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Some interactions between hydrography, krill and fish near Elephant Island in 1977/78 *

by

K.-H. Kock, F. Nast and M. Stein

Institut für Seefischerei
der Bundesforschungsanstalt für Fischerei
Hamburg, Federal Republic of Germany

ABSTRACT

Krill, fish and hydrographical conditions around Elephant Island were studied with a routine grid program of 75 x 75 nm ("box B") which was surveyed 4 times in the course of the Antarctic Expedition 1977/78. The hydrographical situation was characterized by the presence of Drake Passage water in the north and water of Weddell Sea origin in the south of the "box B". Warming of the Antarctic Surface Water started in January. By means of a moored current meter an average current speed of 11 km/day was found. Krill was most abundant north and northwest of the island. Frequencies of the different maturity stages were analyzed for all stations and linked with hydrographical data. A total of 29 fish species were recorded. Relative abundance of mass fish was well correlated with the occurrence of dense krill concentrations.

1. INTRODUCTION

First biological and hydrographical studies of the Federal Republic of Germany around Elephant Island, the northwest part of the South Shetland Islands,

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* Results of the Antarctic Expedition 1977/78 of the Federal Republic of Germany

were carried out mainly on a 4 days time station south of the island in February 1976. Due to the particular hydrographical situation observed (STEIN, 1979 a, b) and the detection of larger concentrations of larval and adult krill and demersal fish during this survey (KOCK, 1978; I. HEMPEL, 1979; NAST, 1979) a routine grid program was established in an area of 75 x 75 nm ("box B") around the island, which was worked 4 times (in November, December, January, March) in the course of the Antarctic Expedition 1977/78. Distance between routine stations was appr. 15 nm in longitudinal and 2o nm in meridional direction. This concept of investigating smaller areas ("boxes") as often as possible within a season was chosen because it gave a much better knowledge of short term fluctuations within the biological and hydrographical parameters studied than an overall survey with widely spaced stations as carried out during the Antarctic Expedition 1975/76.

The present paper gives a description of the hydrographical situation, the distribution and maturity stages of adult krill, the species composition of demersal fish and the abundance of krill and fish in relation to each other and the hydrographical regime.

2. DATA AND ANALYSIS

The temperature field within the margin of "box B" was obtained by means of a KIEL-Multisonde (CTD) fromboard FRV "Walther Herwig". Data processing, calibration, etc. are given by CORNUS & STEIN (1979).

The current measurements referred to, were performed south of Elephant Island on 61°18.2'S, 54°55.2'W with moored current meters of Aanderaa type. Detailed results on the current measurements are published elsewhere (STEIN, 1979 a). The vertical distribution of temperature (T) is given in figs. 1 to 3. Each figure consists of four individual plots showing meridional sections. The uppermost section represents the eastern border of "box B", whereas the western border is given in the lowermost part of the figures. The dotted line in the temperature sections indicates the depth of the temperature minimum layer.

Krill sampling was carried out fromboard FRV "Walther Herwig" with a RMT 8 closing net of 45oo μ mesh size (BAKER et al., 1973; POMMERANZ, 1978 a; WÖRNER, 1979).

Standard single oblique hauls were made down to 14o m depth, then closed and immediately hauled to the surface. A maximum depth of 14o m was chosen according to our experience from the 1975/76 Antarctic Expedition that postlarval krill mainly inhabits the o - 14o m layer. Low abundance of krill or defects in the closing mechanism resulted in a few double oblique hauls. On two stations in March (365, 388) the RMT fished on different depth strata within the o - 14o m layer.

Filtered volumes were calculated on the basis of an equal mouth opening during each haul, although POMMERANZ (1978 b) pointed to the fact that different towing speeds lead to different mouth openings of the RMT. Data on abundance of Krill (n/1ooo m^3) should therefore be regarded as preliminary*.

Obviously due to mesh selection krill smaller than 3o mm is not adequately sampled by the RMT 8 (NAST, 1979; POMMERANZ, 198o), so individuals in maturity stage I were probably underrepresented in the catches.

A total of 79 hauls (62 fished at daylight, 9 at dawn, 8 at night) was analysed.Maturity stages of postlarval krill were determined by external characters using IVANOV's (197o) scale with 3 additional stages described by NAST (1979). Length of specimens was measured to the mm - below from the anterior margin of the eye to the tip of the telson.

Fish investigations were mainly concentrated onboard the chartered trawler FMS "Julius Fock". Due to rough bottom topography trawlable grounds were only found in the western parts of the box. Hauls were not randomly distributed over the fishable area as part of the trawls were specifically shot for fish concentrations which had been detected by vertical echo sounder. A total of 3o hauls down to 5oo m depth could be analysed for species composition. Length (total length, cm - below),sex,maturity stage (according to EVERSON, 1977), stomach contents, fecundity and parasites were determined for the most numerous species.

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* A detailed study using corrected data is in preparation.

3.1. OCEANOGRAPHIC OBSERVATIONS

Water masses in "box B"

The distribution of water masses in the area of "box B" is profoundly influenced by the topography of the Scotia Ridge. The main water masses as denoted in fig. 4 are either to be found north or south of the ridge. The Antarctic Surface Water (ASW) with salinities less than 34.o ‰ is composed of the Warmed Surface Water (WSW) and the remnant of winter convection, the cold, low saline Winter Water (WW). This water mass as well as the Warm Deep Water (WDW), which is centered around 5oo m depth, was found north of the ridge, cf. st. 239, 225 in fig. 4.

The influence of the Weddell Sea on the thermohaline structure in "box B" can be traced south of the ridge. The T,S-curves of the respective stations (cf. st. 237, 232 in fig. 4) are of completely different shape than the T,S-curves of stations north of the Scotia Ridge. Temperatures less than $-1^{o}C$ and salinities larger than 34.5 ‰ were recorded in the deep layers south of Elephant Island. As proposed by FOSTER & MIDDLETON (1979) this water mass is presumably Weddell Sea Bottom Water (WSBW).

The Hydrographic Sections

During the first observation period 16 to 2o November 1977 (fig. 1) the entire "box B" was covered by Surface Water of about $-1^{o}C$. North of the Scotia Ridge the influence of the WDW becomes visible. It is centered around 5oo m depth. Two months later, between 17 and 19 January 1978 the thermal situation reveals a warming of the upper 2oo m. The depth of the T_{min}-layer (dotted line in figs. 1 to 3) has changed drastically in the two easternmost sections. At the northwestern boarder of "box B" the depth of the Winter Water layer remained nearly unchanged from November to January. It ranged at about 8o m water depth. In the beginning of March 1978 (fig. 3) the temperature of the warmed Surface Water amounted more than $2.5^{o}C$ at the northwestern border of "box B". The Warm Deep Water remained more or less unaffected; in the upper 2oo m of the water column, however, a profound warming of the Surface Water can be observed.

South of Elephant Island the whole water column is colder than -1^{o}C (fig. 1). The homothermal situation, however, changes with the seasonal warming. Thus, between 17 and 19 January 1978 a thermal stratification can be observed which results in the formation of cold deep water. In the beginning of March 1978 the cold bottom water is restricted to the lower 5oo m of the water column. Near station 233 (fig. 3) which is situated at 61^{o}3o'S, 54^{o}57'W a similar situation was observed two years ago in the deep water layers (STEIN, 1979 b). During a 4 days time station at 61^{o}3o'S, 55^{o}oo'W the existence of cold saline bottom water, i.e. Weddell Sea Bottom Water was observed.

The change of T,S-characteristics south of Elephant Island between November 1977 and March 1978 is given in fig. 5. The T,S-curves reflect the seasonal influence on the stratification. Being near the pack-ice border stations 7o, 71 represent the nonstratified spring situation south Elephant Island. Low salinities of the Surface Water indicate the proximity of the ice. In the middle of fig. 5 the summer situation shows a stratified water column. The late summer condition (top of fig. 5) very much ressembles the previous stratification during the mid of January.

