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RECENT INCREASE AND SOUTHERN EXPANSION OF ADELIE PENGUIN POPULATIONS IN THE ROSS SEA, ANTARCTICA, RELATED TO CLIMATIC WARMING

Summary: The numbers of Adelie penguins *Pygoscelis adeliae* (Hombron and Jacquinot) in the Ross Sea, Antarctica, have increased markedly over the past 10 years. Proportionally, this increase is most pronounced in McMurdo Sound, where the species' breeding range has recently been extended 3 km south to Cape Barne (77 ∞35'S) with the re-occupation of a former rookery that was abandoned sometime before the present century. These biological trends show remarkable synchronisation with physical evidence of climatic variation in the McMurdo Sound region. We suggest that the dynamics of Adelie penguin populations may be very sensitive indicators of changes in the Antarctic climate.

Keywords: Adelie penguin; *Pygoscelis adeliae;* Ross Sea; population increase; range expansion; climatic change.

Introduction

During the late 1970s it was recognised that certain parameters of seabird and seal populations may provide good indices of the abundance of major prey species (fish, squid or krill), and thus of the state of the marine ecosystem. This led to the further development of population monitoring of these animals in Antarctic and sub-Antarctic regions, and its international co-ordination by the Scientific Committee for Antarctic Research (SCAR) as part of the BIOMASS programme (SCAR, 1979). Such monitoring studies are now seen as important tools in implementing the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), and their utility has recently been reviewed (Croxall *et al.,* 1988).

In the Ross Sea, Antarctica, monitoring of the size of the southernmost Adelie penguin *(Pygoscelis adeliae)* breeding rookeries on Ross Island (Fig. I) has been carried out regularly since the 1960s (Harper *et al.,* 1984; Taylor, Wilson and Thomas, in press; Wilson, in press). Since 1981, we have used aerial reconnaissance and photography to determine the breeding locations and changing numbers of Adelies in the entire Ross Sea region (Taylor *et al.,* in press). A comparison of Adelie penguin census results with physical indicators of climatic variation has now revealed an apparent link between the dynamics of Adelie penguin populations and recent climatic warming in the more southern latitudes of the Ross Sea.

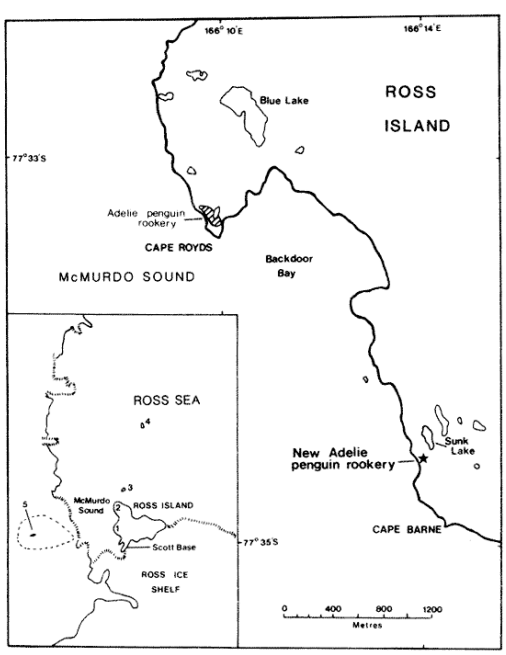

Figure 1: *Map of Cape Royds and Cape Barne area, showing Adelie penguin rookeries. Inset: Location of places named in the text; 1. Cape Royds and Cape Barne area;* 2. *Cape Bird;* 3. *Beaufort Island;* 4. *Franklin Island;* 5. *Lake Vanda and the Dry Valleys region.*

Recent population trends

Although censuses have not been carried out at all breeding rookeries each year and not all counts are of similar accuracy, it is clear that the numbers of Adelie penguins in the Ross Sea have increased greatly over the last 10-20 years to a present population of about 1,082,000 breeding pairs in 39 rookeries spread between 66∞30'S and 77∞3S'S (Taylor *et a1.,* in press). The timing, rate and spatial features of this increase rule out the usual explanation of reduced competition from whales as the major cause (Taylor *et a1.,* in press), and only at Cape Hallett and Cape Royds was there a history of previous human disturbance (Wilson, Taylor and Barton, in press). At capes Bird and Royds, from where continuous long term data exists, by far the greatest increase has occurred since 1981 (Fig. 2a) and it has been most pronounced at the southern extremity of the Adelies' breeding range, as would be expected if it was linked to climatic warming. From 1983 to 1987, the mean annual rate of increase in the breeding population was 3.3% at Cape Adare (71∞18'S) and 6.6% at Cape Hallett (72∞19'S) in the northern Ross Sea; 3.4% at Franklin Island (76º06'S), 4.7% at Beaufort Island (76∞S8'S), 8.0% at Cape Bird (77∞15'S), and 15.3%at Cape Royds (77∞33'S) in the southern Ross Sea. In McMurdo Sound, Adelie penguins have also expanded their breeding range southward, for on 1 December 1988 we found a small previously unreported Adelie penguin rookery at Cape Barne (Fig. 1), 3 km south-east from Cape Royds. Cape Barne (77∞35'S, 166∞13'E) is now the southernmost rookery for Adelie penguins anywhere (Wilson, 1983).

