Proc. NIPR Symp. Polar Biol., 7, 82–90, 1994

WINTER GUT CONTENTS OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA* DANA) COLLECTED IN THE SOUTH GEORGIA AREA

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Abstract: Foregut contents of Antarctic krill *Euphausia superba* DANA which were collected in the South Georgia area in austral winter, July 12–August 4, 1992 were observed. A total of 130 individuals (adults: 78, subadults: 49, juveniles: 3) which were caught by krill trawling from various depths were examined in this study. The foregut contents of the krill consisted of various fragments of crustacean zooplankton in 77 individuals out of 130 examined. Among the fragments a portion of the pereiopods of krill was found from all specimens examined. Although the obtained materials were geographically confined to South Georgian waters, which were free from fast ice throughout the year, the results might imply that *E. superba* seemed to seasonally switch their food source: *E. superba* demonstrated herbivorous food habits during rich phytoplankton bloom, but might change to carnivorous habits in the fall and winter. Strong cannibalistic food habits during the austral winter as found in this study are considered to be important for the population dynamics of krill.

1. Introduction

In the Antarctic marine ecosystem Antarctic krill (*Euphausia superba* DANA) have been considered as the key species which links primary production to various predators during the austral summer when free-living large phytoplankton blooms, but they may change to feed on ice-algae during winter (MARSCHALL *et al.*, 1987; MARSCHALL, 1988). Food habits of Antarctic krill are considered to be essentially herbivorous in contrast to other euphausiid species (MAUCHLINE and FISHER, 1969; MILLER and HAMPTON, 1989). In austral fall and winter the daylight length ranges from constant darkness to only a few hours of dusk, and the phytoplankton growth decreases drastically (EL-SAYD, 1984). Then a herbivorous Antarctic krill must endure the next several months under the situation of extremely limited food supply. For better understanding of the ecology of Antarctic krill it is important to know more detailed feeding habits related to their overwintering mechanisms. Information about the general life pattern of Antarctic krill during austral fall and winter is extremely limited even at present.

This study aims at clarifying the food habits of Antarctic krill during winter by examining their foregut contents.

2. Materials and Methods

Specimens were collected at a total of 15 trawling stations during the by-catch investigations using a midwater trawl net in the krill fishery (Table 1). Mid-winter exploratory fishing was carried out by the Japanese Bottom-Fish Trawlers Association from July 9 to August 4, 1992. Waters in the vicinity of South Georgia and the sea area to the north were surveyed by the Chiyô Maru No. 5 of Taiyô Fisheries Company (Fig. 1). The sea depths at sampling stations were about between 200 and 300 m. Collected specimens were preserved in 10% formalin. At the stations where *E. superba* were collected, about 500 m*l* of surface seawater was also collected from the ship's bottom level and preserved in 5% formalin.

Table 1. List of stations where the krill were collected from July 15 to August 4, 1992.

Local time of sampling	July 15	July 21	July 28	August 4
Nighttime	863	—	—	—
Morning	866	921	982	—
Daytime	867	923	984	1061
Evening	870	926	987	1064

Nighttime : 0600 – 0700 Morning : 1230 – 1330
Daytime : 1600 – 1700 Evening : 2200 – 2300

