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Abstract

This document contains a selection of the scientific papers presented at meetings of the Scientific Committee and Working Groups of the Scientific Committee in 1991. Abstracts of the papers and captions of tables and figures are translated into the official languages of the Commission (English, French, Russian and Spanish).

Préface

Le présent volume contient une sélection de communications scientifiques présentées aux réunions du Comité scientifique et de ses Groupes de travail en 1991. Les résumés des communications ainsi que les légendes des tableaux et des figures ont été traduits dans les langues officielles de la Commission (anglais, français, russe et espagnol).

Резюме

Настоящий том содержит подборку научных работ, представленных на совещаниях Научного комитета и Рабочих групп Научного комитета в 1991 г. Резюме, названия таблиц и подписи к рисункам переведены на официальные языки Комиссии (английский, французский, русский и испанский).

Resumen

Este volumen contiene una selección de los documento científicos presentados en las reuniones del Comité Científico y de los Grupos de Trabajo del Comité Científico en 1991. Los resúmenes de éstos y los títulos de los cuadros y las figuras están traducidoa a los idiomas oficiales de la Comisión (español, francés, inglés y ruso).

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J.A. Frolkina and V.I. Shlibanov*

Abstract

High values of coefficient of variation resulting from the calculation of mackerel icefish biomass (*Champsocephalus gunnari*) from trawl survey data on the South Georgia shelf (Parkes *et al.*, 1989) challenge the rationale for round-the-clock trawling and call for clarification of the techniques used. The objective of the present study is to analyse data on daily vertical migrations of mackerel icefish. The study used data from research vessels which had been fishing for commercial concentrations of *C. gunnari* in years of high abundance of the species (1982/83, 1983/84 and 1986/87). Catch-per-hour of fishing was analysed by the time of day. Catches made by both bottom trawls and midwater trawls were taken into account. Information from the round-the-clock hydroacoustic observations on vertical migrations of *C. gunnari* as well as from observations on fish feeding is also considered in the paper. A distinct pattern of daily vertical migrations of *C. gunnari* was observed on the South Georgia shelf. During the day, fish concentrate near the bottom in concentrations 5 to 7 m thick. At night, fish disperse and migrate to the upper layers 50 to 60 m beneath the surface. The main peak of fish feeding activity was also observed at night. Fishing during this period with bottom trawls had yielded almost no catches at all. The information obtained on vertical migrations of *C. gunnari* may be used for clarification of survey techniques used in stock assessment. For a number of years scientists of AtlantNIRO have been conducting trawl surveys for *C. gunnari* during daylight hours only.

Résumé

Les valeurs élevées du coefficient de variation de la biomasse du poisson des glaces (*Champsocephalus gunnari*) calculée à partir des données des campagnes d'évaluation par chalutages sur le plateau de Géorgie du Sud (Parkes *et al.*, 1989) mettent en question le raisonnement selon lequel les chalutages doivent être effectués jour et nuit et demandent une clarification des techniques utilisées. La présente étude, dont l'objectif est l'analyse des données sur les migrations verticales quotidiennes du poisson des glaces, repose sur les données fournies par les navires de recherche ayant effectué des prélèvements dans les concentrations de type commercial de *C. gunnari.* pendant les années d'abondance de l'espèce (1982/83, 1983/84 et 1986/87). La capture par heure de pêche est analysée en fonction de l'heure à laquelle elle a été réalisée. Il est tenu compte à la fois des captures par chalutages de fond et des captures pélagiques. Ce document examine également les informations provenant tant des observations hydroacoustiques continues sur les migrations verticales de *C. gunnari* que des observations sur le comportement alimentaire de ce poisson. Les migrations nycthémérales de *C. gunnari* sur le plateau de Géorgie

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du Sud présentent de nettes tendances. Pendant la journée, les poissons se rassemblent près du fond, dans des concentrations de 5 à 7 m d'épaisseur. La nuit, les poissons se dispersent et fréquentent les couches supérieures, d'une profondeur de 50 à 60 m. Le principal pic d'alimentation des poissons a également été observé de nuit. La pêche au chalut de fond pendant cette période s'est soldée par des captures pratiquement nulles. Les informations obtenues sur les migrations verticales de *C. gunnari* peuvent servir à clarifier les techniques d'évaluation des stocks utilisées. Depuis plusieurs années, les scientifiques d'AtlantNIRO ont pour principe de ne mener d'évaluations par chalutages de *C. gunnari* que de jour.

Резюме

Высокие коэффициенты вариации, полученные при расчетах биомассы щуковидной белокровки (*Champsocephalus gunnari*) по результатам траловых съемок на шельфе острова Южная Георгия (Parkes *et al.*, 1989), ставят под сомнение правомерность круглосуточных учетных работ и требуют совершенствования методики. Целью данной работы является анализ данных по вертикальным миграциям щуковидной белокровки. В работе использованы данные научно-исследовательских судов, облавливавших промысловые скопления *C. gunnari* в годы с высокой численностью этого вида (1982/83, 1983/84 и 1986/87 гг.) Анализировались уловы за час траления, полученные в течение суток как донными, так и разноглубинными тралами. Приводятся также материалы круглосуточных гидроакустических наблюдений за вертикальными миграциями *C. gunnari*, а также данные суточных станций по питанию рыбы. По результатам наблюдений на шельфе острова Южная Георгия установлено наличие вертикальных миграций *C. gunnari* в течение суток. В светлое время рыба находится у грунта. Вертикальное развитие скоплений составляет 5-7 метров. Ночью они рассеиваются и мигрирует в толщу воды, достигая горизонтов 50-60 м. Пик питания приходился на ночные часы. В это время рыба практически не облавливалась донным тралом. Информация о вертикальных миграциях *C. gunnari* может быть полезна для уточнения методики траловых съемок. В течение нескольких лет АтлантНИРО проводит траловые съемки только в светлое время суток.

Resumen

Los altos valores del coeficiente de variación de la estimación de biomasa de draco rayado (*Champsocephalus gunnari*) calculada de los datos de las prospecciones de arrastre realizadas en la plataforma del archipiélago de Georgia del Sur (Parkes *et al.*, 1989), cuestionan el fundamento sobre el cual se basa la realización de arrastres continuados y destacan la necesidad de especificar las técnicas utilizadas. El objetivo de este estudio es el análisis de datos de la migración vertical del draco rayado. El estudio empleó los datos de los buques de investigación que pescaron concentraciones comerciales de *C. gunnari*

en años de gran abundancia de esta especie (1982/83, 1983/84 y 1986/87). La captura por hora de pesca fue analizada de acuerdo a la hora del día en la cual se realizaron los lances, considerándose las capturas con redes de arrastre de fondo y pelágicas. Este documento incluye también la información obtenida de las observaciones hidroacústicas continuas de la migración vertical de *C. gunnari* y de la alimentación de los peces. En la zona de la plataforma de Georgia del Sur se observó un patrón de migración vertical diaria de *C. gunnari*. Durante el día los peces se concentraron cerca del fondo en cardúmenes de 5 a 7 m de espesor. En la noche los peces se dispersaron, desplazándose a las capas más superficiales, hasta una distancia aproximada de 50 a 60 m de la superficie. El máximo de actividad de alimentación se observó durante la noche, y por consiguiente la pesca con redes de arrastre de fondo durante este período fue casi nula. La información obtenida de la migración vertical de *C. gunnari* podría ser utilizada para especificar las técnicas de prospección para evaluar el estado de las poblaciones. Por muchos años los investigadores del AtlantNIRO han adoptado la práctica de efectuar prospecciones de arrastre de *C. gunnari* durante el día solamente.

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1. INTRODUCTION

Scientists of several nations have in recent years carried out stock assessment studies of channichthyids and nototheniids in shelf waters of the South Georgia by means of trawl surveys. The assessment methodology suggested by Saville (1977) and widely used by Polish, Spanish, British and American scientists includes round-the-clock trawl surveys. However, availability of mackerel icefish, the main target species on the South Georgia shelf, varied considerably throughout the day. Taking into account this biological characteristic AtlantNIRO conducted trawl surveys only during daylight hours.

High values of coefficient of variation resulted from the calculation of mackerel icefish biomass (*Champsocephalus gunnari*) from trawl survey data (Parkes *et al.*, 1989) challenge the rationale for round-the-clock trawling and call for improvement of techniques in order to obtain reliable estimates.

The objective of the present study is to analyse data on daily vertical migrations of mackerel icefish. Results of the study may then be used in improving trawl survey techniques.

2. MATERIALS AND METHODS

The study used data obtained from research vessels which had been fishing for commercial concentrations of *C. gunnari* in years of high abundance (1982/83, 1983/84 and 1986/87). Catch-per-hour of fishing was analysed by time of day. Catches made by both bottom and midwater trawls were taken into account.

Average trawling depth for midwater trawls was measured at the level of the trawl head-rope.

Information from the round-the-clock hydroacoustic observations on vertical migrations of *C. gunnari* as well as observations on fish feeding characteristics is also considered in this paper.

3. RESULTS

Table 1 presents catch data obtained from research vessels fishing for commercial concentrations of *C. gunnari* on the South Georgia shelf. The highest catches were obtained during daylight hours (08:00 to 16:00 hr). With the onset of dusk (17:00 to 19:00 hr) fish begin migrating to the upper layers and the size of catches decreases abruptly from 13-14 to 2-8 tonnes per hour of fishing. At night, catches were usually 2.0 to 2.6 tonnes per hour of fishing. At sunrise, fish migrate to the bottom layers and catches again start to increase. The pattern of catch distribution for bottom trawls at various times of the day was found to be identical for all periods of observation. The combined catch distribution data for all three research cruises are presented in Figure 1. The abrupt decrease in catches during evening hours and the gradual increase of catches in the morning indicates that fish migrate more rapidly to the surface layers than to the bottom layers.

An echo sounder was used to search for fish concentrations when fishing with midwater trawls. Trawls were set at depths where concentration of fish was the highest. Therefore we did not observe any substantial differences in catches according to the time of day, although the highest catches were taken at sunrise and the lowest catches during the first half of the night (Table 1, Figure 2B). From the catch data of midwater trawls it was found that fish concentrations were situated near the bottom or at 10 to 30 m above the bottom during daylight hours (09:00 to 17:00 hr). Fish were found dispersed throughout the water column at night when catches were taken at depths between 60 to 180 m.

Daily vertical distribution of *C. gunnari* was also studied during a census trawl survey by RV *Gizhiga* in May 1984. Catches by bottom trawls demonstrated the same vertical distribution pattern of *C. gunnari* although abundance was low during that season. *C. gunnari* feeding was also examined. Two peaks of feeding activity were observed. Feeding was most intensive (first peak) during the night when fish concentrations moved out of the bottom layers and dispersed. Bottom trawling during this period yielded almost no catches at all. The second peak from 11:00 to 16:00 hr was observed only during cloudy days when fish partially migrated to the upper layers and catches were low.

Hydroacoustic observations on *C. gunnari* vertical distribution were carried out in October 1983. At night (01:00-02:00 hr), concentrations of fish were recorded at 50 to 60 m from the surface in waters from 100 to 200m deep (Figure 3). At sunrise (06:00-07:00 hr), fish were concentrated near the bottom. Concentrations were from 5 to 15 m thick (Figure 4). During the daylight hours (11:10-11:45 hr) fish remained close to the bottom where concentrations were 5 to 7 m thick (Figure 5).

4. CONCLUSION

Trawl surveys and hydroacoustic observations have demonstrated that *C. gunnari* completes vertical migrations on a daily basis. During daylight hours fish remained near the bottom in concentrations of 5 to 7 m thick. At night, fish dispersed and migrated to the upper layers 50 to 60 m beneath the surface. Migration is more rapid in the evening than in the morning.

The results obtained should be used for improving trawl survey techniques for *C. gunnari* stock assessment. For a number of years scientists of AtlantNIRO have been conducting trawl surveys for *C. gunnari* only during daylight hours.

REFERENCES

PARKES, G.B., I. EVERSON, J. SOSINSKI, Z. CIELNIASZEK AND J. SZLAKOWSKI. 1989. Report of the joint UK/Polish fish stock assessment survey around South Georgia, February 1989. *Document WG-FSA-89/6*. CCAMLR: Hobart. Australia. pp. 34.

SAVILLE, A. (Ed.) 1977. Survey methods of appraising fishery resources. *FAO Fish. Tech. Pap. No. 171*: 76.

Table 1: Catches of *Champsocephalus gunnari* (tonnes per hour of fishing) from the South Georgia shelf at various times of the day (n = number of hauls).

Cruise date and vessel name	Trawl type	Time of day											
		00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
April 1983 BMRT Pioner Latvii	Bottom	1.2 n = 3	4.6 n = 4	2.6 n = 4	6.0 n = 10	11.8 n = 9	11.1 n = 9	13.7 n = 8	8.9 n = 5	4.1 n = 8	8.8 n = 8	1.9 n = 3	1.7 n = 3
April-May 1983 BMRT E. Krivosheev	Bottom	4.8 n = 11	2.4 n = 10	2.8 n = 8	6.1 n = 11	4.6 n = 11	11.1 n = 13	6.8 n = 11	14.1 n = 13	2.2 n = 4	2.8 n = 6	2.0 n = 4	2.3 n = 10
November 1986 BMRT Atlant	Bottom	1.5 n = 3	0.7 n = 2	7.7 n = 1	3.6 n = 5	7.6 n = 4	4.9 n = 6	6.6 n = 6	4.4 n = 5	2.4 n = 4	4.1 n = 4	1.4 n = 2	0.9 n = 2
January 1983 BMRT Salekhard	Mid-water	5.3 n = 4	3.8 n = 7	9.6 n = 4	5.1 n = 6	5.7 n = 4	5.5 n = 4	3.6 n = 2	7.1 n = 4	-	7.5 n = 4	0.9 n = 2	2.6 n = 2

Table 2: Catches of *Champsocephalus gunnari* (kg per hour of fishing) from the north-western part of the South Georgia shelf.

Time of the day	07:00-09:00	09:00-10:00	10:00-12:00	12:00-14:00	16:00-19:00	19:00-21:00
Mean catch	2 122	2 054	4 686	2 997	200	300

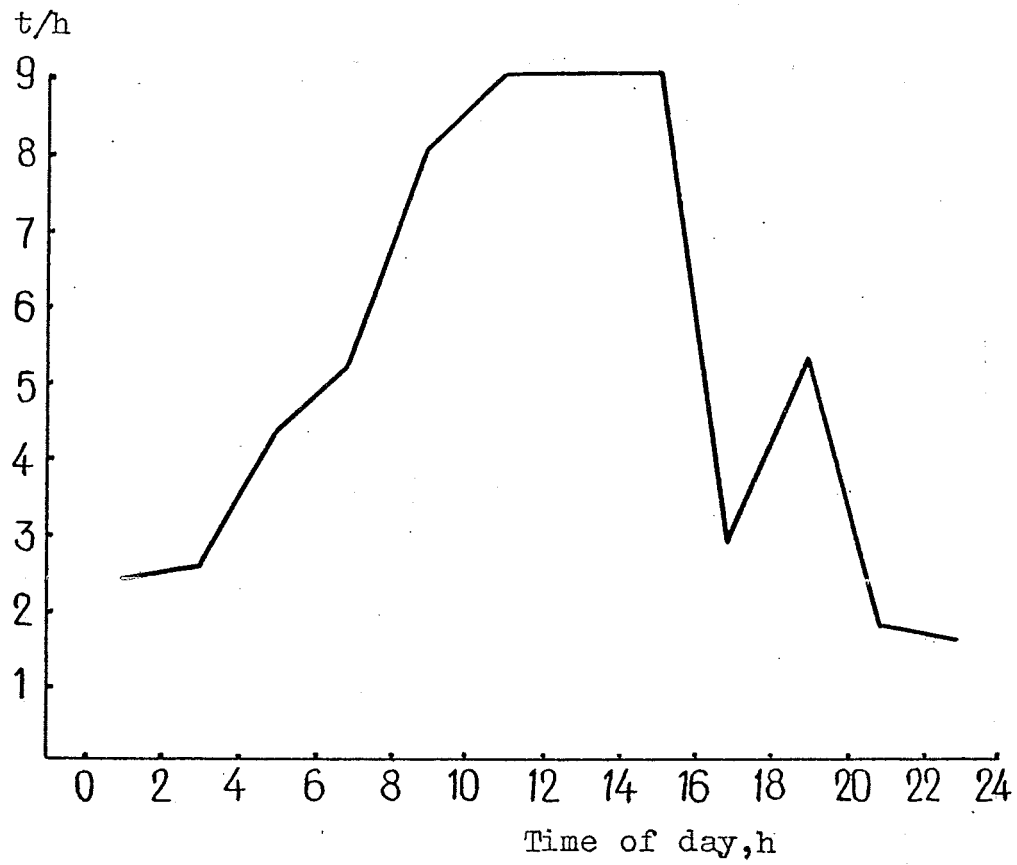

Figure 1: Bottom trawl catches of *C. gunnari* at various times of the day (tonnes per hour of fishing).

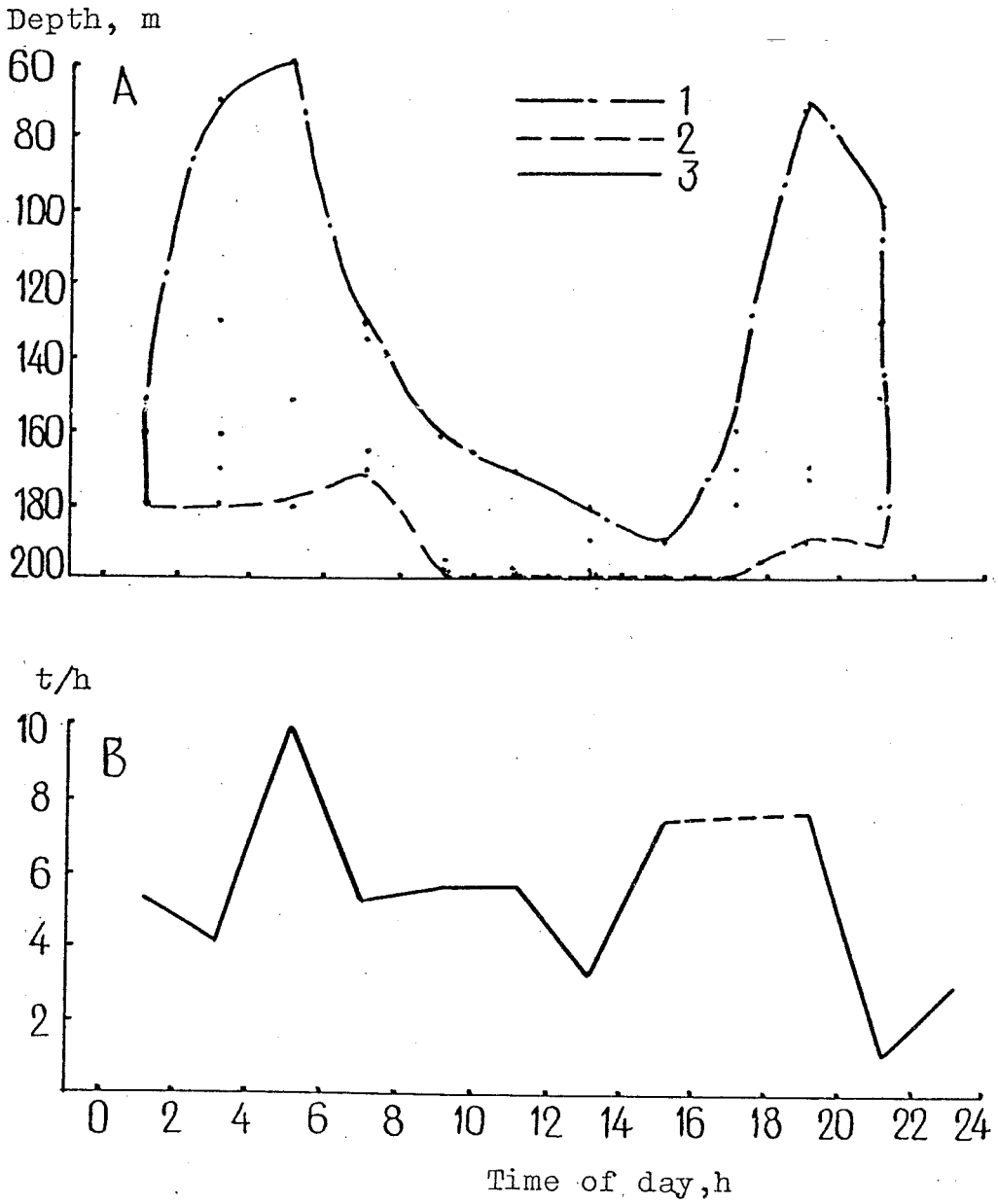

Figure 2: Vertical distribution of fished concentrations of *C. gunnari* (A) and catches per hour of fishing (B) by a midwater trawl in January 1983.
1 - The upper depth limit of catches;
2 - The lower depth limit of catches.

