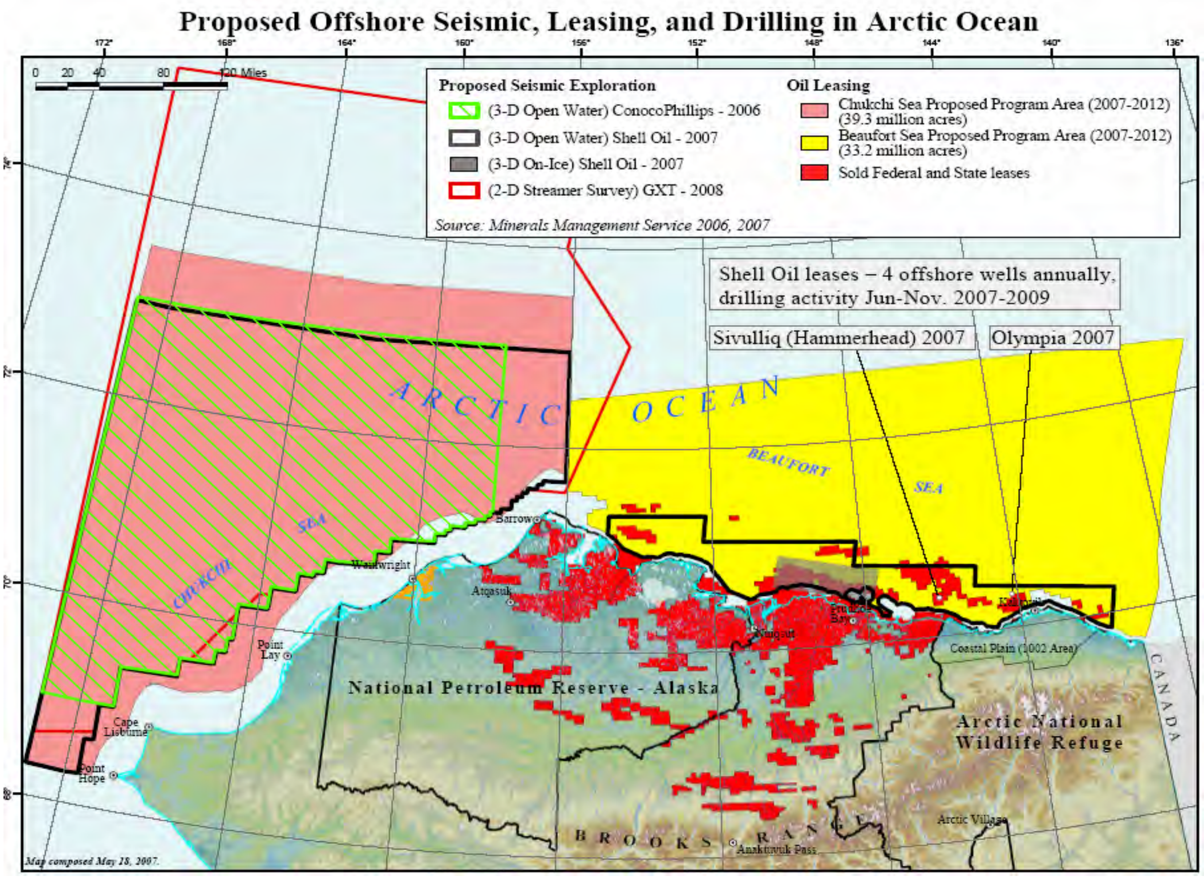
In April 2002, Secretary of Interior Norton issued the Proposed Final 2002-2007 Oil and Gas Leasing Program for the Outer Continental Shelf which resulted in four lease sales in ringed, bearded, and spotted seal habitat which leased ~1,280,000 acres overall (Table 3). In June 2007 Secretary of Interior Kempthorne approved the 2007-2012 Offshore Oil and Gas Leasing Program. In this Program, lease sales in ringed, bearded, and spotted seal habitat are planned in the Chukchi Sea in 2008, 2010, and 2012, in the Beaufort Sea in 2009 and 2011, and in Bristol Bay in the southeastern Bering Sea in 2011 (Table 3, Figure 22) (MMS 2007b). Chukchi Lease Sale 193 occurred on February 6, 2008, with 2.76 million acres of prime habitat for ringed, bearded, and spotted seals on the Chukchi continental shelf ultimately being leased to oil companies. Bristol Bay was cleared for development in January 2007 when President Bush reversed the presidential withdrawal of this region from oil and gas development that was instituted from 1998-2012 to protect its rich biological diversity. In addition to planned lease sales, activity on existing offshore leases is scheduled or now underway, including exploration drilling by Shell Offshore, Inc. and BP's planned development of the Liberty prospect in the Beaufort Sea. With the lease sales in the Beaufort, Chukchi, and Bering Seas that occurred under the 2002-2007 U.S. Oil and Gas Leasing Program and those scheduled during 2007-2012 (MMS 2007b), a substantial proportion of ringed, bearded, and spotted seal habitat subject to U.S. jurisdiction is now open for oil and gas leasing and development.

Table 3. Lease Sales for Oil and Gas Development in the Ringed, Bearded, and Spotted Seal Range Completed and Proposed by the Minerals Management Service in 2002-2012. Source: Minerals Management Service.

