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Penguins as Marine Sentinels

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From the tropics to Antarctica, penguins depend on predictable regions of high ocean productivity where their prey aggregate. Increases in precipitation and reductions in sea ice associated with climate warming are affecting penguins. The largest breeding colony of Patagonian (Magellanic) penguins, at Punta Tombo, Argentina, had approximately 200,000 breeding pairs in October 2006—a decline of 22% since 1987. In the 1980s and 1990s, petroleum pollution was a major source of Patagonian penguin mortality. In 1994, tanker lanes were moved 40 kilometers (km) farther off the coast of Chubut, and the dumping of ballast water and the oiling of penguins are now rare. However, penguins are swimming 60 km farther north from their nests during incubation than they did a decade ago, very likely reflecting shifts in prey in response to climate change and reductions in prey abundance caused by commercial fishing. These temperate penguin species, marine sentinels for southern oceans, demonstrate that new challenges are confronting their populations.

Keywords: penguins, global warming, climate variation, El Niño, marine zoning

Penguins are sentinels of the marine environment, and by observing and studying them, researchers can learn about the rate and nature of changes occurring in the southern oceans. As ocean samplers, penguins provide insights into patterns of regional ocean productivity and long-term climate variation. Having studied several species of temperate penguins for more than 30 years, I know firsthand how sensitive they are to their environment. I synthesize my observations to suggest that we have entered a new era of unprecedented challenges for marine systems.

The Antarctic Treaty protects living resources in Antarctica; the Convention on International Trade in Endangered Species of Wild Fauna and Flora regulates trade in endangered species, including the Peruvian (or Humboldt) penguin (*Spheniscus humboldti*) and African (or black-footed) penguin (*Spheniscus demersus*); and the International Union for the Conservation of Nature (*www.iucn.org*) regards 10 of 17 penguin species as vulnerable to extinction. Legal protections have been insufficient to halt penguins' decline, however. Penguins face a gauntlet of environmental challenges, from climate change to human take. The erect-crested penguins (*Eudyptes sclateri*) that breed on the Antipodes Islands, located over 800 kilometers (km) from the South Island of New Zealand, numbered 50,000 breeding pairs in 1995—only half of what they were in 1978 (Peat 2006). Temperate penguins and those that are inshore foragers, such as the yellow-eyed (*Megadyptes antipodes*) and African penguins, are in decline because they are the most likely to come into conflict with human activities such as commercial fishing, guano mining, and oil and gas development (Boersma and Stokes 1995, Davis and Renner 2003).

Nonetheless, there are success stories. In New Zealand, penguin populations are growing in some areas after the removal of introduced predators. For example, rats were removed from more than 11,000 hectares of Campbell Island, the largest island in the world to be successfully cleared of rats. The island, declared rat free in 2003, is an important breeding ground for the rare endemic yellow-eyed penguin (Peat 2006). Erect-crested penguins, which used to breed on Campbell Island, may recolonize now that rats are gone. On New Zealand's South Island and in Australia, populations of the little blue penguin (*Eudyptula minor*) grew after nesting boxes were placed and predators trapped, resulting in new ecotourism businesses focused on penguins.

There are no safeguards to protect large breeding colonies of penguins, however, and it is these aggregations that people most wish to visit. Only 43 penguin "hotspots"—where at least 1% of the global penguin population aggregates to breed—are left in the world (figure 1; Boersma and Van Buren 2003). Large colonies are important for the survival and health of each penguin species. Determining the status and trends of penguin populations at these 43 sites would provide insight into ocean ecosystem variability and viability, but these sites are rarely, and some almost never, counted. Population surveys twice every decade when penguins have eggs could reliably convey the state of the Southern Ocean. Ideally,

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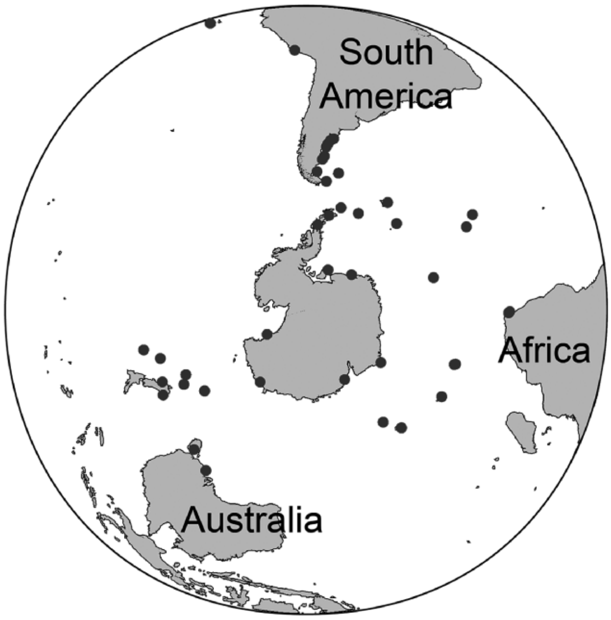

Figure 1. Map showing the 43 colonies that hold 1% or more of the global population for each species of penguin. These are the penguin hotspots of the world.

each colony should be visited annually to determine six sentinel parameters: reproductive failure, adult mortality, foraging changes, reproductive success, breeding phenology, and demographic and range changes. Unfortunately, most of these colonies have not been counted even once a decade. When colonies have been counted more than once, it has been at different times in the breeding cycle, so the population trends of most of the large colonies remain unknown. Indeed, most of the sentinel parameters remain unknown.

