

BEFORE THE SECRETARY OF THE INTERIOR

**PETITION TO LIST THE EMPEROR PENGUIN
(*APTENODYTES FORSTERI*)
AS THREATENED OR ENDANGERED
UNDER THE ENDANGERED SPECIES ACT**



Photo: Michael Van Woert, NOAA

**CENTER FOR BIOLOGICAL DIVERSITY
NOVEMBER 28, 2011**

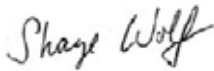
Notice of Petition

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Date: this 28th day of November, 2011

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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 hereby petitions the Secretary of the Interior, through the United States Fish and Wildlife Service (“FWS”), to list the emperor penguin (*Aptenodytes forsteri*) as threatened or endangered under the federal Endangered Species Act (“ESA”), 16 U.S.C. § 1531-1544.

The Center for Biological Diversity (“Center”) is a non-profit, public interest environmental organization dedicated to the protection of imperiled species and their habitats through science, policy, and environmental law. The Center has over 40,000 members throughout the United States. The Center and its members are concerned with the conservation of endangered species, including the emperor penguin, and the effective implementation of the ESA.

FWS has jurisdiction over this Petition. This Petition sets in motion a specific process, placing definite response requirements on FWS. Specifically, FWS 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). FWS must make this initial finding “[t]o the maximum extent practicable, within 90 days after receiving the petition.” *Id.* Petitioners need not demonstrate that

listing *is* warranted, rather, Petitioners must only present information demonstrating that such listing *may* be warranted. While Petitioners believe that the best available science demonstrates that listing the emperor penguin as threatened or endangered *is* in fact warranted, there can be no reasonable dispute that the available information indicates that listing the species as either threatened or endangered *may* be warranted. As such, FWS 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).

As the emperor penguin occurs in areas outside of the United States, Petitioner believes this petition should be processed by FWS's Division of Scientific Authority pursuant to the agency's current policy for listing foreign species. *See* 69 Fed. Reg. 29354 (May 21, 2004)(Annual Notice of Findings on Resubmitted Petitions for Foreign Species; Annual Description of Progress on Listing Actions).

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Executive Summary

The emperor penguin (*Aptenodytes forsteri*) is in jeopardy of becoming extinct in the wild within this century. Global warming represents the gravest threat to the species' long-term survival. The emperor penguin depends on sea ice for most of the year for breeding and foraging, and is threatened by warming-caused loss and instability of sea ice as well as the melting and collapse of ice sheets and ice shelves. Surface and ocean warming, ice loss, and changes in sea ice have already occurred in several parts of Antarctica and the Southern Ocean, and have been particularly dramatic in the Antarctic Peninsula. In addition, the availability Antarctic krill, an important part of emperor penguins' prey, is threatened by changing sea ice, ocean acidification, and an expanding commercial fishery. Several emperor penguin colonies have suffered significant long-term declines in population and reproductive success. Studied populations have declined by upwards of 70% in the face of changing climate conditions. Indeed, warming-induced loss of sea ice has already caused the loss of at least one emperor penguin colony.

The survival of emperor penguins depends on sea ice, and the loss of sea ice caused by global warming poses an overarching threat to the species. This warming is directly attributable to human activities, including greenhouse gas pollution. Loss and instability of sea ice hinders the survival and breeding success of emperor penguins, which forage at the edge of pack ice. With the exception of two colonies, emperor penguins breed exclusively on land-fast ice and rely on this ice for about eight months a year, to raise their chicks.

Climate change has already degraded the emperor penguins' habitat in Antarctica and the Southern Ocean. The Antarctic Peninsula and West Antarctica have experienced the most dramatic warming, and continent-wide temperature increases have occurred. The Southern Ocean has also warmed considerably during the second half of the twentieth century. Climate change has altered sea ice dynamics, reduced mean annual sea ice, and caused ice shelf retreat and disappearance in the Antarctic Peninsula. The sea ice season has also significantly shortened and sea ice extent has declined in certain parts of Antarctica. Climate warming is leading to increased melting, calving and collapse of Antarctic ice shelves, particularly along the Antarctic Peninsula. Additionally, the emperor penguins' range has shifted poleward and contracted in response to altered environmental conditions caused by climate change.

Global warming is accelerating and will enhance changing sea ice conditions in Antarctica in the future. Studies project an increase in Antarctic surface temperature of an average of $2.54 \pm 1.2^{\circ}\text{C}$ within this century, with increases of $3.93 \pm 2.0^{\circ}\text{C}$ during winter. Southern Ocean warming is also expected to continue and cause ice sheet disintegration. Climate change modeling predicts a shorter sea ice season and thinning of ice sheets throughout several regions of Antarctica. These global warming impacts will cause serious negative changes to emperor penguin habitat. As a result of these changes, approximately 40% of the breeding population is in jeopardy of decline or disappearance. In addition, the species' range is expected to contract significantly as penguins struggle to find new nesting areas under changing conditions. The emperor penguin will continue to

suffer reduced population viability under climate change, and evolution or migration is unlikely for this long-lived species.

Carbon dioxide pollution and an expanding commercial fishery in the Southern Ocean also threaten an important component of the emperor penguin's diet, Antarctic krill (*Euphausia superba*). Antarctic krill are sensitive to changes in sea ice, climate, water chemistry, and ocean currents. Large-scale climate change is altering these factors, particularly along the Western Antarctic Peninsula, which has important krill spawning and nursery habitat. Dependant on sea ice for shelter and food (krill eat algae living on sea ice), changes in sea ice dynamics can reduce krill populations and thus availability for predators such as emperor penguins. Containing more than half of Southern Ocean krill stocks, the southwest Atlantic sector has suffered a decline in krill density of as great as 80% since the 1970s, at least in part caused by changes in ocean biological productivity brought on by climate change. Ocean acidification caused by rising atmospheric CO₂ concentrations also threatens krill because it is known to impair calcification in animals that build shells. Ongoing declines in krill biomass abundance are projected for some areas under warmer ocean temperatures and changing sea ice, with associated stresses on emperor penguin populations. Exacerbating these impacts, increased fishing pressure offshore is projected to decrease penguins' intake of food, leading to reduced penguin survival and reproduction. The commercial fishery for Antarctic krill has expanded dramatically and will likely continue to do so.

Global warming has placed the emperor penguin in danger of extinction throughout all or a significant portion of its range in the foreseeable future. This Petition summarizes the natural history of the emperor penguin, its population status and distribution, and the threats to the species and its habitat. The Petition then clearly demonstrates that, in the context of the ESA's five statutory listing factors, the Fish and Wildlife Service should promptly list the emperor penguin as threatened or endangered.

Natural History and Biology of the Emperor Penguin

I. Species Description

The emperor penguin is the largest extant species of penguin, measuring 100-130 cm in length with flippers 30-40 cm long and weighing 20-41 kg (Marchant and Higgins 1990; Shirihai 2002). Adults have black heads grading to a bluish-gray dorsal side, which is delineated from a glossy white ventral side by a black band that extends upwards to the lower neck (Figure 1) (Shirihai 2002). A diagnostic large, oval-shaped pale yellow neck patch, variably tinged orange, is almost entirely enclosed by black above and below (Shirihai 2002). The iris is dark brown and the bill is black with a pinkish or lilac stripe on the lower mandible (Shirihai 2002). Immature birds are paler and browner above and on the head, the neck patch is ill-defined and whitish, and the bill stripe is a dull pinkish-orange (Shirihai 2002). Immatures molt into adult plumage when about 18 months old (Shirihai 2002). The chick is silvery-gray to whitish, with a distinctive white face bordered by a black crown and neck sides (Shirihai 2002).

Figure 1: Emperor penguin and chicks. Photo by National Oceanic and Atmospheric Administration/Department of Commerce.



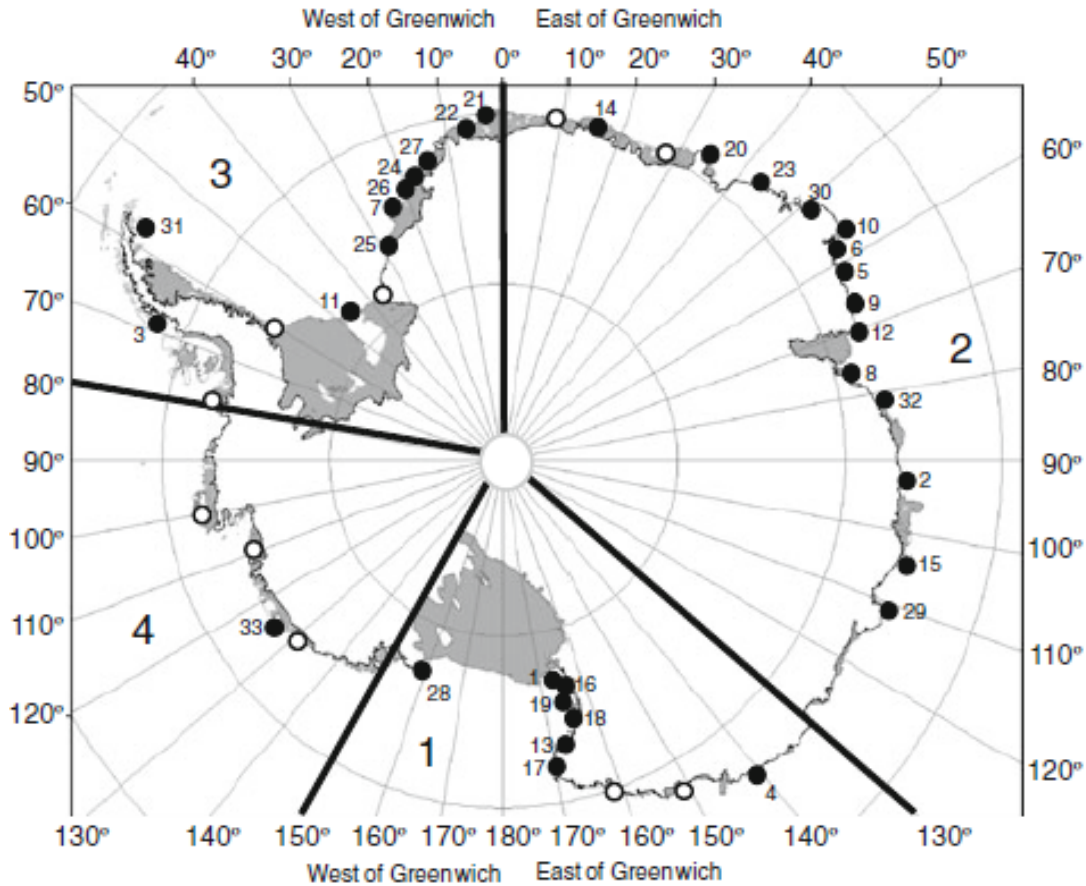
II. Taxonomy

The emperor penguin is monotypic with no recognized subspecies (Shirihai 2002). It diverged from its nearest living relative, the king penguin, during the Middle Miocene Climate Transition between 12 and 14 million years ago (Baker et al. 2006).

III. Distribution and Habitat

Emperor penguins are the most ice-adapted of any penguin species and almost exclusively breed on pack ice. They are distributed in marine, circumpolar areas in and near pack ice of coastal Antarctica (Figure 2) (Marchant and Higgins 1990).

Figure 2: Emperor penguin colony locations. Numbers indicate order of chronological discovery (see Wienecke 2011: Table 1). Closed circles are locations of known colonies; open circles indicate possible new locations (after Fretwell and Trathan 2009). Source: Wienecke 2011.



A. Breeding Range

Emperor penguins have historically been reported to breed at a total of at least 45 widely-spaced colonies rimming the Antarctic continent (Woehler 1993; Melick and Bremmers 1995; Coria and Montalti 2000; Todd et al. 2004; Lea and Soper 2005). Estimates of the number of colonies in existence have been revised over time as sites have been revisited, more data gathered, and colonies lost or formed. Currently, 33 locations have been confirmed to be breeding grounds, although the existence of more colonies is suspected (Wienecke 2010). Of these confirmed colonies, one is in Adélie Land, seven in the Ross Sea area, 14 in East Antarctica, 10 in the Weddell Sea and Antarctic Peninsula, and two in West Antarctica.

Emperor penguins' known breeding distribution extends from the Antarctic Peninsula at Snow Hill Island (64°31'S, 57°27'W) eastwards along the coasts of Dronning Maud Land, Enderby Land, Mac.Robertson Land and Wilkes Land to Cape Crozier on Ross Island (77°31'S, 169°23'E) (Lea and Soper 2005). In the Ross Sea area,

colonies were reported spaced out approximately 50 to 100 km apart (Kooyman 1993). By detecting fecal stains displayed on satellite images, Fretwell and Trathan (2009) found ten new sites likely to be emperor penguin breeding colonies, although further investigation is needed into their size and permanence (Figure 2). The authors suggest that emperor penguins are more widely distributed than previously thought, as these new colonies make the overall colony distribution more even around the Antarctic coast.

Emperor penguins breed almost exclusively on stable pack ice near coastal areas and up to 18 km offshore. Only two small breeding colonies are known to occur on land. Breeding colonies usually occur in sheltered areas, where ice cliffs and icebergs protect the site from the harshest of winds (Williams, 1995). According to Kooyman (1993), the most important physical characteristics of breeding habitats in the Ross Sea appear to be stable fast ice, nearby (<6 km) open water or polynyas, fresh snow, and shelter from wind. For many colonies, at the time the male emperor is relieved by his mate around hatching time, the distance between the colony and the open sea may be 100 km or more (Shirihai 2002).

B. Foraging Range

Emperor penguins forage exclusively in the cold waters of the Antarctic, with only rare individuals having been found further north than 65° S (Williams 1995). While breeding, adults make foraging trips 50 km to 300 km away from breeding sites, probably to the continental shelf and shelf-break (Ainley et al. 1984; Kooyman 2002).

Emperors are considered dispersive but little information exists on non-breeding movements (Marchant and Higgins 1990). Breeding grounds are deserted for only three months each year, so emperor penguins probably do not travel far from the Antarctic (Marchant and Higgins 1990). In the Ross Sea, emperors concentrate during the non-breeding season at the continental shelf slope and Antarctic Convergence. Most adults stay within 300 km of breeding sites, while immature birds made up one-third of the emperors recorded beyond 300 km (Ainley et al. 1984). According to Kooyman et al. (2004), emperor penguins travel more than 2000 km on the return journey to their colonies of the western Ross Sea. Following fledging, emperor penguins may disperse as much as 3000 km from the colony (Kooyman 2002).

