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SHORT NOTE

CHARACTERISTICS OF KRILL AGGREGATIONS IN THE SOUTH SANDWICH ISLANDS SUBAREA IN JANUARY–FEBRUARY 2000

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Abstract

During the survey of Subarea 48.4 from 17 January to 1 February 2000 it was observed that krill was present in non-aggregated and scattered forms, as well as in swarms. Differences between spatial distribution patterns of different krill aggregation forms in relation to water mass structure and dynamics were revealed.

Distributional features and physical characteristics of some 2 400 krill swarms detected in the study area were sized acoustically and are described in this paper. Results of comparisons of swarm parameters by area and season are given.

The effect of spatial distribution patterns of krill aggregations on the horizontal and vertical distribution of krill biomass is shown. About 64% of the krill biomass was concentrated in krill swarms in the upper 80 m depth layer within meander and eddy zones of the Weddell Sea (14% of the study area).

Spatial distribution patterns of krill aggregations and distribution of krill biomass density were analysed with a view to detecting potential fishing grounds where the recommended precautionary catch limit could be taken. Such fishing grounds could be located within the zones in which swarms were concentrated and where the biomass density was greater than 1.5 g m^{-3}. The biomass in these potential fishing grounds amounted to about 1.7 million tonnes. It was shown that the removal of biomass up to a recommended precautionary limit could be possible from such grounds despite a predicted low catch per hour of trawling.

Résumé

Pendant la campagne d'évaluation de la sous-zone 48.4, du 17 janvier au 1er février 2000, il est apparu que, parmi le krill présent, on notait du krill épars, du krill qui s'était dispersé et des essaims. Cette étude a de plus révélé des différences entre les schémas de répartition spatiale de diverses formes de regroupement du krill en rapport avec la structure et la dynamique de la masse d'eau.

Les caractéristiques de la distribution et physiques de quelque 2 400 essaims de krill détectés dans la zone d'étude ont été mesurées par méthode acoustique et sont décrites dans ce document. Les résultats des comparaisons des paramètres des essaims sont donnés par région et par saison.

L'effet des schémas de distribution spatiale des concentrations de krill sur la distribution horizontale et verticale de la biomasse du krill est indiqué. Environ 64% de la biomasse du krill est concentrée dans des essaims de krill situés dans la couche des 80 m supérieurs dans les zones de méandres et de tourbillons de la mer de Weddell (14% de la zone étudiée).

Les schémas de distribution spatiale des concentrations de krill et la répartition de la densité de la biomasse de krill sont analysés dans le but de découvrir de nouveaux lieux de pêche se prêtant à l'exploitation, dans la mesure où elle est restreinte à la limite de capture de précaution. Ces lieux de pêche pourraient se trouver dans les zones de concentration des essaims lorsque la densité de la biomasse y dépasse 1,5 g m^{-3}. Dans ces lieux de pêche possibles, la biomasse s'élevait à environ 1,7 million de tonnes. Le présent document indique qu'un prélèvement de la biomasse, dans les limites de précaution convenues, serait faisable malgré le faible rendement prévu par heure de chalutage.

Резюме

В ходе съемки Подрайона 48.4, проводившейся с 17 января по 1 февраля 2000 г., криль встречался в неагрегированных и рассредоточенных формах, а также в скоплениях. Были выявлены различия в пространственном распределении различных форм агрегаций криля в зависимости от структуры и динамики водных масс.

Особенности распределения и физические характеристики примерно 2400 скоплений криля, обнаруженных в районе исследований, были измерены акустически; результаты описаны в настоящей работе. Также приводятся результаты сравнения параметров скоплений по районам и сезонам.

Показано влияние характера пространственного распределения агрегаций криля на горизонтальное и вертикальное распределение биомассы криля. Около 64% биомассы криля концентрировалось в скоплениях в верхнем 80-метровом горизонте в зонах меандров и вихрей моря Уэдделла (14% района исследований).

Чтобы определить потенциальные промысловые участки, где возможно достижение рекомендуемого предохранительного ограничения на вылов, были проанализированы характер пространственного распределения агрегаций криля и распределение плотности биомассы криля. Такие участки могут находиться в зонах концентрации скоплений, где плотность биомассы превышает 1.5 г м$^{-3}$. Биомасса на этих потенциальных промысловых участках достигает около 1.7 млн. т. Показано, что, несмотря на прогнозируемый низкий вылов за час траления, с этих участков можно изъять биомассу объемом вплоть до рекомендуемого предохранительного ограничения.

Resumen

Durante la prospección de la Subárea 48.4 efectuada entre el 17 de enero y el 1º de febrero de 2000, se observó la presencia de kril disperso y en concentraciones. Se descubrieron diferencias entre la configuración espacial de distintas concentraciones de kril en relación con la estructura y dinámica de la masa hídrica.

El trabajo describe las características de las distribuciones así como las características físicas de unas 2 400 concentraciones de kril medidas en la zona de estudio con técnicas acústicas. Y presenta los resultados de una comparación de las variables de las concentraciones por área y temporada.

Se muestra el efecto de la configuración espacial de las concentraciones de kril en la distribución vertical y horizontal de la biomasa de kril. Un 64% de la biomasa de kril se concentró en profundidades menores de 80 m, en zonas de meandros y remolinos en el mar de Weddell (14% del área de estudio).

Se analizó la configuración espacial de las concentraciones de kril y la distribución de la densidad de la biomasa de kril con miras a detectar los caladeros de pesca donde sería posible extraer el límite de captura precautorio recomendado. Estos caladeros de pesca podrían situarse dentro de las zonas donde se agrupan las concentraciones y donde la densidad de la biomasa es mayor de 1,5 g m^{-3}. La biomasa en estos posibles caladeros de pesca fue estimada en unas 1,7 millones de toneladas. Se demostró que se puede extraer una biomasa equivalente al límite de captura precautorio en estos caladeros a pesar de que se ha previsto una baja captura por hora de arrastre.

Keywords: Antarctic krill, aggregation characteristics, catch, CCAMLR

INTRODUCTION

The study of krill aggregation patterns and schooling behaviour is very important, not only in studies of krill ecology, but also in the management of krill fisheries.

A series of papers has been published on the physical characteristics and spatial distribution of krill (Miller and Hampton, 1989a, 1989b; Miller et al., 1993; Kalinowski and Witek, 1982, 1985; Watkins, 1986; Everson, 1977; Murphy et al., 1988), small-scale processes influencing swarm formation and variability of krill biological characteristics (length, sex and maturity) in aggregations (Siegel and Kalinowski, 1994; Kalinowski and Witek, 1982; Watkins, 1986; Watkins and Murray, 1998), and the impact of characteristics of harvested aggregations on fishing efficiency (Ichii, 1987; Kasatkina and Latogursky, 1990). All these papers are based on the results of acoustic observations made in the Southwest Atlantic Ocean and in the Southwest Indian Ocean primarily during the FIBEX surveys (1981).

