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**Critical Literature Review
(ANTA602)**

***Title: Diet of Adélie penguins (*Pygoscelis adeliae*):
Past, Present and Future***

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Abstract (ca. 200 words):

Adélie penguins (*Pygoscelis adeliae*) are a numerous species of Antarctic penguins. Many studies have examined their diet, both past and present using a variety of methods. However, the conclusions that can be drawn from these studies are limited by the fact that these studies are limited to specific time of the year and the areas which have been studied. Most authors agree that in the past Adélie penguin diets were predominately fish-based, whereas currently the diets are krill-based. Adélie penguins (and their prey) have a strong relationship with the sea-ice. Given that changes in climate and levels of competition have resulted in prey-switching in the past it could be speculated that a change will happen again due to recent climatic and competition changes and what the consequences of this might be. Few studies have given much thought as to how likely this change is. However, researchers are divided as to whether these changes are likely and what the main causes of these changes are. There seems to be much uncertainty surrounding the diet of Adélie penguins, particularly in regards to their diet in the future. Further studies are needed to further reduce this uncertainty.



Source: <http://true-wildlife.blogspot.co.nz/2010/12/adelle-penguin.html>.
Accessed 2nd December 2012.

Introduction

The Importance of Adélie penguins

Adélie penguins (*Pygoscelis adeliae*) are a large group of Antarctic penguins. They are the most abundant of the penguins which live on the Antarctic continent (Green & Johnstone 1988) and the most numerous pygoscelid penguin species with a population of around 2.5 million breeding pairs (Coria *et al.* 1995). Although *P. adeliae* has a circumpolar distribution they are generally only found in specific areas due to their habitat preferences which is one which has more than 70% covered with sea-ice, preferably pack-ice (Rombolá *et al.* 2003). In recent years there has been a decline in the populations of Adélie penguins (Forcada *et al.* 2006). The South Shetland Islands in particular has been the location for significant declines in Adélie penguin numbers. A study by Trivelpiece *et al.* (2011) found that more than 90% of branded chicks are not surviving to breed and that recruitment rates are well below maximum levels of success that this species had in the past.

Antarctic seabirds consume large amounts of prey each year. The direct and indirect consumption of prey by Antarctic seabirds has been estimated to be up to 115×10^6 tonnes per annum, with the major consumers being penguins (Puddicombe & Johnstone 1988). Owing to their large population size Adélie penguins make up a large proportion of the penguin biomass in the Antarctic and are a major group of predator. This was recognised in the BIOMASS Working Party on Bird Ecology in 1978 which noted that this species either competes or has the potential to compete with humans and do compete with other animals, including whales, for prey (Puddicombe & Johnstone 1988). Therefore, Adélie penguins have a central role in the Antarctic marine ecosystem (Kato *et al.* 2003) which needs to be recognised. This review intends to find out what the current opinions in the literature are in regards to the diet of Adélie penguins past, present and future.

Other considerations

There have been a number of studies undertaken which examine the diet of Adélie penguins. Most studies have been done in a limited number of regions, primarily in the Antarctic Peninsula, Ross Sea region (Green & Johnstone 1988) or at the South Orkney Islands (Puddicombe & Johnstone 1988). Also, nearly all of the studies are conducted during the same time of the year (the breeding season, which is from October to February (Puddicombe & Johnstone 1988)) and on adult penguins (Coria *et al.* 1995). Therefore not much is known about the diet of Adélie penguins outside of this time (Tierney *et al.* 2008). These are all potential sources of bias which need to be taken into consideration when examining the diet of this species.

Main

Methods for determining past diets

The diet of Adélie penguins in the past can be determined using several different methods. Most studies are done at abandoned penguin colonies (Emslie & McDaniel 2002; Emslie & Woehler 2005) using the ornithogenic (bird-caused) soils which were created at these locations over time (McDaniel & Emslie 2002). The historical record of the diet of Adélie penguins can be determined using the remains found in these soils. These include: fossilised eggshells (Emslie & McDaniel 2002; Emslie & Patterson 2007), penguin bones and other sources of penguin tissues (including feathers and dried skin) (Emslie & McDaniel 2002) that remain in these soils. The remains of the hard parts of prey (e.g. fish bones, otoliths and squid beaks) in the guano can also be used (McDaniel & Emslie 2002; Polito *et al.* 2002). Prey can then be determined by identifying the prey remains by sight, are dated using radiocarbon dating (which has been used since the 1980s on seabirds) and the temperature of the time can be determined using isotope ratios (Emslie & McDaniel 2002).

