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Biological characteristics of euphausiids preyed upon by Adélie penguin, *Pygoscelis adeliae*, breeding at Hukuro Cove, Lützow-Holm Bay in 1995/1996

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Abstract: Adélie penguins were used as a biological sampler from late December 1995 to late January 1996 to study biological characteristics of euphausiids in Lützow-Holm Bay, which is generally covered with fast sea-ice even in summer. Stomach contents and diving behavior of the penguins were examined. Euphausiids accounted for 73% of total wet weight of stomach contents, and fish 27%. Among euphausiids, *Euphausia superba* occupied 83%, and *E. crystallorophias* 17 %. Females occupied 96 % of the total number of *E. superba*, males only 4%. *E. crystallorophias* consisted of 73% females, 10% males and 17% juveniles. Adélie penguins might eat nutritionally superior female euphausiids selectively, and/or they could not catch male euphausiids which can swim faster. It was suggested that those individuals which dived deeper ate more euphausiids than fish, and larger *E. superba*.

key words: *Euphausia superba, Euphausia crystallorophias*, Adélie penguin, biological sampler, Lützow-Holm Bay

Introduction

Adélie penguins eat euphausiids, amphipods and fish. On oceanic islands, *Euphausia superba* is the main food item (Volkman *et al.*, 1980; Lishman, 1985; Trivelpiece *et al.*, 1990), and in shelf areas a mixture of *E. superba, E. crystallorophias* and fish are eaten (Emison, 1968; Puddicombe and Johnstone, 1988; Thomas and Green, 1988; Ridoux and Offredo, 1989). Lützow-Holm Bay is unique in that *E. superba* is the main food item of Adélie penguins in spite of its location in the shelf area (Watanuki *et al.*, 1994). The distribution of euphausiids in this area is not known because the area is generally covered with fast sea-ice even in summer. Hence, Adélie penguins can be used as a biological sampler of euphausiids in this area where direct sampling of euphausiids is extremely difficult.

As part of the Sea Ice and Penguin Study (SIPENS) program, we studied distribution and biological characteristics of micronekton including euphausiids under fast sea-ice at Hukuro Cove in Lützow-Holm Bay by using the Adélie penguin as a biological sampler. We analyzed stomach contents of Adélie penguins in the 1995/96 season and obtained data on species composition, size frequency distribution and

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maturity stage composition of euphausiids. Previous studies on the diets of Adélie penguins have reported body length of euphausiids but rarely analyzed maturity stages. Furthermore, we used time-depth recorders to monitor the dive depth of penguins so that we could examine the relationship between the dive depth of penguins and food composition and body length of euphausiids.

Materials and methods

Electronic time-depth recorders (19 mm in diameter, 70 mm long, 36 g mass, KS-200DT, Little Leonard, Co. Ltd. Tokyo) were attached to the backs of Adélie penguins to monitor their diving behavior. The recorders were set to log the depth at 2 second intervals, with 0.1 m resolution. Maximum depth, dive duration and post-dive surface time were measured for each dive. As most of the study area was covered with fast sea-ice, penguins walked to their foraging zones, and we assumed that most dives were for foraging or searching. We examined the relationship between the dive depths and food composition and body length of euphausiids found in the stomach. For the dive depth, we took the mean of the dive depths of each penguin.

Penguins were captured when they returned from their foraging trips, and their stomach contents were collected by the stomach flushing method of Watanuki *et al.* (1994, 1999). This work was carried out from late December 1995 to late January 1996 at Hukuro Cove rookery, Lützow-Holm Bay near Syowa Station in Enderby Land, Antarctica. The body mass of the penguins was measured to 50 g with a pesola spring balance. The numbers of Adélie penguins from which stomach contents were sampled were 9 individuals which departed from the rookery on 28–29 December and returned on 29–30 December 1995, 20 individuals which departed on 6–7 January and returned on 6–8 January 1996, 8 individuals which departed on 16–17 January and returned on 17–19 January 1996, and 5 individuals whose departure dates are not known but returned on 31 January 1996. At the beginning of our study in late December 1995, Adélie penguins were brooding chicks, and in mid January chicks began to form crèches.

