University of Canterbury
Graduate Certificate in Antarctic Studies
Personal Project

Global Warming Effects on Antarctic Ecosystems with Special Reference to Consequences for the Krill Dependant Penguins, Fur seals and Whales

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1 Aims

The aim of this project is to find out about possible effects of global warming on selected Antarctic animals.

Through this research, I want to confirm global warming's capacity to not only disturb an individual species but rather alter an entire ecosystem. Climate change is often viewed abstractly, but this analysis is framed to prove how many complex factors associated with global warming intersect to alter entire habitats. I feel this approach is the most effective way to study global warming.

2 Significance

This topic is important since it demonstrates the immense consequences of human actions on various species across the globe. It is clear that the industrialized countries, for example the USA, are the major contributors to the sharp increase in greenhouse gases and subsequent warming in global temperatures. Now we must assume responsibility for the ramifications. Global warming has the potential to alter species' lifestyle and natural habitats.

3 Introduction

In the following I will give a general overview over geography, climate, flora and fauna of Antarctica.

3.1 Antarctica

The name "Antarctica" comes from the Greek *ανταρκτικός* (*antarktikos*), meaning "opposite to the Arctic." **(Liddell, 1996)**

3.1.1 Geography

Antarctica is the world’s southernmost continent and is surrounded by the Southern Ocean. Most of the land mass is located south of the Antarctic Circle (at latitude 66° 33′ 39″). At 14.425 million km², Antarctica is the third-smallest continent before Europe and Australia. The coastline measures 17 968 km and is mostly characterized by ice formations. Physically, it is divided by the Transantarctic Mountains between the Ross Sea and the Weddell Sea. The portion west of the Weddell Sea and east of the Ross Sea is called Western Antarctica and the remainder Eastern Antarctica, because they roughly correspond to the Western and Eastern Hemispheres relative to the Greenwich meridian. About 98% of Antarctica is covered by the Antarctic ice sheet. The ice sheet is, on average, 2.5 kilometers thick. The continent has approximately 90% of the world's ice (approximately 70% of the world's fresh water). If all of this ice were melted sea levels would rise about 61m. The highest peak in Antarctica is the Vinson Massif at 4892 meters. It is located in the Ellsworth Mountains. Although Antarctica is home to many volcanoes, only Mt. Erebus is active. Mount Erebus, located in Ross Island, is the southernmost active volcano. There are no permanent human residents and Antarctica has never had an indigenous population. **(Stonehouse, 2002)**

3.1.2 Climate

On average, Antarctica is the coldest, driest, and windiest continent, and has the highest average elevation of all the continents. **(Sloss, 2006)** It is a frozen desert with little precipitation; the South Pole itself receives less than 10 cm per year, on average. Temperatures reach a minimum of between -80 °C and -90 °C in the interior in winter and reach a maximum of between +5 °C and +15 °C near the coast in summer. Eastern Antarctica is colder than its western counterpart because of its higher elevation. Weather fronts rarely penetrate far into the continent, leaving the center cold and dry. The interior of the continent is technically the largest desert in the world. Despite the lack of precipitation over the central portion of the continent, ice there lasts for extended time periods. Heavy snowfalls are not uncommon on the coastal portion of the continent, where snowfalls of up to 1.22 meters in 48 hours have been recorded. At the edge of the continent, strong katabatic winds off the polar plateau often blow at storm force. In the interior, however, wind speeds are typically moderate. During summer more solar radiation reaches the surface during clear days at the South Pole than at the equator because of the 24 hours of sunlight each day at the Pole. Antarctica is colder than the Arctic for two reasons. First, much of the continent is more than 3 km above sea level, and temperature decreases with elevation. Second, the Arctic Ocean covers the north polar zone: the ocean's relative warmth is transferred through the ice and prevents temperatures in the Arctic regions from reaching the extremes typical of the land surface of Antarctica. **(British Antarctic Survey, 2006)**

3.1.3 Flora

The climate of Antarctica does not allow extensive vegetation. Combinations of freezing temperatures, poor soil quality, lack of moisture, and lack of sunlight in winter inhibit the flourishing of plants. As a result, plant life is limited to mostly mosses and liverworts. The autotrophic community is made up of mostly protists. The flora of the continent largely consists of lichens, bryophytes, algae, and fungi. Growth generally occurs in the summer and only for a few weeks at most. There are more than 200 species of lichens and approximately 50 species of bryophytes, such as mosses. Seven hundred species of algae exist, most of which are phytoplankton. Multicolored snow algae and diatoms are especially abundant in the coastal regions during the summer. There are two species of flowering plants found in the Antarctic Peninsula: *Deschampsia antarctica* (Antarctic hair grass) and *Colobanthus quitensis* (Antarctic pearlwort). **(Australian Government Antarctic Division, 2006)**

3.1.4 Fauna

Land fauna is nearly completely invertebrate. Invertebrate life includes microscopic mites, lice, nematodes, tardigrades, rotifers, krill, and springtails. The flightless midge *Belgica antarctica*, just 12 mm in size, is the largest land animal in Antarctica. The Snow Petrel is one of only three birds that breed exclusively in

Antarctica and have been seen at the South Pole. Varieties of marine animals exist and rely, directly or indirectly, on the phytoplankton. Antarctic sea life includes penguins, blue whales, and fur seals. The Emperor penguin is the only penguin that breeds during the winter in Antarctica, while the Adélie penguin breeds farther south than any other penguin. Rockhopper penguins, King penguins, Chinstrap penguins, and Gentoo Penguins also breed in the Antarctic. The Antarctic fur seal was very heavily hunted in the 18th and 19th centuries for its pelt by sealers from the United States and the United Kingdom. The Weddell Seal, a "true seal", is named after Sir James Weddell, commander of British sealing expeditions in the Weddell Sea. Antarctic krill, which congregates in large schools, is the keystone species of the ecosystem of the Southern Ocean, and is an important food organism for whales, seals, leopard seals, fur seals, squid, icefish, penguins, albatrosses and many other birds. **(Asselbergs, 2002)**

4 Global warming

Global warming is the observed increase in the average temperature of the Earth's atmosphere and oceans in recent decades and its projected continuation. Models referenced by the Intergovernmental Panel on Climate Change (IPCC) predict that global temperatures may increase by 1.4 to 5.8 °C between 1990 and 2100. The uncertainty in this range results from both the difficulty of predicting the volume of future greenhouse gas emissions and uncertainty about climate sensitivity.