The new Cape Barne rookery is situated on a raised gravel beach about S m above sea level, and at the end of the egg-laying period contained only five occupied nests - one with one egg and four with two eggs each - and five unoccupied nest sites. The five incubating birds all behaved like experienced breeders (Ainley, LeResche and Siaden, 1983). Considering the high fidelity of adult Adelies to sites where they have previously nested (Ainley *et al.,* 1983), and the amount of guano staining, it is likely that Cape Barne was recolonised by young birds a few years ago, rather than by experienced breeders in 1988. The Cape Barne birds were obviously breeding successfully, for the mortality of eggs and chicks from 1 December 1988 to 22 January 1989 (when the mean age of chicks was c. 30 days) was 23% compared with an approximate mean mortality of 28% (range 16-37%) at Cape Royds during the same period in three recent seasons.

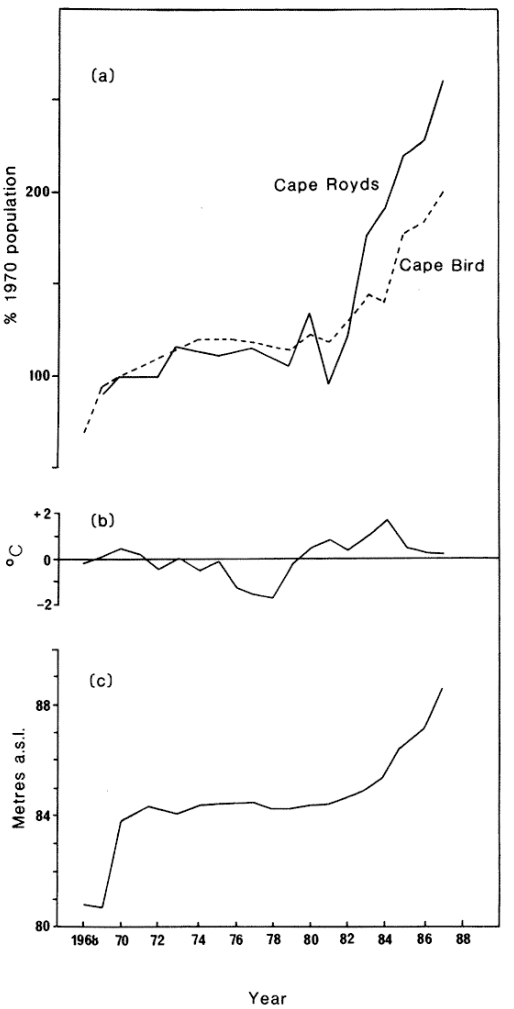

Figure 2: *Apparent correlation between biological and physical indicators of climatic variation in the McMurdo Sound region,*

(a) Trends in numbers of occupied nests at the end of egg-laying (late November/early December) at Cape Bird and Cape Royds Adelie penguin rookeries, 1968-1987, *relative to the 1970 level at each (Taylor et al., in press; and K-J. Wilson, in press).*

(b) Anomalies on three-year running means of December surface air temperatures at Scott Base, 1968-1987 *(raw data provided by New Zealand Meteorological Service).*

(c) End-of-summer lake levels (m asl) at Lake Vanda, 1968-1987 *(Chinn and McSaveney,* 1987).

Recent climatic changes

In the Southern Ocean and East Antarctica an increase in mean annual surface temperature has been apparent since the early 19608 (Jacka, Christou and Cook, 1984; Adamson, Whetton and Selkirk, 1988).

In the McMurdo Sound area, marked climatic warming since the early 1980s is shown by mean December air temperatures at Scott Base (Fig. 2b). Since 1980 there has been a 4.64 m rise in the level of Lake Vanda (Fig. 2c). This large (c. 6 km2) enclosed lake in the Dry Valleys region, 50 km west of McMurdo Sound, is a very sensitive indicator of seasonal climatic variations, as high summer temperatures lead to increased melting of the glaciers that feed it, while only slightly affecting annual evaporation and ablation losses (Chinn and McSaveney, 1987).

