

DIVING DEPTHS OF THE CHINSTRAP PENGUIN *PYGOSCELIS ANTARCTICA*

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ABSTRACT. Diving depths of four breeding chinstrap penguins were recorded throughout complete foraging trips to sea lasting 18–48 h at Signy Island, South Orkney Islands. Deeper dives reached 70 m but 90% of dives were shallower than 45 m and 40% were to less than 10 m. The diving pattern is compared with those of king penguins and Antarctic fur seals. Chinstrap penguins feed on krill and it is suggested that they do so chiefly during shallow dives at night when krill are near the surface. Using data on average measurements and weight of krill taken by chinstraps at Signy Island, and estimates of at-sea metabolic rate and the size of meals delivered to their chicks by the study birds, it is calculated that about 16 krill are caught per dive of duration c. 1.6 min.

INTRODUCTION

The diving depth and performance of penguins is an important aspect of their feeding ecology, as it may influence considerably the type of prey they encounter and can exploit efficiently. Most information on penguin diving depths is anecdotal, usually deriving from birds trapped in fishing nets (Conroy and Twelves, 1972) or based on the type of food captured. The only detailed records are from studies of emperor *Aptenodytes forsteri* and king penguins *Aptenodytes patagonicus* (Kooyman and others, 1971, 1982), the two largest species of penguin. This paper reports the results of the first attempt to obtain records of diving depths of one of the smaller penguins, the chinstrap penguin *Pygoscelis antarctica*, which is also the most important avian consumer of krill in the southern Scotia Sea (Croxall and others, in press a).

METHODS

The multiple maximum depth recorder (MDR) described by Kooyman and others (1983) was used. In brief, it is cylindrical (95.0 mm long by 23.0 mm diameter) and weighs 95 g (approximately 2.4% of adult chinstrap penguin body weight). The MDR contains eight electronic counters which respond to different pressure thresholds, each of which is equivalent to a different depth. The intervals between the thresholds depend on the maximum pressure threshold of each MDR.

The MDR was attached to feathers in the middle of the back with two worm-drive hose clips. MDRs were deployed on four breeding chinstrap penguins captured during the chick crèche period at Signy Island, South Orkney Islands, in January and February 1981. When the birds returned to sea to feed and dived below the surface of the water, the increase in pressure with depth was converted to a voltage shift by a pressure transducer in the MDR. If the voltage exceeded the threshold of one or more of the electronic counters, this was recorded in each of them. On returning to the colony after a single foraging trip, the bird was re-captured and the MDR

removed. When possible, the weight of food given to the chick after the foraging trip was recorded by weighing each chick before and after the feed.

The number of dives logged in each counter was read from a decoding processor which was attached to the MDR in the laboratory. The frequency of dives within the depth ranges corresponding to the eight counters was then calculated.

RESULTS

The number of dives to each depth range made by each bird is shown in Fig. 1. Taking all four birds together, 90% of the dives were shallower than 45 m, and 40% were to less than 10 m. Details of the foraging trips for which the diving depths were recorded (Table I) show that the number of dives per hour during foraging trips of equivalent duration by two females (birds 2 and 3) were similar. A third female (bird 1) and the only male (bird 4) were at sea for similar lengths of time and delivered similar amounts of food to their chicks, but the male made twice the number of dives per hour. A feed size of approximately 480 g is close to other estimates determined by weighing chicks of the same age every 3 hours (Lishman, unpubl.).

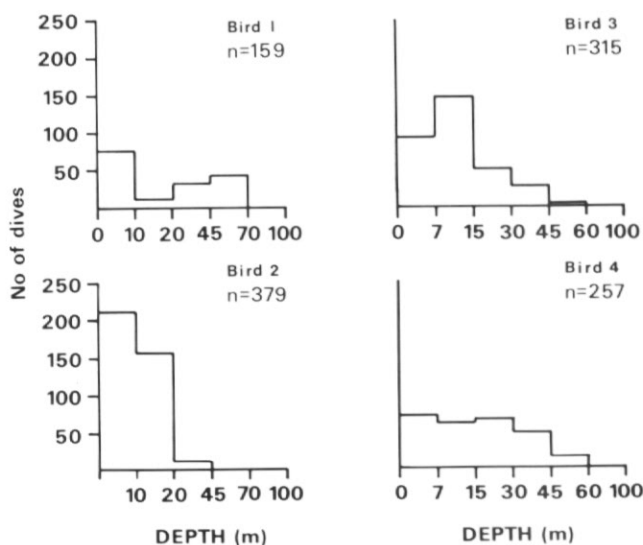


FIG. 1. Diving depths of the chinstrap penguin.

Table I. Details of the foraging trips of the chinstrap penguins studied.

