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BIOMASS AND POPULATION STRUCTURE OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA* DANA) COLLECTED DURING SIBEX II CRUISE OF R. V. KAIYO MARU

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Abstract: Juvenile and adult *Euphausia superba* were collected in the northwest of the Antarctic Peninsula, eastern Drake Passage, and the Scotia and Weddell Seas during the SIBEX II cruise of R. V. KAIYO MARU.

Average biomass estimated from blind tows was 145 g/1000 m³ (838 g/1000 m³, if aimed tows were included). The biomass was especially abundant along the Antarctic Peninsula, in the east of Elephant Island and west and southeast of South Sandwich Islands. *E. superba* wet weight represented 88% of total wet weight from blind tows (99%, if aimed tows were included).

Copulated females and males with developed spermatophores were numerous along the Antarctic Peninsula and in the west of South Sandwich Islands. Copulated females were rather abundant off Queen Maud Land, although male maturity was not high. Juveniles were almost absent in the northwest of the Antarctic Peninsula and in eastern Drake Passage; in number they were dominant in the west and southeast of South Sandwich Islands.

1. Introduction

Many reports have been published on biomass, distribution and population structure of Antarctic krill, *Euphausia superba* DANA through the international BIOMASS programs (*e.g.* HAMPTON, 1983; BRINTON and ANTEZANA, 1984; QUETIN and ROSS, 1984; MILLER, 1986).

Acoustic technique has been commonly used for estimating biomass of the Antarctic krill in recent years although net sampling (*e.g.* GULLAND, 1970), visual estimate (MARR, 1962) and stomach content analysis of whales (MACKINTOSH, 1974) have also been used. Individual methods, however, are suitable for only part of the population and have led to very different results (EVERSON, 1977). Recent estimates from the FIBEX acoustic data are fairly low in comparison with the levels inferred from predation estimates (ANONYMOUS, 1986).

We do not have a clear picture on the population structure of the krill over their whole distributional range, because any survey is restricted to certain areas and times. Recently, the possibility was suggested that industrial krill fishery may alter local population structure as well as biomass (BRINTON and ANTEZANA, 1984; HEYWOOD *et al.*, 1985). Surveys on the population structure are urgent over the whole distributional range of the krill in order to know their life history, which must be indispensable for sound exploitation of the krill. In this paper, the krill biomass estimated by means of KAIYO MARU Midwater Trawl (KYMT) and the krill's population structure during the SIBEX II cruise of R.V. KAIYO MARU are shown.

2. Materials and Methods

Juvenile and adult *E. superba* were collected by means of three kinds of nets, KYMT, ORI-200 net and ORI-300 net, during the SIBEX II cruise of R.V. KAIYO MARU, 9 October 1984–10 March 1985. For the outline of the cruise see SUISANCHÔ (1986). KYMT has the largest mouth area (9 m^2) and the coarsest mesh size (3.4 mm) among the gear employed, and was used most frequently for collecting juvenile and adult krill. Results of KYMT samples, therefore, are presented in this paper. KYMT is a rectangular frame trawl and was towed obliquely from *ca.* 100 m to the surface at fixed stations (blind tow). When a krill swarm was detected on the echogram, KYMT was towed horizontally at the depth of the swarm (aimed tow). A flowmeter was mounted at the mouth of the net to estimate the volume of water filtered.

Specimens of *ca.* 30 mm or more in length were sexed because smaller specimens rarely show secondary sexual characteristics. Usually 100 specimens each were measured for juvenile, female and male. Body length was taken from the anterior end of the eye to the posterior end of telson to the nearest mm.

The maturity state of each krill was determined according to the following system (MAKAROV and DENYS, 1980):

Juveniles:		secondary sexual characteristics not visible
Males	IIA:	developing petasma visible
	IIIA:	petasma fully developed but without fully formed spermatophores
	IIIB:	fully formed spermatophores present
Females	IIB:	developing thelycum present
	IIIA:	thelycum fully developed but no spermatophores attached
	IIIB, C:	spermatophores present, carapace not swollen
	IIID:	spermatophores present, carapace swollen
	IIIE:	spermatophores present, carapace with hollow space owing to recent spawning.

3. Results

Biomass of the krill was high along the Antarctic Peninsula and in the east of Elephant Island in Leg I (27 November–17 December 1984, Fig. 1). Maximum values were 1260 g/1000 m^3 (Stn. 48) and 4260 g/1000 m^3 (Stn. 51) for blind and aimed tows, respectively. Surface chlorophyll *a* was also high in these areas of high krill abundance, more than 1.0 $\mu g/l$ with the highest value of 5.29 $\mu g/l$ at Stn. 39 (SUISANCHÔ, 1986).

