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The Winners and Losers of Climate Change: A Case of the Gentoo Penguins and Adelie Penguins

Name: Madalyn A. Riley

Student ID: 78142111

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Abstract:

The aim of this review is to assess the scientific literature on the effects of climate change on Antarctic fauna with a focus on two pygoscelid penguins, the Adelie (*Pygoscelis adeliae*) and Gentoo (*Pygoscelis papua*) Penguins which are arguably, both affected by changes in the sea ice extent (Forcada *et al.* 2006). It will hope to discover whether or not the Gentoo penguin species will, in fact, displace the Adelie penguin species habitat based on the changing climates and differing physiological and habitat preferences. Based on the evidence put forward, there is still a large amount of research that needs to be completed in order to have a good understanding of the population dynamics of both species, and therefore, how they interact with each other. The increases in climate warming will continue to get worse and therefore, action needs to be taken now to address the impacts on Antarctic wildlife before it is too late and extinctions will begin causing massive alterations in the food chains and shifting the entire Antarctic ecosystem.

The Winners and Losers of Climate Change: A Case of the Gentoo Penguins and Adelie Penguins
Madalyn A. Riley **PCAS 2015/16**

Possibly one of the most discussed areas of concern is the highly unique and arguably pristine continent, Antarctica and within today's scientific community, the issue of climate change and global warming is an ever increasing issue. Within Antarctica's distinctive environment, it encompasses harsh weather patterns and isolated niches on a vast and extensive ice sheet. On earth, sea ice covers 6% of the world's ocean, half of which resides within the Antarctic (Ainley *et al.* 2010). This ice importantly controls many ways that the energy is exchanged between the ocean and the atmosphere and vice versa (Ainley *et al.* 2010). This environment is extremely sensitive to any changes caused by global warming whether it be from the changing temperatures from the ocean and the air, or altering wind patterns, both which will continue to dramatically affect the global climate. However, changes in the climate around the continent are not the same. For example, around the western Antarctic Peninsula, climate warming is amongst the fastest observed anywhere on the Earth (Clucas *et al.* 2014). This is due to an increase in temperature experiencing an increase of 5-6°C during the last 50 years (Peña M. *et al.* 2014).

Antarctica is home to some of the world's most unique species which have adapted to this harsh environment and so will eventually have to adapt to these changes such as the increases in temperatures.

The focus of this review is on two pygoscelid penguins, the Adelie (*Pygoscelis adeliae*) and Gentoo (*Pygoscelis papua*) Penguins which are arguably, both affected by changes in the sea ice extent (Forcada *et al.* 2006). It will hope to discover whether or not the Gentoo penguin species will, in fact, displace the Adelie penguin species habitat based on the changing climates and differing physiological and habitat preferences.

Pygoscelis penguins reside in the Antarctic and are comprised of 70% of the total Antarctic avian biomass (Trivelpiece *et al.* 1987). Within the Antarctic marine ecosystem, they are extremely important mesopredators and for a long time, have been termed indicators for environmental change whether it be for resource extraction, human visitation or climate change (Lynch *et al.* 2012). Throughout the millennia, they have developed adaption processes in order to survive variations in their environment including these great climatic changes such as having long life spans, the ability to accumulate large fat reserves quickly and also fasting for long periods of time (Forcada & Trathan 2009). However, they are very sensitive to the effects of climate change due to their size, morphology and adaptions which restrict foraging ranges and depths (Forcada & Trathan 2009). Both the Adelie and Gentoo penguins may have adapted to their environment they experience located at the centre of their unique ranges which may also depend on important factors such as reproductive success in each species (Trivelpiece *et al.* 1987). Specifically, the Gentoo penguin has become accustomed to being non-migratory, having short nest reliefs and displaying slow growth within chicks due to the milder conditions experienced within its environment (Trivelpiece *et al.* 1987) as opposed to other species, such as the Adelie penguin.

The effects of global warming on the populations of penguins in Antarctica, can be categorised into two main effects; a reduction in food availability and a reduction in ice-pack areas (Dantas *et al.* 2014) and due to these reductions, penguin foraging trips and energy expenditure in individuals has increased which has resulted in an increase in penguin mortality (Dantas *et al.* 2014). The abilities of the penguins to respond to these changes are confined to two main ways, dispersal and adaption (Forcada & Trathan 2009). Dispersal in this context, as compared to the usual demographic exchange between differing colonies or regions at a geographical level, is either displacement or permanent emigration (Forcada & Trathan 2009). The other option is to adapt whereby there must be a change in the distribution of the phenotypes over time which may act through either

phenotypic plasticity or through microevolution (Forcada & Trathan 2009). For example, Adelie Penguins have been observed increasing their dispersion due to a disruption in their habitat (Dugger *et al.* 2010). However, the consequences of dispersal are that it has the ability to cause local extinctions of the species as compared to adaption which can prevent this extinction (Forcada & Trathan 2009).