Figure 3: Echo sounder record of *C. gunnari* concentrations over the South Georgia shelf on 12 October 1983, 01:00 to 02:00 hr local time.

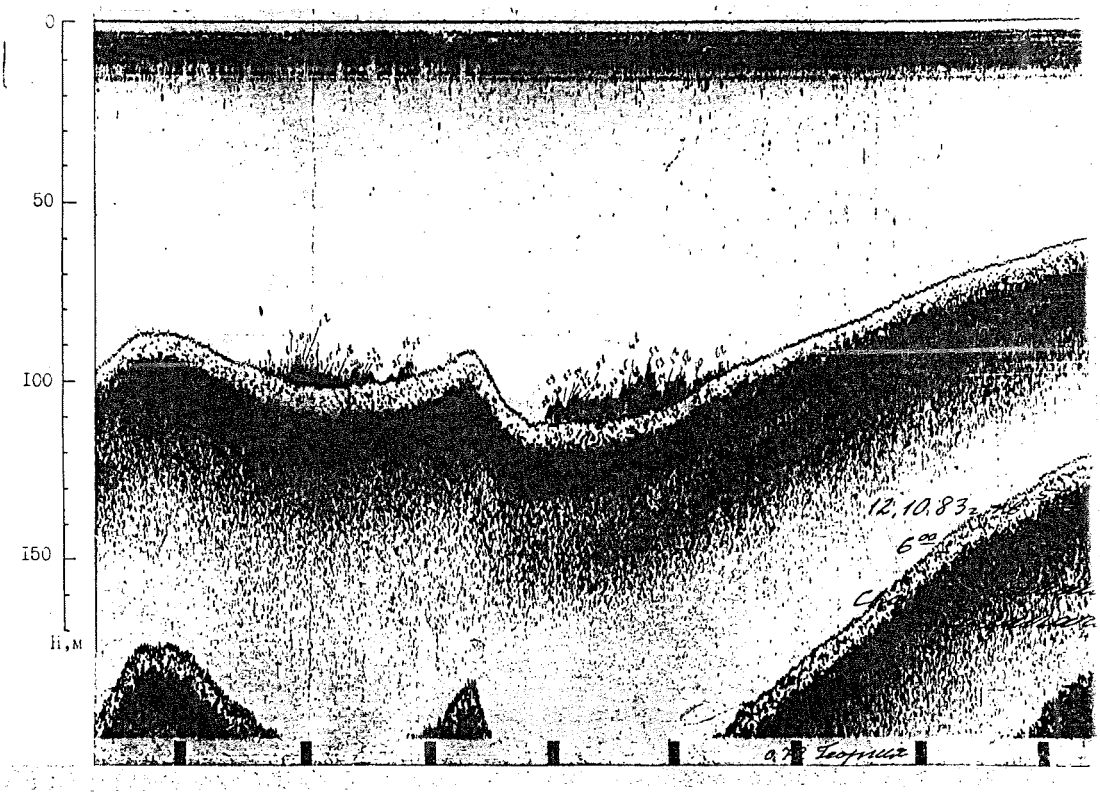

Figure 4: Echo sounder record of *C. gunnari* concentrations over the South Georgia shelf on 12 October 1983, 06:00 to 07:00 hr local time.

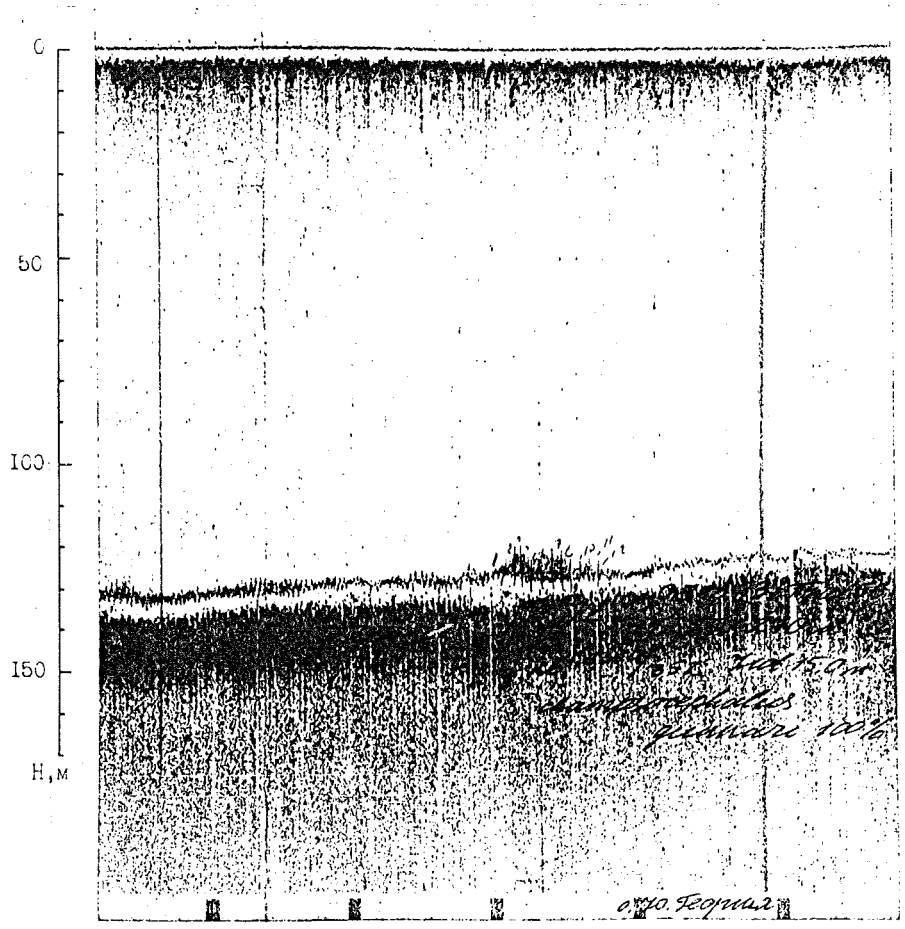

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Figure 4: Enregistrement par écho-sondeur des concentrations de *C. gunnari* sur le plateau de Géorgie du Sud le 12 octobre 1983, de 06h00 à 07h00, heure locale.

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FOOD AND FEEDING OF THE MACKEREL ICEFISH (*CHAMPSOCEPHALUS GUNNARI*) AROUND SOUTH GEORGIA IN JANUARY/FEBRUARY 1991

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Abstract

The diet composition and feeding intensity of mackerel icefish *(Champsocephalus gunnari)* around South Georgia in January/February 1991 were analysed in 3 877 stomachs collected at 44 stations. Both the proportion of krill *(Euphausia superba)* in the stomachs and the feeding intensity were uncommonly low in a period when energy rich food is needed for the final maturation of the gonads.

Résumé

La composition du régime alimentaire et l'intensité de l'alimentation du poisson des glaces (*Champsocephalus gunnari*) autour de la Géorgie du Sud en janvier/février 1991 ont été analysées pour 3 877 estomacs recueillis à 44 stations. La proportion du krill (*Euphausia superba*) dans les estomacs et l'intensité alimentaire relevées étaient particulièrement faibles en une période où des aliments de haute valeur énergétique sont nécessaires pour la maturation finale des gonades.

Резюме

Состав рациона и интенсивность питания ледяной рыбы *(Champsocephalus gunnari)* вокруг Южной Георгии в январе-феврале 1991 г. были проанализированы в 3 877 желудках. Образцы собирались на 44 станциях. Как пропорция криля *(Euphausia superba)* в желудках, так и интенсивность питания были необычно низкими в период, когда высококалорийная пища необходима для окончательного вызревания гонад.

Resumen

Se examinaron 3 877 estómagos de peces recolectados en 44 estaciones de muestreo con el propósito de analizar la composición cualitativa y cuantitativa de la dieta del draco rayado (*Champsocephalus gunnari*) alrededor de Georgia del Sur durante enero/febrero de 1991. Estos análisis demostraron que la proporción de krill (*Euphausia superba*) en los estómagos y la frecuencia de alimentación fueron extraordinariamente bajos durante el período cuando se necesita alimento de gran contenido energético para la madurez final de las gónadas.

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1. INTRODUCTION

The diet of mackerel icefish (*Champsocephalus gunnari)* around South Georgia and its seasonal and interannual variation has been comparatively well studied qualitatively (see reviews in Kock, 1981; Wilhelms, 1986; Kozlov *et al.*, 1988). Main prey items were krill (*Euphausia superba),* the hyperiid *Themisto gaudichaudii* and mysids (predominantly *Antarctomysis maxima).* Other euphausiids, such as *Thysanoessa* species or lanternfish (Myctophidae) are of minor importance. In years when krill is abundant it represents the staple food. Mackerel icefish then tend to aggregate in areas of krill concentrations. In years of low krill abundance it is replaced in the diet by the ubiquitous, albeit much smaller *T. gaudichaudii* which has a much lower caloric value than krill. In these krill-poor seasons mysids are also taken. *C. gunnari* are often more dispersed in these years of krill scarcity (Kock, 1981).

During the UK Demersal Fish Survey around South Georgia in January/February 1991 mackerel icefish were found to be widely dispersed over the upper part of the shelf (Everson *et al.*, 1991a). An unusually high proportion of sexually mature fish showed no signs of the gonad development necessary leading up to spawning in the coming season from March to May (Everson *et al.*, 1991b). It has been demonstrated in other fish species, such as winter flounder, *Pseudopleuronectes americanus,* that in the face of food shortage an adaptative strategy is to sacrifice egg production and maintain body size (Tyler and Dunn, 1976).

We report here on our findings of the food composition and feeding intensity of mackerel icefish in January/February 1991 which may aid in understanding the irregularities in the maturity process of the species around South Georgia in the 1990/91 season.

2. MATERIAL AND METHODS

The stomach contents of mackerel icefish were qualitatively analysed by one of us (K.-H. Kock) in 3 877 fish which were randomly collected on 44 out of 87 stations sampled during the survey.

Depending on the catch the number of fish investigated per station varied between 16 and 184 but comprised with the exception of four stations at least 40 individuals per haul. Stomach fullness was estimated according to a 5-point scale: 0 - empty, 1 - 1/4 full, 2 - 1/2 full, 3 - 3/4 full, 4 - 4/4 full, stomach wall extended. Prey items were identified to the lowest taxon possible, in general this was to species or genus. The occurrence of each taxon in the stomach was recorded and augmented by information on their prevalence. It was then expressed as a percentage of all stomachs containing food. Despite some shortcomings of this 'frequency of occurrence' method (see Pillay, 1952), its advantages are that it is quick, requires a minimum of apparatus and time and that results from a number of similar studies from previous seasons are available for comparative purposes.

3. RESULTS

3.1 Food Composition

Main prey items were *T. gaudichaudii* (62.5%), *E. superba (22.1%)* and mysids (predominantly *A. maxima)* (21.3%). Although krill was present in 22.1% of the stomachs, it formed the sole prey item in only 9.9% of the stomachs and was the predominant food item in another 9.0% of the stomachs. Other prey species or groups occurring were *Thysanoessa sp. (3.3.%),* myctophids *(Electrona sp., Gymnoscopelus sp.)* (1.8%), early life stages of fish (*C. gunnari* primarily age class 0 and 1) (1.4%) and *Euphausia triacantha* (<0.1%).

The occurrence of the main prey items varied locally. Krill was predominantly found in fish collected on the eastern shelf while mysids were prevailing in parts of the northwestern shelf, in the southeast and on coastal stations in the east. *T. gaudichaudii* was the staple food in most of the western part of the shelf. In fish from the westernmost three stations myctophids formed a significant proportion of the diet (Figure 1).

3.2 Feeding Intensity

More than 50% of the stomachs contained little (1) or no food (0):

Degree of Fullness	**n**	%
0	1 306	33.7
1	839	21.6
2	777	20.0
3	803	20.7
4	152	3.9

The proportion of empty stomachs varied considerably among stations (3.9 to 74.0%). The proportion of stomachs containing little or no food was highest in the west of South Georgia (Figure 2).

4. DISCUSSION

Our study albeit the most extensive analysis carried out so far confirmed, in general, results from earlier investigations on the food composition of mackerel icefish around South Georgia in that the hyperiid *T. gaudichaudii,* krill and mysids form their staple food. A comparison with earlier studies revealed a considerable variation in the importance of each of these prey items from year to year (Figure 3). It cannot be excluded that part of this variation may be due to variations in sample size (60 to 3 877) and an unrepresentative coverage of the shelf from year to year. However, two pairs of observations in December/January 1975/76 (Kock, 1981) and February/March, 1976 (Kozlov *et al.*, 1988) and in January/February 1985 (Wilhelms, 1986; Kozlov *et al.*, 1988) which were each based on several hundred stomachs led to essentially very similar results (Figure 3). It is thus likely that differences between years largely reflect the interannual variations in the availability of the preferred prey *E. superba* around South Georgia. If this hypothesis is correct, then the results we have presented here from a large sample suggest that krill availability in January/February 1991 was one of the lowest within the 16-year period of observation (Figure 3).

A lower krill index in the stomachs was only observed in March 1976 (Linkowski and Rembiszewski, 1978) and January/February 1979 (Kozlov *et al.*, 1988). The observations in March 1976, however, are probably largely biased by their small sample size (**n** = 113) and the poor coverage of the shelf. Plankton surveys in the same season indicated a high abundance of krill around the island (Pommeranz, 1978) which is clearly reflected in the high incidence of krill in icefish stomachs investigated between December 1975 and March 1976 in two other studies (Figure 3; Kock, 1981; Kozlov *et al.*, 1988). Krill occurrence in stomachs of *C. gunnari* in January/February 1991 was even lower than in 1977/78 (Figure 3), a season when krill biomass around the island was found to be very low (Bonner *et al.*, 1978; Wörner, 1979) and reproductive success in krill-eating birds was found to be poor (Croxall *et al.*, 1988).

Despite large variations in stomach fullness within or between seasons locally the proportion of empty stomachs of mackerel icefish in the various studies was commonly of the order of 10 to 20% (Kock, 1981; Wilhelms, 1986; Kozlov *et al.*, 1988). Higher proportions of

empty stomachs were observed only in March 1976 (Linkowski and Rembiszewski, 1978; see discussion above) and in material combined for the period January/February 1965 to 1969 (Kozlov *et al.*, 1988). This indicates that the high proportion of stomachs in January/February 1991 containing little or no food again reflected a situation uncommon in most previous observations.

We do not know at present if our findings are representative for a longer period than the three weeks of the survey. The high dispersal of icefish earlier in this season which made any fishing unprofitable may indicate that this may have been the case. Under these circumstances, both the high incidence of low caloric prey *(T. gaudichaudii)* in the food of mackerel icefish and the low feeding intensity of the fish in the period when energy-rich food is needed for the rapid build-up of the ovaries could have had considerable consequences for the final maturation process in that season.

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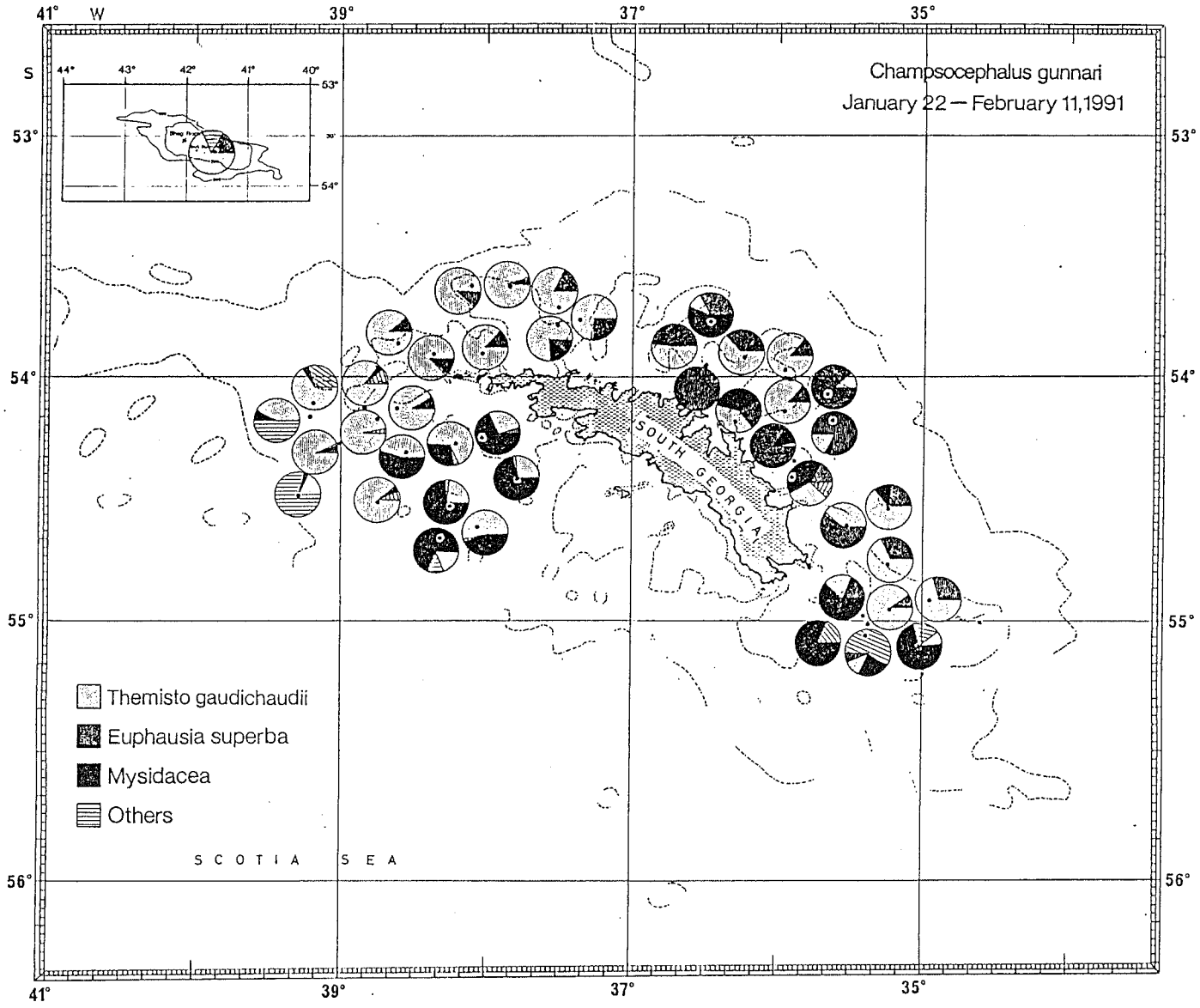


Figure 1: The food composition of mackerel icefish (*C. gunnari)* per station around South Georgia in January/February 1991.