Penguins of the world

Many people think of penguins as existing only in icy parts of the Southern Hemisphere, but only two species of penguins are restricted to Antarctica: the Adélie (*Pygoscelis adeliae*) and the emperor (*Aptenodytes forsteri*). There are 16 to 19 species of penguins, depending on the tools used in classification. The oldest penguin fossil dates to about 55 million years before the present (Fordyce and Jones 1990). Population genetic tools can distinguish differences that are not easily visible, thereby increasing the number of species recognized (Banks et al. 2006). Using both genetic and morphological tools, and estimating divergence time among species, the evolutionary relationship can be shown as a family tree with five distinct branches (Davis and Renner 2003). One of these branches depicts the recent radiation of four species of penguins of the genus *Spheniscus* that occupy mid- to low-latitude temperate areas. These species breed in coastal deserts on the Atlantic and Pacific oceans where they are relatively easily studied. The Galápagos penguin (*Spheniscus mendiculus*), the most northerly species, breeds in shady cracks, crevices, or lava tubes of the equatorial Galápagos Islands.

People travel from all over the world to spend a few hours with penguins. Each year, about 500,000 people visit Phillip Island, Australia, to see little blue penguins; over 100,000 tourists visit Punta Tombo, Argentina, the world's largest colony of Patagonian (or Magellanic) penguins (*Spheniscus magellanicus*); and about 50 cruise boats ply the waters in Antarctica, bringing 35,000 people to penguin colonies. (I use the location name, rather than the more widely used common name, for penguin species [e.g., Patagonian, Galapágos, African, Peruvian] to clarify where most of the individuals for each species are found.) Immersion in a colony of hundreds of thousands of penguins is a profound experience. Emperor penguins on ice, or king penguins (*Aptenodytes patagonicus*) on bare ground, often stand nearly foot to foot among thousands of neighbors when incubating their one egg. To be surrounded by the expanse of their colony, the air filled with their strident calls and with the pungent odor of guano, leaves a lasting impression. In contrast, some species, such as yellow-eyed penguins, breed in forests or among large flax plants and never form dense aggregations. Although they may not be able to see their neighbors because of the vegetation, these penguins are in vocal communication. Their raucous yells and squeaks in the evenings are haunting.

Penguins are highly specialized for swimming and diving, and therefore reflect regional oceanic variation more completely than other seabirds (Boersma et al. 2008). They reflect changes in oceanographic productivity and human-induced changes in the environment, including fishing pressure, climate variation, and oil pollution. Like many other seabirds, penguins are long-lived, lay one or two eggs, and take months to rear their young. Penguins are central-place foragers. Some penguins, such as kings, take 14 to 16 months to successfully reproduce (Williams 1995). King penguins require 10 months to rear one chick because they may leave their chick for more than five months in the winter to forage (Davis and Renner 2003). The chicks overwinter on land, are fed frequently in the spring (September and October), and then fledge when food is abundant. Two king penguins tracked by satellite during winter foraging trips from Possession Island were gone more than 50 days and traveled 1600 to 1800 km away from their chicks (Pütz et al 1999).

In contrast, Galápagos, Peruvian, and little blue penguins are gone less than a day when feeding chicks, and can rear their two chicks in only two months, because they find food close to their breeding sites and time their chick rearing for when prey is most available. The unpredictable nature of oceanographic productivity in the Galápagos archipelago has resulted in selection for molting before breeding, frequent nesting whenever conditions are favorable, and rapid chick growth (Boersma 1977).

Impacts of climate change on Antarctic and sub-Antarctic penguins

The fourth report of the United Nations–sponsored International Panel on Climate Change concluded that there is an 80% probability that anthropogenic warming has influenced many physical and biological systems (Kerr 2007). In the Northern Hemisphere, some butterflies (Parmesan and Yohe 2003) and intertidal invertebrates (Barry et al. 1995) have moved north. Plants bloom earlier as the climate warms (Stenseth et al. 2002). Spring blooming in plants for temperate species is five days earlier than it was a decade ago (Root et al. 2003). The timing of breeding and hibernation for some birds and mammals is consistent with anticipated responses to global warming (Inouye et al. 2000). The impacts of global warming are predicted to be most severe at the poles, and they can already be seen in Antarctic and sub-Antarctic penguins.

In the heart of East Antarctica, far from the equator and El Niño, changes in the breakup of sea ice affect penguin reproductive success. Annual winter sea-ice cover has decreased over the last 50 years, and the regional warming has reduced krill abundance, altering the marine food web (Loeb et al. 1997, Smith et al. 1999). The geographic and oceanographic setting of colonies, and the differences in life-history patterns among penguins, can obscure population trends. This is why large colonies should be counted at least twice a decade during incubation. The East Antarctic ice sheet, the largest reservoir of ice on the planet, shows little variability in its mass balance (Shepherd and Wingham 2007), but other glaciers and sea ice are retreating, and even small variations can have major consequences for penguins. I witnessed firsthand one colony's reproductive failure.