In order to make successful and accurate representations as to how the two species may react to the changing climate, 5 considerations need to be made (Ainley *et al.* 2010). There needs to be an understanding of the environment that these species live within specifically the sea ice conditions, wind, sea and air temperatures and also precipitation over the Southern Ocean (Ainley *et al.* 2010). Secondly, is the ways in which the penguins respond to the spatiotemporal variations in the Southern Ocean at all scales and therefore based on this, a selection can be made for the correct climate models which replicate these conditions (Ainley *et al.* 2010). These models need to then run to reflect the changes in penguin habitat to finally make qualitative projections based on the "habitat optimum" conceptual model for the species response (Ainley *et al.* 2010). However, due to the complexity of the interactions in the climate and how it influences the ecosystem, this can cause different consequences for the differing populations occurring within different years (Forcada & Trathan 2009). It has been acknowledged that the responses of these animals cannot always be directly associated and therefore determined by these climates modes which in turn complicates the ability to predict and forecast such changes (Forcada & Trathan 2009).

The distribution of the Adelie's is circumpolar and continental, breeding farthest south of the two species compared to the Gentoos who breed farthest north but also have a circumpolar distribution, however, breed on the sub-Antarctic islands (Trivelpiece *et al.* 1987). Colonies of the Adelie penguins are restricted to the ice-free areas of the continent, south of latitude 54°S (Dantas *et al.* 2014) extending north along the Antarctic Peninsula and Scotia Arc, effectively to the South Orkney Islands (Forcada *et al.* 2006). There is a small outlying population that is the only one outside this range residing on the Southern South Sandwich Islands (Forcada *et al.* 2006). The Gentoo penguin is a year round resident and is confined to inshore water however its habitat during the winter on the Antarctic Peninsula is unknown (Forcada *et al.* 2006).

Gentoo Penguin colonies are restricted to areas that contain <50% ice cover within November and the population increase is significantly correlated with the loss of this sea ice with new colonies being established with rapid growth near the boundaries of their southern ranges on the western Antarctic Peninsula (Lynch *et al.* 2012). This southward movement of the populations is expected to increase (Lynch *et al.* 2012). A report on 7 sites recorded near the southern most boundary of the breeding range displayed the fastest increase in numbers in the colonies that have newly been established within the last 20 years (Lynch *et al.* 2012).

Over the past 50 year time period where increase in temperatures has been recorded, specifically in the Antarctic Peninsula, there has been a significant decrease in the sea ice causing a loss in the winter habitat such as for krill, therefore, decreasing their stocks negatively impacting the Adelie Penguins but (arguably) not Gentoo Penguins, who, possibly, aren't as reliant on the krill as a food resource (Clucas *et al.* 2014). Adelie Penguin spatial patterns highlight the decline in populations with a strong correlation with the loss of phytoplankton biomass and, therefore, krill stocks possibly due to the climate changing or an increase in the whale populations following the cessation of intense harvesting (Lynch *et al.* 2012).

There has been some suggestions of little overlapping between the differing feeding niches of the Pygoscelis penguins in the Scotia Sea area of the Antarctic Peninsula and that the Gentoo Penguin was a piscivore consuming mainly fish, and the Adelie being a planktivore consuming mainly Antarctic Krill, *Euphausia superba* (White & Conroy 1975). When Gentoos and Adelies share the

niche, Gentoos have been observed disturbing the Adelies and the Adelies residing in a Gentoo-dominated niche (>80%) have significantly low reproductive success compared to the Adelie dominated colonies (>80%) (Lynch *et al.* 2012).

However, it has been stated that krill was the main source of food within the diets of both species being 99 and 86.5% wet mass for Adelie and Gentoo respectively, concluding that the diets did overlap however broadly within the summer and that the type and size of the prey were not an important factor that affected the ecological segregation between the penguin species (Volkman *et al.* 1980, 1987). Again, it has been stated that all penguin species rely heavily on krill although this was distinctively in the austral summer and that the size classes of krill taken did broadly overlap (Trivelpiece *et al.* 1987). Gentoo Penguins require the highest amount of krill per day in order to bring up their chicks although they have the most restricted foraging range which includes breeding in the same area as other penguin species such as the Adelie (Trivelpiece *et al.* 1987).

