CHARACTERISTICS OF KRILL *EUPHAUSIA SUPERBA* EATEN BY ANTARCTIC FUR SEALS *ARCTOCEPHALUS GAZELLA* AT SOUTH GEORGIA

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Abstract. Samples of krill taken from lactating female fur seals in six seasons at Bird Island, South Georgia showed that they almost exclusively ate mature krill of 40–60 mm length, including gravid females. In each of four samples from Jan–Feb 1983, female krill outnumbered males by four to one. Extensive krill samples from net-hauls around South Georgia contained very few mature krill; only 1% were longer than 50 mm, compared with 75% in fur seal samples. Net avoidance by large krill and biases in vertical sampling by nets and predators are discounted and it is suggested that breeding fur seals are exploiting, especially within 100 km of north-west South Georgia, rich local resources of mature krill which are so far unsampled by net hauls.

Introduction

Although Antarctic krill *Euphausia superba* is the staple diet of many Southern Ocean vertebrates (Laws, 1977), including Antarctic fur seals *Arctocephalus gazella* (Doidge and Croxall, in press), there are very few published details of the size of the krill eaten by these predators, with the exception of baleen whales (Mackintosh, 1974). In particular no information is available for seals and, apart from whales, there has been no attempt to relate such data to information on the krill caught by net hauls in similar areas at appropriate times of year.

In this paper we present some data on the length-distribution and sex ratio of krill taken by lactating female Antarctic fur seals breeding at Bird Island, South Georgia and compare this with net haul samples taken around South Georgia and within the seals' normal foraging range. Bird Island is one of the main fur seal breeding sites at South Georgia and some 35000 pups are born there each year (Doidge and others, 1984).

Methods

Krill from fur seal stomachs were obtained either as the complete stomach contents or a sub-sample of this. All specimens were preserved in formalin. For a random sample of intact krill, we measured standard length (anterior edge of eye to tip of telson). For the 1982–83 samples all intact specimens from the complete stomach contents were sexed and the extent of sexual maturity assessed where possible. Krill from net haul samples were similarly treated. Specimens for weighing were lightly blotted first, following Lockyer (1973).

Length measurements of krill from fur seal stomach contents were available for the Antarctic summer seasons (designated by the year in which they start) of 1971–73 (see Doidge and Croxall, in press, for details), 1976 (see also Croxall and Prince, 1980), 1977 and 1982 (see Doidge and Croxall, in press). The 1982 samples and those from net hauls were measured by MNP; other samples were measured by JPC.

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Because extensive published data exist on krill caught around South Georgia, additional information was only sought for krill from net hauls at sampling stations within the foraging range of female seals from Bird Island. Female fur seals make about 17 trips to sea, each of about four days duration, while rearing pups (Doidge and others, in press). Their maximum foraging range on these trips, estimated from analysis of activity patterns obtained from time–depth recorders operating continuously throughout these trips (Croxall and others, in press *a*), is *c*. 150 km and the realistic range is probably less than 100 km (see Fig. 1). Furthermore, all 35 arrival and departure tracks of seals rearing pups at Bird Island that bore radio transmitters and were followed for at least 5 km offshore were within a 90° quadrant (Fig. 1), centred on a bearing of 320° from Bird Island (J. L. Bengtson, unpublished data). Nine sampling stations of the BAS Offshore Biological Programme (OBP) fall