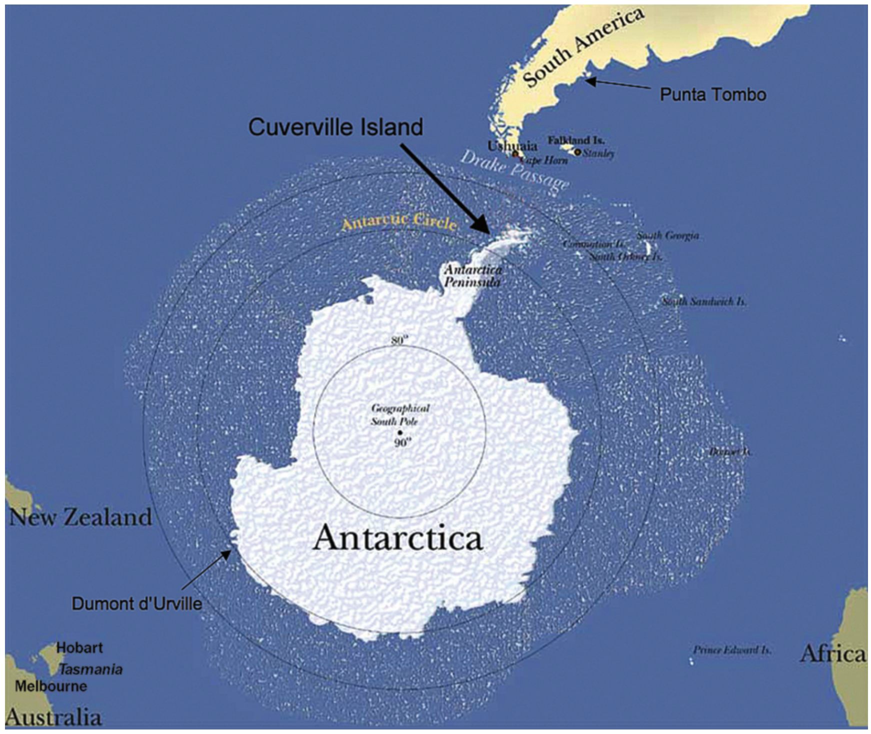

Figure 2. Map showing locations of study sites at Punta Tombo, Argentina, and in Antarctica.

In 2006, I visited the French base at Dumont d'Urville in East Antarctica (figure 2), where the movie *March of the Penguins* was filmed, in hopes of seeing the colony of emperor penguins that breeds there. This most Antarctic of species incubates its eggs in the middle of the South Polar winter, and the chicks usually fledge in December and early January (Williams 1995). On 20 December 2006, as the ship anchored in front of the base, I saw no sea ice and fewer than a dozen small icebergs in the waters around the station. It was the first time Rodney Russ, Heritage Expeditions' founder and expedition leader, had seen the area free of sea ice since he started visiting the area in the 1980s.

The emperor penguin colony in 2006 bred in the same location as in other years, on the shore-fast sea ice behind two small islands. The ice here is protected from the open sea, and the winds howling off the ice cap blow the snow so it does not accumulate and destroy the eggs or chicks. In September, when the chicks were a little more than half grown, the adults started marching with their chicks across the ice. After several days, the colony had moved more than 5 km from where the eggs had hatched. Apparently the penguins sensed they were in danger and found more stable sea ice. In late September, a large storm hit, and the strong winds and waves broke up and blew out the remaining sea ice and the penguins. Although the penguins were where the ice had remained the longest, the ice was gone long before late November, when the chicks could be independent. Chicks in late September are downy, not waterproof, and are unable to survive in the sea for any period of time. The storm most likely caused the reproductive failure of the entire colony. The population trend for emperor penguins may not yet be clear, but it is apparent that global warming will be a problem for emperor penguins, which are dependent on stable sea ice to breed.

Some of the best-documented signals of regional warming come from the western Antarctic Peninsula (WAP) (Cook et al. 2005, Shepherd and Wingham 2007). In the WAP, the mean winter air temperature has risen more rapidly (6 degrees Celsius since 1950) than anywhere else in the world (Stokstad 2007). By the 1990s, a reduction in winter sea-ice cover caused shifts in penguin abundance and distribution (Fraser et al. 1992, Trathan et al. 1996, Nicol and Allison 1997). Smith and colleagues (1999) showed that the modern and paleoclimate records of these penguins are consistent with a rapid warming in the WAP during the past century.

Climate warming and sea-ice reduction have induced population responses among Adélie, chinstrap, and gentoo penguins and other seabirds (Croxall et al. 2002, Forcada et al. 2006). Gentoo and chinstrap populations, which have expanded southward in the past 50 years with regional warming (Emslie et al. 1998), grew at a mean annual rate of 5.5% from 1979 to 2004 (Forcada et al. 2006). In contrast, in the

Antarctic Peninsula region, from King George Island to the South Shetlands, both Adélie and chinstrap populations have declined by 50% from the mid-1970s to the present (Hinke et al. 2007). The extensive ice cover in 1998 reduced reproductive success in chinstrap penguins (Lynnes et al. 2004). Sea-ice reduction can benefit relatively ice-intolerant species such as chinstrap and gentoo penguins and cause ice-requiring species like Adélie and emperor penguins to decline.

Between 2003 and 2004, I visited Cuverville Island, a small island near the Lemaire Channel, and saw how global warming was affecting one of the most southerly colonies of gentoo penguins (figure 2). Cuverville Island has approximately 4000 pairs of gentoo penguins. On my three visits, 23 November 2003 and 15 and 26 January 2004, I observed that increased precipitation associated with global warming was affecting nesting times. Several meters of snow covered the island in November, and even the tops of rocky areas were snow covered. The penguins were milling, copulating, sleeping, and standing in the snow (figure 3). The ground in their nesting area, covered with more than a meter of snow, provided no exposed rock where they could lay eggs, so they waited (figure 4a). Some rested on the snow, melting a hollow and creating an ice platform, but they could not melt enough snow to reach the underlying rock (figure 4b).

Climate warming on the Antarctic Peninsula increases snowfall, a change that at first glance may appear counterintuitive. This happens because the warmer air holds more moisture, leading to more snow and rain. When I returned on 15 January, I expected to find chicks a few weeks old. I enlisted tourists to look for chicks and report what they saw. One guest saw an egg and a tiny chick at the topmost peak. The wind exposed the peaks of islands, making these bare areas the first places where penguins laid their eggs (figure 5a).

The onset of egg laying in gentoo penguins, even at the same colony, can vary by three to five weeks from year to year. Cuverville Island is so far south that eggs are usually laid between late October and mid-November. The incubation period is 34 to 42 days, and chicks fledge in about 80 days (Williams 1995). During the period of my visits to Cuverville Island, the first egg was probably laid in early December 2003, about two weeks late.

When I next returned on 26 January, I found that most of the nests had small chicks, but many nests still had unhatched eggs. To keep the eggs and chicks dry, gentoo penguins had gathered rocks and pebbles, sometimes more than a thousand,

Figure 3. Gentoo penguins on Culverville Island on the Antarctic Peninsula copulating in the snow, which has not yet melted to expose breeding sites. Photograph: P. Dee Boersma.