The foraging ranges can be based on the nest relief intervals of each species where in early December, Adelies relieved every 24 h compared to Gentoos every 12.5 h in late December (Trivelpiece *et al.* 1987). This may also predict why Gentoos have significantly higher amounts of fresh krill in their stomachs compared to Adelies (Trivelpiece *et al.* 1987). On Average, the mass of the Gentoo Penguins is 20% bigger than the Adelies (Trivelpiece *et al.* 1987). This also means that the Gentoo chicks need to attain more adult mass than the Adelies (104% compared to 79%) and also requiring more days to fledge (72 days compared to 52 days) (Trivelpiece *et al.* 1987).

The ability for all penguin species to dive deep and deeper than most other seabirds has come with some sacrifice such as flightlessness which restricts breeding distribution and overall distribution to cold temperate islands or isolated shorelines off Australia and Antarctica (Kooyman 2002). This also makes them almost defenceless on land even against the medium-sized terrestrial predators (Kooyman 2002). This ability of the Gentoo and Adelie species to coexist is thought be due to the
Gentoo species being capable of diving to the deeper depths which allows them to not only exploit the deeper krill swarms which the Adelie species cannot access, but also have access to the bottom dwelling fish, primarily being the notothenioid species (Trivelpiece *et al.* 1987). As the Adelies do not have access to the larger swarms, they must spend a greater amount of time searching for the available krill they need to survive (Trivelpiece *et al.* 1987).

In terms of the diet of the penguins reflecting changes in the climate, Adelie populations were observed to be significantly positively correlated with the amount of mean summer chlorophyll-a which is the proxy for the amount of phytoplankton and their consumers, the krill, within the Southern Ocean (Lynch *et al.* 2012). Over the last two decades, the chlorophyll-a concentrations have been shown to be decreasing in the waters of the Antarctic Peninsula which, again, correlates with the decrease in krill over the same time period (Lynch *et al.* 2012). The krill stocks may also be arguably sufficient for the Adelies suggesting that the breeding success decline is due to other factors such as snow accumulation and, therefore, meltwater runoff increase ((Clucas *et al.* 2014, Lynch *et al.* 2012). This melt-water has the potential to drown chicks within their nests as the snow has built up higher than in previous years.

As compared to the Adelie Penguins, who are a migrant species and disperse travelling hundreds to thousands of kilometres to reach the edge of the pack ice in winter to forage (Clucas *et al.* 2014), the Gentoo Penguins feed close to their colonies in ice-free areas (Forcada *et al.* 2006). It has been observed that species that display this migratory behaviour, the Adelies, do not have the higher levels of population structure as compared to the resident species, the Gentoos (Clucas *et al.* 2014). This pattern is particular for the majority of seabirds and is an important factor in population structure when studying winter dispersal (Clucas *et al.* 2014). Evidence also shows that the migrant

species may not be able to respond appropriately to the phenological effects of climate change which can impact the competitive relationships when breeding within the same area (Lynch *et al.* 2012). As the Gentoo Penguins feed inshore, they can experience and, therefore, take advantage of the warm spring which brings early melting of the snow compared to the Adelies, who must make a decision as to when they will return to their colony without already being aware what is occurring within the area (Lynch *et al.* 2012). Another advantage of being a resident species is that although they may have short and limited foraging times, they can potentially maximise their breeding aggregations (Forcada *et al.* 2006).

Observations have indicated that climate change can impact both the absolute and relative timing of clutch initiation in both species (Lynch *et al.* 2012). As compared to the Adelies, Gentoos have a more asynchronous and display higher plasticity in breeding phenology (Lynch *et al.* 2012). This higher plasticity compresses a breeding headstart that the Adelies once had during the warmer years adding to the disadvantages of climate change (Lynch *et al.* 2012). An advantage of the Gentoos breeding at the same time as the Adelies is that there will be a smaller proportion of adult mortality by leopard seals *(Hydrurga leptonyx)* and egg and chick mortality by the skuas *(Catharacta* spp.) (Lynch *et al.* 2012).

A decline in the extent and duration of the winter sea ice and also a retreat in the ice shelves has previously been experienced by the Antarctic during a warming climate period in the last glacial maximum which allowed all penguin species to expand their ranges to the south (Clucas *et al.* 2014). During this period, Southern Gentoo Penguins expanded more than their Northern populations which are profoundly similar to what is being observed today as the climate warming is similar to the current climate change observed within the sea ice of the Western Antarctic Peninsula (Clucas *et al.* 2014). However, compared to the LGM climate warming benefitted all penguin species, the current climate warming is arguably only benefitting the Gentoo Penguins who are the most opportunistic and generalist species with a flexible foraging niche which ultimately reduces the impact of krill declines as a food resource (Clucas *et al.* 2014). This incident has been stated as a "reversal of fortunes" for the two previously climate change "winners" represented by the increase in anthropogenic impacts which have exceeded warming past previous natural variations (Clucas *et al.* 2014).