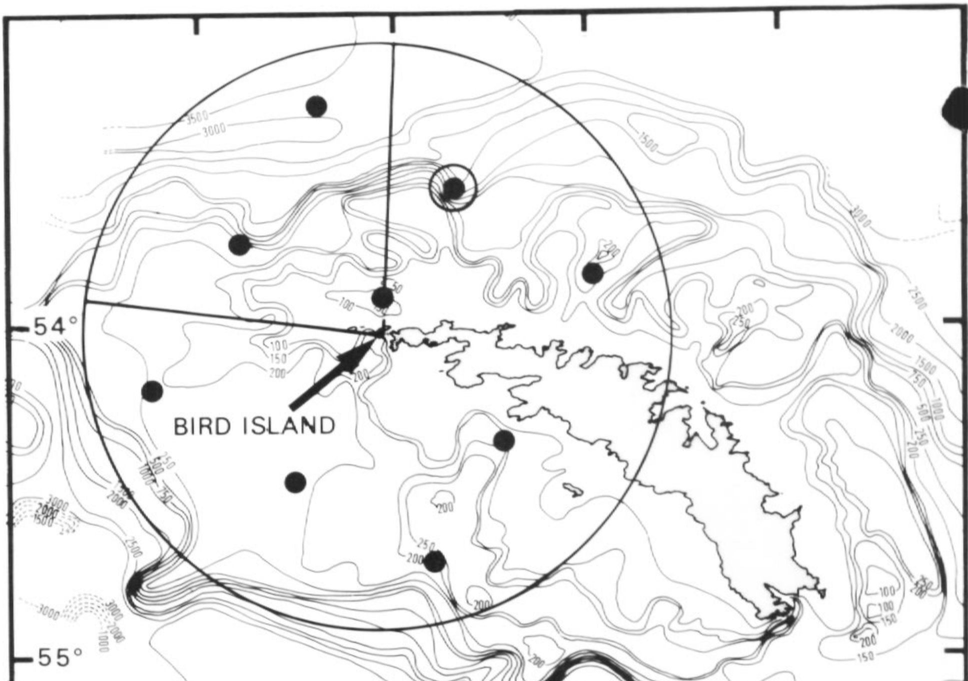

Fig. 1. South Georgia, showing the surrounding bathymetry, the locations of Bird Island and of the OBP sampling stations (solid circles) and the likely foraging range (circle of radius 100 km) and area (90° quadrant, north-west of Bird Island) of Antarctic fur seals. The krill sample analysed in Fig. 4 came from the encircled sampling station.

within the 100 km radius; at four no krill were recorded. At another four, only a small number of immatures was obtained and only one station (3 Dec 1981; encircled in Fig. 1) provided a sufficient sample for analysis.

Results

Length-distributions of krill taken by lactating female fur seals from Bird Island are given in Appendix 1 and summarized in Fig. 2. Although these data cover three months and come from six seasons, the overall picture is remarkably consistent. The

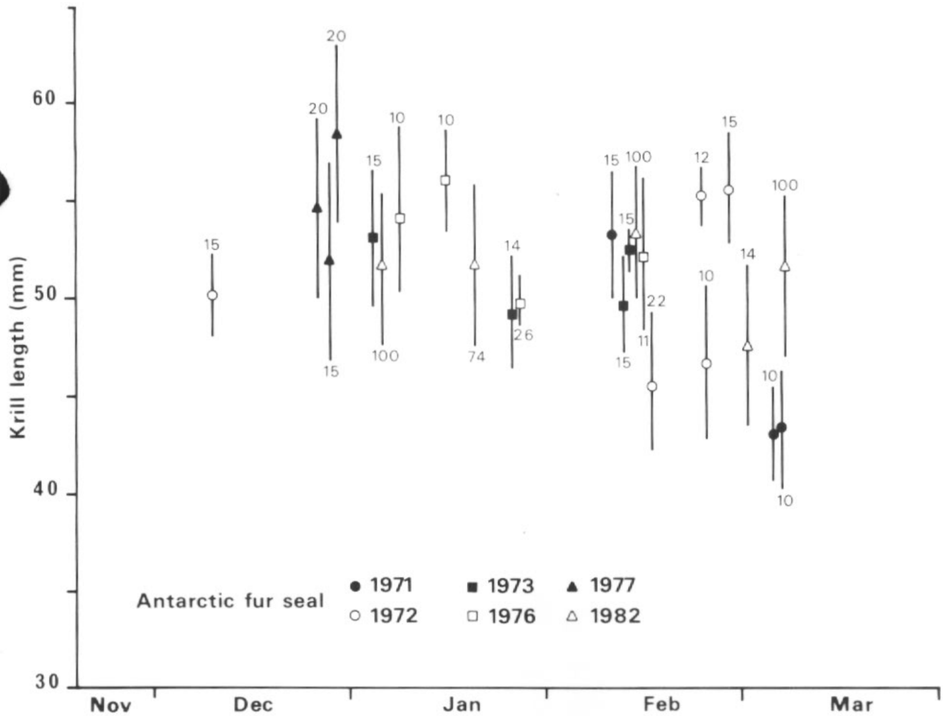

Fig. 2. Length of krill taken by Antarctic fur seals at Bird Island, South Georgia, 1971–1982. Mean values, with standard deviation and sample size are shown.

Table I. Weight of krill in Antarctic fur seal stomachs, Bird Island, 1982–83

Seal No	*Seal Wt (kg)*	*Date*	*Total number*	*Total weight (g)*	*Krill Mean weight (g) Actual*	*Krill Mean weight (g) Theoretical**	*Theoretical total weight (g)*
1050	28	4 Jan 1983	621	270	0.43	1.13	702
1058	37	19 Jan 1983	1058	460	0.43	1.14	1206
1114	50	14 Feb 1983	985	500	0.51	1.26	1241
1142	46	1 Mar 1983	811	370	0.46	0.85	689
1164	37	7 Mar 1983	1006	410	0.41	1.12	1127
Mean			896	402	0.45	1.10	993
S.D.			180	89	0.04	0.15	275

*Applying length–weight relationships in Lockyer (1973) to mean length of each sample from Table II.