In Leg II (3–28 January 1985), high biomass of the krill was found throughout the survey area south of the Antarctic Polar Front (APF) but especially high in the area west and southeast of South Sandwich Islands (Fig. 2). Maximum values were 1233 g/1000 m^3 (Stn. 110) and 28019 g/1000 m^3 (Stn. 112) for blind and aimed tows, respectively. Surface chlorophyll *a* was higher near South Sandwich Islands than at southern stations in Leg II, mostly from 0.5 to 1.0 $\mu g/l$. At the stations east of 10°E, values more than

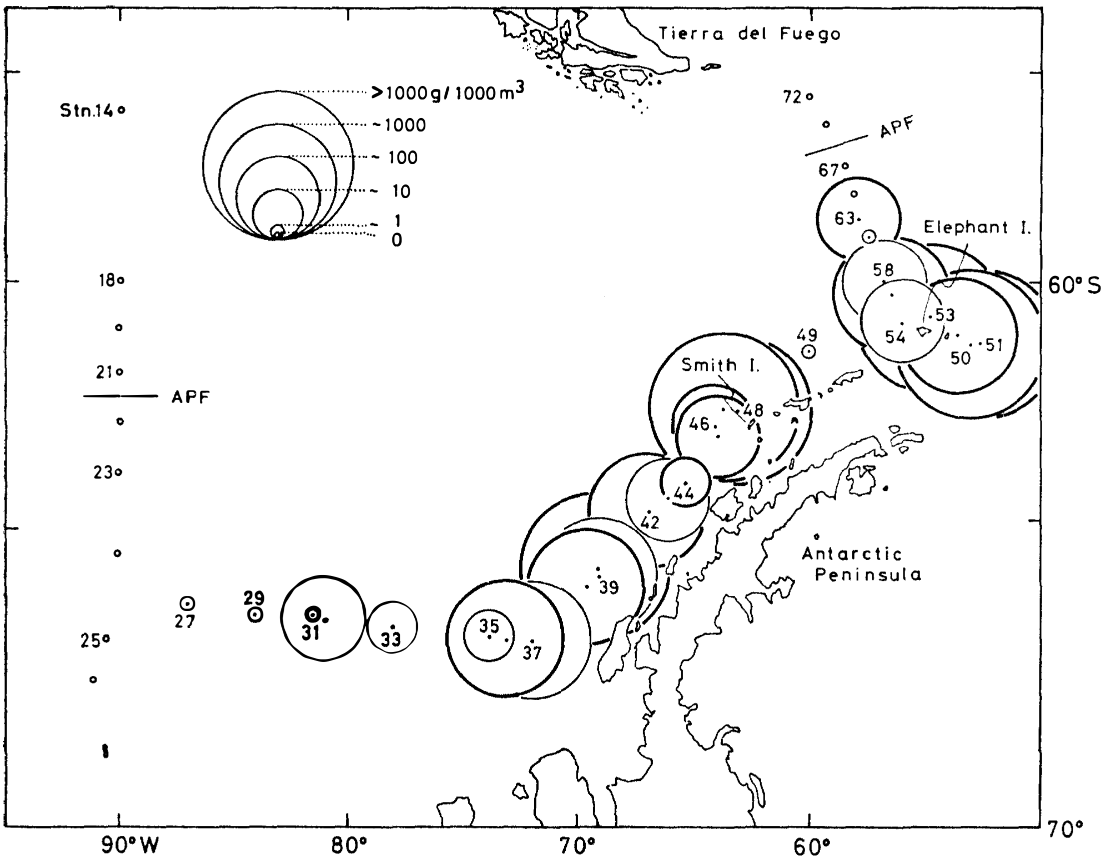

Fig. 1. Station positions and biomass (wet weight) of the krill in Leg I (27 November–17 December 1984). Thick and thin circles indicate aimed and blind tows, respectively.

1.0μg/l were observed (SUISANCHÔ, 1986).

Average biomass of the krill south of APF in Leg II was double that in Leg I; 85g/1000m^3 for Leg I and 193g/1000m^3 for Leg II, when estimated from blind tows (Table 1). These values are one order of magnitude higher than those of other workers; two order of magnitude higher than that estimated using the same trawl in the Indian Sector (SUISANCHÔ, 1980).

However, densities within swarms estimated from aimed tows were not high in this study. Although these values are comparable to that obtained by BRINTON and ANTEZANA (1984), they are one order of magnitude lower than those of NAST (1982) and SUISANCHÔ (1983) and two order of magnitude lower than those of NEMOTO (1983), DOI and KAWAKAMI (1979) and TERAZAKI and WADA (1986).

If aimed and blind tows were combined, average biomass of the krill would be 425 and 1108g/1000m^3 for Legs I and II, respectively.

On the average, the krill wet weight in blind tows represented 78 and 96% of total zooplankton wet weight in the area south of APF in Legs I and II, respectively. If aimed tows were combined, these values would be 96 and 99%, respectively.