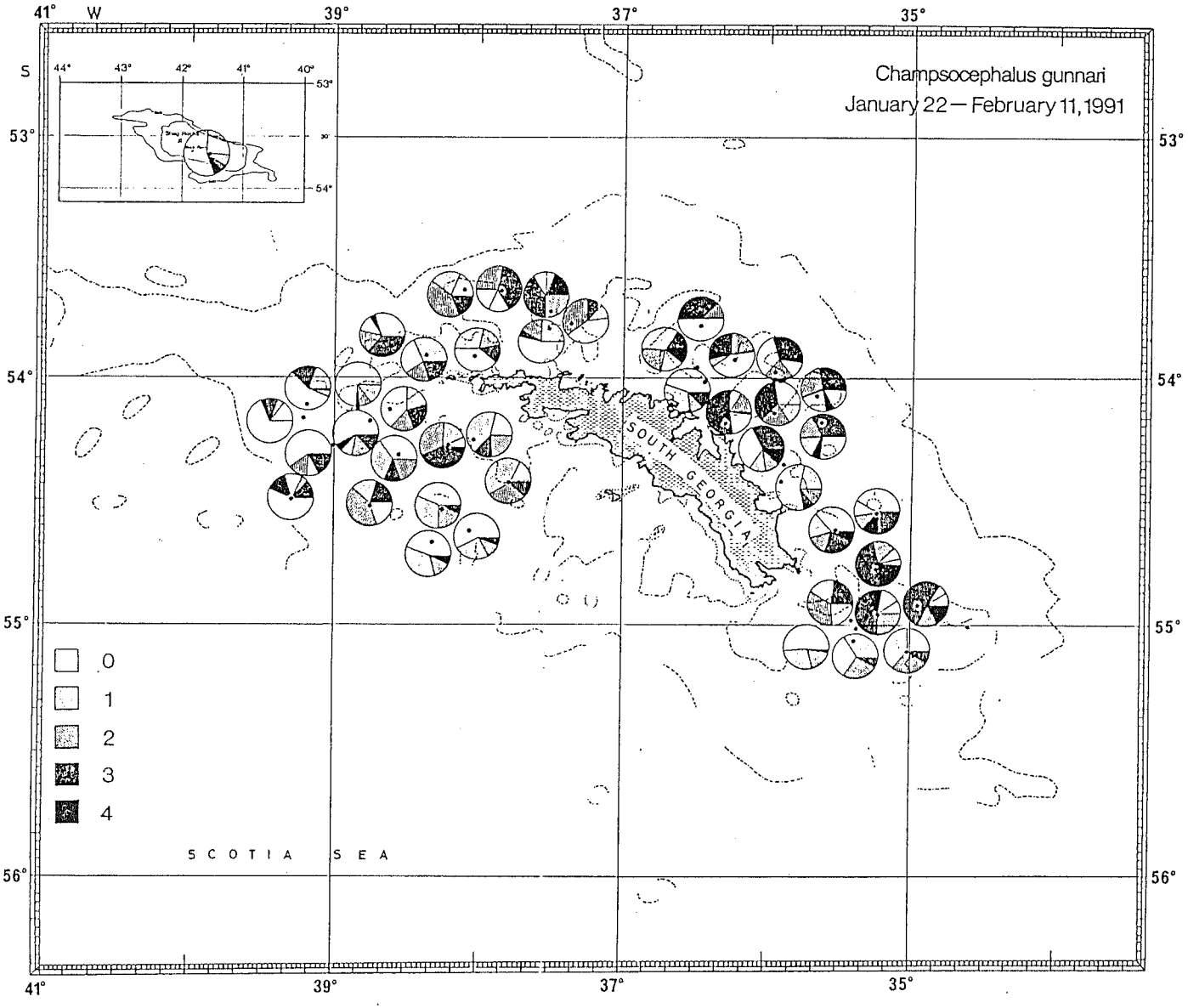
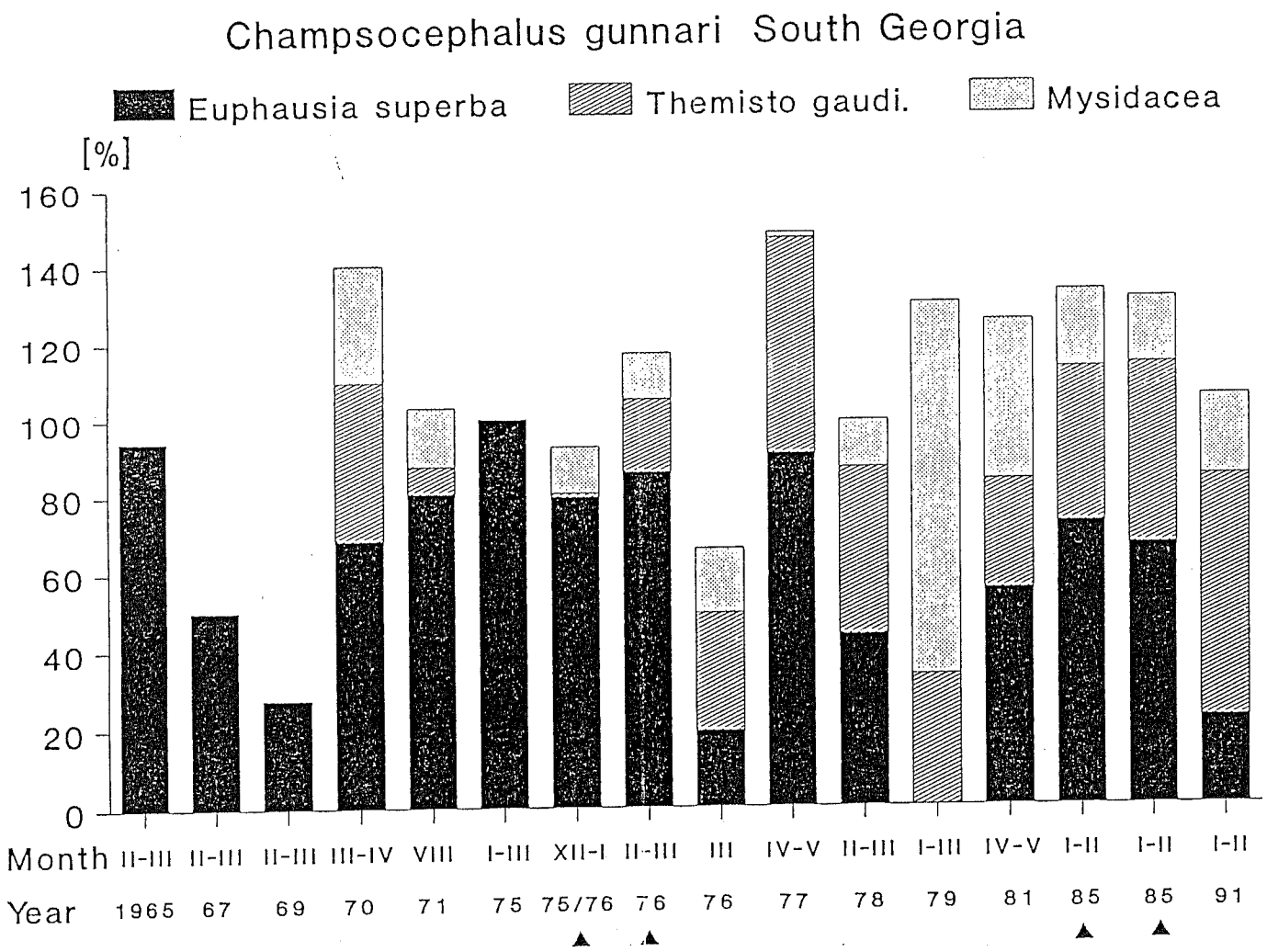


Figure 2: Stomach fullness (5-point scale) per station in mackerel icefish (*C. gunnari)* around South Georgia in January/February 1991.



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FISH STOCK ASSESSMENT SURVEY IN SUBAREA 48.3

I. Everson[1], G. Parkes[2], K.-H. Kock[3], S. Campbell[1], Z. Cielniaszek[4] and J. Szlakowski[4]

Abstract

A demersal fish survey in the vicinity of South Georgia, CCAMLR Subarea 48.3, is described. Details are given of positions of hauls, catch rates and size composition of catches. The standing stock of one of the most important commercial species in the area, *Champsocephalus gunnari*, is shown to have undergone a major decline by comparison with results from the 1989/90 season. Other species do not show a similar dramatic reduction. No commercial fishing on *Champsocephalus gunnari* has been reported from the area. It is suggested that this decline may be due to either a massed migration or high mortality.

Résumé

Description d'une campagne d'évaluation des poissons démersaux aux environs de la Géorgie du Sud, sous-zone 48.3 de la CCAMLR. Précisions sur la position des chalutages, les taux de capture et la composition en taille des captures. Il est révélé que le stock existant de l'une des espèces commerciales les plus importantes dans la région, *Champsocephalus gunnari*, a subi un déclin considérable par comparaison aux résultats de la saison 1989/90. D'autres espèces ne paraissent pas présenter une réduction aussi notable. Aucune pêche commerciale de *Champsocephalus gunnari* n'a été déclarée dans la région. Il est suggéré que ce déclin pourrait avoir deux causes possibles : une migration de masse ou une mortalité élevée.

Резюме

Описана съемка демерсальных рыб вблизи Южной Георгии, Подрайон АНТКОМа 48.3. Приведена информация о положениях тралений, темпах вылова и размерном составе уловов. Выявлено значительное уменьшение биомассы одного из наиболее важных коммерческих видов этого района, *Champsocephalus gunnari*, по сравнению с результатами сезона 1989/1990 г. Подобного драматического уменьшения в запасах других видов не обнаружено. Поскольку сведений о коммерческом промысле *Champsocephalus gunnari* из этого района не поступало, предполагается, что упадок мог произойти вследствие массовой миграции или высокой смертности рыб.

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Resumen

En este documento se describe una prospección de peces demersales realizada cerca de Georgia del Sur, en la Subárea 48.3 de la CCRVMA, y se proporcionan detalles de la posición de los lances, índices de capturas y composición por talla de las capturas. Al comparar la población fija de una de las especies comerciales más importantes de este área, *Champsocephalus gunnari*, con los resultados de la temporada 1989/90, se observa que ha ocurrido una gran disminución. Otras especies no presentan una reducción tan drástica. No se ha notificado ninguna pesquería comercial de *C. gunnari* en esta zona. Se sugiere que esta disminución puede deberse a una migración masiva o a una alta mortalidad.

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1. INTRODUCTION

The fish stocks in Subarea 48.3, South Georgia, have been the subject of considerable interest for many years mainly because this area has formed the focus for much of the commercial fishing activity for finfish within the CCAMLR area. The need for further assessment of the stocks within this subarea has been emphasised by the CCAMLR Working Group on Fish Stock Assessment (WG-FSA) (SC-CAMLR, 1990a).

This report presents the results from a fish stock assessment survey undertaken by the United Kingdom in January and February 1991 within Statistical Subarea 48.3 (South Georgia). The main aim of the study was to determine the standing stock of the commercially important demersal fish species with particular reference to the icefish, *Champsocephalus gunnari*. Information is presented in accordance with the recommendations of the Task Group for Information Reported to WG-FSA (SC-CAMLR, 1990a) .

2. SURVEY AREA AND DESIGN

The survey was aimed at providing information representative of the shelf area within Subarea 48.3. Effectively this is the shelf area of South Georgia and Shag Rocks.

The survey design was similar to those of previous years (Parkes *et al.*, 1990) with a series of randomly located trawl stations down to a depth of 500 m. The same three depth strata, 50 to 150, 150 to 250 and 250 to 500 m, were used as on previous surveys. To ensure adequate coverage the area was divided into CCAMLR 'fine-scale rectangles' half a degree of latitude by one degree of longitude. Within each of these rectangles the numbers of stations within each of these depth strata were allocated in proportion to the area of seabed and expected fish concentration of *Champsocephalus* within the stratum. Wherever possible proposed trawling locations were chosen from those successfully sampled on previous surveys. Sampling locations were allocated to all fine-scale rectangles with the exception of those to the south of the centre of South Georgia. These three rectangles, numbers 19, 20 and 24 on Figure 1, are known to contain large areas of bad ground and thus have a high risk of trawl damage.

The survey design provided for 72 stations to be sampled at South Georgia and 12 at Shag Rocks. Due to time constraints and also because some intended sites were unsuitable for fishing not all sites were fished. A total of 66 sites was fished at South Georgia and 12 at Shag Rocks. The locations of the sites actually sampled are shown in Figure 1 and the positions given in Table 1. The mean area assumed to be representative of a station within each depth stratum and at each location is shown in Table 2.

A standard haul duration of 30 minutes with the net on the bottom was used. However if the net came fast, or bad ground was encountered during the tow necessitating early retrieval of the net, providing the net had been on the bottom for more than fifteen minutes the haul was considered representative. All hauls were undertaken during the hours of daylight to minimise the possible underestimation of those species that migrate off the bottom at night.

3. DESCRIPTION OF VESSEL AND SAMPLING METHODS

A stern trawler converted for use as a fishery survey vessel was used for the survey, it had the following characteristics:

Name:	*Falklands Protector*
Call sign:	GYMA
Type:	Stern trawler (modified by conversion of part of hold to laboratories)
Length overall:	69.15 m
Breadth:	12.0 m
Main Power	2500 bhp

Two echosounders were used during the study. A Kelvin Hughes MS 44 echosounder operating at a nominal frequency of 30 kHz was used for bottom detection and a Koden 'Chromascope' operating at 48 kHz was used to indicate the hardness of the bottom. The latter echosounder was also connected to a Biosonics Echosignal Processor for fish quantification and was continually monitored for the presence of schools of fish above the bottom.

A net as close as possible to that used for the *Professor Siedlecki* survey (Parkes *et al.*, 1989) in 1989 was used, full net drawings with nominal mesh sizes are given in Figure 2. All netting was composed of diamond meshes. Mesh sizes were measured, in accordance with CCAMLR procedures, at the end of the survey and the results set out in Table 3. Field trials undertaken by the Sea Fisheries Industry Authority (UK) provided data on the dimensions of the trawl when in operation and these were latter confirmed by tests in a flume tank on a model of the trawl. Equations relating the principal dimensions to the towing speed are as follows:

$$A = [-2.295\ S] + [-78067\ (S^{-10})] + 29.08$$

where **A** = horizontal opening (m), and

S = towing speed (knots)

Positions were fixed using either Global Positioning System (GPS) or by satellite navigator. Satellite navigator fixes were available at irregular intervals of up to six hours. The GPS was operational for only part of the cruise and then, because of the incomplete satellite cover, only for about half the day.

The landed catch of all fish species at each station was measured. Further analyses were made for the following species: *Champsocephalus gunnari, Chaenocephalus aceratus, Pseudochaenichthys georgianus, Notothenia gibberifrons, Notothenia rossii, Notothenia squamifrons, Dissostichus eleginoides* and *Patagonotothen brevicauda guntheri.* Total length (to the nearest centimetre below), sex and maturity (SC-CAMLR, 1989) were determined for a representative sample of fish of these species in the catch. Weight, stomach fullness, otoliths and, where possible, scales, were also taken for particular fish according a pre-determined sampling scheme. Otoliths were read at the Sea Fisheries Institute in Poland.

4. RESULTS

4.1 Distribution of Catches

All species were identified in the catches. Samples of catches from the following species of current or recent commercial importance, *C. gunnari, C. aceratus, P. georgianus, N. gibberifrons, N. rossii, N. squamifrons, D. eleginoides and P. b. guntheri,* were analysed. This involved measurement of length and weight, estimation of sex, maturity stage and stomach fullness, extraction of otoliths and, where appropriate, scales. Other species were counted and their total weight measured.

The number of stations at which individual species were found and the total weight caught within each depth stratum are shown in Table 4 for South Georgia and Table 5 for Shag Rocks. The distribution of catch rates for the major species are shown in Figures 3 to 9.

Several species, *C. gunnari, C. aceratus, P. georgianus and N. gibberifrons*, were widespread around South Georgia, being found at nearly all stations. *N. rossii*, although present at most stations down to 250 m was caught in only one haul from water deeper than 250 m whilst *D. eleginoides* was only caught sporadically.

At Shag Rocks *C. gunnari* was caught at all stations shallower than 250 m while *D. eleginoides* was caught at all except one of the total stations sampled.

At 94% of the stations where it was caught, the catch rates of *C. gunnari* were less than 200 kg for a 30 minute tow. No aggregations suitable for commercial fishing were seen either at South Georgia or Shag Rocks. The two largest catches, one of 696 kg at Shag Rocks and the other of 336 kg from the eastern end of South Georgia, were still very small relative to previous surveys (SC-CAMLR, 1990a). At most stations where *C. gunnari* were caught there was generally an equal or even greater catch of other species.

A single large catch of 1 169 kg of *D. eleginoides* exceeded, by an order of magnitude, catches of this species elsewhere. Although present in all except one haul at Shag Rocks this species only occurred sporadically around South Georgia.

N. rossii was not present at Shag Rocks but was present at South Georgia, although at low catch rates in all except one instance, in hauls from water shallower than 250 m.

P. b. guntheri was taken in small amounts from hauls around Shag Rocks. As on all previous surveys, none were taken from the South Georgia shelf region.

4.2 Standing Stock Estimates

Examination of the distribution of catch rates indicated that there were no outlying values resulting from isolated large catches. There was therefore no need to apply a large haul adjustment (SC-CAMLR, 1990b) to the analyses. Standing stock estimates by the swept area method were made for the species of commercial importance by the same method as used in SC-CAMLR (1990a). The data were stratified by depth zone and for the two regions, South Georgia and Shag Rocks.

Standing stock estimates for the species of current or recent commercial interest are shown in Table 6 for South Georgia and Table 7 for Shag Rocks. The coefficients of variation of the estimates for South Georgia are much lower than from previous surveys indicating a much more uniform distribution with little tendency to aggregation.

4.3 Length to Weight Relationships

Length to weight relationships were determined from measurements made at sea for all the major fish species. The results are summarised in Table 8. Due to the increase in size of the gonads in the months prior to spawning the simple linear relationships set out in Table 8 are not valid necessarily for all sizes and maturity states of fish.

There are some differences between areas and for different maturity stages of the mackerel icefish, *C. gunnari,* and a full analysis for this species is planned.

The equations for *C. aceratus* are valid for most fish in the size range 12 to 72 cm. However, stage 2 and 3 males of length 46 to 56 cm and stage 3 females of 59 to 64 cm were significantly heavier than indicated by the simple logarithmic relationship.

Similar increases were noted for *P. georgianus* where stage 2 and 3 males and females greater than 46 cm total length were heavier than indicated by the equations.

4.4 Length and Age Distributions

Aggregated length distributions for the eight species sampled on the survey are presented in Figures 10 to 17. These have been calculated by weighting the length distributions by the catch-per-unit-effort (total area swept by the net) prior to summing across the stations (equation 1 in Parkes, 1991b).

For *C. gunnari* at South Georgia there is a clear modal peak at 16 cm and a second, less distinct peak at 23 cm (Figure 10). There is no distinct mode for fish >25 cm as there was in last year's survey (Parkes *et al.*, 1990). By contrast, at Shag Rocks two distinct modal values were present at 26 and 32 cm and few small fish were present (Figure 11).

An age/length key was prepared using age data derived from otoliths. Unfortunately, no fish of either 18 or 19 cm were sampled for otoliths. Use of the age/length, in its raw format, would give rise to misleading results because fish of length 18 and 19 cm would not be allocated an age class. Combining the length distributions of *C. gunnari* from Shag Rocks and South Georgia indicates that there is a well defined peak extending from 11 to 20 cm, with a peak at 16 cm and a trough at 20 cm. We have therefore adjusted the age/length key prepared from the raw data by allocating fish of length 18 and 19 cm to age class 1. The revised age/length key, including the values for 18 and 19 cm fish shown in parenthesis, is shown in Table 9. In this form it gives a 'knife-edge' change from age class 1 to age class 2 at 20 cm, which coincides with the trough in the length distribution.

The length frequency distribution for *C. aceratus* (Figure 11) shows modal values at 17, 26, 32 and 49 cm. There are no distinct modes for larger fish due to dimorphic growth rates. Two clear modes, at 24 and 36 cm, are also present for *P. georgianus.*

The distribution for *D. eleginoides* has several modes which are indicative of year classes, these have been analysed further by Everson (1991).

The distributions for *N. rossii* and *N. gibberifrons* each have several peaks although none are sufficiently pronounced to indicate year classes reliably.

Ages of individual fish have been determined from otolith and scale readings and these have been used to provide age distributions in terms of numbers and biomass. The results are shown in Tables 10 and 11.

The data from the age and length distributions have been combined to provide mean length and mean weight at age, these are presented in Tables 12 and 13. All the calculations use

overall age/length keys and, in the case of the mackerel icefish, *C. gunnari*, all fish of length 18 and 19 cm have been assigned to age 1 (SC-CAMLR 1991).

The results for the mackerel icefish, *C. gunnari*, are considered further in a separate paper (Parkes, 1991c).

4.5 Maturity Stages

The length at which 50% of the population are sexually mature, L_{50}, has been derived from the logistic equation used in Everson *et al.* (1991) from samples examined during the survey. The results are given in Table 14. Even though this year's survey was slightly later in the year than the 1990 survey the results are broadly similar for most species.

For *C. gunnari* many of the Stage 2 ovaries looked abnormal and samples were collected for histological examination. A preliminary report is presented in a separate paper (Everson *et al.*, 1991).

4.6 Stomach Contents

The level of stomach fullness from samples examined was estimated and categorisation of the dominant food items was made for the major species. Krill, which have been a major component in the diet of *C. gunnari* in previous years, were rarely the dominant component of the diet in the stomachs examined. The results from this study are examined in a separate paper (Kock *et al.*, 1991).

4.7 Acoustic Observations

Each trawling site was monitored acoustically during the course of the haul, no indications were seen that indicated the presence of large schools of fish. In addition, most trawling sites were examined prior to hauls being made either during the hours of darkness or immediately in advance of fishing. No large schools of fish were detected during these investigations.