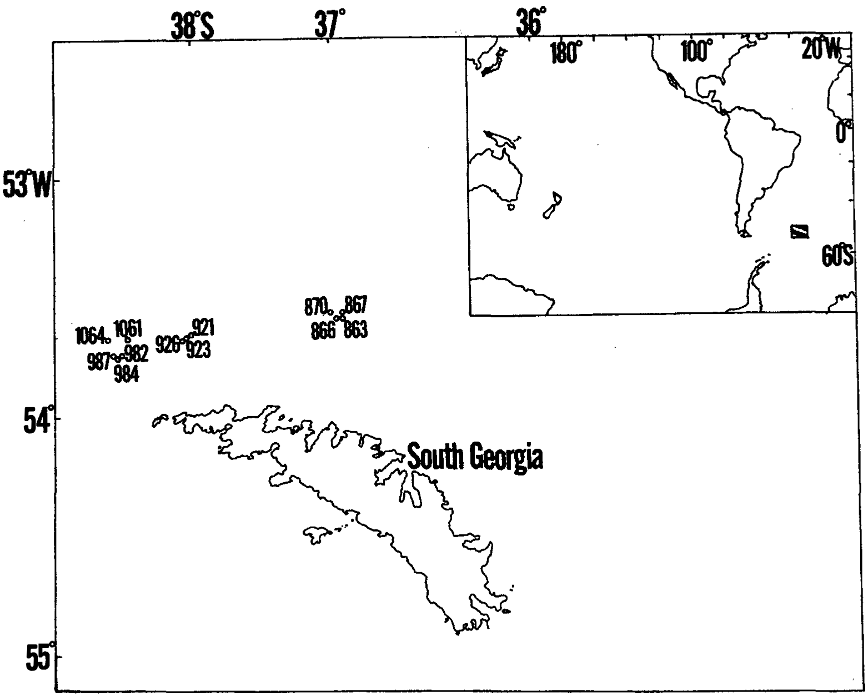

Fig. 1. Locations of sampling stations occupied during mid-winter krill fishing by Chiyô Maru No.5 of Taiyô Fisheries Company July 12–August 4, 1992.

The foregut was dissected out on a slideglass and fullness of the foregut was scored into four categories (0: empty, +:some, ++: moderate, +++: full) under a stereoscopic microscope. Then those were loosened by using a needle for inverted microscopic observations. The degree of cannibalism was scored into four grades (nil, some, moderate, much) under an inverted microscope. Fullness of the foregut and the degree of cannibalism were independent of each other. Among 130 individuals examined 78 were adults, 49 were subadults and 3 were juveniles.

3. Results

Seventy-seven specimens out of 130 were found to contain zooplankton appendages of varying sizes. Among these fragments, a portion of the pereiopods

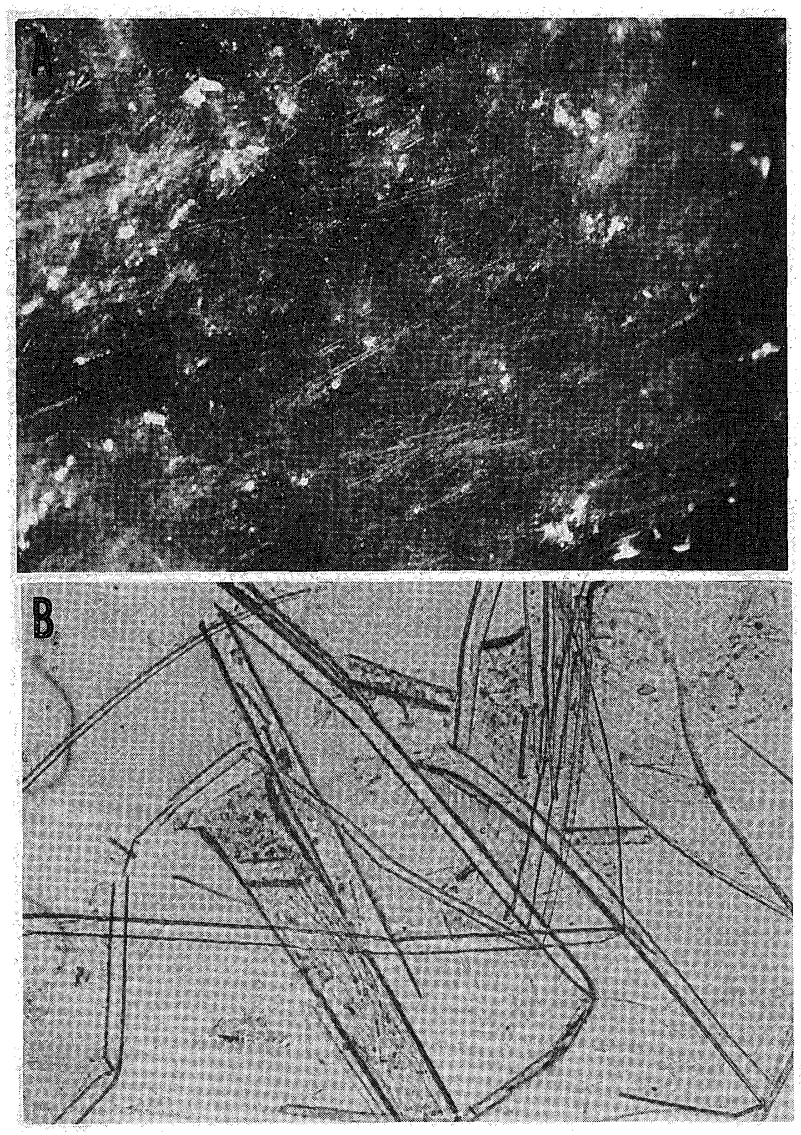

Fig. 2. Micrograph showing (A) a foregut filled with pereiopods (×10) and (B) a magnified photograph (×200). Specimens collected at St. 863, on July 15, 1992.

of *E. superba* was identified from almost all foreguts (Fig. 2). Other parts of the body such as carapace, antenna and ganglion, and even exuvia were often found in the foregut of *E. superba* (Fig. 3). Very few examples contained fragments of copepods (Fig. 3).