Previous 5-Year Program (2002-2007)	
Sale Location and Number	**Sale Year**
Beaufort Sea Sale 186	2003
Norton Basin Sale 188	2004
Beaufort Sea Sale 195	2005
Beaufort Sea Sale 202	2007
Chukchi Sea Sale 193	Delayed
Current 5-Year Program (2007-2012)	
Sale Location and Number	**Proposed Sale Year**
Chukchi Sea Sale 193	2008
Beaufort Sea Sale 209	2009
Chukchi Sea Sale 212	2010
Beaufort Sea Sale 217	2011
North Aleutian Basin Sale 214	2011
Chukchi Sea Sale 221	2012

The pace of the industrialization of America's Arctic by oil and gas development shows no signs of slowing and, in fact, is being actively promoted by the U.S. government (NRC 2003). Since oil and gas production began on Alaska's Arctic Slope in the early 1970s, about 14 billion barrels of oil have been extracted from underground deposits (NRC 2003). As much as 20 billion additional barrels of oil may be extracted in the future (NRC 2003). In 2001, President Bush issued Executive Order 13212 which directed U.S. departments and agencies to take appropriate actions to expedite projects that increase the production, transmission, or conservation of energy (MMS 2003, 2004). Of concern for the ringed, bearded, and spotted seal, offshore oil development in particular is expanding now and will continue to do so in the future. Thus far, offshore oil development has accounted for only a small percentage of oil production on Alaska's Arctic slope – only about 0.429 billion barrels have been produced offshore compared to approximately 13.256 on shore as of December 2001 (NRC 2003). In total, 7 of 31 producing oil fields on Alaska's Arctic Slope were offshore (MMS 2004). However, reasonably foreseeable future development includes 16 discoveries, 9 of which are offshore oil fields that may undergo some development-related activities such as site drilling, permitting, appraisal drilling, or construction, within the next 15-20 years (MMS 2004:Table V1a). Therefore, offshore oil development represents a large proportion of reasonably foreseeable future development in the U.S. Arctic.

Figure 22. Proposed Offshore Seismic, Leasing, and Drilling in the Chukchi and Beaufort Seas during 2007-2012.
Source: Minerals Management Service.



Russia

Growing oil and gas development in the Okhotsk, Bering, and Chukchi Seas in Russian Federation waters represent a grave threat to the survival of the ringed, bearded, and spotted seal. In particular, a large oil spill would have catastrophic impacts on large breeding populations of Okhotsk ringed seal, bearded seals, and spotted seals in the Sea of Okhotsk and nearshore foraging and breeding areas in the Bering and Chukchi Seas. Oil and gas companies have already begun or are planning ambitious development projects in the Sakhalin, Magadan, and Kamchatka regions of the Sea of Okhotsk and in the Chukotka region of the Bering and Chukchi Seas (Lapko and Radchenko 2000).

In the Sakhalin region of the Okhotsk Sea, large-scale offshore oil and gas development has already begun off northwest Sakhalin Island. Specifically, at least six oil operations (Sakhalin-1,2,3,4,5,6) have already begun to exploit the oil and gas fields on the shelf off the northeastern coast of Sakhalin Island (Figure 23). Sakhalin-1 is estimated to contain 310 mt of oil, 425 billion m^3 of gas and 33 billion m^3 of gas condensate (Lapko and Radchenko 2000. Sakhalin-2 is estimated to contain 140 mt of oil and 408 billion m^3 of gas (Lapko and Radchenko) and will liquefy and export gas to Japan, Korea, and the U.S. (Chernenko 2007). Oil extraction from these projects has already started about 18.5 km from the northeastern coast, with a platform, a terminal for oil shipment and a floating oil tank with a capacity of one million barrels (Lapko and Radchenko 2000). According to the 10th International Conference "Oil and gas of Sakhalin" which was held in Yuzhno-Sakhalinsk on September, 27-28, 2006, it was noted that the projects Sakhalin-3, Sakhalin-4 and Sakhalin-5 have begun to work on Sakhalin Island with participation of the company Rosneft (Chernenko 2007). Seismic prospecting was carried out as part of the project Sakhalin-6 in the summer of 2002 (Chernenko 2007). In a study of spotted seals, Bradford and Weller (2005) note that activity and potential disturbance sources in Piltun Lagoon on Sakhalin Island have greatly increased since 1998, mostly associated with the expansion of oil and gas development off the northeastern coast of Sakhalin Island. Illustrating the hazards of this growing oil and gas development, the Sakhalin 1 and Sakhalin 2 projects have already been charged with significant environmental violations, which led to the company Gazprom taking over the Sakhalin-2 project in 2006.