5. DISCUSSION

The standing stock estimates for all species, with the exception of *C. gunnari*, are broadly similar to those from the most recent surveys at South Georgia; these are compared in Table 15. A similar picture is not present for surveys at Shag Rocks (Table 16) probably because there are fewer species, fewer surveys and a many fewer hauls in that locality.

The estimated standing stock of *C. gunnari* from this year's survey is very much lower than that from either of the two independent surveys undertaken during 1989/90. It is however broadly similar to those from earlier years with the exception of 1985/86 when a totally different type of net was used.

Acoustic observations indicate that schools of *C. gunnari* were not present anywhere during the current survey, and, that those fish that were present were distributed more or less randomly in the area. Such a distribution would explain the low variance and CV of the standing stock estimate from the trawl survey. We therefore conclude that the standing stock during 1990/91 survey is substantially lower than that from the previous year and is not an artefact of the sampling technique or survey design.

Further evidence for this reduction is available from the commercial fishing fleets in the area. A single Polish trawler *Lepus* was operating in the area and reported catch rates of less than one tonne per day; after several days this vessel left the area. Several Russian trawlers reported to the Harbourmaster, South Georgia, that fishing for *C. gunnari* was extremely poor and that they would move to other grounds.

These observations provide support for the suggestion that there has been a significant reduction in the standing stock of *C. gunnari*. We consider three possible reasons for such a change:

(a) intense fishing between February and December 1990;
(b) migration from the area; and
(c) unusually high natural mortality.

We know of no fishing activity in the area which could have accounted for such a large reduction in standing stock and therefore consider it highly unlikely that the first possibility is the cause.

Any migration would need to take the fish to an area of shelf some considerable distance away. The nearest such shelf area is in the South Orkneys, which, although remote, is not an impossible distance for the fish to migrate. Comparison with samples obtained in that area may confirm whether or not this has occurred .

The third possibility, that there has been an unusually high natural mortality, would be surprising but consistent with the season being characterised by poor krill availability affecting feeding (Kock *et al.*, 1991) and the fish undergoing abnormal gonad maturation processes (Everson *et al.*, 1991). We are investigating all three hypotheses.

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Table 1: Times (GMT-3 hours) and locations of sampled stations.

Station No.	Date day	mnth	Time hr	min	Latitude deg	min	Longitude deg	min	Depth m	Duration min
1	22	1	6	13	53	19.80	42	44.30	463	27
2	22	1	10	10	53	28.40	42	18.20	232	30
3	22	1	14	20	53	26.00	41	48.00	146	29
4	22	1	18	50	53	37.00	42	7.00	168	30
5	23	1	4	23	53	33.50	41	46.40	139	29
6	23	1	7	10	53	34.10	41	24.50	126	30
7	23	1	9	45	53	34.10	41	24.50	121	30
8	24	1	6	43	53	39.10	41	14.90	135	29
9	24	1	9	15	53	46.60	41	45.90	220	35
10	24	1	12	0	53	47.00	41	21.70	198	25
11	24	1	14	42	53	50.60	41	13.50	196	30
13	25	1	9	17	54	4.50	39	41.50	371	30
14	25	1	13	32	53	50.70	38	37.40	234	24
15	25	1	16	57	53	44.00	38	35.00	318	30
16	25	1	19	35	53	45.40	38	19.50	203	30
17	26	1	4	25	53	38.00	38	6.00	188	30
18	26	1	11	58	53	48.20	38	23.80	183	30
19	26	1	14	32	53	38.00	37	51.00	176	21
20	27	1	4	29	53	54.60	38	2.50	126	30
21	27	1	10	15	53	46.70	37	30.70	121	28
22	27	1	14	57	53	45.80	37	22.00	280	30
23	27	1	17	50	53	38.50	37	10.00	161	30
24	27	1	19	30	53	40.00	37	0.00	212	30
25	28	1	4	26	53	46.50	36	54.00	203	20
26	28	1	6	43	53	43.70	36	37.00	218	30
27	28	1	9	18	53	45.50	36	28.00	304	30
28	28	1	11	45	53	55.00	36	13.50	187	30
29	28	1	15	23	54	1.00	36	26.00	178	28
30	28	1	18	26	53	57.50	35	58.00	287	30
31	29	1	4	32	54	8.00	35	58.00	231	30
32	29	1	9	50	54	14.00	36	36.00	251	30
33	29	1	12	46	54	11.50	36	16.50	183	20
34	29	1	14	56	54	12.80	36	18.30	112	18
35	29	1	17	57	54	11.00	35	48.00	231	30
36	30	1	4	16	54	11.00	35	37.00	192	30
37	30	1	6	30	54	19.00	35	53.50	207	24
38	30	1	9	3	54	20.50	35	53.70	198	30
39	30	1	13	18	54	32.00	35	45.00	174	27
40	30	1	16	34	54	26.00	35	23.00	269	30
41	31	1	4	27	54	33.00	35	16.20	196	26
42	1	2	9	45	54	37.30	35	31.50	124	30
43	1	2	12	30	54	46.00	35	16.50	324	30
44	1	2	16	40	54	47.00	34	55.00	359	30
45	1	2	18	58	54	55.00	34	57.50	181	30
46	2	2	4	34	54	56.60	35	15.10	102	24
47	2	2	6	58	54	58.00	35	23.60	124	30
48	2	2	9	52	55	1.50	35	22.00	113	30
49	2	2	12	25	55	3.80	35	23.00	130	30

Table 1 (continued)

Station No.	Date day	mnth	Time hr	mi	Latitude deg	min	Longitude deg	min	Depth m	Duration min
50	2	2	14	44	55	5.60	35	1.00	139	30
51	2	2	17	4	55	12.20	34	46.40	176	31
52	3	2	4	37	55	28.00	35	20.20	368	30
53	3	2	6	20	55	25.60	35	22.90	210	15
54	3	2	10	10	55	18.00	35	53.00	223	26
55	3	2	12	54	55	4.60	35	44.30	123	30
56	3	2	15	50	54	56.50	35	47.30	154	10
57	3	2	19	20	55	5.90	36	8.00	167	30
58	4	2	5	2	54	50.40	38	13.40	285	30
59	4	2	8	39	54	39.30	38	20.80	188	30
60	4	2	11	51	54	36.80	38	5.40	165	30
61	4	2	13	42	54	32.00	38	15.00	183	19
62	5	2	4	20	54	25.00	37	49.00	172	30
63	5	2	6	0	54	16.00	37	49.00	137	30
64	5	2	11	45	54	15.40	38	2.80	185	29
65	5	2	13	48	54	15.70	38	13.10	243	30
66	5	2	16	43	54	18.60	38	32.70	214	22
67	5	2	19	19	54	8.80	38	36.10	216	30
68	6	2	4	38	54	6.40	38	2.10	134	25
69	6	2	16	21	54	13.50	37	48.20	127	14
70	6	2	19	32	54	9.20	37	50.20	161	6
71	7	2	4	25	54	31.00	38	46.00	229	15
72	7	2	10	22	54	28.70	39	16.40	284	30
73	7	2	13	8	54	16.00	39	0.00	245	15
74	7	2	16	25	54	9.50	39	14.00	223	30
75	7	2	18	33	54	7.00	39	12.00	240	30
76	8	2	4	36	54	7.90	38	51.30	198	3C
77	8	2	6	36	54	10.20	38	46.20	238	30
78	8	2	10	15	53	53.50	38	22.30	134	30
79	8	2	15	58	53	40.30	37	35.30	231	30
80	8	2	18	19	53	41.50	37	29.80	322	24
81	9	2	5	38	53	56.80	36	29.60	185	27
82	9	2	9	S0	53	51.80	37	15.10	284	30
83	9	2	19	15	54	4.20	35	40.00	212	30
84	1	2	5	42	54	17.10	3S	37.40	234	30
85	10	2	9	57	54	25.00	35	54.70	113	30
86	11	2	11	30	53	50.60	40	47.10	350	30
87	11	2	17	13	53	41.00	41	33.90	150	9

Table 2: Sampling coverage around South Georgia and Shag Rocks.

Depth Stratum	Coverage km² Per Station		Number of Stations	
	South Georgia	Shag Rocks	South Georgia	Shag Rocks
50 to 150 m	554	295	16	5
151 to 250 m	519	374	37	5
251 to 500 m	613	805	13	2

Table 3: Mesh size measurements from the bottom trawl used in the 1990/91 South Georgia survey.

	Fornet		Belly		Codend		Liner	
	165	149	124	125	85	97	50	57
	148	148	126	129	92	97	57	57
	148	148	125	128	95	93	53	55
	148	146	128	131	90	96	52	54
	148	149	129	129	93	97	54	53
	149	152	124	127	91	97	56	51
	147	152	127	129	92	95	57	52
	154	148	128	130	94	93	54	54
	158	144	126	125	96	94	55	54
	148	147	128	129	94	94	53	53
Mean:	149.8		127.3		93.8		54.1	
Var:	4.69		2.00		2.84		1.99	

Table 4: Total catch and number of stations at which species were caught from the South Georgia region.

Depth	50 to 150 (m)		150 to 250 (m)		250 to 500 (m)	
	kg	n	kg	n	kg	n
Commercial species:						
C. gunnari	616	15	1 779	36	171	10
C. aceratus	452	15	965	36	103	10
P. georgianus	508	15	1 039	36	51	9
N. gibberifrons	931	15	1 455	37	854	12
N. rossii	408	11	106	24	7	3
N. squamifrons	0	0	2	5	140	11
D. eleginoides	17	7	29	9	26	7
P.b. guntheri	0	0	0	0	0	0
Other species:						
N. augustifrons	0.1	2	0	0	0	0
N. larseni	9.5	8	118	34	21	12
N. nudifrons	14.5	15	27	28	0.4	4
P. hansoni	1.8	5	6.8	7	4.4	1
A. mirus	0.2	9	1.2	20	0.3	6
Diplospinosus spp.	0	0	0.2	2	0.1	3
Electrona spp.	0	1	0.1	2	0	1
Paraliparis spp.	0	0	0 1	4	0.2	2
M. m. antarctica	0	0	1.2	1	5.6	6
Melanostigma spp.	0	0	0	3	0	1
Muranolepis spp.	1.5	4	29	0	9	12
G. nicholsi	0	1	28	13	31	11
P. georgianus	18	14	169	30	1.4	4
P. breviceps	0	0	1.3	5	0.3	3
R. georgiana	30.5	3	59	11	72	7

Table 5: Total catch and number stations at which species were caught from the Shag Rocks region.

Depth	50 to 150 (m)		150 to 250 (m)		250 to 500 (m)	
	kg	n	kg	n	kg	n
Commercial species:						
C. gunnari	774	5	55	5	0	0
C. aceratus	0	0	0	0	0	0
P. georgianus	0	0	3	2	0	0
N. gibberifrons	16	4	6	3	0	0
N. rossii	0	0	0	0	0	0
N. squamifrons	1	1	16	2	41	2
D. eleginoides	120	5	34	4	1 183	2
P.b. guntheri	69	5	42	5	1	1
Other species:						
N. nudifrons	1.6	4	1.2	3	0	0
K. andersoni	0	0	0	1	0	0
A. mirus	0.2	1	0	1	0	0
Diplospinosus spp.	0	0	0	0	0	1
Electrona spp.	0	0	0.2	0	0	0
M. m. antarctica	0.3	1	0	0	0.4	2
Muranolepis spp.	1	1	0.2	1	0.4	2
G. nicholsi	0	0	1.4	1	0	0

Table 6: Biomass estimates for South Georgia of the most common species around South Georgia, calculated using the 'swept area method'. CV = coefficient of variation of the estimate (Saville 1977).

	Depth Stratum				
Species	50 to 150 m	151 to 250 m	251 to 500 m	Total	CV (%)
C. gunnari	5 445	15 256	1 583	22 285	16
C. aceratus	3 888	8 623	963	13 474	15
P. georgianus	4 457	8 902	590	13 948	19
N. gibberifrons	7 832	12 624	7 768	28 224	18
N. rossii	3 335	896	64	4 295	49
D. eleginoides	157	262	465	885	37
N. squamifrons	0	14	1 361	1 374	43
Number of stations	16	37	13	66	

Table 7: Biomass estimates for South Georgia of the most common species around Shag Rocks, calculated using the 'swept area method'. CV = coefficient of variation of the estimate (Saville 1977).

	Depth Stratum				
Species	50 to 150 m	151 to 250 m	251 to 500 m	Total	CV(%)
C. gunnari	3 573	346	0	3 919	75
C. aceratus	0	0	0	0	
P. georgianus	0	15	0	15	62
N. gibberifrons	79	38	0	117	34
N. rossii	0	0	0	0	
D. eleginoides	581	206	18 527	19 315	94
N. squamifrons	3	93	535	631	33
P.b. guntheri	322	245	16	584	45
Number of stations	5	5	2	12	

Table 8: Length/weight relationships from measurements taken during the survey; length in cm, weight in g, (least squares linear regression on $\log_e$ transformed data).

Species		Length/weight relationship (W=L*b)		
	Sex	a	b	Number of fish
C. gunnari	M	3.36	0.00180	230
C. gunnari	F	3.36	0.00180	231
C. aceratus	M	3.69	0.00047	186
C. aceratus	F	3.65	0.00054	232
P. georgianus	M	3.61	0.00095	120
P. georgianus	F	3.53	0.00122	120
N. gibberifrons	M+F	3.28	0.00389	349
N. rossii	M+F	2.94	0.01668	181
D. eleginoides	M+F	317	0.00477	198

Table 9: Age/length key for *C. gunnari* prepared from otolith readings from the *Falklands Protector* survey January/February1991, augmented to allocate lengths 18 and 19 cm to age class 1. Figures in parentheses have been added as explained in section 4.4 of this report.

Age >	0	1	2	3	4	5	6	7	8	9	10
Length 0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0

Table 9 (continued)

Age >	0	1	2	3	4	5	6	7	8	9	10
Length 9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	0	0	0	0	0	0
13	0	2	0	0	0	0	0	0	0	0	0
14	0	3	0	0	0	0	0	0	0	0	0
15	0	3	0	0	0	0	0	0	0	0	0
16	0	1	0	0	0	0	0	0	0	0	0
17	0	1	0	0	0	0	0	0	0	0	0
18	0	(1)	0	0	0	0	0	0	0	0	0
19	0	(1)	0	0	0	0	0	0	0	0	0
20	0	0	2	0	0	0	0	0	0	0	0
21	0	0	6	0	0	0	0	0	0	0	0
22	0	0	10	0	0	0	0	0	0	0	0
23	0	0	12	0	0	0	0	0	0	0	0
24	0	0	15	0	0	0	0	0	0	0	0
25	0	0	24	0	0	0	0	0	0	0	0
26	0	0	21	1	0	0	0	0	0	0	0
27	0	0	11	6	0	0	0	0	0	0	0
28	0	0	11	11	0	0	0	0	0	0	0
29	0	0	4	10	1	0	0	0	0	0	0
30	0	0	2	11	0	0	0	0	0	0	0
31	0	0	0	18	3	0	0	0	0	0	0
32	0	0	1	22	6	0	0	0	0	0	0
33	0	0	0	12	7	0	0	0	0	0	0
34	0	0	1	12	8	0	0	0	0	0	0
35	0	0	0	11	11	0	0	0	0	0	0
36	0	0	0	10	13	0	0	0	0	0	0
37	0	0	0	7	11	0	0	0	0	0	0
38	0	0	0	4	14	1	0	0	0	0	0
39	0	0	0	3	5	2	0	0	0	0	0
40	0	0	0	1	9	0	0	0	0	0	0
41	0	0	0	0	12	2	0	0	0	0	0
42	0	0	0	0	5	3	0	0	0	0	0
43	0	0	0	0	1	2	0	0	0	0	0
44	0	0	0	0	1	2	0	0	0	0	0
45	0	0	0	0	1	2	0	0	0	0	0
46	0	0	0	0	1	2	0	0	0	0	0
47	0	0	0	0	0	2	1	1	0	0	0
48	0	0	0	0	0	4	3	0	0	0	0
49	0	0	0	0	0	1	3	0	0	0	0
50	0	0	0	0	0	2	1	1	0	0	0
51	0	0	0	0	0	0	1	1	1	0	0
52	0	0	0	0	0	0	2	0	0	0	0
53	0	0	0	0	0	0	1	1	0	0	0
54	0	0	0	0	0	0	0	3	0	0	1
55	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	1	0	0
57	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0

Table 10: Age distributions of the catch (numbers %) for length, weight and age samples taken during the survey. All values are for South Georgia, and both sexes except where indicated.

Species	Age (years)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
C. gunnari	62.4	17.6	13.8	5.8	0.3	0.1									
C. gunnari Shag Rocks	0.4	44.7	45.0	9.8											
C. aceratus (male)	7.7	19.8	27.8	13.7	5.0	21.2	3.9	0.2	0.4	0.4					
C. aceratus (female)	4.3	17.2	14.4	13.6	10.7	19.8	7.7	5.2	3.6	2.7	0.7				
P. georgianus	10.9	41.6	30.3	11.4	5.8	0.1									
N. gibberifrons		7.2	11.0	11.9	15.1	15.0	15.4	11.0	3.5	3.8	2.3	2.4	1.1		0.4
N. rossii			1.6	3.8	25.5	30.0	19.0	7.9	7.9	3.7	0.7				

Table 11: Age distributions of the catch (biomass %) for length, weight and age samples taken during the survey. All values are for South Georgia, and both sexes except where indicated.

Species	Age (years)												
	1	2	3	4	5	6	7	8	9	10	11	12	13
C. gunnari	17.4	21.2	36.2	21.9	2.3	0.7	0.4						
C. gunnari Shag Rocks	0.1	33.0	51.7	15.1	0.1								
C. aceratus (male)	0.4	4.4	13.4	14.9	7.3	48.1	8.9	0.6	1.0	1.0			
C. aceratus (female)	0.1	2.2	3.6	6.8	9.0	29.8	15.9	14.0	9.2	7.2	2.3		
P. georgianus	1.3	25.4	39.2	22.3	11.6	0.2							
N. gibberifrons		0.9	2.4	4.7	9.0	12.8	17.7	16.3	7.1	9.9	7.2	8.0	4.2
N. rossii			0.4	1.8	16 8	28.1	21.6	10.4	12.8	6 7	1.4		

Table 12: Mean length (cm) at age for length and age samples taken during the survey. All values are for South Georgia, except where indicated.

Species	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14
C. gunnari	15.7	24.7	31.4	35.2	42.2	48.9								
C. gunnari Shag Rocks	18.0 *	26.6	30.3	33.2	39.9*									
C. aceratus (male)	17.8	26.2	32.0	40.0	43.3	49.1	49.1	53.1	51.0	51.0				
C. aceratus (female)	18.1	26.6	31.9	38.4	44.6	52.4	57.4	61.4	60.9	61.2	65.0			
P. georgianus	22.5	35.5	43.5	49.5	49.8	54.0					42.4			
N. gibberifrons		15.6	18.8	22.5	25.4	28.4	31.1	33.7	37.1	40.2	64.2	43.1	44.5	48.0
N. rossii			30.8	39.0	43.5	49.1	52.6	55.2	59.3	61.8				

* Small sample size

Table 13: Mean weight (g) at age for length and age samples taken during the survey. All values are for South Georgia, except where indicated.

Species	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14
C. gunnari (male)	20.4	87.8	191	275	493	780								
C. gunnari (female)	31.2 *	109	169	225	404*					1 147				
C. gunnari (male) Shag Rocks	15.2	114	197	254	415									
C. gunnari (female) Shag Rocks	22.9	111	168	217										
C. aceratus (male)	20.0	81.1	175	394	528	824	823	1 083	939	939				
C. aceratus (female)	21.3	88.3	175	348	589	1 051	1 442	1 870	1 779	1 834	2 236			
P. georgianus (male)	72.5	378	853	1 219	1 208									
P. georgianus (female)	76.0	374	724	1 195	1 347	1 591								
N. gibberifrons		33.3	60.3	108	163	233	314	406	554	714	854	898	995	1 271
N. rossii			404	795	1 112	1 572	1 914	2 213	2 728	3 086	3 479			

* Small sample size

Table 14: Length at which 50% of the population are sexually mature (L_{50}) and percentage of fish by maturity stage from samples collected during the survey. All results refer to South Georgia unless specified.

