FOOD DIGESTION AND ENERGY CONSUMPTION EXPERIMENTS ON A KING PENGUIN *Aptenodytes patagonicus*

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Abstract. A fortuitously captive king penguin was used in a series of experiments on food consumption and weight change. On fish diets averaging 1 400–1 700 g d^{-1} (1 900–2 300 kcal d^{-1}), weight loss between feeds was *c.* 60 g h^{-1} and overall weight gains of 100–200 g d^{-1} were recorded. On a krill (packaged in agar) diet averaging 1 250 g d^{-1} (700 kcal d^{-1}) weight loss between feeds was only 30 g h^{-1} and a weight gain of 300 g d^{-1} was achieved. When fed fish, weight and energy surpluses are consistent with the weight increase. With krill, although assimilation is clearly more efficient, the weight increase can only be accounted for by assuming appreciable water retention. During a five-day fast, energy consumption, calculated from weight loss, was *c.* 1 500 kcal d^{-1}, higher than theoretical estimates but similar to other results with captive king penguins.

The king penguin *Aptenodytes patagonicus* breeds on most islands in sub-Antarctic and cool temperate waters, between latitudes 52° and 55° S (Conroy and White, 1973). The distribution and size of the colonies on South Georgia were reviewed by Smith and Tallowin (1979).

Although the performance of king penguins as aquatic pursuit divers has been studied (Kooyman and others, 1982) little work has been done on their food and feeding ecology, but it is generally accepted that squid and fish form the bulk of their diet (Stonehouse, 1960; Croxall and Prince, 1980).

A badly oiled king penguin was found on 1 April 1980 on the beach at King Edward Point, South Georgia (54° 17′ S, 36° 30′ W), and taken to the nearby Grytviken station for cleaning. During three weeks captivity the bird became very tame and could be fed by hand. The opportunity was taken to conduct some simple experiments on digestion rates of krill and fish meals (squid being unavailable) and on the rate of weight loss during a short fast to obtain information on metabolic costs.

Methods

General

The king penguin was kept indoors in a concrete floored room, illuminated for 13 h d^{-1}, commencing at 0600, by artificial light only. Room temperature, which fluctuated between 6 and 12°C, was recorded whenever the bird was weighed.

The experiments lasted for 22 days. Fish meals were given for the first eight days; the bird was allowed to fast for the next six days and was then fed on krill for four days. It was released in good condition after a further seven days during which it was fed on fish and weighed on four consecutive days. It was not possible to collect faecal material during any of the experiments.

Food and feeding

Initially fish (southern mackerel *Trachurus* sp.) were given in 3 × 10 cm filleted portions; subsequently whole fish 15–30 cm long, with forward-projecting spines removed, were used. Mature krill, *Euphausia superba*, were encased 50:50 by weight in agar jelly (70 g l^{-1}), to facilitate feeding; each portion weighed 50 g. Feeds were usually given twice daily, in the morning and late evening and force feeding was never used. The calorific content of krill was assumed to be 1.11 kcal g^{-1}, the average of values given by Clarke (1980) for mature males and gravid females and in line with other determinations. Fish samples could not be returned from Grytviken; the average calorific content for fish of this type is *c*. 1.32 kcal g^{-1} (Department of Agriculture and Fisheries for Scotland, personal communication).

Weighing

A 1-m^2 wooden weighing platform was constructed and attached to a 20 kg Pesola balance. The bird was weighed (to the nearest 100 g) before and after each feed or, while fasting, at regular intervals.

Data analysis

The weight loss during the five complete days of the fast was described as an exponential function of time, $W_t = W_0 e^{kt}$, where W_0 is the weight at the start, W_t the weight t days later and k is a rate constant which here is the proportion of the bird's weight lost each day.

Energy consumption during fasting is calculated as described in Croxall (1982) and, in the present paper, only the lower calculated value, based on the assumption that the material lost comprises 55.5% fat, 9.2% protein and 35.3% water (Groscolas and Clément, 1976), is given.

Metabolic rate at other times was regarded as equivalent to existence metabolic rate (*EMR*) as defined and derived by Kendeigh and others (1977). EMR (kcal d^{-1}) $= a - bT$, where a is EMR for non-passerines at 0°C (given by $EMR = 4.142\, W^{0.5444}$ (W = body weight in g)), b is a temperature coefficient (given by $b = 0.2761\, W^{0.2818}$) and T is the ambient temperature in °C.

RESULTS

Although beak, flipper and tarsus were measured, the sex of the bird could not be determined with certainty from reference to Stonehouse's (1960) data, but it was most probably a female.

The mean food consumption and weight changes of the bird in the three separate feeding experiments are shown in Table I. The results from the two periods on a fish diet are in good agreement and the period of greater weight gain reflects a higher daily input. In comparison, the krill data are anomalous with a 60% greater weight increase deriving from a 65% lower level of energy input.