Juveniles were rare at Leg I stations (Fig. 3). They appeared at only three stations, Stns. 32, 42 and 63, and represented 0.6, 2.9 and 3.0% in number, respectively. Male percentage in adult population ranged from 11.9% (Stn. 48) to 64.8% (Stn. 37) with the

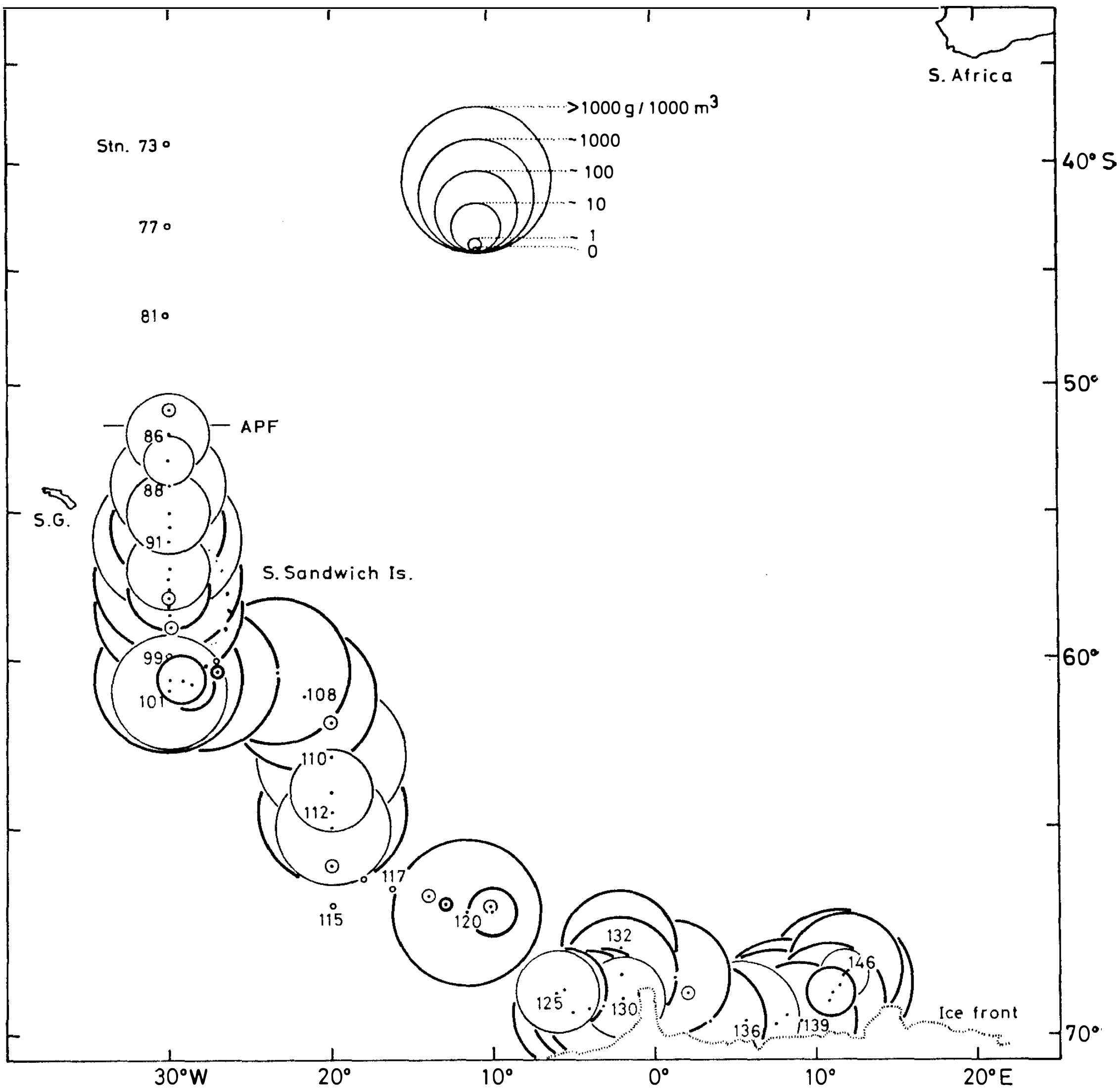

Fig. 2. Station positions and biomass (wet weight) of the krill in Leg II (3–28 January 1985). Thick and thin circles as in Fig. 1.

average of 39.9%, which was weighted by individual number. Females were predominant in the area along the Antarctic Peninsula and northeast of Elephant Island. In contrast with Leg I, juveniles were popular, often predominant at Leg II stations (Fig. 4). Juveniles occupied 45.5% of Leg II populations, on the average. They were especially abundant in the west and southeast of South Sandwich Islands. Male percentage in adult population in Leg II ranged from 22.6 to 90.8% with the weighted average of 53.3%. Males were abundant just south of APF, around Stns. 120 and 122 and at stations east of 10°E.

Mean body length increased eastward until Smith Island in Leg I (63°W, Fig. 5). The largest mean body length of females was 52.7 mm (Stn. 47) and of males 51.5 mm (Stn. 46). Individuals larger than 47 mm dominated in this area (Fig. 6). No juveniles smaller than 25 mm, however, occurred at Leg I stations. Mean body length decreased to 42–43 mm in the east of Elephant Island, where the population was mono-modal with

Table 1. Average biomass of krill (g/1000 m^3, wet weight) estimated by net sampling.