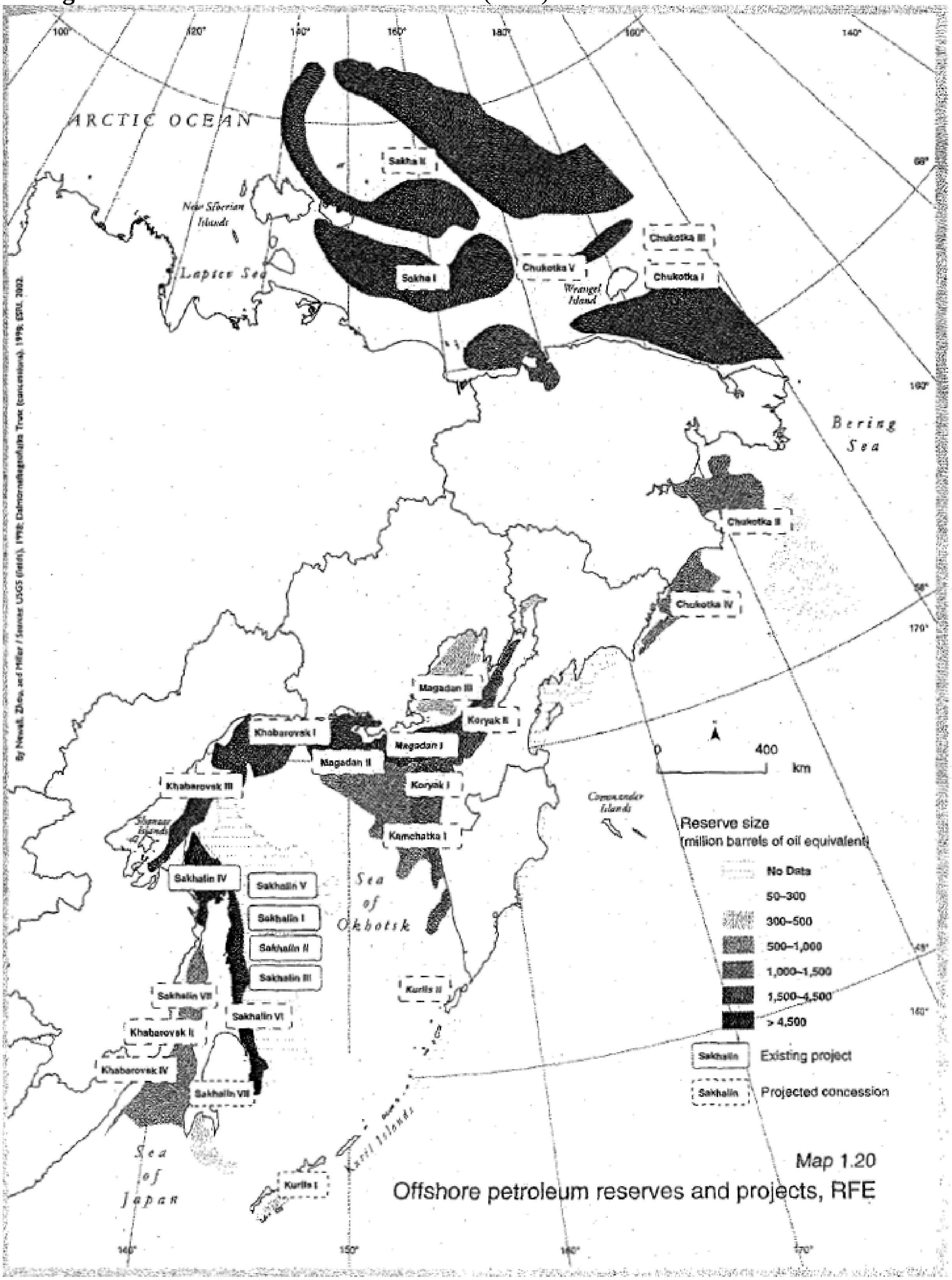
In the Magadan Region in the northern Okhotsk Sea, an investment project called "Prospects, investigation and development of oil and gas fields in offshore sectors of the Sea of Okhotsk - Magadan 1 and Magadan 2" is planned for development through initiation by the Ministry of Natural Resources of the Russian Federation and the Administration of the Magadan Region (Figure 23) (Chernenko 2007). Each sector includes three blocks that are subject to licensing. These sectors will enable the annual extraction of 15-20 million tons of oil and 35-50 billion m^3 of gas (Chernenko 2007). The oil company Rosneft is showing interest in Magadan projects, but it can pursue these projects only after the commencement of operations in offshore zones of Sakhalin and Western Kamchatka (Chernenko 2007).

Five prospective petroleum basins in the Chukotka Autonomous District and offshore zones have been identified: Anadirsky, East-Khatirsky, South-Chukotsky, North-Chukotsky and East-Siberian. The total volume of reconnoitered gas stocks equals 11.8 billion m^3 (Chernenko 2007). The company Sibneft-Chukotka has been finishing work on drilling and exploratory well in the Anadirsky petroleum basin for the purpose of identifying its oil and gas content (Chernenko 2007). According to the newspaper *Kommersant*, the quaterly report "Gazprom of oil" indicates that Sibneft-Chukotka completed geologic exploration of the Bering and Central blocks on April 1, 2007 (Chernenko 2007).

Offshore oil and gas development off Siberia has already resulted in a large oil spill in 1999, and future oil spills are very likely. Lapko and Radchenko (2000) warned against the future impacts from oil spills and dredging in Russian waters on the marine ecosystem:

> Unfortunately, oil exploration and development on the shelf cause dredging, leaking oils and oil pollution. Already by the end of September 1999 an accident on one production complex resulted in a spill of about 3.5 t of oil. No doubt other cases will occur in the future. This kind of industrial activity, as well as the commercial fisher, can seriously degrade the marine ecosystem (Lapko and Radchenko 2000: 186).