Global average near-surface atmospheric temperature raised 0.6 ± 0.2 °Celsius in the 20th century. (See fig. 1 and 2) **(Alley, R., Berntsen, T., Bindoff, L. et al. 2007)**

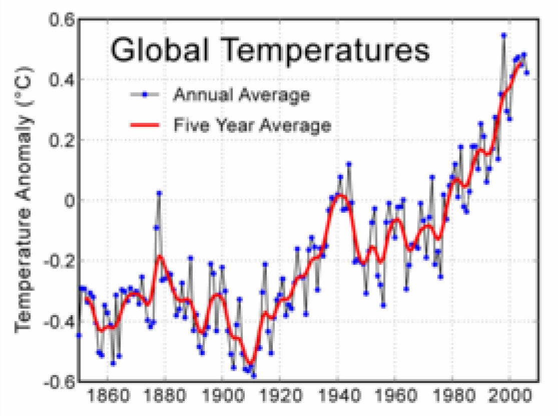

Fig.1: Global surface temp. 1850 to 2006 (Alley, 2007)

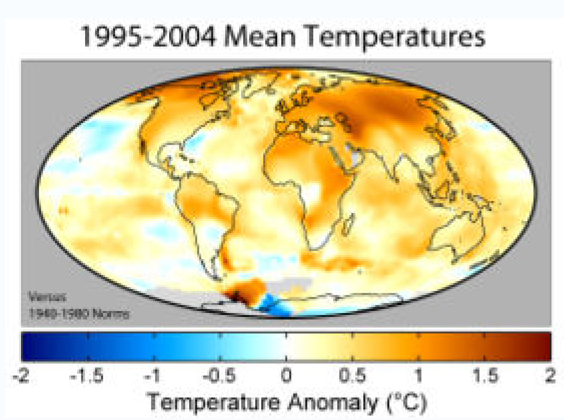

Fig2: Mean surface temperature anomalies during the period 1995 to 2004 with respect to the average temperatures from 1940 to 1980 (Alley, 2007)

The prevailing scientific opinion on climate change is that most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. **(Alley, R., Berntsen, T., Bindoff, L. et al. 2007)** The main cause of the human-induced component of warming is the increased atmospheric concentration of greenhouse gases (GHGs) such as carbon dioxide (CO_2), which leads to warming of the surface and lower atmosphere by increasing the greenhouse effect. Greenhouse gases are released by activities such as the burning of fossil fuels, land clearing, and agriculture. An increase in global temperatures can in turn cause other changes, including a rising sea level and changes in the amount and pattern of precipitation. These changes may increase the frequency and intensity of extreme weather events, such as floods, droughts, heat waves, hurricanes, and tornados. Other consequences include higher or lower agricultural yields, glacier retreat, reduced summer stream flows, species extinctions and increases in the ranges of disease vectors. Warming is expected to affect the number and magnitude of these events; however, it is difficult to connect particular events to global warming. Although most studies focus on the period up to 2100, even if no further greenhouse gases were released after this date, warming (and sea level) would be expected to continue to rise since CO_2 has a long average atmospheric lifetime. Remaining scientific uncertainty comes from the exact degree of climate change expected in the future and particularly how changes will vary from region to region across the globe. A hotly contested political and public debate has yet to be resolved, regarding whether anything should be done, and what could be cost-effectively done to reduce or reverse future warming, or to deal with the expected consequences. Most national governments have signed and ratified the Kyoto Protocol aimed at combating global warming. **(U.S. Environmental Protection Agency**, **2006)**

5 Climate change in Antarctica

The area of strongest cooling appears at the South Pole, and the region of strongest warming lies along the Antarctic Peninsula (See fig. 3). One possible explanation for this is that the warmer temperatures in the surrounding ocean have produced more precipitation in the continent's interior, and this increased snowfall has cooled the high-altitude region around the pole. Another possible explanation is that loss of UV-absorbing ozone may have cooled the stratosphere and strengthened the polar vortex, a pattern of spinning winds around the South Pole. The vortex acts like an atmospheric barrier, preventing warmer, coastal air from moving in to the continent's interior. A stronger polar vortex might explain the cooling trend in the interior of Antarctica. **(NASA Earth Observatory, 2006)** There is also evidence for widespread glacier retreat around the Antarctic Peninsula. **(Vaughan, D. 2005)**