Author	Blind tow	Aimed tow	Net: mouth area	Area
Doi and Kawakami (1979)		100000	Commercial trawl: ?	Australian Sector
Suisanchô (1980)		332	KOC-A: 9 m^2	Indian Sector
	18		ORI-100: 2 m^2	
	6	485	KYMT: 9 m^2	
Nast (1982)	14	10726	RMT: 8 m^2	Scotia and Weddell Seas
Nemoto (1983)		150000	Trawl: 15 m^2	Indian Sector
Suisanchô (1983)		14490	KOC-A: 9 m^2	Indian Sector
Brinton and Antezana (1984)	26	1260	Bongo net: 0.4 m^2	Scotia Sea and Bransfield Strait
Siegel (1985)	25		RMT: 8 m^2	Bransfield Strait
This study Leg I	85	765	KYMT: 9 m^2	Antarctic Pen. and E. Drake Passage
Leg II	193	1795	KYMT: 9 m^2	Scotia and Weddell Seas

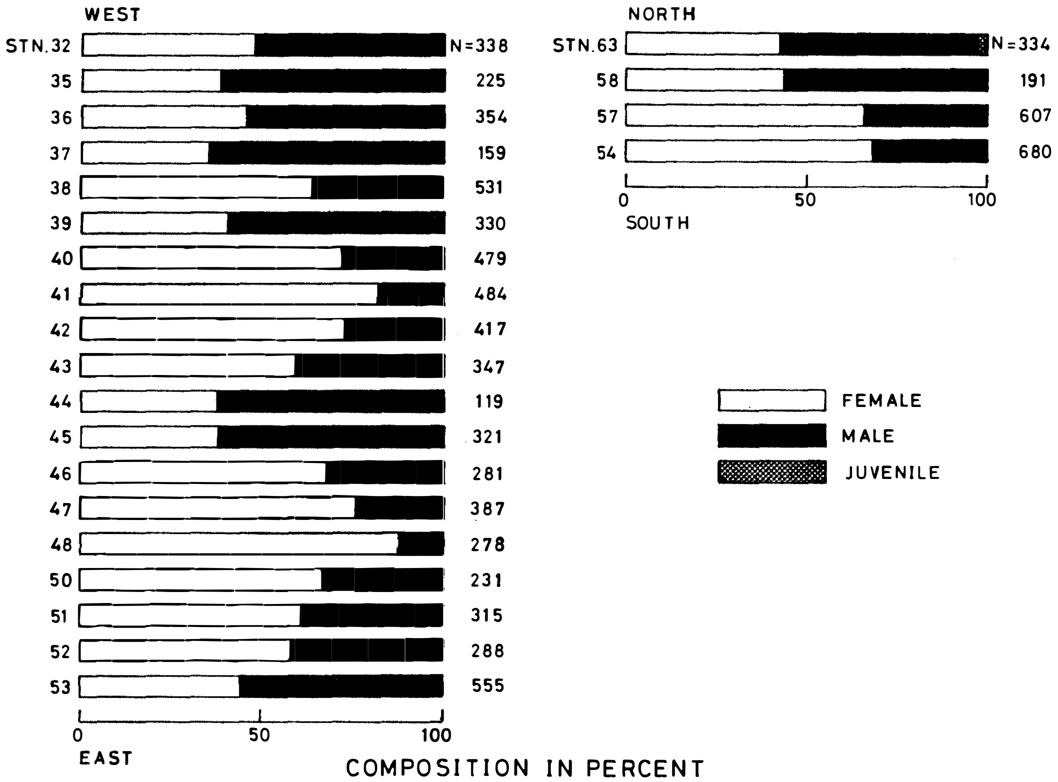

Fig. 3. Percentage composition in number of juveniles, females and males at each station in Leg I (27 November–17 December 1984).

a mode at 44–45 mm. In other areas, however, size-frequency histograms were more complex (Fig. 6). Mean body lengths for eastern Drake Passage were intermediate (from 42.4 to 48.3 mm).

At stations west of South Sandwich Islands and at northern stations, females were large, with mean body length exceeding 55 mm except Stns. 88 and 91 (Fig. 7). In contrast, males were not so large, as much as 8 mm smaller than females (Stns. 86 and