Core datasets (acoustic, biological and CTD data) obtained during the CCAMLR 2000 Krill Synoptic Survey of Area 48 (CCAMLR-2000 Survey) enable scientists to continue investigations of krill aggregation characteristics. It should be noted that the improved technologies and methodologies of data collection and processing used during this survey have made it possible to investigate different aspects of spatial distribution of krill aggregations within the whole of Area 48.

This paper deals with analyses of krill aggregation characteristics in the South Sandwich Island area (Subarea 48.4) obtained from data collected during the survey, which was carried out within the framework of the international CCAMLR-2000 Survey. The authors are not aware of other publications in which krill aggregation patterns in this sector of Antarctic waters have been discussed. The analysis focuses on horizontal and vertical biomass distribution relative to characteristics of registered krill aggregations. In addition, the authors' intention was to analyse the spatial distribution of different krill aggregation forms in order to detect potential fishing grounds where the precautionary catch limit recommended by CCAMLR (2000) could possibly be taken. Hypotheses concerning biomass estimates and the size of possible catches from potential fishing grounds were then put forward.

MATERIALS AND METHODS

The survey in Subarea 48.4 was carried out from 17 January to 1 February 2000 by the Russian research vessel *Atlantida*. Acoustic measurements were made using a Simrad EK500 echosounder at frequencies of 38, 120 and 200 kHz. SonarData's Echoview software was used for data collection and processing. Survey design, acoustic sampling protocols and data processing methods based on a two-frequency algorithm were detailed in papers by Hewitt et al. (2002), Trathan et al. (2001) and SC-CAMLR (2000). Maps of survey tracks and trawl station locations in Subarea 48.4 were published in Kasatkina et al. (submitted).

The horizontal and vertical distribution of krill biomass density was mapped based on the integration of hydroacoustic results per nautical mile for each 5 m depth layer up to 500 m. Density strata of horizontal krill distribution were created using SURFER software.

The classification scheme described by Miller and Hampton (1989b) was used to analyse the distribution of various types of krill aggregations. Krill swarm parameters (length, vertical extension or thickness, depth, volume, biomass density) from acoustic observations were obtained using the Schools Detection Module of SonarData's Echoview software.

Additional parameters calculated for the analysis of krill swarm spatial distribution were (Kadilnikov, 1991):

- relative density of swarm distribution in three-dimensional space, β (ratio of sum of swarm volumes to the volume of their habitat);
- two-dimensional density of swarm field, λ_s (number of swarms per unit of their distribution area);
- horizontal extent of krill swarm fields; and
- number of swarms per unit of distance along a transect.

The probabilistic–statistical theory model of trawl fishing developed by AtlantNIRO (Kadilnikov et al., 1989; Kadilnikov, 1993) was used to detect potential fishing grounds. A pelagic trawl PT 72/308 (Table 1), traditionally used by Russian vessels fishing for krill, was chosen as basic fishing gear. The catchability of this trawl was calculated as a function of krill distribution patterns and fishing gear parameters. Potential fishing grounds were identified by analysing possible catches forecast from trawl catchability and characteristics of krill distribution along the survey transects.

All mathematical formulas for calculating catchability, characteristics of krill swarm spatial distribution and possible catch are given in full in a series of publications (Kadilnikov et al., 1989; Kadilnikov, 1991, 1993; Kasatkina and Latogursky, 1990).

RESULTS

Horizontal Distribution of Krill

The horizontal distribution of krill biomass density (g m^{-2}) in Subarea 48.4 is illustrated in Figure 1 by strata of different density gradations. As shown in this figure, the major krill biomass was located south of the Weddell Gyre frontal zone (Weddell–Scotia Confluence – WSC) formed by waters of the Antarctic Circumpolar Current (ACC) and the Weddell Sea. Over 90% of the krill biomass was distributed in this area, and maximum biomass values were confined to Weddell Sea waters (Kasatkina et al., submitted). Density did not exceed 2 g m^{-2} over most of the study area. More than 60% of total krill biomass was concentrated in 14% of the survey area within two zones, with average biomass densities of 252.1 g m^{-2} and 56.0 g m^{-2} (Table 2). These zones were associated in time with the formation of meanders and eddies favourable for krill concentration.

According to the classification scheme by Miller and Hampton (1989b), the basic types of krill distribution in the study area were non-aggregated, scattered forms and swarm fields. The first two types were found all over survey area and were dominant in low-density strata of less than 2 g m^{-2} (Table 2).

Over 85% of all swarms observed in Subarea 48.4 were recorded mainly in Weddell Sea waters and were associated in time with the formation of meander and eddy zones (Figure 1). Swarm fields were dominant in the zones of high density (over 20 g m^{-2}) observed there.

Vertical Distribution of Krill

Krill was recorded within the 0–250 m depth layer (Figures 2 to 3). Non-aggregated and scattered forms were observed throughout that layer. Volume biomass density in respect of those forms did not exceed 0.02 g m^{-3}.

Krill swarms were recorded in the upper 80 m depth layer. Sites with increased biomass density (over 0.2 g m^{-3}) were adjacent to the same depth level. A comparison of maps of vertical and horizontal biomass density distribution is indicates that the formation of zones of high horizontal density (over 20 g m^{-2}) was related to krill swarm concentrations within the 15–80 m depth layer.

Swarms remained in the upper pycnocline layer and/or above it, moving no deeper than the layer of cold intermediate waters, the 'core' of which, on transect SSc, was observed in the 75–100 m layer in the south and in deeper waters (up to 120–130 m depth) in the northern part of the transect (Figures 2 and 3).

Non-aggregated and scattered forms observed at depths below 80 m were confined to zones of sinking cold water masses. This was especially evident in the WSC area (transects SSa and SSb north of 55°S and transect SSc north of 54°30'S) where colder Weddell Sea waters sink beneath warmer Scotia Sea waters.

Characteristics of Krill Swarm Distribution

The mean length of krill swarms was 28.9 m, with a mean depth of 5.6 m and an average biomass density of 21.7 g m^{-3} (Table 3). Histograms of distribution of these parameters are shown in Figure 4. Distribution of swarm length and biomass estimates are presented as log-transformed

Table 1: Principal parameters of the midwater trawl PT 72/308.

Parameter	Trawl 72/308
Vertical opening (m)	35
Horizontal opening between trawl boards (m)	100
Horizontal opening between wings (m)	40
Total trawl length along topenant (m)	182
Trawl bag length (m)	37
Mesh size in trawl bag (mm)	6.5
Trawl speed (knots)	3.5

Table 2: Distribution of krill density and biomass in Subarea 48.4.