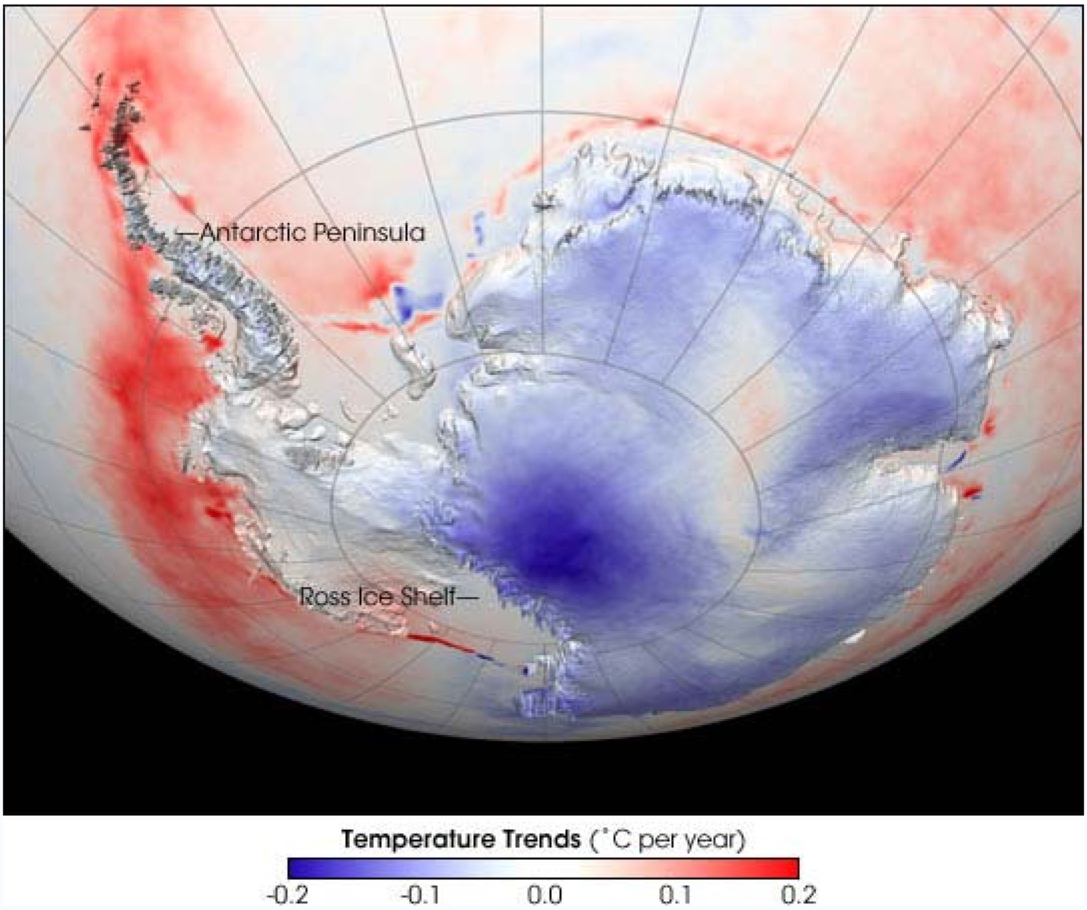

Fig.3: NASA Earth Observatory, 2006

The recent retreat of ice shelves on the Antarctic Peninsula has been widely attributed to warming atmospheric temperatures. There is, however, little published work describing the response of glacier margin positions to this regional climate change. In the paper “Retreating Glacier Fronts on the Antarctic Peninsula over the Past Half-Century” recently published in *Science*, new data were presented describing trends in 244 marine glacier fronts on the Antarctic Peninsula over the last 50 years. The data come from matching archives of over 2000 aerial photographs of the Antarctic Peninsula to satellite images, and represent about three years of work by Alison Cook. The work was carried out at British Antarctic Survey, but was funded by the US Geological Survey, as part of a larger programme to map change in the coastline of all Antarctica. Analysis of the data reveals that 87% of glaciers have retreated and that the change from advance to retreat has occurred progressively with latitude. In 1950s only the most northerly glaciers appeared to be retreating, but a transition from advance to retreat appeared to move down the Antarctic Peninsula over a period of about 10 to 20 years, broadly in line with what would be expected if this was a consequence of the warming that has been measured in this area. However, there are features of the pattern of change that are difficult to explain by atmospheric warming alone. In particular, there was a period in the late-1980s and early-1990s when retreat slowed down along most of the coast, and scientists don't see any cause for this in the temperature records - so there may be some other factors, perhaps ocean temperature. The retreat of these glaciers in itself will have a negligible effect on sea level, since most of the ice that has retreated was in the water already. However, if as a consequence of shortening, the glaciers are also flowing faster, then we would be seeing another (small) contribution to sea level rise. **(Cook, 2005)**

6 Consequences of global warming for Antarctic animals

In the following I want to have a closer look at the (direct and indirect) effects of global warming on several Antarctic species.

6.1 Alteration of the food web along the Antarctic Peninsula

In the near shore coastal waters along the Antarctic Peninsula, a recurrent shift in phytoplankton community structure, from diatoms to cryptophytes, has been documented. The shift was observed in consecutive years (1991-1996) during the austral summer and was correlated in time and space with glacial melt-water runoff and reduced surface water salinities. Elevated temperatures along the Peninsula will increase the extent of coastal melt-water zones and the seasonal prevalence of cryptophytes. This is significant because a change from diatoms to cryptophytes represents a marked shift in the size distribution of the phytoplankton community, which will, in turn, impact the zooplankton assemblage. Cryptophytes, because of their small size, are not grazed efficiently by Antarctic krill, a keystone species in the food web. An increase in the abundance and relative proportion of cryptophytes in coastal waters along the Peninsula will likely cause a shift in the spatial distribution of krill and may allow also for the rapid asexual proliferation of carbon poor gelatinous zooplankton, salps in particular. This scenario may account for the reported increase in the frequency of occurrence and abundance of large swarms of salps within the region. Salps are not a preferred food source for organisms that occupy higher trophic levels in the food web, specifically penguins and seals, and thus negative feedbacks to the ecology of these consumers can be anticipated as a consequence of shifts in phytoplankton community composition. **(Moline, 2004)**

6.2 The Adélie Penguin

Regarding the consequences of climate change the Adélie Penguins are a very well studied species. Looking at these animals shows clearly the effects of global warming. For this reason I decided to describe that species more detailed and extensively than the other animals I am looking at.