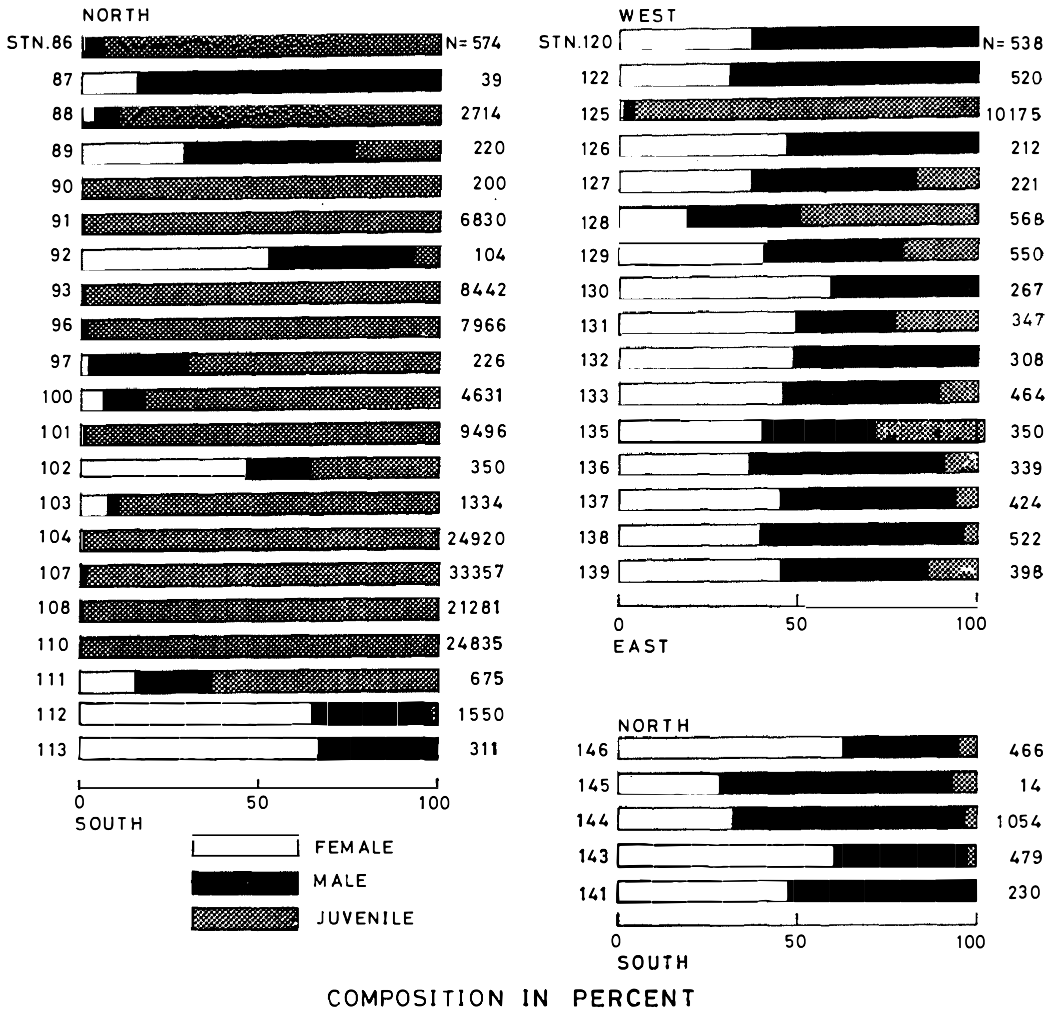

Fig. 4. Percentage composition in number of juveniles, females and males at each station in Leg II (3–28 January 1985).

93). The largest mean body length was found at stations west of South Sandwich Islands, 57.7 mm for females and 53.8 mm for males at Stn. 95. Largest individuals were 61 mm (2.5 g) for females at Stn. 92 and 60 mm (2.3 g) for males at Stn. 89. Adults larger than 50 mm were rare in the area southeast of South Sandwich Islands in contrast to the western area. Instead, 35–45 mm animals were dominant (Fig. 6). Mean body length decreased southward. The smallest mean body length was found at Stn. 110; 38.5 mm for females and 34.1 mm for males. Individuals off Queen Maud Land (Stns. 117–139) are small, mostly around 42 mm or smaller. At stations east of 10°E they became a little larger. These populations consist of juveniles, 20–30 mm, and adults, 35–45 mm. The latter was more numerous.

Percentage of copulated females (IIIB, C and IIID; IIIE did not occur) and that of males with fully formed spermatophores (IIIB) are shown in Figs. 5 and 7. High percentage of copulated females was found along the Antarctic Peninsula, although males with fully formed spermatophores were not necessarily abundant. Adult populations in the west of South Sandwich Islands were sexually mature; very high percentage of