Characteristics of Density Stratum	Density Stratum					
	<0.2 g m^{-2}	0.2–2 g m^{-2}	2–20 g m^{-2}	20–200 g m^{-2}	>200 g m^{-2}	Total Area
Mean area density (g m^{-2})	0.1	1.5	10.1	56.3	252.1	13.0
Area (km^2)	19 237.0	154 855.0	158 613.4	49 084.1	2 284.5	384 074.0
Biomass (tonnes)	1 269.6	236 928.2	1 603 581.5	2 763 433.7	575 917.4	5 181 130.4
Types of krill aggregation forming the density stratum	non-aggregated forms	scattered forms	fields of swarms and scattered forms			

Table 3: Mean values of krill swarm parameters.

Parameters of Krill Swarms	Subarea 48.4			Fishing Grounds						
				Subarea 48.4		South Orkney Islands Area			Elephant Island Area	
	January 2000	March 1983	March–April 1990	Potential Fishing Grounds (January 2000)	March 1983	January 1985	January 1990	February 1990	November 1984	January 1985
Mean depth range (m)	70	80	80	50	62	44.0	77.0	70.0	52.0	39.0
and CV (%)	25.3	31.3	29.3	25.5	36.9	19.5	29.3	19.5	29.6	25.2
Mean depth (m)	55.3	43.0	51.0	58.4	43.5	29.0	35.0	32.0	25.0	21.0
and CV (%)	41.2	36.6	30.1	45.2	40	18.9	25.5	30.3	36.6	41.1
Mean thickness (m)	5.6	7.0	4.9	7.7	8.1	9.0	5.0	19.0	6.0	7.0
and CV (%)	46.6	55.1	48.8	39.9	48.8	50.1	29.9	38.8	40.2	39.9
Mean length (m)	28.9	29.5	26.3	33.0	37	35.0	28.0	75.0	18.0	29.0
and CV (%)	61.5	59.9	53.5	46.6	41.6	51.3	39.9	40.2	39.9	30.3
Mean density (g m^{-3})	21.7	35	26.1	37.8						
Mean swarm biomass (tonnes)	0.169	0.271	0.129	0.538						
Percentage of swarms with biomass less than 1 tonne	96%	94.6%	95%	78%						
Number of recorded swarms	2 400	850	1 120	1 875	920	1 100	530	720	700	680

values. As is evident from Table 3, mean swarm parameters observed in Subarea 48.4 in January 2000 are comparable with those obtained from the same subarea in recent years (March 1983 and March–April 1990). A comparison of krill distribution patterns in different areas shows that mean swarm parameters in Subarea 48.4 are lower than those obtained during FIBEX and SIBEX for the Scotia Sea and Antarctic Peninsula region (Miller and Hampton, 1989b; Miller et al., 1993; Siegel and Kalinowski, 1994; Kalinowski and Witek, 1985). Mean swarm parameters observed in Subarea 48.4 are more comparable with parameters obtained in the Indian Ocean Sector where, according to FIBEX results, the mean length of krill swarms was 17.1 m, with a mean depth of 6.5 m and an average biomass density of 18.8 g m^{-3} (Miller and Hampton, 1989b; Siegel and Kalinowski, 1994).

Observed regularities in parameter distribution, namely the lognormal distribution of swarm lengths and swarm density and a trend towards the formation of smaller swarms, conform to those revealed in different regions of the Antarctic by other authors (Miller and Hampton, 1989a, 1989b; Kalinowski and Witek, 1982, 1985; Siegel and Kalinowski, 1994). As was found in this study, a large proportion of the biomass was contained in a relatively small percentage of the aggregations. As shown in Figure 4, approximately 96% of swarms have a biomass of less than 1 tonne. According to Miller and Hampton (1989b), approximately 95% of the swarms recorded in the southwest Indian Ocean during FIBEX had a biomass of less than 1 tonne.

Detection of Potential Fishing Grounds

The analysis of the horizontal and vertical distribution of krill density biomass in the study area shows that only the zones with densities greater than 20 g m^{-2}, formed by swarm fields distributed within the 0–80 m layer, may be of interest to commercial fishing. It was in these zones that the characteristics of krill swarm spatial distribution and its importance to trawl catchability were tested (Kadilnikov, 1991; Kasatkina and Latogursky, 1990; Zimarev et al., 1990).

The potential fishing grounds detected are shown in Figure 5. Mean swarm parameters in these grounds exceed mean estimates obtained in the entire study area in Subarea 48.4 (Tables 3 and 4), but they are comparable to those observed on conventional fishing grounds in other Scotia Sea regions. The results of trawl catchability assessments and probable catch per hour of trawling, estimated according to the probabilistic–statistical theory model of trawl fishing relative to trawl PT 72/308, are given in Table 4. Predicted catch size per hour of trawling and the extent of fishable aggregations are 1.97 ± 1.7 tonnes and 1.8 ± 1.3 n miles respectively. However, on some fishing grounds, the catch per hour of trawling may amount to 4.3 ± 2.0 tonnes (Table 4). The amount of biomass concentrated on potential fishing grounds is almost 1.7 million tonnes and the mean biomass density observed here is 1.7 g m^{-3}.

The characteristics of the spatial distribution of krill and sizes of possible catches on potential fishing grounds calculated for 2000 are comparable with those observed for the krill fishery in March 1983 (Table 4). It should be noted that potential fishing grounds for 2000 overlap with actual fishing grounds for 1983 (Figure 5).

DISCUSSION

During the survey carried out from 17 January to 1 February 2000 the spatial distribution of krill in Subarea 48.4 was characterised by the presence of non-aggregated, scattered forms and swarms.

Differences between the spatial distribution of various types of krill aggregations with respect to water mass dynamics and structure were studied. Although low-density, non-aggregated and scattered forms were distributed within the entire study area both in Weddell Sea and ACC waters, over 85% of all recorded swarms were confined to Weddell Sea waters, especially to meander and eddy zones. This is consistent with the findings of Miller and Hampton (1989b) that krill aggregations in regions without pronounced topographic or hydrographic features tend to be widely and evenly dispersed by the prevailing quasi-laminar water flow. Over 96% of the swarms with a biomass of greater than 1 tonne were encountered in the meander and eddy zones. This supports the hypothesis of Witek et al. (1982) that it is less likely that large aggregations may be formed in hydrographically ‘featureless’ regions. Similar results were also obtained in the West Atlantic Ocean Sector and the Indian Ocean Sector (Miller and Hampton, 1989b).

In this connection, it is interesting to note that about 64% of total krill biomass was associated with krill swarms located in the upper 80 m depth layer in meander and eddy zones of the Weddell Sea (14% of the survey area). Potential krill fishing grounds in Subarea 48.4 were linked to the same zones. Krill biomass concentrated there has been estimated at 1.7 million tonnes. This estimate exceeds the CCAMLR precautionary catch limit of

Table 4: Characteristics of potential fishing grounds in Subarea 48.4 obtained from the January 2000 acoustic survey.