Figure 4. (a) Penguin group in the snow. (b) The penguin in the foreground has rested on the snow long enough to melt it but still has not reached the rocks beneath. Photographs: P. Dee Boersma.

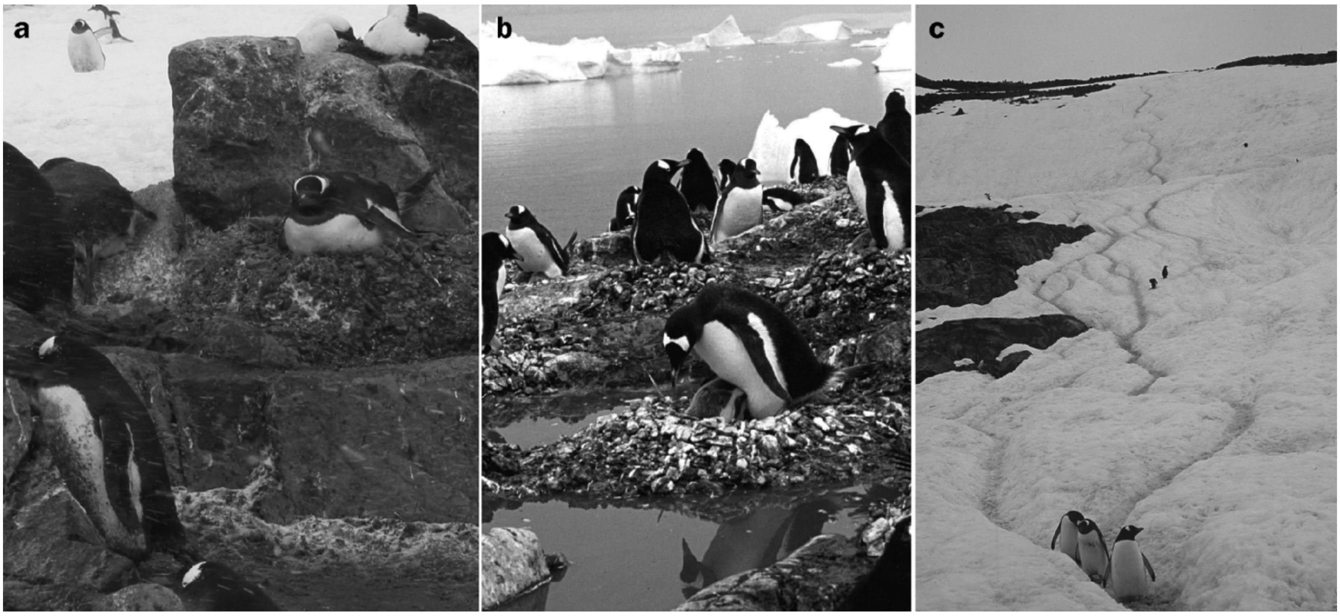

Figure 5. (a) On the Antarctic Peninsula, the first place where the snow is blown away and melts is on the rocky peaks of islands. (b) Gentoo adults with their one- and two-week-old chicks are surrounded by meltwater on their nests. (c) Gentoo penguins breeding at the first exposed sites at the top of the island must make long treks, leaving deep paths in the snow that they use to reach nesting sites. Photographs: P. Dee Boersma.

to build nests that acted as little islands (figure 5b). To get to the snow-free ridges, penguins walked through deep snow, creating paths (figure 5c). The oldest chicks I saw were probably 10 to 14 days old.

The heavy snow cover placed the gentoo chicks on Cuverville Island in a time squeeze. Could the chicks grow fast enough to fledge before their parents had to desert them to molt? A quick calculation suggested that fledging would be in April and May. Parents fattening for the molt would have to either desert their offspring before they were ready to fledge or die themselves.

Increases in rain or snowfall and reductions in ice cover (such as the early breakup of ice or blocking of entrances and exits to colonies by icebergs) can cause penguin nest failure. In addition, climate variation can cause timing mismatches between reproduction and prey availability (Durant et al. 2007). Snow and rain affect penguin species differently. For chinstrap and gentoo penguins, the advantage conferred by sea-ice reductions may be negated by increases in snowfall that delay or prevent breeding. For Adélie penguins at Paulet Island in the Weddell Sea, increased rain causes chicks to die. Adélie chicks are adapted to cold weather and light snow. Snow can build up on their down, but beneath the feathers they are dry and warm (figure 6a). If they get wet in the rain, the chicks die from hypothermia (figure 6b). Adélie chicks need juvenile plumage under their chick down to tolerate rain. With global warming and increases in climate variation, some colonies and populations of penguins will do better and others worse. We can be confident that the changes will continue to be dramatic.

Impacts of environmental cycles on temperate penguins

The first seabird reported to show the biological effects of El Niño farther west than the South American coast was the Galápagos penguin (Boersma 1978). El Niño, with its warm, unproductive waters, caused adult Galápagos penguins to desert their eggs and chicks to search for food to save themselves while their chicks starved to death. One of the predicted results of climate warming is an increase in the frequency and severity of El Niño events. Galápagos penguin populations are now about 25% of what they were in the 1970s (Boersma 1998a). After the 1982–1983 and 1997–1998 events, Galápagos penguins declined by more than 65% (Vargas et al. 2005, 2007). In May 1998, both males and females weighed less than during the 1972 El Niño, reflecting the 1998 event's greater severity (Boersma 1998b). At the end of the 1998 El Niño, female penguins were only 80% and males 90% of their average body weight in the absence of El Niños.

Female penguins are probably more likely than males to die during El Niño because of poor body condition. If the sex ratio becomes skewed—and it was already biased toward males in the early 1970s and in 1998—population recovery will be slow, because many males will not find mates. So what will happen to Galápagos penguins if the climate warms and El Niños, as predicted, become more severe and frequent? Using population viability analyses, researchers estimate that the chance of Galápagos penguins' becoming extinct in the next 100 years is 30% without assuming more frequent and more severe El Niños (Boersma et al. 2005, Vargas et al. 2007).