IV. Life History

A. Diet and Feeding Behavior

Emperor penguins forage only at sea and mainly take krill (*Euphausia superba* and *E. crystallorophias*), fish (primarily *Pleuragramma antarcticum*), and small cephalopods (Shirihai 2002; Zimmer et al. 2007; Cherel and Kooyman 1998). The proportions of prey types vary depending on locality and time of year (Kirkwood and Robertson 1997; Zimmer et al. 2007). At the Drescher Island colony, which is near the continental shelf slope, krill is the predominant prey (Kooyman 2002). In contrast, for the Ross Sea colonies where the nearest foraging areas are over the shelf, emperors eat fish

almost exclusively (Kooyman 2002). At the Auster colony, emperors switched from a diet of only 5% squid to one of over 60% squid between spring and summer in a single season (Kooyman 2002). At Pointe Géologie in Adélie Land, emperor penguins ate mainly fish and squid during late winter (Zimmer et al. 2007; Cherel 1998).

Emperor penguins search for prey in the open water of the Southern Ocean or in ice-free polynyas and tidal cracks in pack ice (Shirihai 2002; Williams 1995). They have been recorded diving to depths of 400 to 500 meters and traveling 150 to 1000 km in a single foraging trip (Williams 1995; Shirihai 2002). Emperors take krill and fish from the undersurface of the sea ice and benthic prey from deeper waters (Kooyman 2002).

The distance between the colony and open sea may be over 100 km when males transfer chick rearing to returning females (Shirihai 2002). Ancel et al. (1992) satellite monitored the foraging routes taken by emperor penguins and compared them with satellite images of sea ice. Emperor penguins walking over fast ice traveled up to 296 km to feed in polynyas, whereas those swimming in light pack-ice traveled as far as 895 km from the breeding colony (Ancel et al. 1992).

At Pointe Géologie in the winter, foraging trip lengths have been recorded at ~70 days for females and ~25 days for males, with mean swimming distances of ~930 km for females and ~520 km for males (Zimmer et al. 2008). Maximum distances to the colony ranged from 62-134 km during these trips. Mean dive depths were ~70 meters for males and ~55 meters for females, with maximum depths of 438.4 meters for males and 338.8 meters for females (Zimmer et al. 2008). In the spring, foraging trips of chick-rearing parents lasted 2-19 days with swimming distances of 21-163 km (Zimmer et al. 2008). Mean maximum dive depth of spring-foraging birds was ~100 meters, higher than those of winter foraging birds. In the summer, having left the colony after breeding, penguins were recorded to forage widely in deep water in the open ocean, with trips lasting 31-54 days and covering distances of 1,762–3,686 km (Zimmer et al. 2008).

Robertson and Newgrain (1996) examined the food and energy requirements of adult emperor penguins raising chicks at Auster (about 11,000 pairs) and Taylor Glacier (about 2,900 pairs) colonies during the winter, spring and summer of 1988. Adults assimilated 84–92% of their daily food intake themselves and retained the remainder for the chick. The food ration of chicks for the three seasons (42 kg) constituted only about 9.5% of adult maintenance requirements during the same period. Adults consumed an estimated 482 kg of food (including the ration for the chick), which amounted to about 10,700 tons and 2,800 tons of fish and squid consumed by the breeding populations at Auster and Taylor Glacier, respectively (Robertson and Newgrain 1996).

B. Breeding Behavior

The annual breeding cycle of the emperor penguin is among the most improbable of any vertebrate. The emperor penguin is the only species to breed during the Antarctic winter. The unique breeding cycle begins in early winter (April/May) when male and female emperors congregate on fast ice in a traditional colony area. Adults arrive at

breeding sites weighing up to 40 kg. Courtship involves trumpeting calls and displaying of the yellow neck patches (Shirihai 2002). Emperor penguin pairs are monogamous in a given season, but have low pair fidelity with a comparatively high percentage of pairs not renewing their bond the following season (Shirihai 2002). Females lay a single large greenish-white egg in May/June, which is transferred to and incubated on the feet of the male for 62-67 days (Shirihai 2002). Females return to sea to forage during this time. Males fast during incubation and can lose up to 45% of their body weight during this period. Incubating males form large groups that huddle together as a conglomerate mass during the coldest weather which can reach negative 30°C and below (Shirihai 2002). Huddling males move collectively by taking small steps every 30-60 seconds, which results in a coordinated, large-scale reorganization of the huddle so that individuals do not spend too long on the outside (Zitterbart et al. 2011).

Females return to the colony near the time of hatching, providing the first food to the newly hatched chick. At this point the male, which has fasted for four months since arriving on the breeding grounds, transfers responsibility for the chick to the female and walks the 6-100+ km to open water to forage. Over the next five months the male and female alternate tending the chick and foraging, with trips away shortening from 3 weeks long in August to as short as 3 days in December when the chick is near ready to fledge (Kooyman 2002).

Shortly after hatching, chicks molt into a suit of down, and fledge at about 150 days. Chicks are abandoned prior to acquiring their full complement of adult feathers. When the fast ice has broken up, chicks enter the water, weighing 9.9-14.8 kg. They will then spend about four years entirely at sea before returning to the colony and breeding the subsequent year (Shirihai 2002).

Given Antarctica's extreme temperatures and winds, in some years chick survival is low, with chicks lost to starvation, predation, cold, and entrapment in tidecracks (Lavery 1986). Strong winds may also cause the ice to break up early, causing the loss of the entire cohort of chicks from the colony that year (Kooyman 1993). At other times the winds may take their toll by forcing adults to desert eggs or chicks when the thermoregulatory needs of the adult take priority over survival of the chicks (Kooyman 1993). In the emperor penguin colony at Pointe Géologie, successful breeding seasons have coincided with lower-than-average fast ice extents, pointing to the influence of fast ice extent and distance to its edge on breeding success in this colony (Massom et al. 2009).

Abundance and Population Trends of the Emperor Penguin

The best available long-term data on abundance and population trends show worrying declines for many emperor penguin colonies. Not all colonies have been consistently censused because of difficulties in monitoring; for example, accurate censuses must be made when penguins are at their breeding colonies, but breeding occurs

in winter and colonies are generally at very remote locations. However, multiple colonies for which data do exist have declined or even disappeared.

The accuracy of global population numbers of emperor penguins is unreliable because of incomplete data (Wienecke 2011). In the 1980s, the total emperor penguin population was estimated to be around 270,000 to 350,000 breeding adults (Marchant and Higgins 1990; del Hoyo et al. 1992). More recently, Micol and Jouventin (2001) estimated the global population to be around 220,000 individuals. The low extinction risk assigned to emperor penguins by the International Union for Conservation of Nature in 2009 has been brought into question by the best available science (IUCN 2011). Wienecke (2011) reviewed available information on emperor penguin populations, and questioned the IUCN's assumption that the global population is stable, as available data are inadequate for a global population trend assessment. Wienecke (2011) asserted that published global emperor penguin population estimates have largely quoted the same questionable and highly uncertain figures. This has created the general assumption that enough information exists to conclude that the global population is stable, when in fact verifiable and accurate counts are only available for only a minority of colonies. Thus, in order to assess the status and trends of emperor penguin populations, one must rely on the best available data for individual colonies. This long-term data demonstrates that many colonies have experienced significant declines, as is detailed below.

I. Terre Adélie

The best studied emperor penguin colony is located near the French research station Dumont d'Urville Station (66.78 S, 140.08 E) at Pointe Géologie, Terre Adélie. The population has been monitored continuously since 1952, the longest data set for an Antarctic seabird (Woehler et al. 2001; Barbraud and Weimerskirch 2001; Micol and Jouventin 2001). Ainley (2005) found that the population has undergone a 70% decline since the 1960s. After serious declines occurring in the late 1970s and early 1980s, the population has remained at low numbers and has not recovered (Barbraud and Weimerskirch 2001; Jenouvrier et al. 2009). The number of breeding pairs has decreased from over 6,000 to around 2,700 during 1952-1999, a decline of 55%. A prolonged decrease in adult survival related to a period of warming and of reduced sea-ice extent was the likely driver of this decline (Barbraud and Weimerskirch 2001). In addition, reproductive success has also declined: 72% success for 1962-1971, 57% success for 1974-1989, and 38% success for 1990-1998 (Micol and Jouventin 2001).

II. Ross Sea

This region contains seven confirmed emperor penguin colonies, all of which have been surveyed long-term (Wienecke 2011). Five colonies are located along the coast of Victoria, one at Cape Crozier, and one at Cape Colbeck. There may be two additional colonies between Victoria Land and Terre Adélie, but they are still unconfirmed (Fretwell and Trathan 2009).

At Cape Roget in Victoria Land, the breeding population declined from an estimated 11,700-17,000 pairs in the early 1960s to only 3,777 pairs in 1983 and 3,851 pairs in 1990 (Marchant and Higgins 1990; Kooyman and Mullins 1990). Barber-Meyer et al. (2008) found live chick counts in this colony to increase from 1983-1996, although this trend was dependent upon the low 1983 count. Removal of the 1983 year resulted in a fluctuating but relatively stable trend from 1990-1996, with live chick counts ranging from ~6,300 to ~7,200, an overall decrease since the early 1960s. Based on satellite imagery, Barber-Meyer et al. (2007) estimated that the Cape Roget colony consisted of >5000 adult birds during 2005 and 6006.

The nearby colony at Cape Crozier, Ross Island, has declined overall since the 1960s. The colony declined from the 1960s to the 1980s (Kooyman et al. 2007); these declines have been linked to several years of early sea-ice breakouts in the 1970s (Harper et al., 1984). Colonies began to increase in the 1990s until 2001 (Kooyman et al. 2007). In 2001, the arrival of two giant icebergs caused the colony to fail, as one iceberg collided with the Ross Ice Shelf and destroyed the colony's nesting habitat. The icebergs were from a large piece of the Ross Ice Shelf that calved in 2000 (Kooyman et al. 2007). Following the colony's failure in 2001, in subsequent years production levels were 0-40% of chick levels in 2000 (Kooyman et al. 2007). Barber-Meyer et al. (2008) found neither increasing nor decreasing long-term chick abundance trends at Cape Crozier from 1983-2005, although chick counts were highly variable through time, with counts of zero live chicks in 2001 and 2005 (Kooyman et al. 2007). Chick counts in the early 2000s were in the low hundreds, as compared to well over 1000 in the early 1960s (Kooyman et al. 2007). In October 2005, 437 adults were observed at the colony, with no sign of breeding (Kooyman et al. 2007; Barber-Meyer et al. 2008).

The two giant icebergs also impacted the colony at Beaufort Island by separating the colony from the Ross Sea Polynya, which had been a route for penguins to travel to feeding and wintering areas (Kooyman et al. 2007). Although Barber-Meyer et al. (2008) found neither increasing nor decreasing trends from 1983-2005 at this colony, live chick counts during 2003-5 were substantially lower than the previous three years, with chick production declining to 6% of 2000 levels by 2004 (Kooyman et al. 2007). In 2005 and 2006, 1,222 and 1,312 adults were counted (Barber-Meyer et al. 2007), a continuation of low population numbers as compared to the early 2000s.

Barber-Meyer et al. (2008) found highly variable trends in chick abundance at Franklin Island, Cape Washington, and Coulman Island from 1983-2005, although they did not detect significant long-term changes in abundance. Chick abundance at Franklin Island in 2005 declined 62% from the previous year. Cape Washington live chick counts declined by 41% from 2001-2002, reaching a record low, and then increased over the next three years. At Coulman Island, after record high counts in 1992, the following year chick counts also declined to a record low (46% decline), and then increased again in 2005. Despite this above variability, Barber-Meyer et al. (2008) found colonies in the western Ross Sea to be stable overall from 1983-2005. The Ross sea is subject to different weather patterns than other sites in the Antarctic (Parkinson 2004; Zwally et al.

2002), and thus Ross Sea emperor penguins may exhibit population trends that are dissimilar to other colonies (Barber-Meyer et al. 2008).

In a review of historical population information on emperor penguins, Wienecke (2011) listed several studies that have estimated emperor penguin population sizes in the Ross Sea. Because of the studies' different count units, methodologies, and seasons, long-term trends are difficult to discern, but population counts range from ~55,000 to ~340,000 birds spanning years from 1976 to 2005. Wienecke (2011) assessed the population trend in Ross Sea colonies to be stable overall.

In sum, although the population trend for the Ross Sea region appears to be stable overall, available data display substantial variation and fluctuations in counts for individual colonies. In addition, calving from the Ross Ice Shelf in 2000 had significant negative impacts on two colonies, which will likely have limited abilities to grow in the future (Kooyman et al. 2007).

III. East Antarctica

Fourteen confirmed colonies exist in East Antarctica. Long-term, systematically gathered data are available for Taylor Glacier, one of the few colonies known to exist on land rather than sea ice (Wienecke 2011). Annual counts have been made since 1988 and have averaged ~3000 individuals (Robertson and Wienecke, unpubl. data, as cited in Wienecke 2011).

At Fold Island in Kemp Land, the population of emperor penguins has declined by more than half (Marchant and Higgins 1990). In 1957, there were an estimated 2000 birds, by 1977 the population was reduced to 900, and by 1985 only 700 individuals remained. The last known visit to the colony was in 2001 (Wienecke 2009), but published population data is not available.

The colonies on the Riiser-Larsen Peninsula and Umebosi Rock have shown strong fluctuations (Kato et al. 2004). Breeding colonies of emperor penguins on the Riiser-Larsen Peninsula and Umebosi Rock are located on the fast sea-ice at the foot of a cliff of the ice shelf. Population size fluctuated between 4,000 and 9,000 pairs on the Riiser-Larsen Peninsula and between 200 and 600 pairs at Umebosi Rock during 1984-2000. Populations of both colonies during the mid-1990s were twice to three times greater than those during the 1980s, but rapidly decreased to half of the 1990s populations in 2000.

At the Auster colony, 10,963 pairs produced 6350 fledglings in 1988 (Robertson 1992). The population appears to have been stable from 1988 until 1999 (Woehler and Croxall 1997; Woehler et al. 2001). Subsequent data is unavailable.

At Hasswell Island, the management plan for the Antarctic Specialty Protected Area provides data on the emperor penguin colony since 1956 (Secretary of the Antarctic

Treaty 2006). The size of the breeding population has declined by about 50% from 1950 to 2000, with a drop in population from 14,000-20,000 to 7,000-9,000 birds.

Long-term data on the population of the colony at Amanda Bay since 1956 indicates a population of several thousand penguins, though most data are from snap estimates or rough counts (Wienecke and Pedersen 2009). Thus, although there has been a long history of visits to the colony, reliable long-term trends cannot be determined.

Systematically gathered, long-term data on other colonies in East Antarctica is lacking (Wienecke 2009, 2011). In sum, although scarce data exists for most colonies in East Antarctica, several colonies for which data are available have undergone declines.

IV. Weddell Sea and the Antarctic Peninsula

Ten breeding locations are known in the Weddell Sea, and another three are suspected to exist (Wienecke 2011). A small colony of emperor penguins on Dion Island in the Western Antarctic Peninsula has recently been recorded as lost after a decline over several decades (Trathan et al. 2011). When discovered in 1948 (Stonehouse 1952), the colony comprised approximately 150 breeding pairs, but after 1970 the colony began a continuous decline (Trathan et al. 2011). The colony saw a decline from 250 pairs in 1960 to 10 pairs in 2001 (Ainley et al. 2006), and in 2009 no sign of the colony appeared on high-resolution aerial photography (Trathan et al. 2011). Population estimates for the rest of the region are mostly rough estimates only, and long-term data are generally lacking (Wienecke 2011). Thus other than the likely disappearance of the colony at Dion Island, trends for colonies in the Weddell Sea and Antarctic Peninsula are unknown.

