PCAS 19 (2016/2017)

Critical Literature Review

(ANTA602)

How will habitat changes arising from climate change impact the Emperor penguin population?

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Word count: 2811 (excluding abstract and references)

Abstract:

Climate change is rapidly changing the environment of Antarctica through warmer air and ocean temperatures, changes in sea-ice distribution, and associated cascades in the food web. Emperor penguins need the marine ecosystem and sea-ice for survival, hence are extremely sensitive to habitat changes. The climatic changes occurring will alter the predictability of their habitat and have a range of effects on the survival of emperor penguin populations. Environmental change is complex, and its impacts on organisms are difficult to predict but numerous studies have identified sea-ice as a main critical factor in the future survival of the emperor penguin. Sea-ice has flow on effects in a variety of life aspects. These include loss of suitable habitat at latitudes lower than 70°S which will force populations to move southward, alterations in primary production that will shift food web dynamics, and impacts on reproductive success. A lack of long term population data limits the accuracy of predictions and more research is needed in order to better understand how the population will change.

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Introduction

Climate change is an issue of critical importance in the present day, with human activities contributing to a rapidly changing global environment (Clarke et al., 2007). We are experiencing the highest ever recorded carbon dioxide levels in the atmosphere alongside global increases in atmospheric and oceanic temperatures and sea level rise. In the Polar Regions we are also witnessing pronounced changes in the ice. In Antarctica, ice shelves are collapsing and sea ice extent and duration is changing (National Aeronautics and Space Administration [NASA], 2016). There is growing concern regarding the potential impacts that environmental change might have on the ecosystem and the flora and fauna that call the continent home.

A major factor of climate change in the Antarctic region is changes in the sea-ice. This could be increases or decreases in the extent of the ice as well as changes in the seasonal duration and averages. Sea-ice is a critical factor in habitat of many organisms. Changes in the sea-ice can result in significant alterations in the habitat of a species as well as influencing nearly all aspects of the animals' lifestyle. For example, the emperor penguin is affected by sea-ice in multiple ways from population distributions, food availability to reproduction.

Emperor penguins are a well-known Antarctic species with a number of colonies distributed around the circumference of the continent (Williams, 1995). Due to their large biomass and distribution around the coast near research stations, the emperor penguins have been the focus of much research including a number of studies aiming to assess the species' capacity for adaptation and predict the effects of climate change on these animals (Ainley et al., 2010; Barbraud & Weimerskirch, 2001; Forcada & Trathan, 2009; Jenouvrier et al., 2012). There are many interlinked variables that impact on the penguins and their survival rates but a critical factor is alterations of habitat. These birds are dependent on both the marine ecosystem and sea-ice so changes to their habitat optimums can have complex ripple effects.

This literature review will look at how a changing climate and therefore a changing habitat will affect emperor penguin populations in terms of their distribution, food availability and reproduction.

Adaptations to the Antarctic

The Emperor penguin is a species well designed for life in the Antarctic. Their physiological adaptations reflect the lifestyle of a marine animal, and they spend most of their time at sea foraging in the open water at depths between 100-200 m although they have been recorded at depths up to 500 m (Australian Antarctic Division, 2014b; Williams, 1995). They have streamlined bodies with modified wings for optimum propulsion through water and solid, heavy bones to help when diving deep. They lay down large amounts of fat with densely packed feathers for insulation as well as wind and water resistance (Australian Antarctic Division, 2014a). The only times they are not in the water is during the breeding season and moult when they "haul out" onto sea ice. When they are out of the water their marine adaptations limit their habitat choices. Their large size and bulkiness inhibit the ability to climb or scramble over rocks so they rely on sea-ice and predictable conditions to facilitate movement out of the water (Ainley et al., 2010; Kooyman, 2001).

Population Distribution

Emperor penguins have a circumpolar distribution between about 66°S and 78°S and the population is estimated to be at almost 600,000 individuals spread between 45 colonies of varying sizes. Most of the known demographic data on the penguins is gained from colonies close to research stations but over half of the known colonies have never been visited by humans due to logistical challenges. The development of high-resolution satellites has allowed for observation and counting of colonies that are inaccessible to humans on the ground but a lack of long term data means that demographic information on populations is still lacking.

