SHORT-TERM VARIATION IN THE WINTER DIET OF GENTOO PENGUINS *PYGOSCELIS PAPUA* AT SOUTH GEORGIA DURING JULY 1989

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SUMMARY

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During winter 1989 at South Georgia, Gentoo Penguins *Pygoscelis papua* showed a very rapid change in diet over a 10-day period. On 11-12 July, food samples were of low masses (150 g) and had a high proportion of fish prey (75%) and of heavily digested material (33%). On 21-22 July, samples had higher masses (485 g), consisted predominantly of crustacean prey (99%) and had little, heavily digested material (2%). Antarctic Krill *Euphausia superba* was the most abundant crustacean species, forming 80% and 99% by number of individuals in the two sample periods. Data on winter diet are also compared over three years (1987-89). There was close similarity, between years, in the mass and composition of the two 'alternative' diets: low-mass, fish-dominated and high-mass, krill-dominated diets. However, there was no consistent pattern in the seasonal occurrence of these changes in diet between years. It is suggested that the change in diet reflects short-term, local decreases in availability of Antarctic Krill in the inshore waters exploited by Gentoo Penguins.

INTRODUCTION

Seabirds, and in particular penguins, are a major component of the predator-prey system in the Southern Ocean (Croxall 1984, Everson 1984, Croxall & Prince 1987). A large amount of data has now been obtained on the diet of penguins during the breeding season (see reviews by Croxall & Lishman 1987, Cooper *et al.* 1990), but there is still much less known about the diet of non-breeding penguins in winter. Consequently, until recently there have been few data available with which to assess the extent of intra-annual variation in diet or the time-scale over which changes in diet occur. Most penguin species show little variation in diet composition through the chick-rearing period (Croxall & Lishman 1987), but longer-term studies on the King Penguin *Aptenodytes patagonicus* (Adams & Klages 1987, Hindell 1988), Jackass Penguin *Spheniscus demersus* (Wilson 1985) and Gentoo Penguin *Pygoscelis papua* (Adams & Klages 1989, Hindell 1989, Williams 1991) have shown temporal variation in diet occurring over periods of several months. Croxall & Lishman (1987) reviewed data on annual variation in the diet of chick-rearing penguins (see also Croxall *et al.* 1988b) but so far no study has considered inter-annual variation in diet during the winter.

In this paper we present data showing a very rapid temporal change in the diet of Gentoo Penguins during the 1989 winter at Bird Island, South Georgia. In addition, we compare these data with those from two previous years (1987 and 1988) to assess annual variation in the winter diet of this species at South Georgia.

METHODS

Field work was carried out in July 1989 at Bird Island, South Georgia (54 00S, 38 02W) as part of a larger study of Gentoo Penguin foraging ecology (T.D. Williams unpubl. data). Stomach samples were obtained from Gentoo Penguins, as they emerged from the sea at the Johnson Cove colony, randomly sampled on 11-12 July (n=10) and 21-22 July (n=8). Each bird was weighed, sexed by bill measurements (Williams 1990) and the food sample obtained by stomach flushing (Wilson 1984). This technique has been shown to be an efficient method of obtaining complete stomach contents in penguins provided multiple-flushing is used (Jablonski 1985, Gales 1987). Stomach content samples were analysed as described in Williams (1991). However, otoliths were not recovered in this study. Data on diet composition are presented as percentage by wet mass of each item, number of individuals (for crustacean prey only), and frequency of occurrence by number of samples. Statistical tests were carried out using Minitab (Ryan *et al.* 1985).

TABLE 1

MASS AND COMPOSITION OF FOOD SAMPLES OBTAINED FROM MALE AND FEMALE GENTOO PENGUINS *PYGOSCELIS PAPUA* ON 11-12 AND 21-22 JULY 1989 AT SOUTH GEORGIA. VALUES ARE MEAN WET MASS (g) ± S.E., FREQUENCY BY NUMBER OF SAMPLES AND, FOR CRUSTACEANS, MEAN NUMBER OF INDIVIDUALS ± S.E. FOR MASS. FIGURES IN PARENTHESES ARE PERCENTAGES OF IDENTIFIABLE MATERIAL FOR FISH/ CRUSTACEANS AND PERCENTAGES OF TOTAL SAMPLE MASS FOR UNIDENTIFIED MATERIAL

		11-12 July		21-22 July	
		Male	Female	Male	Female
Sample Size		5	5	4	4
Total mass		171 ± 24	128 ± 17	519 ± 126	452 ± 97
Crustacean	Mass	27 ± 14	23 ± 10	459 ± 126	443 ± 95
	(%)	(24)	(27)	(89)	(99.9)
	Freq.	4 (80)	5 (100)	4 (100)	4 (100)
	Ind.	102 ± 79	86 ± 48	583 ± 160	603 ± 259
Fish	Mass	85 ± 24	64 ± 15	54 ± 54	1.0 ± 0.6
	(%)	(76)*	(73)*	(11)	(0.1)
	Freq.	5 (100)	5 (100)	1 (25)	1 (25)
Unidentified	Mass	58 ± 18	41 ± 12	5 ± 2	8 ± 2
material	(%)	(34)	(32)	(1)	(2)
	Freq.	5 (100)	5 (100)	4 (100)	4 (100)

* Including less than 1% Octopoda.