V. West Antarctica

Very little is known about emperor penguin colonies in West Antarctica, the least visited region of the continent (Wienecke 2011). One colony has been sighted from a tourist vessel in 2004, and satellite imagery suggests the existence of another three breeding sites (Wienecke 2011; Fretwell and Trathan 2009).

In summary, while many emperor penguin colonies remain uncensused and a range-wide population trend is not available, what data that are available show that the species is undergoing substantial declines in at least a significant portion of its range. Moreover, as discussed below, given the ongoing and projected impacts from global warming, such declines are likely to become more widespread and pronounced, putting the species as a whole at risk.

The Emperor Penguin Warrants Listing Under the ESA

I. Criteria for Listing Species as Endangered or Threatened

Under the ESA, 16 U.S.C. § 1533(a)(1), FWS 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.¹ In making such a determination, FWS 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,” the FWS 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.

The minimum time period that meets these criteria is 100 years. There is ample precedent for use of a timeframe of 100 years or longer as the “foreseeable future,” and no support for using a timeframe of less than 100 years. Because global warming is one of the foremost threats to the emperor penguin, the FWS should consider the timeframes used in climate modeling. 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.” Climate scientists routinely look at much longer time periods, and therefore a time horizon of 100 years or more with regard to this threat would be eminently reasonable. The National Oceanic and Atmospheric Administration followed this logic in its proposed rule for the for the bearded seal, stating, “because the climate projections in the Intergovernmental Panel on Climate Change’s (IPCC’s) *Fourth Assessment Report* extend through the end of the century (and we note the IPCC’s *Fifth Assessment Report*, due in 2014, will extend even farther into the future), we used those

¹ In making this determination, the FWS must rely “solely on the best scientific and commercial data available.” 16 U.S.C. § 1533(b)(1)(A). Regrettably, political considerations are routinely inserted by political appointees at the Department of Interior into determinations that should be entirely science-based (Union of Concerned Scientists 2005, 2004a-d). Petitioner urges the FWS to consider only the best scientific information available in its determination on this Petition.

models to assess impacts from climate change through the end of the century” (75 Fed Reg. 77497). The IUCN threatened species classification system also uses a timeframe of 100 years. Moreover, in planning for species recovery, the FWS (as well as its sister agency, the National Marine Fisheries Service) routinely considers a 75-200 year foreseeable future threshold (Suckling 2006). For example, the Alaska Region has previously 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% probability of extinction in the next 100 years; 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% probability of extinction in the next 100 years 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 FWS stated “At least 10 years will be needed to stabilize the Mt. Graham red squirrel population and at least 100 to 300 years will be needed to restore Mt. Graham red squirrel habitat” (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 for 200 years” (Suckling 2006 (emphasis added)). The National Marine Fisheries Service stated of the Northern right whale: “[g]iven the small size of the North Atlantic population, downlisting to threatened may take 150 years even in good conditions” (Suckling 2006 (emphasis added)).

Perhaps most importantly, the time period the FWS 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 emperor penguin, 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. The FWS must include these considerations in its listing decision.

For all these reasons, Petitioner suggests a minimum of 100 years as the “foreseeable future” for analyzing the threats to the continued survival of the emperor penguin. 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.

As detailed throughout, neither anthropogenic greenhouse gas emissions nor other threats to the emperor penguin are speculative or too far in the future to understand or address. Tragically, these threats are already here, and the impacts are already

manifesting in penguin populations. Urgent action, including listing under the ESA and dramatic cuts in greenhouse gas emissions levels, is needed now to ensure that the emperor penguin does not become extinct in the foreseeable future.

II. The Emperor Penguin Qualifies for Listing under the ESA

Petitioner believes that all but one, disease or predation, of the five listing factors threaten the future existence of the emperor penguin. Global warming poses the most immediate and grave threat to the emperor penguin, since this species is at risk of extinction with the loss of Antarctic sea ice and ice shelves, changing ice dynamics, and resulting effects on foraging conditions and Antarctic krill, an important prey species for the emperor penguin. In addition, an expanding commercial fishery for krill, ocean acidification, and signs of declining krill stocks risk causing local depletions of krill as prey for penguins. Existing regulatory mechanisms have been ineffective in mitigating these threats to the emperor penguin. Accordingly, the emperor penguin warrants listing under the ESA.

On November 28, 2006, the Center submitted a petition to list 12 penguin species, including the emperor penguin, under the Endangered Species Act. In its 12-month finding for four penguin species, FWS found that the emperor penguin was “not currently threatened or endangered in any portion of its range or likely to become so in the foreseeable future” (73 Fed Reg. 77300). In particular, FWS concluded, “to date, evidence does not support the conclusion that directional changes in temperature or sea-ice extent are already occurring in the habitat of the emperor penguin” (p. 77297) and that there was insufficient evidence to find that “climate change effects to the habitat of the emperor penguin are likely to be a threat to the emperor penguin in the foreseeable future” (p. 77300).

This finding’s conclusions, however, were flawed. Multiple scientific studies have documented long-term emperor penguin population declines (Barbraud and Weimerskirch 2001; Ainley 2005; Marchant and Higgins 1990; Kooyman et al. 2007; Ainley 2006). The FWS finding failed to acknowledge anthropogenic climate change as a driver of habitat change in the Antarctic continent and Southern Ocean, and drew a scientifically unsupported conclusion by not considering the best available science on anthropogenic climate change relevant to emperor penguins (e.g. Gillett et al. 2008). As described in this Petition, the observed and potential impacts of climate change pose serious and varied threats to the emperor penguin, including a warming Antarctic continent and Southern Ocean, losses in sea ice and shelf ice, and declining krill populations.

These threats are supported by numerous scientific papers, detailed in this Petition, including multiple recent studies published since FWS’s 2008 finding. These studies document dramatic impacts of global climate change, including to Antarctica and the Southern Ocean, and predict continued impacts into the future. They also present new data on colony declines and point to specific threats of climate change to emperor penguins, including reductions in sea and shelf ice, alterations in ice dynamics, and

reductions in prey availability. These new scientific studies include, but are not limited to: Fussel 2009; McMullen and Jabbour 2009; Richardson et al. 2009; Convey et al. 2009; Mayewski et al. 2009; Schofield et al. 2010; Cook and Vaughan 2010; McNeil et al. 2010; Kawaguchi et al. 2011; Yin et al. 2011; Ainley et al. 2010; Jenouvrier et al. 2009; Fretwell and Trathan 2009; Forcada and Trathan 2009; and Trathan et al. 2011.

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

1. Global Climate Change

Global warming represents the gravest threat to the long-term survival of the emperor penguin. The emperor penguin depends on sea ice for most of the year for breeding and foraging, and is threatened by warming-caused loss and instability of sea ice as well as the melting and collapse of ice sheets and ice shelves. Surface and ocean warming, ice loss, and shifts in sea ice dynamics have already occurred in several parts of Antarctica and the Southern Ocean, and have been particularly dramatic in the Antarctic Peninsula. In addition, changing sea ice and ocean acidification threaten to reduce the availability of an important part of emperor penguins' prey, Antarctic krill.

Antarctic warming, changes in sea and land ice, and ocean acidification are expected to continue into the future, and will result in significant negative impacts to emperor penguins' habitat and prey. Already facing the loss of and population declines at several locations, emperor penguin colonies will suffer additional losses and declines under these changing conditions. As long-lived species, emperor penguins are unlikely to adapt quickly enough or easily find suitable new breeding locations. Without immediate and dramatic reductions in greenhouse gas emissions, detrimental impacts to emperor penguins are essentially assured and will put the species at risk of extinction.

This section reviews the best available scientific information regarding (a) current levels of greenhouse gases and climate change risks; (b) observed and predicted effects of climate change on Antarctica and the Southern Ocean; and (c) observed and predicted effects of climate change on emperor penguins.

a. Climate Change Overview, Current Emissions Trajectory, and Current Levels of Greenhouse Gases

In the 2007 Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) 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: 30). The international scientific consensus of the IPCC is that most of the recent observed warming has been caused by human activities (IPCC 2007). The U.S. Global Change Research Program in its 2009 report *Climate Change Impacts in the United States* also

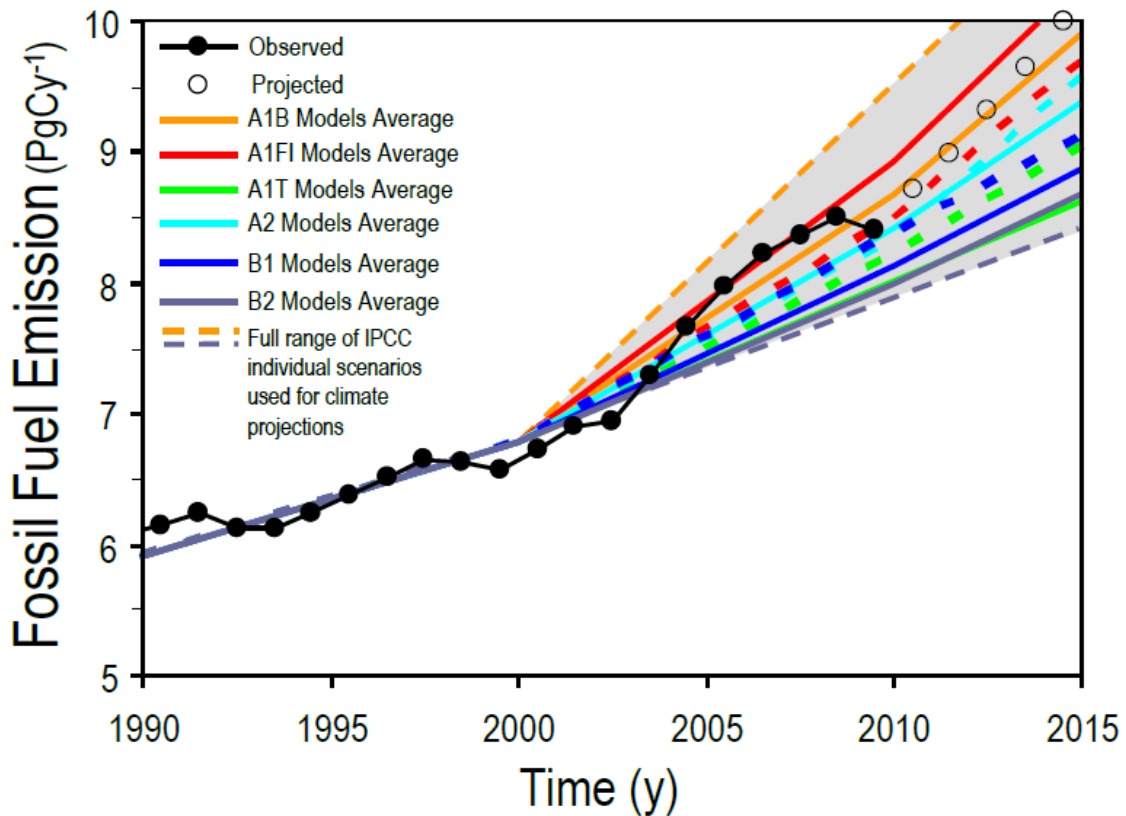
stated that “global warming is unequivocal and primarily human-induced” (USGCRP 2009: 12).

Although the IPCC Fourth Assessment Report provides an important synthesis of climate change science, numerous studies published since the AR4 indicate that many climate change risks are substantially greater than assessed in the AR4. These studies have found that many climatic indices are changing more quickly than projected by earlier IPCC reports; climate impacts are occurring at lower surface temperatures than previously estimated; temperature change and sea level rise during this century will be greater than previously projected; and the climate is approaching tipping points beyond which the climate system is expected to switch to a different state (Lenton et al. 2008, Fussel 2009; McMullen and Jabbour 2009; Richardson et al. 2009). As summarized by Fussel (2009), “many risks are now assessed as stronger than in the AR4, including the risk of large sea-level rise already in the current century, the amplification of global warming due to biological and geological carbon-cycle feedbacks, a large magnitude of ‘committed warming’ currently concealed by a strong aerosol mask, substantial increases in climate variability and extreme weather events, and the risks to marine ecosystems from climate change and ocean acidification” (Fussel 2009: 4649). In reviewing the projected impacts from continuing climate change, Anderson and Bows (2011: 20) concluded that the impacts associated with 2°C temperature rise have been “revised upwards, sufficiently so that 2°C now more appropriately represents the threshold between ‘dangerous’ and ‘extremely dangerous’ climate change.”

By the time of the IPCC AR4, the atmospheric concentration of CO₂ had increased by 36% since 1750 to a level that has not been exceeded during the past 800,000 years and likely not during the past 15 to 20 million years (Denman et al. 2007, Tripathi et al. 2009). Of foremost concern, the rate of increase of global atmospheric CO₂ emissions is accelerating, with especially rapid increases observed in the 2000s (Canadell et al. 2007, Raupach et al. 2007, Friedlingstein et al. 2010, Global Carbon Project 2010). The global mean CO₂ concentration in 2010 averaged 389 ppm (<http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>). The global fossil fuel CO₂ emissions growth rate rose from 1.1% per year during 1990-1999 to 3.2% during 2000-2008, and has largely tracked the emissions trajectory of the most fossil-fuel intensive IPCC SRES emissions scenario, A1FI, since 2000 (Figure 3) (Raupach et al. 2007, McMullen and Jabbour 2009, Richardson et al. 2009, Friedlingstein et al. 2010, Global Carbon Project 2010). The emissions growth rate between 2000 to 2009 fell slightly to 2.5% per year (Global Carbon Project 2010) due largely to the global financial and economic crisis that resulted in a 1.3% decrease in global fossil fuel emissions in 2009 (Friedlingstein et al. 2010). However, the observed emissions decrease in 2009 was less than half of the projected decrease of 2.8% (Friedlingstein et al. 2010). Even more striking, global CO₂ emissions increased by more than 5% in 2010 resulting in 33.0 billion tones of CO₂ (Olivier et al. 2011), which is the highest in human history. These increased emissions have been attributed to rises in fossil fuel burning and cement production rather than from increased emissions from land-use change (Canadell et al. 2007). During the past 50 years, carbon dioxide sinks on land and in the oceans have also become less efficient in absorbing atmospheric CO₂, which is also contributing to the

observed rapid rise (Canadell et al. 2007). With atmospheric CO₂ at ~392 ppm and worldwide emissions continuing to increase by more than 2 ppm each year (<http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html>), rapid and substantial reductions are clearly needed immediately.