Species	Sex	L_{50}	Maturity Stage 2	3	4	5
C. gunnari	M	27.3	62.9	36.3	0.8	0.0
C. gunnari	F		86.8	12.4	0.2	0.6
C. gunnari Shag Rocks	M	37.4	19.9	80.1	0.0	0.0
C. gunnari Shag Rocks	F	39.0	45.3	54.5	0.0	0.2
C. aceratus	M	42.7	53.2	46.8	0.0	0.0
C. aceratus	F	40.0	60.2	39.2	0.0	0.6
P. georgianus	M	42.4	43.4	56.2	0.0	0.4
P. georgianus	F	35.1	67.3	32.0	0.0	0.7
N. gibberifrons	M	27.8	82.6	17.2	0.0	0.2
N. gibberifrons	F	27.8	91.5	5.6	0.0	2.9
N. rossii	M	37.0	10.4	89.6	0.0	0.0
N. rossii	F	39.7	25.6	73.7	0.0	0.7
D. eleginoides	M		100.0	0.0	0.0	0.0
D. eleginoides	F		100.0	0.0	0.0	0.0
D. eleginoides Shag Rocks	M	56.4	100.0	0.0	0.0	0.0
D. eleginoides Shag Rocks	F		100.0	0.0	0.0	0.0

Table 15: Comparison of biomass estimates (tonnes) with the results from previous surveys around South Georgia, including coefficient of variation (%).

Species	Season																	
	1984/85		1985/86		1986/87		19886/87		1987/88		1987/88		1988/89		1989/90		1989/90		1990/91	
	A	CV %	B	CV %	C	CV %	D		E	CV %	F		G	CV %	H	CV %	I	CV %	J	CV %
C. gunnari	15821	101	151293	95	50414	18	47312	-	15086	21	17913	-	21069	50	95405	63	333515	42	22285	16
C. aceratus	11542	41	2659	31	11743	13	8621	-	6642	12	6209	-	5770	14	14226	37	14424	26	13474	15
P. georgianus	8134	33	2010	50	5240	15	5520	-	11412	24	9461	-	8278	53	5761	28	12200	28	13948	19
N. gibberifrons	15762	28	3252	28	13544	15	11234	-	7189	13	7621	-	8510	17	12417	28	21891	23	28224	18
N. rossii	12718	100	11471	167	4582	69	1634	-	1049	26	1699	-	2439	54	1481	76	3915	30	4295	49
D. eleginoides	8159	76	-	-	1601	34	1208	-	697	21	674	-	326	66	335	39	3020	33	885	37
N. squamifrons	-	-	-	-	39991	76	13950	-	384	25	409	-	131	98	1690	-	5977	98	1374	43

References:

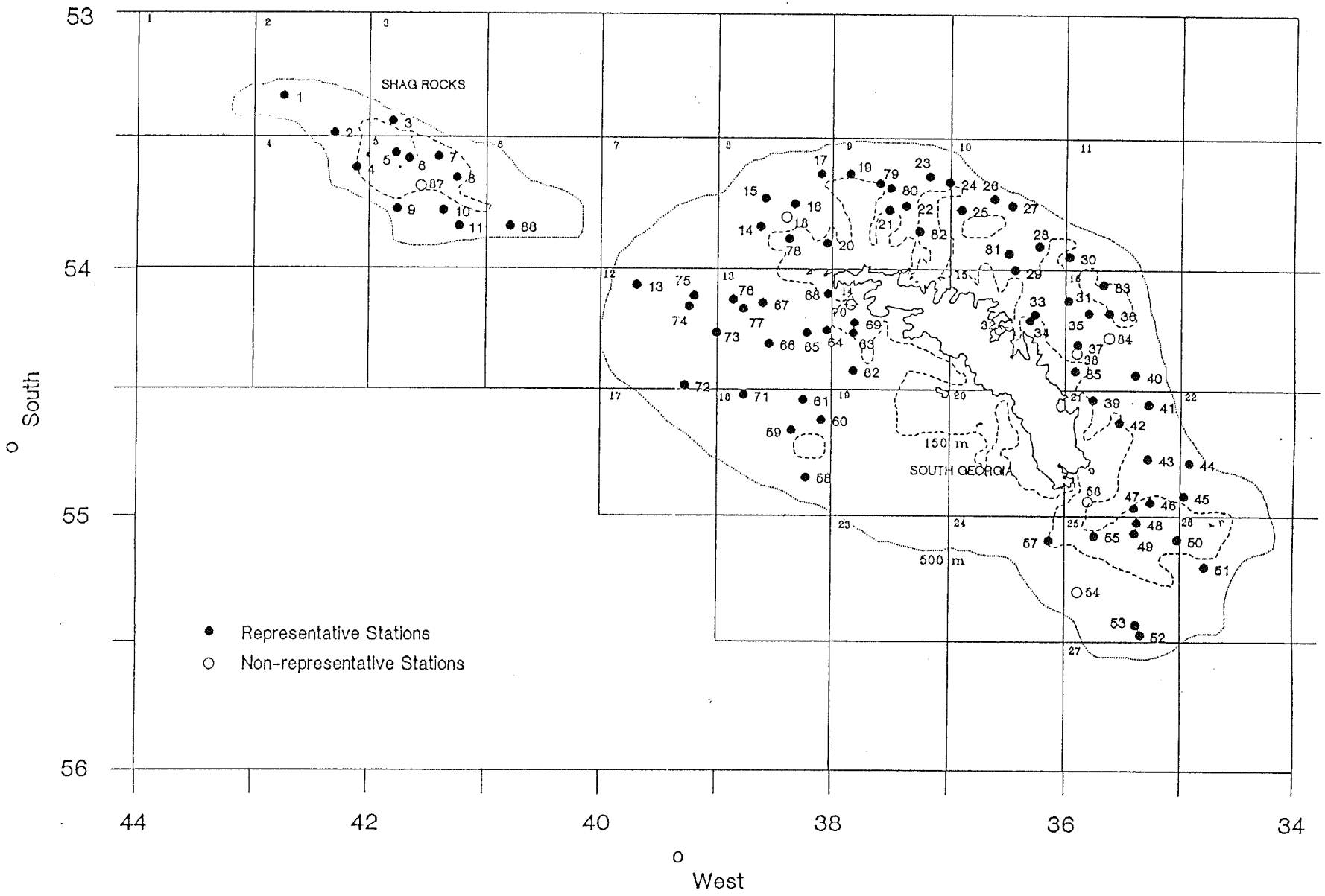
A - Kock (1985) SC-CAMLR-IV-BG/ll
B - Balguerías *et al.* (1987) (Pelagic Trawl)
C - Gabriel (1987) SC-CAMLR-VI-BG/12
D - Sosinski and Skora (1987)
E - McKenna and Saila (1988) SC-CAMLR-VII-BG/23
F - Sosinski (unpubl.)
G - Parkes *et al.* (1989) WG-FSA-89/6
H - Parkes *et al.* (1990) WG-FSA-90/11
I - USSR *Akademik Knipovich* survey (1990) WG-FSA-90/13
J - UK *Falklands Protector* survey (1991) WG-FSA-91

Table 16: Comparison of biomass estimates (tonnes) with the results from previous surveys around Shag Rocks, including coefficient of variation (%).

Species	Season											
	1985/86		1986/87		1987/88		1989/90		1989/90		1990/91	
	A	CV%	B	CV%	C	CV%	D	CV%	E	CV%	F	CV%
C. gunnari	62867	84	10023	55	1447	78	108653	31	54193	38	3919	75
C. aceratus												
P. georgianus									37	73	15	62
N. gibberifrons	81690	44	363	45	609	10			267	39	117	34
N. rossii												
D. eleginoides			763	40	408	17	1693	21	9631	55	19315	94
N. squamifrons			30	57	42	-	414	55	120	44	631	33
P. b. guntheri			331	45	999	27	1918	45	13608	90	584	45

References:

A - Balguerías *et al.* (1987) (Pelagic Trawl)
B - Gabriel (1987) SC-CAMLR-VI/BG/12
C - McKenna and Saila (1988) SC-CAMLR-VII/BG/23
D - USSR *Akademik Knipovich* survey (1990) WG-FSA-90/13
E - Parkes *et al.* (1990) WG-FSA-90/11
F - UK *Falklands Frotector* survey (1991) WG-FSA-91



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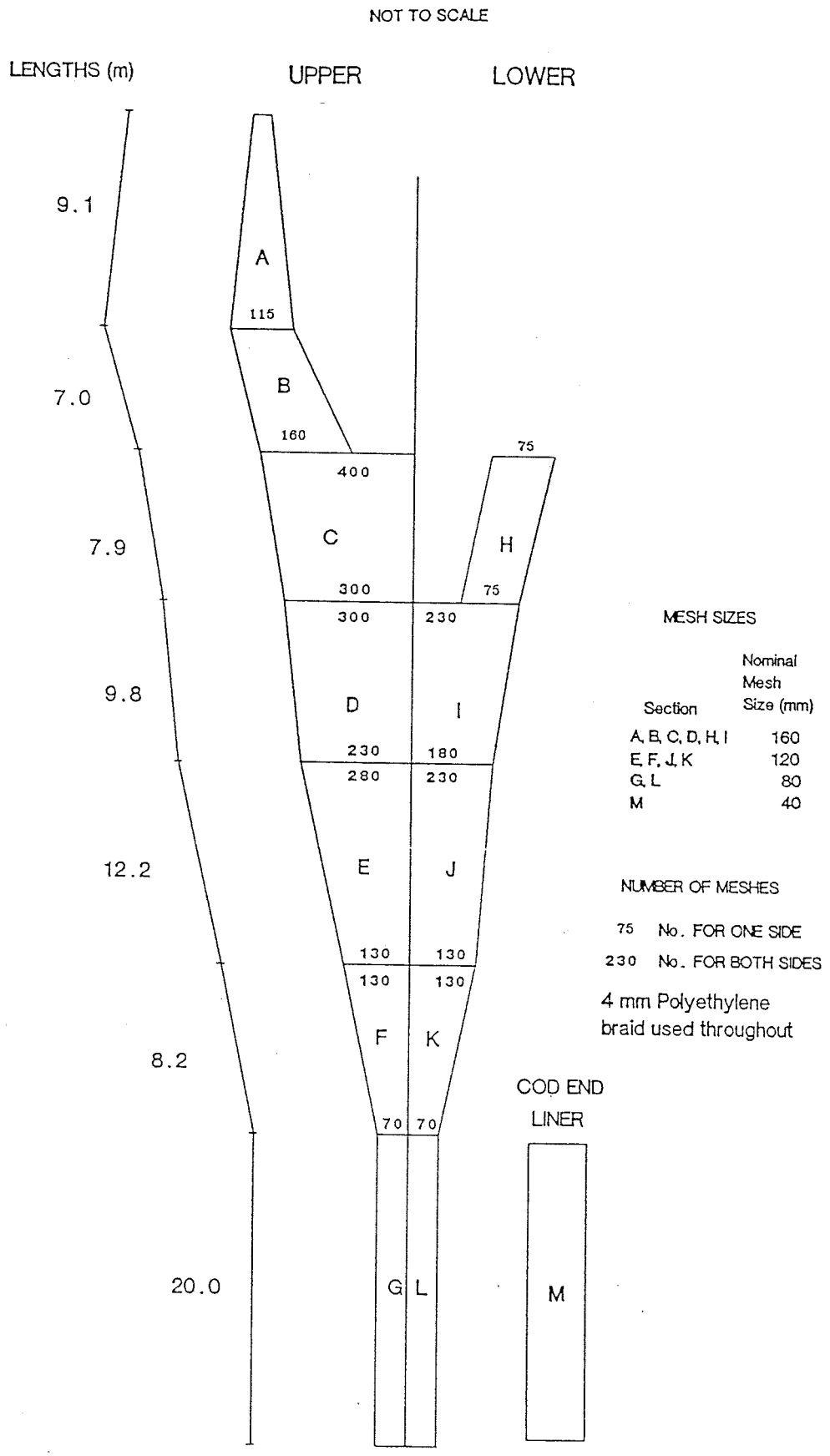
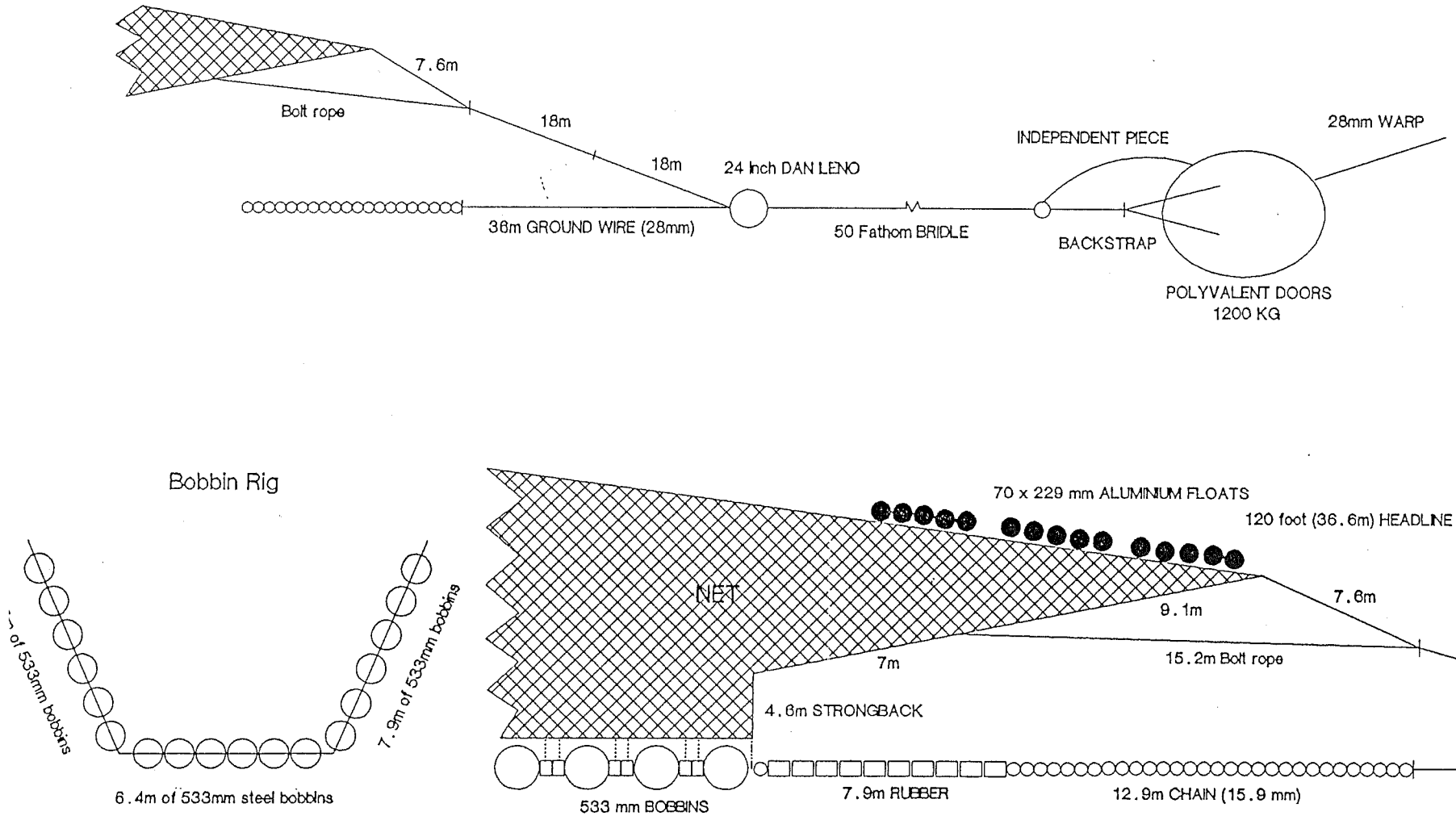


Figure 2a: Construction of the FP-120 Net.



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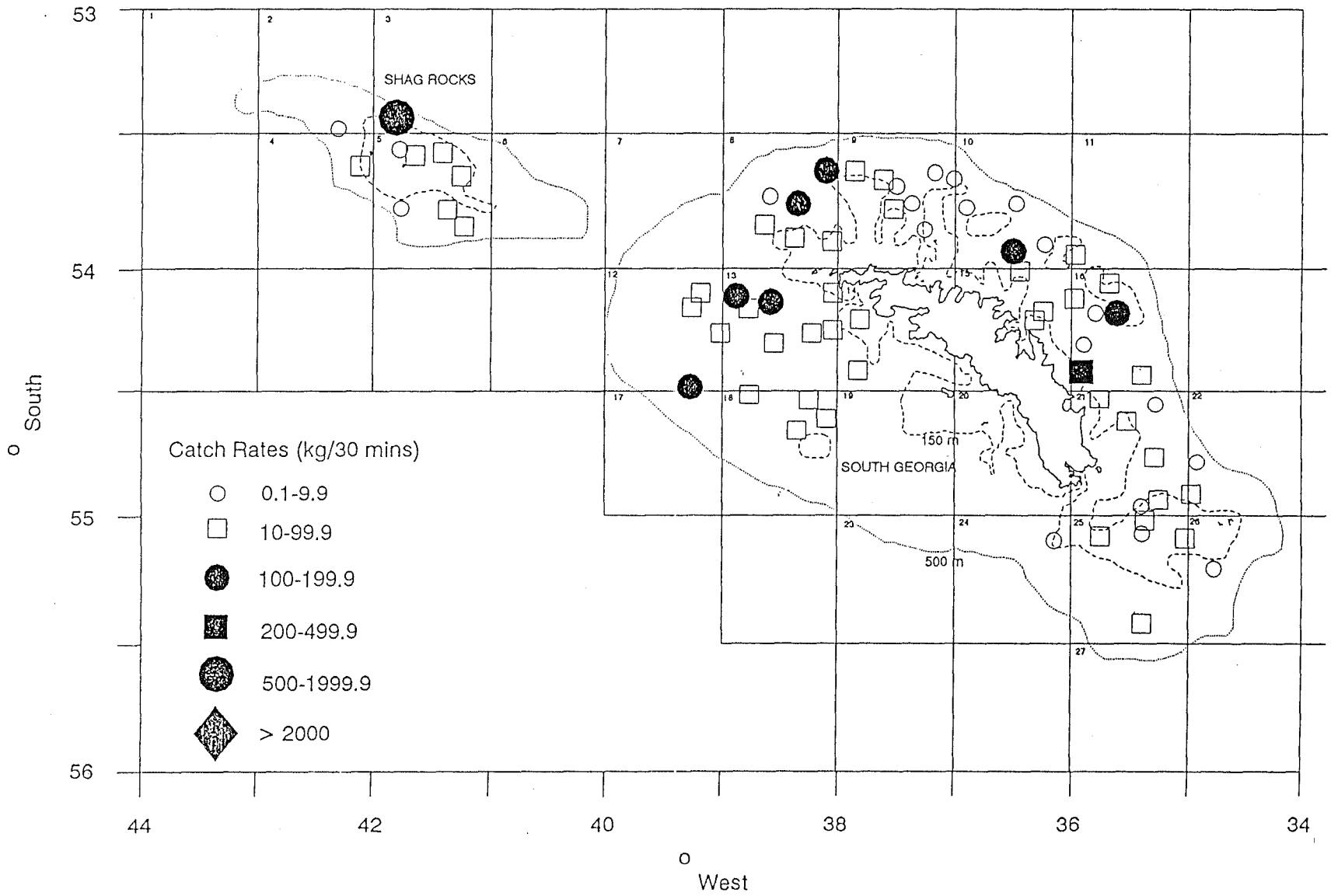


Figure 3: Catch rates, *C. gunnari*, *Falklands Protector*, January/February 1991.