Parameters	January 2000		March 1983
	Potential Fishing Grounds		Fishery Statistics Data for Entire Area
	Total Fishing Grounds	Zone of Max. Catch	
Area (km^2)	26 190.0		
Mean density ($g\ m^{-2}$)	64.9		
Mean biomass density ($g\ m^{-3}$)	1.7	4.2	2.1
Biomass (tonnes)	1 699 667		
Horizontal length of swarm fields (n mile)			
mean	2.5	1.8	4.5
SD	1.4	1.3	2.1
Mean depth range (m)	52.0	60.0	60.0
Mean swarm depth (m)	55.3	45.0	43.0
Mean swarm length (m)	33.0	46.8	37.0
Mean swarm thickness (m)	7.7	11	8.1
Density of a swarm field in two-dimensional space ($g\ m^{-2}$)	1×10^{-4}	2.9×10^{-4}	1.6×10^{-4}
Relative density of swarm distribution in 3-dimensional space	0.021	0.164	0.039
Estimates of trawl catchability	0.049	0.07	0.043
Calculated catch per hour of trawling (tonnes)			
mean	1.9	4.3	
SD	1.7	2.0	
Data on fishing statistics			
Catch per hour of trawling (tonnes)			
mean			2.2
SD			1.9

0.832 million tonnes (CCAMLR, 2000). However, estimates of possible catch per hour of trawling based on characteristics of the spatial distribution of krill aggregations predict a low catch per hour of trawling. The results obtained show that removal of krill biomass from potential fishing grounds in conformity with the precautionary catch limit may be possible irrespective of the predicted low catch per hour of trawling.

In can be seen that the potential fishing grounds, the krill distribution pattern and sizes of predicted catches from these grounds in 2000 are comparable with those reported for the krill fishery in March 1983. Similar results were obtained by comparing mean krill swarm parameters observed in January 2000 with those reported in the past from Subarea 48.4 (March 1983 and March–April 1990).

However, to date, Subarea 48.4 is the least studied and only a limited quantity of fisheries statistics is available compared with other subareas (48.1–48.3). In this context, the authors are not in a position to infer that their evaluation of the fishery potential in Subarea 48.4 is well substantiated.

Incidentally, it is worth noting that according to Sushin and Shulgovsky (1999), and despite the fact that the oceanographic situation in 2000 (poor water inflow from southern areas of the Scotia Sea and the southeastern sea proper, with krill concentrations 'cut off' from distribution in more northern areas by rather intensive easterly currents) was not favourable for krill drifting to South Georgia (as was the case in 1983/84), the possibility of direct krill transport towards the South Sandwich Islands and krill concentration in these waters has not been excluded. It would seem that the distribution of krill and fishing conditions in 1983/84 were different from those observed in January 2000.

It might also be noted that the analysis undertaken has demonstrated that the modelling based on the probabilistic–statistical theory of trawl fishing and data on krill distribution from hydroacoustic surveys could be used for the location of potential fishing grounds. As applied to krill, this analytical method seems to be reliable enough inasmuch as it is based on close correlation between experimental and estimated values (Kadilnikov et al., 1989; Zimarev et al., 1990).

CONCLUSION

Acoustic surveys of krill aggregations are important for an understanding of patterns in the spatial distribution of krill biomass and the detection of potential fishing grounds. Recent improvements in acoustic data collection and analytical methodology enable the reliable monitoring of spatial distribution patterns. In future, the status of krill stocks may be monitored more effectively by the combined analysis of fishery data and acoustic survey data. These two complementary approaches could also be used in combination to allow reliable management of krill fisheries and rational exploitation of krill resources.

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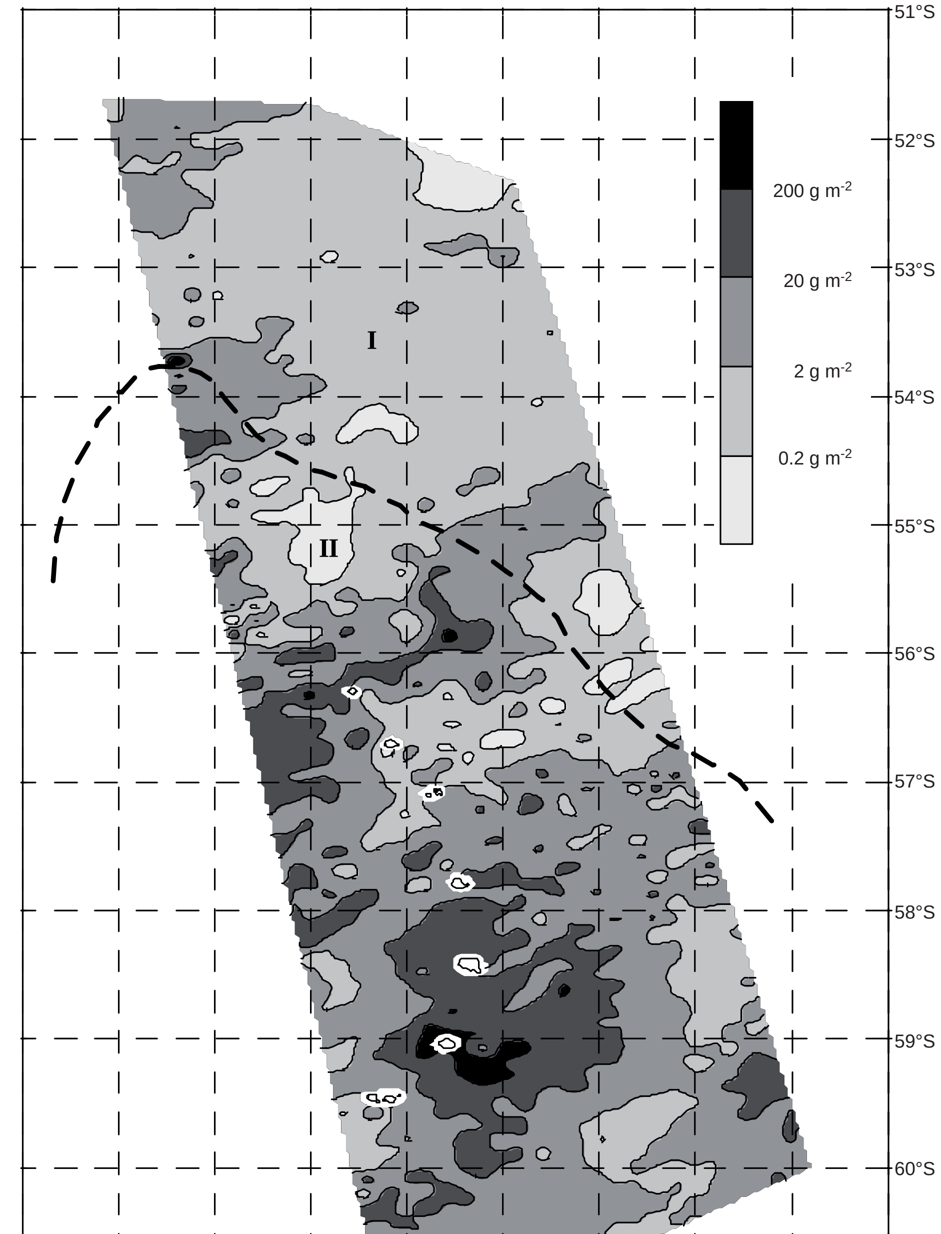


Figure 1: Krill density (g m^{-2}) distribution detected acoustically in the South Sandwich Islands area (Subarea 48.4) during January 2000. I – waters of the southern branch of the Antarctic Circumpolar Current; II – waters of the Weddell Sea and Weddell–Scotia Confluence.

