Responses of Antarctic Penguins to the Effects of Climate Change

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Penguins are adapted to live in extreme environments, but they can be highly sensitive to climate change, which disrupts penguin's life history strategies when it alters the weather, oceanography and critical habitats (Forcada & Trathan, 2009)

Introduction

Penguins have adapted to their environment through millenia of great climate changes. This makes them more susceptible to climate change as their size, morphology and other cold weather adaptations restricts their ability to feed and travel. They are living at the extreme of their capabilities and small changes can have a huge impact on them.

For Antarctic penguins the process of adapting to the polar climate has taken millennia to achieve and the current climatic changes are happening too fast for them to keep up. The effects of Antarctic warming are influencing the penguins breeding habitats, chick success, food availability, competition and distribution.

The specific responses of penguins to climate change include: poleward shifts in geographic distribution; range contraction (or expansion); changes in the timing of biological events (their phenology) and changes in predator/prey interactions.

This review will overview the current knowledge of how Adélie and Emperor penguins specifically respond to the current changing climate.

Habitats

The role of sea ice

Sea ice extent is a critical factor for the habitats of Adélie and Emperor penguins. It is dramatically different between winter and summer. In both seasons ice forms from the edge of the Antarctic continent to an isotherm line at -1.7C, as near or far from the continent as it happens to be. As the temperature in the region rises, that isotherm retreats towards the pole creating less sea ice in the area. Adélie and breeding Emperor penguins travel no farther north than they are pushed in winter by the limit of the winter ice, so this plays an important role in their lives. (PenguinScience)

Adélie habitat

Over 95% of the Antarctic coastline is sheer cliffs of ice sheets and rock, with a steep drop to sea ice at the base. Penguins need gently sloping, ice free ground close to the coast with a supply of small rocks to build nests. Steep cliffs are unsuitable, so that leaves just 5% of the coastline for Adélie penguins. (PenguinScience)

Emperor habitat

Emperor penguins are also restricted in their habitat. They breed on the sea ice, but the surrounding landforms and glaciers need to be large enough to protect the ice from melting too early in spring. Due to this, both species find it difficult to locate suitable nesting sites, and are very sensitive if changes occur to the good sites they currently have.

As the temperatures continue to rise, eventually all of Antarctica's sea ice will be retreating. Adélie and Emperor penguins are critically dependent on sea ice and although the retreating ice initially allows Adélies more locations to colonise, this is merely temporary. Both Adélies and Emperors will continue to disappear southward as the sea ice retreats until they can go south no further and the species is lost.

The West Antarctic Peninsula has proven especially vulnerable to climate change. The peninsula's mean winter temperature has risen 6°C since 1950--the fastest rate on the planet. The ocean has warmed by nearly 0.7°C. (Stokstad, 2007). The same report decscribes how ecologist William Fraser has carried out research into the impact of climate change on the polar ecosystem at Palmer Station. He observed that increased snowfall was detrimental to nesting penguins, and this resulted in future generations choosing to nest in other areas and left the Palmer Station population to rapidly decrease. His studies also showed the previously 'polar' ecosystem at Palmer Station has been replaced by a 'sub-Antarctic' environment due to the presence of fur seals and southern elephant seals instead of Adélie penguins and silverfish. (Stokstad, 2007)

Smith (et al, 1999) describes the Antarctic Peninsula as a highly sensitive location for assessing the ecological responses to climate variability as the position of the climate gradient can be tracked over time.