The observed increase in the Gentoo populations along the Antarctic Peninsula during the last 50 years has mainly been attributed to the sudden increases in temperatures in the area which have affected the extent of the sea ice which in turn has altered the access to breeding sites and also the establishment of krill stocks (Peña M. *et al.* 2014), a key element in not only both specified species, but also to the wider Antarctic ecosystem. As climate change has slowly caused these changes within the sea ice dynamics, the Gentoo species has efficiently moved southward (Peña M. *et al.* 2014) and increased their area of habitat compared to a decrease in the populations of the Adelie species within the western Antarctic Peninsula due to a reduction in the krill (Peña M. *et al.* 2014) caused again by these changes in sea ice dynamics. This increase in Gentoo Penguins has also been observed by others in the same area (Lynch *et al.* 2012).

However, during the past decades, observed increases in the breeding populations of Adelie penguins located in the Ross Sea and eastern Antarctic has been reported as well as a positive population increase in the Gentoo species, but also states the original decreasing trend located on the Antarctic Peninsula as well as within the South Orkney Islands (Lima & Estay 2013). This may reflect the idea that the species was not correlated with the change in the November sea ice which suggests that sea ice does not represent a significant constraint for the existing colonies (Lynch *et al.* 2012).

Increases have also been observed in areas of the Indian Ocean, many colonies close to Syowa Station and again in East Antarctica and the Ross Sea where there is the idea that food chains here may be less dependent on Antarctic krill and the conditions at the local scale may not be as severe as compared to the Antarctic Peninsula (Forcada *et al.* 2006). However, at Signey Island and the Antarctic Peninsula, some global climate effects may have caused interannual reductions in the populations at Ross Island and possibly at Syowa Station (Forcada *et al.* 2006). Others have suggested that the Gentoo Penguin populations are decreasing or are highly variable on the eastern Antarctic Peninsula, contradicting these original reports of an increase and range expansion (Lynch *et al.* 2012).

A study completed on the Antarctic Peninsula which covered 24 Adelie Penguin breeding sites observed a significant decline in numbers at 18 of the sites but an increase within 3 sites (Lynch *et al.* 2012). However, other literature vaguely states that overall, Adelie Penguins in the Antarctic Peninsula are currently in decline but then state there is either an increase or a decrease within the southern sector (Clucas *et al.* 2014). Within the same area, Gentoo Penguins were observed to be significantly increasing at 32 of 45 sites and similarly significantly decreasing at only nine sites (Lynch *et al.* 2012). Overall, the differences in the dynamics of populations when observing at small scales within the Antarctic Peninsula region presents the difficulty of identifying any sort of trend (Clucas *et al.* 2014). The trends in Adelie populations were not observed to be significantly correlated with the loss of November sea ice (Lynch *et al.* 2012). This is compared to the Gentoo species which is restricted to areas with <50% November sea ice and are significantly correlated with the loss of this ice (Lynch *et al.* 2012).

As stated, both species are ideal models for reflecting and trying to gain an understanding the many effects that climate change and global warming will have on the natural fauna, particularly in the Antarctic Peninsula (Dantas *et al.* 2014). The already observed specific responses of penguins to climate change include contraction or expansion in ranges, changes in the timing of biological events, predator-prey interactions and poleward shifts in geographic distributions (Forcada & Trathan 2009), however, it is the impacts between regions, species and populations that differ (Forcada & Trathan 2009). At this stage, there is no other “reversal of fortunes” examples within the Antarctic environment, however, it is expected that more will become apparent as the climate continues to warm and the biodiversity declines (Clucas *et al.* 2014).

Both the reduction in sea ice and krill, appears to be causing the observed population trend in both species, although there is a close relationship between the sea ice cover and the krill recruitment which makes trying to figure out the linkages between climate, food resources and penguin population dynamics hard to monitor and understand (Lima & Estay 2013). The current estimates of krill consumption for both penguins and whales are lacking, however, further knowledge into this data (e.g. by the Commission for the Conservation of Antarctic Marine Living Resources’ Status and Trend Assessment of Predator Populations) may allow this krill hypothesis to be tested (Lynch *et al.* 2012). As hard as it may be to predict future changes in the sea ice over the Antarctic Peninsula, there is an expectation that there will be a continued decrease in the spring sea ice allowing the Gentoo Penguins to expand their population ranges south to the Berthelot Islands and even further (Lynch *et al.* 2012).

Based on the evidence that has been put forward, there is still a large amount of research that needs to be completed in order to have a good understanding of the population dynamics of both species, and therefore, how they interact with each other. The increases in climate warming will continue to get worse and therefore, action needs to be taken now to address the impacts on Antarctic wildlife before it is too late and extinctions will begin causing massive alterations in the food chains and shifting the entire Antarctic ecosystem.

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