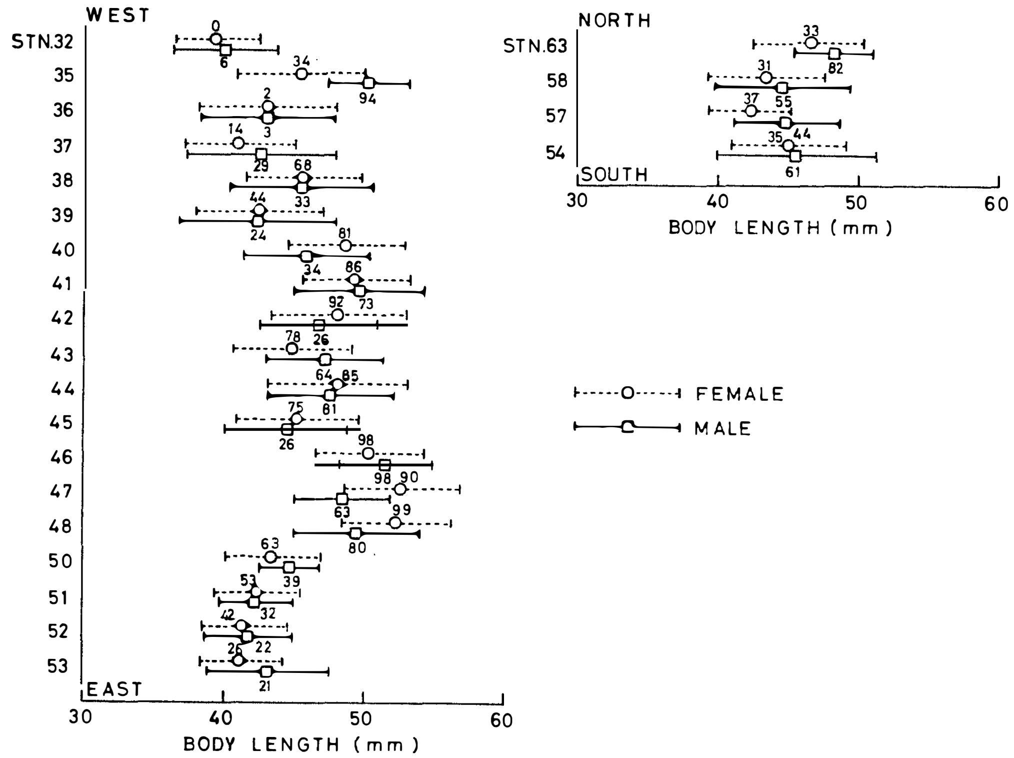

Fig. 5. Mean body length and its standard deviation of the krill at each station in Leg I (27 November–17 December 1984). Figures indicate percentages of copulated females (above the female bars) and of males with fully formed spermatophores (below the male bars).

copulated females, and relatively high percentage of IIIB males (Fig. 7). Fairly high percentages, up to 93% at Stn. 141, of copulated females were found east of 10°E off Queen Maud Land. In contrast to females, males with fully formed spermatophores were rare except for Stn. 143, where 67% of males had developed spermatophores. At Stns. 117–139 maturity was low.

4. Discussion

The krill biomass estimated from blind tows was 85 and 193 g/1000 m^3 for Legs I and II, respectively. The overall average was 145 g/1000 m^3. When aimed and blind tows are combined the krill densities would be 425 and 1108 g/1000 m^3 for Legs I and II, respectively (838 g/1000 m^3, overall average). Mean density estimated by the FIBEX acoustic survey was 11000 g/1000 m^2, or 110 g/1000 m^3 assuming 100 m for the depth range of the species, for the West Atlantic Sector (HAMPTON, 1983). This value is closer to our estimate from blind tows but is one order of magnitude lower than that including aimed tows.

Our estimate of the krill biomass from blind tows is one order of magnitude higher than those of other workers who used net sampling for the Atlantic Sector (Table 1). This may partly because KYMT was towed from *ca.* 100 m depth, while other workers towed from 200 m depth. It is estimated that over 80% of the krill in 200 m water column

