FORAGING BY ADÉLIE PENGUINS DURING THE INCUBATION PERIOD

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ABSTRACT

Nine Adélie Penguins (*Pygoscelis adeliae*), 4 females and 5 males, were tracked by radio telemetry when they went to sea from the Northern Rookery, Cape Bird, Antarctica, on their first foraging trips of the incubation period. Each penguin took a different direction on leaving the rookery but maintained its approximate heading, suggesting that it was navigating. Radio contact was lost after 2-12 days as birds moved beyond the 100 km radio horizon. The penguins spent about one-third of their time on ice floes. Most of their time in the water was spent diving and feeding. Dives (including underwater swimming) lasted for a mean of 92.5 s, followed by a mean recovery period of 33.8 s. The length of the recovery period was significantly correlated with the length of the dive. From the maximum dive times, the duration of "feeding" dives, and the dive: pause ratios, Adélie Penguins seem to have diving abilities between those of the other two pygoscelid penguins, the Gentoo and Chinstrap. We hypothesize that the Adélie Penguins may travel large distances from the rookery during the incubation period so as to forage on the larger and more pelagic krill, *Euphausia superba*.

INTRODUCTION

Adélie Penguins (*Pygoscelis adeliae*) feed mostly on krill, small euphausiid shrimps (Emison 1968, Lishman 1985). Observations from ships suggest that the penguins forage mainly in association with the pack ice (Fraser & Ainley 1986). Chicks must be fed regularly, and the average trip to sea after their chicks have hatched lasts only 1-2 days (Penney 1968, Davis 1982a). However, while the eggs are being incubated, each parent makes one long foraging trip to sea: first the female is away for about 17-19 days, and then the male goes for about 13 days (Davis 1982b, in press). Birds not returning from these long foraging trips in time to relieve their mates on the nest are a major cause of breeding failure (Davis & McCaffrey 1986). Where, then, do the penguins go on these long trips at sea? If they forage close to the rookery, they would presumably return more often, making breeding failure less likely.

We know little of what Adélie Penguins do once in the water because they are hard to follow in the ice-filled waters of Antarctica. Trivelpiece *et al.* (1986), to track Chinstrap (*P. antarctica*) and Gentoo (*P. papua*) Penguins at sea, used small radio transmitters attached to the penguins' backs and two land-based receiving stations. They also demonstrated that differences in the signals received were associated with different activities of the penguins. We used the same technique on Adélie Penguins during the incubation period.

METHODS

This study was made from the Northern Rookery at Cape Bird, Ross Island, Antarctica (77 ° 13′ 10″ S, 166° 28′ 30″ E), between 17 November and 16 December 1985.

Each transmitter (Austec Electronics model KG80) was sealed in a waterproof, streamlined package, together with three 1/2AA lithium cells that gave a theoretical transmitting life of 28 days. Its total weight was 50 g. It was fixed by epoxy resin to the feathers on a penguin's back and switched on by means of a reed switch.

Two tracking towers were established: one on New College Hill (230 m above sea level) and the other on Inclusion Hill (338 m above sea level) (Fig. 1). The baseline distance between the two towers was 2742 m. Each receiving antenna consisted of a single 6-element yagi antenna mounted on a rotatable 5 m mast fitted with a compass rose. Custom Electronics CE12 and Merlin 12 receivers were used to receive signals from the transmitters in the 160.1-160.3 MHz waveband. The maximum radio horizon was 75 km from Inclusion Hill and 60 km from New College Hill. The signal of the transmitters was strong enough to be received at up to 100 km, provided that the receiving antenna was high enough (i.e. 600 m). For example, strong signals were received at 600 m when transmitters were tested between Cape Bird and Cape Roberts, a distance of 83.2 km.

In addition, a 3-element yagi antenna mounted on the outside of an Iroquois helicopter was used to search for birds if they moved beyond the range of the land-based antennae. The helicopter was not permitted to fly over open water, and so the procedure was to hover about a known landmark at 600 m and make a systematic scan search to seaward.