Ainley et al. (2010) predicted a narrowing of the penguins' geographic range and the disappearance of colonies north of 70°S should the global tropospheric temperature increase to 2°C more than pre-industrial levels. This equates to approximately 35% of the total breeding population. The disappearance of one colony in the West Antarctic Peninsula has already been seen, with aerial photography of the Dions Island colony in 2009 showing no remaining traces (Trathan, Fretwell, & Stonehouse, 2011). A sharp decline in population by almost 50% also occurred at Terre Adélie in the 1970's which the population has not recovered from (Barbraud & Weimerskirch, 2001). Despite being located at opposite sides of the continent, both of these losses in population arose from a prolonged period of warming and reduced sea-ice extent and duration. This lends support to a number of studies that found sea-ice to be a main determining factor of Emperor penguin population survival (Ainley et al., 2010; Barbraud & Weimerskirch, 2001; Jenouvrier et al., 2009).

Research by Ainley et al. (2010), Constable et al. (2014), Forcada and Trathan (2009) and Jenouvrier et al. (2009) has correlated with these observations suggesting that the emperor penguin range will contract and shift toward the pole as populations are more likely to survive by dispersal to new locations that provide conditions within their ecological capacity rather than surviving by adaptation to changes at their current sites.

A potential disadvantage to the survival of the population is the lack of gene flow and interaction between different colonies. Colonies tend to be very geographically separate, often over 1000 km away from the next breeding site and penguins remain faithful to the site they were hatched at year after year (Williams, 1995). This limits the ability to transfer favourable traits that may enhance population survival.

Food Availability

As a large animal near the top of the marine food web, emperor penguins consume large quantities of food each day. The typical diet consists of a combination of krill, small fish, and squid, the quantities of each varying with the local availability and abundance (Australian Antarctic Division, 2014a). Changes in the ocean habitat and marine ecosystem will affect a number of trophic levels and the availability of food for higher predators (Loeb et al., 1997). Krill is a keystone species in this system as it is the major link between the primary producers such as algae and phytoplankton and the consumers which range from small fish to the top predators like the emperor penguin. Krill stocks depend on the algae and phytoplankton that grow on the underside of sea-ice, therefore a greater sea-ice extent promotes growth at the lower trophic levels of the food web and provides more abundant source of food for the higher predators such as emperor penguins.

Krill populations have been well studied in terms of their influence on the food web, Hill, Phillips, and Atkinson (2013) suggested that ocean warming could reduce the area suitable for krill growth by up to 20% and Atkinson, Siegel, Pakhomov, and Rothery (2004) found significant regional variation in krill density but the areas of highest production were also showing declines. A decrease in the survival ability of this keystone species at higher temperatures will have a ripple effect across many trophic levels and it may add constraints to the growth of large animals that require substantial quantities of food to survive (Clarke et al., 2007).

Additional to environmental changes, human impacts on the food web are also critical. Fisheries that remove large quantities of Antarctic fish and krill will be important drivers of population change and combined with environmental effects that are reducing krill stocks, may drastically alter the food web dynamics to the point of species endangerment (Atkinson et al., 2004).

The relationship between the emperor penguin and the rest of the food web is complex, and it is difficult to distinguish anthropogenic fishery impacts from environmental changes. One advantage the emperor penguin does have is that it is able to forage at a range of depths and it is flexible with its prey depending on what is easiest to find. This may add to the species' survivability by allowing the birds to tolerate changes in the food web dynamics. One issue with this is that regardless of changes, if the quantity of available prey declines significantly, the penguins will face challenges to satisfy their energy demands if longer foraging trips are needed to find food. This is particularly important during the breeding season as it could be detrimental to the survival of chicks.

Reproduction

Emperor penguins have a unique reproductive cycle compared to most other penguins. Usually, penguins have a short breeding season that lasts through spring into summer but the emperor begins its season in March-April and continues throughout winter into the following summer. All the penguins return to the breeding site where they were first hatched to begin the mating season. After mating, the male penguins will incubate the egg through the harsh Antarctic winter while the female forages until the chick hatches in the spring. When the female returns, the parents alternate foraging trips throughout the springtime to get food for the chick and fledging will begin when the chick has grown and matured enough to leave its parents – usually around December (Williams, 1995).