The foregut fullness and the degree of cannibalism were given for each sampling station in Tables 2 and 3, respectively. No diurnal change in the foregut fullness was found over the sampling hours. The degree of cannibalism showed a local trend, becoming higher at the station groups occupied of July 15 than other stations. There were few specimens showing cannibalism at the stations sampled on August 4.

From a total of 130 foreguts examined, the following organisms were found: diatoms (7 genera, 12 species), dinoflagellates (5 genera, 5 species), silicoflagellates (1 genus, 1 species), unidentified foraminifera and radiolarians, tintin-

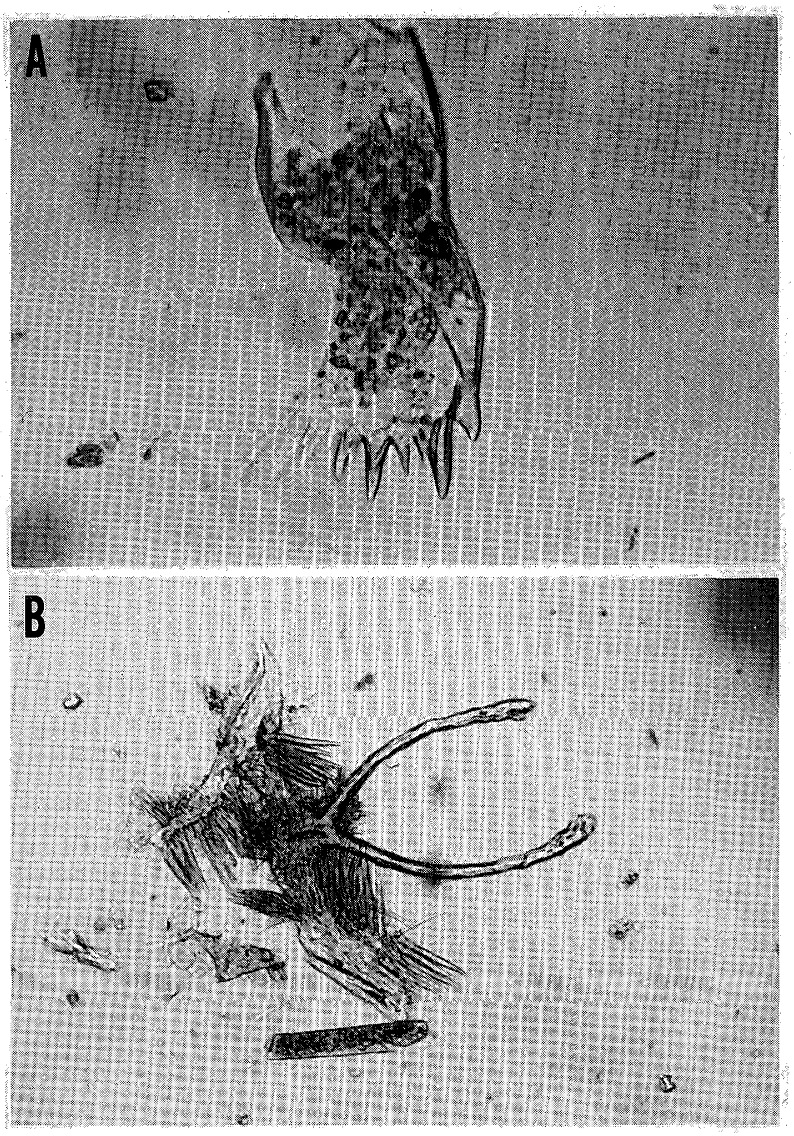

Fig. 3. Micrograph showing (A) a masticatory edge of the mandible of carnivorous copepods (×400) and (B) a ganglion of crustacean zooplankton (×200). Specimens collected at St. 863, on July 15, 1992.

Table 2. Change in foregut fullness of E. superba.