RESULTS

Mean total mass and composition of food samples obtained from Gentoo Penguins, for each sample period and by sex, are given in Table 1. There were no significant differences in the mass of food samples from male and female birds within either sample period so data were pooled for further comparison between sample periods. Mean total food sample mass was significantly less on 11-12 July (150 ± 49 g) than on 21-22 July (485 ± 211 g, $t=4.41$, $P<0.01$).

The only difference in diet composition between male and female birds was that male samples contained more fish than did female samples on 21-22 July (11% and 0.1% respectively). Fish prey formed 75% of identifiable material by wet mass on 11-12 July but only 5% on 21-22 July (Table 1). Conversely, crustacean prey accounted for 25% of identifiable material by mass on 11-12 July and 95% on 21-22 July. Fish prey occurred in 100% (n=10) of samples on 11-12 July but in only two of eight samples (25%) on 21-22 July. There was no significant difference in the mass of the fish component between the two sample periods (Table 1). The proportion of heavily digested (unidentified) material in the samples was greater on 11-12 July (33%) than on 21-22 July (2%, Table 1).

Food samples from 21-22 July contained a greater mass of crustaceans ($t=5.79$, $P<0.001$) and a greater number of individual crustacean prey ($t=4.63$, $P<0.01$) than did those from 11-12 July (Table 1). Antarctic Krill *Euphausia superba* was the most abundant species in the crustacean component, forming 80% and 99% by number of individuals on 11-12 and 21-22 July, respectively, and occurring in 17 of 18 samples (94%). In samples from 11-12 July, the amphipod *Themisto gaudichaudii* and the mysid *Antarctomysis maxima* were the next most abundant crustaceans, accounting for 12% and 5% respectively by number of individuals. Other crustacean species recorded, all of which accounted for less than one per cent, were the amphipod *Byblis securiger* and the decapods *Notocrangon antarcticus* and *Chorismus antarcticus*. Five individuals of an unidentified species of Octopoda were also recorded. Fish remains were not identified to species.

TABLE 2

TOTAL LENGTH (mm) AND MASS (g) OF ANTARCTIC KRILL *EUPHAUSIA SUPERBA* IN FOOD SAMPLES OBTAINED FROM GENTOO PENGUINS *PYGOSCELIS PAPUA* ON 11-12 JULY AND 21-22 JULY 1989 AT SOUTH GEORGIA. VALUES ARE MEAN ± S.E. DATA FROM MALE AND FEMALE BIRDS ARE POOLED

Sample period		All krill	Adult male krill	Adult female krill
11-12 July	N	45	23	15
	Length	47.4 ± 1.1	51.6 ± 0.9	46.5 ± 1.2
	Mass	0.90 ± 0.06	1.16 ± 0.06	0.72 ± 0.05
[illegible]2 July	N	741	437	230
	Length	50.6 ± 0.2	52.7 ± 0.2	48.3 ± 0.2
	Mass	1.05 ± 0.01	1.22 ± 0.01	0.79 ± 0.01

Adult male (MA) and adult female (FA) krill accounted for 49% and 32%, respectively of all krill on 11-12 July and 60% and 30%, respectively of all krill on 21-22 July (Fig. 1). Mean individual length and mass of krill for these two predominant age/sex classes, and for all krill, are given in Table 2. There was no significant differences in the size of krill in samples obtained from male and female birds in either period. Mean individual length and mass of all krill were significantly greater in samples from 21-22 July than those from 11-12 July (length, $t=2.90$, $P<0.01$; mass, $t=2.57$, $P<0.05$, Table 2). However, there were no significant differences in mean individual length or mass of adult male or adult female krill between the two sample periods (Table 2).