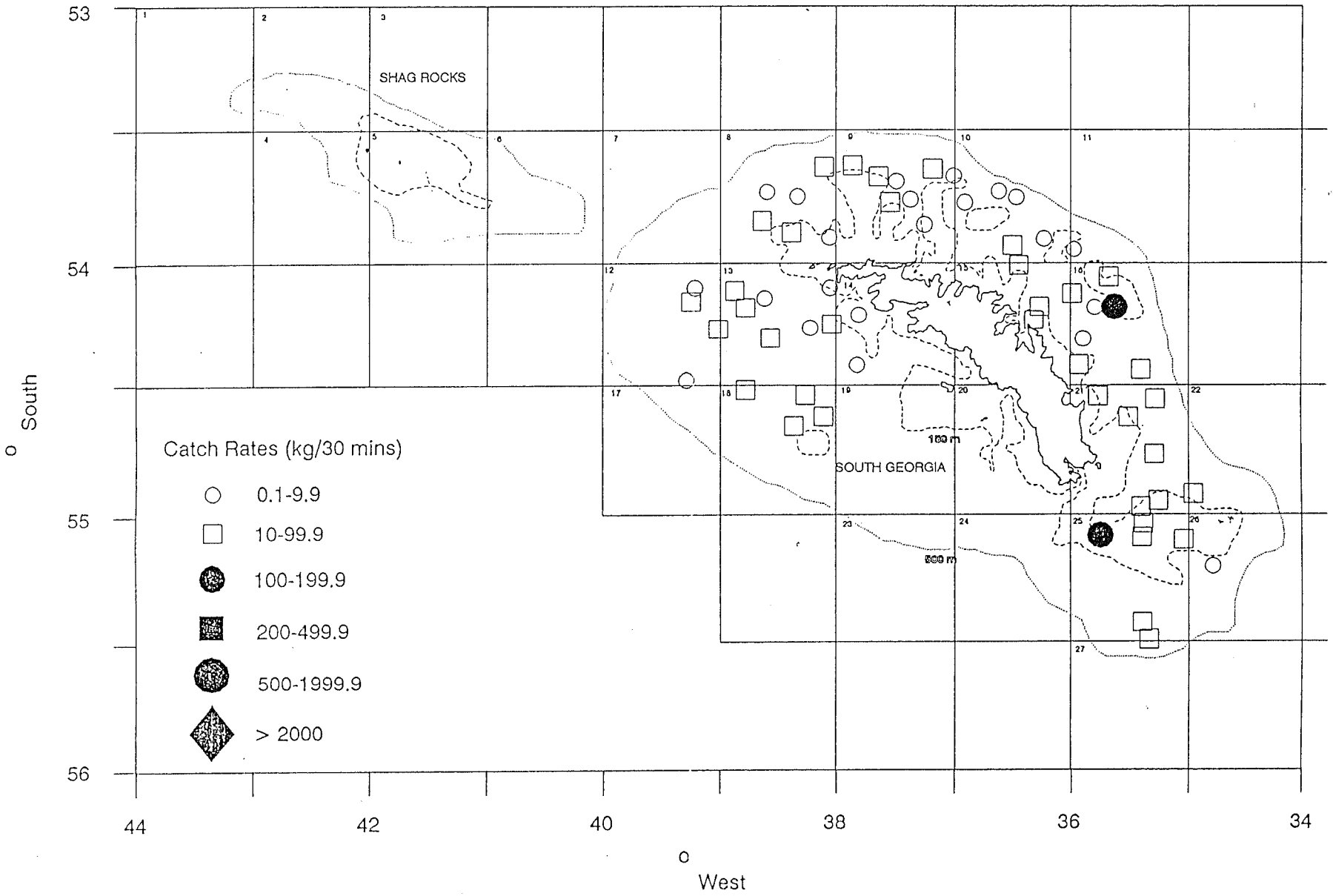


Figure 4: Catch rates, *C. aceratus*, *Falklands Protector*, January/February 1991.

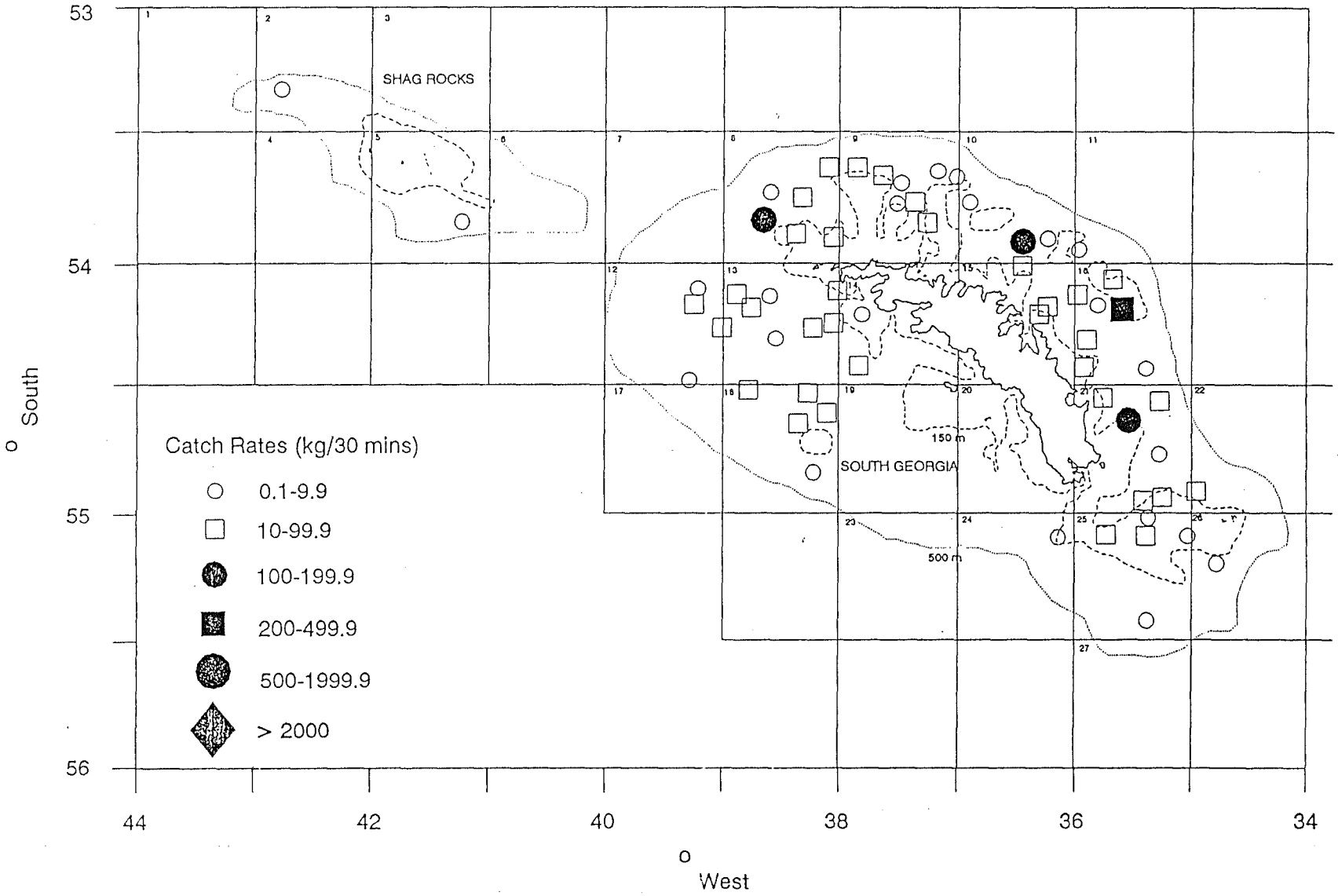
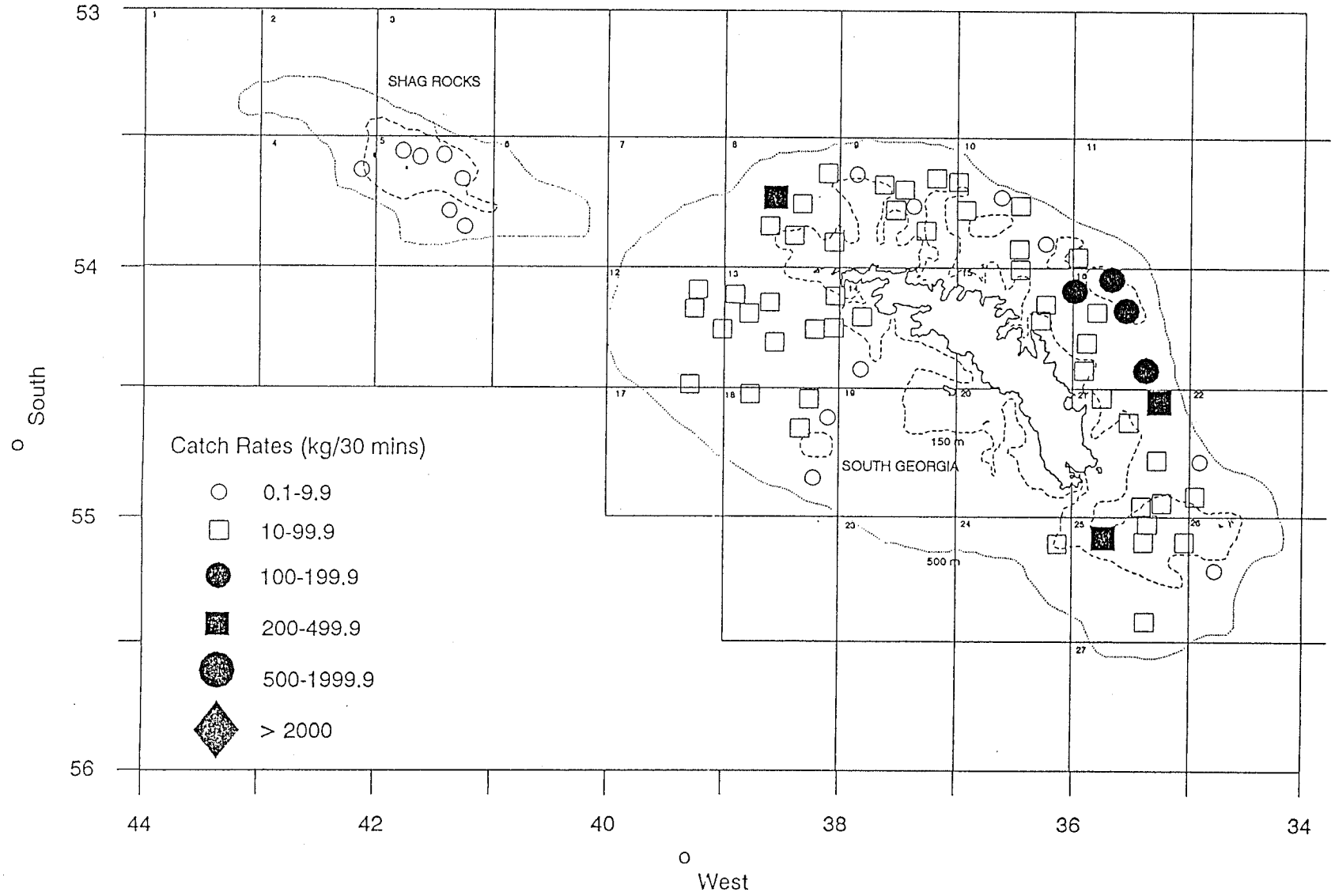


Figure 5: Catch rates, *P. georgianus*, *Falklands Protector*, January/February 1991.



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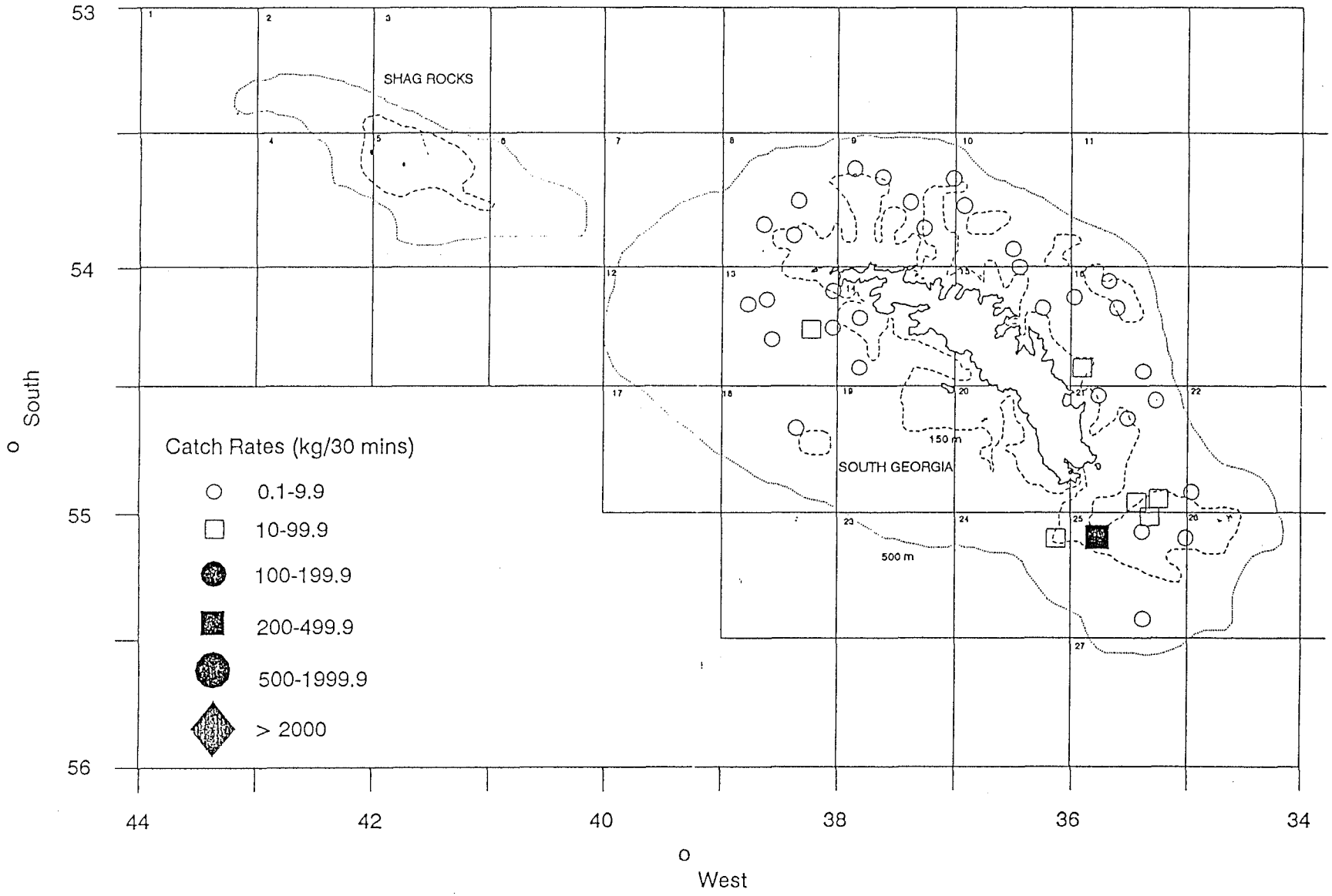
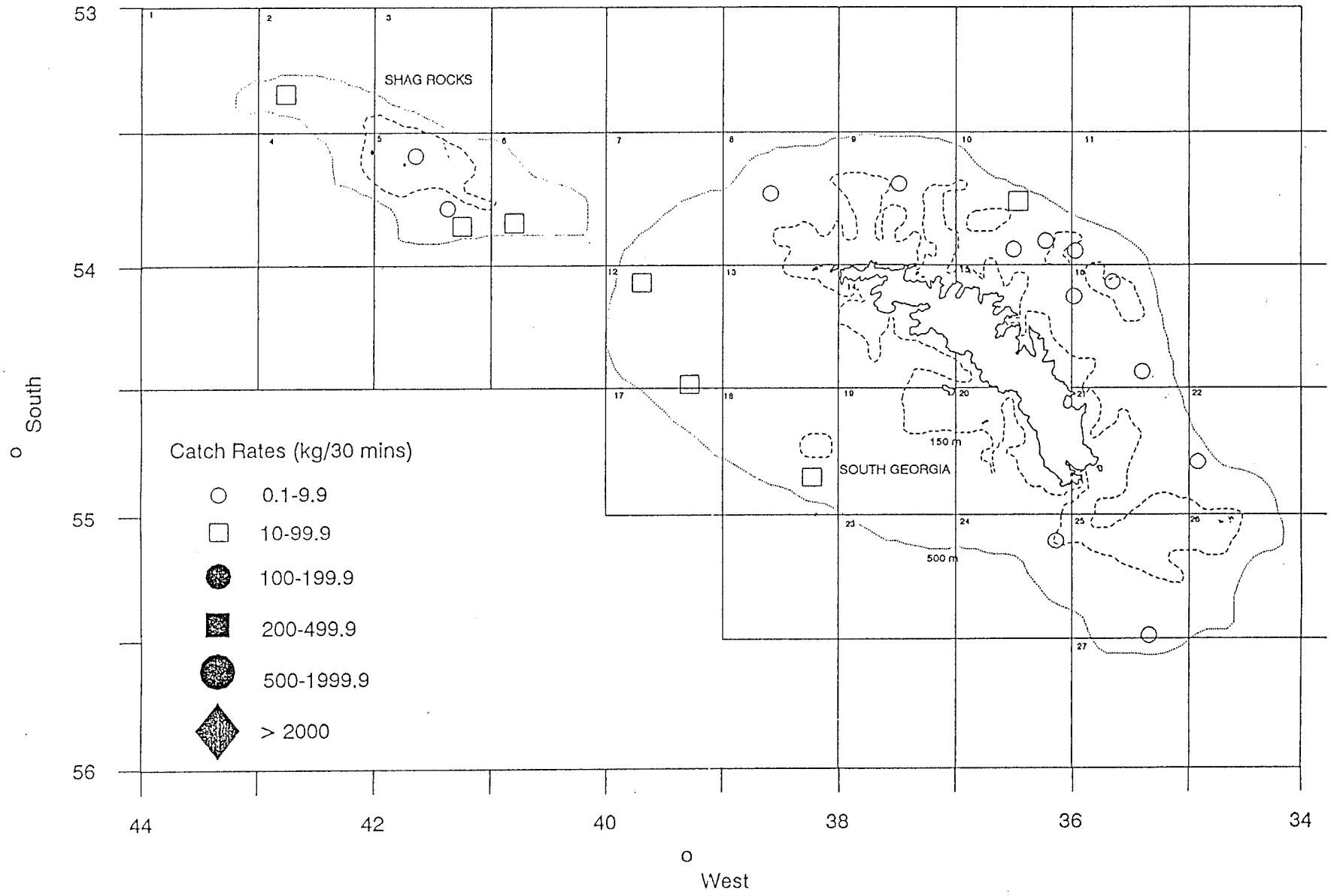


Figure 7: Catch rates, *N. rossii*, *Falklands Protector*, January/February 1991.