6.2.1 Introduction

Based on various scientific evidence, rapid climate change is leading to population decline of the Adélie Penguins on the Antarctica Peninsula. Scientists predict that the rise in the temperature of air and surrounding oceans of Western Antarctica will continue to cause significant melting and calving of pack ice on the Antarctic Peninsula. If the global population does not alter its current lifestyle in order to reduce CO2 levels in the atmosphere, the Adélie penguin population will be driven to a quick extinction from irreparable destruction of their habitat. Total disruption of the food chain, and the subsequent homogenization of the ecosystem, will be a likely end result. **(Forcada, 2006)**

Recent studies indicate that there have been significant declines in the Adélie penguin population over the past fifty years. An analysis of these studies has shown that continuation of temperature rise and melting of the pack ice will only result in further decline. Since these penguins are especially dependent upon the presence of ice in their habitat for survival, the effects will be largely exacerbated as global warming trends become more drastic. Scientists affirm that although complete extinction may seem improbable, it is a realistic possibility for the near future. **(Forcada, 2006)**

6.2.2 General information about the Adélie penguins

The Adélie Penguins, Pygoscelis adeliae, are the smallest penguin species on the Antarctic Peninsula. They average around thirty inches in height and weigh eleven pounds **(British Antarctic Survey, 2006).** This particular species are most vulnerable to the rapid climate change because of their ice-dependent lifestyle. The Adélie's main food source is the Antarctic krill which feed on the deep sea algae. The algae can be found only in the nutrient rich regions of lower pack ice. The Adélie forage for krill by diving to depths of up to 175m but usually feed within the upper 70m of the water column where the krill are easily accessible. The Antarctic krill make up 99% of the penguins' food source **(Croxall, 2002).**

In addition to their ice dependence for foraging, the Adélie also need firm, frozen, rocky areas for nesting. These areas not only provide the Adélie with a secure base for their eggs, but also provide protection from predators on the Peninsula such as the brown skuas and sea leopard **(Forcada, 2006).**

6.2.3 Area of Study

Antarctica is home to 177 colonies (locations see fig. 4), which is equivalent to approximately 2 million pairs of Adélie penguins. The cold temperature provides the perfect habitat for the Adélie penguins. On the Antarctic Peninsula the average temperatures are relatively less severe, varying from 0 to -10° C throughout the year. The peninsula area is the predominant home to the Adélie penguins who are also accompanied by other populations of penguins, seals, and whales. **(British Antarctic Survey, 2006).**

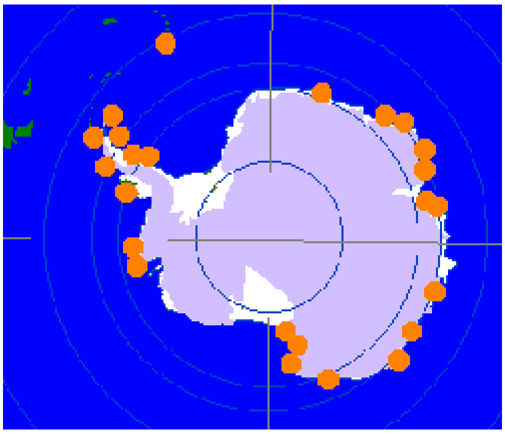

Fig.4: Antarctic Map showing location of Adélie Colonies

(British Antarctic Survey, 2006)

6.2.4 Temperature Information

Graph 5 below shows the global temperature change over the course of 140 years. The rapid increase in temperature since the Industrial Revolution is predominantly due to the swell in CO_2 concentration in our atmosphere.

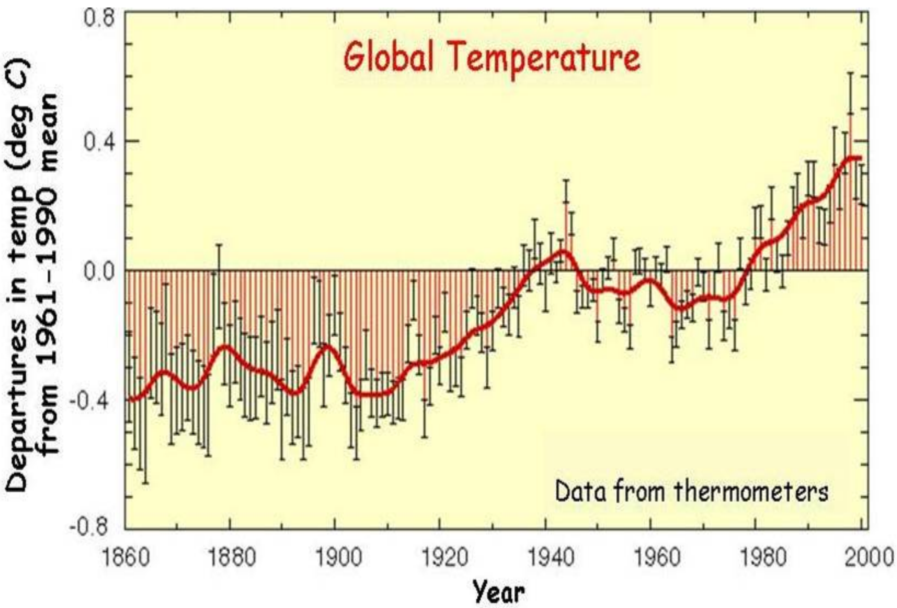

Fig. 5: Global temperature change from 1860 to 2000 (Kling, 2006)

This graph (above) shows the global temperature change from 1860 to 2000. Though the change of only a few degrees may seem insignificant, it is a rapid escalation relative to past climate trends spanning thousands of years. This increase has resulted in the warming of the ocean water surrounding the peninsula, which leads to the subsiding of pack ice and glaciers in the region. **(Kling, 2006)**

6.2.5 The Temperature and Adélie Relationship

Graph 6 shows the ice dependence of the Adélie penguins for persistence. It compares the relationship of sea ice extent and Adélie abundance over time.