Past penguin diet

Studies have shown in the past the diet of *P. adeliae* was diverse. Their diet mainly consisted of cephalopods (Emslie & McDaniel 2002) and many different taxa of fish (with at least 23 different types of teleost fish) (Emslie & Woehler 2005). Studies at Anvers Island and Rothera Station indicate that Antarctic silverfish (*Pleuragramma antarcticum*) was an important part of the diet of Adélie penguins (Polito *et al.* 2002) in the past. The two most abundant prey taxa according to a study by Emslie & Woehler (2005) were *P. antarcticum* (which agrees with the findings of Polito *et al.* (2002) and Southern Ocean squid (*Psychroteuthis glacialis*). Some studies such as Emslie & Woehler (2005) did not find any evidence of krill in their diet of the Adélie penguins at Windmill Islands, East Antarctica whilst other studies (Emslie & McDaniel 2002; Polito *et al.* 2002) only briefly mention krill. However, the diet of the Adélie penguins was not constant over time. A study by Emslie & Woehler (2005) found that some species fluctuated in the proportions that they made up in the diet of Adélie penguins over time. For example the amount of Antarctic silverfish (*Pleuragramma antarcticum*) in the diet of Adélie penguins at Adelaide Island (in the Antarctic Peninsula) decreased as the nests got older.

Methods for determining current diets

There are many different ways to determine the current diet of Adélie penguins. The use of stomach contents to determine the current diet of Adélie penguins is the main way that current diets are determined at present (Ainley *et al.* 2003). Stomach samples are generally collected using the water off-loading method, which has several ethical issues attached, including the fact that it causes the

chick to lose a meal and there is no mention of providing the chick a supplementary meal by many authors (Jarman *et al.* 2002; Tierney *et al.* 2008; Offredo *et al.* 1985). Due to the ethical and practical considerations associated with this method (such as the penguin needing to have a full stomach) other methods are beginning to be more widely used. Another method which is increasingly being used over the last 25 years is stable isotope analysis (SIA) which uses the isotopic ratios of carbon ($^{13}\text{C}/^{12}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$) in the tissues of the predators as these reflect its diet in both a reliable and predictable way (Tierney *et al.* 2008). Less accurate, but less invasive methods involve the observation of the adult feeding chick and determining the prey composition by the colour of the regurgitated matter, with krill-based diets being pink in colour and fish-based diets grey (Tierney *et al.* 2008). DNA-based methods are also emerging for modern day diets (Jarman *et al.* 2002), but have not yet been applied in studies examining past diets.

Current diet

Adélie penguins have a varied diet, although there is much that is still unknown about it. Prey consumption varies both during the breeding season and between years (Coria *et al.* 1995). Therefore it is not possible to extrapolate out the diet of *P. adeliae* using data collected during the breeding season for other parts of the year (Tierney *et al.* 2008). Many studies (Coria *et al.* 1995; Kato *et al.* 2003; Lynnes *et al.* 2002) have found that the krill are the main dietary item, with Antarctic krill (*Euphausia superba*) and crystal krill (*Euphausia crystallorophias*) being found in roughly equal proportions (Puddicombe & Johnstone 1988). Other major dietary items include fish (including Antarctic silverfish) and cephalopods (Offredo *et al.* 1985). Minor dietary items include mysids, pteropods, isopods and amphipods (Coria *et al.* 1995; Puddicombe & Johnstone 1988).

It is well known that Adélie penguins mainly consume krill when foraging. This has led to some authors (e.g. Polito *et al.* 2002; Reid *et al.* 2004) calling *P. adeliae* a krill predator. However, Ainley *et al.* 2003 disagrees with this classification, arguing that since Adélie penguins have a varied diet such a classification is not appropriate. In addition to this Ainley *et al.* (1998) found that the penguins at their study sites (Cape Crozier and Cape Bird) had a diet which consisted primarily of fish, and not krill. This further strengthens the claim that they should not be known as krill predators as that implies that krill are always the key prey of this species (which is not always the case, Figure 1).