Stomach samples were drained with a set of sieves of 1 and 4 mm mesh size by squeezing gently by hand. Samples were washed with the sieves afterwards, and prey items remaining on the 4 mm mesh sieve were hand sorted. Each item was weighed to the nearest 0.1 g and preserved in formalin. In the land laboratory, euphausiids were identified into species, sexed, maturity stage was determined and body length was measured. Only two species, *Euphausia superba* Dana and *E. crystallorophias* Holt and Tattersal, occurred in the stomach samples. Maturity stages were determined according to the method of Reid *et al.* (1996) adapted for predator samples. There are 3 maturity stages for female euphausiids: sub-adult female (FS, corresponds to IIB of Makarov and Denys, 1981), non-sexually mature adult female (females without spermatophores) (FA1, corresponds to IIIA), and sexually active adult female (females with spermatophores) (FAS, corresponds to IIIB,C, IIID and IIIE). There are 2 maturity stages for males: sub-adult male (MS, corresponds to IIA) and adult male (MA, corresponds to IIIA and IIIB). Juveniles form a separate category. Body length was taken from the anterior tip of the rostrum to the distal end of the telson (Standard 1 of Mauchline, 1980).

Results

Food items identified in the stomachs of Adélie penguins were euphausiids, amphipods, and fish. As a whole, euphausiids were the most important food item occupying 73.3% of the total wet weight of stomach contents; fish comprised 26.6% and amphipods 0.1%. The percent contribution of amphipods decreased from 0.16% in late December to 0.06% or less from early January onward. No systematic change was found in other food items. Among euphausiids, *E. superba* comprised 82.9%, and *E. crystallorophias* 17.1%.

Size frequency distributions of *E. superba* in the stomach are shown for each 10-day period of the month in Fig. 1. The body length ranged from 26.5 mm to 56.6 mm, with mean body length of 38.9–41.8 mm. There was no apparent growth during the sampling period from late December to late January.

Females comprised 96% of the total number of *E. superba*. Males occupied only 4%. No juveniles of *E. superba* occurred in the stomachs (Fig. 1, Table 1). Sexually active adult females (FAS) occupied from 53–79% of total females whose maturity stages are known, with the lowest percentage in late January (Table 1). All the males were adult males (MA).

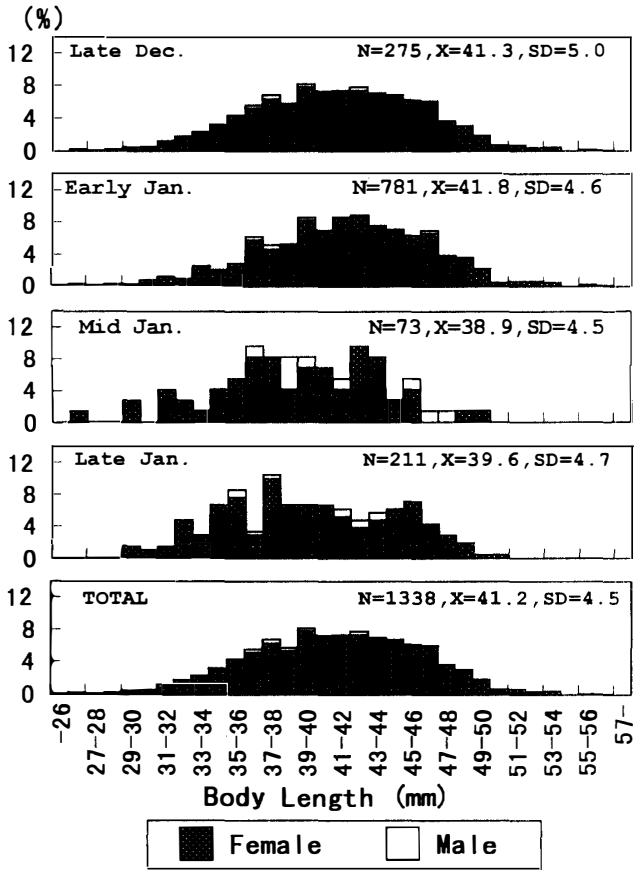

Fig. 1. Size frequency distributions of *Euphausia superba* in the stomachs of Adélie penguins in each 10-day period from late December 1995 to late January, 1996.

Table 1. Maturity stage composition of *Euphausia superba* in the stomachs of Adélie penguins in each 10-day period from late December 1995 to late January 1996. Percentages are in parentheses.