Figure 3. Observed fossil fuel CO₂ emissions from 1990 to 2009 compared with six IPCC emissions scenarios. Source: Global Carbon Project 2009. Figure updated from Raupach et al. 2007, PNAS; Data: Gregg Marland, Thomas Boden-CDIAC 2010; International Monetary Fund 2010.



b. Observed and Predicted Effects of Climate Change on Antarctica and the Southern Ocean

Although the effects of climate change in the Antarctic have exhibited regional variation, the recent and best available science clearly supports that changes as a result of warming are continent-wide and particularly evident in certain regions. Furthermore, these changes will continue into the future unless greenhouse gas emissions are dramatically and immediately reduced. This section reviews the best available science on observed and predicted changes in Antarctic climate conditions that are most relevant for emperor penguins.

Antarctic warming

Some previous research has reported inhomogeneous or statistically insignificant surface temperature changes over the last ~50 years across much of Antarctica (Turner et al. 2005; SCAR 2009). Trends have differed regionally, however, with significant warming occurring in some areas, particularly in the Antarctic Peninsula and also in West Antarctica (Steig et al. 2009; Chapman and Walsh 2007; Convey et al. 2009; Mayewski et al. 2009; Schofield et al. 2010). In a review of research on the historical Antarctic and Southern Ocean climate in relation to the global climate system, Mayewski et al. (2009) suggested that these regional differences are a result of both short- and long-term climatic variability, the various factors that affect that variability (e.g. orbital insolation, solar variability, ice dynamics), and anthropogenic impacts. In particular, a more positive phase of the Southern Annual Mode (SAM) in the last 50 years, likely a result of anthropogenic forcing, has been linked to a warming of the Antarctic Peninsula region and cooling in other regions of the Antarctic continent (Marshall et al. 2006). The SAM is the principal mode of variability (climate pattern) in the Southern Hemisphere circulation (Marshall et al. 2006).

Despite these regional differences, several recent studies have documented continent-wide temperature increases (Steig et al. 2009; Convey et al. 2009; Schneider et al. 2006). Monaghan et al. (2008) reconstructed Antarctic near-surface temperature from 1960-2005 and noted that the last fifteen years have shown warming (although statistically insignificant) over nearly all of Antarctica, with several stations in interior and coastal East Antarctica exhibiting statistically significant warming trends. Steig et al. (2009) found a continent-wide warming trend in Antarctica between 1957 and 2006 of 0.12 ± 0.07 °C per decade, where West Antarctica warmed at a rate of 0.17 ± 0.06 °C per decade, the Antarctic Peninsula warmed at 0.11 ± 0.04 °C per decade, and East Antarctica warmed at 0.10 ± 0.07 °C per decade (1957–2006). The authors concluded (p. 459):

Here we show that significant warming extends well beyond the Antarctic Peninsula to cover most of West Antarctica, an area of warming much larger than previously reported. West Antarctic warming exceeds 0.1 °C per decade over the past 50 years, and is strongest in winter and spring. Although this is partly offset by autumn cooling in East Antarctica, the continent-wide average near-surface temperature trend is positive. Simulations using a general circulation model reproduce the essential features of the spatial pattern and the long-term trend, and we suggest that neither can be attributed directly to increases in the strength of the westerlies. Instead, regional changes in atmospheric circulation and associated changes in sea surface temperature and sea ice are required to explain the enhanced warming in West Antarctica.

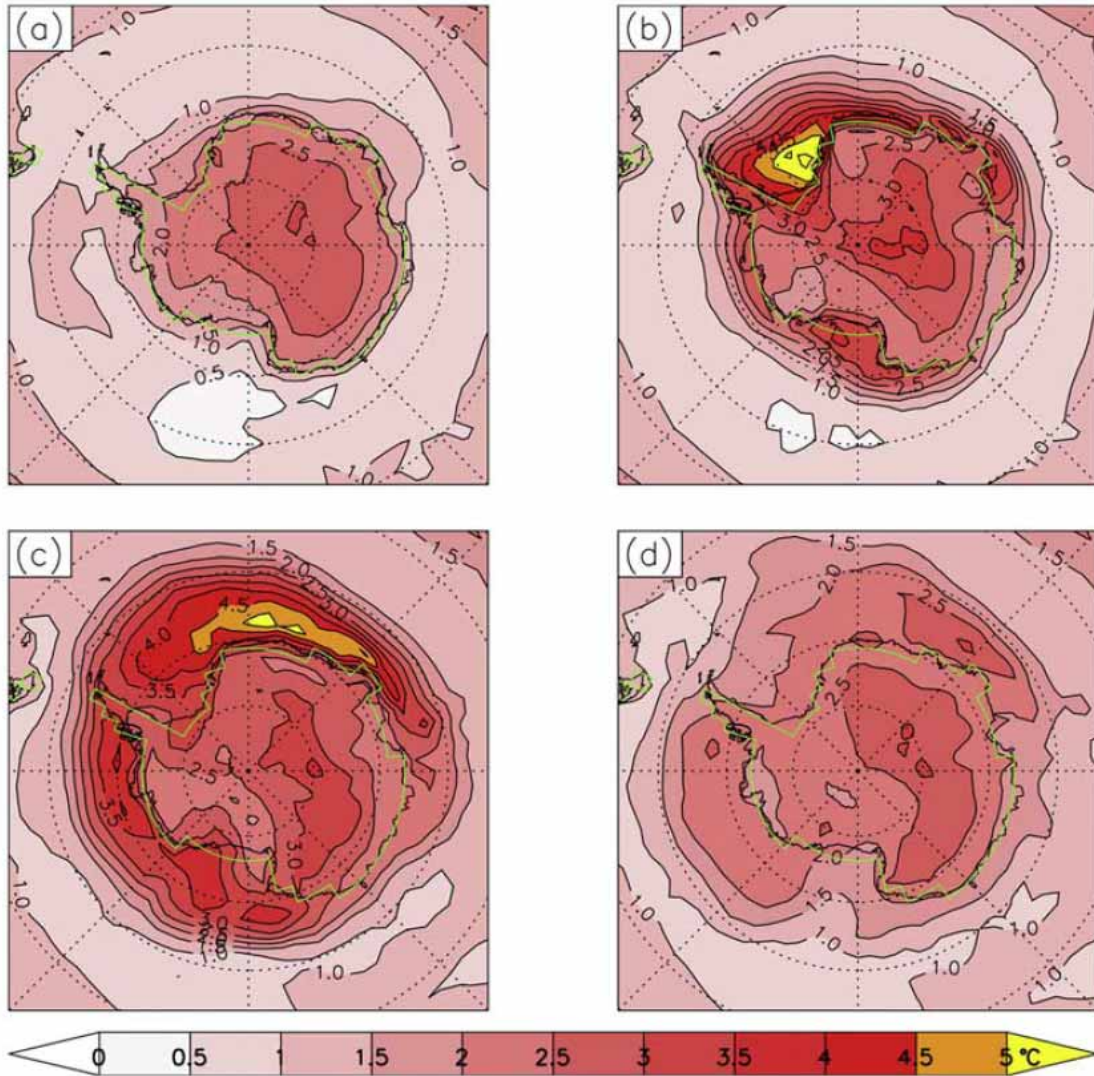
Other research has documented warming of surface air temperatures in Antarctica over recent decades, particularly in the Antarctic Peninsula (Chapman and Walsh 2007; Convey et al. 2009; Mayewski et al. 2009). In a review of historical variations in the Antarctic climate system, Convey et al. (2009) noted that the western and northern parts

of the Antarctic Peninsula have experienced the greatest warming, and West Antarctica has also experienced significant warming. These authors reported that across the continent as a whole, temperatures have risen by an average of 0.2°C since the late 19th century. Ding et al. (2011) used data on Antarctic surface temperature, global sea surface temperature, and atmospheric circulation patterns to demonstrate that the significant warming over continental West Antarctica has occurred in the last several decades is connected to sea surface temperature changes in the tropical Pacific Ocean.

Gillett et al. (2008) conducted a formal attribution study of Antarctic temperature change and demonstrated that rising temperatures are directly attributable to human activities. The authors used a gridded data set of land surface temperatures for Antarctica from 1950-2008 and simulations from four coupled climate models to assess the causes of observed temperature changes. These researchers found that anthropogenic influence on Antarctic temperature is detectable and distinguishable from the influence of internal climate variability or natural climate drivers alone, and that Antarctic warming is directly attributable to anthropogenic climate forcings, including greenhouse gas emissions, stratospheric ozone depletion, and sulphate aerosol. The researchers concluded that “human activities have already caused significant warming in both polar regions, with likely impacts on polar biology, indigenous communities, ice-sheet mass balance and global sea level” (p. 1).

The best available science predicts that this warming will increase into the future over large portions of Antarctica. Bracegirdle et al. (2008) assessed Antarctic climate change over the 21st century using IPCC Fourth Assessment Report climate models and a middle-of-the-road A1B emissions scenario. To provide more reliable estimates of future change, Bracegirdle et al. (2008) applied a weighting scheme to model output based on each model’s ability to reproduce the mean climate of the late 20th century. Their results projected an increase in surface temperature by an average of $2.54 \pm 1.2^\circ\text{C}$ south of 62.5°S by 2080-2099, with the most rapid warming during winter of $3.93 \pm 2.0^\circ\text{C}$ (Figure 1) (Bracegirdle et al. 2008: Table 4). The largest warming is projected to occur during the winter over the marginal ice zone off East Antarctica due to the retreat of the sea-ice edge (Figure 4). Additional modeling studies and reviews support these predictions of increasing temperatures under future climate change scenarios (Chapman and Walsh 2007; Mayewski et al. 2009; Walsh 2009).

Figure 4. Projected surface warming in (a) December-January-February, (b) March-April-May, (c) June-July-August and (d) September-October-November, given as the difference between 2080–2099 mean and 2004–2023 mean. Source: Bracegirdle et al. (2008): Figure 10.



Southern Ocean warming

The Southern Ocean has warmed considerably during the second half of the 20th century, with temperature increases larger than those of the global ocean as a whole. Gille (2008) examined long-term temperature change throughout the upper 1000 m of the Southern Hemisphere Ocean between 0 and 60°S by comparing 1990s observations from ships and floats with historic hydrographic observations collected in the same geographic area, extending the work of Gille (2002). When using only summer observations to remove sampling biases, Gille (2008) detected a net increase in heat content of the Southern Hemisphere Ocean of $10 \text{ to } 11 \pm 2 \text{ (} \times 10^{22} \text{ J)}$ from the 1950s to the present, which is double the net heat content increase for the global ocean of $5.4 \text{ (} \times 10^{22} \text{ J)}$

reported by Levitus et al. (2005) for the same time period. Importantly, Gille (2008) found that most of the warming in the Southern Hemisphere during this period was concentrated within the Antarctic Circumpolar Current (ACC).

Whitehouse et al. (2008) also found significant warming in the ocean surrounding South Georgia in the Atlantic sector of the Southern Ocean during 1925-2006. These researchers detected significant warming in this ocean region during the 81-year study period, including a mean temperature increase of $\sim 0.9^{\circ}\text{C}$ in January and $\sim 2.3^{\circ}\text{C}$ in August in the top 100m of the water column and evidence that late 20th century summer temperatures peaked ~ 6 days earlier. These researchers noted that long-term warming around South Georgia is substantial and more than documented previously for the circumpolar warming of the Southern Ocean.

Other studies and review papers also support that the Southern Ocean is warming (Convey et al. 2009; Mayewski et al. 2009; Levitus et al. 2005; Fyfe et al. 2007; SCAR 2009). Surface waters around the western Antarctic Peninsula have warmed by more than 1°C since the 1950s (Clarke et al. 2007). Fyfe et al. (2007) attributed temperature changes in the Southern Ocean to both increasing CO_2 emissions and poleward-intensified winds. Furthermore, these researchers demonstrated that if volcanic aerosols are left out of climate modeling simulations, the simulated temperature increases are almost double, indicating that anthropogenic impacts on Southern Ocean warming would be significantly greater were it not for the cooling effects of aerosols.

Research demonstrates that Southern Ocean warming will continue into the future. Yin et al. (2011) used 19 climate models to quantify subsurface ocean warming in the next 200 years and found that the ocean surrounding Antarctica warms $0.4\text{-}0.6^{\circ}\text{C}$ under future climate change conditions. They argued that this warming, in turn, could cause substantial increases in the loss of ice mass, through melting ice at the ice sheet/ocean interface and persistently eroding the marine-based sections of the Antarctic ice sheet. This warming, if continued into the future, could cause partial disintegration of the ice sheet if a tipping point is reached (Yin et al. 2011; Kriegler et al. 2009).

During the 21st century, the average over the ensemble of 19 IPCC AR4 models projects sea surface temperatures to be $0.5\text{-}1.0^{\circ}\text{C}$ warmer south of 60°S in the summer, except in the Admundsen Sea, where projections indicate increases of $1.0\text{-}1.25^{\circ}\text{C}$ (Convey et al. 2009). In winter, the sea surface temperature in waters offshore of Dronning Maud Land, West Antarctica and Queen Mary Land may increase by 1.0°C (Convey et al. 2009). Bottom water temperatures at 200 m on the continental shelf are projected to warm by $0.5\text{-}0.75^{\circ}\text{C}$, except in the Weddell Sea where warming will be $0\text{-}0.5^{\circ}\text{C}$ (Convey et al. 2009). Along the continental margin to a depth of 4000 m, bottom waters are predicted to warm by $\sim 0.25^{\circ}\text{C}$ during the whole year (Convey et al. 2009). Models also project significant warming at the surface of the Antarctic Circumpolar Current between $40\text{-}60^{\circ}\text{S}$, with temperatures rising 0.75°C to almost 2°C in all seasons (Convey et al. 2009).

Antarctic sea ice retreat

In a review of the effects of climate change on the western Antarctic Peninsula, Clarke et al. (2007) noted rapid rates of climate change, including shifts in winter sea ice dynamics. These alterations in the timing and extent of ice habitat are likely to have directly impacted ice-associated marine organisms (Clarke et al. 2007). Ducklow et al. (2007) also found that mean annual sea ice has decreased in this region from 1979-2004.

Stammerjohn et al. (2008) also found that the sea ice season has significantly shortened along the Antarctic Peninsula and southern Bellingshausen Sea during 1979–2004. Sea ice in this region retreated 31 ± 10 days earlier and advanced 54 ± 9 days later, resulting in a decrease of 85 ± 20 ice season days. In contrast, sea ice in the western Ross Sea region retreated 29 ± 6 days later and advanced 31 ± 6 days earlier, resulting in an increase of 60 ± 10 ice season days. The researchers linked these trends to the more positive phase dominance of the Southern Annular Mode (SAM) in recent decades, which influences wind-driven advection of heat, moisture, and momentum which in turn influence sea ice cover. In addition, the researchers noted that the recent more positive phase dominance of the SAM is thought to be caused by rising anthropogenic CO₂ concentrations and stratospheric ozone depletion. Thus, Stammerjohn et al. (2008) warned that continuing increases in greenhouse gases might lead to more positive phase dominance of SAM, a continuing contraction of the sea ice season in the west Antarctic Peninsula and southern Bellingshausen Sea, and thinning of the West Antarctic ice sheet.