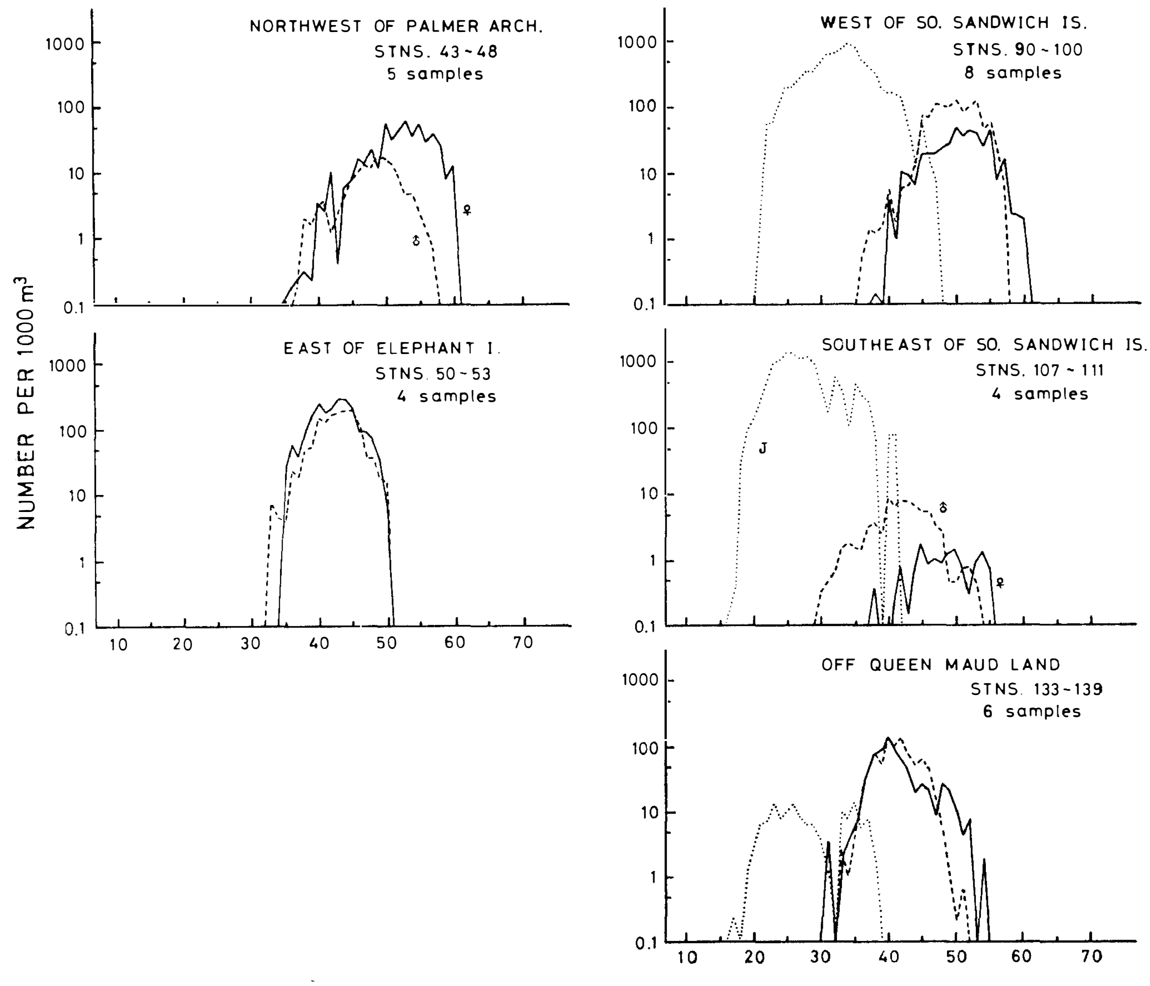

Fig. 6. Mean size-frequency distributions of the krill in five regions.

was in the upper 100 m by a scientific echo integrator during this study (SUISANCHÔ, 1986). So KYMT must have been towed at the main distributional depth of the krill in our study area. On the other hand, other workers towed nets from 200 m depth, which may lead to an underestimation of the krill biomass. A low value reported by TERAZAKI and WADA (1986) was probably attributable also to the deeper depth from which IKMT was towed, *ca.* 1000 m.

As for the densities within swarms estimated from aimed tows, our estimate is within the range of the previously reported values (Table 1). Though it is not known whether it is characteristic to these areas, high values over 100000 g/1000 m^3 were reported in the Indian and Australian Sectors.

EVERSON (1977) considers that the krill may constitute as much as 50% of the herbivorous zooplankton in biomass in the Antarctic Ocean. The contribution of the krill to the total zooplankton wet weight is very high in this study; 87.5% when the results of blind tows are used and 98.8% when aimed tows are included. These high values might be attributable to the coarser mesh of the KYMT, 3.4mm, resulting in underestimation of smaller zooplankton.