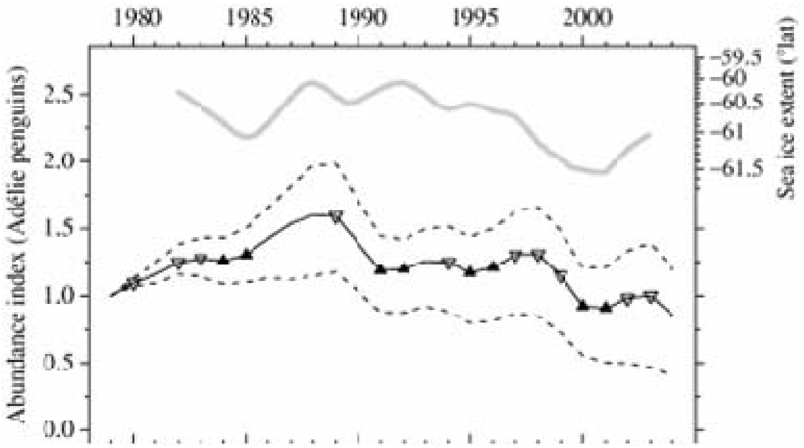

Fig. 6: Relationship between sea ice extent and Adélie abundance (Forcada, 2006)

Over the last 20 years, the sea ice has shown a diminishing trend (grey line) correlated with a decline of Adélie penguins (shown in the dark lines). This correlation reflects the Adelie's extreme reliance on pack ice for survival. Compared to other species of penguins in the same area, the Adélies are experiencing the greatest struggle. The Chinstrap and Gentoo penguins have greater foraging capability as well as more flex in their diet which explains their successful adaptation to warming **(Forcada, 2006).**

In the graph below, Adélie population is compared with the Chinstrap and Gentoo penguins.

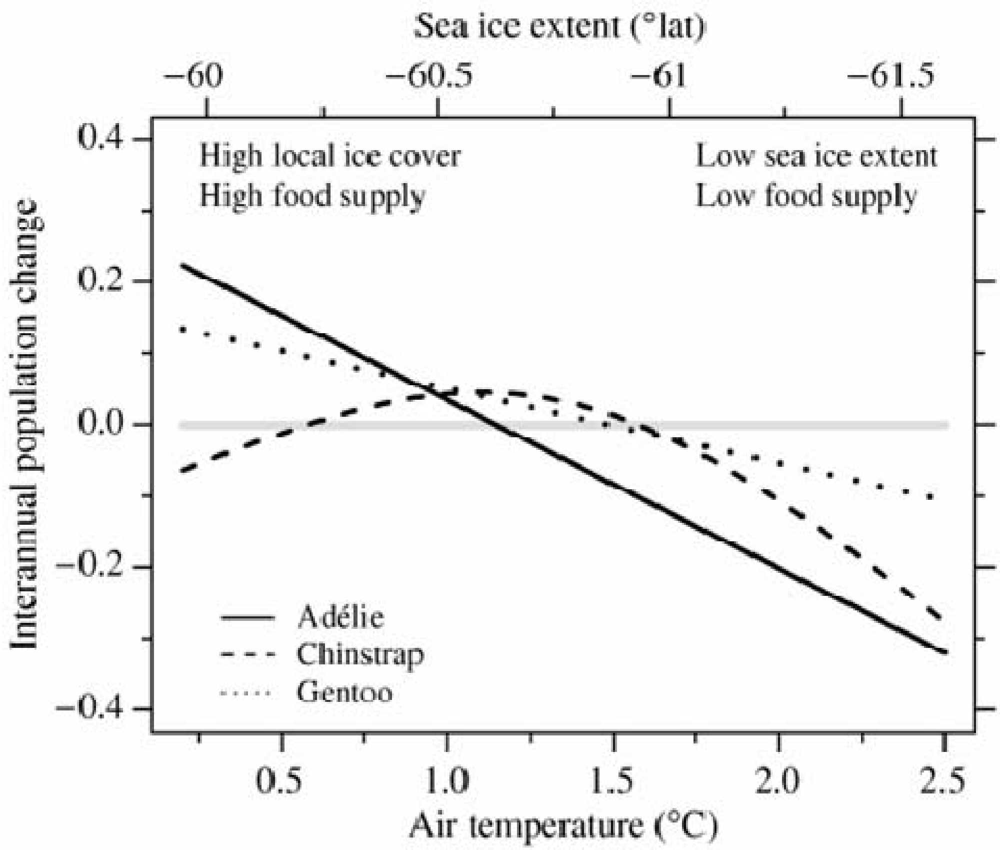

Fig.7: Comparison of Adélie population with Chinstrap and Gentoo penguins (Forcada, 2006)

6.2.6 Connection with Krill

To fully understand why this decline occurs you must consider the beginning of the food chain. Scientists found that with a deterioration of winter sea ice there was a decline of sea algae, which in turn led to the reduction in Antarctic krill. This shrinkage is demonstrated in graph 8 below.

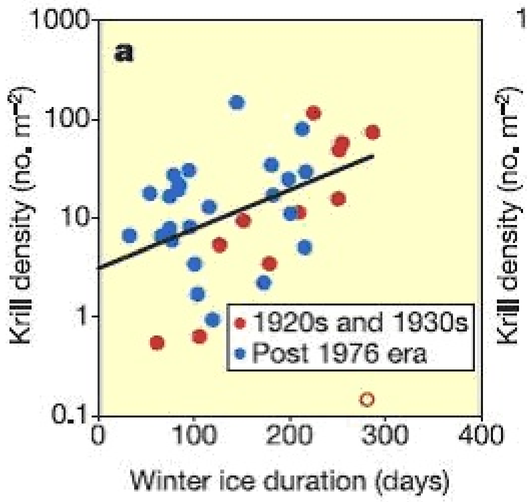

Fig. 8: Relationship between krill density and winter ice duration (Atkinson, 2004)

There is much evidence to support this sequence of trends. One source, The Los Angeles Times, cautions, “Krill—the heart of the rich Antarctic food chain nourishes whales, seals and penguins—have declined by more than 80% in the last 25 years in key ocean regions, according to a new study that links the loss to warming temperatures.” The result of the higher temperatures, writes reporter Usha Lee McFarling, “is a diminished ice cover in some parts of the waters surrounding Antarctica.” No ice means no krill. She reports: “Krill larvae require sea ice to survive the winter. Without sea ice, the larvae starve.” **(Atkinson, 2004)**

The Food Chain:

(sea algae) (krill) (Adélie penguins)

Fig.9: The food chain (Roach, 2004)

The algae upon which the krill feed inhabit the nutrient-rich substructure of sea ice (first picture above). Ninety-nine percent of the Adélie penguins' diet consists solely of Antarctic krill **(Roach, 2004).** Fig.9 displays the interconnected relationships on the Peninsula.