Remote Sensing

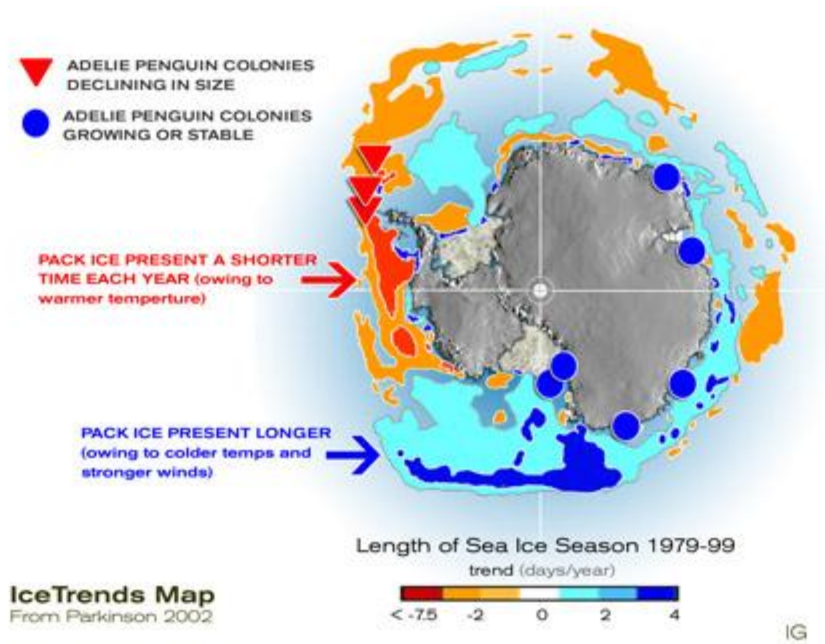


Image 4: Satellite data ***Image from*** www.penguinscience.com

Images from NASA show the change in persistence of sea ice that rings Antarctica in any year. This data has been collected since 1979 and shows a period of accelerated warming in western Antarctica, and cooling in eastern Antarctica. Both cooling and warming are the result of climate change, and the reason it is not uniform all over is due to Antarctica's wind and weather patterns which adjust differently to the changing atmosphere over the continent.

Note that the areas on the Antarctic Peninsula where sea ice has reduced correlate with dissapearing Adélie penguin colonies. On the remainder of the continent Adélie populations remain stable where sea ice has not reduced. Also, in some areas the decreasing sea ice has created more available ice-free ground for breeding, so the populations have increased in these areas . (PenguinScience.com; Parkinson et al, 2002)

Nesting and Reproduction

Image 1 - Adélie and chick
Adélie penguin incubating its egg.
Image from www.penguinscience.com

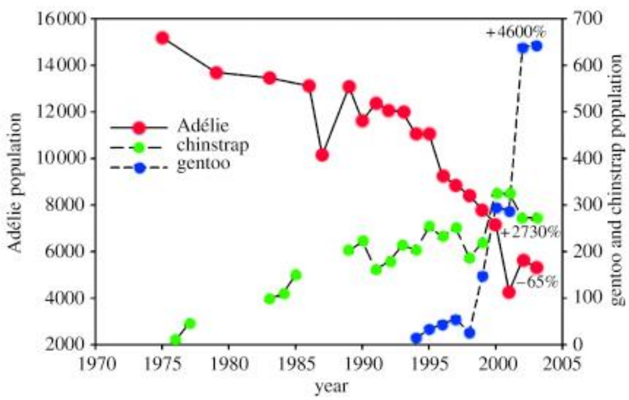
Adélie Penguins
Studying Adélie's is easier than studying other penguins because they nest in areas close to the coast in such huge numbers that scientists have been able to make detailed observations for the last 50 years.
In places, retreating glaciers benefit the Adélie penguins because they expose rocky areas which tend to be good breeding grounds. The piles of gravel crushed up by the retreating glacier are called moraines and the stones are used by Adélie penguins to build their nests and are essential for keeping their eggs off the cold ground. (Jenouvrier et al, 2006)
E*mperor Penguins*
Emperor penguins breed on the areas of sea ice that are supported by grounded icebergs, islands or capes. They need the ice to remain stable from April to the end of December to complete an entire breeding season. The emperor chicks need this time to grow enough to take care of themselves in the open ocean. (Forcada and Trathan, 2009)
Studying breeding Emperor penguins is more difficult two reasons. Firstly, they breed during the very depths of winter, in conditions of -40C, which makes it extremely difficult for researchers to study. Secondly they breed on sea ice which melts every summer so all traces of the site are lost. Finding the nesting sites of Emperor penguins is a difficult job due to these unique breeding habits. However, remote sensing has revealed a novel method of locating Emperor penguin colonies - by their faeces. Fretwell and Trathan (2009) have revealed 38 sites in total, including 10 sites previously unknown. This is a vital geographical resource for future studies and will help preserve an iconic species believed to be threatened by climate change.