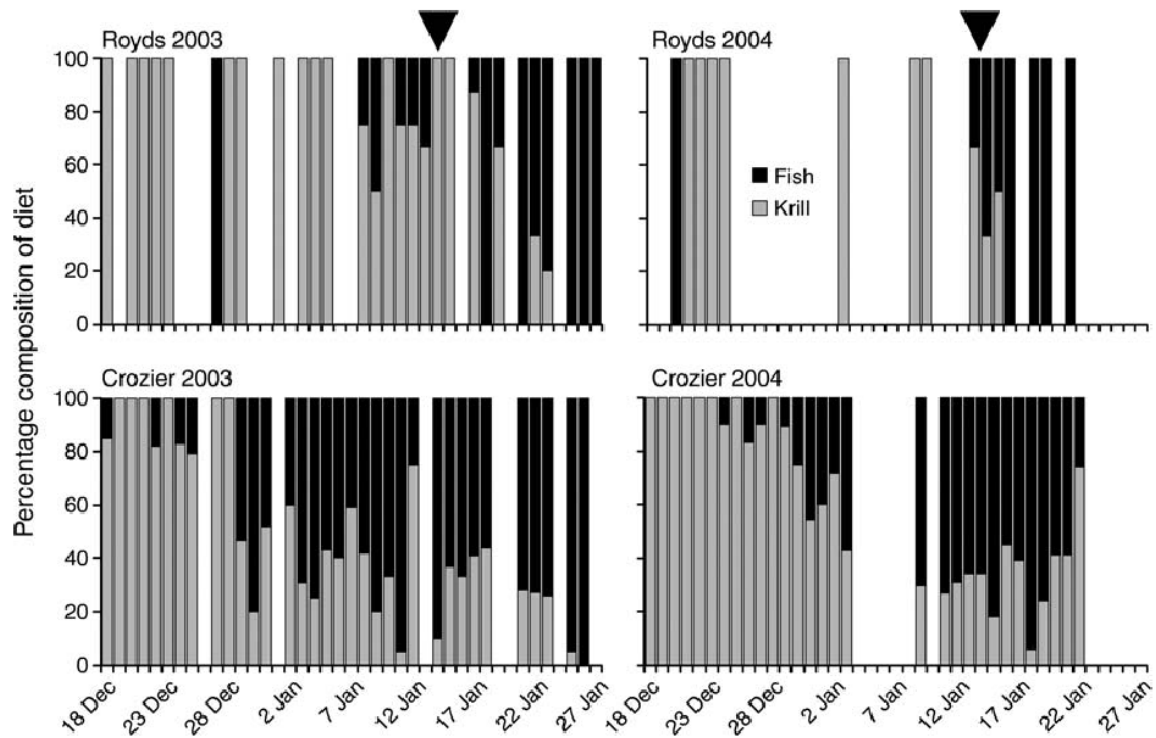


Figure 1- "The percentage of fish and krill in the diet of Adélie penguins at Cape Royds and Cape Crozier 2003-2004 and 2004-2005. A blank column indicates that no data were available due to storms or absence observers for other reasons" (Ainley *et al.* 2006).

Discussion

Relationships of penguins and their prey with sea ice

Adélie penguins (and some of their prey) are an ice-obligate species, which are dependent on the sea-ice throughout the entire year. They over-winter in the pack-ice and their breeding success is linked to timing of the formation and break-up of the sea-ice (Tierney *et al.* 2008). This is because they use the sea-ice as a platform during their foraging trips and their reliance on it can be determined using statistics which compare their diet, breeding success and the extent and thickness of the sea-ice (Kato *et al.* 2003). Their dependence on the sea-ice is linked to the fact that krill recruitment is also strongly correlated with the sea-ice. A link has been made between the recruitment of krill in the South Atlantic and sea-ice extent and there are increases in the recruitment when there is heavier winter sea-ice (Nicol *et al.* 2008). This in turn has impacts on the diet of Adélie penguins as it influences prey availability.

Mechanisms of dietary changes

Climatic changes

Due to this species' dependence on sea-ice it can be expected that changes in climate would have considerable impact upon their diet. Climatic-driven dietary changes have been both speculated

(Polito *et al.* 2002) and partially proven (Emslie *et al.* 1998) to have a correlation with the abundance of some prey species including *P. antarcticum*. Both of these authors, however, concluded that further studies of ornithogenic soils and isotopic analyses of the otoliths are needed to test the assumption on the strength of the correlation between climate and prey availability using the paleo-diet records. The evidence for the links between krill density and sea-ice at present is much stronger. Atkinson *et al.* (2004) found that there has been a decline in krill density of up to 80% in around the last 30-40 years and that this reduction is associated with a decline in sea-ice. Given that the penguins have a krill-based diet, it may be expected that there will be evidence of the Adélie penguins changing their diet in response to this.