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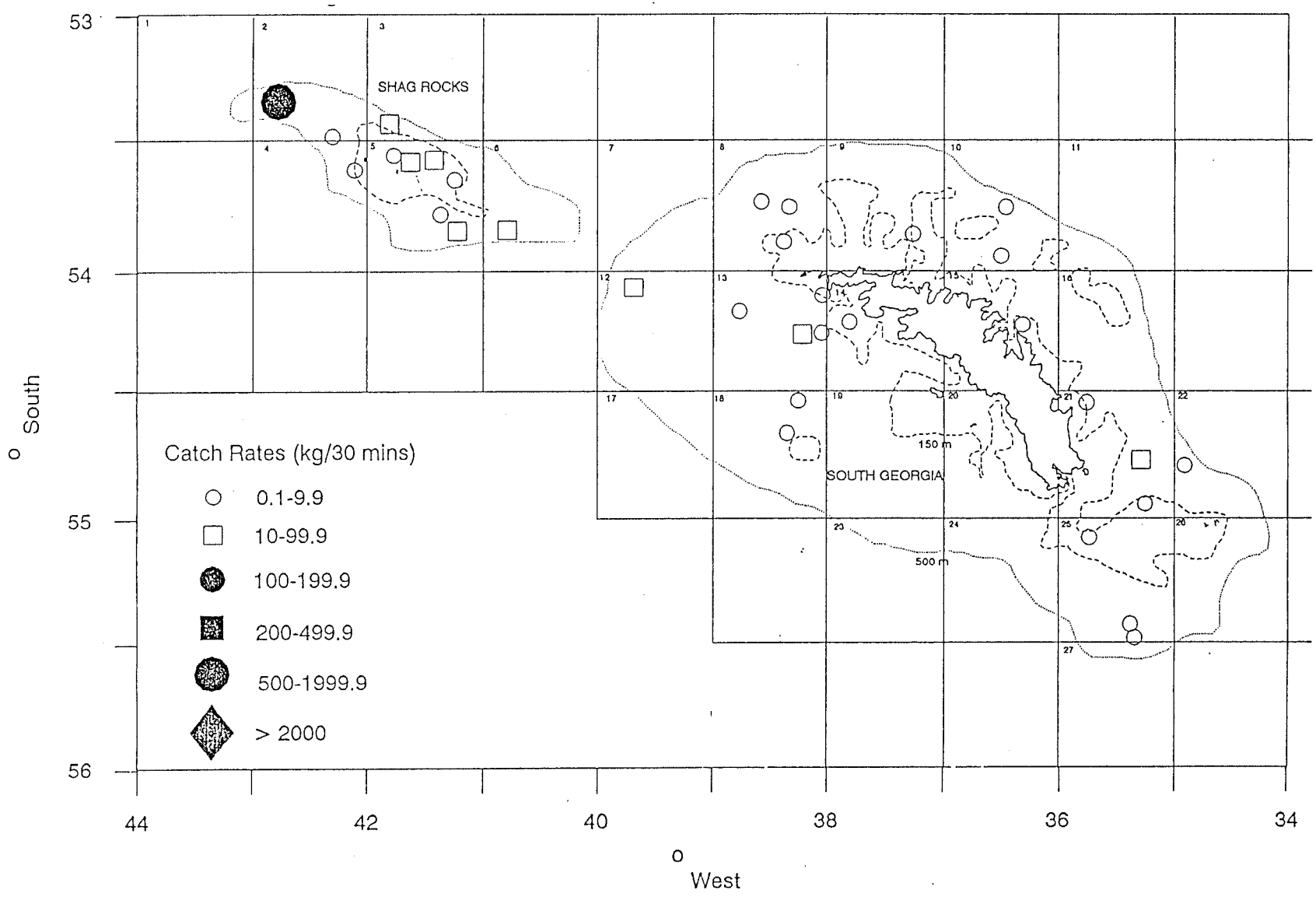

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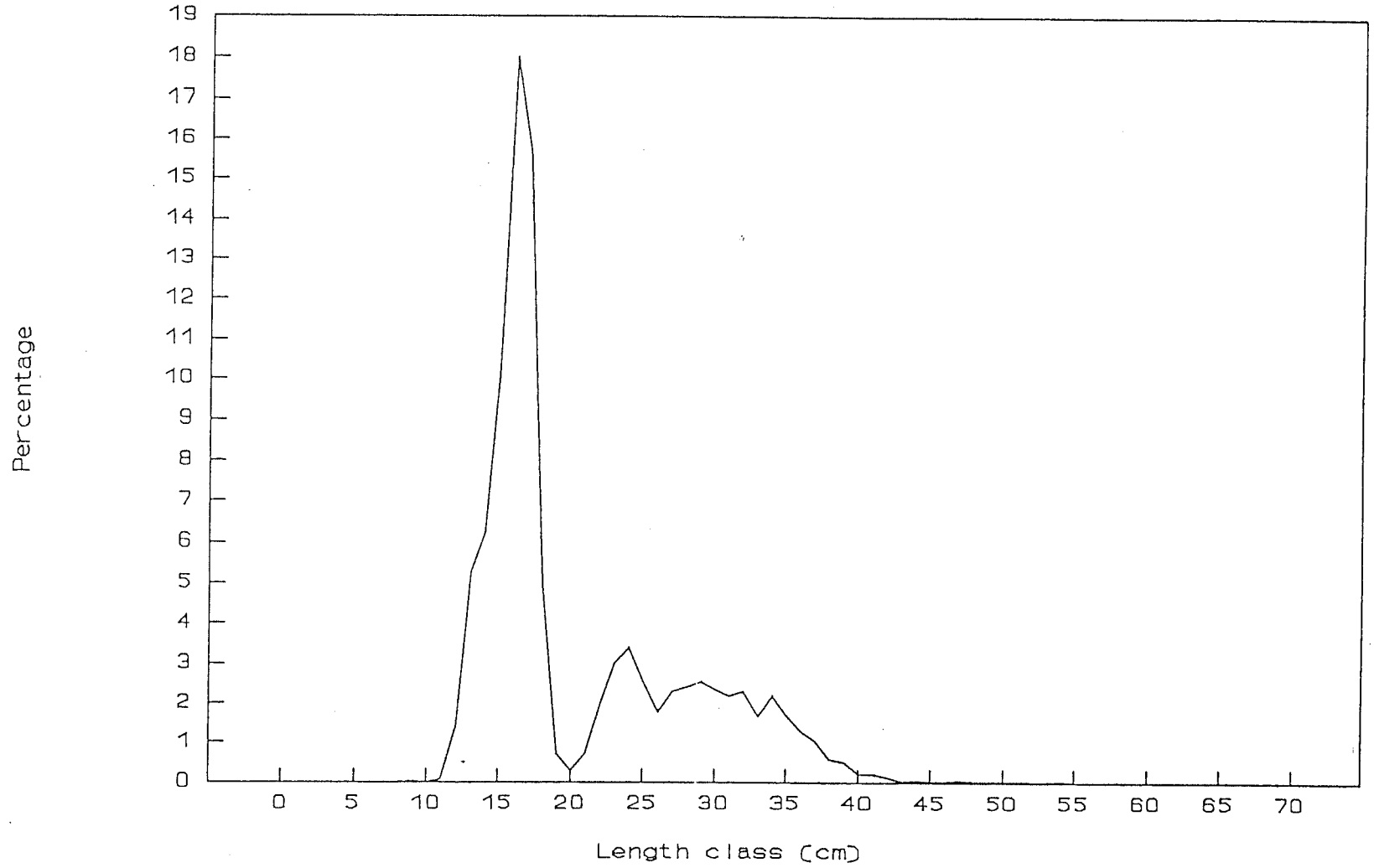

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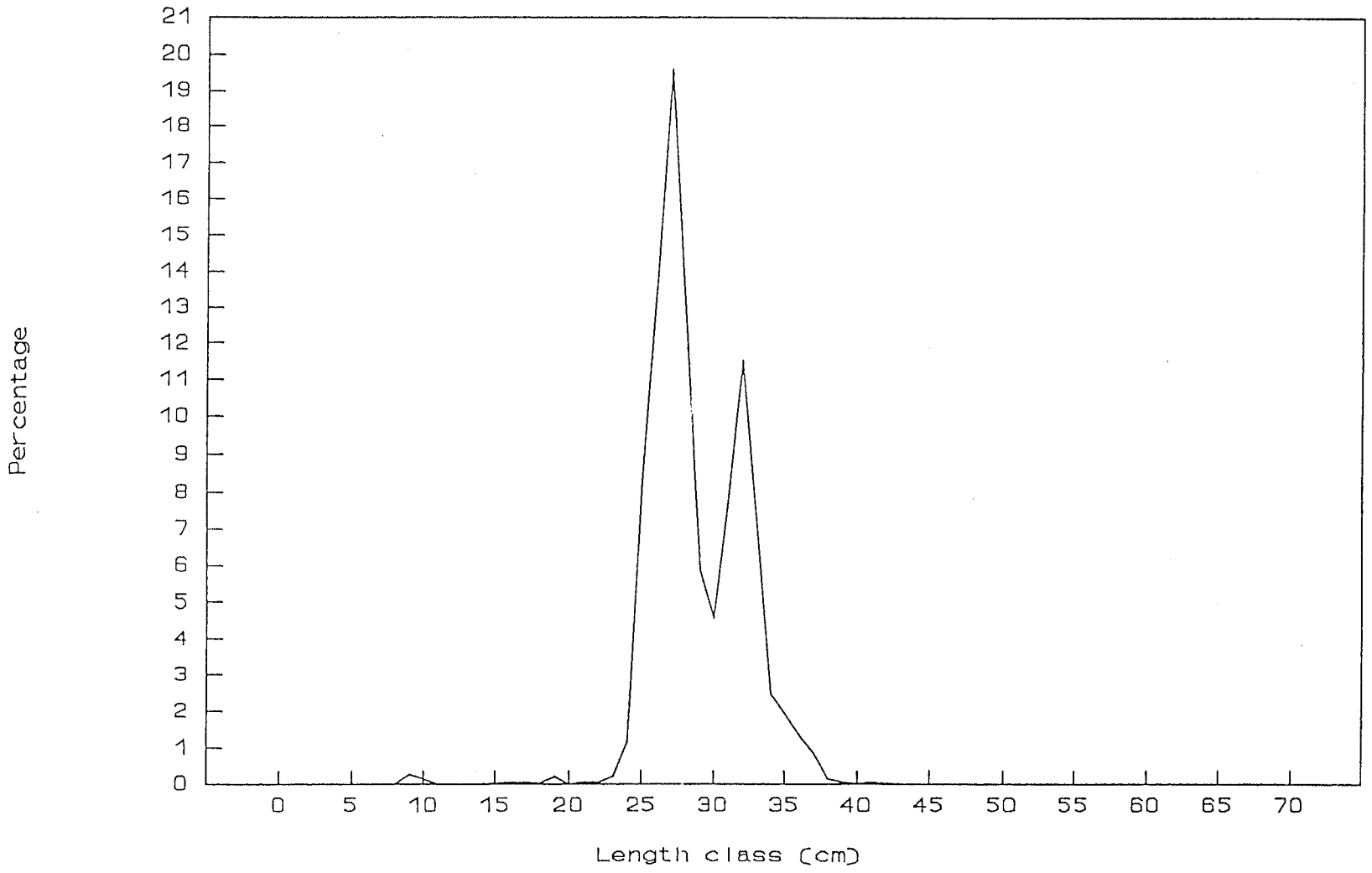

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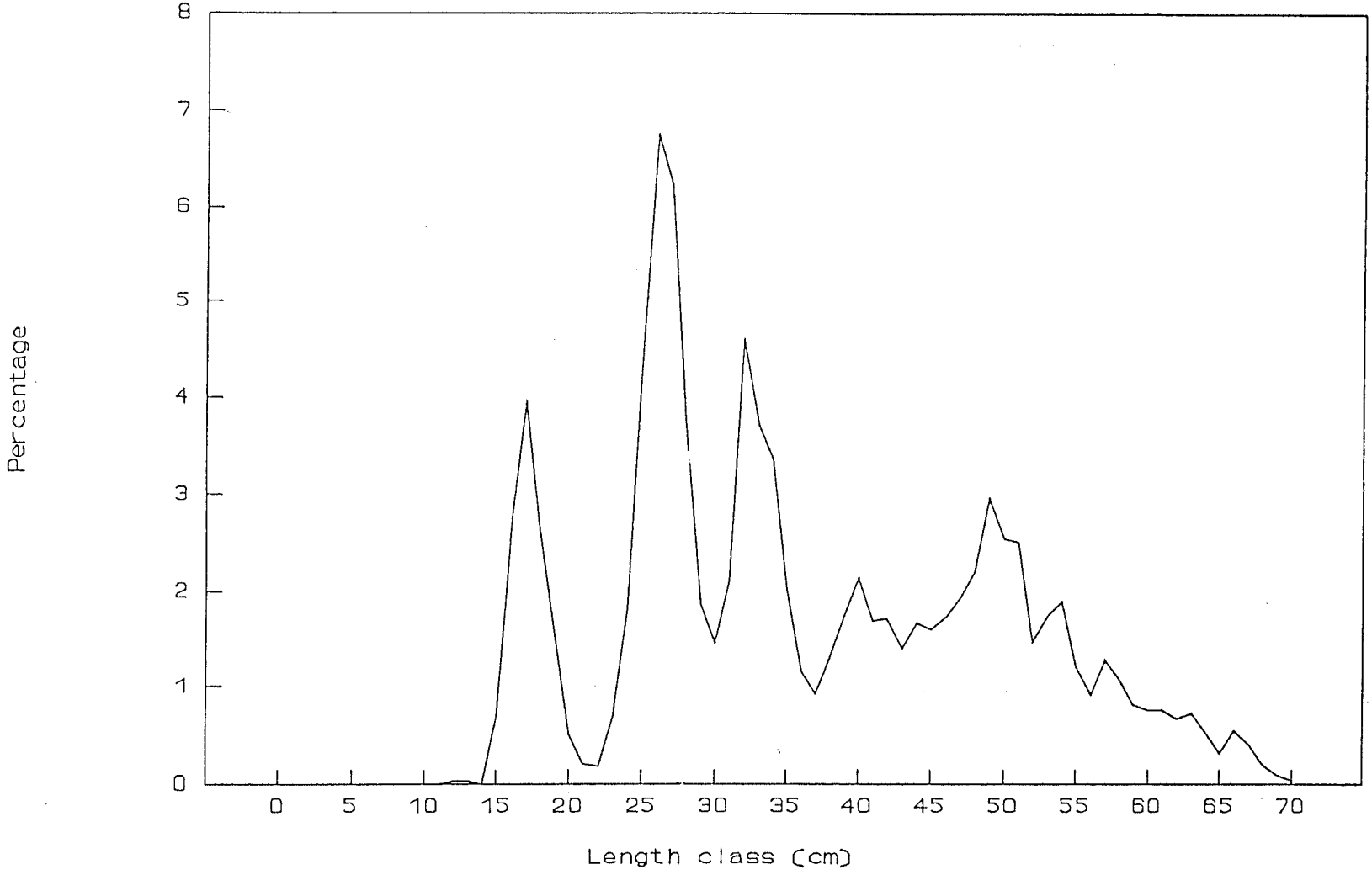

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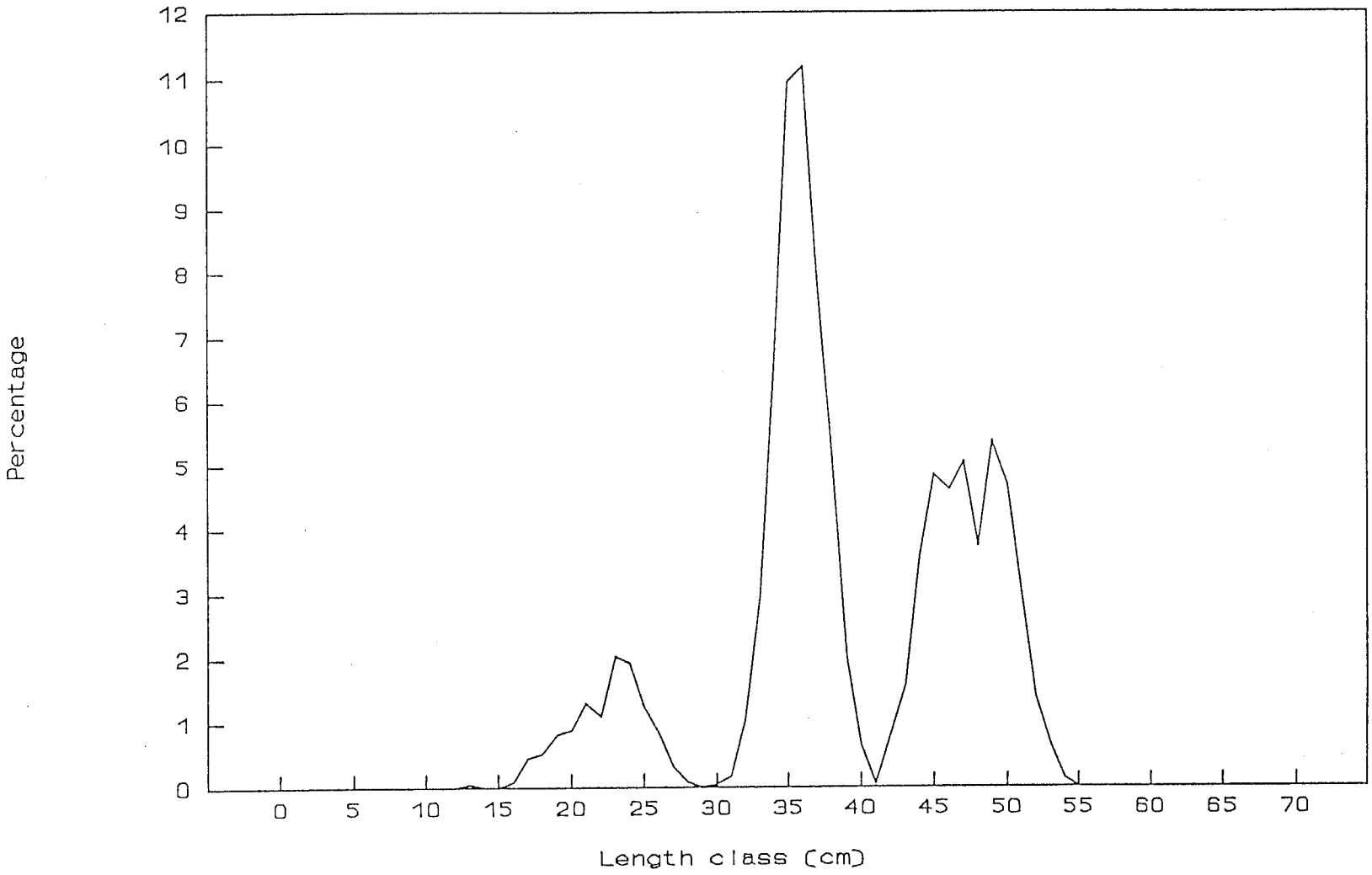

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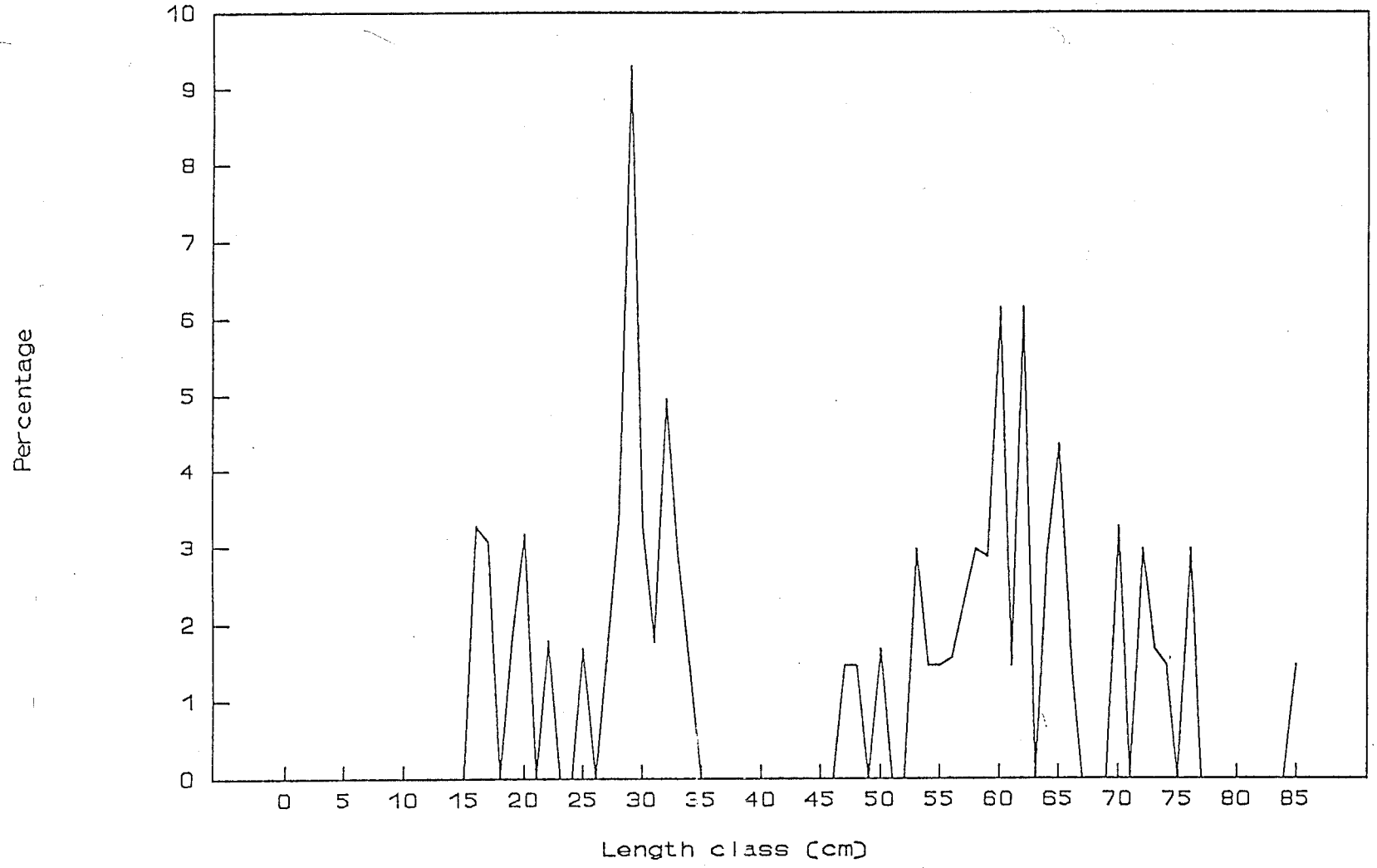