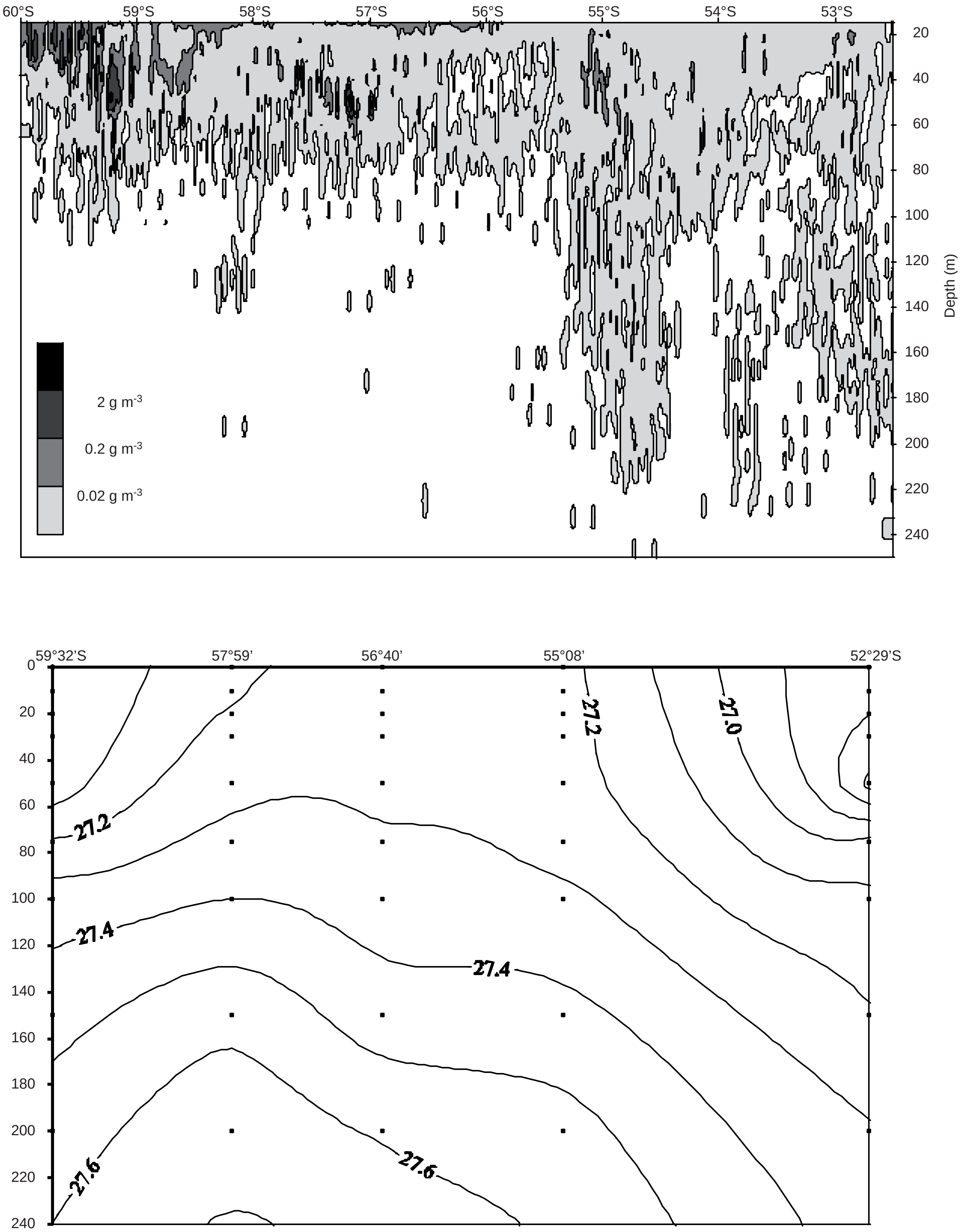


Figure 2a: Distribution patterns of krill density along the SSa transect in relation to water density, based on the results of the acoustic survey in Subarea 48.4 during January 2000. Upper pattern – vertical distributions of krill biomass density (g m^{-3}); lower pattern – vertical distribution of water density, sigma-*t* (kg m^{-3}).