Feeding/Predation

Food chains in the southern ocean are relatively short., with few trophic components and relatively low prey diversity (Laws, 1985) A few key species dominate in the marine ecosystem and they are all dependent on the periodicity of sea ice cycles, so any shift can cause mismatches between phytoplankton blooms, krill development/recruitment and krill availability for penguins. Less krill means more time spent foraging, reduced breeding success and low return of breeders. (Forcada and Trathan, 2009)

Penguins are extremely sensitive to prey availability and this is evident from data matching population growth/decline to phytoplankton blooms in the area. (Forcada & Trathan, 2009) Phytoplankton blooms are related to the extent of sea ice, so lack of sea ice again affects penguins from another perspective. They are limited as to how far they can travel for food and depend on predictable food sources in predictable places.

Population Trends

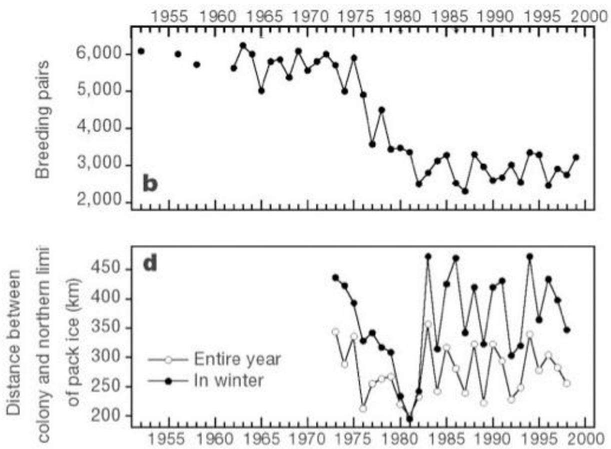


Graph 1 - Population Trends
Population trends for three penguin species in the Anvers Island vicinity, 1975–2003. The numbers on the graph indicate percentage change from initial sampling year for each species. Adapted from Ducklow et al, 2007.

As shown on the graph, Adélie populations have been decreasing in some locations as Chinstrap and Gentoo species take over. The warmer temperature means that all species can move their range further south, and Adélie's aren't able to compete with their cousins so they move move south too.

As mentioned above, another reason for population decrease is loss of food sources. Decreasing sea ice has a negative effect on food sources in the southern ocean, and on top of overfishing this can have a detrimental effect on penguin populations.

The Gentoo population at Iles Kerguelen has exhibited a decreasing population trend over the last 15 years of approximately 30%. This decrease is likely to be related to food availability as it is a coastal species. This decrease in food availability may be due to overfishing and it has implications for the potential effects of climate change on marine food webs. (Lescroel and Bost, 2006)



Graph 2 - Emperor Penguins - Pt Geologie
This graph shows how warming in the late 1970's lead to decreased sea ice and decreased population for the Emperor penguins. Adapted from Barbraud & Weimerskirch, 2001.

Emperor penguins have been studied for a long time by French biologists associated with the Dumont Du'Ville research station nearby. As shown in this graph (data from Barbraud & Weimirskirch 2001), the Pt. Géologie colony began a sudden decline in the mid-1970s and has since failed to recover, probably due to warming winter temperatures that have resulted in thinner fast ice on which they breed. The strong Antarctic winds have thus been able to blow the ice away before the chicks were ready to fledge. It is this loss of chicks from these years that has prevented the colony's recovery.

Adélies on Ross island - The colonies on Ross Island especially the small ones, have been growing as a result of changes in their environment brought by two important factors. Increased wind strength and warmer winter temperatures has resulted in thinner sea ice and more holes in the ice where two growing colonies are located. Therefore penguins can eat their fill of food much more quickly and can bring more food back. This leads to increased chick success and their population has grown.

Also as a result of warming air temperatures, especially around the Peninsula, there is increased snowfall and this has been observed to completely bury some Adélie colonies. (Ferocious summer)

Emperors are very sensitive to changes in sea ice. They nest at the harshest time of winter to allow their chicks enough time to grow before the ice breaks up and they need to fend for themselves.

Oceanic/Atmospheric influences

There are regional, large scale influences affecting the Antarctic climate. Domack (et al, 2003) concludes penguin species in the Antarctic area are benefitting both positively and negatively from the warming air temperatures in the area.