Bird	Sex	Number of chicks	Number of dives	Maximum time absent (h)	Dives per hour	Feed size (g)
1	Female	1	159	22	7.2	495
2	Female	1	379	44	8.6	no data
3	Female	1	315	48	6.6	no data
4	Male	1	257	18	14.3	470

DISCUSSION

There has been only one previous study of the diving depth profiles of penguins. Kooyman and others (1982) found that 50% of dives by king penguins were deeper than 50 m and two dives exceeded 240 m. This contrasts markedly with the chinstrap penguin pattern. Although king penguins, being approximately three times the size of chinstraps, will have a greater diving capacity (Butler and Jones, 1982), the difference in diving depths probably also reflects their different diets. Thus, king penguins feed mainly on squid and some fish (Croxall and Prince, 1982) and the former are particularly characteristic of deeper waters. Chinstrap penguins almost exclusively eat krill *Euphausia superba* (Croxall and Furse, 1980; Volkman and others, 1980; Lishman, unpubl.), which is often abundant much nearer the surface. Krill is, however, widespread at least as deep as 200 m (Everson, 1982), but the study birds did not dive below 70 m to feed and mainly made shallow dives to around 10 m. There are two possible reasons for this. Firstly, chinstraps may be physiologically incapable of diving to greater depths. Chinstrap penguins are of similar size to Adélie penguins *Pygoscelis adeliae*, whose maximum enforced submergence time is 6 min (Kooyman, 1975). Emperor penguins reach depths of 250 m and can remain submerged for 18 min (Kooyman and others, 1971). If dive depths are proportional to dive duration then chinstrap penguins submerging for 6 min might only be able to reach c. 80 m. Secondly, if chinstraps can catch all the food they require above 70 m, there is no reason for them to exceed this depth. This was concluded to be the reason for only 3% of 4273 dives by Antarctic fur seals *Arctocephalus gazella*, which feed almost exclusively on krill during their breeding season (Bonner, 1968), being to below 75 m, despite the fact that over 40% of the krill in the water column was below this depth (Croxall and others, in press *b*). Of seal dives, 76% were to less than 40 m and 26% shallower than 20 m, a pattern very similar to that of chinstrap penguins. Furthermore, 75% of these dives were at night when they were consistently shallower than 30 m, in contrast to most daytime dives being to between 40 and 75 m. This diving pattern can be interpreted as reflecting diurnal differences in the vertical distribution of krill, as acoustic echo-integration surveys of krill around South Georgia (Everson, 1982) showed a clear pattern of vertical migration toward the surface at night. Thus, nearly all krill in the water column were below 75 m between 0600 and 1500 GMT and 23–38% of krill were above 40 m between 2100 and 0600 GMT.

A broadly similar pattern of vertical migration prevails around the South Orkney Islands (Kalinowski and Witek, 1980) and chinstrap penguins may, therefore, feed mainly on krill at night when it is abundantly available above 45 m, a depth above which 90% of their dives terminate. If it is assumed that all dives shallower than 45 m are at night, then with an average of 5 h of darkness at this latitude in January–February, the frequency of dives would be 38.2 ± 9.3 dives per hour (all errors quoted are 1 standard deviation). This is equivalent to one every 1.6 min, which is well within a maximum submergence time of 6 min. The number of krill caught per dive can be estimated if the mean length and weight of krill taken is known and if the energy and food requirements of the adult and its chick can be calculated. The mean length of krill caught by chinstraps at the South Orkney Islands in 1981 was 36.3 ± 0.92 mm ($n = 665$) (Lishman, unpubl.). Using Lockyer's (1973) relationship, individual krill of this length weighed 0.331 g. About 480 g of krill were delivered to the chicks after the foraging trips in this study (Table I), which represents 1450 krill.

The average daily metabolic rate (ADMR) at sea of the macaroni penguin *Eudyptes chrysolophus*, which is a krill-eating penguin of similar mass to the

Table II. Energy consumption and weight and number of krill caught during foraging trips.

Bird	Foraging trip		Krill consumption					
	Duration	Energy consumption ¹	Adult		Chick	Total	Per dive	
	(h)	(kJ)	Weight ²	No. ³	No.	No.	Weight	No.
1	22	2328	633	1912	1495	3407	7.1	21.4
2	44	4657	1265	3822	c. 1450	5272	4.6	13.9
3	48	5080	1380	4169	c. 1450	5619	5.9	17.8
4	18	1905	518	1565	1420	2985	3.8	11.6

*Notes:*¹ At 8.4 W kg⁻¹ (see text).² With average calorific value of krill = 4.6 kJ g⁻¹ (Clarke and Prince, 1980) and 80% conversion efficiency (Costa, in Kooyman and others, 1982).³ Average weight 0.331 g (see text).

chinstrap penguin, is 2.9 times the standard metabolic rate (SMR) (Davis and others, 1983). In 1981, the average SMR of 215 fasting chinstrap penguins, with a mean weight of 3.5 kg, was 2.9 W kg⁻¹ (Lishman, unpubl.) and thus the ADMR at sea of chinstrap penguins would have been 8.4 W kg⁻¹.

The energy consumption for each of the study birds on its foraging trip is calculated in Table II, together with the estimated weight and number of krill caught. Adults consume 949 ± 436 (range 518–1380) g of krill per feeding trip, which represents 2867 ± 1318 (range 1565–4169) krill of 36.3 mm length. Combining this with the food delivered to the chick means that on average 16.2 ± 4.3 (range 11.6–21.4) krill are caught in each dive, i.e. one krill is caught every 6s. While this may not be unrealistic, especially considering the potential ability of krill to avoid capture, it is as likely that on finding a krill swarm, chinstrap penguins will dive for longer periods and catch as many krill as possible in each dive. Many dives, including the deeper ones, may be exploratory and not necessarily successful in terms of foraging.

ACKNOWLEDGEMENTS

We are grateful to Dr C. M. Perrins and Dr T. R. Birkhead for helpful comments on the manuscript. We also thank members of the British Antarctic Survey station at Signy Island, South Orkney Islands for assistance in the field.

Received 4 May 1983; accepted 19 May 1983

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