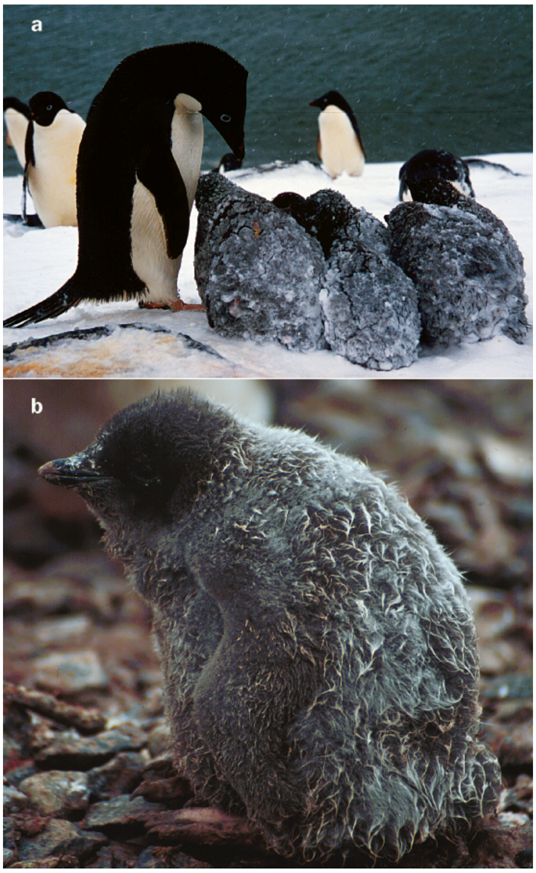

Figure 6. (a) Adélie penguin chicks may get covered in snow during storms, but beneath the snow their down is warm and dry. (b) When rain falls, downy Adélie chicks can get wet and, when soaked, can become hypothermic and die. Photographs: P. Dee Boersma.

We now know that the impacts on seabirds from El Niños are global (Schreiber and Schreiber 1984, Duffy et al. 1988). Peruvian penguins, like Galápagos penguins, show flexibility in breeding; if food is available, they can breed in any month of the year. Peruvian penguins have two peaks in reproduction—a large one in spring (October) and a smaller one in winter (May)—and, like Galápagos penguins, they molt before they breed. Although penguins show adaptations to environmental variability, environmental perturbations take a toll on their populations.

Climate variation is at least partly to blame for the decline of temperate penguins, but human impacts are also influencing their demise. All the temperate species of penguins are declining (Boersma and Stokes 1995). Populations of African, Peruvian, and Galápagos penguins have collapsed. In the past hundred years, African penguins have decreased from 1.5 million to 63,000 pairs (Roberts et al. 2005), with the harvest of guano and eggs the major reason for their decline. Oil spills slowed African penguins' recovery in 1994 and 2000, and then the penguins' distribution shifted eastward, apparently to follow their prey (Koenig 2007). Commercial fishing has reduced the carrying capacity of the Benguela ecosystem for penguins to only 10% to 20% of what it was in the 1920s (Crawford et al. 2007).

Peruvian penguins show a similar pattern of decline—their population is only a fraction of what it once was. In the mid-1800s, about a million Peruvian penguins existed; by the 1930s, the population had precipitously declined because of fishing and guano harvest (Murphy 1936). The current population may be only 30,000 birds or pairs, but the precise population size remains unknown. Estimates are as low as 10,000 to 30,000 Peruvian penguins in Peru and Chile (*www.iucnredlist.org,* Cheney 1998, Luna-Jorquera et al. 2000). Although human disturbance and fishing activities have caused colonies to be abandoned, in some protected sites, such as reserves, populations are stable or increasing (Paredes et al. 2003). Peruvian penguins, like Galápagos penguins, responded to El Niño periods by moving, dying from starvation, and raising no young (Hays 1986, Paredes and Zavalaga 1998).

The most abundant of the temperate penguins is the Patagonian penguin. Living in Argentina, Chile, and the Falkland Islands, it has a population of more than one million breeding pairs (Gandini et al. 1996). Although the Patagonian penguin is more abundant than any other temperate penguin, judging from the serious threats this species faces, it also will most likely continue to decline. Expanding fisheries compete with these penguins for prey (Skewgar et al. 2007). A new Argentinean anchovy fishery was announced in November 2007, to start in the Golfo San Matias near important breeding colonies of Patagonian penguins.

Focus on Patagonian penguins

The largest Patagonian penguin colony in the world is at Punta Tombo, where I have studied these temperate penguins for almost 25 years. The population probably peaked at nearly 400,000 pairs between the late 1960s and the early 1980s, declining to approximately 200,000 breeding pairs in October 2006. Climate is an important factor in the distribution and abundance of penguins, often playing a critical role in determining productivity and prey abundance. Penguins first colonized Punta Tombo around 1924, and their population expanded rapidly (Boersma et al. 1990). With the population increase, breeding colonies expanded north. Penguins colonized Peninsula Valdés in 1969. The most northern colony is now at the Complejo Islote Lobos (41°25'S, 65°01'W) in the province of Río Negro, Argentina, about 150 km north of Peninsula Valdés. When it was discovered in 2002, the colony had about 20 nests, but by November 2007, 200 to 300 penguins were present (Pablo García-Borboroglu, Consejo Nacional de Investigaciones Científicas y Técnicas, Puerto Madryn, Argentina, personal communication, 7 November 2007).

Most penguins are faithful to their colony. Once they breed, they often return each year to the same nest site. One Patagonian penguin pair at Punta Tombo bred together for 16 years in the same nest. Out of the 54,361 penguins volunteers and I banded at Punta Tombo between 1982 and 2005, only 149 have been seen elsewhere. By far the majority of penguins sighted at least 25 km from Punta Tombo (48) were penguins banded as juveniles (one-year-olds) on the beaches at Punta Tombo. Although resting on the beach at Punta Tombo as yearlings, they may not have hatched at Punta Tombo. Juveniles must return to shore to molt their feathers, but they need not return to a colony until they breed. One banded juvenile, instead of molting at 15 months, waited until the following February when over two years of age to molt to adult plumage.