	July 15				July 21			July 28			August 4	
	863	866	867	870	921	923	926	982	984	987	1061	1064
Fullness	N	M	D	E	M	D	E	M	D	E	D	E
	n=12	*n*=12	*n*=15	*n*=12	*n*=10	*n*=10	*n*=10	*n*=6	*n*=11	*n*=12	*n*=10	*n*=10
Empty	16.7%	25.0	37.5	50.0	40.0	60.0	40.0	33.3	36.4	50.0	50.0	30.0
+	33.3	16.7	37.5	33.3	30.0	30.0	20.0	33.3	36.4	25.0	20.0	40.0
++	25.0	33.3	12.5	8.3	10.0	10.0	30.0	0.0	0.0	25.0	20.0	20.0
Full	25.0	25.0	12.5	8.3	20.0	0.0	10.0	33.3	27.3	0.0	10.0	10.0

+ : some ; ++ : moderate
N : Nighttime ; M : Morning ; D : Daytime ; E : Evening

Table 3. Change in degree of cannibalism of E. superba.

	July 15				July 21			July 28			August 4	
	863	866	867	870	921	923	926	982	984	987	1061	1064
Degree	N	M	D	E	M	D	E	M	D	E	D	E
	n=12	*n*=12	*n*=15	*n*=12	*n*=10	*n*=10	*n*=10	*n*=6	*n*=11	*n*=12	*n*=10	*n*=10
nil	16.7%	33.3	37.5	50.0	40.0	60.0	40.0	33.3	36.4	50.0	50.0	40.0
+	25.0	16.7	37.5	25.0	30.0	30.0	40.0	33.3	27.3	16.7	40.0	60.0
++	25.0	8.3	12.5	8.3	10.0	10.0	10.0	16.7	9.1	25.0	0.0	0.0
+++	33.3	41.7	12.5	16.7	20.0	0.0	10.0	16.7	27.3	8.3	10.0	0.0

+ : some ; ++ : moderate ; +++ : much
N : Nighttime ; M : Morning ; D : Daytime ; E : Evening

nids (3 genera) and naked ciliates (3 genera) (Table 4). Of these, foraminifera were sometimes found but radiolarians were scarcely found. Microzooplankton such as naked ciliates and tintinnids were less frequent and rarely found, possibly due to the use of formalin for preservation.

When examining the foregut contents of *E. superba* which were collected in the waters around the South Shetland Islands in summer (NISHINO, 1992 unpubl. data), cannibalism could not be found and the amount and composition of phytoplankton found in the foregut contents were far more than this result.

In this study most of the microplankton cells found from the foregut were diatoms with few dinoflagellates. Among the diatoms, *Nitzschia kerguelensis* was the most dominant species throughout the present study. The changes in the number of diatom cells found from the foregut contents showed considerable day-to-day and location-to-location variations (Table 5).

The microplankton in the surface seawater was represented largely by diatoms. But *N. kerguelensis*, which was found frequently in the foregut contents, did not predominate in the surface seawater. Naked ciliates and tintinnids were few. The number of diatom cells in the surface seawater showed frequent changes on daily and local bases, with an extreme range of 88.3 to 2423.1 (cells/*l*) (Table 6). For example, the number of diatoms collected on the morning

Table 4. List of microplankton species found from the foregut of E. superba.

Diatoms		
Centrales		
Corethron criophilum	*Coscinodiscus* spp.	*Rhizosolenia alata*
Rhizosolenia setigera	*Rhizosolenia* spp.	*Streptotheca* spp.
Thalassiosira antarctica	*Thalassiosira gracilis*	
Pennales		
Cocconeis sp.	*Nitzschia angulata*	*Nitzschia cylindrus*
Nitzschia kerguelensis	*Nitzschia lecointei*	*Nitzschia pseudonana*
Nitzschia sublineata	*Nitzschia seliata*	
Dinoflagellates		
Ceratium sp.	*Dinophysis* sp.	*Gymnodinium* sp.
Phalacroma sp.	*Warnowia* sp.	
Silicoflagellates		
Distephanus speculum		
Foraminifera		
Unidentified species		
Radiolarians		
Unidentified species		
Tintinnids		
Codonellopsis spp.	*Cymatocylis* spp.	*Tintinopsis* spp.
Naked ciliates		
Didinium spp.	*Strobilidium* spp.	*Tiarina* sp.

Table 5. Change in the average number of diatom cells in the foregut of E. superba *(cells/individual).*

Sampling time	July 15	July 21	July 28	August 4
Nighttime	230.0 (*n*=10)	—	—	—
Morning	275.6 (*n*=9)	246.7 (*n*=6)	27.5 (*n*=4)	—
Daytime	159.0 (*n*=10)	137.5 (*n*=4)	82.9 (*n*=7)	210.0 (*n*=5)
Evening	93.3 (*n*=6)	131.7 (*n*=6)	46.7 (*n*=6)	637.1 (*n*=7)
Average	189.5	171.9	52.3	423.6

Table 6. Change in the number of diatom cells in surface seawater (cells/l).