Ten birds (4 females, 6 males) had radio transmitters attached to them between 17 and 23 November. From 18 November the tracking towers were manned for 1-2 hours each day (usually between 1530 and 1730). A systematic search was made for each bird that was at sea, and if located, its direction was fixed by taking the mid-point between the two null-points of the signal. Locations and distances were calculated later by triangulation.

In addition, because transmissions could be received only when the transmitter aerial was above the surface of the water, the activity of the animal could be deduced from the signal, rather as Trivelpiece *et al.* (1986) did: (a) a continual, regular signal indicated that the bird was out of the water and so probably on an ice floe; (b) a regular signal interspersed with periods of silence indicated that the bird was diving (either foraging or swimming underwater) with recovery periods at the surface; and (c) an irregular signal indicated porpoising (confirmed when a porpoising penguin was seen while being radio-tracked) and short bursts of signals from the surface were associated with swimming. If the bird was diving and signal strength was good, focal animal sampling was done to measure duration of dives and duration of recovery periods at the surface.

To check the accuracy of land-based fixes, a helicopter was used to take four readings of a bird from the other side of McMurdo Sound. At distances of around 40 km and over a baseline of 46 km, the helicopter fixes gave the bird's position as within 6 km of the position given from the land-based towers 2 hours later. This would indicate an approximate error of $\pm 1°$ in the land-based fixes. The effect of such an error on the accuracy of calculated locations of foraging penguins depended on the orientation of the penguin to the baseline of the tracking towers. The location of a penguin foraging at 20 km perpendicular to the baseline could be fixed with an accuracy of ± 3 km, but a bird 20 km away more-or-less in line with the baseline could have been calculated as being anything from 10 km to 70 km away. However, a crude indication of distance could also be derived from the signal strength, as typically the further a penguin was away, the weaker was the signal. Although signal strength varied according to atmospheric conditions, it could be used as a rough check on the calculated locations of the penguins.

We left Cape Bird on 16 December. The average length of foraging trips was 19.0 days for females (SD = 3.4, n = 23) and 12.6 days for males (SD = 2.7, n = 23) during the 1985/86 season (Davis, in press), and so, as we had expected, most birds did not return to the rookery before the end of the study. One male (#5) did not go to sea at all, remaining on his nest throughout the study. Of those birds that went to sea, only #10 returned before 16 December. In January 1986 another field party staying at Cape Bird saw three more and retrieved the radios from two of them. Finally, in a thorough search of the colonies by one of us (LSD) during the courtship period the following season (1986/87), 7 of the 10 birds that had been carrying transmitters were found (unretrieved transmitters would have fallen off when the penguins moulted at the end of the breeding season).

On 5 December a storm damaged the antenna on Inclusion Hill, making accurate fixes possible only from a helicopter. However, by then all birds (except #5) had gone to sea and only three remained in radio contact. Their direction and signal strength continued to be monitored daily from New College Hill, and their positions were checked from a helicopter when possible.

Directions are given in degrees, north being 0°.

RESULTS

Patterns of departure

Nine of the 10 radio-tagged Adélie Penguins (4 females, 5 males) went to sea. Their mean direction taken on the day of departure from the rookery was 324° (SD = 40, n = 9) (Table 1).

One radio (#10) emitted intermittent signals and functioned for only a few hours. When recovered later it was found to have been corroded after water penetration. The rest produced normal signals and were tracked

TABLE 1 — Results of radio tracking nine Adélie Penguins as they left the Northern Rookery, Cape Bird, on their first foraging trip of the incubation period. Shown are the initial and final recorded directions of the penguins from the rookery (0° = north), the duration of radio contact, the maximum recorded distance from the rookery (km), and whether they were known to return to the rookery

Penguin	Sex	Date Depart	Initial Direction	Days to Last Contact	Final Direction	Maximum Distance	Return
#1	F	20/11	312	12	303	44	Y
#2	F	19/11	13	3	59	23	N
#3	M	1/12	266	2	216	26	Y[2]
#4	F	18/11	293	2	276	63	N
#6	M	4/12	300	2	294	40[1]	N
#7	M	3/12	313	5	17	60[1]	Y
#8	M	28/11	311	11	13	24	Y[2]
#9	M	22/11	1	12	102	60	Y
#10	F	24/11	24	0	(24)	-	Y[2]

[1] deduced from signal strength

[2] radio recovered

for a mean of 6 days (range 2-12). The two that were recovered were undamaged.