Geostrophic computations

For the second and third cruise leg geostrophic computations were accomplished for the area of "box B" (figs. 6, 7). The figures represent the dynamic topography of the 7o dbar surface relative to the horizontal level. The 7o dbar surface was chosen due to the fact that this depth is approximately the upper limit of the Winter Water layer. As reported by KOCK & STEIN (1978) in oceanic areas this layer is a boundary for the vertical extension of krill swarms. Additionally to the relative dynamic topography the direction of the relative geostrophic current is given by arrows. Thus the relative motion of the upper layer of "box B" is delineated for the summer and late summer situation. North of the Scotia Ridge the dynamic topography indicates currents to the northeast (figs. 6, 7). Between 17 and 19 January 1978 northwest of Elephant Island a current border emerges. The water flowing in from the west turns back when approaching the shelf break. To the east of this border the current flow is directed eastwards.

The central region of "box B" is characterized by weak gradients of the dynamic contour lines. South of Elephant Island a square in fig. 6 marks the mooring site. The mean current as recorded between 2o November 1977 and 24 January 1978 (STEIN, 1979 a), in the middle of "box B" was directed to the northeast, i.e. to the passage between Elephant Island and Clarence Island. For the surface layer a mean current direction of 68° (5o m) was observed whereas the meter in 25o m depth recorded a mean current into 64°. The average speed was found to be 11 km/day.

Whereas the geostrophic flow in the southern parts of the "box" is directed northeastwards during the mid of January,a divergent flow was observed in that area in the beginning of March.

3.2. KRILL OBSERVATIONS

November

Krill was found to be most abundant northwest of Elephant Island (stations 63, 6o, 59; see fig. 8), less abundant at the eastern border of "bøx B" (stations 69, 57) and rare in the center of the "box". A line drawn from station 54 to 71 through stations 57, 69 and 7o indicates approximately the pack-ice-border When calculating means of the maturity-stage-frequency, both of the pack-ice-stations and the northwestern stations (table 1), it is obvious that juveniles and young females II were abundant near the pack-ice-border while almost absent from the northwest stations. The adult males (III) and females (III_a) were more frequent in the northwest than in the east at the pack-ice-border.

December

The largest catch of the entire expedition was recorded north of Elephant Island at station 135 (see fig. 9) in December. The RMT 8 yielded 37o liters of krill, equvalent to 11ooo individuals per 1ooo m^3 water filtered. The second most abundant catch (at station 114) yielded about 6ooo individuals/1ooo m^3, at the western boarder of the "box". The third largest catch of krill was from station 128, south of the island and located directly on the 1oo-fathom-line.

A result becomes obvious when the means of maturity stage composition of stations 135, 114 are compared with those of stations 124, 125 (table 2). Although stations 135 and 114 are distant from each other they show the same composition of maturity stages : The mature females that have not yet been fertilized (♀ III_a) dominate, followed by the adult males. Juveniles and the younger stages (♂ I_b and ♀ II) were rare in both catches. These two stations, in addition to displaying an equal maturity stage composition are connected by the -o.7^{o}C-isotherm (STEIN, 1979 a), suggesting more than solely coincidence. In contrast to these stations, the easterly stations are dominated by the juvenile krill with 1oo and 86 %, although only 29 and 68 juveniles respectively were caught by the RMT 8. This was probably due to net selection, mentioned above.

January

The summer situation (fig. 1o) shows a more even distribution of krill abundance, although none of the 18 RMT 8 - catches yielded abundance values in the order of 1ooo individuals per 1ooo m^3. Krill was most abundant south of Elephant Island (station 234 : 7oo Krill/1ooo m^3), but also abundant in the northwest (station 24o, 241 with values of 3oo individuals per 1ooo m^3).

The frequency of maturity stages was more even than in November and December : Adult males (♂ III) and fertilized females (♀ III_b) were the dominant stages. For the first time during the investigation gravid females were caught. They occurred in 1o of the 18 hauls with a 2o % frequency at both stations 232 and 244. Station 24o is aberrant from the above described scheme, because of a 4o % proportion of juveniles. All other catches yielded o - 6 % juveniles and less than 8 % young females.

Means of maturity stage frequency (table 3) for three groups of stations corresponding to the main water masses (fig. 6) were calculated. The results indicate that the frequency of maturity stages is more or less even in, and between, the three groups of different water masses.

March

Between January and March the roughly even krill distribution in "box B" changed dramatically. In March (fig. 11) krill was only found abundant to the north and northwest of Elephant Island (stations 365, 388, 389) and appeared absent from other parts of the "box". Abundance values of less than 1o krill /1ooo m^3 predominated (with values of less than 1/1ooo m^3 common).

According to table 4 the three stations at which krill was most abundant differ in their maturity stage composition. At station 365 the adult males and fertilized females contributed 96 % of the animals caught, while at stations 388, 389 the adolescent males and not yet fertilized females (♀ III_a) amounted to about 7o %. Juvenile krill was caught at the stations of low abundance, 366 , 376 and 39o; i.e. in the west and the east of the "box". At station 386 in the southern part of the "box" adult males predominated (87 %).

Summarizing the abundance analysis, it is apparent that during all four periods of investigation krill was most abundant north and northwest of Elephant Island. The highest abundance values ranged from o.1 to 11 krill individuals/m^3. EVERSON (1977) reviewed available information on krill densities in swarms : They range from 2ooo - 4oooo animals / m^3 of water. Hence it follows that the RMT 8 never fished through a swarm. Even aimed hauls following echotraces of krill (stations 365, 388) only yielded a maximum abundance of 9 krill/m^3. An explanation for these rather low values might be given by MAUCHLINE's concept of krill patches (ANON., 1979) : "Density throughout patches is extremely irregular but average densities are probably in the range 1 - 1o/m^3 of water". A patch of Euphausia superba can consist of schools and swarms (with or without a parallel orientation to each other). Thus when highest values of abundance were recorded in this study, it is likely that the RMT 8 sampled patches of krill, but encountered neither schools nor swarms.

When fishing upon echotraces in "box B" with a commercial pelagic net from the "Walther Herwig", catches in the range of 1 - 8ooo kg per hour were obtained.

Gravid females were absent in November, occurred rarely in December, often (although in small numbers) in January, and again only rarely in March (equivalent to the spring situation). So a succession of maturity stages is apparent.

Any relationship between maturity stage composition and different water masses would appear to be complex. This would agree with the report of JAŻDŻEWSKI et al. (1978), who did not find a general regularity in the occurence of different stages of krill in different water layers. Probably length distribution analysis of particular maturity stages would throw more light on attempts to relate krill to water masses.

3.3. ICHTHYOLOGICAL OBSERVATIONS

Intensive ichthyological research in Westantarctic waters in the last two decades, particularly by Soviet scientists, has intensified our knowledge on the distribution of demersal fish species to a large extent. According to PERMITIN (1977) 46 species of 29 genera and 1o families have been recorded from the South Shetland area.

During our survey a total of 24 species * could be identified from the hauls (table 5). Together with the 1975/76 caught Anotopterus pharao Zugmayer 1911, Pseudoicichthys australis (Haedrich, 1966), Neopagetopsis ionah Nybelin 1947, Trematomus newnesi Boulenger 19o2 and Bathyraja maccaini Springer 1971 at least 29 species can be recorded for the area.

By far the most numerous species were Notothenia rossii marmorata and Champsocephalus gunnari, yielding catches of more than 1o - 2o t/h. Analysis of more than 9oo stomach contents of both species showed that they fed almost exclusively on krill (> 99 %). As demonstrated in figs 8 - 11 the areas of densest krill aggregations were mainly confined to the north and northwest of the "box". Abundance (kg/h) of the two species was highly correlated with the occurrence of krill concentrations (figs. 12, 13), i.e. large catches were only obtained in the vicinity of krill swarms. Similar observations were made off South Georgia in the austral summer of 1975/76. In contrast to this the abundance of fish feeding species, such as Chaenocephalus aceratus, was much more even (fig. 14). In the main fishing area Notothenia rossii marmorata and Champsocephalus gunnari exhibit a distinct separation in bathymetric distribution (fig. 15), whereas in other areas of the "box" Champsocephalus gunnari were found down to 49o m depth.

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* The list may be longer as the rajids are still under examination (STEHMANN, in prep.)

Length frequency distributions of Notothenia rossii marmorata(fig. 16) show a predominance of 45 - 49cm specimens at the end of January, while in February/March the bulk was made up of individuals of 48 - 52 cm length. According to FREYTAG (198o) these belong to age groups VII+ and VIII+. Sex ratio (♀:♂) was 4o.8 : 59.2 in January and 46.5 : 53.5 in February/March. More than 9o % were sexually mature. Gonads were prior to spawning (stage III), so it can be assumed that spawning takes place from the middle or end of March onwards, which is several weeks earlier than reported for the South Georgia stock (PERMITIN & SILYANOVA, 1971).