DISCUSSION

Short-term change in diet

In this study, Gentoo Penguins showed a very rapid change in diet, within a 10-day period. Food samples obtained on 11-12 July were of low masses (150 g) and contained a high proportion of fish (75%) and of heavily digested material. Conversely, those obtained on 21-22 July had higher total masses (485 g) and consisted predominantly of crustacean prey, mainly Antarctic Krill. Croxall *et al.* (1988a) reported that either krill or fish dominate in diet of Gentoo Penguins in summer, but that near equal shares of the two prey types are very rarely encountered at South Georgia. Williams (1991) reported a similar change in the diet of Gentoo Penguins in the 1987 winter at South Georgia, though over a much longer time-scale, with low-mass, fish-dominated samples in May-August and high-mass, krill-dominated samples in September. In both studies, all the fish identified from food samples were benthic or benthic-demersal species occurring in continental shelf waters. Williams (1991) suggested that the change in the diet was due to decreased local availability of Antarctic Krill, the preferred prey of Genoo Penguins at South Georgia (Croxall *et al.* 1988a, Williams 1991). This is supported by the fact that in all sample periods the absolute mass of the fish component remained the same and it was the presence or absence of krill in the diet which accounted for the large difference in sample mass. Priddle *et al.* (1988) have suggested that unusually low abundance of krill may last for several months in the Scotia Sea around South Georgia. Long-term data on breeding biology of predator species which are dependent on krill suggest that such events may occur two or three times in a decade (Priddle *et al.* 1988). Unfortunately, little is known about the dynamics of krill distribution in winter around South Georgia. However, the present study shows that an increase in krill availability, as indicated by the change in Gentoo Penguin diet, can occur very rapidly. Furthermore, a switch in diet of Gentoo Penguins to low-mass, fish-dominated samples has now been recorded in two out of three winters at South Georgia suggesting that, at least locally in inshore waters, marked variation in krill availability may be a relatively frequent event in winter. This supports the suggestion of Adams & Klages (1989) that switches in diet of the Gentoo Penguin may largely reflect local changes in availability of particular prey species within the inshore area exploited by this species.

Inter-annual variation in winter diet

Throughout the 1988 winter, and in September 1987, Gentoo Penguins at South Georgia preyed almost exclusively on Antarctic Krill and mean food sample masses were relatively high (440 g). Conversely, in May-August 1987 food samples were dominated by fish, sample masses were low (150 g) and there was a high proportion of heavily digested material (30%) (Williams 1991). There is therefore very close similarity between these data and those of the present study, in the mass and composition of the two 'alternative' diets: low-mass, fish-dominated and high-mass, krill-dominated diets. However, there does not appear to be any consistent pattern in the seasonal occurrence of these changes in diet. The lengths of krill taken by Gentoo Penguins in 1989 (47-51 mm) were greater