Sampling time	July 15	July 21	July 28	August 4
Nighttime	2423.1	—	—	—
Morning	484.9	189.7	102.0	—
Daytime	655.4	502.7	383.3	828.8
Evening	921.0	476.2	88.3	360.4
Average	921.0	389.5	191.2	594.6

of July 15 was about five times as many as that in the daytime. The relation between the foregut contents and seawater samples as to the composition and number of phytoplankton was not resolved in this study. We think the reason may be the difference in the composition of phytoplankton between surface seawater and feeding layer or selective feeding by krill.

4. Discussion

Several wintering-over mechanisms for *E. superba* have been proposed. QUETIN and ROSS (1991) suggested the following mechanisms: 1) shrinkage, 2) lipid utilization, 3) change of food sources, 4) "Hibernation" and 5) Ice-algae. Of these shrinkage, change of food sources and ice-algae have been the subjects of greater attention. An adult *E. superba* survived for over 211 days without food in the laboratory (IKEDA and DIXON, 1982), suggesting that *E. superba* could use their own body lipids and proteins when starved. Shrinkage in total length is also a strategy to reduce metabolic rates. From this experiment, IKEDA and DIXON (1982) considered that *E. superba* could easily survive during winter without eating. BOYD *et al.* (1984) mentioned that *E. superba* might be able to feed on copepods that had laid down lipid reserves sufficient for the winter. KAWAGUCHI *et al.* (1986) have suggested that in Lützow-Holm Bay *E. superba* change habitat from the pelagic zone in summer to the benthopelagic zone in the dark winter period, and ingest detritus as a food source. Using a high-speed macro-photo-registration technique, KILS (1983) has indicated that *E. superba* is not limited to a single mode of feeding but employs a variety of highly efficient feeding mechanisms. Depending on several factors such as quality and quantity of food, size of *E. superba* and , probably, activity level of the animal, different feeding methods are probably employed. Recent diving observations indicate that *E. superba* may live in the cryopelagic zone (O'BRIEN, 1987). Direct *in situ* observations using a Remotely Operated Vehicle showed that the krill can survive on the ice-bottom as well as in the water column. The results of underwater observations suggest that *E. superba* feed heavily on ice-algae (MARSCHALL *et al.*, 1987; O'BRIEN, 1987; MARSCHALL, 1988; STRETCH *et al.*, 1988).

HIROTA (1984) suggested that euphausiids fed in the plankton net after capture (net feeding), and mentioned that on collecting samples to examine the stomach contents of euphausiids, care should be taken to consider the possibility of net feeding. Though we cannot rule out the possibility of net feeding in this study, the cannibalism seem to have been take place before capture since appendages of zooplankton, probably *E. superba*, have been frequently found from the hindguts.

It is noted that the results obtained in this study are based on specimens from the first-ice-free South Georgian waters. It can be suggested however that *E. superba* seem to switch their feeding targets during winter, when their food habits change from phytoplankton to zooplankton including their own population (cannibalism). There have been some examples in feeding experiments in which *E. superba* ingested zooplankton (BOYD *et al.*, 1984; PRICE and BOYD, 1988), and cannibalism has often been observed during rearing experiments. The results of the present study demonstrated cannibalistic feeding of *E. superba* in a natural habitat. If *E. superba* survive on cannibalism during winter, this food habit must be considered important for the population dynamics of krill.

The number of diatom cells in the surface seawater varied from time to time, but was found to not be related to the degree of cannibalism. Our results suggest that *E. superba* may depend on cannibalism as one of their winter-over mechanisms. The density of diatoms in the surface water observed in this study may indicate a threshold density level at which krill switch from herbivorous to carnivorous feeding.

Acknowledgments

We wish to thank Dr. M. NAGANOBU of National Research Institute of Far Seas Fisheries for his helpful arrangements in obtaining materials. Mr. M. MOTEGI of Tokyo University of Fisheries kindly collected the samples on board the CHIYÔ MARU No. 5 of Taiyô Fisheries Company. Thanks are also due to Dr. H. SEKIGUCHI of Mie University for his valuable suggestions and information.

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(*Received May 18, 1993; Revised manuscript received August 2, 1993*)