Except for November, length frequency curves of Champsocephalus gunnari were nearly unimodal and made up by individuals of 26 - 4o cm length (fig. 17). More than 98 % of these specimens were sexually mature. In contrast to Notothenia rossii marmorata, only appr. 1 % show signs of gonad development, so fecundity estimations were limited to a few specimens. Data were therefore combined for the whole South Shetland area. Absolute fecundity was positively correlated with length and weight :

(1) $F = 0.1384 \cdot L^{2.9066}$ ($= 0.91$)

(n = 17)

(2) $F = 84.2 + 16.5\ W$ ($= 0.96$)

Fecundity was lower than reported for South Georgia (KOCK, 1979). Analysis of covariance demonstrated that only the intercepts of both regression lines were significantly different from those given for South Georgia, whereas slopes were not statistically different. This indicates a similar relationship of fecundity to length and weight in both areas. Difference in intercepts may be explained by the presence of two populations of Champsocephalus gunnari with different fecundities in the South Shetland and South Georgia area (KOCK, in prep.).

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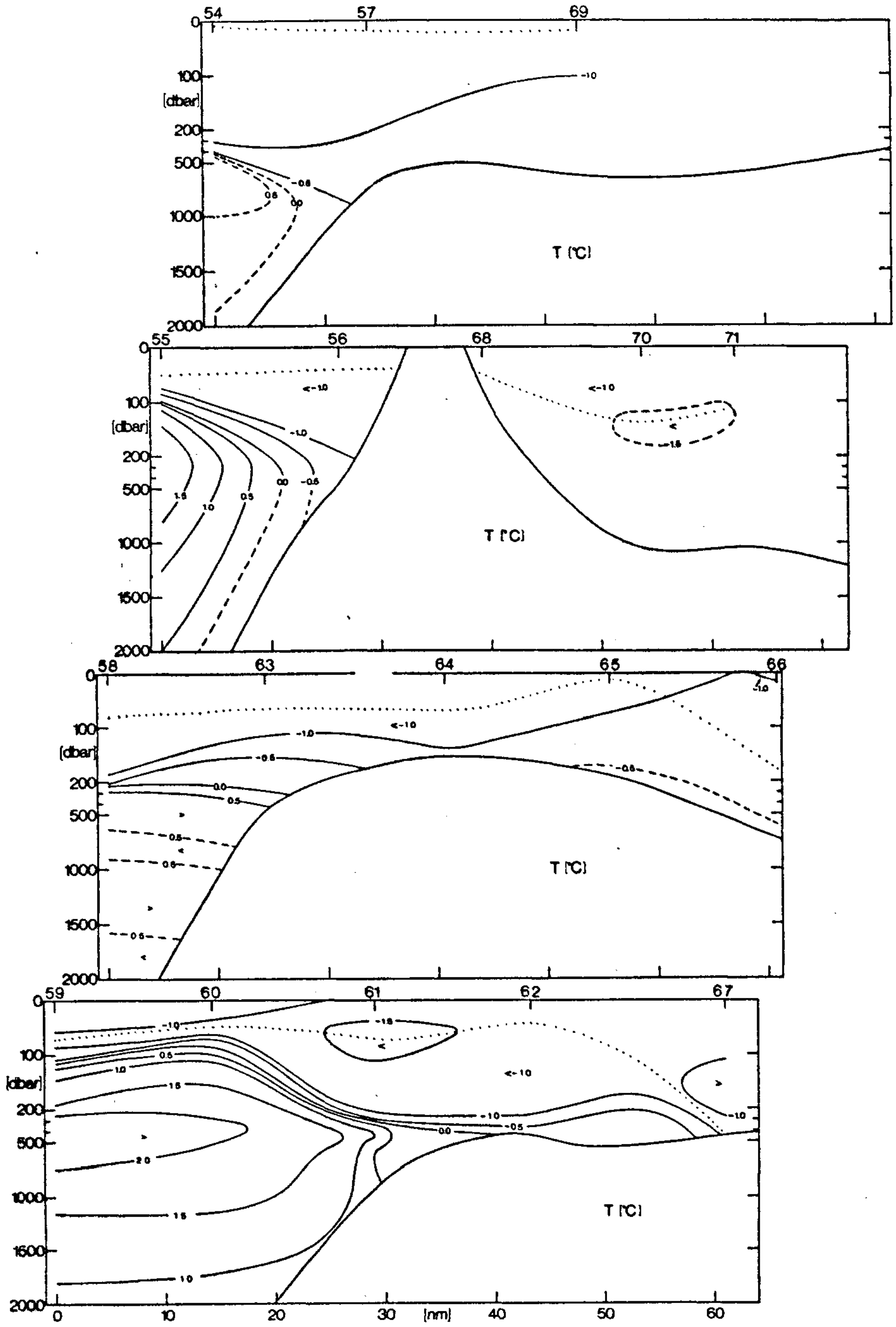

Fig. 1 : The vertical distribution of temperature (T) between 16 and 2o November 1977 in "box B", for explanation see text. Dotted line = T_{min}-layer.

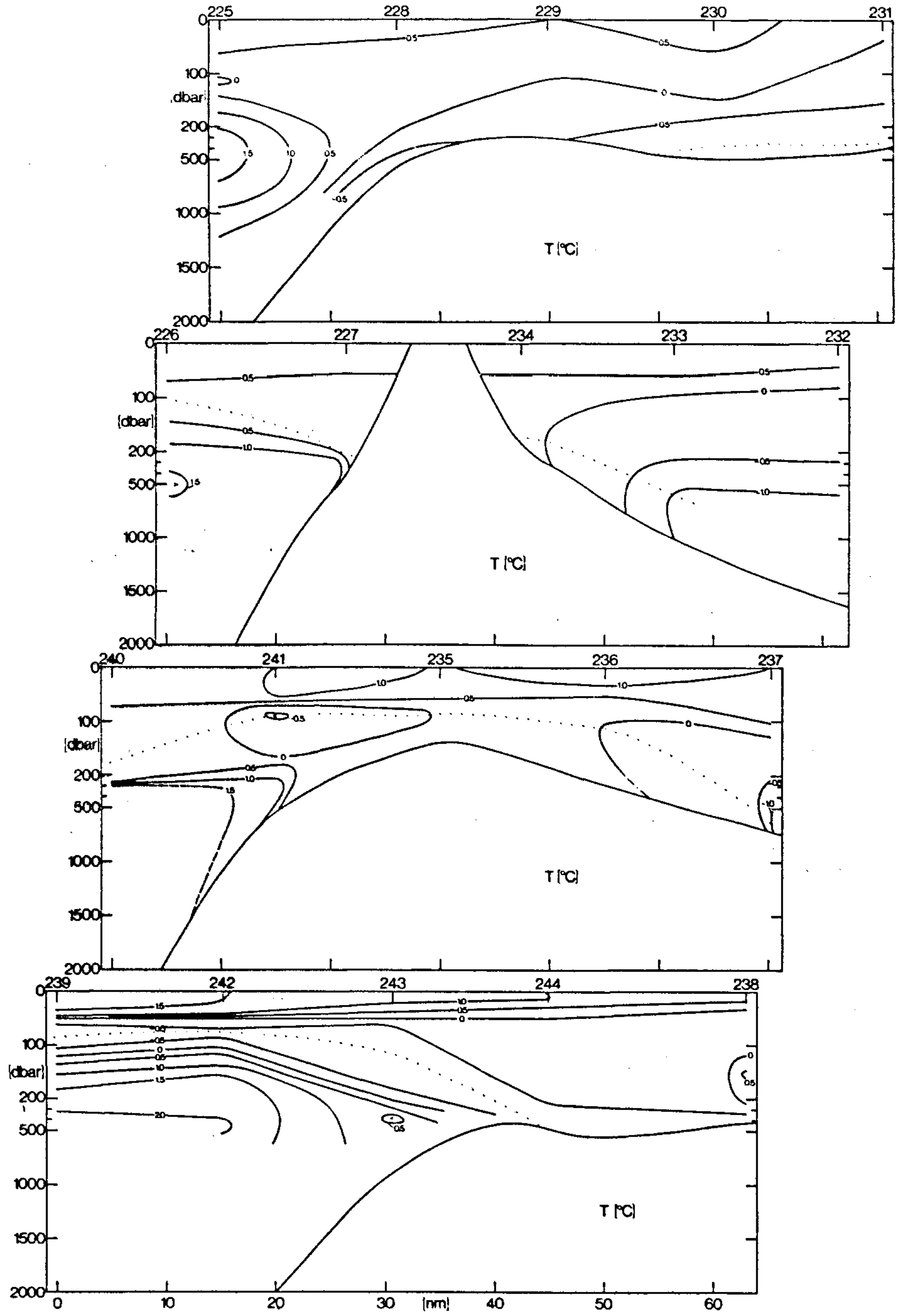

Fig. 2 : The vertical distribution of temperature (T) between 17 and 19 January 1978 in "box B", for explanation see text. Dotted line = T_{min}- layer.