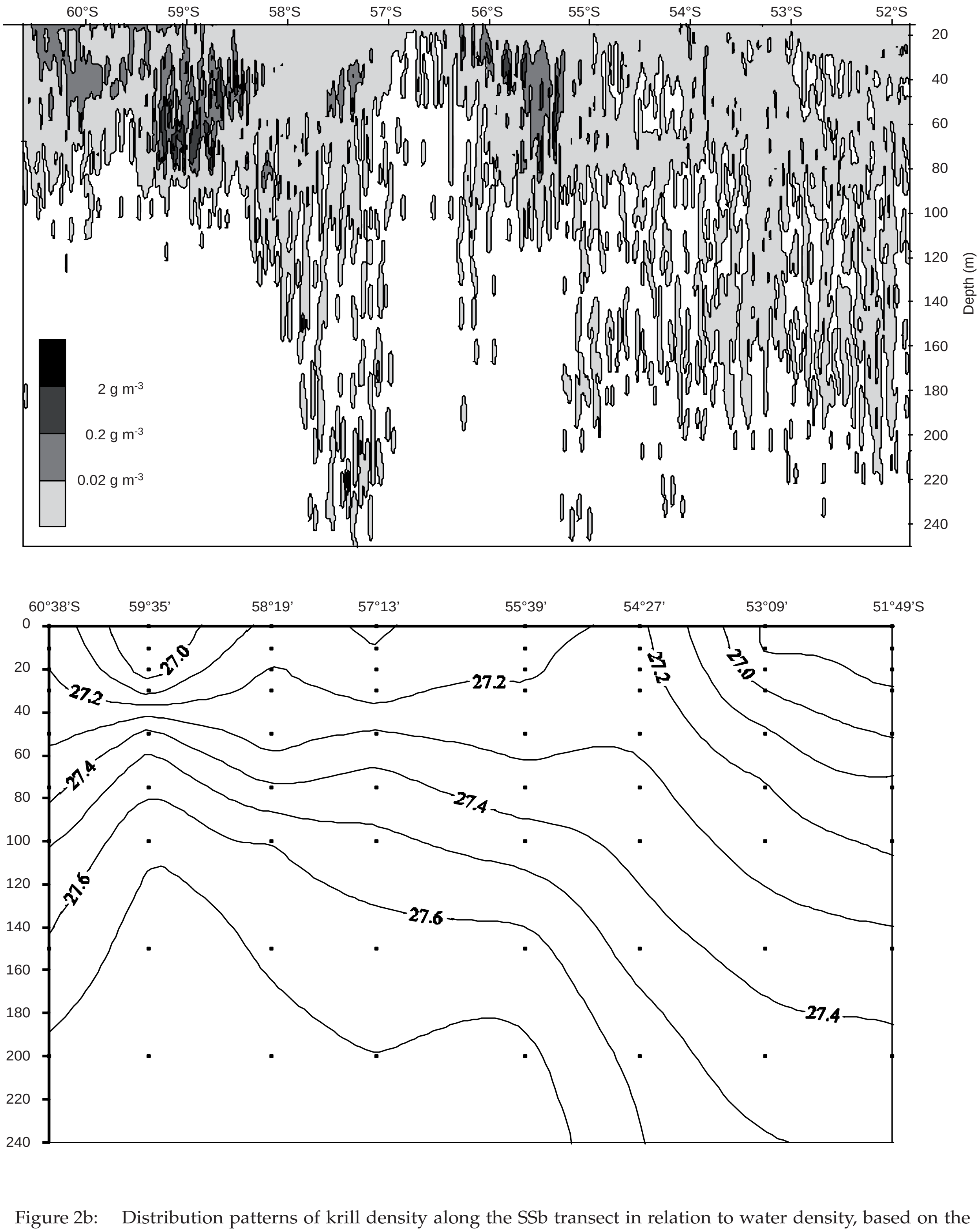
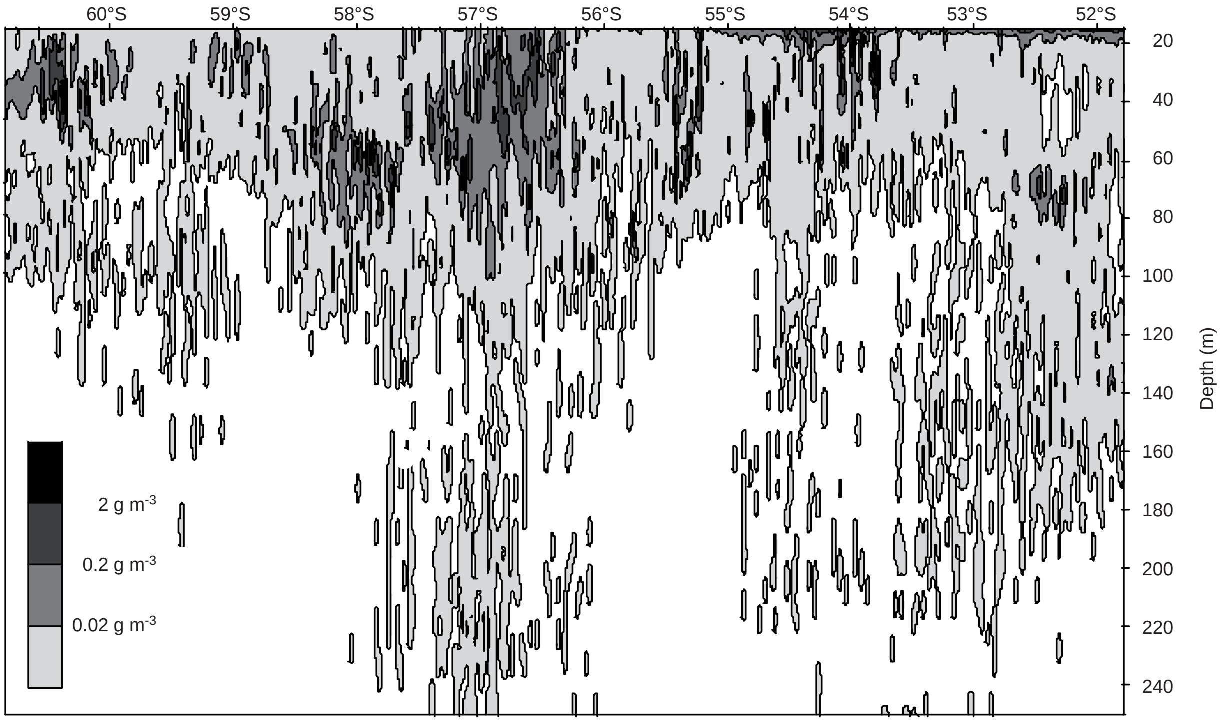


Figure 2b: Distribution patterns of krill density along the SSb transect in relation to water density, based on the results of the acoustic survey in Subarea 48.4 during January 2000. Upper pattern – vertical distributions of krill biomass density (g m^{-3}); lower pattern – vertical distribution of water density, sigma-*t* (kg m^{-3}).