Table II. Length and sex of krill in Antarctic fur seal stomachs, Bird Island, 1982–83.

Seal No	*Sample size**	*Length (mm)*			*Sex*			
					Male		*Female*	
		Mean	*S.D.*	*Range*	*No*	*%*	*No*	*%*
1050	100	51.7	3.8	42–59	19	19	79	81
1058	74	51.8	4.1	41–60	15	22	54	78
1114	100	53.4	3.5	46–61	17	17	83	83
1142	14	47.6	4.1	39–53	5	45	6	55
1164	100	51.6	3.6	42–59	24	25	73	75
Overall		52.5	3.7	39–61	80	21	295	79

*A few krill could not be sexed reliably.

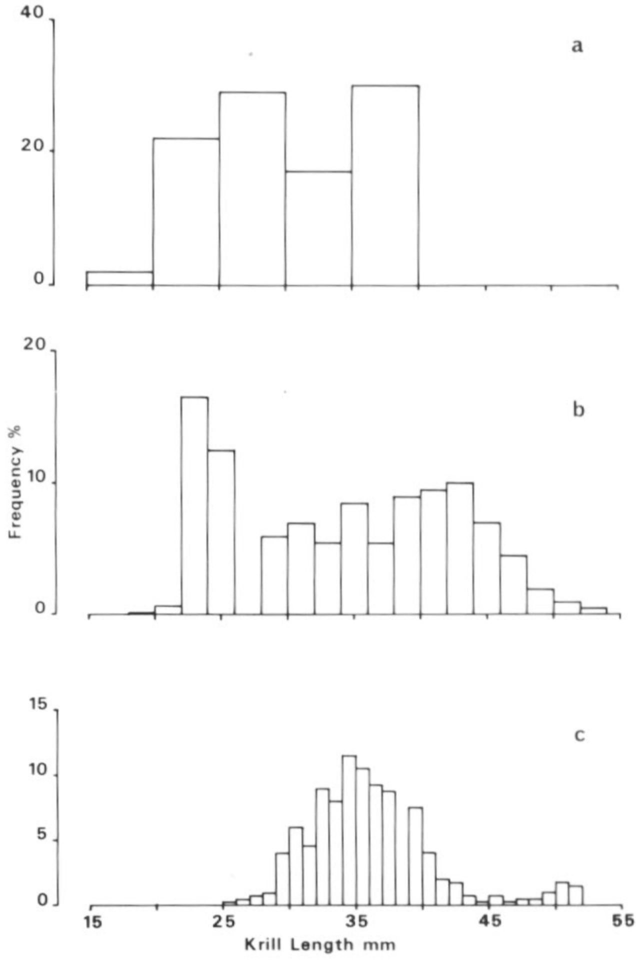

Fig. 3. Length–frequency distribution of krill taken by net hauls around South Georgia. (a) Dec 1972–Jan 1973; calculated from Nemoto and others (1981, fig. 12B). (b) Feb–March 1976; $n = 1472$; calculated from Jazdzewski and others (1978, fig. 19A, III). (c) Feb–March 1981; $n = 300$; from BIOMASS (1982, fig. 2).

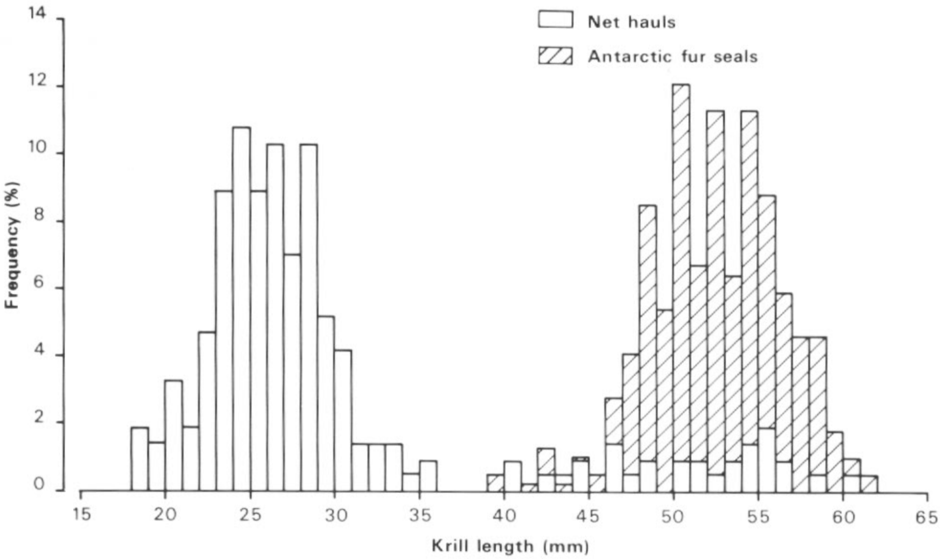

Fig. 4. Length–frequency distributions of krill taken by Antarctic fur seals ($n = 375$) and net hauls ($n = 223$) in the vicinity of Bird Island.