Patagonian penguins breed as young as four years of age, but most do not lay eggs or find a mate until they are five to eight years old. A few females wait until they are 12 or 14 years old and some males may never win a mate. Patagonian penguins have high fidelity to their colony, to their nest, and to the beaches closest to their nest site or the nest where they hatched . One young male returned to breed in a nest within a meter of where he hatched. A few penguins are seen in colonies other than where they hatched, but that is rare. Five adults out of 8712 adults banded at Punta Tombo were seen at another colony, 2 moved to the south, and 3 were sighted on Peninsula Valdés. Nine out of 40,322 chicks banded at Punta Tombo were seen in another colony, all on Peninsula Valdés, at locations closer to their foraging grounds. These data suggest that metapopulation dynamics are important in sustaining the species and may become more important in the face of greater climate variation. Punta Tombo is very likely a source population for other colonies and may be providing the individuals that are colonizing new sites and extending or shifting their breeding range northward.

About half of the Patagonian penguins at Punta Tombo live in burrows, and the other half live in bushes (Stokes and Boersma 1991). The best nest sites are those with the most cover from the elements. Small increases in nesting cover increase fitness (Stokes and Boersma 1998, 2000). My students and I followed the reproductive success of Patagonian penguins in the same two areas each year for 24 years. Reproductive success varied widely among years. When more than 60 millimeters of rain fell between 15 October and 15 December, reproductive success was unusually low (figure 7). Nests filled up with water; burrows collapsed; and chicks got wet, became cold, and died. In nests with a northern exposure, chicks were more likely to survive. Climate variation that brings more water to desert environments may benefit humans, but it will not help penguins, as our data on Patagonian penguins show.

Each year since 1983, students and volunteers have helped me follow individual penguins; measure chick growth; determine reproductive success; attach satellite tags to determine where penguins forage; census the colony during incubation and the early chick-rearing period; and walk beaches to look for banded, recently dead, and oiled penguins. From the early 1980s until the early 1990s, many penguins died during their fall and spring migration. We estimated that petroleum from illegal ballast-water dumping killed approximately 20,000 adults and 22,000 juveniles each year (Gandini et al. 1994). Petroleum pollution is an important factor in the decline of the penguin population because it kills adults that

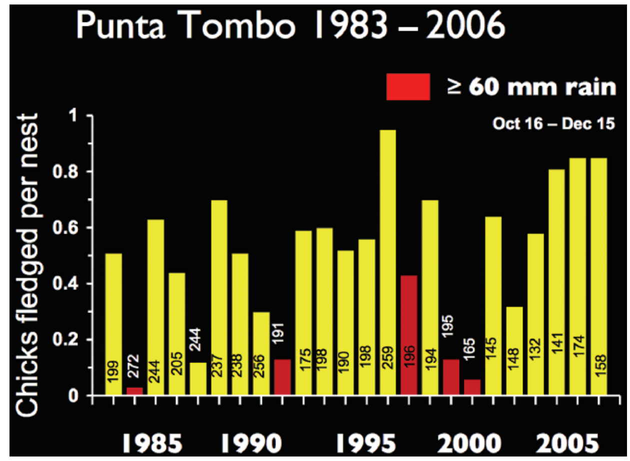

Figure 7. Reproductive success of Patagonian (Magellanic) penguins at their largest breeding colony, at Punta Tombo, Argentina. In years when at least 60 millimeters of rain fall between 15 October and 15 December (shown in red), the penguin nests fill with water and young chicks get wet. Some burrows collapse, and many chicks become hypothermic and die.

would not die otherwise. Even small amounts of petroleum can harm penguins, causing declines in breeding and increases in levels of stress hormones (Fowler et al. 1995).

For nearly a decade, the large number of penguins covered in petroleum each year drew the attention of newspapers, television, corporations, local environmental groups, and the general public. As a result of public concern, the provincial government of Chubut in 1997 moved tanker lanes 40 km farther offshore. In March 2001, 2003, 2005, and 2007, when Esteban Frere and I walked along the beaches in Chubut looking for dead birds, we were elated to find few dead penguins covered with petroleum (figure 8). The oiled penguins we did find were feathered around the bill and very dry, which indicated that they probably died during migration between August and early October. Penguins have bare skin

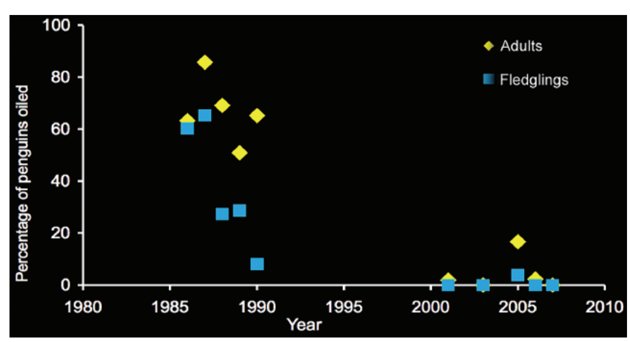

Figure 8. The percentage of dead penguins along two kilometers of coast at 6 to 15 locations along the coast of the Chubut province has declined significantly since the early 1980s. Tanker lanes were moved farther offshore in 1997, and illegal ballast water dumping is rare, so few penguins are encountering petroleum along the Chubut coast.

around the bill during the breeding season, but they are fully feathered following the molt, between April and early September. During the winter months, penguins are most likely to encounter petroleum between southern Brazil and northern Argentina. They probably become oiled while returning in the spring to their breeding colonies, because at Punta Tombo this is when we most often find penguins covered with petroleum.