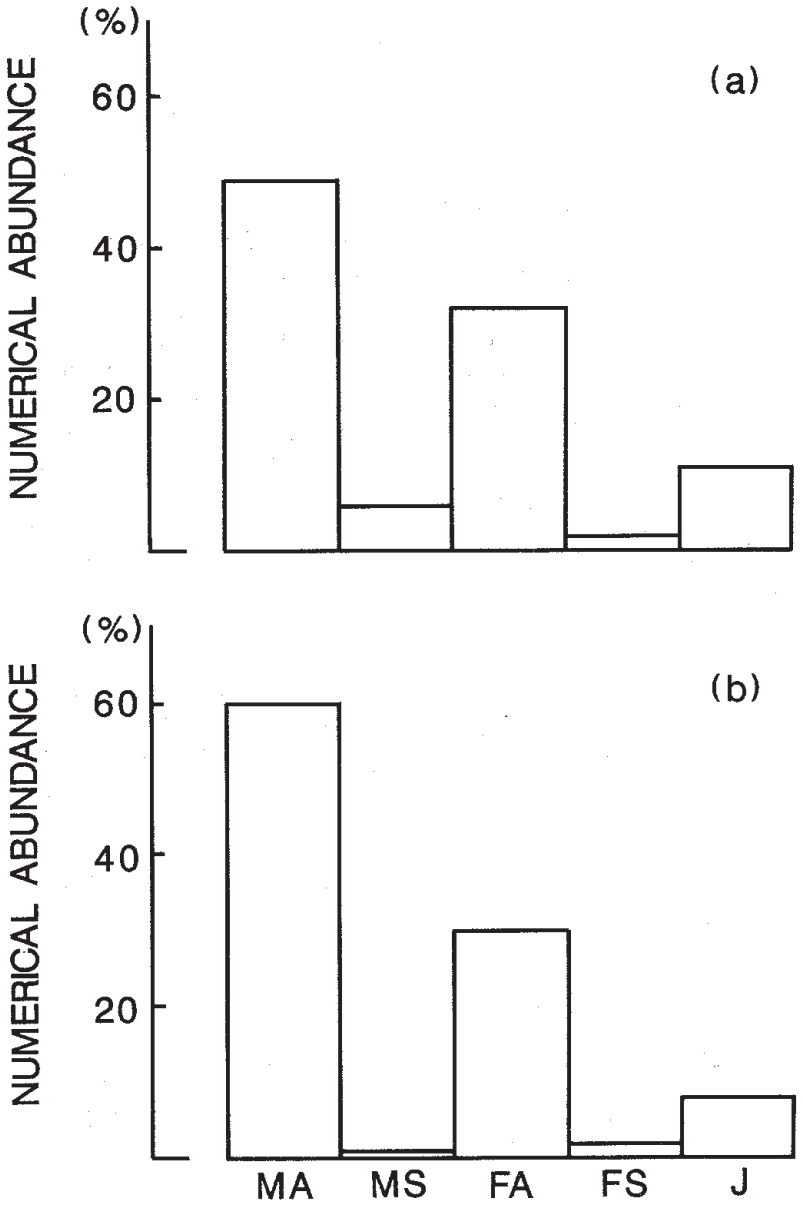

Figure 1

Sex and stage of sexual maturity of Antarctic Krill *Eupausia superba* in food samples obtained from Gentoo Penguins *Pygoscelis papua* at South Georgia on (a) 11-12 July, n=45 krill, and (b) 21-22 July, N=741 krill. MA = adult male, MS = sub-adult male, FA = adult female, FS = sub-adult female and J = juvenile.

than those recorded in 1987-88 (42-46 mm; Williams 1991), but less than those recorded in chick-rearing birds (50-56 mm; Croxall *et al.* 1988a). Also, in the 1987-88 winter samples most krill were sub-adults, in contrast to the 1989 winter samples, although the proportion of male and female krill was very similar (55% male: 35% female, in July 1987 and 1988; Williams 1991). The other major difference in diet between years was that in the present study, on 11-12 July, samples from both male and female birds comprised mainly fish whereas in 1987, females continued to take crustacean prey even when total sample masses were low (Williams 1991). Trivelpiece *et al.* (1983) and Williams (1991) suggested that male Gentoo Penguins may be better able to catch fish prey because they are larger, more powerful swimmers than are female birds. The fact that female birds also took mainly fish prey on 11-12 July 1989 may be due to variation in the availability of other crustacean prey between years.

The greater diversity of prey types in the fish-dominated samples is consistent with the idea that birds were having difficulty finding food and, in particular, that krill availability was low (Williams 1991). It is interesting that the mass of the fish component did not increase during the period when krill availability was low. This may be partly due to more rapid rates of digestion of fish prey compared to crustaceans (Jackson & Ryan 1986), which is supported by the greater proportion of highly digested material in the fish-dominated samples. However, foraging trip durations of Gentoo Penguins are only about six hours in winter (Williams 1991), and Gales (1987) has shown that 88-100% of ingested fish are recovered by stomach-flushing 8-16 hours after ingestion. This suggests that Gentoo Penguins did not markedly increase the amount of fish consumed in response to reduced krill availability. Two possible reasons for this are firstly, that fish prey are not readily available or abundant in winter, and secondly, that Gentoo Penguins can not readily switch their foraging pattern to take advantage of alternative prey types. The latter hypothesis is supported by the fact that there were no differences in foraging trip duration, dive frequency, dive depth and dive duration of Gentoo Penguins (with time-depth recorders) during the first and second sample period in 1989 (T.D. Wiliams unpubl. data; see appendix). The similarity in the other prey species recorded in this study and in winter 1987-88 further supports the idea of a 'conservative' foraging pattern in Gentoo Penguins, primarily adapted to exploiting Antarctic Krill.

More data are required on diets of penguins in winter to assess the frequency and duration of periods of low availability of preferred prey (such as Antarctic Krill). If these are frequent and/or prolonged they may represent a major factor determining the over-winter survival of resident, sub-Antarctic penguin species.

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APPENDIX

SUMMARY OF DIVING DATA OBTAINED FROM GENTOO PENGUINS *PYGOSCELIS PAPUA* ON 11-12 JULY AND 21-22 JULY 1989 AT SOUTH GEORGIA

Diving parameters	11-12 July	21-22 July
Sample size (trips)	6	4
Foraging trip duration (h)	6.8 ± 2.6	6.8 ± 0.4
Deep dive frequency (dives/h)	7.2 ± 2.6	10.8 ± 5.9
Mean deep dive depth (m)	101.2 ± 32.5	81.7 ± 29.6
Mean deep dive duration (min)	3.3 ± 0.6	2.6 ± 0.5