The relationship between atmospheric dynamics, ocean circulation and temperature is changing and past responses of penguin life cycles to climate modes may not necessarily reflect future responses to climate change. (Forcada & Trathan, 2009)

The Southern Annular Mode occurs more in high latitudes and results from shifting wind patterns and the El Nino Southern Oscillation results from ocean-atmosphere interactions and affects more the lower latitudes . Both play a major role in Antarcticas climate, ENSO affecting sea surface temperature variability and SAM affecting the winds which distribute sea ice. Around the Antarctic continent. (Meredith et al, 2008; Forcada & Trathan, 2009)

ENSO and SAM are climatic influences that already affect penguins, and their presence complicates future predictions of penguins responses. (Forcada & Trathan, 2009)

However there have been studies of Emperor penguins in the Dumont Du'Ville area which show sea surface temperature anomolies or sea ice extent did not affect the success of chicks born that year. (Barbraud and Weimerskich, 2001)

Paleohistory

Adélie penguins are very informative about how climate change affects their species. For one, they breed in relatively accessible areas of the continent, enabling solid scientific observations from the last 50 years about their current habitat requirements.
Secondly, breeding in such a cold environment has preserved their bone fragments exceptionally well. These fragments can be radiocarbon dated which provides data on their habitat and how they responded to environmental changes even before the last ice age 12,00 years ago.

Image 3 - Penguin remains
This penguin mummy is several hundred years old and has been worn down by the feet of other penguins walking over it and by being sand and snow blasted by the wind. Image www.penguinscience.com

Having the coldest, driest climate on earth, Antarctica can preserve organic remains very well, and the lack of scavengers means the bones can remain untouched for thousands of years. These remains are very useful as they can be radiocarbon dated. These dates can be compared with climate data from ice core samples and marine sediments.
A study by Emslie and McDaniel dated 12 samples from two islands in Marguerite Bay and concluded that penguins lived in these colonies (located in the Antarctic Peninsula) for the last 6000 years. They abandoned the site when the climate cooled and the sea ice presumably blocked off the bay. Then they re-inhabited the site when it warmed and the glacier had retreated enough to make the site accessible again. (Emslie and McDaniel 2002)

This research has been complemented by a study of Adélie populations in the Ross Sea which goes back 45,000 years. This data indicates there was an open water marine environment in the Ross Sea region from approximately 45,000 to 27,000yrs before present. Penguins only just recolonised the Ross Sea region in the last 8000 yrs after the early Holocene retreat of the Ross Ice Sheet. Then there were two subsequent periods of abandonment at 5000-4000ybp and 2000-1100ypb, which correlate with cooling episodes that caused unfavorable marine conditions for breeding penguins. (Emslie, Coats, Litch, 2007)

Another study, this time on the east side of Antarctica in the Vestfold Hills, again showed through C14 dating that penguins occupied the area as soon as the local ice retreated and the ice free ground formed, approximately 8500 yrs ago (Tao et al, 2009)

Microevolution Responses

Penguins can respond to climate change either by adaptation or dispersal.

The most highly supported theory is dispersal – that penguins will abandon sites during unfavorable condition and recolonize when it is suitable again.

Dispersal

This theory is supported by penguin paleohistory. As described above, preserved Adélie remains have been recovered from numerous abandoned colonies in the Ross Sea region. Radiocarbon dating these remains shows the time periods that penguins occupied each location, and interestingly in the last 8000 years there were two major periods of abandonment and they both correlate with cooling episodes which caused unfavorable breeding conditions. (Emslie et al 2007)

The dispersal theory is also supported by current first hand research from Bill Fraser at Palmer Station. As the ecosystem in the Antarctic Peninsula changes from polar to sub-Antarctic (Stokstad, 2007) Adélie penguins are finding it difficult to compete with other species such as the chinstrap penguin who are increasing their range south in response to the warmer climate. Adélies are also struggling with increased snowfall on the coast, which buries the nesting birds as they lay and who have such a strong nesting instinct they wont get off the egg to save themselves, ending up buried. The next generations of first year breeding birds are moving to locations further south and decreasing the population at Palmer Station. As a temporary solution this is fine, however if the climate keeps warming and the ice keeps melting soon they will have nowhere to go. (Ferocious Summer, 2007)