There are 25 organizations dedicated to penguin rehabilitation from southern Brazil to northern Argentina. The first group began in northern Argentina in 1980, which suggests that petroleum pollution is a long-standing problem (García-Borboroglu et al. 2006). The petroleum problem is much improved along the coast of Chubut province, but it is still a large problem north of Chubut to Southern Brazil. Although large spills are uncommon events, smaller, chronic leakages of petroleum can case serious harm to a penguin that encounters the oil. One unlucky penguin, oiled in 2002 in Uruguay and cleaned and released in 2002, ran into petroleum a second time in 2007. He arrived onshore in July at Mar del Plata, Argentina, about 25% of his body covered in petroleum. How lucky he was to land below the Mar Del Plata aquarium, where he was rehabilitated a second time. The coast of northern Argentina and Uruguay appears to be an area where petroleum in the water is common. Rigorous ocean zoning and new marine parks can help keep penguins, petroleum, and fishers apart not only in Argentina but also throughout their range.

Although the population at Punta Tombo started declining in the early 1980s, it was not until 1987 that I placed 47 permanent stakes in the ground, 100 meters apart, along a transect at the colony. My students and I counted all the active nests within a 100-square-meter circle around 19 stakes that we surveyed each year. The pattern of decline at the 47 stakes that we counted irregularly showed the same trend as at the 19 stakes we counted annually. The colony declined nearly 22% between 1987 and 2006 (figure 9). The biggest decline was in 1991 following an oil spill. After this spill, volunteers walked over 250 km of the Chubut coast, and we calculated that more than 20,000 penguins were killed in this one event.

Petroleum is not the only thing causing the penguin population to decline; other human factors are taking a toll on the birds. Penguins are caught and killed in fishing nets. The collapse of some fisheries, and the development of others targeting the fish that penguins prey on, may do further harm to all temperate penguins. The large amount of small fish that humans remove from the productive system on which penguins depend is likely to diminish the prey available for penguins, thereby causing their populations to decline.

Close encounters with tourists may also have an impact on penguin populations, as these encounters affect the penguins' stress response. Although penguins become habituated to controlled tourism, chicks in tourist areas develop their stress response much earlier than chicks in areas without tourists (Walker et al. 2005, 2006). When people walk close to a penguin with small chicks, the adult often stands, exposing the chick to light, so that the chick peeps to be fed or burrows under the adult to be safe. These are physiological and probably energetic costs that penguins must pay because of human visitation.

Tourism is growing rapidly at Punta Tombo, and the number of people worldwide who visit penguin colonies will continue to grow. In the 1960s, before Punta Tombo became a provincial reserve, fewer than 100 people per year visited the colony. By the 1980s, visitors numbered in the thousands; by the 1990s, they reached the tens of thousands. In January 2007 more than 900 tourists walked into the reserve in one hour; that year, the number of visitors surpassed 105,000 (figure 10).

The visitors who flock to Punta Tombo are loving the penguins to death. In September 2006, the provincial director of conservation started a tourist trail expansion that destroyed about 50 penguin nests before the season began and later caused penguins to desert existing nests adjacent to the new trail. The director planned to join the trail extensions in November 2006, making one large, circular trail. Our data showed the new trail would destroy 197 nests that had eggs close to hatching and would affect 10,000 more nests by forcing penguins to cross the new trail. Crossing the trail and dodging tourists would delay penguins returning from foraging from feeding their chicks.

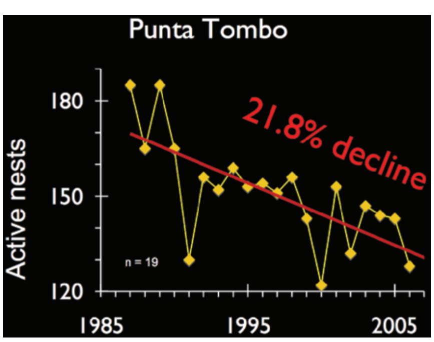

Figure 9. Patagonian penguins have declined by nearly 22% at Punta Tombo since 1987.

Figure 10. Tourism at Punta Tombo has grown to more than 105,000 visitors per year and is overwhelming the very resource people come to see—penguins. Photograph: P. Dee Boersma.

In addition, in January 2007, five penguins were killed on the road by tourist traffic. The on-site warden at the provincial park responded responsibly by closing the road to vehicles—a request that the Wildlife Conservation Society and I had made for more than 20 years. With the evidence of damage to the penguins provided by our data, and following a change in leadership at the provincial level, the director of conservation was fired and the new trail extensions were removed, returning the trail to its 2005 configuration. In addition, a new bridge was built to allow penguins to move to and from their nests unhindered. In September 2007, the Punta Tombo Management Plan, a community-based project that had taken two years to produce (and the provisions of which the former director of conservation ignored), was formally adopted by the Province of Chubut and an oversight committee established.

Oceanic productivity and the locations where penguins find their prey vary among years. We know from tracking Patagonian penguins by satellite that the distance they must swim to find food affects their reproductive success. Penguins that forage close to the nest have greater reproductive success than those that must go farther. Penguins that swam 150 km or less from the nest had the highest probability of raising a chick. If a breeding adult penguin went more than 350 km, it had almost no chance of raising a chick. Breeding adults forage in roughly the same areas each year, but in some years they remain closer to the colony than in others (figure 11). When penguin prey is farther from the nest, reproductive success declines.

Penguin distribution and abundance in both the short and the long term are closely tied to their prey. In some years, such as 1987, 2000, and 2002, incubation trips were longer and adults went farther north, presumably to meet the returning migration of their prey, but the chicks starved to death before the adults returned to their nest (figure 12). Penguins are going about 60 km farther to find food than they did a decade ago (figure 13). Foraging grounds for penguins with chicks are well defined, making it possible to reduce conflicts between fishers and penguins by ocean zoning. For example, in the area "de veda de Isla Escondida"—appropriately 25,000 km^2, just offshore from Punta Tombo—large fishing boats are excluded from October to April to protect the spawning hake. A by-product of this restriction is that it affords protection to some of the foraging grounds of breeding penguins.