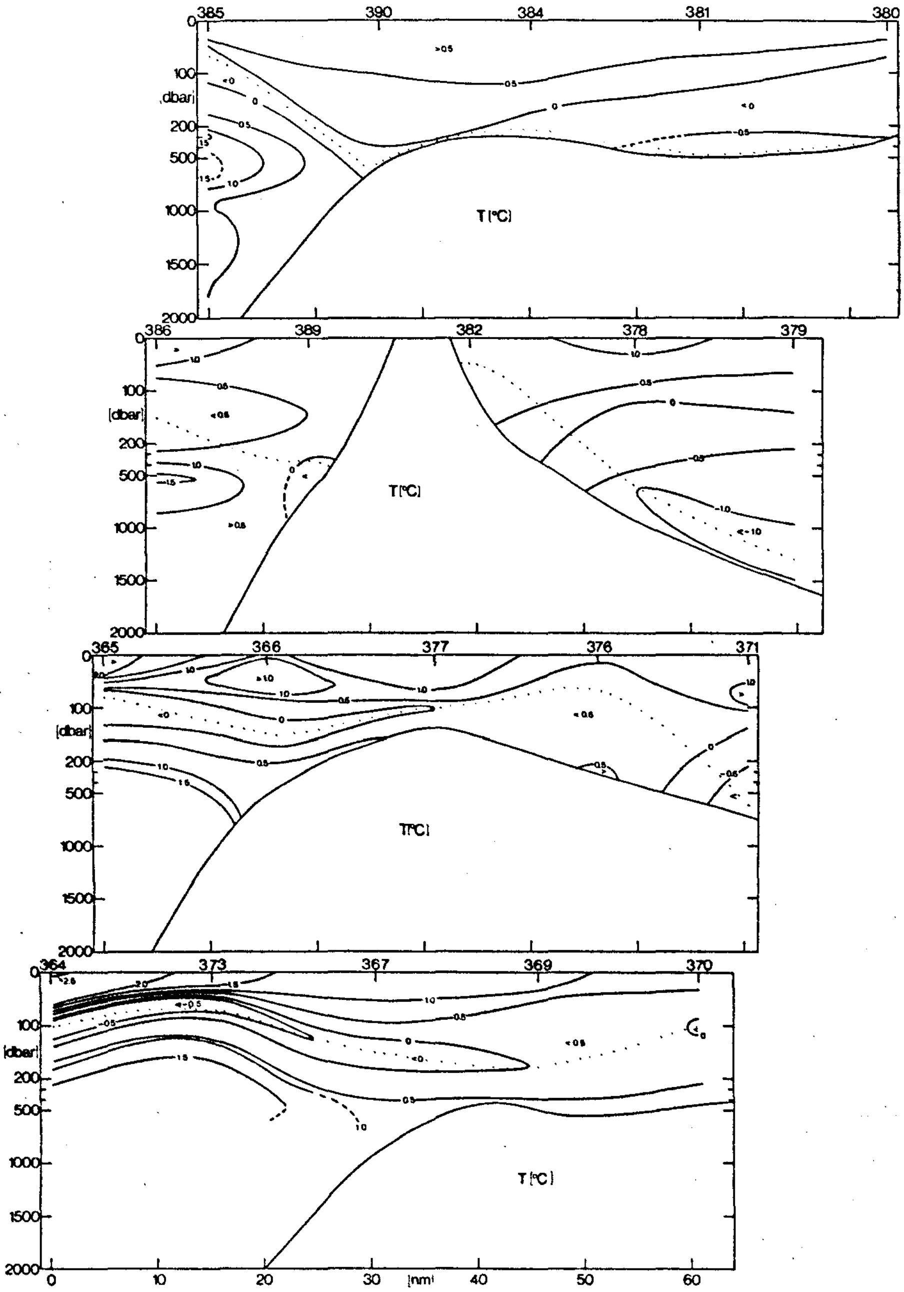

Fig. 3 : The vertical distribution of temperature (T) between o3 and o7 March 1978, for explanation see text. Dotted line = T_{min}-layer.

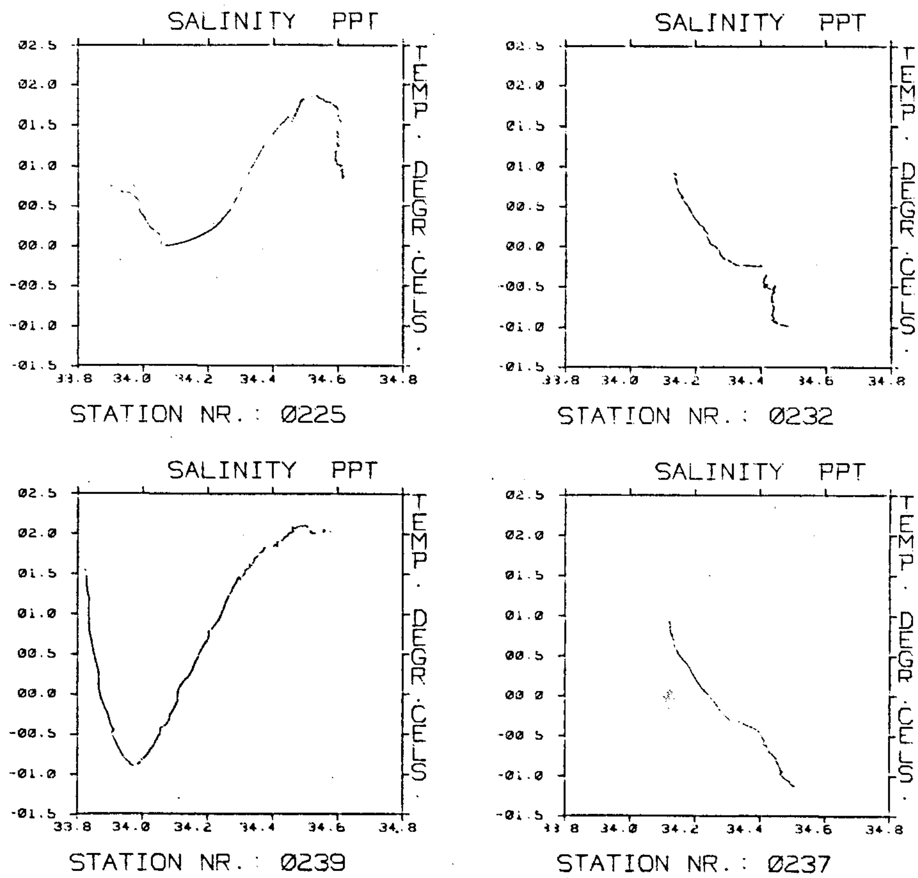

Fig. 4 : T,S-diagrams of two stations north (stations 239, 225) and south (stations 237, 232) of the Scotia Ridge.