Discussion

It is likely that Adelie penguins have bred on the shores of the Ross Sea since the Thermal Maximum of 10,000 BP to 6000 BP (Young, 1981; Salinger. 1989), the earliest colonisation presumably occurring in the north. Adelie penguin remains over 4000 years old have been discovered at Franklin Island (Denton *et al.,* 1975). McMurdo Sound and the present coast of the southwestern Ross Sea became free of glacial ice about 6000 years BP (Denton *et al.,* 1975), and Adelie rookeries there will be younger than those further north. During the last thousand years a fluctuating climate probably led to one or more temporary desertions of these rookeries. In New Zealand (34° - 47°S), past temperatures estimated from speleothems and summer tree-ring growth rates, and actual temperature readings since the 1850s (Salinger, 1989), indicate three recent southern hemisphere cold periods: 6000 BP-500 BP, 400 BP-300 BP, and in the mid-nineteenth century.

The location of the new Cape Barne Adelie rookery is on the site of a long-abandoned penguin breeding ground first recognised and mapped during the 1910-1913 British (Terra Nova) Antarctic Expedition (Debenham, 1923). New Zealand and American field parties have visited Cape Barne at least once every three or four years since 1959, but up until the 1988-89 summer no penguins have been reported breeding, although during the 196Os a few fresh nest scrapes, empty nests and adult birds were recorded (Stonehouse, 1910; Spellerberg, 1970). In 1964, Stonehouse (1970) dug up a mummified penguin chick from the subsurface debris of the ancient colony at a site very close to the nests we found in 1988. This bird yielded a "C age estimate (corrected to NZ Antarctic Standard) of 374 ± 57 years. Another three mummified chicks were collected from Cape Barne in 1966. Their radiocarbon dates were 116 ± 51, 179 ± 103 and 274 ± 45 years (Spellerberg, 1970), but they could be much older, since all samples were from above the permafrost and almost certainly contaminated by bacteria (Whitehouse *et al.,* 1988). Thus it appears that in the past Adelies nested at Cape Barne for several hundreds of years before abandoning the site sometime in the 19th century and then recolonising it in the mid-1980s.

Stonehouse (1970) considered that the Cape Barne rookery's previous existence indicated a larger breeding population of Adelie penguins in McMurdo Sound a few hundred years ago, when relatively mild climatic conditions would have led to the more regular annual formation of a polynya, or area of open water, in the fast ice of northern McMurdo Sound during late winter and early spring, before the breakup of the main ice sheet. When this polynya occurs early it allows penguins to feed close to the McMurdo Sound rookeries during courtship, laying and early incubation (Stonehouse, 1967). Over the last 10 years it formed with increasing frequency. Cape Royds was still ice-bound in late November in four of the ten seasons between 1956 and 1965, but in only two of 10 seasons between 1980 and 1989 (Stonehouse, 1967; pers. obs.).

During the last 25,000 years the whole range of mean annual temperatures between glacial and interglacial periods was only about 6°C (Wilson, 1910; Salinger, 1989). The average global temperature has risen about 0.5°C since the beginning of the century, with the six warmest years being in the 1980s (Houghton and Woodwell, 1989). Similar warming has occurred in the Southern Hemisphere (Salinger, 1989) and in Antarctica (Raper, 1983; Maxwell and Barrie, 1989) — especially in Eastern Antarctica (Jacka *et al.,* 1984) where recent increases of Adelie penguins have also been reported (Woehler, Tierney and Burton, 1989).

The increasing number of Adelie penguins, particularly in the extreme south, and the southward extension of their breeding range appear to be very sensitive responses to the present-day amelioration of the Ross Sea climate. Although the precise processes causing these increases in Adelie penguin populations are unknown, year-round changes in sea-ice conditions, increased productivity and availability of food, lower winter mortality and enhanced breeding success of the penguins are probably all involved - and could have led to, or followed from, an increase in the abundance of krill. The consequences of

environmental change on the population dynamics of krill in the Ross Sea needs further study, as does the link between changes in krill abundance and Adelie penguin populations.

Monitoring studies of Adelie penguins in the Ross Sea have so far shed little light upon their reliability as indicators of over-exploitation of the Antarctic fishery (Wilson, in press), and are unlikely to do so until complementary surveys can be carried out into the distribution, composition and abundance of krill stocks (Taylor *et al.,* in press). However, we suggest that the dynamics of Adelie penguin populations may have an equally important role as sensitive indicators of wider environmental changes in Antarctica.

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