Figure 23. Offshore petroleum reserves and projects in Russian Federation waters of the Bering and Chukchi Seas. Source: Chernenko (2007): Exhibit 1.

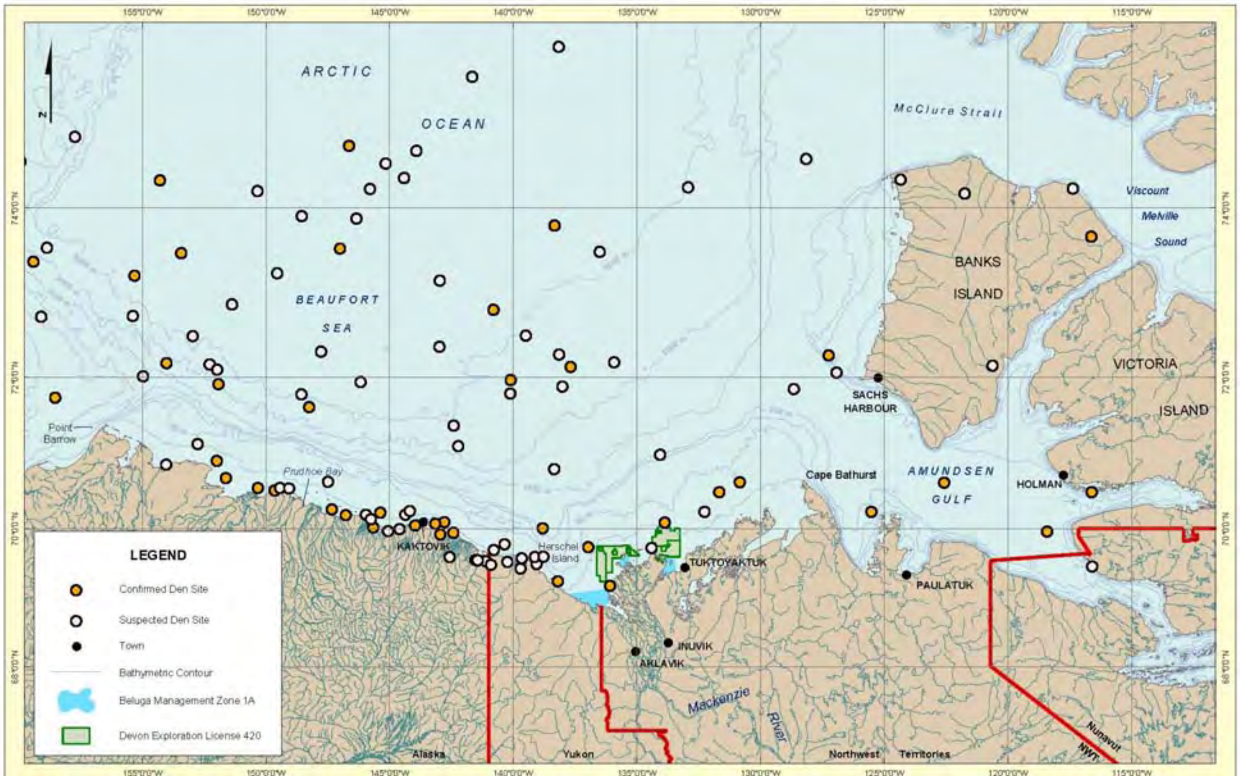


Plans for oil and gas development in the Russian Barents Sea are also moving forward. The Russian government has approved plans for a privately owned oil pipeline from Russia's oil fields to Murmansk in North-west Russia (WWF 2003). Approximately 2.5 million barrels of oil a day would be transported by tanker from Murmansk to the US through the Barents Sea (WWF 2003).

Canada

Drilling in the Canadian Beaufort Sea is occurring in core areas of ringed and bearded seal breeding and foraging habitat. Intense offshore oil and gas exploration occurred in the Canadian Beaufort Sea in the 1970s and 1980s, including 85 offshore exploration programs that resulted in significant oil and gas discoveries (Devon Canada Corporation 2004). After a lull of two decades, activity is once again increasing. The Canadian government has granted the Devon Canada Corporation Exploration License ("EL") 420 to conduct petroleum exploration in the Southern Beaufort Sea (Figure 24) (Devon Canada Corporation 2004). Devon has identified nine offshore drilling targets within the landfast ice zone (Devon Canada Corporation 2004). Under Canadian law, Devon must commence drilling at least one well in each of the four areas by the end of the license period on August 15, 2009, or lose the license in that area, with rights reverting back to the federal government (Devon Canada Corporation 2004). Devon plans to drill the first well during the winter of 2005-2006, and one well per winter season thereafter through 2009 (Devon Canada Corporation 2004).

Figure 24: Exploration License 420 Project Area.
Source: Devon Canada Corporation (2004:16-6).



The only other producing facility in the area is the Ikhil project, a single gas well that supplies natural gas to the town of Inuvik (Devon Canada Corporation 2004). The largest potential future development in the region is the Mackenzie Gas Project, a pipeline through the Mackenzie River corridor to transport natural gas to market (Devon Canada Corporation 2004). The proposed gas pipeline has spurred a great deal of exploration for natural gas in the Mackenzie Delta and parts of the Tuktoyaktuk Peninsula (MMS 2003; Devon Canada Corporation 2004).