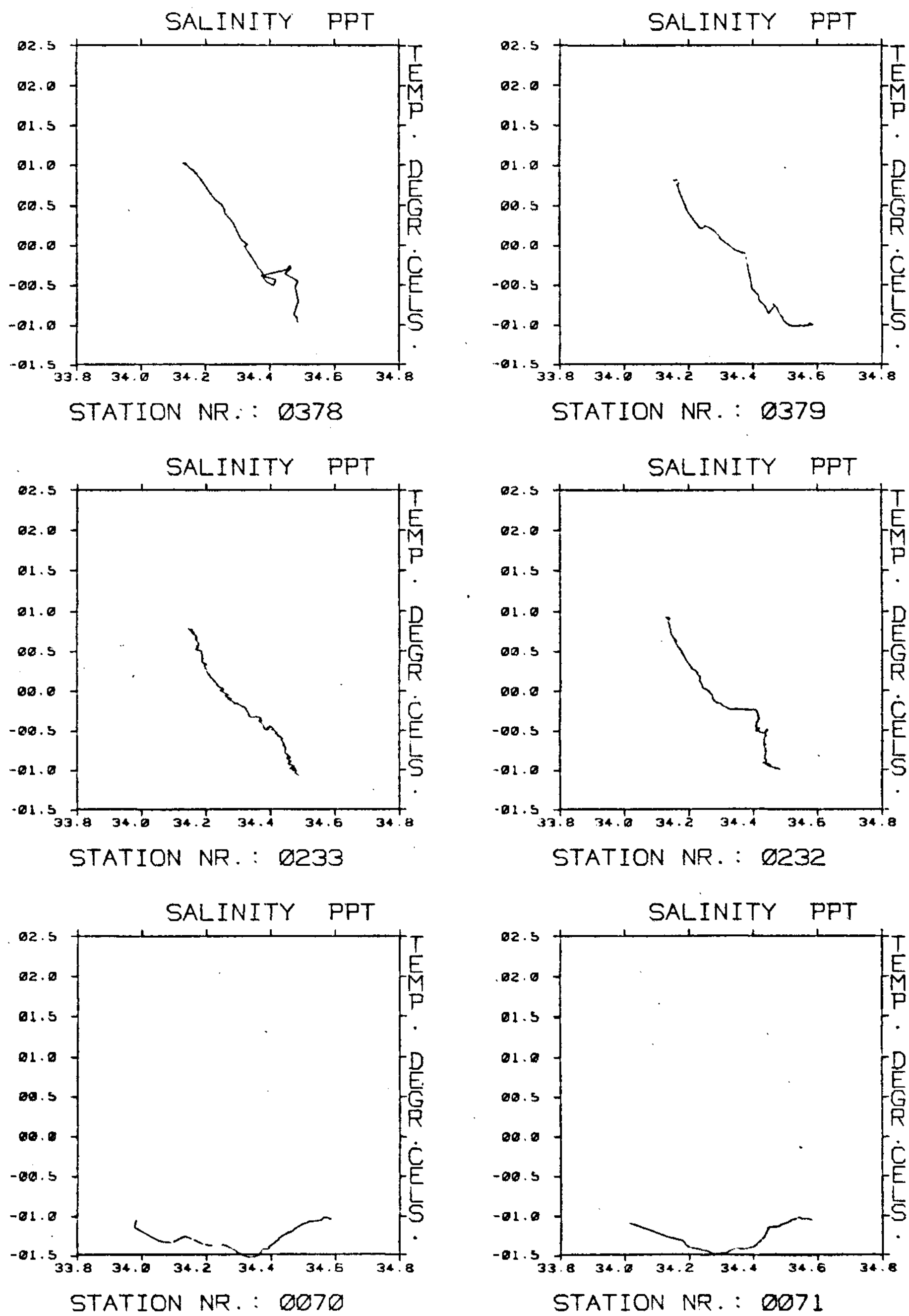

Fig. 5 : T,S-characteristics showing the spring, summer and late summer conditions (cf. stations 7o, 71; 233, 232 and 378, 379) in "box B" between November 1977 and March 1978.

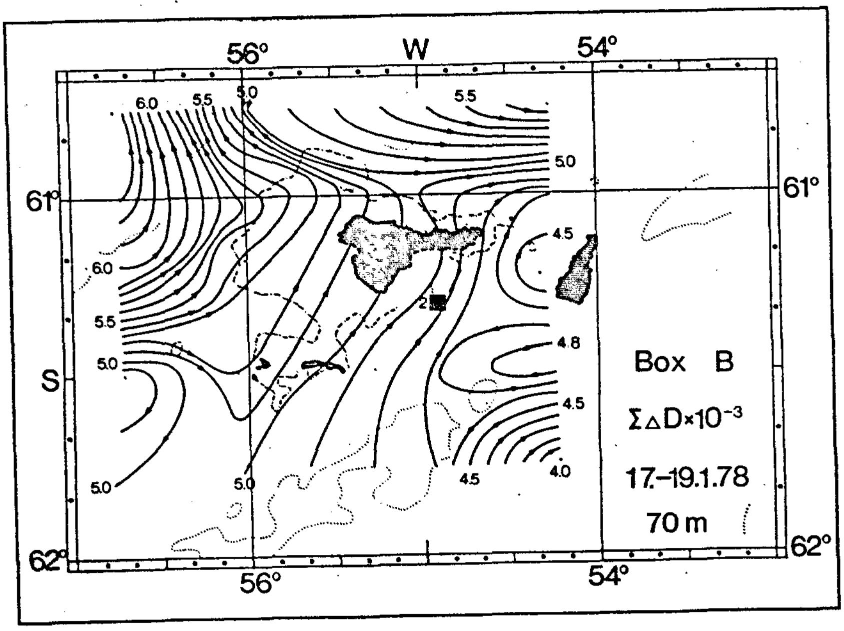

Fig. 6 : Relative dynamic topography of the 7o dbar surface and the distribution of the relative geostrophic current, given by arrows for the area of "box B" in January.

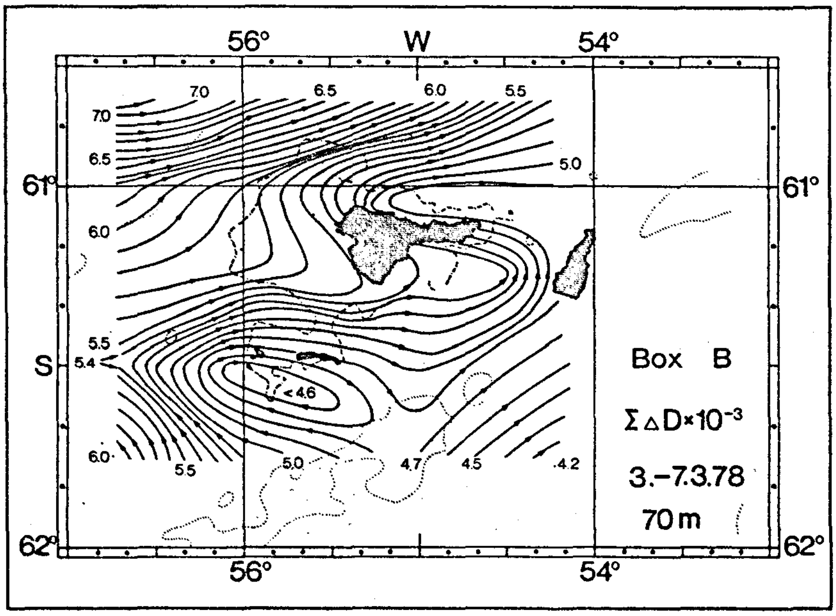

Fig. 7 : Relative dynamic topography of the 7o dbar surface and the distribution of the relative geostrophic current, given by arrows for the area of "box B" in March.

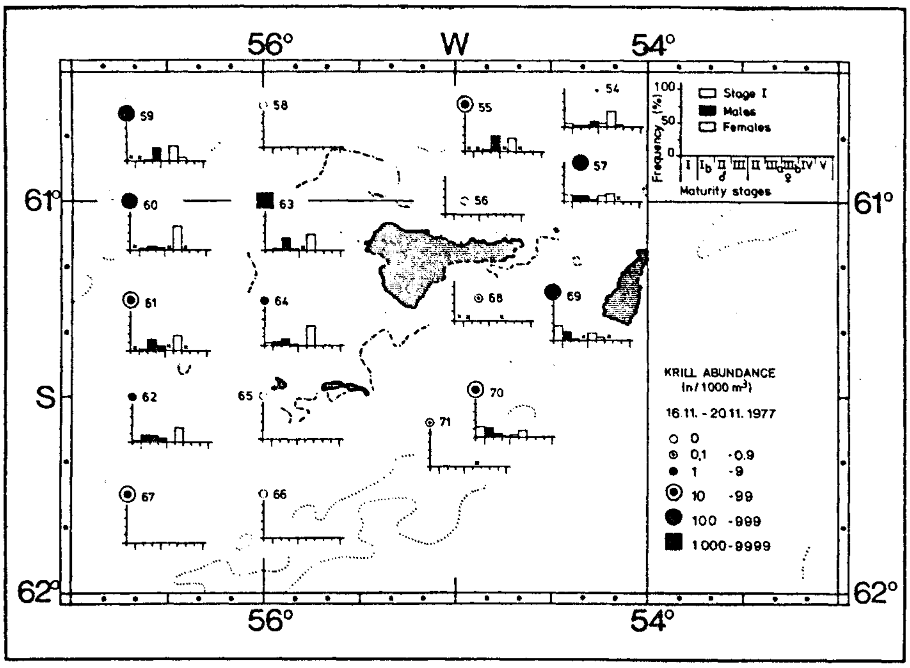

Fig. 8 : The abundance of krill (No./1ooo m^3) and the maturity stage composition of krill catches in the area of "box B" in November 1977.