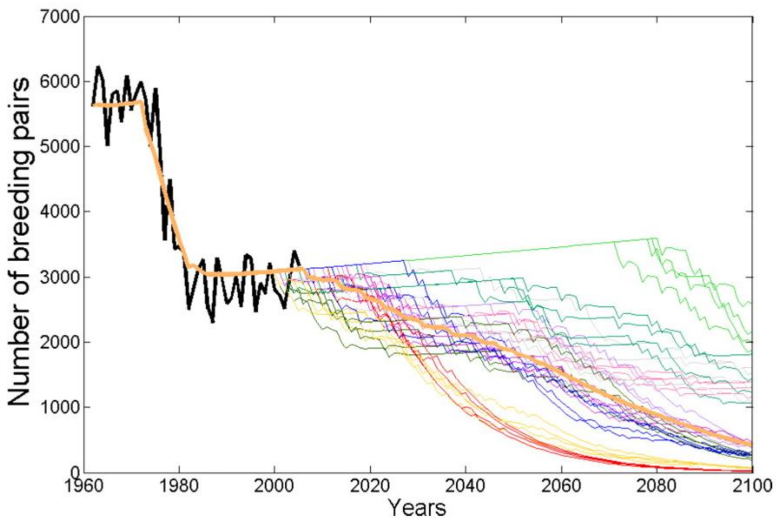
Microevolution
There is little evidence for adaptation by microevolution. Penguins are long lived creatures and this makes them slow to adapt. A 50 year data set from the Dumont DuVille station on the Antarctic peninsula shows Antarctic seabirds are lagging behind northern hemisphere sea bird species who have adapted faster to the changing climate. The northern birds are starting their breeding season earlier to compensate for warmer spring temperatures that cause a premature abundance in the availability of their prey (3).

Comparison with northern hemisphere seabirds
Over the last two decades northern hemisphere birds have been moving their range 91kms further north, but the temperature has had a northern shift of 273kms, triple the distance. Therefore northern birds are currently lagging 180kms behind temperature change. (Devictor et al 2008)

And Antarctic birds are not speeding up their breeding at all. A study by Barbraud and Weimerskirch of nine Antarctic seabird species (at the Dumont du'ville station on the warming Antarctic Peninsula) shows they are arriving an average of 9.1 days *later* in the season, and laying eggs an average of 2.1 days later. This is counter intuitive, but they suggest a possible explanation - that due to reduced sea-ice and reduced prey availability the birds must spend more time eating and building their fat reserves before beginning the breeding season. It makes sense, but Antarctic seabirds still risk being caught out of synch with their prey if they don't start some sort of biological response soon.

Future Predictions

Jenouvrier (et al 2008) concludes that if winter sea ice extent declines at the rates projected by IPCC models and continues to influence Emperor penguins as it did in the second half of the 20th century, then the Emperor penguin population in Terre Adélie will decline dramatically by 2100, with a 36% chance of extinction.



Graph 3 - Observations and projections of the emperor penguin population.
The thick dark line is the observed number of breeding pairs. The thick orange line from 1962 to 2000 is the projected number of breeding pairs based on the observed sequence of warm events. The thick red line from 2005 to 2100 is the median projection based on the forecasts produced by the IPCC models. projections from 2005 to 2100 are shown to give a sense of variability in this model. Adapted from Jenouvrier et al 2008.

To avoid extinction, the emperor penguin must adapt by microevolutionary changes or phenotypic plasticity e.g., by changing timing of their growth stages. So far, the dates of arrival to the breeding colony and of egg laying have not changed in emperor penguins as they have in other Antarctic seabirds in Terre Adélie, suggesting a slow rate of adaptation

Conclusion

In conclusion, most studies have found that sea ice is very influential on populations. The lack of it is having positive and negative effects on penguins. In the short term more habitat is being made available for Adélie penguins, and in areas like Terra Adélie the population is steadily increasing. However this seems to be the only positive effect - the increasing temperatures encourage all species to move their range further southward and this intrudes on the Adélie's habitat, making it harder for them to hunt and maintain their large nesting grounds.

Penguins seem to be very slow adapters, and information from the last 8000 years suggests they will respond to a changing environment by dispersal rather than microevolution. But Adélie's and Emperor’s can only go so far south and eventually they will be the first to disappear.

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