As the morning and evening feeds were given at much the same time of day in all experiments, weight loss between feeds can be assessed and compared directly

Table I. Food consumption and weight changes of captive king penguin.

Diet	*Calorific content (kcal g^{-1})*	*Time (d)*	*Mean temp (°C)*	*Amount fed*				*Weight*		*Weight gain*	
				g	*g d^{-1}*	*kcal*	*kcal d^{-1}*	*Initial*	*Final*	*g*	*g d^{-1}*
Fish	1.32	7.08	11.2	10 050	1 419	13 266	1 874	10 750	11 500	750	106
Fish	1.32	4.0	7.4	6 900	1 725	9 108	2 277	10 600	11 400	800	200
Krill*	1.11	4.0	9.2	2 500	625	2 750	688	10 100	11 400	1 300	325

* Excluding equal weight of agar.

Table II. Weight loss between feeds.

	Fast periods		*Weight loss ($g\,h^{-1}$)*			
Diet	*No.*	*Mean duration (h)*	*Mean*	*SD*	*Range*	*$g\,d^{-1}$*
Fish	13	13	55	16	29–81	1 320
Fish	8	12	63	12	42–78	1 512
Krill	8	12	32	5	25–42	768

(Table II). The results from the periods of fish diet are reasonably similar, both within and between the two experiments. On a krill diet, however, the weight loss is very consistently and significantly ($p < 0.001$) lower than on a fish diet.

The results of the fasting experiment are compared with other studies in Table III. Our results are similar to those from other captive birds and further emphasize that rates of weight loss are appreciably higher in captive birds than in birds in their natural environment. That our bird had the highest rate of weight loss and energy consumption yet recorded may be due to the short duration of the experiment, whereby weight loss through excretion (confined to the first one to two days of fasting) makes a greater contribution than in other studies.

Discussion

There have been few studies of digestion rates in seabirds and although it is believed that different prey are digested at different rates there has been little attempt to investigate this further.

Although the present study is very preliminary there are two encouraging features. First, the rates of weight loss after feeds are very consistent, especially considering the difficulties of weighing accurately large birds over short time periods. Second, the various results from the fish diet experiments show good agreement (Table IV).

The results from the krill/agar diet are more difficult to interpet. Half the material ingested is agar, which, although it has a calorific content of 0.28 kcal g^{-1} at the dilution used, is probably impossible for birds to metabolize. Its indigestibility may account for the low elimination rates on a krill diet and accumulation of agar must be largely responsible for the recorded weight gain. This cannot derive from nutrients and energy in krill since for the weight increase to comprise lipid and protein would require a positive energy balance, whereas we estimate there to be a small deficit.

Table III. Weight loss and estimated energy consumption of fasting king penguins.

			Weight (g)			*Mean weight loss*		*Energy consumption ($kcal\,d^{-1}$)*		
Status	*Sex*	*No.*	*Initial*	*Final*	*Time (d)*	*$g\,d^{-1}$*	*$g\,g^{-1}\,d^{-1}$*	*Calculated*	*EMR*	*Reference*
Incubating	♂	23	14 230	12 600	10.7	147	0.0114	829	732	Stonehouse (1960)
Incubating	♀	8	14 590	13 150	9.9	166	0.0105	936	745	Stonehouse (1960)
Captive		57	14 600	*c.* 10 500	18	245	0.0183	1 382	706	Mougin (1974)
Captive		4	12 100	*c.* 8 190	17	230	0.0229	1 297	628	Barré (1975)
Captive	?♀	1	11 400	10 100	5	260	0.0240	1 467	608*	This study

*Corrected for mean experimental temperature of 10.3°C.

Table IV. Energy budget of captive king penguin.

Diet	Input (I) $g\,d^{-1}$	Input (I) $kcal\,d^{-1}$	Weight loss (W) ($g\,d^{-1}$)	Metabolism (EMR) ($kcal\,d^{-1}$)	Excretion (E)* $g\,d^{-1}$	Excretion (E)* $kcal\,d^{-1}$	Balance $I-W$ ($g\,d^{-1}$)	Balance $I-EMR+E$ ($kcal\,d^{-1}$)	Weight gain ($g\,d^{-1}$)
Fish	1 419	1 874	1 320	618	404	118	+99	+1 138	106
Fish	1 725	2 277	1 512	629	404	118	+213	+1 530	200
Krill†	625	688	768	613	404	118	−143	−43	325

* Data from Burger and others (1978).
† Including agar input would give a weight balance of + 482 g.

On all diets, however, water may constitute an appreciable portion of the weight gain as it is likely that this is conserved and stored in the body tissues whence it can later be eliminated (in substantial quantities) during fasts, especially those associated with moult (Groscolas and Clément, 1976; Williams and others, 1977).

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