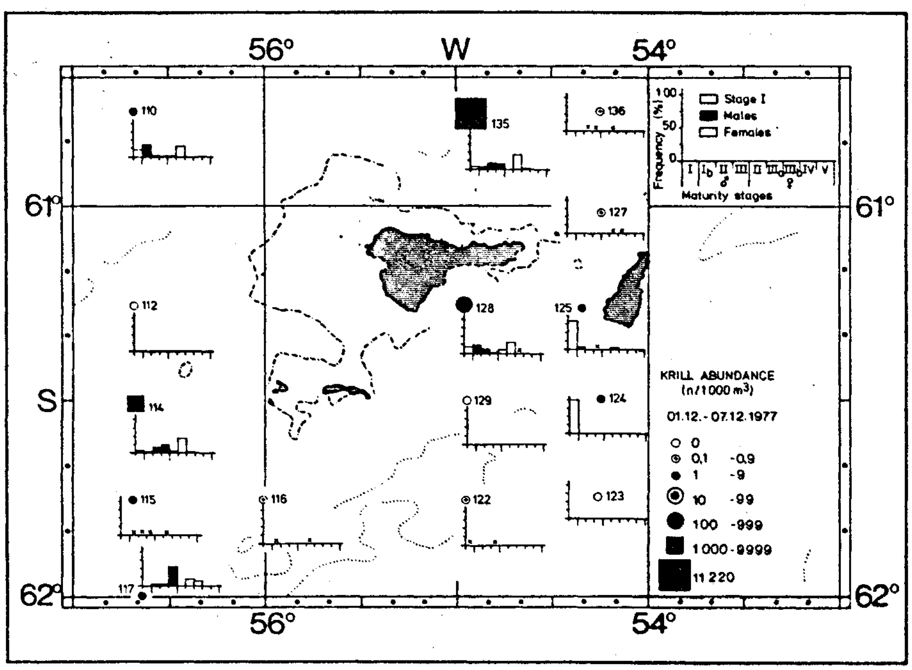

Fig. 9 : The abundance of krill (No./1ooo m^3) and the maturity stage composition of krill catches in the area of "box B" in December 1977.

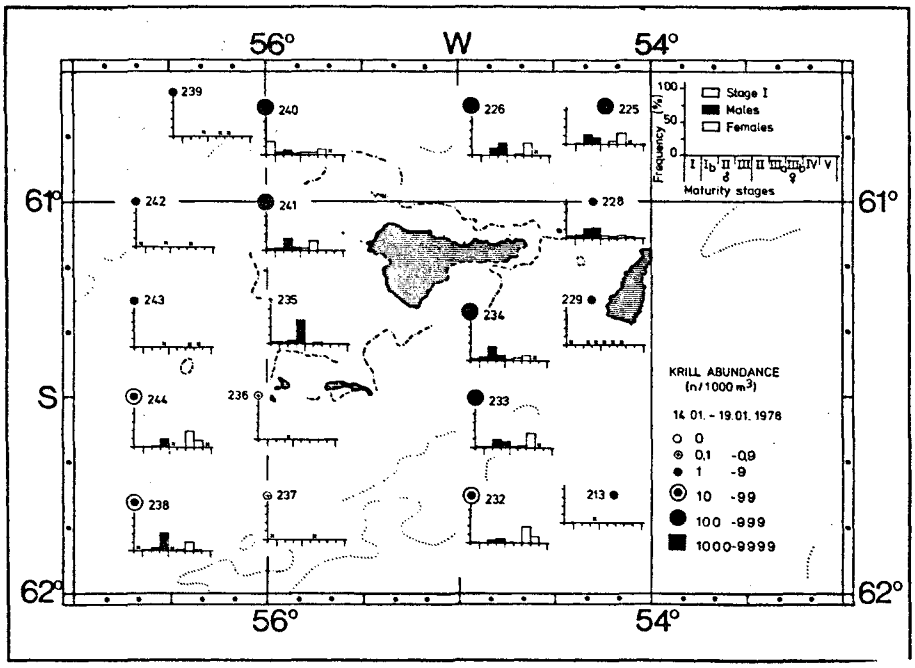

Fig. 1o : The abundance of krill (No./1ooo m^3) and the maturity stage composition of krill catches in the area of "box B" in January 1978.

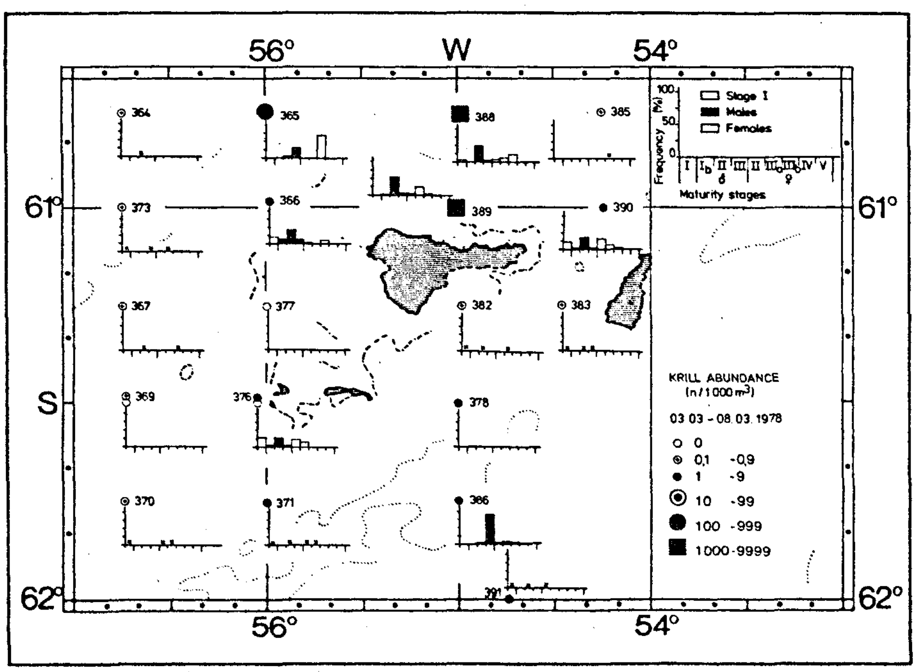

Fig. 11 : The abundance of krill (No./1ooo m^3) and the maturity stage composition of krill catches in the area of "box B" in March 1978.