While oil and gas exploration and development are not as active in the rest of the Canadian Arctic as it is in the Southern Beaufort Sea region, these areas are not protected from future development. As oil and gas infrastructure is introduced, development of adjacent areas becomes increasingly cost-effective and therefore increasingly likely. Future development of unprotected areas threatens the ringed and bearded seal.

Norway

Oil and gas development in ringed and bearded seal habitat in Norwegian territory is a relatively recent phenomenon, because the vast majority of previous development has occurred in the North and Norwegian Seas. In May 1997, the Norwegian government awarded production licenses for seven areas of the Barents Sea, including four as seismic testing areas (Figures 25 and 26) (Larstad and Gooderham 2004). In December 2003, the Norwegian government opened areas of the southern Barents Sea to continued year-round petroleum operations, with the exception of certain areas that will be re-assessed in an integrated management plan for the Barents Sea (Andresen and Gooderham 2004).

The first producing oil field in this area, the Snøhvit field, was approved in 2002 and was scheduled to begin producing in 2005 (Andresen and Gooderham 2004, Larstad and Gooderham 2004). A facility is also under construction at Melkøya outside of Hammerfest to process gas and natural gas liquids from Snøhvit, with plans calling for production to begin in 2006 (Andresen and Gooderham 2004). While the government has recognized the special environmental constraints of oil production in the Barents Sea region (Andresen and Gooderham 2004, Larstad and Gooderham 2004), this has not stopped exploration and development activities, and oil and gas development in the Norwegian Arctic in ringed and bearded seal habitat can be expected to continue to increase.

Figure 25: Norwegian Oil and Gas Licensing in the Barents Sea South of Svalbard.
Source: Larstad and Gooderham (2004:52).

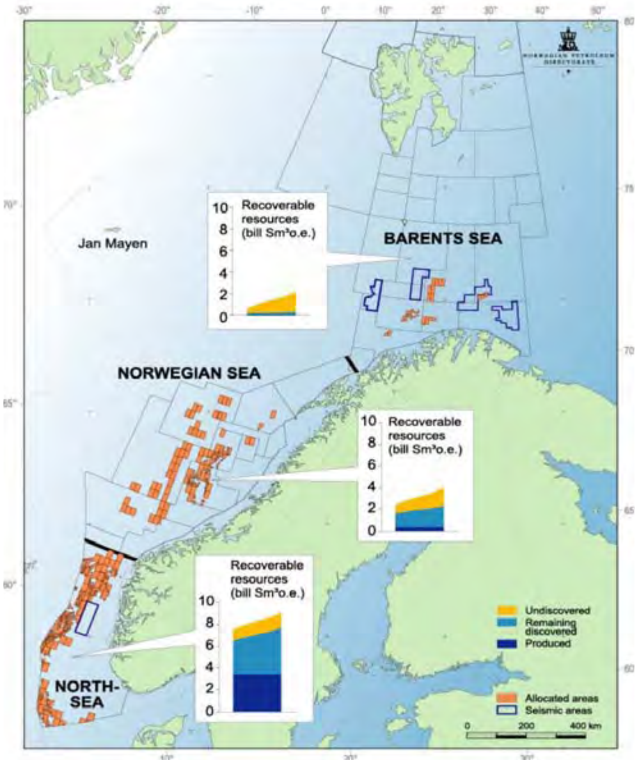


Figure 26: West Greenland Oil Exploration Licensing Areas.
Source: Adapted from GBMP (2005b:3).

Denmark (Greenland)

The Greenland and Danish governments have been actively promoting oil and gas exploration and development off the coast of Greenland, and oil and gas activities have been increasing steadily in the past several years (GBMP 2004). Following licensing rounds in 2002, the 3,985 km^2 Attamik license area about 200 km northwest of Nuuk, Greenland was licensed to the private oil company EnCana corporation and NUNAOIL A/S, a state-owned oil company (GBMP 2004). In 2003, EnCana carried out extensive exploration off the coast of West Greenland (GBMP 2004). An area of over 50,000 km^2 has been subjected to seismic testing since 1990, and seismic testing was conducted over a 9,000 km^2 area in 2003 alone (GBMP 2004).

In 2004 Greenland opened four areas off the west coast of Greenland in the Labrador Sea, Davis Strait, and Baffin Bay to oil exploration. Following this licensing round, a 2,897 km^2 area was licensed to EnCana and NUNAOIL over the Lady Franklin Basin (GBMP 2005b). Recent testing has indicated possible large petroleum deposits offshore of Western Greenland (GBMP 2005a). The Labrador Sea, Davis Strait, and Baffin Bay all pose serious challenges to oil exploration and development, including extreme climates and broken ice conditions for much of the year (GBMP 2004). For these reasons, increasing oil exploration and development off the West Coast of Greenland pose a significant threat to ringed and bearded seals in Baffin Bay and Davis Strait. Due to the Greenland and Danish governments' active promotion of hydrocarbon development, oil exploration and development off the East Coast of Greenland may increase rapidly in the future as well.

b. Impacts of Oil Pollution on Ringed, Bearded, and Spotted Seals

The threat posed to the ringed, bearded, and spotted seal by oil spills is increasing with the rapid growth in offshore oil and gas development and shipping across the range. Of added concern, oil spill clean-up in broken ice and open water conditions is largely ineffective (MMS 2007a), making ringed, bearded, and spotted seals highly susceptible to injury and mortality even if a spill is detected and clean-up is attempted. As detailed below, oil spills can produce population-level impacts on ringed, bearded, and spotted seals by decreasing survival and reproductive success, inhibiting their normal behaviors, and exerting deleterious effects on their health.