Each season a breeding pair will have only one chick, and because the cycle takes nearly a year to complete, the reproductive rate is relatively low. Reproduction is affected by changes in habitat in multiple ways, sea-ice, temperature and weather patterns play a big role in the survival rate of chicks year to year. Changes in the duration or extent of sea-ice can have multiple effects. A decrease in the seasonal duration of sea-ice could mean the ice forms later and the penguins must delay the start of the breeding season until stable ice forms, or it may break out earlier at the end of winter which could jeopardise the survival of chicks who may not have developed enough to be ready for fledging (Ainley et al., 2010; Barbraud & Weimerskirch, 2001).
The extent of the sea-ice also plays a role because of the fidelity of the penguins to their breeding sites. An increase in sea-ice extent may mean the birds have to travel further on land which is time and energy consuming. This is less than ideal when caring for a chick, a longer foraging time means the chick must go without food for longer periods which can be detrimental to the chick's growth.
Paradoxically, beneath the sea-ice is a major source of primary production so greater sea-ice extent has benefits for the adults through increased food abundance. These contradicting effects present a trade-off between the advantage of better adult survival, and the disadvantage of higher chick mortality. Barbraud and Weimerskirch (2001) proposed that having higher adult survival for further reproduction would outweigh the loss of a reproductive season, but if those conditions were to persist year after year it may begin to have an effect on the population numbers (Jenouvrier et al., 2012).
Temperatures and weather patterns such as wind also influence the sea-ice. Strong winds provide more open water but in conjunction with increasing temperature, the fast ice becomes more unstable and areas where colonies are located may not have stable sea-ice for the entire breeding season. Unstable sea-ice may mean the ice breaks out

earlier in the year and if chicks are not ready to fledge, they will not survive and breeding failure could occur (Ainley et al., 2010).
The breeding season is a crucial factor when it comes to climate change, as reproduction allows for microevolution and the chance for favourable mutations to develop. Emperor penguins have a very slow generation time, adults do not begin to reproduce until they are 5-6 years old and then can only produce one chick per year. If a breeding failure occurs that further limits the potential for microevolution to occur and the penguin populations remain susceptible to climate changes (Jenouvrier et al., 2014).

Conclusions

Based on information found in the literature of this review, sea-ice is a critical factor in the survival of emperor penguins. The extent and duration of sea-ice has widespread impacts on the distribution of colonies, reproductive cycles and food availability. When there is extensive sea-ice, the survival of chicks decline due to the greater distance and longer time parents must travel for on foraging trips. Although more sea-ice is beneficial for food productivity, it is still uncertain whether the survival of adults outweighs the loss of a reproductive season. On the other hand, little or absent sea-ice has detrimental impacts on the availability of food, particularly krill, and penguin mortality increases due to the instability of the ice. If the ice breaks out early before chicks are ready to fledge there could be widespread reproductive failure.

The dependence of the emperor penguins on sea-ice may limit their adaptation ability in light of future environmental change, although there are known examples of emperor penguin colonies using ice shelves or breeding on land instead of sea-ice . This is a positive sign but very little is known about these rare cases and whether it could be a successful long term strategy for other colonies.

In conclusion, current evidence suggests that changes will first be observed at the regional level, smaller colonies that are already near their biological and geographical upper limits may be more susceptible to environmental change and have lower capacity to adapt. To be able to accurately predict or estimate the scale of change that may occur, further research on population trends is required. A lack of long term data limits the accuracy of estimations but with advances in satellite technology, monitoring of geographically isolated colonies is becoming more accessible. There is a great deal of uncertainty around the precise responses that the emperor penguin populations may have to climate change, the drivers of change are complex and anthropogenic activities may be playing a larger role than anticipated.

Also of interest is whether emperor penguins are able to relocate their colonies if conditions require, study of the ability of young penguins to relocate could provide insight as to the ecological flexibility of the emperor penguin species.