The loss of radio contact with these eight birds after 2-12 days, then, was almost certainly due to the animals moving beyond the radio horizon (i.e. 100 km from a searching helicopter). The evidence for this is three-fold: (i) mean distances of penguins from the rookery increased each day (r = 0.70, $P < 0.01$, n = 13), (ii) the last contacts were usually associated with faint signals indicating transmitters operating close to the limits of their transmitting distances, and (iii) when contact was lost with the two land-based antennae, contact was sometimes re-established from the helicopter, which had a larger radio horizon and larger search area.

The final direction of the foraging penguins, before they went beyond the radio horizon, was quite variable ($\bar{x}$ = 345°, SD = 78, n = 9) (Fig. 1). However, two basic patterns were apparent: four penguins went in a westerly direction across McMurdo Sound; while the other five headed in a north-easterly direction, past Beaufort Island and east of the tip of Cape Bird. The final direction for each penguin was highly correlated with the initial direction it took when leaving the rookery (r =0.91, $P < 0.01$, n = 8 excluding #10), suggesting that the penguins were navigating and not just moving randomly.

Behaviour at sea

A rough approximation of the proportion of time penguins spent in each activity was determined from 33 observations where the signal was certain: swimming/ porpoising, 24%; diving/feeding, 42%; and on ice floes, 33%.

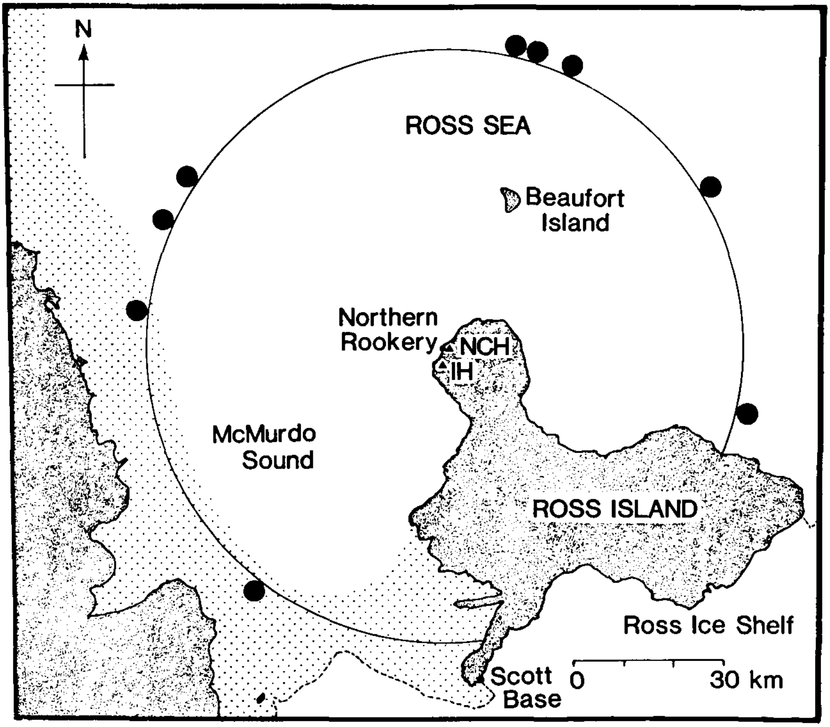

FIGURE 1 — Final recorded directions of Adélie Penguins (n = 9) departing from the Northern Rookery, Cape Bird, on their first foraging trips of the incubation period. The horizon is set at 60 km, which was the maximum radio horizon from New College Hill and corresponded with the maximum recorded distances of penguins from the rookery (see Table 1). The positions of the tracking towers on New College Hill (NCH) and Inclusion Hill (IH) are shown, and the lightly stippled area represents the approximate extent of the sea ice at the time of this study