The ringed, bearded, and spotted seal live in an environment that is energetically very demanding because of the characteristic low temperatures of the Arctic. Fur is an effective thermal barrier because it traps air and repels water; however, petroleum reduces the insulative value of fur by removing natural oils that waterproof the pelage (St. Aubin 1990). Seals exposed to oil are more likely to experience severe low temperatures reducing their chances of survival, especially for newborns and juveniles that have not yet developed a thick layer of subcutaneous insulative fat (St. Aubin 1990).

The reproduction of the ringed, bearded, and spotted seal can be adversely affected by oil exposure in multiple ways. Seals depend on scent to establish a mother-pup bond, and mothers often do not recognize their oil-coated pups (St. Aubin 1990). Oiled pups may be prematurely abandoned, reducing the pup's chances of survival. During the nursing period, ringed, bearded, and spotted seals return to the water several times a day between nursing bouts, increasing the chances of repeated contact with oil (St. Aubin 1990).

Oil spills also impede seals' foraging activities. When oil is present in the sea seals are reluctant to enter into the water (St. Aubin 1990), reducing their chances of getting food. Exposure to oil may also interfere with locomotion, especially in young seals. Davis and Anderson (1976, cited in St. Aubin (1990)) observed two gray seal pups drowning because their flippers were stuck to the sides of their bodies, preventing them from swimming.

Contact with oil and inhalation of hydrocarbon fumes poses a health risk to ringed, bearded, and spotted seals. Petroleum hydrocarbons are extremely irritating to the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices of pinnipeds. After a few minutes of experimental exposure to crude oil-covered water, ringed seals began to lacrimate profusely and eventually had difficulty keeping their eyes open (Smith 1975). Within 24 hours they developed severe conjunctivitis, swollen nictitating membranes and corneal abrasions and ulcers (Smith 1975).

Inhalation of hydrocarbon vapors can be toxic for pinnipeds. In particular, free-ranging pinnipeds stressed by parasitism or other metabolic disorders may be susceptible to even brief exposure to relatively low concentrations of hydrocarbon vapors. The exposure may even be fatal if combined with other factors that could elicit a major adrenal response (St. Aubin 1990). Parasitized lungs, a relatively common finding in pinnipeds, can exacerbate the effects of even mild irritation of respiratory tissues (St. Aubin 1990).

Some of the components of petroleum are toxic if ingested (St. Aubin 1990). Ingested hydrocarbons irritate and destroy epithelial cells in the stomach and intestine, affecting motility, digestion, and absorption (St. Aubin 1990). Ingestion of petroleum hydrocarbons has been the cause of several deaths of gray and harbor seals along the coast of France (St. Aubin 1990). Apparently all pinnipeds have enzymatic systems that help them convert absorbed hydrocarbons into polar metabolites that can be excreted in urine, and extraordinary concentrations of "detoxifying" enzymes have been found in the liver and kidney of oil-exposed seals (St. Aubin 1990). These enzymatic systems help pinnipeds tolerate the toxic effects of oil. However, the activation and production of these enzymes could represent an energetic cost that could reduce pinniped reproduction or survival, and some portion of the ingested oil is stored in blubber (St. Aubin 1990). This may present a problem during times of increased metabolic stress such as molting or pregnancy/lactation, when those blubber stores are used, releasing the hydrocarbons into the system of the animal, or passing them to a pup through the mother's milk (St. Aubin 1990). Ingestion of hydrocarbons by pups is a serious threat because they have significantly less of the enzymes needed to break down the hydrocarbons and thus may have a much stronger reaction than an adult (St. Aubin 1990).

Oil spills may also decrease the availability of benthic prey for the bearded seal. Benthic invertebrates in the vicinity of an oil spill would either be killed immediately by oiling or would likely become contaminated from oil in bottom sediments. Bivalve molluscs are not effective in processing hydrocarbon compounds, which results in highly concentrated accumulations and long term retention of the contamination within individuals (Neff et al. 1987). This would likely result in further declines of prey populations since oil contamination in molluscs has been found to impair growth, fertilization, and development of embryos, kill gill tissue, and encourage cancerous growths (Neff et al. 1987). Furthermore, many bivalve mollusc prey species are long-lived and slow-growing, meaning that prey populations may take a long time to recover from oil impacts.

c. Impacts of Noise Pollution on Ringed, Bearded, and Spotted Seals

Activities associated with oil and gas drilling and exploration that produce anthropogenic noise under water and in air that could affect the ringed, bearded, and spotted seal include seismic surveying, drilling, offshore structure emplacement, offshore structure removal, and production-related activities, including helicopter and boat activity for providing supplies to the drilling rigs and platforms. Sources of underwater anthropogenic noise in the 0.1-1 kHz band come from shipping, explosives, seismic surveying sources, aircraft sonic booms, construction and industrial activities, and naval surveillance sonars, while the noise from nearby ships and seismic air-guns can extend up into the 1-10 kHz band (Ocean Studies Board 2003).