	Female				Male	Sex Unknown	Total
	FS	FA1	FAS	Unknown	MA		
Late Dec.	1 (0.3)	65 (21.7)	198 (66.0)	22 (7.3)	13 (4.4)	1 (0.3)	300
Early Jan.	6 (0.7)	149 (18.0)	591 (71.3)	54 (6.5)	26 (3.1)	3 (0.4)	829
Mid Jan.	5 (6.5)	15 (19.5)	50 (64.9)	0 (0.0)	7 (9.1)	0 (0.0)	77
Late Jan.	18 (8.3)	78 (36.1)	110 (50.9)	0 (0.0)	10 (4.7)	0 (0.0)	216
Total	30 (2.1)	307 (21.6)	949 (66.8)	76 (5.3)	56 (3.9)	4 (0.3)	1422

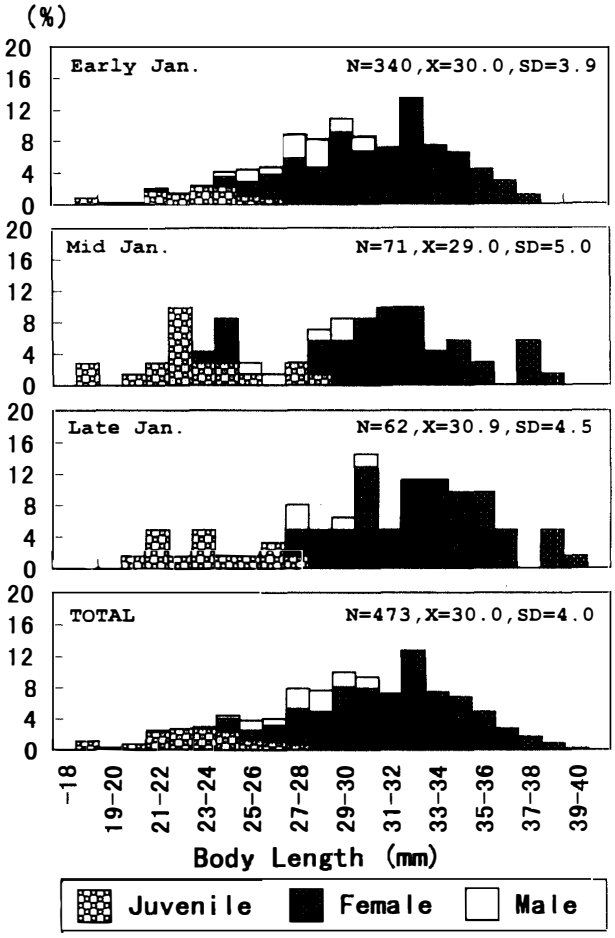

Fig. 2. Size frequency distributions of *Euphausia crystallorophias* in the stomachs of Adélie penguins in each 10-day period from early to late January 1996.

The body lengths of *E. crystallorophias* ranged from 18.4 mm to 39.6 mm, with mean body length of 29.0 mm to 30.9 mm (Fig. 2). Females comprised 73.4%, males 9.8% and juveniles 16.6% (Table 2). Females thus outnumbered males and juveniles in *E. crystallorophias* as well. The percentage of sexually active adult females (FAS) in *E. crystallorophias* was smaller, 0–27%, than that of *E. superba*. Adult males ranged

Table 2. Maturity stage composition of *Euphausia crystallorophias* in the stomachs of Adélie penguins in each 10-day period from early to late January 1996. Percentages are in parentheses.

	Juvenile	Female				Male		Sex Unknown	Total
		FS	FA1	FAS	Unknown	MS	MA		
Early Jan.	42 (13.3)	37 (11.7)	130 (41.1)	63 (20.0)	4 (1.3)	21 (6.6)	19 (6.0)	0 (0.0)	316 (70.7)
Mid Jan.	15 (25.9)	5 (8.6)	32 (55.2)	0 (0.0)	5 (8.6)	0 (0.0)	0 (0.0)	1 (1.7)	58 (13.0)
Late Jan.	17 (23.3)	8 (11.0)	41 (56.2)	3 (4.0)	0 (0.0)	3 (4.1)	1 (1.4)	0 (0.0)	73 (16.3)
Total	74 (16.6)	50 (11.2)	203 (45.4)	66 (14.7)	9 (2.0)	24 (5.4)	20 (4.5)	1 (0.2)	447 (100.0)