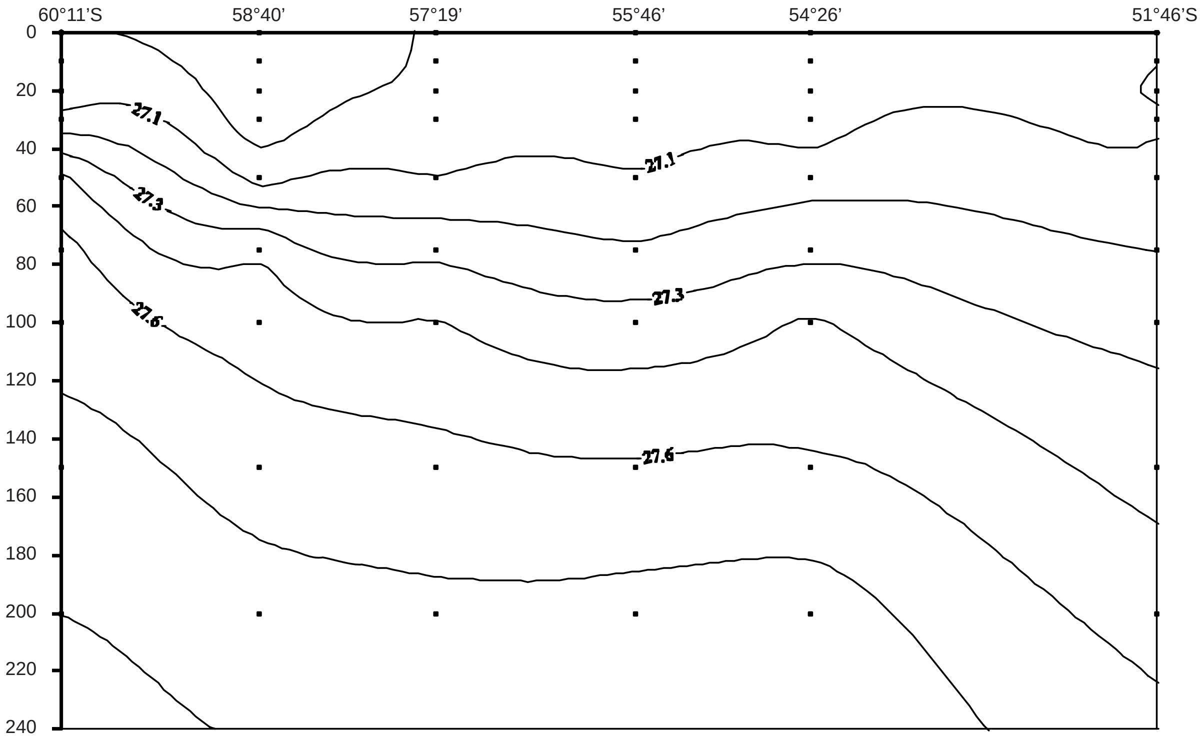


Figure 3: Distribution pattern of krill density in relation to environmental conditions, based on the results of the acoustic survey in Subarea 48.4 during January 2000. Data were obtained along the SSc transect. Upper pattern – vertical distributions of krill biomass density (g m^{-3}), water density distribution, sigma-*t* (kg m^{-3}); lower pattern – temperature distribution (°C), distribution of salinity (‰).