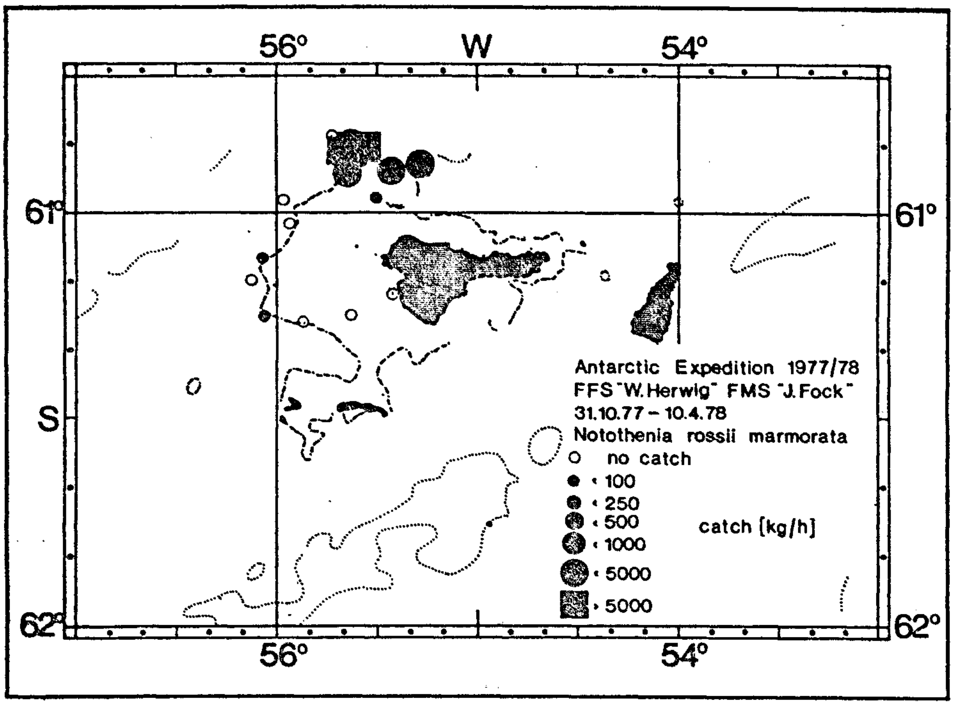

Fig. 12 : Abundance of Notothenia rossii marmorata west and northwest of Elephant Island.

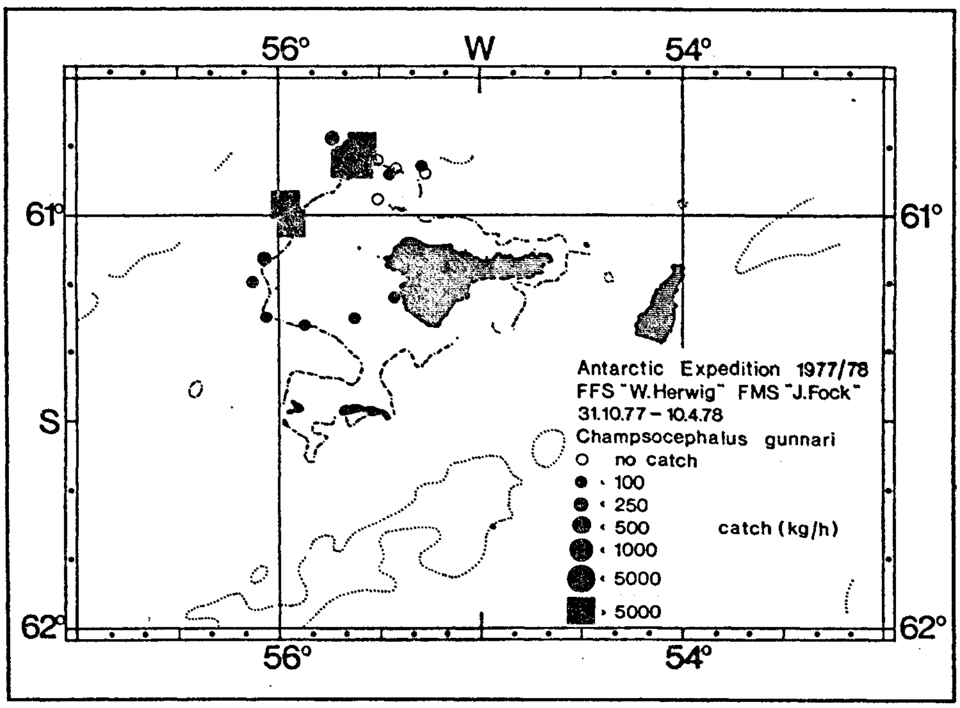

Fig. 13 : Abundance of Champsocephalus gunnari west and northwest of Elephant Island.

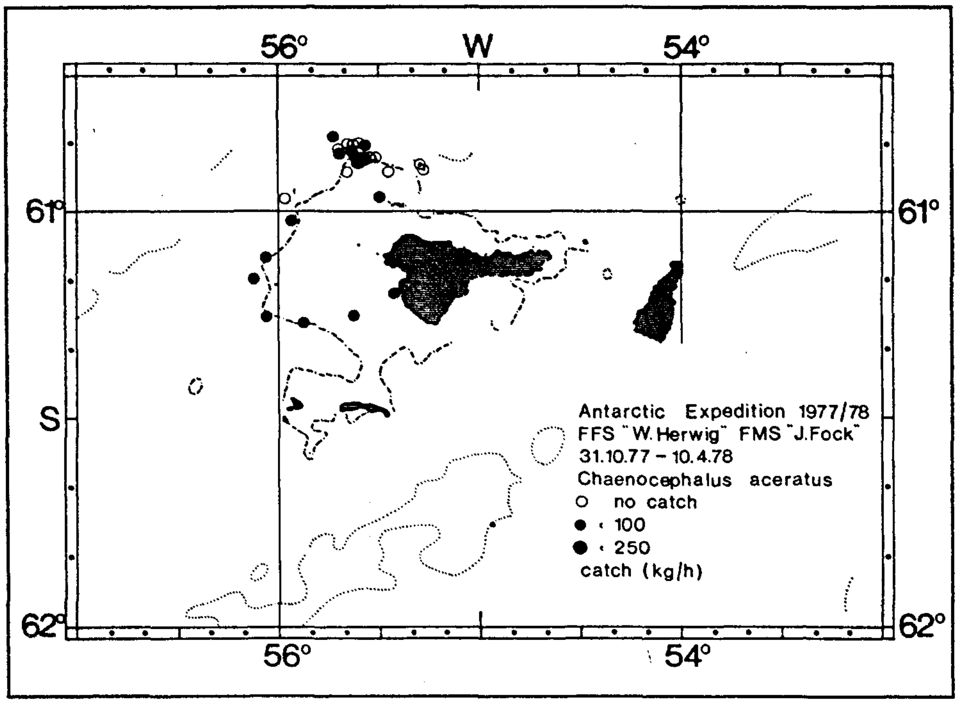

Fig. 14 : Abundance of Chaenocephalus aceratus west and northwest of Elephant Island.

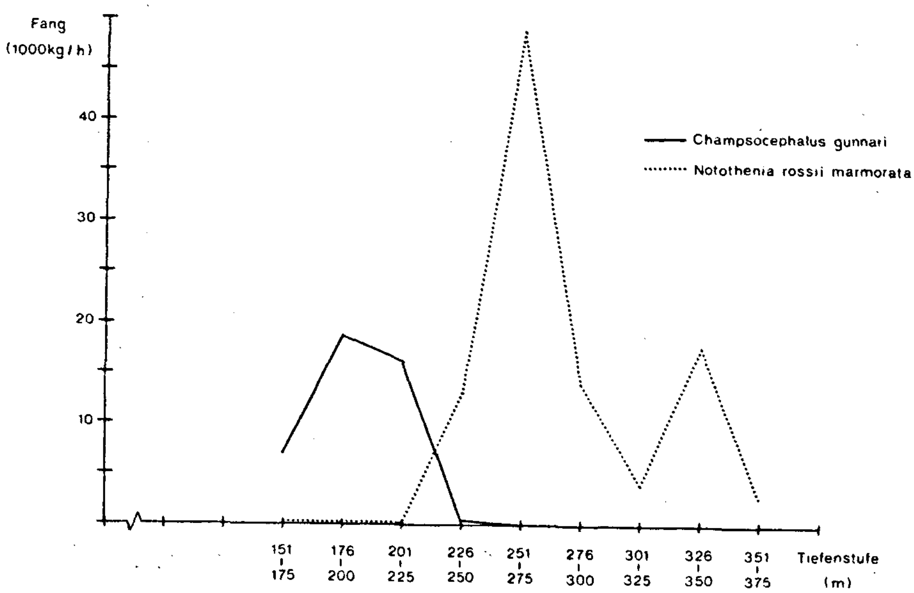

Fig. 15 : Bathymetric distribution of Notothenia rossii marmorata and Champsocephalus gunnari in the main fishing area.