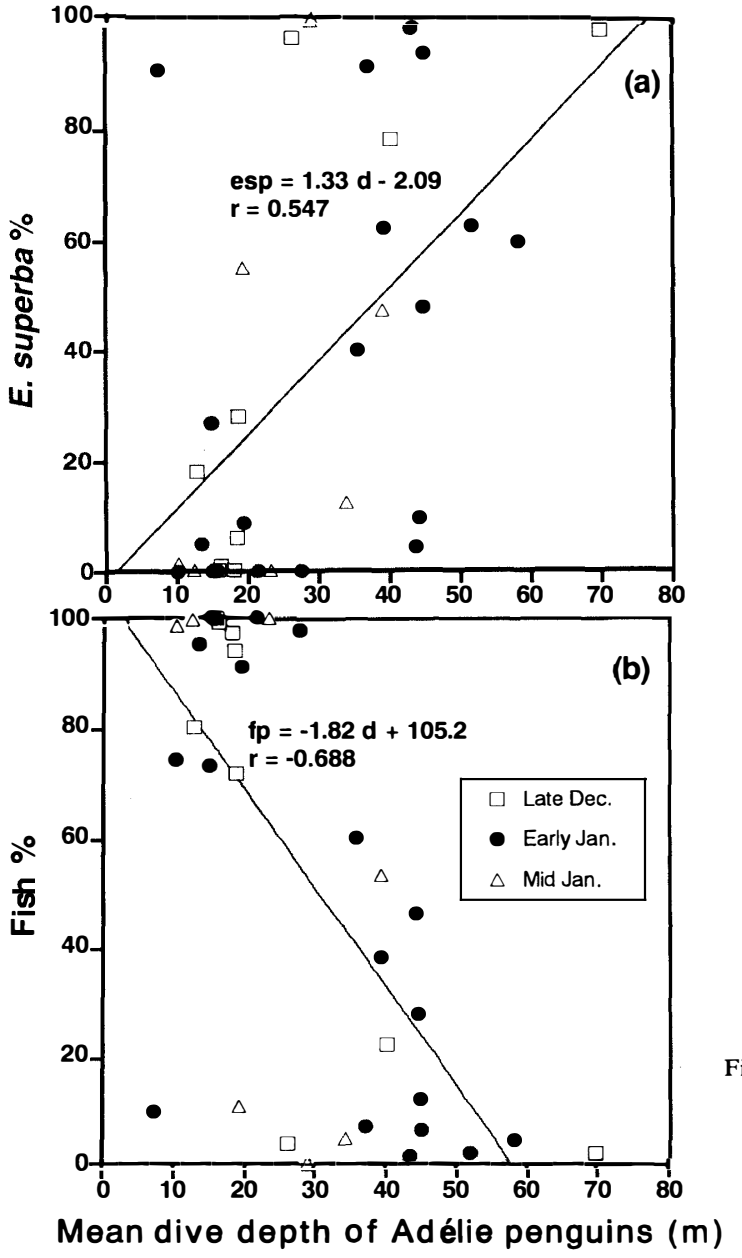

Fig. 3. The relationship between the mean dive depth (m) of Adélie penguins and *E. superba* percent (a) and fish percent (b) to the total wet weight of stomach contents.

from 25–48% of total males whose maturity stages are known.

To examine the relationship between the body weights of Adélie penguins and the body lengths of euphausiids in the stomachs, penguins which contained more than 30 measurable *E. superba* in the stomach were selected. No significant relationship was found between body weight of penguins and mean body length of *E. superba* ($r=0.146$, $n=10$, $P>0.05$). It was concluded that large and small penguins eat krill of similar size.

The mean dive depths of Adélie penguins were 26.1, 30.8 and 23.7 m in late December, early and mid January, respectively. A Mann-Whitney U-test showed that there was no significant difference between any pair of mean dive depths. There was a significant positive correlation between the mean dive depth and the percentage of *E. superba* in wet weight in the stomach contents ($r=0.547$, $n=37$, $P<0.01$, Fig. 3a), and a significant negative correlation between the dive depth and the percentage of fish ($r=-0.688$, $n=37$, $P<0.01$, Fig. 3b). Therefore, the deeper the penguins dive, the more they eat *E. superba* relative to fish.

Among Adélie penguins which contained more than 30 measurable *E. superba* in the stomach, there was a significant positive correlation between the mean dive depth of each penguin and the mean body length of *E. superba* in the stomach ($r=0.728$, $n=10$, $P<0.05$, Fig. 4). There was a tendency for the body length of *E. superba* in the stomach to be larger when Adélie penguin dived deeper not only over the whole survey period, but also in late December and early January (Fig. 4).