The loss of sea ice caused by global warming is not consistent across Antarctica because of the effects of other atmospheric and oceanographic forces. The primary example of this is sea ice in the Ross Sea, which has increased in extent from 1978-2008 (Comiso et al 2011). In this region, which has also experienced cooling over recent decades, changes in sea ice are linked to dynamics in the Southern Annual Mode (SAM) and the Antarctic Circumpolar Wave (Comiso et al. 2011). Changes in near-surface winds, including colder southerly wind anomalies, are associated with a more positive phase of the SAM and are thought to increase sea ice in the Ross Sea (Convey et al. 2009; Lefebvre et al. 2008; Stammerjohn et al. 2008). This increase in sea ice in the Ross Sea is primarily responsible for the overall positive trend in sea ice extent in the Southern Ocean (Comiso et al. 2011). In other areas, however, the reduction of sea ice has been significant. For example, by correlating data from ice core records and satellite-derived sea ice extent, Curran et al. (2003) deduced that there has been a 20% decline in sea ice extent since ~1950 in the 80°E to 140°E sector of Antarctica.

Modeling studies predict future losses of Antarctic sea ice under climate change. Lefebvre and Goosse (2008) used the suite of simulations performed with atmosphere-ocean general circulation models (AOGCMs) for the Fourth Assessment Report of the IPCC to project changes in sea ice in the Southern Ocean through the 21st century. By the end of the 21st century, all models predicted a decrease in annual mean sea ice extent. The average of all models predicted a decrease of 3.02 million km, a 25% reduction from the sea ice extent in the 20th century. The maximum decrease occurred in the Weddell Sea and the Admunsen-Bellingshausen Seas. In the abovementioned modeling study by

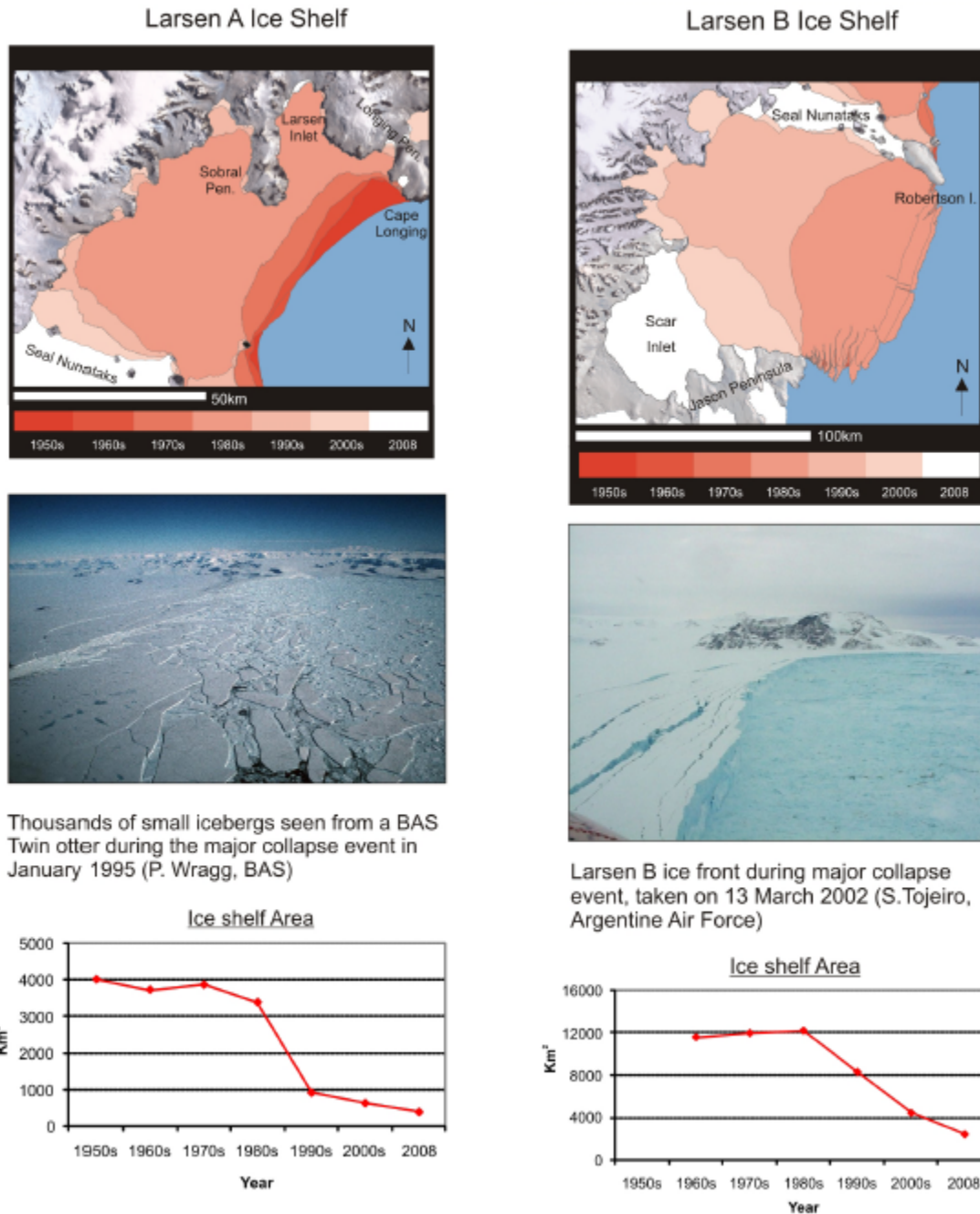
Bracegirdle et al. (2008), sea-ice area was projected to decrease around the Antarctic continent by an average of $2.6 \pm 0.73 \times 10^6 \text{ km}^2$, which equates to a large-scale decline of $33 \pm 9\%$. Most of the ice retreat was projected to occur during winter (June-August) and spring (September-November) when the sea ice extent is largest. In summer and autumn, sea-ice was projected to decrease most in the Weddell Sea. Other research also supports this projected future decrease in sea ice extent (Flato 2004; Arzel et al. 2006; SCAR 2009).

Antarctic ice shelf and ice sheet melt

Climate warming is leading to the increased melting, calving and collapse of Antarctic ice shelves, particularly along the Antarctic Peninsula (Clarke et al. 2007; SCAR 2009; Bindschadler 2008). Ice calving and collapse are often followed by glacier acceleration (e.g. thinning and ice discharge of glaciers into the ocean). Rignot et al. (2005) documented thinning, mass loss, and acceleration of glaciers flowing into the former Wordie Ice Shelf in the West Antarctic Peninsula over the previous decade. The effects of climate warming were also demonstrated in 1995 when the northernmost section of the Larsen A ice shelf collapsed, followed in 2002 by the Larsen B ice shelf, which had existed for at least the last 12,000 years (Bindschadler 2008) (Figure 5). Convey et al. (2009) reviewed historical variations in the Antarctic climate system and also reported a warming-caused retreat of ice shelves on the Antarctic Peninsula, as well as a decrease in areas covered by permanent ice or snow.

Several feedback mechanisms that link atmospheric and oceanic changes to changes on the ice sheet could accelerate the melting of ice shelves and have been linked to ice melting and calving in Antarctica (Bindschadler 2008). One is a strengthened westerly Antarctic Circumpolar Current (ACC) in the Southern Ocean, caused by increased circumpolar atmospheric circulation. This stronger ACC combines with the compensating easterly boundary current to increase upwelling of Circumpolar Deep Water onto the continental shelf. This upwelling of warmer water hits the bottom of the ice shelf and the ice sheet grounding line, quickening ice flow and grounding line retreat. Second, warmer air creates ponds of meltwater on the ice sheet surface, ponds that absorb additional radiation and melt fissures into ice shelves that facilitate their disintegration. Third, meltwater can move through cracks in the ice and reach the base of the ice sheet, warming deeper ice and acting as a lubricant to accelerate the ice's movement over underlying rock. Finally, ice shelf disintegration removes the buttressing effect that ice shelves have on land-based glaciers, speeding up glacier movement and causing a net loss of grounded ice.

Figure 5. Left: Larsen A and Larsen Inlet shelves. Right: Larsen B ice shelf. Source: Cook and Vaughah (2010).



Cook and Vaughah (2010) used an updated USGS coastal-change dataset to examine changes in ice shelf areas on the Antarctic Peninsula as compared to historical maps, aerial photographs and satellite images. They found a total reduction in ice-shelf area by over 28,000 km² over the last 50 years, a decrease of 18% of the original area of floating ice. This decline began in the 1970s and continued to the present. The authors reported that seven out of twelve ice sheets in this area have almost disappeared or have

retreated significantly, at least some of which can be attributable to atmospheric and oceanic changes. Furthermore, retreating ice shelves have generally followed a pattern that would accompany a southward movement of a climatic boundary, supporting the connection with increasing atmospheric temperatures and production of melt-water. The authors warn that the Larsen C ice shelf may follow the same pattern of retreat as the Larsen A and B shelves (Figure 5), should warming continue into the future.

The West Antarctic ice sheet has shown several changes in the last few decades that demonstrate effects of climate warming, including ice sheet thinning near the coast, ice stream acceleration, grounding line retreat, and increased calving of large icebergs (Bindschadler 2008). Warming of the ocean and atmosphere threaten to diminish or eliminate the floating ice shelves that provide a buttressing effect for the ice sheet (Joughin & Alley, 2011). Were these ice shelves to disintegrate, the non-floating ice near the coast would accelerate and thin, raising the possibility of collapse of the entire West Antarctic ice sheet (Joughin and Alley 2011). Wingham et al. (2009) documented rapid and accelerating thinning of the Pine Island Glacier in West Antarctica from 1995-2006. These authors predicted that with continuing acceleration at the present rate, the glacier will be afloat within 100 years, six times sooner than originally predicted. Jacobs et al. (2011) and Jenkins et al. (2010) also documented increased thinning and melting under this ice shelf.

Pritchard et al. (2009) mapped changes along grounded margins of the Antarctic ice sheets using high-resolution Ice, Cloud and Land Elevation Satellite laser altimetry. They found that “dynamic thinning of glaciers...has intensified on key Antarctic grounding lines, has endured for decades after ice-shelf collapse, penetrates far into the interior of each ice sheet and is spreading as ice shelves thin by ocean-driven melt” (p. 1). The authors attribute glacier and ice stream thinning to ocean-driven melting.

As the climate warms, the mass balance of Antarctica is determined by two competing processes: ice discharge by glaciers and ice streams at the coast as warmer air and ocean temperatures erode the buttressing ice shelves, and the increase in snowfall in the continent’s interior which is also enhanced by climate warming. Rignot et al. (2008) estimated the total mass balance of the Antarctic ice sheet and found that Antarctica has undergone a net loss of ice mass from 1992-2006, particularly due to widespread ice loss from West Antarctica and the Antarctic Peninsula. Specifically, Rignot et al. (2008) estimated total mass balance using satellite interferometric synthetic-aperture radar observations covering 85% of Antarctica’s coastline to estimate the total mass flux of ice into the ocean compared with interior snow accumulation calculated from a regional atmospheric climate model. Over the study period, mass loss from the Antarctic ice sheet increased by 75% over 10 years. Most of the mass loss was from Pine Island Bay sector of West Antarctica and the northern tip of the Peninsula due to ongoing, pronounced glacier acceleration. In West Antarctica, widespread losses along the Bellingshausen and Amundsen seas increased the ice sheet loss by 59% in 10 years, and in the Peninsula, losses increased by 140%. In East Antarctica, the mass loss was near zero but the researchers warned that “thinning of its potentially unstable marine sectors calls for attention” (p.109). In contrast to major increases in ice discharge, snowfall integrated

over Antarctica did not change in 1980–2004. Rignot et al. (2008) concluded that changes in glacier flow are having a significant impact on reducing the mass balance of the Antarctic ice sheet.

Expanding upon the work of Rignot et al. (2008), Rignot et al. (2011) presented a longer, finer and complete mass balance of the Antarctic ice sheet over the last 20 years, validated by comparing two independent techniques, the mass budget method and the gravity method. They estimated a 5.5 ± 2 Gt/yr² decrease in surface mass balance since 1992, and an acceleration rate in ice discharge of 9.0 ± 1 Gt/yr² for 1992-2009. The authors predicted that dynamic losses of ice from Pine Island Glacier will continue and expand inland in the future.

Other research has also documented a loss of Antarctic ice (Chen et al. 2009; Clarke et al. 2007; Mayewski et al. 2009; Vaughan 2006; ATME 2010a; Shepherd and Wingham 2007). Using Gravity Recovery and Climate Experiment (GRACE) data from 2002-2009, Chen et al. (2009) estimated a total loss of 190 ± 77 Gt yr⁻¹ from Antarctic ice, with 132 ± 26 Gt yr⁻¹ coming from West Antarctica. In contrast with earlier studies using GRACE data, Chen et al. (2009) found that East Antarctica is also losing ice at a rate of -57 ± 52 Gt yr⁻¹, likely from increased ice loss since 2006. In a review of climate change impacts on the western Antarctic Peninsula, Clarke et al. (2007) noted that in the last 50 years, the majority of glaciers in the region have retreated at an accelerating average rate and multiple ice shelves have collapsed. Marcott et al. (2011) linked subsurface ocean warming to Heinrich events, episodic discharges of large icebergs from ice sheets. This study found that subsurface ocean warming significantly increased the rate of mass loss from the ice shelf in the Hudson Strait Ice Stream in the North Atlantic. The authors compared the process behind the triggering of Heinrich events – a weakened or disintegrated ice shelf brings on an ice-stream surge – to the recent response of Antarctic glaciers to the collapse of buttressing ice shelves. This suggests that subsurface warming from climate change has the potential to trigger additional ice-sheet instabilities in the future, as warmer water penetrates beneath ice shelves that are buttressing ice sheets.

Ocean acidification

The world's oceans are an important part of the planet's carbon cycle, absorbing large volumes of carbon dioxide and cycling it through various chemical, biological, and hydrological processes. As the ocean absorbs carbon dioxide from the atmosphere, it changes the chemistry of the sea water by lowering its pH, thereby acidifying it. Cao and Caldeira (2008) found that increasing atmospheric CO₂ concentrations over the past two centuries have caused a 0.1 unit decrease in average pH for the global surface ocean, corresponding to a 30% increase in acidity. This has ecosystem impacts that affect emperor penguins, including negative effects on important prey such as krill, squid and other calcifying organisms.