Diving/feeding times and the associated recovery period at the surface were recorded for 108 dives from four penguins (#1, #3, #7, and #8) (range 15-43 dives each). The mean dive time was 92.5 seconds (SD = 45.1, n = 108), and the mean recovery period was 33.8 seconds (SD = 32.9, n = 108). The recovery time was significantly correlated with the duration of the dive (r = -0.63, $P < 0.001$), the longest dives being followed by the longest periods at the surface. To distinguish between underwater swimming and feeding dives, the latter were taken to be dives exceeding 60 seconds in a sequence of at least two such dives. The mean "feeding" dive was 114.9 seconds (SD = 29.7, n = 72) and the mean recovery period 44.6 seconds (SD = 35.2, n = 72, giving an average dive : pause ratio of 2.58 : 1. The dive : pause ratio varied, however, and tended to diminish as the mean duration of dives increased ($r = -0.90$, $P < 0.1$, $n = 4$) (Table 2). The maximum dive recorded was 182 seconds.

Use of radio telemetry

We could not tell whether wearing radio transmitters affected the length of the penguins' foraging trips because most birds were not expected to return to the rookery before the study ended on 16 December. Males #8 and #9 had deserted their nests and so were not expected to return

TABLE 2 — Feeding dives of Adélie Penguins (i.e. dives longer than 60 seconds and in a sequence of at least two such dives). Times are given in seconds (mean ± SD)

Penguin	n	Dive Time	Recovery Time	Dive : Pause Ratio	Maximum Dive
#1	15	140.8 ± 8.2	105.7 ± 15.0	1.33	156
#3	17	105.8 ± 37.4	32.0 ± 15.5	3.31	182
#7	15	111.3 ± 25.2	32.5 ± 22.3	3.42	156
#8	25	107.7 ± 27.1	23.6 ± 9.1	4.59	171
Overall	72	114.9 ± 29.7	44.6 ± 35.2	2.58	182

to their colony until the reoccupation period (Davis 1982a), beginning in late December. Both were seen back in their colonies the next season. When the study ended on 16 December, the times that the other three males (#3, #6, and #7) had been at sea still had not exceeded one standard deviation from the average foraging trip for males. The following season only #6 failed to return to the rookery. However, while all four females (#1, #2, #4, and #10) had been due to return before 16 December, only #10 did so. Next year #10 and #1 were back on a nest. The radioed bird that did not go to sea during this study (#5) also returned the next season. Although male #6 and females #2 and #4 may have died, they need not have died because of wearing radio transmitters, as an annual mortality of 30% is within normal limits for Adélie Penguins.

DISCUSSION

Patterns of departure

Where Adélie Penguins go once they leave the land is still a mystery. In the ice-filled waters of Antarctica, telemetry offers the only practical way to solve that mystery. As a first attempt at radio tracking Adélie Penguins, this study has shown that telemetry can be successful; but it has raised more questions about the penguins than it has provided answers.

Clearly, both male and female Adélie Penguins travel long distances, over 100 km from the rookery, on their first foraging trip of the incubation period. The direction each penguin takes is variable, though each appears to keep roughly to its path. Thus, the penguins may be navigating, especially as on ice floes, where they spent one-third of their time, wind and currents would take them off course. Adélie Penguins have been shown to be quite capable of navigation (Emlen & Penney 1964).

Where, then, are they going, and why? The diving records indicate that they are able to feed near to the rookery. So why do they go so much further, risking loss of eggs and chicks through desertion and starvation (Davis 1982b, Davis & McCaffrey 1986)?

The diet of penguins returning to Cape Bird during the incubation period, analysed while we were there (van Heezik 1988), consisted mostly of the smaller krill species, *Euphausia crystallorophias*. By contrast, on the Antarctic Peninsula (Lishman 1985) and at Cape Hallet (Logan, pers. comm.) Adélie Penguins feed mainly on the larger *E. superba*. Little is known of the seasonal patterns of abundance of the two krill species in the waters off Ross Island. *E. superba* is the more pelagic species and is not abundant close to Ross Island (Marr 1962). It was not a major food of penguins sampled at Cape Bird (van Heezik 1988), Ross Island's Cape Crozier, Beaufort Island, or of one individual captured 140 km north of Cape Bird (Emison 1968). Due to digestion rates of stomach contents, these two studies could only sample food eaten within a short travelling time of the rookery. Digestion rates for Adélie Penguins are not available, but experiments on Yellow-eyed Penguins (*Megadyptes antipodes*) show that most stomach contents are digested within 24 hours (van Heezik, pers. comm.).