The Adélie Population Decline as it relates to temperature increase on the Antarctic Peninsula:

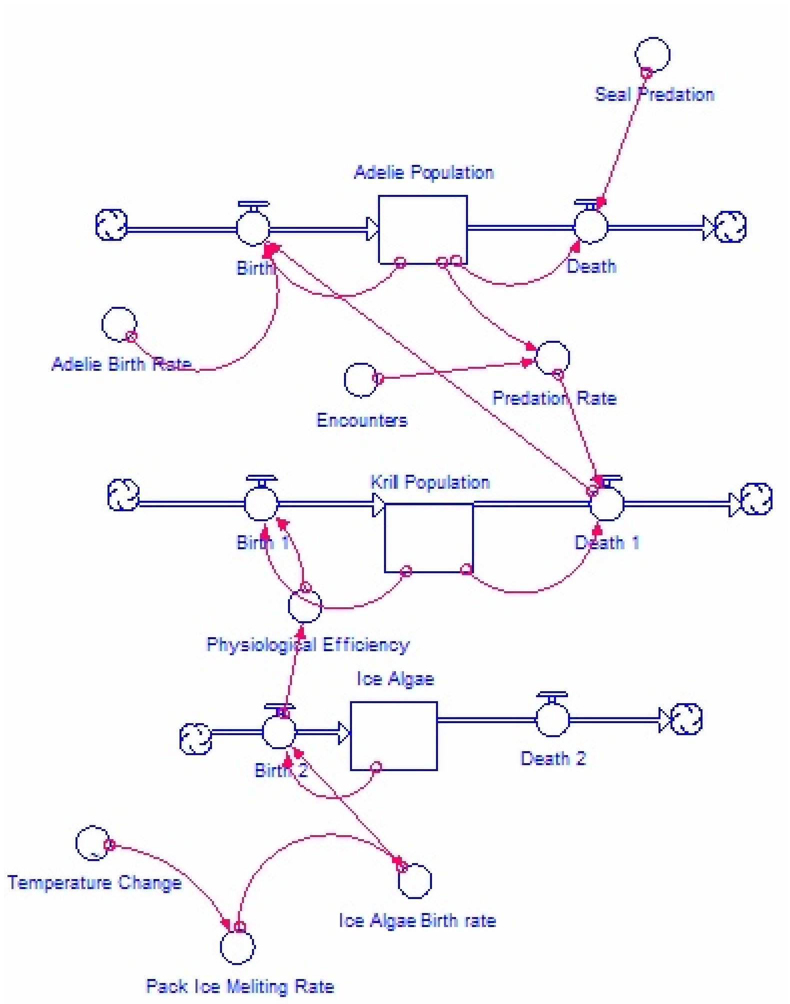

Fig.10: Adélie population decline (Clarke, 2006)

Assumptions:

In this model, multiple assumptions were made in order to express these relationships. It is assumed that...

-There were 1 billion sea algae in the region.
-The algae birth rate = ice melting rate * 0.3
-The rate of physiological efficiency for the krill's consumption of algae = Birth of

Algae * 3.

-The chance of an Adélie encountering a krill while foraging is 0.0005.

-The krill death rate is 0.2 krill/yr.

-The Adélie Birth rate = 0.4 Adélie/yr.

These assumptions were derived from previous models demonstrating the predator vs. prey relationship **(Clarke, 2006).**

The Stella Model:

The three stocks shown in this model represent the population of three species in a food chain. Due to the rise in temperature, the pack ice melting rate will increase, affecting the birth rate of sea algae. This, in turn results in a decrease of the Antarctic krill's food source, which leads to the reduction of krill in the area. There are positive correlations between each stock. When the population of a prey diminishes, their predator population also lessens. Therefore, the initial decline in temperature will eventually cause a subsequent decrease in Adélie population.

These two graphs clearly demonstrate these relationships. The first graph shows the inverse relationship between temperature and the penguin population.

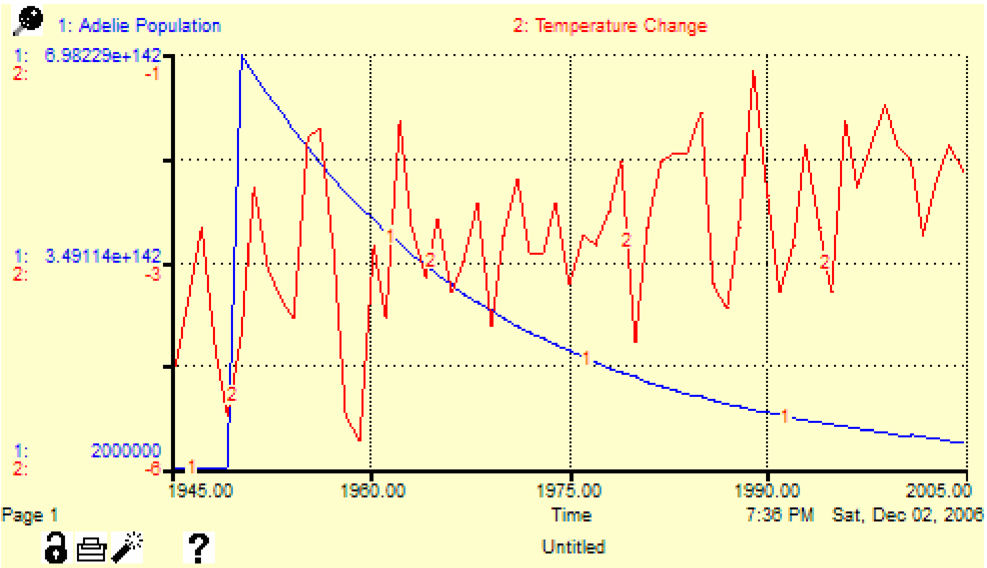

Fig.11: Adélie population and temperature change (Clarke, 2006)

In Fig. 11 you can see the rapid rise in temperature (red line) from 1945 to 2005, which correlates to the data found from the Bellingshausen Station on the Antarctic Peninsula (above). The blue line shows the dramatic decline of the Adélie population in reaction to this temperature change. **(Clarke, 2006).**

The second graph includes the other two factors affected in this ecosystem: the sea algae and the Antarctic krill.