Ocean acidification has numerous impacts on marine life, impacts which are generally large and negative (Kroeker et al. 2010). Fabry et al. (2008) reviewed the impacts of ocean acidification on marine fauna and ecosystem processes. Laboratory and mesocosm experiments indicate that larval fish, crustaceans, and squid, which comprise emperor penguins' principal prey groups, are susceptible to detrimental impacts from ocean acidification. Studies indicate that larval fish experience higher mortality rates when exposed to higher-than-normal CO₂ concentrations, crustaceans (including krill and copepods) experience higher mortality rates with increasing CO₂ levels and decreasing pH, and copepod egg hatching success decreases with increasing CO₂ (Fabry et al. 2008: Table 1). Fabry et al. (2008) concluded that "ocean acidification and the synergistic impacts of other stressors provide great potential for widespread changes to marine ecosystems" (Fabry et al. 2008: 414). Squid are particularly sensitive to changes in pH; their ability to bind oxygen becomes impaired and their metabolic activity declines under decreases in pH of as little as 0.15 units (Fabry et al. 2008). Marine species are also affected when increases in the ocean's CO₂ concentration results in the accumulation of carbon dioxide in tissues and fluids, called hypercapnia, which leads to an increase in internal acidity (Fabry et al. 2008). Hypercapnia can impact acid-base regulation, metabolic activity, respiration, and ion exchange, leading to impairment of growth and higher mortality rates (Fabry et al. 2008).

Ocean acidification reduces the availability of chemical components, such as calcium carbonate, needed by marine life to build shells and skeletons (Ruttimann 2006). Calcified organisms in Antarctica are particularly at risk from ocean acidification, as many species are weakly calcified, calcium carbonate dissolution rates decrease as temperatures increase, and climate change is expected to have negative impacts on aragonite saturation (McClintock et al. 2009; Moy et al. 2009; Fabry et al. 2009). McClintock et al. (2009) found four species of Antarctic benthic marine invertebrates to suffer significant dissolution of their shells under acidified seawater as compared to non-acidified seawater. Crustaceans are thought to be particularly vulnerable to ocean acidification because of their dependence on the availability of calcium and bicarbonate ions for the mineralization of their exoskeleton after molting (Royal Society 2005). Already in the Southern Ocean, plankton are growing thinner and weaker shells due to ocean acidification (Moy et al. 2009).

The impacts of ocean acidification will grow more severe in the future. Surface waters of the high latitudes, including the Southern Ocean, are expected to become persistently undersaturated with respect to aragonite in the next several decades, before oceans at lower latitudes (Fabry et al. 2009). Cao and Caldeira (2008) examined the consequences of different CO₂ stabilization levels for under-saturation of calcite and aragonite in the near-surface ocean and for ocean pH levels. They predicted that high-latitude oceans would be the first to become under-saturated with respect to calcium carbonate with increasing atmospheric CO₂ concentrations, especially since aragonite and calcite saturation levels are naturally low in cold polar waters of the Arctic and Antarctic. Strikingly, the researchers found that parts of the Southern Ocean (7% of the ocean area south of 60°S) would become under-saturated with respect to aragonite at a CO₂ stabilization level as low as 450 ppm. At 550 ppm, half of the ocean south of 60°S would

become under-saturated, and at 750 ppm, 95% of this area would become under-saturated. In addition, Cao and Caldeira (2008) found that regions of the Southern Ocean would become under-saturated with respect to calcite at CO₂ stabilization levels above 600 ppm, and that the area with calcite under-saturation would cover 68% of the ocean south of 60°S at 1000 ppm. When atmospheric CO₂ is stabilized at levels as low as 450 ppm, a large portion of the Southern Ocean experiences a pH decrease of 0.2 units or more (Cao and Caldeira 2008). When atmospheric CO₂ is stabilized at 550 ppm, most of the surface ocean experiences a pH decrease of more than 0.2 units and the Southern Ocean experiences a pH decrease of more than 0.3 units (Cao and Caldeira 2008). Furthermore, freshening from melting sea ice will contribute to lowering pH.

Other studies also support observed Southern Ocean acidification and predictions that acidification and aragonite undersaturation will continue under future atmospheric carbon dioxide levels, with resulting impacts on marine species and ecosystems (Orr et al. 2005; Ruttimann 2006; Russell et al. 2006). McNeil et al. (2010) used surface CO₂ data in a regional ocean/sea ice model to demonstrate that the Ross Sea will experience ocean acidification, but other Antarctic coastal waters will experience effects even sooner. Continuing carbon dioxide emissions could result in calcification rates decreasing by up to 60% by the end of this century (Ruttimann 2006). Under current emissions trends, the pteropod—a planktonic snail which forms a key part of the food web in the Southern Ocean—may be unable to survive as early as 2030 (McNeil and Matear 2008), as it is unable to maintain shells in waters that lack aragonite (Orr et al. 2005). Along with rising temperatures and ocean invasions, ocean acidification is expected to have large effects on planktonic and benthic marine communities in Antarctica (Fabry et al. 2009). These changes in plankton communities can affect the abundance of Antarctic krill and silverfish as prey for emperor penguins, as krill and silverfish depend on plankton blooms as a food source (Montes-Hugo et al. 2009). Even if carbon dioxide emissions stopped immediately, the ocean would continue to absorb excess carbon dioxide in the atmosphere, resulting in further acidification until the planet's carbon budget returned to equilibrium.

c. Observed and Predicted Effects of Climate Change on Emperor Penguins

Emperor penguins rely on relatively stable oceanographic, weather, and sea ice conditions, environmental factors which affect the availability of prey and breeding and molting habitats and are susceptible to shifts caused by climate change (Forcada and Trathan 2009). These environmental factors can determine the colony arrival, body condition, nutrition, egg laying and size, breeding success, and ultimately survival of penguins (Forcada and Trathan 2009). This section reviews the documented effects that changing environmental conditions, brought on by climate change, have had on emperor penguins. Given that at current greenhouse gas emissions levels, our 'climate commitment' is ~2°C warming (Hansen et al. 2008), these effects will likely continue into the future.

Antarctic warming

Air temperature increases negatively affect emperor penguins by altering their habitat. For example, Fretwell and Trathan (2009) documented the likely loss of three emperor penguin colonies between Princess Elizabeth Land and Queen Mary Land, a region in East Antarctica that is experiencing similar mean temperatures as the northern Antarctic Peninsula. These researchers suggest that these temperatures result in sea ice conditions that may be at the limit of suitability for these colonies and thus the colonies are more vulnerable to environmental changes. Jenouvrier et al. (2005a) also found that higher air temperatures negatively affected adult survival, and suggested that in years with low sea ice extent and warmer air and water temperatures, penguins may struggle to find enough food to obtain the body condition for successful breeding or later chick-rearing. Additional impacts posed to emperor penguins from the effects of rising temperatures on sea ice and other habitat conditions are discussed below.

Southern Ocean warming

Like rising air temperatures, the impacts of higher ocean temperatures on emperor penguins occur through altered habitat conditions. Barbraud and Weimerskirch (2001) used the long-term data set from 1952-2000 from the emperor penguin colony located near Dumont d'Urville Station in Terre Adélie (the most well-studied emperor penguin colony) to examine relationships between penguin vital rates and climate conditions, and found that adult penguins survived significantly better when sea surface temperatures were lower. Additional impacts from Southern Ocean warming on habitat characteristics important for emperor penguins are discussed below.

Antarctic ice shelf and ice sheet melt

As described above, climate change is leading to an increased rate of ice shelf calving and disintegration, which has proven detrimental to several emperor penguin populations. Kooyman et al. (2007) and Arrigo et al. (2002) documented impacts on two emperor penguin populations of the calving of a giant piece of the Ross Ice Shelf in 2000, which formed the largest iceberg ever recorded from Antarctica. After fragmentation of the iceberg into two pieces, the resulting B15A iceberg (165 km long) collided with the Ross Ice Shelf at Cape Crozier in 2001, destroying the nesting habitat of the Cape Crozier emperor penguin colony and causing incubating adults to be crushed, be trapped in ravines, or abandon the colony. Following the complete failure of the colony in 2001, breeding attempts in subsequent years (2002-2004) produced few chicks, and adult penguins failed to breed entirely in 2005. At the Beaufort Island colony 70 km northwest of Cape Crozier, the B15A iceberg separated Beaufort Island from the Ross Sea polynya, blocking a formerly direct route for penguins to important feeding and wintering areas. At Beaufort Island, the significant decrease in the number of breeding adults from 2001 to 2005 and the high mortality of chicks in 2001 and 2004 were linked to poor foraging conditions for the penguins due to the iceberg. Overall, the icebergs resulting from the collapse of the Ross ice sheet altered current flow, sea ice and fast ice distribution, and routes of access to the colonies and the foraging areas, all of which exerted significant

negative effects on Emperor penguin colonies in the five years following ice shelf collapse.

A side effect of melting ice shelves and glaciers may be the accelerated release of DDT into the Antarctic environment. Geisz et al. (2008) reported that levels of DDT in Adélie penguins have not declined for >30 years in the Western Antarctic Peninsula, despite the restriction of DDT use since the 1970s. The authors suggested that this implicates glacier meltwater as the source of DDT contamination in coastal Antarctic waters, and estimated that 1-4 kg/year of Σ DDT (p,p'-DDT + p,p'-DDE) are currently released into the ocean from the Western Antarctic ice sheet because of glacier melting or collapse. This DDT release can be expected to increase in the future as climate change causes further melting of ice sheets. Although no comparable study has been undertaken for emperor penguins, the existence of DDT in the Adélie penguin, also an ice-obligate and Antarctic penguin species, suggests another potential threat to emperor penguins that may be exacerbated by climate change.

Changes in sea ice

Sea ice refers to both fast ice and pack ice (Trathan et al. 2011). Most emperor penguin colonies breed on fast ice (Massom et al. 2009; Fretwell and Trathan 2009), which forms over shoals and shallows and also around ice shelves, coastlines and between archipelagos and grounded icebergs. It remains in place despite ocean currents or wind, unlike pack ice (Giles et al. 2008). Emperor penguins depend on pack ice that does not stand far above the ocean surface to access the ocean for foraging (Ainley et al. 2010), and also feed via polynyas or cracks in pack ice (Shirihai 2002, Williams 1995). Emperor penguins rely on stable fast ice for about eight months each year, and thus late fast ice formation in winter or early disintegration in spring can have negative impacts on a colony's breeding success (Trathan et al. 2011). An additional reason stable fast ice is important for emperor penguins is during their ~30 day molt period, they must not enter the water because their old and new feathers are not waterproof, and could suffer hypothermia and death if they became waterlogged (Kooyman et al. 2004). Given the importance of sea ice to the species' breeding and foraging, changes in sea ice caused by climate change pose a grave threat to emperor penguins.

Changes in sea ice extent have been shown to influence emperor penguin reproduction, including chick abundance (Barber-Meyer et al. 2007). Barbraud and Weimerskirch (2006) examined the effects of climate change on timing of breeding of emperor penguins at Terre Adélie, and found that emperor penguins laid their first eggs significantly later in years with greater sea-ice extent. Boersma (2008) reviewed the status of and threats faced by penguin species, and highlighted the negative impacts of sea ice loss and instability to breeding success of emperor penguins. In years of very low sea ice, colonies can undergo complete breeding failure from early break-up of fast ice or protracted blizzards during the early chick-rearing period (Barbraud and Weimerskirch 2001). Although Barber-Meyer et al. (2008) did not find significant relationships between chick abundance and climate variables across all emperor penguin colonies in the western Ross Sea (and as the authors noted, they were constrained by missing chick abundance

data at many colonies), when relationships were significant, they were consistent across colonies. Importantly, Barber-Meyer et al. (2008) found that at some colonies, there were fewer chicks in years with when winter sea-ice extent was lower and when summer sea surface temperature was higher (p. 9):

In our study western Ross Sea chick abundances were positively correlated with SIE [sea ice extent] during July–September (two colonies) and negatively correlated with SST [sea surface temperature] during January–March (two colonies). If SIE is reduced during July–September, adults may be challenged to find sufficient food to feed their chicks because of the relationships between SIE and prey distribution and abundance, however, chick needs are very low so soon after hatching and adult foraging behaviour and prey type at this time of year are unknown. During January–March higher SST may lead to reduced ice floes suitable for moulting and reduced foraging opportunities. Both conditions would affect the number of adults prepared to breed the following season. We also found chick abundances were negatively correlated with SIE five years prior during April–June and July–September. Because all of these correlations were only detected at Cape Crozier and Beaufort Island, we suspect that the effects from iceberg B15A (present from 2001–04) may have influenced our results (*internal citations omitted*).

Ainley et al. (2005) examined possible causes of shifts in population trajectories of penguins in the western Pacific and Ross Sea sectors of the Southern Ocean during the 1970s and 1980s. In the mid 1970s, numbers of emperor penguins began to decline, which continued into the early 1980s. Since then, numbers have remained at that low level. The authors attributed these population changes to shifts in coastal wind strength and air and sea temperatures, which are linked to changes in the semi-annual oscillation (SAO) and Antarctic oscillation (AAO), or Southern Annual Mode. The magnitude of the SAO decreased in the mid-late 1970s, and was linked to rising ocean temperatures at mid-latitudes (Meehl et al. 1998). These changing winds and temperatures impacted formation and deterioration of seasonal sea ice and polynyas, which in turn influenced the proportion of breeding penguins and thus their reproductive success.

In addition to affecting reproductive success, changes in sea ice induced by climate change pose threats to emperor penguin survival. Using long-term data from 1952-2000 from the emperor penguin colony located near Dumont d'Urville Station in Terre Adélie, Barbraud and Weimerskirch (2001) examined relationships between penguin vital rates and climate conditions and found that adult penguins survived significantly better when sea-ice extent was greater. Forcada and Trathan (2009) reviewed the climate drivers of ecosystem change, including changes in sea ice, and the response mechanisms of ice-obligate emperor penguins. They noted that emperor penguins' distributional range has shifted poleward and contracted. Other studies have also documented the importance of sea ice to emperor penguins or negative impacts from limited sea ice or early sea-ice break up (Kooyman 1993; Jenouvrier et al. 2005a; 2005b).

Trathan et al. (2011) documented the decline and loss of an emperor penguin colony in the Dion Islands, close to the West Antarctic Peninsula, and related it to rising local mean air temperatures and a concurrent reduction in seasonal sea ice duration. The breeding population in this colony was stable from its discovery in 1948 to 1970, but for the next ~30 years it rapidly declined. Trathan et al. (2011) found that the major cause of this demise was a chronic decrease in the duration of seasonal sea ice caused by local atmospheric warming, which reduced breeding habitat and exposed the colony to ocean swell during storms. They also suggested that warming and shorter duration of sea ice could have altered important trophic interactions with fish, krill and squid on which emperor penguins feed, also contributing to the colony's demise. This study highlights the vulnerability of emperor penguin colonies, particularly in the West Antarctic Peninsula, to altered sea ice duration and distribution, and suggests we can expect additional impacts on the species with continuing effects of climate change.