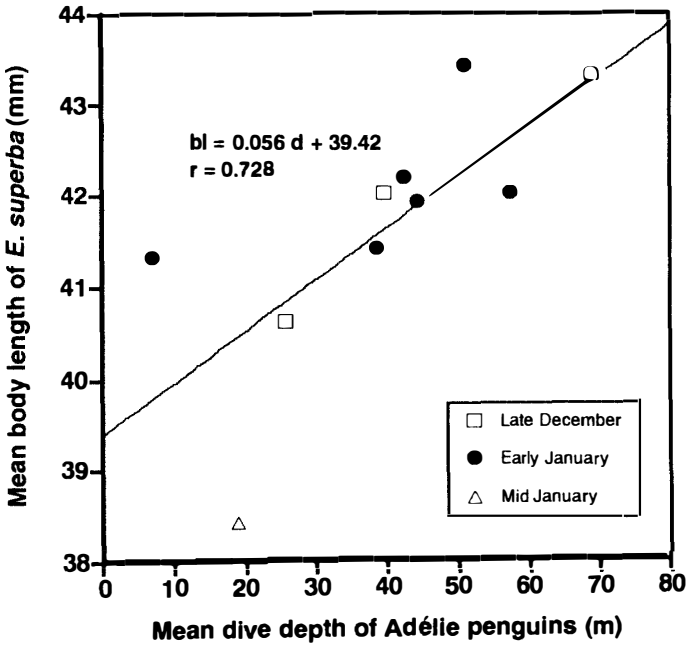

Fig. 4. The relationship between the mean dive depth (m) of Adélie penguins which contained 30 or more measurable *Euphausia superba* in the stomach and the mean body length (mm) of *Euphausia superba*.

Discussion

Food items identified in the stomachs of Adélie penguins were as reported previously, namely, euphausiids, amphipods and fish (see Volkman *et al.*, 1980). It has been reported that the relative importance of these three prey items varies with season or breeding phase. For instance, the relative importance of amphipods is high, 40–58% by weight, before hatching and low, 0.1–1.0%, after hatching at Davis station (Green and Johnstone, 1988; Puddicombe and Johnstone, 1988). At Hukuro Cove, euphausiids (mainly *E. superba*) are dominant in January in wet weight, and fish become dominant in February in some years (Watanuki *et al.*, 1994). In our study *E. superba* was the main food item with very small contribution of amphipods, which is consistent with the previous studies in the chick rearing phase. Our study confirmed the results of Watanuki *et al.* (1994) that Hukuro Cove is a unique area where Adélie penguins eat mainly *E. superba* on the continental shelf.

The mean body length of *E. superba* in the stomachs of Adélie penguins, 37.9–41.8 mm, was similar to that reported by Watanuki *et al.* (1994) at Hukuro Cove in 1990 and 1991. The size range was also similar to that found in stomachs of Adélie penguins at Davis Station (Green and Johnstone, 1988; Puddicombe and Johnstone, 1988), but larger than that from Signy Island, South Orkney Islands (Lishman, 1985) by 4–10 mm. There may be competition over euphausiids between Adélie penguins and Chinstrap penguins, the latter having longer culmen length so that they ate larger euphausiids near Signy Island, as suggested by Lishman (1985).

Since juveniles of *E. crystallorophias*, which is smaller than juveniles of *E. superba*, appeared in the stomach, juvenile *E. superba* does not seem to have occurred in the foraging area of Adélie penguin in this study. Females predominated in the stomach contents both in *E. superba* and *E. crystallorophias*, occupying 96% and 73% of all the individuals of each species, respectively. Sexually active adult females occupied 53–79 % of total females in *E. superba*. As we did not perform net sampling of euphausiids around Hukuro Cove, we do not know the exact sex ratio or maturity stage composition of both species in the sea area. It is likely, however, that Adélie penguins took nutritionally superior female euphausiids (Clarke, 1980, 1984) selectively and/or they could not catch male euphausiids because males can swim faster than females as hypothesized by Hill *et al.* (1996) for macaroni penguins *Eudyptes chrysolophus*.

Maturity of *E. crystallorophias* was generally lower than that of *E. superba*, with sexually active adult females occupying from 0–27% of total females. This is probably because the spawning period of *E. crystallorophias* is at least a month earlier than that of *E. superba* (Brinton and Townsend, 1991).

Radio transmitters were attached to the backs of other penguins than those examined for stomach contents to monitor the foraging location of each penguin (Watanuki *et al.*, 1999). They showed that the depth of the sea at the foraging site did not affect the maximum dive depth. In our study there was a tendency for penguins which dived deeper to take more *E. superba* than fish and to take larger *E. superba*. This suggests that fish were in shallower layers than *E. superba*, and smaller *E. superba* were in shallower layers than larger ones, in the water column.

The body length of *E. superba* did not show apparent growth during the survey

period, and the maturity stage regressed at the end of the survey period. The decline in mature stages could be related to the end of the spawning season. Adélie penguins may have taken larger *E. superba* selectively in the foraging area and reduced the number of larger individuals. Or Adélie penguins may not have taken the same population of *E. superba*, but different ones which entered the foraging area.

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