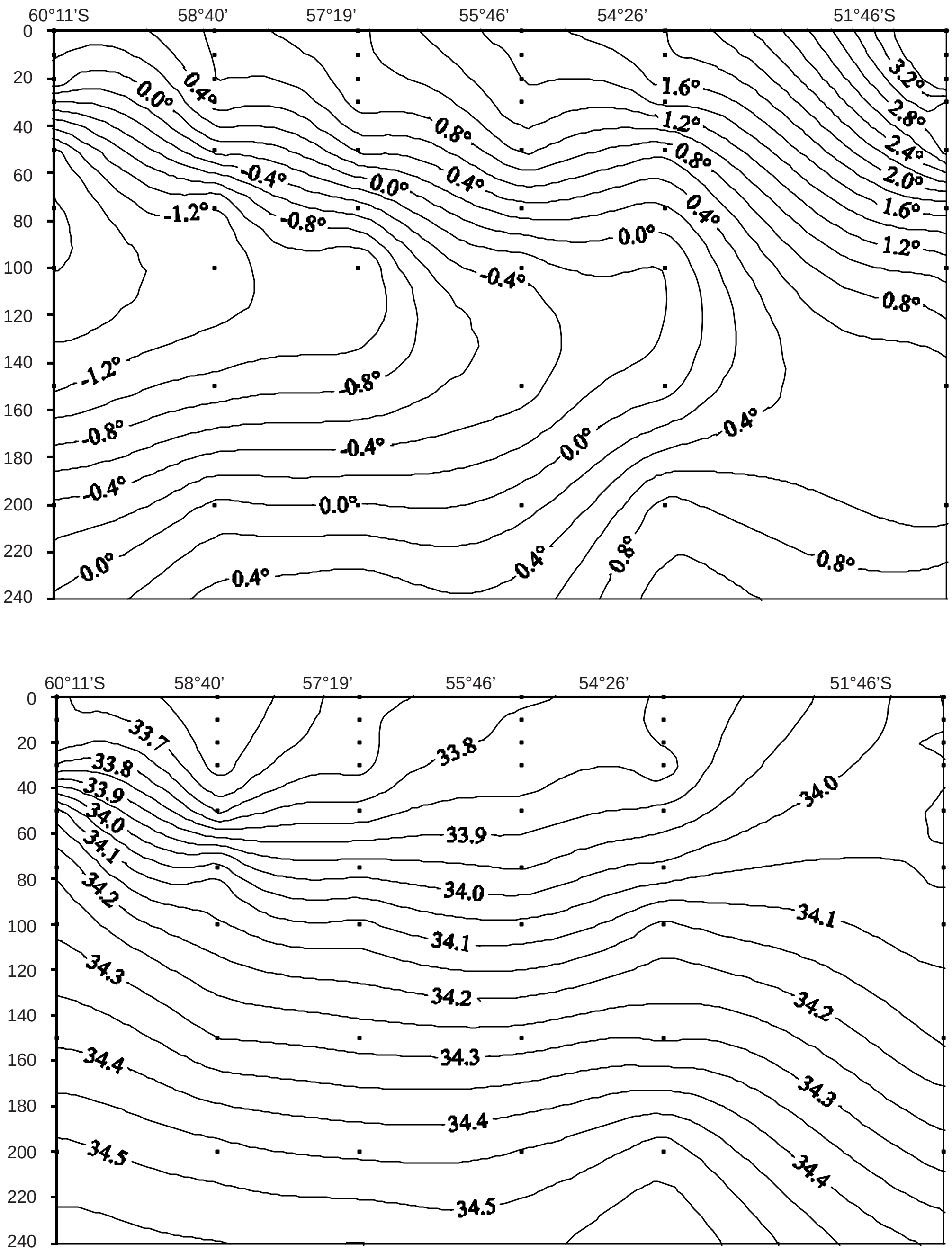


Figure 3 continued

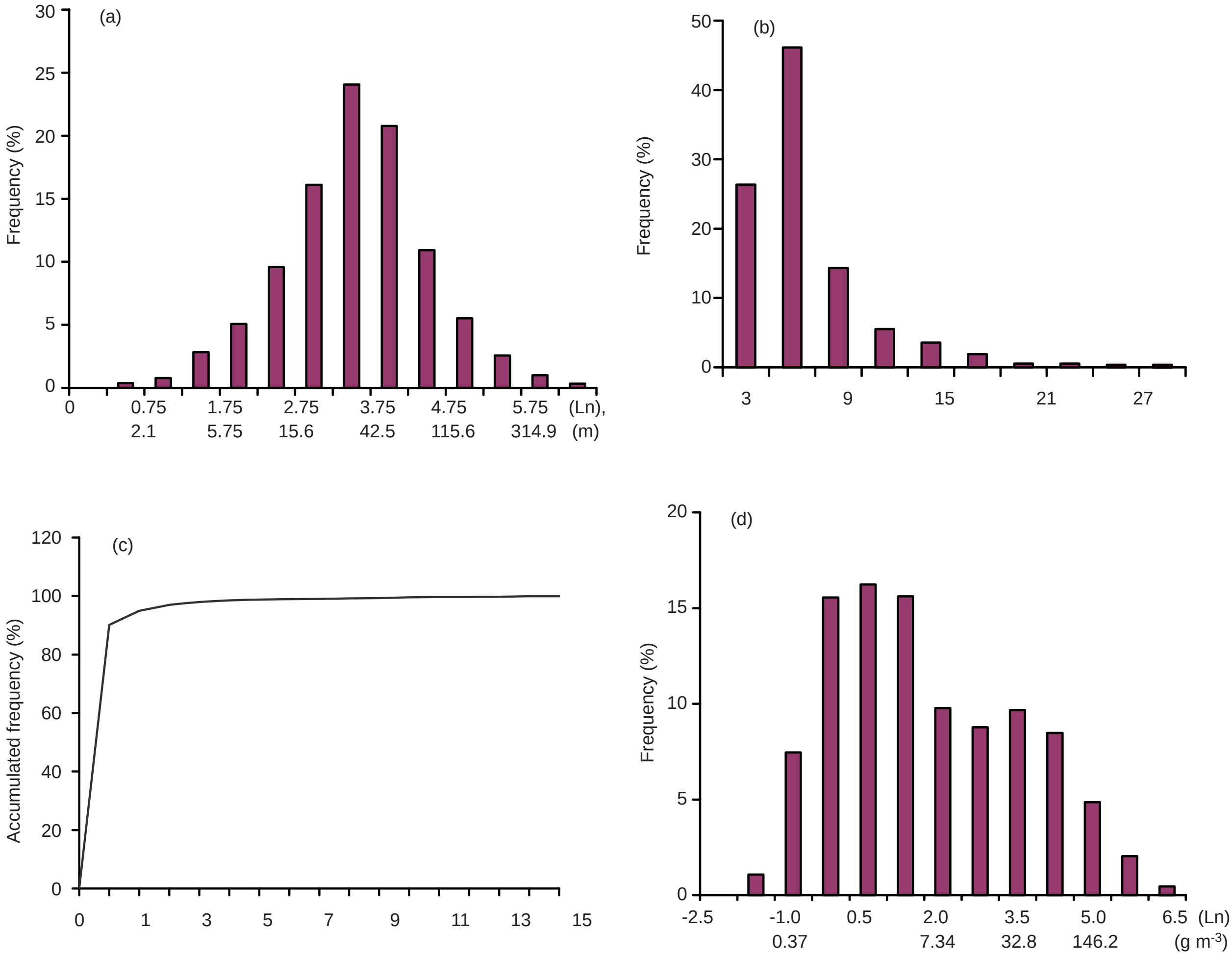


Figure 4: Krill swarm characteristics in Subarea 48.4 in January 2002: (a) the distribution of the natural log-transformed swarm length (m); (b) swarm thickness distribution (m); (c) accumulated frequency of swarm biomass (tonnes); and (d) the distribution of the natural log-transformed swarm density (g m^{-3}).

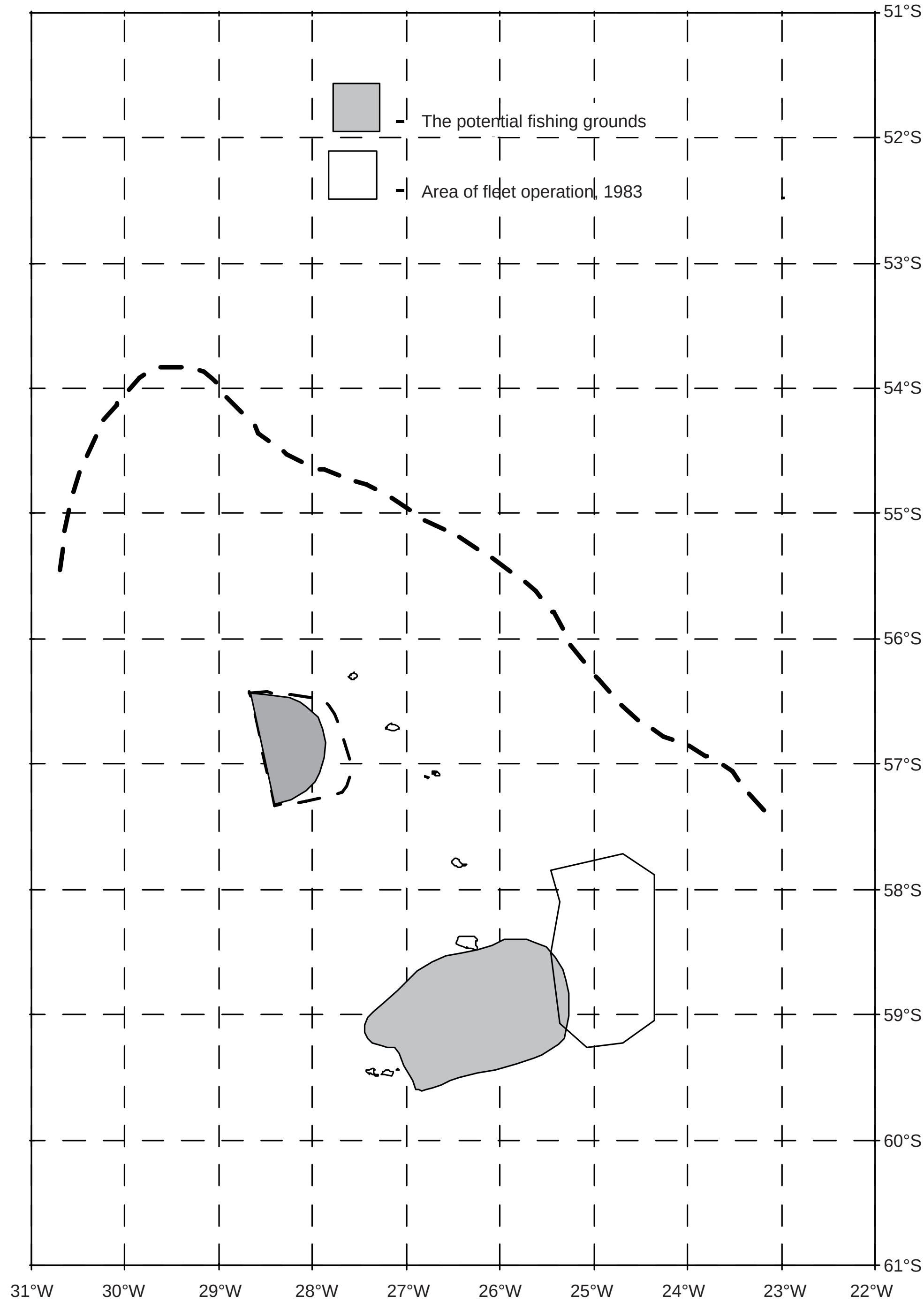


Figure 5: Location of krill fishing grounds based on results of the January 2000 survey and the area in which the fleet operated in 1983.

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