Research predicts continued impacts of changes in sea ice and other effects of climate change on emperor penguins into the future. In a review paper, Ainley et al. (2010) examined the response of emperor penguins to habitat variability, and modeled the impacts that habitat alterations caused by a 2° C temperature rise from ~1860 would have on the species' populations, size and distribution. They used an ensemble of the IPCC Fourth Assessment Report climate models that best simulated observed climate change in the Southern Ocean and the composited model ENSEMBLE, and also considered other recent modeling studies. Their modeling results projected major changes to penguin habitat, including a >0.5° C increase in ocean surface temperature, thinning of sea ice, 1-2° C increases in air temperatures, and 10-15% and 5-10% decreases in annual mean sea ice coverage at 70° S and 60° S, respectively, occurring everywhere but strongest around the Antarctic Peninsula. The authors predicted that the decrease in sea ice coverage and thickness north of 70° S would cause a significant restricting of penguins' zoogeographic range by 2025-2052. Specifically, they projected that ~50% of colonies north of 70° S, representing 40% of the breeding population, were in jeopardy of decline or disappearance. Furthermore, colonies would be under increased susceptibility to the impacts of temperature increases greater than 2° C. Colonies towards the end of the Antarctic Peninsula would be most vulnerable. The authors argued that emperor penguins will be especially challenged to find new nesting areas under changing climate conditions because they nest and rear their young on fast ice over a prolonged approximately nine-month period. They projected that decreases in sea ice thickness and coverage across many regions, including the inner regions of the Ross Sea, will make it difficult for penguins to find stable long-lasting fast ice even at higher latitudes. The authors concluded (p. 63):

...on the basis of changes in the physical habitat alone and the penguin life cycle, it appears from our analysis that by the time Earth's troposphere reaches +2°C above preindustrial levels, we can expect major reductions and alterations in the abundance and distribution of pack ice penguins...

Jenouvrier et al. (2009) projected emperor penguin population responses to future sea ice changes, providing further evidence that emperor penguins are imperiled by

climate change. Jenouvrier et al. (2009) used a stochastic population model that combines a unique long-term demographic dataset (1962–2005) from a colony in Terre Adélie and projections of sea-ice extent from the IPCC Fourth Assessment Report. As Jenouvrier et al. (2009) noted, “Antarctic sea ice extent (SIE) is projected to shrink as concentrations of atmospheric greenhouse gases (GHGs) increase, and emperor penguins (*Aptenodytes forsteri*) are extremely sensitive to these changes because they use sea ice as a breeding, foraging and molting habitat” (p. 1844). Importantly, these researchers showed that the increased frequency of warm events associated with projected decreases in sea-ice extent will reduce the emperor penguin population viability, where the probability of quasi-extinction (a decline of 95% or more) is at least 36% by 2100. The authors concluded (p. 1844):

To avoid extinction, emperor penguins will have to adapt, migrate or change the timing of their growth stages. However, given the future projected increases in GHGs and its effect on Antarctic climate, evolution or migration seem unlikely for such long lived species at the remote southern end of the Earth.

Forcada and Trathan (2009) predicted that although penguin responses to climate change will vary according to interactions between different modes of climate variability and drivers of ecosystem change, overall, penguins’ long life spans and slow microevolution are unlikely to improve their tolerance to rapid warming. Instead, the authors predict that penguins will more likely disperse, rather than adapt, to climate change. Ice-obligate emperor penguins may struggle to disperse and colonize new habitats with future contraction of Antarctic sea ice.

Climate change effects on krill

Antarctic krill (*Euphausia superba*) are an important part of the food web in the marine Antarctic ecosystem and serve as prey for a number of predator species (ATME 2010a; Ducklow et al. 2007; Meyer 2010). Antarctic krill demography and life history are dependent upon sea ice dynamics, climate, ocean water chemistry, and ocean currents (ATME 2010a; Quetin and Ross 2003; Ducklow et al. 2007; Kawaguchi et al. 2011), factors that climate change is affecting. In particular, important spawning, recruitment, and nursery areas are located in the southwest Atlantic and along the coast of the Western Antarctic Peninsula (Meyer 2010), which is experiencing dramatic changes from warming (ATME 2010b; Steig et al. 2009; Champan and Walsh 2007; Convey et al. 2009; Clarke et al. 2007; Stammerjohn et al. 2008). Deviations from average sea ice timing, extent and duration have negative effects on krill recruitment, which in turn impacts krill availability for predators such as emperor penguins (Quetin and Ross 2001, 2003; Ducklow et al. 2007).

In the Atlantic sector of the Southern Ocean, ocean warming and the melting of sea-ice have been linked to the decline of Antarctic krill. Atkinson et al. (2004) examined spatial and temporal changes in Antarctic krill using all available scientific net sampling

data from 1926 to 2003. This analysis showed that the productive southwest Atlantic sector containing more than half of Southern Ocean krill stocks has suffered a decline of as great as 80% in krill density since the 1970s. Summer krill density correlates spatially with chlorophyll concentrations and temporally with sea-ice extent the previous winter (Atkinson et al. 2004). Since krill graze on algae that grow on the bottom of sea ice, the loss of ice leads to the loss of krill. Summer food and winter sea ice extent are thus important determinants of the high krill densities in the southwest Atlantic (Atkinson et al. 2004). Whitehouse et al. (2008) also detected a significant negative relationship between summer water temperatures and mean summer density of Antarctic krill across the southwest Atlantic sector of the Southern Ocean from 1925-2006, indicating that habitat suitability for Antarctic krill is declining.

Montes-Hugo et al. (2009) suggested that an additional cause of declining krill populations along the Western Antarctic Peninsula may be changing ocean biological productivity and associated changes in phytoplankton brought on by rapid regional climate change. They documented significant latitudinal shifts in phytoplankton patches, and suggested that these changes may be reorganizing penguin prey such as krill and Antarctic silverfish, which are dependent on ice-edge diatom (phytoplankton) blooms. The authors predicted that such shifts will continue to decrease krill abundance in the northern Western Antarctic Peninsula into the future.

Ocean acidification also poses a threat to krill. In a laboratory study examining the effects of ocean acidification on Antarctic krill, Kawaguchi et al. (2011) found that high levels of CO₂ (2000 $\mu\text{m pCO}_2$) disrupted development in 90% of embryos and prevented successful hatching of 100% of larvae. Using IPCC projections, their results predicted that by 2100, sea water $p\text{CO}_2$ could reach 1400 μm in the ocean depth occupied by krill, potentially resulting in detrimental impacts on the species. The authors warned that although it is unknown whether 1400 $\mu\text{m pCO}_2$ would necessarily disrupt embryo development and larvae hatching, it could have serious impacts especially when combined with other threats to krill, including reductions in sea ice area, recent regional recovery of krill predators, and expanding krill fisheries. They also noted that as the sea water in their study was undersaturated with respect to calcite, the negative impacts on krill demonstrated by their results could have arisen because of calcite undersaturation. Although most ocean acidification studies have focused on impacts to tropical and temperate shallow-water calcifying organisms (Doney et al. 2009), threats to other calcifying organisms (McClintock et al. 2009; Moy et al. 2009) lend support to the risk ocean acidification poses to Antarctic krill.

Altered krill abundance and recruitment associated with decreased sea ice and extent may be important factors behind local declines in ice-dependent Adélie penguin populations in the West Antarctic Peninsula (Ducklow et al. 2007; Montes-Hugo et al. 2009). Trivelpiece et al. (2011) argued that reduced abundance of Antarctic krill as prey have been the main cause of recent decreases in the populations of Adélie and chinstrap penguins in the Western Antarctic Peninsula and Scotia Sea. The authors argued that the availability of krill as prey, in turn, has been affected by climate-driven declines in sea ice and increased competition from recovering whale and fur seal populations. The

implications of this study are that declines in krill associated with reduced sea ice suggest future limitations in availability of krill for penguins and other predators.

Barbraud and Weimerskirch (2001) documented a decline of 50% at the emperor penguin colony at Terre Adélie, linked to a decrease in adult survival during the late 1970s. The decline coincided with prolonged higher-than-usual sea-surface temperatures in foraging areas and reduced sea ice extent. The authors identified sea-ice associated prey availability as the likely mechanism behind the link between warm sea surface temperatures and population declines:

Prey availability is influenced by physical parameters such as sea-ice extent or sea-surface temperature (or both). Decreased frequency of krill recruitment associated with a decreased frequency of extensive winter sea-ice may be responsible for low population sizes of krill, and lower krill abundance is associated with areas with less winter sea-ice cover. In years with high SSTs [sea surface temperatures], emperor penguins probably have difficulties in finding food, which could increase mortality (p. 184-5).

Barbraud and Weimerskirch (2006) also suggested that the negative effects of declining sea ice extent on krill availability have made it more difficult for emperor penguins in Terre Adélie to acquire enough food necessary for breeding, resulting in later egg-laying over the period 1950-2004. Reductions in krill and other prey availability would be particularly detrimental to emperor penguins immediately after they have moulted and fasted, a time period in which it is critical they reach an abundant food supply (Kooyman et al. 2004).

Modeling studies project dramatic declines in krill under future climate change scenarios. Climate change impacts on sea ice dynamics have the potential to dramatically change the productivity in the Antarctic region, partly through changes in Antarctic krill, important prey for numerous species (Nicol et al. 2008). Murphy et al. (2007) explored how a 1°C rise in sea surface temperature would affect Antarctic krill populations in the Atlantic sector of the Southern Ocean, which has important implications for krill predators. First, Murphy et al. (2007) examined how climate processes affect krill population dynamics, and detected strong relationships between sea surface temperature and winter sea-ice extent and the recruitment and dispersal of Antarctic krill. Based on these relationships, Murphy et al. (2007) then modeled how a 1°C rise in sea surface temperature (a likely scenario in this century) would affect krill biomass and abundance, and projected a more than 95% reduction in krill biomass in approximately 50–60 years (100% probability of local extinction) and a more than 95% reduction in krill density in less than 50 years (85% probability of local extinction) across the Scotia Sea. The researchers reported that krill-dependent predators suffer from low reproductive success in years of low krill abundance in this region. Therefore, projected large-scale declines in krill biomass within this century due to climate warming pose a significant threat to emperor penguin colonies that forage in the Atlantic sector of the Southern Ocean.

The effects of a warming Southern Ocean on krill will likely be strongest in warmer regions. Wiedenmann et al. (2008) projected growth trajectories for cohorts of krill and how krill biomass fluctuations change with temperature. These authors predicted decreasing individual krill size with increasing temperatures in warmer waters around South Georgia Island, and increasing individual krill size with increasing temperatures in cooler waters around the Antarctic Peninsula. Years with many cohorts of small individual were accompanied by below-average levels of krill biomass. Atkinson et al. (2006) also showed that even small temperature increases have negative effects on optimal growth in krill.

As summarized by Chapin et al. (2005), continued anthropogenic greenhouse emissions pose a major threat to penguin populations as mediated by impacts on krill species (p. 728):

This tight but complex linkage of krill population dynamics to sea ice suggests that any future changes in timing, duration, or extent of sea ice will strongly affect the community composition of phytoplankton, krill, and their predators. Because advection of biological material is important in maintaining Southern Ocean ecosystems, the potential impacts of regional changes may extend well to the north of the main sea-ice-covered regions.

In sum, global warming is already changing Emperor Penguin phenology, survival, reproductive success, and population size. As emissions continue to rise, the consequences will only become more severe. Accordingly, global warming is the primary driver placing the emperor penguin in danger of extinction throughout all or a significant portion of its range in the foreseeable future.

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

Emperor penguins are not currently harvested or collected for commercial, recreational, scientific, or educational purposes. However, although not traditionally considered “overutilization,” tourism in Antarctica has arisen as a potential threat to emperor penguins. While well-managed tourism is likely compatible with emperor penguins, current rates of growth call into question whether it is in fact well-managed.

Antarctic tourism is a rapidly growing industry. From 1958 until 1987, an average of fewer than 1000 tourists visited Antarctica each season (Enzenbacher 1992). Since then, the number of tourists has increased exponentially to reach over 26,000 in the 2006 season (IAATO 2006). This trend is likely to continue as much larger ships enter the market and tour operators continue to acquire more aircraft. So called “ecotourism” generally remains largely unregulated and can have negative consequences for native species (Jaffe 2006).

Burger and Gochfeld (2007) studied the effects of people on emperor penguins traveling between the Snow Hill breeding colony and the sea to forage. The distances at which emperor penguins took notice of people and switched direction increased significantly with more tourists in the penguins' path. Penguins that noticed people often stood up and called, whereas undisturbed penguins usually tobogganed on their ventral side over the ice. Penguins traveling near people paused for longer durations and more frequently when passing people than penguins traveling >200 m from people, suggesting that proximity to people increased the energetic cost of commuting.

The use of helicopters is of particular concern for species such as emperor penguins that breed in remote areas and are not accustomed to disturbance. Harris (2005) examined the potential of aircraft operations to disturb penguins. The authors concluded that disturbance is likely to have impacts on the health, breeding performance and survival of individual birds, and perhaps bird colonies. Giese and Riddle (1999) studied possible disturbance by helicopters of emperor penguin chicks at the Amanda Bay colony. All chicks became more vigilant when approached by a helicopter, and 69% of chicks either walked or ran, generally towards other chicks. A majority of chicks (83%) flapped their flippers when approached by helicopters, suggesting nervous apprehension, but chicks rarely displayed this behavior when undisturbed.

While guidelines for the operation of aircraft in Antarctica have been adopted, the interactions between aircraft and birds in Antarctica, and the consequent impacts on individual birds and on bird populations are still so poorly understood that aircraft should be considered a potential threat to penguins (Harris 2005). In addition, enforcing such guidelines on tour operators given the vast expanse of the Antarctic will likely prove difficult if not impossible.

C. Inadequacy of Existing Regulatory Mechanisms

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

Regulatory mechanisms at the national and international level do not require the greenhouse gas emissions reductions necessary to protect the emperor penguin from climate change threats and are therefore inadequate. Although existing regulatory mechanisms in the United States, including the FWS's own authorities under the Endangered Species Act, can play an important role in regulating and ultimately reducing greenhouse gases, until and unless these mechanisms are fully implemented and combined with additional national and international efforts, climate change will continue to pose a significant threat to the emperor penguin.

a. National and International Emissions Reductions Needed to Protect the Emperor Penguin

The best available science indicates that atmospheric CO₂ concentrations should be reduced to at most 350 parts per million (ppm) to protect the emperor penguin, its sea-

ice breeding habitat, and its foraging habitat in the Southern Ocean. Numerous studies have demonstrated that current levels of greenhouse gases are already having significant impacts on species and ecosystems in all regions of the world, including changes in distribution, phenology, physiology, demographic rates, genetics, ecosystem services, as well as climate-related population declines and extinctions (Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003, Walther et al. 2005, Parmesan 2006, Leadley et al. 2010, Mooney et al. 2010, Chen et al. 2011, Dawson et al. 2011, Warren et al. 2011). Because greenhouse gas emissions to date commit the earth to substantial climatic change in the coming decades and because climate change is occurring at an unprecedented pace with multiple synergistic impacts, climate change is predicted to result in large-scale species losses during this century. The IPCC has warned that 20-30% of plant and animal species will face an increased risk of extinction if global average temperature rise exceeds 1.5-2.5°C relative to 1980-1999, with an increased risk of extinction for up to 70% of species worldwide if global average temperature rise exceeds 3.5°C relative to 1980-1999 (IPCC 2007). Thomas et al. (2004) projected that 15-37% of species will be committed to extinction by 2050 under a mid-level emissions scenario, which the world has been exceeding. Maclean and Wilson (2011) found that the harmful effects of climate change on species exceed predictions and that one in 10 species could face extinction by the year 2100 if climate change continues unabated. As documented in this Petition, climate-vulnerable species like the emperor penguin are highly susceptible to extinction absent immediate and significant cuts in global emissions.