In years when prey is less available, ocean zoning could be used to exclude potential competition between fishers and penguins in the core area that penguins use. Penguins are following their prey and using areas of high productivity (Boersma et al. 2008). How long a penguin is gone from its nest is closely related to how far it goes (Boersma et al. 2007). Thus, when penguins are gone longer, a larger area should be closed to fishers than when their foraging trips are short. As data have shown, Patagonian penguin populations are expanding at the northern part of their range in the Atlantic Ocean, as would be predicted if being closer to their prey is important. Unfortunately, data like these do not exist for other colonies of Patagonian penguins and are absent for other penguin species.

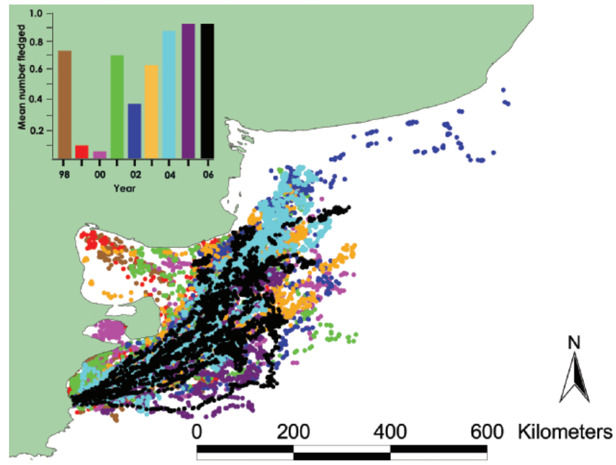

Figure 11. Each year during incubation, Patagonian penguins forage hundreds of kilometers north of their nest at Punta Tombo.

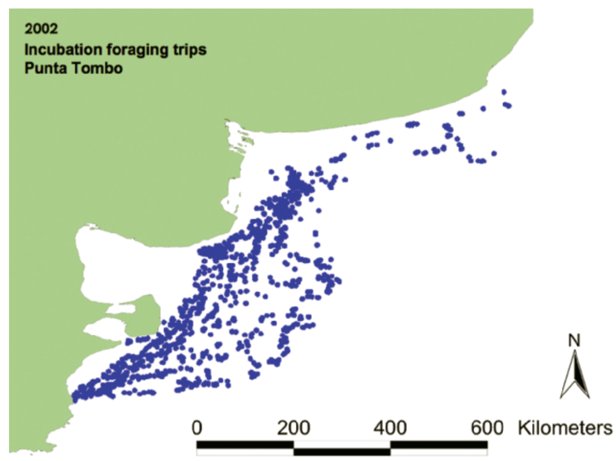

Figure 12. Patagonian penguins foraged farther north in 2002 than in other years. Many chicks died because penguin mates did not return in time to feed the hatchlings before they starved.

Penguins as marine environmental sentinels

Scientific knowledge of penguin population trends is meager. We know that many species and colonies are most likely in decline, but we have few systematic counts of colonies. Systematically monitoring the 43 penguin aggregations worldwide would provide the data necessary to determine the status and trend of all penguin species. With this information, scientists could identify trouble spots and intervene before populations crash. Furthermore, the status of penguin populations reflects the state of the oceans they inhabit. Penguins are sentinels, so why not use them? I recommend the formation of a nongovernmental organization dedicated to determining the population size, status, and trend of the major aggregations of penguin species. Such an organization

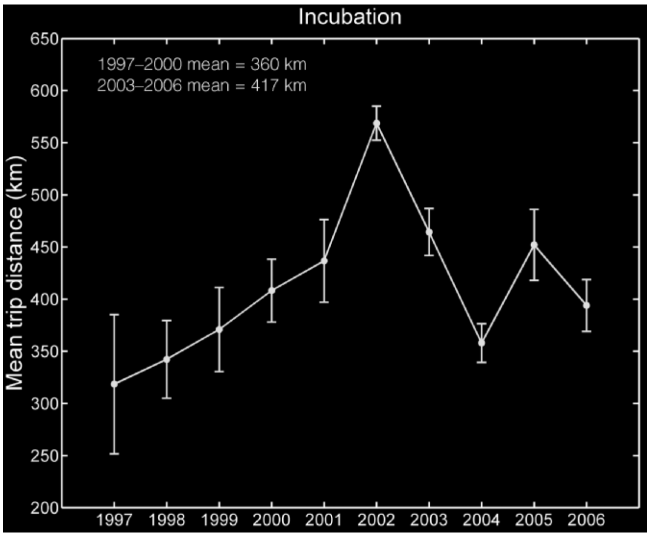

Figure 13. Patagonian penguins are traveling farther north during incubation than they did a decade ago. Climate variation is probably delaying the return of penguin prey, creating a mismatch between prey and predator.

could be supported by funds from a combination of the United Nations, national governments, private foundations, and the interested public. With international support, an organization focused on penguins could provide the data on penguin population trends needed to inform the public and policymakers of where penguins are in decline and what needs to be done.

Life is not likely to get easier for penguins. They have to withstand both climate variation and human development. They may not be able to follow their food as coastal development claims their breeding habitat, or their food may disappear as fishers take more and more of their prey. Climate warming is likely to shift prey species, reduce productivity, and make penguin life more difficult. Climate change, petroleum pollution, and changes in their prey distribution and abundance are causing Patagonian penguin populations to move and decline. A 10% decline per decade, in the biggest colony for this species, is simply not sustainable.

The changes in penguin populations reflect rapid changes in the marine environment and show that people are doing a poor job of managing the oceans. We are changing the world, the course of evolution, and the species with which we share the planet. Can people change to allow other species to persist and coexist? That is the real question: can we, and will we, manage ourselves?

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