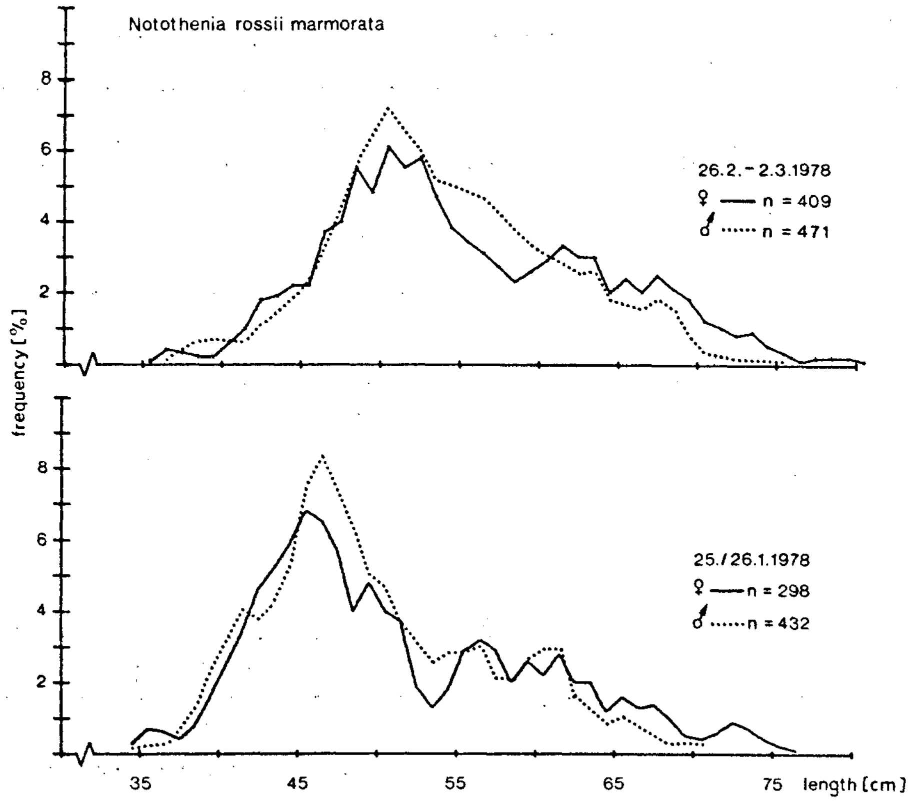

Fig. 16 : Length frequency distribution of Notothenia rossii marmorata.

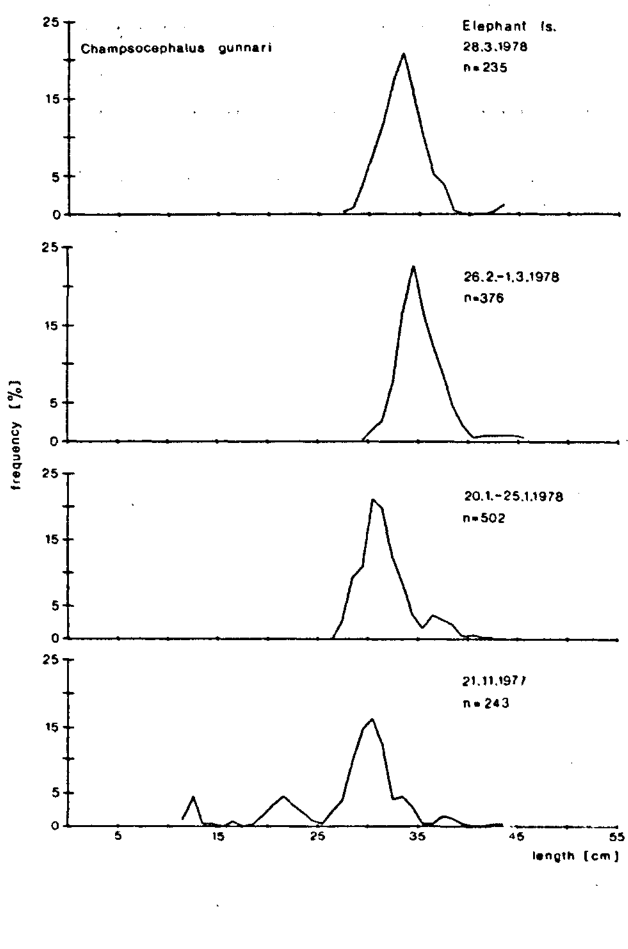

Fig. 17 : Length frequency distribution of Champsocephalus gunnari.

Station	Mean maturity stage frequency in %								
		♂♂			♀♀				
	I	I_b	II	III	II	III_a	III_b	IV	V
54, 57, 69, 7o & 71	26	19	1o	6	13	25	1	o	o
59, 6o & 63	+	6	18	18	+	55	3	o	o

Table 1 : Mean frequency (in %) of krill maturity stages in two groups of stations in November 1977.

Station	Mean maturity stage frequency in %								
		♂♂			♀♀				
	I	I_b	II	III	II	III_a	III_b	IV	V
114	4	3	18	24	4	45	2	o	o
135	7	6	21	18	o	46	3	o	o
124	1oo	o	o	o	o	o	o	o	o
125	86	8	o	+	o	6	o	o	o
mean of 114/135	5.5	4.5	19.5	21	2	45.5	2.5	o	o
mean of 124/125	93	4	o	+	o	3	o	o	o

Table 2 : Mean frequency (in %) of krill maturity stages in two groups of Stations in December 1977.

Stations		Mean maturity stage frequency in %								
			♂♂			♀♀				
		I	I_b	II	III	II	III_a	III_b	IV	V
A	225	o	3	31	2o	o	11	34	+	o
	226	o	o	22	37	o	o	38	+	o
	228	5	1o	31	33	7	5	7	2	o
B	235	6	6	11	72	o	6	o	o	o
	236	o	o	o	+	o	o	o	o	o
	238	+	2	11	53	+	4	27	2	o
	239	o	o	o	+	o	+	+	o	o
	24o	4o	8	14	5	8	8	17	+	o
	241	6	7	37	11	7	29	3	o	o
	242	+	o	o	+	o	o	+	o	o
	243	o	o	o	+	o	o	+	+	o
	244	o	o	3	25	+	o	51	2o	+
C	213	o	o	o	+	o	o	o	o	o
	229	+	o	+	+	+	+	+	o	o
	232	2	o	8	16	2	o	51	2o	o
	233	2	3	25	18	3	6	42	+	o
	234	4	11	43	16	2	8	16	+	o
	237	+	o	o	o	o	+	o	o	o
Mean of Stations group A		1.7	4.3	28	3o	2.3	6	26.3	o.7	o
Mean of Stations group B		1o.4	4.6	15.2	33.2	3	9.4	19.6	4.4	+
Mean of Stations group C		2.7	4.7	25.3	16.7	2.3	4.7	36.3	6.7	o

Table 3 : Mean frequencies (in %) of krill maturity stages in three groups of stations in January 1978.

Stations	Mean maturity stage frequency in %								
		♂♂			♀♀				
	I	I_b	II	III	II	III_a	III_b	IV	V
365	0	0	4	29	0	0	67	0	0
388	6	+	47	4	8	12	22	0	0
389	+	2	54	6	6	26	5	0	0

Table 4 : Maturity stage frequency (in %) on three stations in March 1978

Nototheniidae

Dissostichus eleginoides Smitt, 1898
D. mawsoni Norman, 1937
Pleuragramma antarcticum Boulenger, 1902
Notothenia rossii marmorata Fischer, 1885
N. (coriiceps) neglecta Nybelin, 1951
N. gibberifrons Lönnberg, 1905
N. larseni Lönnberg, 1905
N. kempi Norman, 1937
N. nudifrons Lönnberg, 1905
Trematomus eulepidotus Regan, 1914
T. bernacchii Boulenger, 1902
T. hansoni Boulenger, 1902

Muraenolepidae

Muraenolepis microps Lönnberg, 1905

Lampridae

Lampris guttatus (Brünnich, 1788)

Channichthyidae

Champsocephalus gunnari Lönnberg, 1905
Chaenocephalus aceratus (Lönnberg, 1906)
Pseudochaenichthys georgianus Norman, 1937
Chionodraco hamatus (?)(Lönnberg, 1905)
Cryodraco antarcticus Dollo, 1900

Bathydraconidae

Parachaenichthys charcoti (Vaillant, 1906)
Gymnodraco acuticeps Boulenger, 1902

Gadidae

Micromesistius australis Norman, 1937

Trichiuridae

Paradiplospinus gracilis (Brauer, 1906)

Rajidae

Raja spec.

Table 5 : List of the species identified