mean values for all samples lie between 43 and 58 mm, the overall range of individual krill being 39–66 mm. There is no evidence of any systematic change in the size of prey taken, the suggestion of a reduction in size at the end of the summer being statistically insignificant, though the two samples from March 1972 are statistically different in length ('*t*'-test) from all others.

The five samples from 1982–83 were analysed in greater detail (Tables I, II). On average each stomach contained *c.* 900 krill weighing *c.* 400 g with females outnumbering males by four to one. All individuals were sexually mature. Statistically ('*t*'-tests) samples 1114 and 1142 are different in length from all others ($P \leq 0.01$). Many females were gravid but the exact proportion could not be determined because of the digested state of part of the material from all samples.

Length–frequency distributions of krill from net hauls around South Georgia are summarized in Fig. 3. The length–frequency distribution of krill in the only good net haul sample from within the foraging range of breeding female fur seals is compared with that of the krill taken by the seals in 1982–83 in Fig. 4. The only sexually mature krill in this net haul sample were individuals longer than 40 mm. Of the 15% of krill in this category, 50% were males, 40% gravid females and 10% females with spermatophores attached.

Discussion

The krill in the five complete stomach contents from 1982 were already appreciably digested. A mean individual weight of 0.45 g compares with a theoretical mean weight of a whole krill of their average length of 1.10 g (Table I). This suggests that the average fresh weight of the krill actually present in the stomachs would have been *c.* 990 g (Table I). Lactating female fur seals need to catch *c.* 5.8 kg of krill to meet their daily energy requirements (Kooyman and others, in press). The krill in the stomach, therefore, originally represented one sixth (17%) of this daily requirement. Because fur seals feed largely at night (Croxall and others, in press *a*) these krill were probably caught early in the morning of the seals' last day at sea before coming ashore and being collected. The krill caught earlier that night would already have passed through the stomach and perhaps even been voided in the faeces. Seals that have not fed shortly before arriving ashore, or are not taken within perhaps 12 h of arrival, are unlikely to contain much, if any, undigested food in the stomach.

There are three particularly interesting features of the krill taken by fur seals: their size, that they include many gravid females and their sex ratio. Between December and March female fur seals feed almost exclusively on mature krill, judging from the results of the detailed analysis of the 1982 samples and the comparability of the length–frequency distributions from all seasons. The composition of krill catches from net hauls around South Georgia, however, is consistently different. Using the most detailed recently published data, from 68 net hauls and measurements of over 5000 specimens from much of the north-east and east coast of South Georgia in Feb–March 1976 (Jazdzewski and others, 1978), adult krill were almost entirely unrepresented and sub-adult male and female krill (the only categories with individuals greater than 40 mm length) were only locally common. Less than 1% of krill were longer than 50 mm, compared with 75% in the fur seal samples. The pattern described by Jazdzewski and others (1978), of a preponderance of juveniles of *c*. 25 mm length and a subsidiary peak of some adults at *c*. 42 mm is not radically different from that found by others workers (see Fig. 3), nor from the extensive unpublished data obtained by BAS during OBP. Similarly, of 100 South Georgia swarms analysed by Marr (1962, fig. 156), only 18% contained krill of modal length greater than 40 mm and only 7% greater than 50 mm. Relatively few of all these samples were taken from areas within the likely foraging range of breeding female fur seals but the composition of the only BAS sample from within this area (Fig. 4) is similar to those from hauls elsewhere around South Georgia.

Given these disparities in length–frequency distributions of krill from seals and nets it is hardly surprising that the former contain a high proportion of the large gravid females, which are rare in the latter. This is significant because the scarcity of gravid females (and of larvae and eggs) led Marr (1962) to conclude that krill do not breed around South Georgia and that the population there is maintained by influx from further south.