Several studies provide strong support that the current atmospheric CO₂ concentration already constitutes ‘dangerous climate change’ for species and ecosystems, and must be reduced to at most 350 ppm to protect them (Hansen et al. 2008, Lenton et al. 2008, Jones et al. 2009, Smith et al. 2009, Warren et al. 2011). As summarized by Hansen et al. (2008):

If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO₂ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that.

In order to reach a 350 ppm CO₂ target or below, global CO₂ emissions must peak before 2020, and likely by 2015, followed by rapid annual reductions bringing emissions to or very close to net zero by 2050 (CBD 2010, UNEP 2010). Baer et al. (2009) outlined a trajectory to reach a 350 ppm CO₂ target by 2100 that requires 2020 global emissions to reach 42% below 1990 levels, with emissions reaching zero in 2050. This study concluded that Annex I (developed country) emissions must be more than 50% below 1990 levels by 2020 and reach zero emissions in 2050 (Baer et al. 2009). However, rather than declining, the global emissions trajectory has largely tracked that of the most fossil-fuel intensive IPCC emissions scenario, A1FI, since 2000 (Raupach et al. 2007, McMullen and Jabbour 2009, Richardson et al. 2009, Friedlingstein et al. 2010, Global Carbon Project 2010).

b. United States Climate Initiatives Are Insufficient

The United States, with only 4.5% of world population, is responsible for approximately 20% of worldwide annual CO₂ emissions (U.S. Energy Information Administration 2010, <http://www.eia.gov>), yet does not currently have adequate regulations to reduce greenhouse gas emissions. This was acknowledged by the Department of Interior in the final listing rule for the polar bear, which concluded that regulatory mechanisms in the United States are inadequate to effectively address climate change (Fed. Reg. 73: 28287-28288). While existing laws including the Clean Air Act provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the U.S., these agencies are either failing to implement or only partially implementing these laws for greenhouse gases.

For example, the EPA issued a rulemaking regulating greenhouse gas emissions from automobiles (Fed. Reg. 75: 25324, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule), has initiated a process for issuing rules for greenhouse gas emissions from power plants and oil refineries (see, e.g., Fed. Reg. 75:82392, Proposed Settlement Agreement, Clean Air Act Citizen Suit), and on January 2, 2011, began implementing, in a slow, cautious, and phased manner, the new source review program for greenhouse gases (Fed. Reg. 75: 17004, Reconsideration of Interpretation of Regulations That Determine Pollutants Covered by Clean Air Act Permitting Programs). However, the EPA has as yet failed to implement the critically important criteria air pollutant/national ambient air quality standards program for greenhouse gases, and has failed to issue any greenhouse rules for many other stationary and mobile sources, and there is no evidence that existing and currently proposed rulemakings would provide anything close to the greenhouse reductions needed to avert the warming that jeopardizes the emperor penguin. In addition, the USFWS has not exercised its authority, despite the legal mandate through the ESA Section 7 inter-agency consultation process, to consider the impacts of major new federal actions that result in large quantities of greenhouse gases on listed species. The Service has long consulted on a wide range of impacts, such as logging that harms owls, pesticides that harm frogs, and mercury emissions that harm fish. Greenhouse gas emissions are not fundamentally different than other pollutants that accumulate in the land, air, and water and damage wildlife and ecosystems. There is no legal or logical reason why greenhouse gases could be somehow exempt from the Section 7 consultation process, and the USFWS's failure to exercise its authority is unsupportable.

While full implementation of the nation's flagship environmental laws, particularly the Clean Air Act, would provide an effective and comprehensive greenhouse gas reduction strategy, due to their non-implementation, existing regulatory mechanisms must be considered inadequate to protect the emperor penguin from climate change.

c. International Climate Initiatives Are Insufficient

The primary international regulatory mechanisms addressing greenhouse gas emissions are the United Nations Framework Convention on Climate Change (UNFCCC)

and the Kyoto Protocol. As acknowledged by the Department of Interior in the final listing rule for the polar bear, these international initiatives are inadequate to effectively address climate change (Fed. Reg. 73: 28287-28288). Under the UNFCCC, signed by the first President George Bush and ratified by the U.S. Senate, the U.S. agreed to take action necessary to avoid dangerous climate change. However, the U.S. is the only developed country in the world that has to date refused to ratify the Kyoto Protocol. The Kyoto Protocol's first commitment period sets targets for action through 2012. Importantly, there is still no binding international agreement governing greenhouse gas emissions in the years beyond 2012.

While the 2009 U.N. Climate Change Conference in Copenhagen called on countries to hold the increase in global temperature below 2°C (an inadequate target for avoiding dangerous climate change), the *non-binding* "Copenhagen Accord" that emerged from the conference failed to enact binding regulations that limit emissions to reach this goal. Even if countries did meet their pledges, analyses of the Accord found that collective national pledges to cut greenhouse gas emissions are inadequate to achieve the 2°C limit, and instead suggest that these pledges would lead to 2.5°C to 5°C warming (Rogelj et al. 2010, UNEP 2010). The United States pledge to reduce emissions by 17% below 2005 levels in 2020, or 3% below 1990 levels, has been rated as completely insufficient to stay within the 2°C target². Ironically, the single greatest barrier to international progress has long been U.S. inaction, despite the fact that the U.S. has the strongest domestic environmental laws in the world. In short, international regulatory mechanisms must be considered inadequate to protect the emperor penguin from climate change.

2. Regulatory Mechanisms Addressing Other Threats Are Inadequate

a. Commission for the Conservation of Antarctic Marine Living Resources

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) came into being in 1980 and is the first international body to adopt an ecosystem approach to management. The goals of the CCAMLR are to conserve Antarctic marine living resources by taking an ecosystem approach to management and exploitation. CCAMLR sets the harvest levels for all commercially important fisheries in the Antarctic Treaty Area. In particular, CCAMLR places catch limits on penguin prey species, including krill.

While CCAMLR is more precautionary than most Regional Fishery Management Organizations, current management of krill does not directly incorporate the needs and specific foraging areas of krill predators such as emperor penguins, at neither spatial nor temporal scales (Nicol et al. 2011; ATME 2010a). Additionally, the current CCAMLR quota setting system fails to take into account the effects of climate change on krill stocks (Marris 2004; ATME 2010a). Finally, even if CCAMLR adequately managed krill

² <http://www.climateactiontracker.org/country.php?id=2920>

harvest, it can do nothing to address the climate-related declines of krill that are underway. Although CCAMLR has acknowledged that it needs to develop a “feedback management procedure,” it still has yet to develop a management scheme for krill that incorporates interactions between the fishery, climate change, and krill predators (ATME 2010a).

There is a need for more information on the effects of the krill fishery on krill-dependent predators such as the emperor penguin. The CCAMLR Ecosystem Monitoring Program was established in 1986 to detect changes in the ecosystem caused by the krill fishery, particularly impacts on krill predators (Kock et al. 2007). Members submit data on a voluntary basis (Kock et al. 2007). However, the emperor penguin is not currently on the list of predators monitored by this program (Kock et al. 2007). Another program, the CCAMLR International Observer Scheme, is intended to gather and confirm information on the status of species potentially impacted by the fishery, as well as related and dependent species (CCAMLR 2011). However, current krill fishing grounds in the southwest Atlantic are still exempt from mandatory scientific observation (Nicol et al. 2011), and thus collection of data on ecosystem impacts has been inconsistent.

D. Other Natural and Anthropogenic Factors

1. Fisheries Interactions: Competition for Limited Marine Resources

Antarctic krill (*Euphausia superba*) is harvested primarily for use in aquaculture feed, but is also used as fish bait, for human consumption, and in products for human use (e.g. medical applications and food additives) (Nicol et al. 2011). Currently, Norwegian and Korean companies dominate the krill catch, but Chinese and Russian vessels are also harvesting krill (Nicol et al. 2011). The fishery for Antarctic krill is the largest by weight in the Southern Ocean (Nicol et al. 2011). This fishery is the largest crustacean fishery in the world and, if fully exploited, it has prospects for becoming the largest global fishery (Nicol and Endo 1997). It has recently increased to greater than 200,000 tons per year after having been at ~120,000 tons for 17 years until 2009 (Nicol et al. 2011). Furthermore, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) precautionary catch limits for Antarctic krill are over 8.6 million tons per year, so current harvesting of >200,000 tons per year still has significant potential to increase (Nicol et al. 2011). In addition, there have been significant recent advances in harvesting technology and efficiency, growing interest in krill-based aquaculture feed and products for human use, restrictions and concerns over krill fishery development in the northern hemisphere, and new countries entering the Southern Ocean krill fishery (Nicol et al. 2011). All of these trends, along with a perceived massive abundance of krill stocks in the Southern Ocean, indicate a growing demand for Antarctic krill into the future.

The expanding krill fishery raises concerns about the impacts of the krill fishery on emperor penguins and the future of the vulnerable and still little-understood Antarctic marine ecosystem. Emperor penguins are dependant at different times and locations on krill, fish and squid (Shirihai, 2002). Emperor penguins operate near their metabolic

limits and any reduction in food availability can lead to mortality, reduced breeding success, and population declines (Barbraud and Weimerskirch 2001; Jenouvrier et al. 2005a; Kooyman et al. 2004). Given that krill are the main food source for many emperor penguin populations in winter, increased harvest of Antarctic krill has the potential to remove vital food resources from breeding adults at their most vulnerable stage (Ellis et al. 1998).

Although krill catches in the Southern Ocean are currently below catch limits set by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), there is a risk of localized, excessive fishing effort that might affect emperor penguins that depend on krill for food, particularly during the breeding season. Krill fishing generally operates in the late summer to mid winter and is currently concentrated in the southwest Atlantic, which is thought to contain most of the krill stock (Atkinson et al. 2004, 2009). Furthermore, 99% of krill fishing occurs along the continental slope (ATME 2010a). These fished waters are adjacent to the Antarctic Peninsula, which has both known and suspected emperor penguin breeding colonies (Fretwell and Trathan 2009). Penguins forage along the Antarctic continental shelf (Wienecke and Robertson 1997), which extends into the area fished for krill (Ingólfsson, 2004). In addition, numerous colonies exist in surrounding areas, such as the nearby Weddell Sea (Fretwell and Trathan 2009). Given that breeding emperor penguins make foraging trips 50-300 km away from breeding sites and newly fledged penguins disperse up to 3000 km from the colony into waters that may be commercially fished (Ainley et al. 1984; Kooyman 2002; Kooyman et al. 1996), there is a high likelihood that the krill fishery overlaps with emperor penguin foraging ranges in the area surrounding the Antarctic Peninsula. In addition, female penguins forage in the ocean for approximately two months after laying an egg in May or June (Shirihai 2002), which are peak months of high catch in the krill fishery (Nicol et al. 2011). Thus there is potential for krill fisheries in the southwest Atlantic to both spatially and temporally coincide with emperor penguin foraging. More overlap can be expected as the krill fishery expands to new regions in the future.

Alonzo et al. (2003) used a behavioral model to determine indirect effects of krill fisheries on penguin foraging success and behavior in nearby breeding locations. The authors found that increased fishing pressure offshore is projected to decrease penguins' intake of food, leading to reduced penguin survival and reproduction. The results suggested that krill behavior will cause krill fisheries to have larger impacts on penguins than solely from a removal of krill biomass. Environmental conditions that reduce krill growth rates (i.e. low water temperature or reduced phytoplankton abundance) or result in krill occupying deeper water (and therefore becoming less accessible to diving penguins) are expected to exacerbate negative impacts of krill fishing on penguins.

Finally, evidence suggests that krill stocks in the southwest Atlantic Ocean have declined by 38-80% (Atkinson et al. 2004; Loeb et al. 1997). When an expanded fishery is superimposed on top of this climate-related decline in krill abundance, krill harvesting has the potential to exacerbate other threats to emperor penguins. In conjunction with the already observed and projected impacts of global warming on emperor penguins, fishing poses a significant and growing threat to the continued existence of the species.

2. Contaminants

Although Antarctica is remote and considered by some to be an area of untouched wilderness, environmental contamination from human activities have indeed reached the continent and surrounding waters (Bargagli 2008). Research and tourism over the last half-century have caused local impacts to terrestrial and marine coastal ecosystems from fuel combustion, oil spills, sewage, and waste incineration (Bargagli 2008). Population growth and industrial development in the Southern Hemisphere have caused new classes of chemicals to enter the Antarctic environment (Bargagli 2008). Corsolini (2009) reviewed the literature on industrial contaminants in biota from Antarctica and the Southern Ocean. Although Corsolini (2009) found low concentrations of industrial contaminants in biota relative to other regions of the world, some species had high levels of contaminants. The review showed that many contaminants occur in highest concentrations in low trophic level species, indicating that bioconcentration occurs at lower trophic levels of pelagic food webs. Biomagnification can result in contamination at higher trophic levels. As emperor penguins are predators of species at lower trophic levels, the accumulation of contaminants poses another risk.

Although the accumulation of anthropogenic contaminants in emperor penguins has not been studied extensively, fish-eating seabirds are at risk of accumulating toxic contaminants because of their relatively high trophic level and their difficulty in metabolizing xenobiotic compounds (Corsolini, Borghesi, Schiamone, & Focardi, 2007). Several studies have detected persistent organic pollutants (POPs) in Antarctic ecosystems, including: in Adélie penguin stomach contents, krill, and silverfish in the Ross Sea (Corsolini et al. 2003); in Adélie, Gentoo and Chinstrap penguins at King George Island (Corsolini et al. 2007); at higher concentrations in soil at Adélie penguin colonies in Hop Island as compared to reference sites, pointing to bioaccumulation of POPs (Roosens et al. 2007); and from Ross Sea emperor penguin eggs and other Antarctic seabird eggs (Corsolini et al. 2011). Although these studies generally reported low concentrations of contaminants relative to other areas of the globe, given that contaminant threshold levels in penguins are unknown and contaminant input through penguin diet can be quite high, the relatively understudied risk that contaminants pose to emperor penguins should not be neglected (Corsolini et al. 2003).

Conclusion

The emperor penguin warrants listing as threatened or endangered under the ESA. Such status is appropriate based on observed and projected population declines correlated with increasing sea temperatures, changes in sea-ice extent and duration, and declines in krill availability. Global warming and ocean acidification resulting from anthropogenic greenhouse gas emissions is the primary driver of significant changes in the Antarctic marine ecosystem upon which the emperor penguin depends. For these reasons, detailed in the Petition, Petitioner Center for Biological Diversity requests that FWS list the emperor penguin as threatened or endangered under the ESA, as it is currently at risk of extinction in all or a significant portion of its range within the foreseeable future.

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