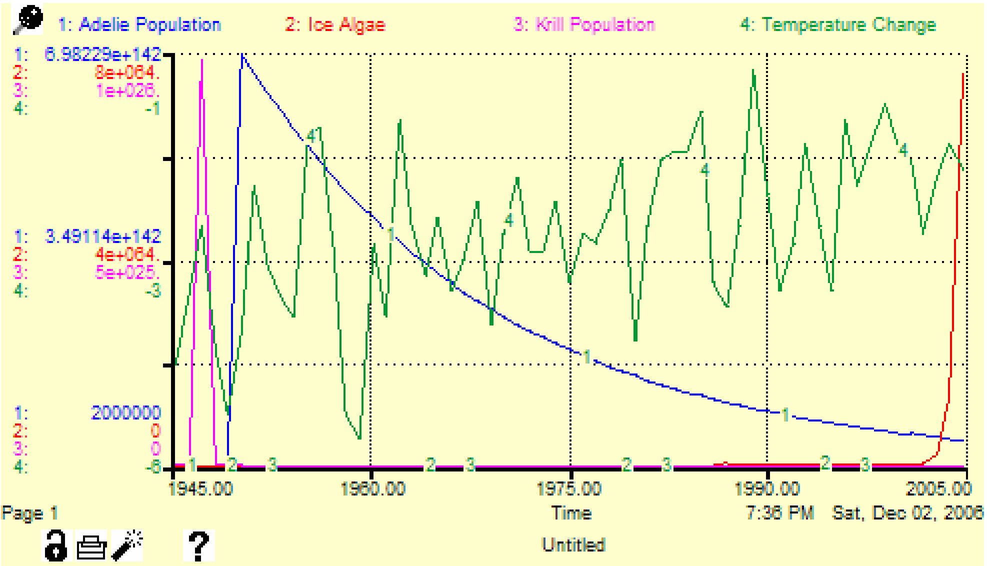

Fig.12:Relationship between temperature change, Adélie population, sea algae and krill (Clarke, 2006)

Graph 12 indicates that a rapid temperature rise (green line) correlates with a decrease in the sea algae, krill, and penguin populations. The anomalies (drastic spikes in krill and algae populations) in this graph are contributed to the assumptions made in the design of our Stella model. However, the overall trend of the graph correctly represents the hypothesis. **(Clarke, 2006)**

6.2.7 Predictions

Unfortunately predictions for the future aren't too optimistic for the Adélie penguin species. If the rates of global warming continue at their current pace, or even worse, accelerate, scientists believe the Adélie population will no longer be able to support itself. They will essentially starve to death. Because of the Adelie's complete dependence on pack ice for survival, one factor in the elimination of the Adélie penguins will be the continuation of ice-mass melting surrounding the Antarctic Peninsula. As the temperature rises, the surrounding air is capable of holding more moisture. When there is more moisture in the air, the snowfall on the Peninsula becomes heavier. It is anticipated that this occurrence will have huge implications on Adélie habitat: the penguins' nesting sites, which are normally located on dry, frozen, rocky areas, will be transformed into slush, decreasing the survival rate of the chicks. **(Clarke, 2006).**

The speedy destruction of the ice sheets will alter the native foraging paths of the Adélie penguins. With glaciers calving and the land changing, the penguin species will have a difficult time finding food and returning it to their chicks. The calving of glaciers is already occurring in Antarctica as the temperature climb has begun, yet further and more severe climate changes are predicted for the future. As underwater pathways become disturbed and vast chunks of glacier calve into the sea, penguins will be forced to travel an extra 30 miles to a food source. Some will survive the exhausting trek; others won't be so fortunate. **(Clarke, 2006)**

The shrinking Adélie penguin population will cause further break down of the food chain. This phenomenon will be well represented in the relationship between the Adélie penguin and their primary predator, the leopard seal. Since the leopard seal relies on the Adélie penguins for a stable food sources, scientists believe the decline in Adélie numbers will result in the same fate for the seal population. Although there is a natural prey and predator cycle that occurs within food chains, the abnormal effects of global warming will prevent the species’ populations from ever rebounding.

In the end, the species will either have to entirely change their niches and adjust to new lifestyles or proceed to die off as global warming accelerates. **(Ainley, 2005)**

6.3 The Emperor penguin

Over the past 50 years, the population of Antarctic emperor penguins has declined by 50 percent. Using the longest series of data available, researchers have shown that an abnormally long warm spell in the Southern Ocean during the late 1970s contributed to a decline in the population of emperor penguins at Terre Adélie, Antarctica. "We knew since the 1980s that emperor penguins had declined, but it is only today, because of the improvements of our knowledge in the climate-ocean processes, that we have been able to understand why they have decreased," said Henri Weimerskirch of the French National Center for Scientific Research in Villers en Bois, France. The warm spell of the late 1970s is related to the Antarctic circumpolar wave—huge masses of warm and cold water that circle Antarctica about once every eight years. In response to this cycle, Terre Adélie experiences a warming period every four or five years that generally lasts about a year. In the late 1970s, however, the warming continued for several years. Whether it was the result of natural climate variability in the Antarctic circumpolar wave cycle or an anomaly related to global warming is not possible to determine because air and sea surface temperature data from many years ago are not available. Weimerskirch thinks the unusually warm spell was probably the result of global warming. **(Roach, 2001)**