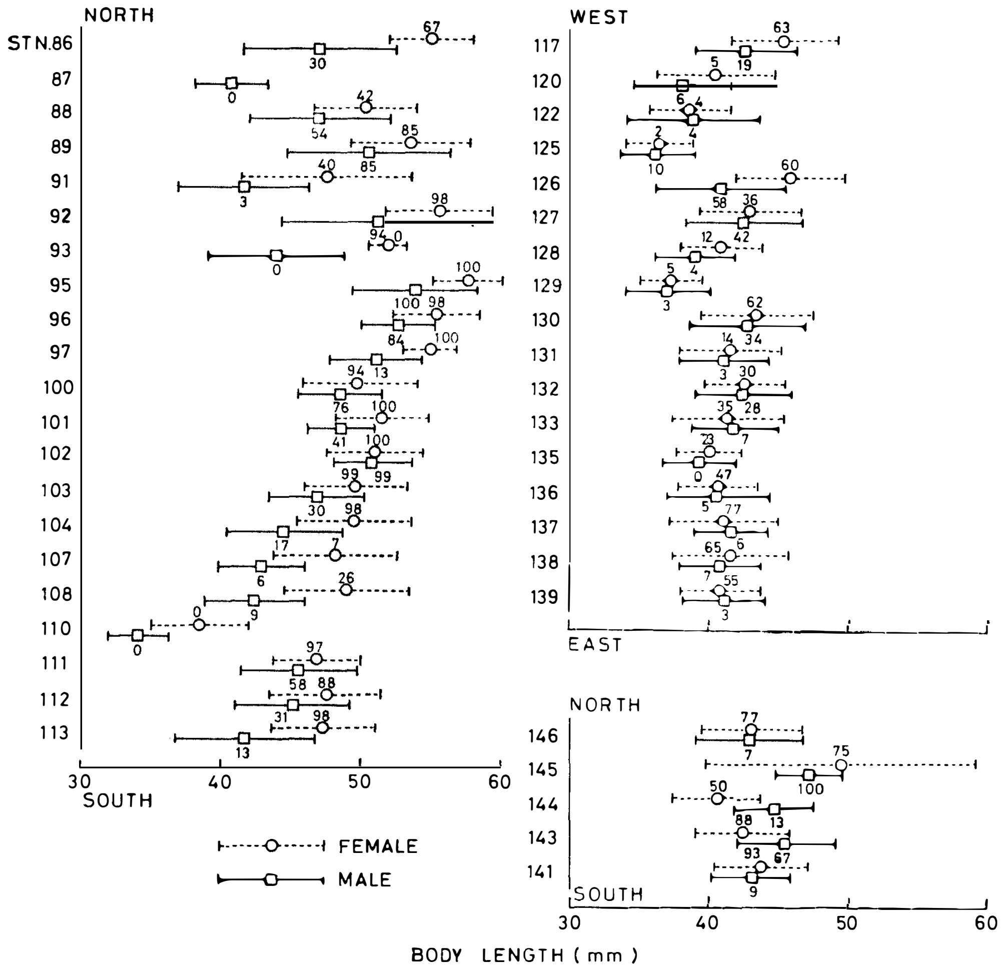

Fig. 7. Mean body length and its standard deviation of the krill at each station in Leg II (3–28 January 1985). Figures as in Fig. 5.

EVERSON (1977) listed previous estimates on zooplankton standing crop, excluding the krill, which ranged from 10 to 100 g/1000 m^3 over the top 1000 m of the Antarctic Ocean. If the value, 145 g/1000 m^3, obtained from blind tows in this study for the krill and EVERSON's (1977) highest value, 100 g/1000 m^3 for other zooplankton were used, the krill represent 58% of total zooplankton. If aimed tows were included for the krill biomass, 89% would be represented by the krill. Using Bongo nets, with 0.5 mm mesh width, BRINTON and ANTEZANA (1984) obtained 25% in the Scotia Sea, 70% in the area north of Elephant Island, and 69% in Bransfield Strait from blind and aimed tows. HOPKINS (1985) reported that the krill represented 94% of zooplankton standing stock in Croker Passage, Antarctic Peninsula from the results of Tucker Trawl with 0.16 mm mesh width without an acoustic aid. Our estimates, therefore, do not seem unrealistic.

Juveniles were very rare at Leg I stations, although they were abundant at Leg II stations (Fig. 3). The discrepancy can not be explained by the difference in sampling dates. Spawning of this species starts in late November and juveniles occur *ca.* 5 months after hatching (WITEK *et al.*, 1980; IKEDA, 1984). Juveniles collected in this study, then, were spawned in the previous austral summer.

FEVOLDEN and GEORGE (1984) reported that juveniles dominated in all schools from Bransfield Strait and in the vicinity of the Palmer Archipelago in 1983. Their stations were closer to the Antarctic Peninsula than ours, which may be why juveniles were rare at our Leg I stations. Juveniles are reported to be more abundant near the Antarctic Peninsula than offshore (WOLNOMIEJSKI *et al.*, 1982; QUETIN and ROSS, 1984). In this study, juveniles were most abundant in the area west and southeast of South Sandwich Islands (Fig. 4). FOSTER and MIDDLETON (1984) described a zone of eddy-like structures in the eastern Scotia Sea resulting from mixing of the two easterly currents, the Weddell Drift and the flow from Drake Passage. BRINTON (1985) found that high density of krill larvae was associated with subsurface thermal domes and suggested that ascent of the larvae from hatching depths was accelerated by mixing processes there. The Scotia Sea might be a nursery ground for krill larvae.

Adult populations with larger body size and high maturity were found in the areas along the Antarctic Peninsula and west of South Sandwich Islands, where high chlorophyll *a* concentrations were also observed. The highest chlorophyll *a* concentration was found at stations east of 10°E off Queen Maud Land. Although populations at those stations consisted of smaller adults, more than 77% of females were copulated at four out of five stations.

Sex ratios of males were 39.9 and 53.3% in Legs I and II, respectively. The difference is highly significant ($p<0.001$). Whether the difference in sex ratio is temporal or geographical is not known, because samplings in both legs were made at temporarily and geographically different stations.

A relationship, however, can be seen between the sex ratio and the percentage of copulated females. At those stations where females were predominated, the percentages of copulated females were also high. This is true of the populations along the Antarctic Peninsula, at Stns. 112 and 113 and at Stns. 143 and 146. Copulated females may show a distinct behavioral pattern as shown by TERAZAKI (1981) in *Euphausia pacifica*. Station 54 is an exception; although females represented 69% of adult population only 35% of females were copulated.

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