Limited plankton sampling indicates that the distribution of *E. superba* stocks coincide with the outer edge of the continental shelf, the nearest stocks to Cape Bird being 400-500 km away (Marr 1962). Perhaps it is energetically more efficient for the penguins to exploit the larger species of krill, even if they have to travel further. Might this explain why Adélie Penguins travelled more than 100 km beyond the rookery during the long foraging trips of the incubation period?

Behaviour at sea

Trivelpiece *et al.* (1986) showed that, for Gentoo and Chinstrap Penguins, dives consisted of underwater swimming and feeding dives. Underwater swimming dives averaged 50 seconds with short pause times, 12 seconds, in between. By contrast, mean feeding dive times were 128 and 91 seconds for Gentoo and Chinstrap Penguins, respectively. Therefore, we have assumed in this study that consecutive dives lasting more than 60 seconds were feeding dives. Both the mean "feeding" dive time and maximum dive times for Adélie Penguins were intermediate between those recorded for the other two pygoscelid species (Trivelpiece *et al.* 1986). Adélie Penguins are intermediate in body size between the larger Gentoo and smaller Chinstrap Penguins (Stonehouse 1967), and so the results of this study fit with the hypothesis that diving ability is correlated positively with body size in penguins (Stonehouse 1967). The mean dive : pause ratio we observed for Adélie Penguins was the same as the mean dive : pause ratio reported for Chinstrap Penguins (2.6) and less than that for Gentoos (3.4) (Trivelpiece *et al.* 1986). However, dive : pause ratios were affected by the length of the dives, longer dives requiring longer recovery periods. In fact, three of the four Adélie Penguins had dive : pause ratios greater than any reported for Chinstrap Penguins, and one was greater than any reported for Gentoo Penguins (Trivelpiece *et al.* 1986). This lends further support to the suggestion that Adélies are intermediate in diving ability between Chinstraps and Gentoos, and that body size is a major factor influencing diving ability.

Use of radio telemetry

The present system could be improved by means of stronger transmitters, a much longer baseline, and the receiving antennae being at higher elevations. In Antarctica, where suitable locations for tracking towers are not readily available, the best option may be satellite telemetry. The effect, if any, of wearing transmitters on the penguins' behaviour and survival prospects needs to be studied. From this study, no direct effect is apparent because the mortality in the sample of radioed birds was within normal annual limits (Ainley *et al.* 1983).

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A preliminary note on the radio telemetry technique used in this study was published in the bulletin *New Zealand Antarctic Record*, 1986, vol. 7, no. 2, pp. 14-18. The purpose of that report was to advertise the technique from a technical perspective. By contrast, this paper deals with the behaviour of the penguins, using the complete and substantially different data set, analysed in a totally different way.

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SHORT NOTE

Diet of Adélie Penguins during the Incubation Period at Cape Bird, Ross Island, Antarctica

The food of the Adélie Penguin (*Pygoscelis adeliae*) has been examined at only a few localities — at Cape Crozier, Ross Island, Beaufort Island, and Franklin Island (Emison 1968), at Signy Island, South Orkney Islands (Lishman 1985, White & Conroy 1975) and at King George Island, South Shetland Islands (Volkman *et al.* 1980). Although euphausiids comprise the largest proportion of the diet by numbers and by weight at all localities sampled, on the islands of the Antarctic Peninsula *Euphausia superba* were taken, whereas at Cape Crozier, Beaufort Island and Franklin Island *E. crystallorophias* formed the bulk of the diet of parents feeding chicks.

Information on the diet of Adélies on Ross Island during the incubation period is scarce, although 10 of the 37 complete samples taken by Emison (1968) were obtained from incubating birds towards the end of the incubation period. Foraging trips during the incubation period can last up to 2 weeks or more; the female taking the first foraging trip after laying the eggs and, after 2 weeks, returning to relieve the male, which takes the second foraging trip. In this study I collected stomach contents from Adélie Penguins returning from the first and second foraging trips during the incubation period.