Competition-based changes

In the recent past there has been a major shift in the diet of Adélie penguins, which is linked to prey availability. Research has shown that there was an abrupt shift in the diet of Adélie penguins since the 19th century, which Emslie & Patterson (2007) and Trivelpiece *et al.* (2011) attribute to the large numbers of seals and whales killed during the sealing and whaling era. As a result of sealing and whaling more krill was available to the penguins than before (>150 million tonnes) (Emslie & Patterson 2007; Trivelpiece *et al.* 2011). The authors suggest that the diet of Adélie penguins switched from being primarily fish to krill during the 18th-19th centuries when the krill surplus began to manifest (Emslie & Patterson 2007). The authors believe that the penguins will continue to feed on krill (with variations throughout Antarctica in the proportions that krill and fish that are consumed) (Emslie & Patterson 2007). Trivelpiece *et al.* (2011) hypothesised that the recovery of fur seal and whale populations and bottom-up, climate driven changes have increased the competition for krill and caused significant changes within this ecosystem during the last 20 to 30 years (Trivelpiece *et al.* 2011). These changes also indicate that there is a possibility that the Adélie penguins may react to changing prey availability once more.

Evidence for changing diet

There are many pressures for the Adélie penguins to shift in their diet, but whether they are is uncertain. Emslie & Patterson (2007) wrote that the dependence of Adélie penguins on krill in their diet is only a relatively recent occurrence. This supports the theory that they would be able to change their diets again. However, while there are records of regional, seasonal and annual variations in the diet of Adélie penguins, as of yet no studies have been undertaken which have reported seeing any definitive changes in their diet in more recent times. Yet even if there were long-term changes in their diet, the cause/s may not be able to be fully determined. This is because

currently the question of whether they eat more krill when there is less sea-ice is due to an increase in number of availability of krill ,(as well as many other questions) is not clear (Rombolá *et al.* 2003). Some authors have done studies which suggest that there may have been changes over large time scales. Emslie & Patterson (2007) indicate that they believe that krill will only be the major dietary item of Adélie penguins until the marine mammal populations recover to their former levels (Emslie & Patterson 2007). This indicates that they believe the Adélie penguins to be capable of changing their diets again in response to changing prey availability. Nicol *et al.* (2008) also believes that, given the behavioural flexibility of this species, they will be able to adapt. Studies at Palmer Station have found that the diet of Adélie penguins may have changed the proportion that fish and squid comprise of in their diet during the last 700 years as a result of climate change (Emslie & McDaniel 2002). However, studies during the last 30 years show that krill are still a dominant prey species of Adélie penguins even though there has been a decrease in krill biomass of around 38-81% (Trivelpiece *et al.* 2011). This may mean that the pressure on Adélie penguins to change their diet might be less than it is currently believed to be.

In the past environmental changes have occurred much more slowly than they are at present. Trivelpiece *et al.* (2011) are unsure as to whether the Adélie penguins could revert back to a fish-based diet. They are also uncertain as to whether or not large populations of penguins would be able to be supported by a reversal in dietary preferences. Given that not much is known about what they eating during winter (Emslie & Patterson 2007) it could be that their diet could be changing and we just do not know it (yet). Whether or not the Adélie penguins will be able to adapt in time is also not clear and requires research.

Importance of their diet

Energetic requirements and health

The diet of Adélie penguins is important in terms of energetic requirements, both for themselves and for their chicks. Different prey species have different energetic values (Ainley *et al.* 2006; McDaniel & Emslie 2002). Given that Adélie penguins are believed to target the most abundant species in their foraging range, regardless of their energetic value (Puddicombe & Johnstone 1988), the availability of prey types can have a profound impact upon the health of adult penguins as well as that of their chicks. Antarctic silverfish have more calories than krill so it has been speculated that the adults target these at times to be able to fulfil their chicks' energetic demands (Ainley *et al.* 2006). However, it is noted that in other parts of Antarctica Adélie penguins have been recorded as having successfully raised their chicks to fledgling stage with a krill only diet (Ainley *et al.* 2006),

which increases the uncertainty over this issue. Ainley *et al.* (2006) were contradictory when they wrote that although it is likely that the dietary shift has to do with the availability of prey, and then wrote that “we do not favour this hypothesis”. What they meant by that is not entirely clear.

Species management

Understanding the diet of Adélie penguins and the likelihood of it changing (and when) is important in terms of the management of this species. This is especially true given that Adélie penguins are important consumers of high biomass species such as krill and several fish species (Tierney *et al.* 2008). There have been significant changes in the Antarctic marine ecosystem in the last 80 years due to large declines in the populations of baleen whales (and seals) as well as the expansion and growth of the krill fishery (Puddicombe & Johnstone 1988). These changes need to be understood in order to better manage the conservation of Adélie penguins as well as to improve the management of fisheries in the Southern Ocean. In order to better understand the dynamics of marine ecosystems it is important to have knowledge of the variability top predator diets in both space and time (Tierney *et al.* 2008). This information can also be used to evaluate the “impacts of ecological variation” of the creation of management strategies for both conservation and fishery activities (Tierney *et al.* 2008).