References

Ainley, D., Russell, J., Jenouvrier, S., Woehler, E., Lyver, P. O. B., Fraser, W. R., & Kooyman, G. L. (2010). Antarctic penguin response to habitat change as Earth's troposphere reaches 2°C above preindustrial levels. *Ecological Monographs, 80*(1), 49-66.

Atkinson, A., Siegel, V., Pakhomov, E., & Rothery, P. (2004). Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature, 432*(7013), 100-103.

Australian Antarctic Division. (2014a). Emperor Penguins. Retrieved from http://www.antarctica.gov.au/about-antarctica/wildlife/animals/penguins/emperor-penguins

Australian Antarctic Division. (2014b). Emperor Penguins Diving and Travelling. Retrieved from http://www.antarctica.gov.au/about-antarctica/wildlife/animals/penguins/emperor-penguins/how-deep-can-they-dive

Barbraud, C., & Weimerskirch, H. (2001). Emperor Penguins and Climate Change. *Letters to Nature, 411*, 183-186.

Clarke, A., Murphy, E. J., Meredith, M. P., King, J. C., Peck, L. S., Barnes, D. K. A., & Smith, R. C. (2007). Climate change and the marine ecosystem of the western Antarctic Peninsula. *Philosophical Transactions of the Royal Society B: Biological Sciences, 362*(1477), 149.

Constable, A. J., Melbourne-Thomas, J., Corney, S. P., Arrigo, K. R., Barbraud, C., Barnes, D. K. A., . . . Ziegler, P. (2014). Climate change and Southern Ocean ecosystems I: how changes in physical habitats directly affect marine biota. *Global Change Biology, 20*(10), 3004-3025. doi:10.1111/gcb.12623

Forcada, J., & Trathan, P. N. (2009). Penguin responses to climate change in the Southern Ocean. *Global Change Biology, 15*(7), 1618-1630. doi:10.1111/j.1365-2486.2009.01909.x

Hill, S. L., Phillips, T., & Atkinson, A. (2013). Potential Climate Change Effects on the Habitat of Antarctic Krill in the Weddell Quadrant of the Southern Ocean. *PLOS ONE, 8*(8).

Jenouvrier, S., Caswell, H., Barbraud, C., Holland, M., Stroeve, J., & Weimerskirch, H. (2009). Demographic models and IPCC climate projections predict the decline of an emperor penguin population. *Proceedings of the National Academy of Sciences of the United States of America, 106*(6), 1844-1847. doi:10.1073/pnas.0806638106

Jenouvrier, S., Holland, M., Stroeve, J., Barbraud, C., Weimerskirch, H., Serreze, M., & Caswell, H. (2012). Effects of climate change on an emperor penguin population: analysis of coupled demographic and climate models. *Global Change Biology, 18*(9), 2756-2770.

Jenouvrier, S., Holland, M., Stroeve, J., Serreze, M., Barbraud, C., Weimerskirch, H., & Caswell, H. (2014). Projected continent-wide declines of the emperor penguin under climate change. *Nature Climate Change, 4*, 715-718.

Kooyman, G. L. (2001). Evolutionary and Ecological Aspects of some Antarctic and sub-Antarctic Penguin Distributions. *Oecologica, 130*(4), 485-495.

Loeb, V., Siegel, V., Holm-Hansen, O., Hewitt, R., Fraser, W., Trivelpiece, W., & Trivelpiece, S. (1997). Effects of sea-ice extent and krill or salp dominance on the Antarctic food web. *Nature, 387*(6636), 897-900. doi:10.1038/43174

National Aeronautics and Space Administration [NASA]. (2016). Global Climate Change. Retrieved from http://climate.nasa.gov/

Trathan, P. N., Fretwell, P. T., & Stonehouse, B. (2011). First Recorded Loss of an Emperor Penguin Colony in the Recent Period of Antarctic Regional Warming: Implications for Other Colonies. *PLOS ONE, 6*(2), e14738. doi:10.1371/journal.pone.0014738

Williams, T. D. (1995). *The Penguins Spheniscidae*. New York: Oxford University Press.