Spotted seals are easily disturbed by anthropogenic noise and activity (Frost et al. 1993, Rugh et al. 1997), making the increase in anthropogenic noise and activity under water and in air from oil and gas exploration a cause for concern. A study of spotted seal haulout patterns in Piltun Lagoon on Sakhalin Island noted that small motorboats operated by local fishers and hunters and helicopters related to offshore oil and gas development activities caused the majority of hauled-out seals to quickly flee into the water (Bradford and Weller 2005). Ringed seals also are sensitive to aircraft noise and escape into the water in response (Born et al. 1999). Thus low-flying aircraft and vessel noises cause hauled-out seals to move into the water, disrupting the animals' normal behavior and causing additional and unnecessary energy expenditures. Anthropogenic noise can also mask important communications with conspecifics, increase stress levels, and induce temporary or permanent hearing threshold shifts in pinnipeds (Kastelein et al. 2002).

3. Contaminants

Many Arctic marine mammal species, as long-lived apex predators with high lipid content, have a high potential to accumulate contaminants and carry high contaminant loads (Tynan and DeMaster 1997, Becker 2000, AMAP 2002). The Arctic contains high concentrations of many toxic pollutants that are transported by air, ocean currents, and ice from distant sources (AMAP 2002). Important sources of anthropogenic contaminants for Arctic marine ecosystems include the atmospheric transport of semi-volatile organic compounds such as lipophilic organochlorine compounds (polychlorinated biphenyls, PCBs), chlordanes, and toxaphene from industrial and agricultural areas; coastal mining; and circumpolar runoff particularly from the north-flowing rivers of Siberia that discharge large volumes of freshwater containing suspended contaminants derived from large drainage basins (Becker 2000). Of concern for the ringed, bearded, and spotted seal, increasing precipitation and ice melt as a result of global warming will increase the potential for large introductions of river-borne pollutants and contaminants trapped in sea ice into Arctic marine ecosystems (Tynan and DeMaster 1997, ACIA 2005). Studies that report levels and trends of heavy metals and organochlorine contaminants in ringed, bearded, and spotted seals in different regions of their range include the following: (Muir et al. 1999, Bang et al. 2001, Kucklick et al. 2002, Dehn et al. 2005, Riget et al. 2005, Kucklick et al. 2006, Riget et al. 2006, Riget et al. 2007).

Contaminant exposure poses a significant threat to the Baltic and Saimaa ringed seals by causing reproductive impairment, including uterine occlusions leading to infertility, that have contributed to population declines in recent decades (Sipilä et al. 1996, Kokko et al. 1997, Kokko et al. 1999). High mercury levels in Ladoga ringed seals similarly threaten to impact reproductive success of this subspecies (Kunnasranta et al. 2001).

4. Commercial Fisheries

Commercial fisheries pose a threat to the ringed, bearded, and spotted by causing direct mortality through incidental take as fisheries bycatch and have the potential to impact these species by depleting essential prey resources. As sea-ice extent decreases, there will be new opportunities for commercial fisheries in previously inaccessible regions (AMAP 2003) which could increase mortality and physiological stress.

Bycatch

Ringed Seal

In the US, bycatch of ringed seals in the Bering Sea/Aleutian Islands groundfish trawl, longline, and pot fisheries was monitored by NMFS observers during 1990-2004, and appears to be at low levels (Angliss and Lodge 2002, Perez 2006). However, bycatch mortality from fisheries poses a significant threat to three other ringed seal subspecies: Baltic ringed seal (Ministry of Agriculture and Forestry 2007), Ladoga ringed seal (Sipilä et al. 1996) and Saimaa ringed seal (Kokko et al. 1999).

Bearded Seal

In the US, bycatch of bearded seals in the Bering Sea/Aleutian Islands groundfish trawl, longline, and pot fisheries was monitored by NMFS observers during 1990-2004, and appears to be at low levels (Angliss and Lodge 2002, Perez 2006).

Spotted Seal

In the US, bycatch of the spotted seal is not being monitored in all commercial fisheries that are known to take spotted seals, making estimated mortality of spotted seals in these fisheries unreliable. Specifically, bycatch of spotted seals is not being monitored in the Alaska-based set and drift gillnet fisheries targeting salmon in the Bristol Bay and Aleutian Islands regions that overlap the range of the spotted seal (Angliss and Outlaw 2008). Bycatch of pinnipeds is typically highest in gill-net and drift-net fisheries (Read et al. 2006). During 1990-1993, logbooks maintained by vessel operators in the Bristol Bay salmon set and drift gillnet fisheries reported spotted seal mortalities (Angliss and Lodge 2002). Furthermore, serious injury and mortality of harbor seals as fisheries bycatch has occurred within the past five years, and some of the reported harbor seal take may involve spotted seals (Angliss and Outlaw 2008). As documented below, spotted seals are caught in Japanese coastal salmon gillnet fisheries, making mortality of spotted seals in U.S. gillnet fisheries likely. Bycatch levels in the Bering Sea/Aleutian Islands groundfish trawl, longline, and pot fisheries were monitored by NMFS observers during 1990-2004, and appear to be low. From 1990-1995, three spotted seal mortalities were reported in the Bering Sea groundfish trawl fishery, resulting in a mean mortality rate of 1 (CV = 1.0) seal per year (Angliss and Lodge 2002). Between 2000 and 2004, four spotted seals were reported caught in the Bering Sea/Aleutian Islands flatfish trawl, resulting in a mean mortality rate of 0.88 seals per year (Perez 2006).