6.3.1 Shrinking Levels of Ice

Warmer air and sea surface temperatures in the Antarctic reduce the amount of ice in the sea. This, in turn, leads to smaller populations of krill, as already mentioned, that is a staple of the emperor penguin's diet. With less food to eat, emperor penguins die as it also happens to the Adélies. Reporting in the May 10 issue of *Nature,* Weimerskirch and his colleague Christophe Barbraud say this is the scenario that led to the sharp decline in the penguin population at Terre Adélie. "The population decreased because of the low rates of survival over four to five successive years," said Weimerskirch. In the early 1980s the winter air and sea surface temperatures dropped, and the emperor penguin population stabilized. Although higher levels of sea ice increase the food supply, such conditions have a negative effect on reproduction because emperor penguins hatch fewer eggs when sea ice is more extensive. After laying eggs, a female travels across the ice and out to sea to feed on krill, fish and squid that she regurgitates to feed her young. The male keeps the eggs warm until she returns. But when the sea ice is extensive, the female may be gone for months. The male eventually gives in to his hunger and abandons the egg or chick. **(Roach, 2001)**

6.4 Fur seals

There was an investigation of changes in Antarctic fur seal pup production at South Georgia over a 20-year period in response to environmental autocorrelation created by global climate perturbations; these were identified in time series of monthly averaged sea surface temperature (SST). Environmental autocorrelation at South Georgia was evident with frequent SST anomalies between 1990 and 1999, during a decade of warm background (time-averaged) conditions. SST anomalies were preceded by, and cross-correlated with, frequent El Niño-La Niña events between 1987 and 1998, which was also a decade of warm background conditions in the tropical Pacific Ocean. Nonlinear mixed-effects models indicated that positive anomalies at South Georgia explained extreme reductions in Antarctic fur seal pup production over 20 years of study. Simulated environmental time series suggested that the effect of anomalies on Antarctic fur seals was only detectable within a narrow range of positive SST, regardless of the distribution, variance, and autocorrelation structure in SST; this explained the observed nonlinearity in responses in pup production, which were observed only under persistent high SST levels. Such anomalies at South Georgia were likely associated with low availability of prey, largely krill, which affected Antarctic fur seal females over time scales longer than their breeding cycle. Reductions in Antarctic fur seal pup production could thus be predicted in advance by the detection of large-scale anomalies, which appeared to be driven by trends in global climate perturbation. **(Forcada, 2006)**

6.5 Whales

By observing more than 1,800 right whales in the Southern Atlantic (fig.13), researchers have determined that changes in climate are affecting the whales' reproductive success. The problem, experts believe, is not that whales suffer directly from warm conditions, but it is again the shrinking amount of krill, their main food supply. (Bakalar, 2006)

Fig. 13: right whales (Bakalar, 2006)

Since 1971 scientists have conducted yearly photo-identification studies of a population of southern right whales. The whales gather off Argentina's Peninsula Valdés every year between June and December. Using detailed photographic information on individual females, researchers have created an annual index that charts the deviation of known whale births from the expected number of calves. **(Bakalar, 2006)**

6.5.1 Whale Births

Right whales were given their name by 19th-century whalers, who considered them the right whales to hunt because they float when dead. Today the ocean mammals live in three groups, which are found in the North Atlantic, the North Pacific, and the sea region around Antarctica known as the Southern Ocean. There are about 300 whales in the North Atlantic and an unknown number in the northern Pacific. The southern group, about 8,000 strong, is healthy, according to the International Whaling Commission, and growing in number. Under normal circumstances, a female right whale requires three years between births. But if a calf aborts or dies a female needs two years to recover, and the interval expands to five years. "The relatively large number of five-year calving intervals can be explained by whales needing two years to recover from a failed pregnancy," said lead study author

Russell Leaper of the International Fund for Animal Welfare. This evidence does not suggest that whales are failing to get pregnant, but rather that unborn and newborn calves are not surviving. The scientists' explanation is that the reduced availability of krill during the summer feeding season is causing pregnant mothers to abort and calves to die. **(Bakalar, 2006)**

6.5.2 Sea Surface Temperatures

In their study, scientists compared sea-surface temperatures in the southwest Atlantic to their index of the yearly calving success of whales that breed off the Argentine coast. Researchers found a strong correlation between the number of right whale calves born and changes in sea-surface temperature in the autumn of the preceding year. Charles H. Greene, professor of earth and atmospheric science at Cornell University in Ithaca, New York, said: "The authors provide compelling evidence that South Atlantic right whale calving rates are correlated with climate variability, once one takes into account the appropriate time lags." The study authors were able to chart the sea-surface temperature against whale calf output for the years 1983-2000, and the results were clear: As the water temperatures rise from the norm, calf output declines. According to the scientists, it doesn't take much warming to affect the species. Even small changes in the oceanographic conditions in the Southern Ocean, the circumpolar sea around Antarctica, could affect southern right whale population dynamics. **(Bakalar, 2006)**

6.5.3 Krill Supplies

While the authors concede that there is limited data on the diet of southern right whales, it is highly probable that their main food is krill. But sufficient data probably don't exist to tie krill concentrations in the southwest Atlantic firmly to whale reproductive success, the authors say. Greene agrees. "The key missing link is still prey abundance," the factor that will link ocean temperature changes and calving rates, he said. "The role of krill in this story," he continued, "must be worked out to develop a truly predictive understanding of climate impacts on predator populations in the South Atlantic." The authors strongly suspect, however, that there is an inverse relationship between krill density and sea surface temperature. The warmer the water gets, the less krill there are. **(Bakalar, 2006)**

7 Results and discussion

These studies show that whole ecosystems are negatively affected by global warming. This is not only happening in Antarctica; you can find examples for this development all over the world. If climate change progresses it could even lead to a total extinction of some species. These species must not necessarily be suffering directly from climate change because within the food chain one species depends on the other as we have seen.

8 Conclusion

After complete analysis of the available data and the models, I can conclude that the hypothesis proves accurate. The rapid ascend in temperature on the Antarctic Peninsula, due to global warming, is leading to a decline in several Antarctic species. This phenomenon begins at the very foundation of their food chain. Their core food source, the Antarctic krill, is quickly diminishing in response to the absence of sea algae. The krill dependant animals are simply dying of starvation.
The only way to stop this development and to prevent the endangered species from extinction is to do something about global warming. Therefore it is necessary to find alternatives for fossil fuels to reduce greenhouse gases.

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