Females comprise 79% of the krill caught by fur seals in Jan–Feb 1982 and this is remarkably consistent for all four of the large samples, especially considering that these span two months. From Jazdzewski's and others (1978, fig. 4) data, excluding his area III (containing almost exclusively juveniles), of *c*. 1440 sexed krill in Feb–March, 812 (56%) were male, with a range between individual hauls of 32–77%. The two hauls analysed from the South Georgia area in Feb–March 1981, during FIBEX, contained 98% males (BIOMASS, 1982); the sample from within the seals' foraging range in December 1981 had equal numbers of male and female krill. Croxall and others' (in press *b*) reanalysis of Nemoto and others' (1981, fig. 19) data on 58 swarms from the general area of South Georgia showed that, while 78% of December swarms contained more than 80% female krill, by January only 14% of swarms had more than 70% females and most showed only a slight bias in favour of females. Thus the fur seal samples have a rather different sex composition from the net haul data with the exception of some December samples.

Mature (and especially gravid) female krill have an energy content up to *c*. 60% greater than males and immatures (Clarke, in press) and so are potentially a particularly attractive prey for their predators (Croxall and others, in press *b*). The fur seals sampled in 1983 were certainly availing themselves of this, though the present data do not constitute evidence for deliberate selection of female krill.

These differences between krill samples from predators and net hauls are not confined to fur seals. Croxall and others (in press *b*) have shown that penguins breeding at Bird Island, which have broadly similar (or more restricted) foraging ranges compared with seals, take krill similar in size to those eaten by fur seals (Croxall and Prince, 1980). The same is true of various Bird Island albatrosses and petrels (Croxall and others, in press *b*). With baleen whales, however, the mean size of krill eaten around South Georgia in summer ranges from 37 to 45 mm (Mackintosh, 1974, table 4) rather closer to the mean lengths of the sub-adult krill in Jazdzewski and others' (1978) net hauls.

How then can these differences be explained? One possible explanation is that seals and penguins in particular catch krill in depth strata inadequately sampled by nets. Jazdzewski and others (1978) suggested that the largest krill are mainly found below 50 m depth. However, fur seals do 75% of their feeding at night and their dives then rarely exceed 30 m (Croxall and others, in press *a*). Chinstrap penguins *Pygoscelis antarctica*, which eat krill almost exclusively, do not dive deeper than 70 m and 40% of dives were shallower than 10 m (Lishman and Croxall, 1983). This, and the data on the surface feeding albatrosses and petrels, would suggest rather that nets might fail to catch large krill near the surface. However, because krill populations undergo regular vertical migrations in the South Georgia area (Kalinowski, 1978; Everson, 1983) the nets should be sampling these krill at some stage. Also, large krill are sampled perfectly adequately by similar nets further south, around the South Shetland and South Orkney islands, where there are only minor discrepancies between predator and net haul samples (Croxall and others, in press *b*). For this reason, net avoidance by large krill (Marr, 1962; Mackintosh, 1973) cannot provide an explanation either.

Most sampling for krill at South Georgia using net hauls has been away from the major concentrations of krill-eating birds and seals (which are chiefly at the north-west end of the island) and outside their main potential foraging areas. It seems possible that the birds and seals are sampling mature krill from relatively small areas of high abundance that have not yet been sampled by net hauls. It is obviously of considerable interest to try to discover these areas as the consumption of krill by birds and seals breeding at South Georgia (Croxall and others, in press *b*) indicates that the stocks of mature krill must be substantial and may play a significant role in the life history and population dynamics of krill around South Georgia.

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APPENDIX 1
Length of krill taken by Antarctic fur seals at Bird Island, South Georgia, 1972–1977

Date	Sample size	Length (mm)		
		Mean	S.D.	Range
9 Feb 1972	15	53.3	3.4	47–61
5 Mar 1972	10	43.1	2.4	40–45
5 Mar 1972	10	43.5	2.5	40–46
9 Dec 1972	15	50.2	2.1	48–53
16 Feb 1973	22	45.5	3.2	41–49
22 Feb 1973	10	55.3	1.5	53–58
23 Feb 1973	12	46.7	4.0	43–49
26 Feb 1973	15	55.7	2.8	51–63
4 Jan 1974	15	53.1	3.5	46–61
25 Jan 1974	10	49.3	2.8	43–52
25 Feb 1974	10	49.8	1.4	48–52
11 Feb 1974	15	49.7	2.5	44–52
11 Feb 1974	15	52.5	1.1	51–54
14 Feb 1974	11	52.2	4.0	42–57
8 Jan 1977	14	54.1	3.8	45–61
15 Jan 1977	26	56.0	2.7	53–62
27 Dec 1977	20	58.4	4.6	48–63
27 Dec 1977	15	51.9	5.1	40–60
27 Dec 1977	20	54.6	4.7	44–66