Bycatch mortality also poses a threat to spotted seals in other portions of their range. In the Sea of Okhotsk, a large number of spotted seals are killed as bycatch in salmon trap nets and a smaller number in gillnets off Hokkaido in the fall (the salmon fishery is the largest net fishery in Hokkaido) and for “damage control” during the sea-ice season (Mizuno et al. 2001, Mizuno

2002). There are no legal obligations to report taking of seals nor science-based regulations on the taking of seals in Japan (Mizuno et al. 2001). In Peter the Great Gulf, bycatch of spotted seals in the saffron cod trap net fishery is also significant. Bycatch in stationary trap nets set under landfast ice was monitored in the winter of 1996-1997, and 100-150 seals were killed, mostly large adults, which represented a 10-15% mortality rate for the population (Trukhin and Mizuno 2002). At Bak-ryoung Island, an important haulout site for spotted seals off western South Korea in the Yellow Sea, residents reported in the early 2000s that spotted seals come into conflict with commercial fisheries and have been persecuted (Won and Yoo 2004).

Competition for prey resources

Commercial fisheries may impact ringed, bearded, and spotted seals by competing with them for prey resources. Both the Bering and Okhotsk Seas are heavily fished, and many species targeted by commercial fisheries (pollock, Pacific cod, herring, capelin) are important prey species for the ringed and spotted seal. NMFS determined that prey depletion by commercial fisheries in the Bering Sea poses a threat to the western population of Steller's sea lion (NMFS 2007), and commercial fisheries could similarly impact ringed and spotted seals, especially as they face growing stress from sea-ice loss. In the Okhotsk Sea, over-fishing is thought to have contributed to the long-term decline in walleye pollock, which began in the early 1990s and is ongoing (Lapko and Radchenko 2000, PICES 2005). Recent declines in biomass of all major demersal fish species (cod, flatfishes) have also occurred (PICES 2005).

Specifically, commercial fisheries may affect ringed, bearded, and spotted seals through overall ecosystem-wide reductions in prey biomass, local and temporal depletions of prey, and reduced quality (size, age and caloric value) of individual prey by selective removal of larger, older individuals (NMFS 2007). For example, many US fisheries in the North Pacific are managed using a maximum sustainable yield (MSY) single-species strategy. The MSY strategy will eventually reduce the average spawning stock size to 40% and total biomass to approximately 50% of the theoretical pre-harvest levels. On a finer scale, fisheries can also reduce the local abundances of prey when individual vessels concentrate in discrete areas. The potential for fisheries to reduce local abundances of fish was shown for Pacific cod fishery, where local, short-term harvest rates were much greater than the annual target harvest rates on the stocks as a whole (NMFS 2007). Additionally, fisheries generally target larger, older individuals. As a result, a fished population will be composed of smaller, younger individuals, and have a smaller average size and age than an unfished population of the same species (NMFS 2007).

These fishery-related changes may have two consequences for ringed, bearded, and spotted seals. First, the distribution of fish within the water column and geographically, which often correlates with age (NMFS 2007), will be altered in a way that potentially affects availability to foraging seals. Second, a reduction in the average size of individual fish will reduce the per capita energy content and may necessitate increased foraging effort by seals to obtain the equivalent amount of energy in a larger number of small fish (NMFS 2007).

Critical Habitat

The ESA mandates that, when NMFS lists a species as endangered or threatened, the agency generally must also concurrently designate critical habitat for that species. Section 4(a)(3)(A)(i) of the ESA states that, "to the maximum extent prudent and determinable," NMFS:

> shall, concurrently with making a determination . . . that a species is an endangered species or threatened species, designate any habitat of such species which is then considered to be critical habitat . . . .

16 U.S.C. § 1533(a)(3)(A)(i); *see also id.* at § 1533(b)(6)(C). The ESA defines the term "critical habitat" to mean:

> i. the specific areas within the geographical area occupied by the species, at the time it is listed . . . , on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and
>
> ii. specific areas outside the geographical area occupied by the species at the time it is listed . . . , upon a determination by the Secretary that such areas are essential for the conservation of the species.

Id. at § 1532(5)(A).

The Center for Biological Diversity expects that NMFS will comply with this unambiguous mandate and designate critical habitat concurrently with the listing of the ringed, bearded, and spotted seal. We believe that all current and historic areas utilized by these species for reproduction and foraging meet the criteria for designation as critical habitat and must therefore be designated as such.

Conclusion

For all the reasons discussed above, the Center for Biological Diversity requests that NMFS list the ringed, bearded, and spotted seal as threatened or endangered species because each of these species is currently in danger of extinction in all or a significant portion of its range or likely to become so in the foreseeable future. Delaying protection of these species until populations have declined further will only undermine any future conservation efforts. If, however, federal regulatory forces can be mustered to protect these ice-dependent seals from multiple ongoing threats, then they will have a renewed chance at survival. Listing the ringed, bearded, and spotted seal now will allow the necessary conservation mechanisms to be implemented to the fullest extent possible.

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[6] All references will be provided in pdf format on an accompanying compact disk. We are happy to provide NMFS with copies of any references upon request.

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