CCAMLR and fishing

An understanding of the diet of Adélie penguins is also important in terms of managing Southern Ocean fisheries. This is especially important as Adélie penguins have been selected by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) as an indicator species for managing the krill fishery (Tierney *et al.* 2008). Also, there are signals that the fishery is likely to expand further in the near future (Trivelpiece *et al.* 2011) and concerns have been raised over the overlaps between Adélie penguins and fisheries. It is believed that penguins may be especially sensitive to prey fluctuations given that they are tied to a single location for 5- 6 months as they raise their offspring (Croll & Tershy 1998), which must be taken into account when fishery quotas are set. However, Ichii *et al.* (1996) concluded in their study that the penguins and fishery at South Shetland Islands was not significant. Therefore the impact on the fishery in the Southern Ocean could potentially have very little impact on the diet of the Adélie penguins. However, if the penguins were faced with severe declines in prey availability even this small amount of competition could be disastrous in reducing their chances for survival by affecting the tipping point of this species. Therefore the cumulative effects (although recognised to some degree (Figure 2)) of prey reduction need to be investigated thoroughly, which has not yet been done.

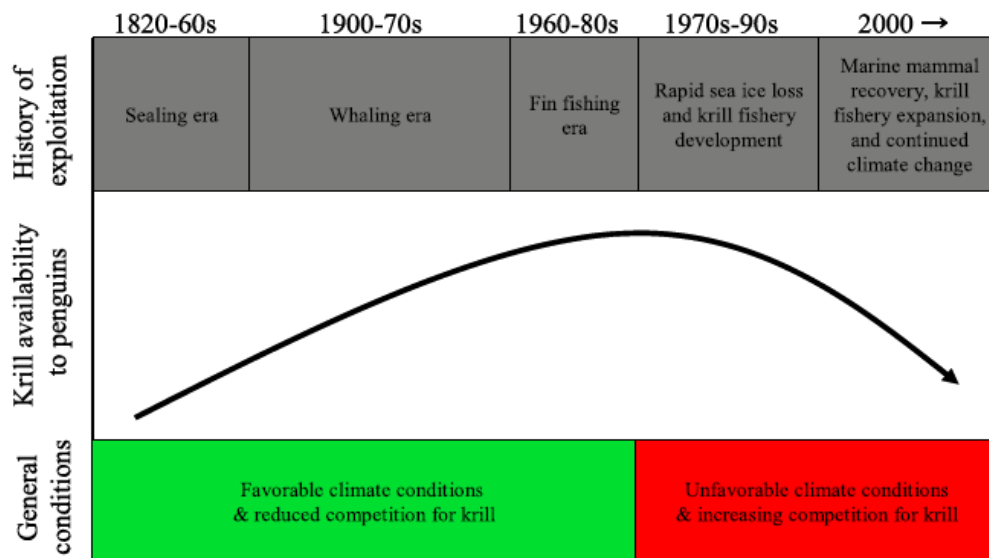


Figure 2- “Schematic diagram of ecosystem perturbations in the Scotia Sea. Shows the changing availability of krill available to penguins as a result of sealing at the South Shetland Islands 1820-1860), commercial whaling (1900-1970), fishing for ice fishes and Notothenioids (1960-1980), followed by increases in Adélie populations. Climatic changes became obvious from 1970-1990 and a krill fishery was developed. By the 2000s the marine mammal populations are recovering or recovered and there are expansions in the kill fishery and increased effects of climate change. Adélie penguin populations are beginning to decline (Trivelpiece *et al.* 2011)

Conclusions

Adélie penguins are an important predator in the Southern Ocean. Given that they have undergone dietary shifts from being fish-based to krill-based in the past as a result of changing prey availability it could be expected that they will once again change their diet in response to changing prey abundance. However, it is not as simple as it seems, and the situation is proving to be difficult to both understand and assess. There is much natural variation within the system, which has the potential to mask changes, particularly due to the fact that most studies are over short time periods in few locations. If researchers cannot decide on what they eat now then predicting how their diet might be in the future is nearly impossible. Clearly, there are many gaps in the current understanding of this topic, and many areas which remain either inadequately researched or not studied at all which needs to be addressed.

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