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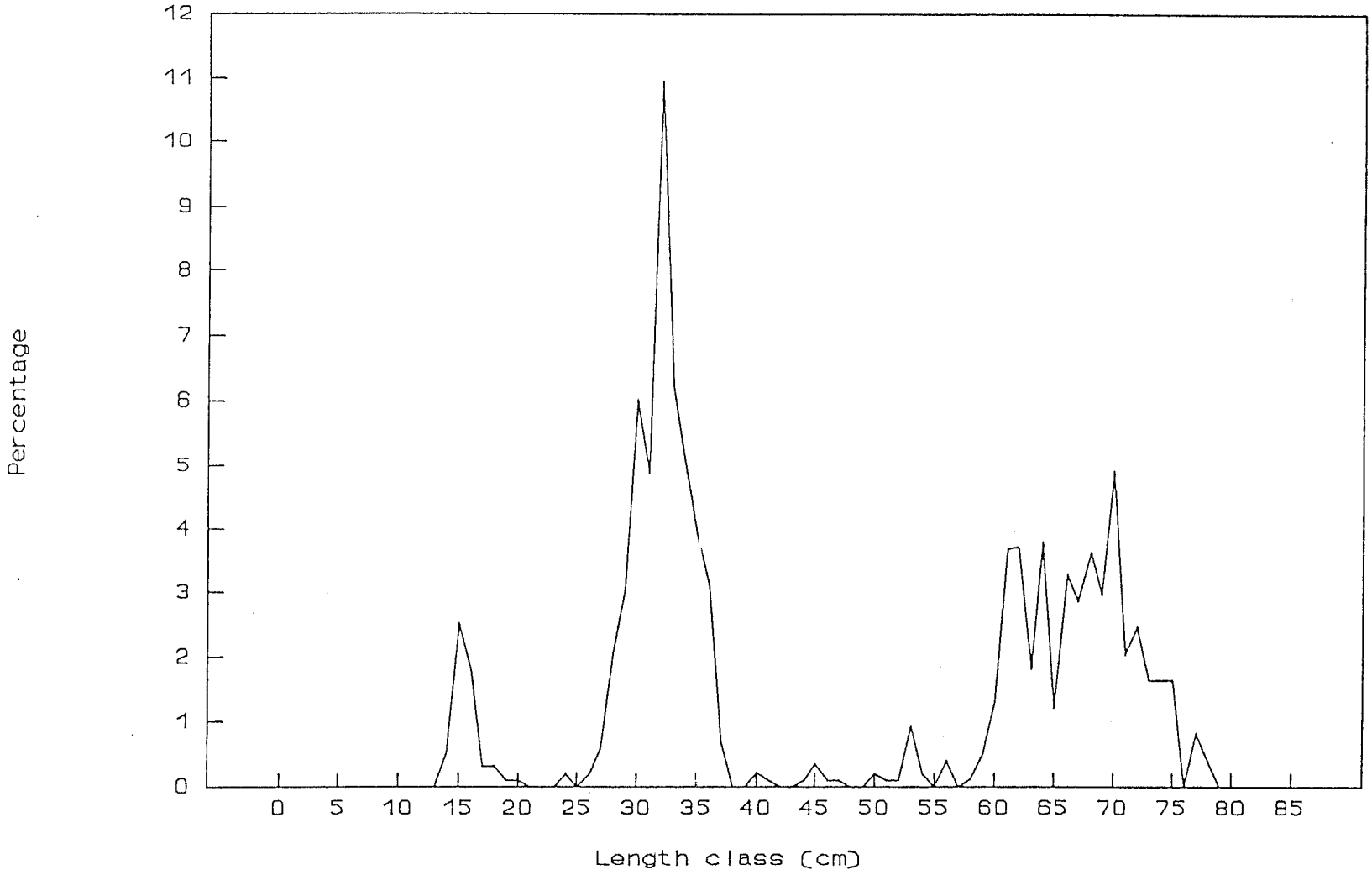

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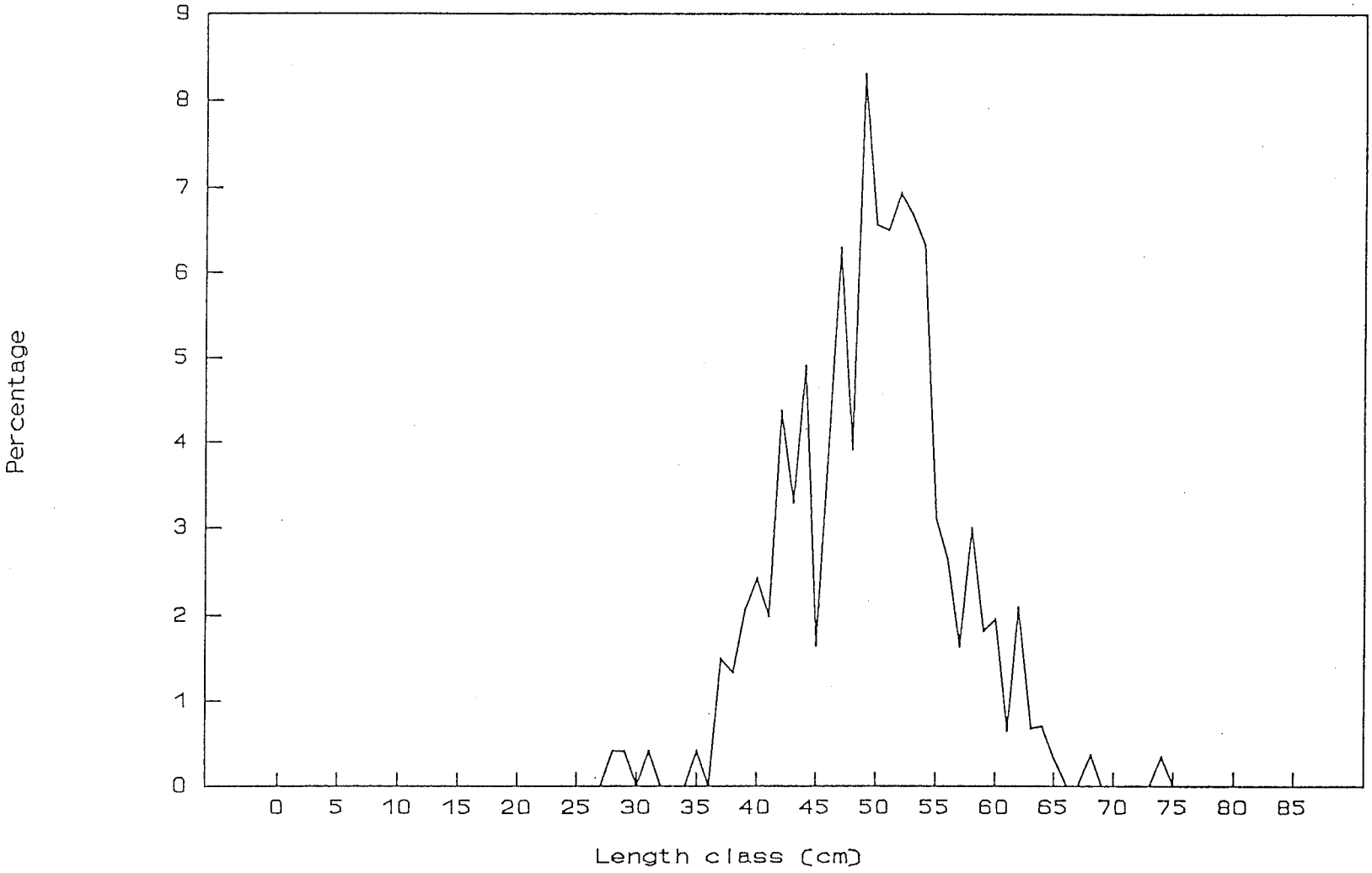

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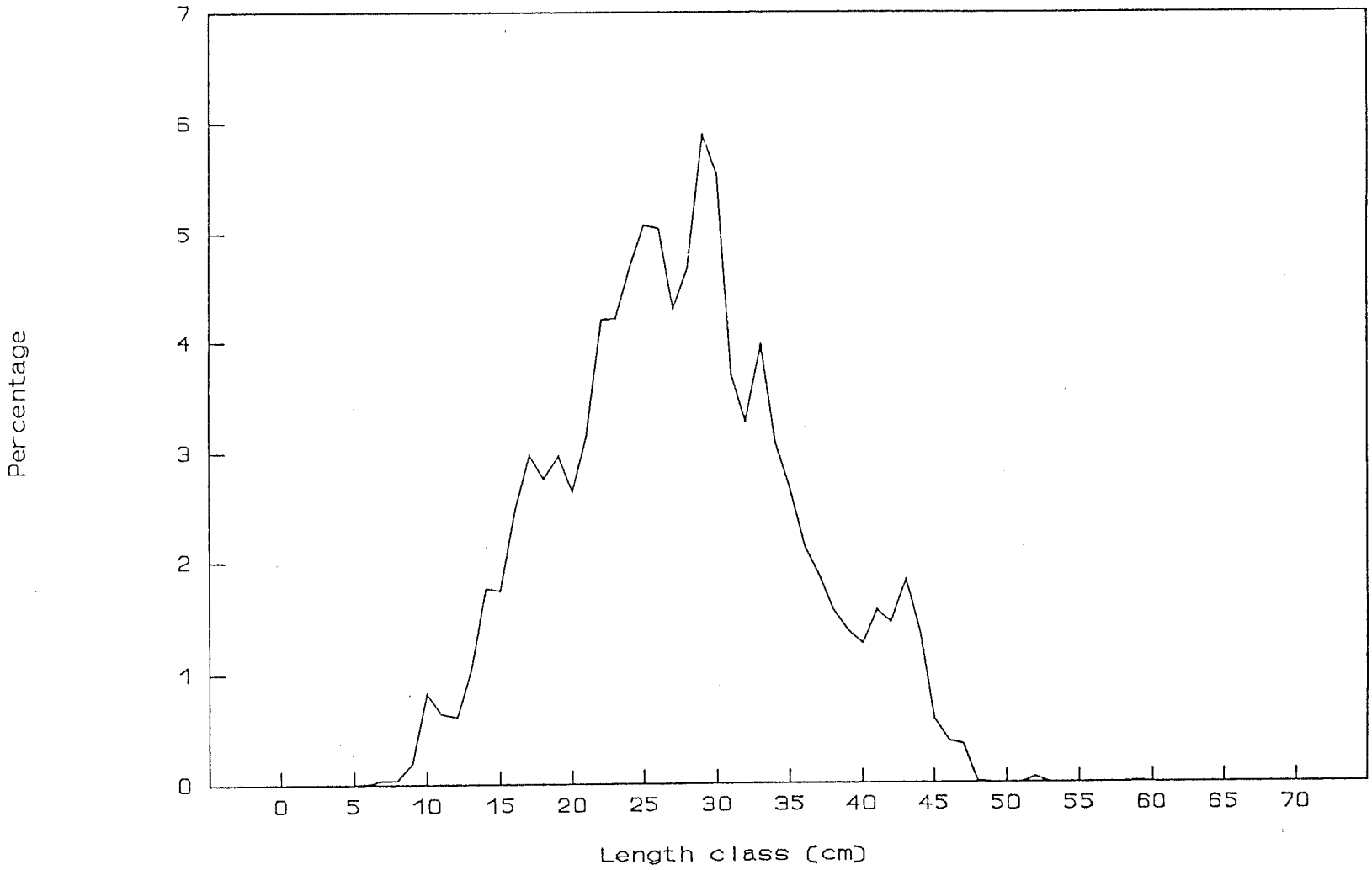

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A SIMULATION STUDY OF THE METHOD OF DERIVING NATURAL MORTALITY RATE USING DATA FOR *CHAMPSOCEPHALUS GUNNARI* IN SUBAREA 48.3

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Abstract

A method of determining the rate of natural mortality, based on the construction of a regression between the rate of annual fishing mortality (determined by VPA) and fishing effort, is described. The intersect of this regression must be equal to zero if the natural mortality rate has been correctly identified and something other than zero if it has not been correctly chosen. Data for *Champsocephalus gunnari* in Subarea 48.3 are used to show that the described method is sound. When a mistake is made in the choice of natural mortality coefficient, the estimate of the intercept of the regression is other than zero. A bias in the intercept will be positive if the assumed natural mortality coefficient is less than the "true" value and close to zero or slightly greater than zero if the assumed value is greater than the "true" one.

Résumé

Description d'une méthode permettant de déterminer le taux de mortalité naturelle à partir de la construction d'une régression entre le taux de mortalité par pêche annuel (établi par VPA) et l'effort de pêche. Le point d'intersection de cette régression doit être égal à zéro si le taux de mortalité naturelle a été identifié correctement, et, s'il est différent de zéro, celui-ci est incorrect. Les données sur *Champsocephalus gunnari* de la sous-zone 48.3 sont utilisées pour prouver que la méthode décrite est fiable. Si le taux de mortalité naturelle n'est pas correctement choisi, l'estimation du point d'intersection de la régression est différente de zéro. Tout biais dans le point d'intersection sera positif si le taux présumé de mortalité naturelle est inférieur à la valeur "réelle".

Резюме

Описан метод расчета коэффициента естественной смертности, основанный на построении регрессии между коэффициентом ежегодной промысловой смертности (определенным при помощи VPA) и промысловым усилием. Свободный член этой регрессии должен равняться нулю, в случае если коэффициент естественной смертности определен правильно, и быть отличным от нуля, в случае ошибки. Данные по *Champsocephalus gunnari* в Подрайоне 48.3 использованы для подтверждения целесообразности описанного метода. При совершении ошибки в выборе коэффициента естественной смертности, свободный член этой регрессии будет отличен от нуля. Наклон пересечения будет положительным, если предположенный коэффициент естественной смертности меньше чем "истинное" значение.

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Resumen

Se describe un método para determinar el índice de mortalidad natural basado en la construcción de una regresión entre el índice de mortalidad por pesca anual (determinado por el VPA) y el esfuerzo pesquero. Si el índice de mortalidad natural se ha identificado correctamente, la intersección de esta regresión deberá ser igual a cero. Se emplearon los datos de *Champsocephalus gunnari* de la Subárea 48.3 para demostrar que el método descrito está correcto. Cuando la selección del índice de la mortalidad natural es errónea, la estimación de la intersección de la regresión es diferente a cero. El sesgo de la intersección será positivo si el índice de mortalidad natural supuesto es menor que el valor "real".

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1. INTRODUCTION

In 1989, in the papers by Shlibanov (1989) and Sparre (1989) natural mortality rates for *Patagonotothen guntheri* estimated by different methods were calculated as 0.48, 0.63, 0.72, 0.83, 0.94 and 1.06. The values were so obviously scattered that they gave rise to extreme uncertainty in assessment of this commercial species. In a special study of this species, Gasyukov and Dorovskikh (1990) suggested a new approach to the determination of natural mortality. They concluded that the natural mortality rate of 0.9 was the most likely value for *P. guntheri* in Subarea 48.3.

A similar situation arose regarding estimation of the natural mortality rate for *Champsocephalus gunnari* in Subarea 48.3. A value of 0.56 obtained by Frolkina and Dorovskikh (1989) differed from the value of 0.35 used by the Working Group on Fish Stock Assessment (WG-FSA) in previous years. In 1990 the same authors confirmed the natural mortality rate of 0.56 by using a large amount of original data and the approach outlined in Gasyukov and Dorovskikh (1990).

A discussion of this approach for verifying the natural mortality rate calculation held at the meeting of the WG-FSA (CCAMLR, 1990) indicated that the scientific justification for using the method of Gasyukov and Dorovskikh (1990) would be improved if its behaviour and performance were to be studied by means of mathematical simulation.

2. METHODS FOR REFINING NATURAL MORTALITY RATE CALCULATIONS

The method of Gasyukov and Dorovskikh, (1990) is very close to Paloheimo method (Ricker, 1975). It is based on the construction of a regression between the rate of annual fishing mortality and fishing effort and the premise that the intersect of this regression should be equal to zero when the value of natural mortality chosen is correct (see Frolkina and Dorovskikh, 1990). Age composition of the catches, $C_{a,y}$, for a series of years and standardised values of fishing effort E_y, $y = 1,2 \ldots .n$ were used as the initial data. A set of possible values of natural mortality M_i, $i = 1,2, \ldots .j$ is assumed to be known. Then the algorithm for the determination of natural mortality consists of the following steps:

Mortality Algorithm

(i) a specific value of natural mortality M_i is selected from the set of its possible values;

(ii) a VPA is run, tuned to fishing effort data by one of the methods of Pope and Shepherd (1985). The tuning method which would correspond studies of a given fish species is preferable;

(iii) the VPA is used to compute the annual fishing mortality $\mathbf{F}_{a,y}$, and abundance $\mathbf{N}_{a,y}$ rates by age and fishing year, where terminal fishing mortality rates and fishing mortality rates for the oldest age group by fishing year are estimated by the tuning algorithm;

(iv) mean weighted values of annual fishing mortality, $\mathbf{F}_y$, for all age groups fully represented in the catch beginning from age $\mathbf{a}_f$ is:

$$\mathbf{F}_y = \sum_{a=a_f}^{a_k} w_{a,y} \times \mathbf{F}_{a,y} \tag{1}$$

where $w_{a,y}$ are weight factors.

(v) regression equation parameters $\mathbf{a}_i$, $\mathbf{a}_d$ and $\mathbf{b}_i$ are found from:

$$\mathbf{F}_y = \mathbf{a}_i + \mathbf{b}_i \, \mathbf{E}_y \tag{2}$$

where the index i corresponds to selected natural mortality rate;

(vi) steps 2 to 5 are then repeated for a range of values of natural mortality.

The main principle of the natural mortality rate verification is based on an assumption that if the selected natural mortality rate **M** is correct, then the factor **a** in regression equation (2) will be equal to zero (fishing effort is proportional to fishing mortality). In practical calculations, with regard for the random pattern of the initial data and the final sample amount it will be reasonable to apply the statistical null hypotheses that this factor is equal to zero.

It should be noted that steps (iv) and (v) can be accomplished by a number of methods. Mean weighted fishing mortality rates in particular, can be estimated using corresponding age group abundance values,

$$w_{a,y} = \frac{\mathbf{N}_{a,y}}{\Sigma \mathbf{N}_{a,y}} \tag{3}$$

or using factors recommended by Shepherd (1982):

$$w_{a,y} = \frac{\mathbf{F}_{a,y} \, e^{-\mathbf{Z}_{a,y}} \left[1 - e^{-\mathbf{Z}_{a,y}}\right]}{\mathbf{Z}_{a,y}} \tag{4}$$

For determination of regression equation parameters (2) both the algorithm of simple and that of functional regressions can be used (Ricker, 1975).

3. SIMULATION DESCRIPTION

The method of simulation has been widely used, especially recently, for resolving various problems and a description can be found in Butterworth (1988). This method has been

used in CCAMLR by Basson and Beddington (1989), Kock (1989), De la Mare and Constable (1990).

A model proposed by Butterworth (ICSEAF, 1989) and simplified for our modelling study seems to be most consistent with our objectives.

The basic relationships in the Butterworth (1988) model are:

Simulation model

(i) Main relationships of abundance dynamics

$$\mathbf{N}_{a+1,y+1} = \mathbf{N}_{a,y} e^{\left(-\mathbf{Z}_{a,y}\right)} \tag{5}$$

$$\mathbf{Z}_{a,y} = \mathbf{M} + \mathbf{S}_{a,y}\,\mathbf{F}_y \tag{6}$$

$$\mathbf{S}_{a,y} = \mathbf{S}_a \tag{7}$$

where $\mathbf{S}_a$ is selectivity at age a ;

$\mathbf{F}_y$ is total fishing mortality at year y;

$a = 1,2, \ldots, a_k$;

$y = 1,2, \ldots, y_k$.

(ii) "Stock recruitment" ratio:

$$\mathbf{N}_{0,y+1} = e^{\left\{\varepsilon_y - \frac{\sigma_r^2}{2}\right\}} \bullet \Phi\left(\mathbf{B}_y\right); \tag{8}$$

$$\mathbf{B}_y = \sum_{a=a_m}^{a_k} \left\{w_{a,y}\,\mathbf{N}_{a,y}\right\}; \tag{9}$$

$$w_{a,y} = \frac{1}{2}\left[w_{a+1/2,y} + w_{a-1/2,y}\right] \text{ for } a > 0,$$

$$\mathrm{w}_{a,y} = \mathrm{w}_{0,y} = w_{1/2,y} \text{ for } a = 0, \tag{10}$$

a_m = age at first maturity;

where Φ is an expression which describes dependence of recruitment rate on parent stock size;

ε is random number from normal distribution with mean 0 and variance σ_r^2.

$$\varepsilon \in \mathbf{N}\left(0, \sigma_r^2\right); \tag{11}$$

(iii) The catch weight:

$$\mathbf{C}_y = \Sigma\, w_{a+\frac{1}{2},y}\, \mathbf{N}_{a,y}\, \mathbf{S}_{a,y}\, \mathbf{F}_y \left(1 - e^{-\mathbf{Z}a,y}\right) / \mathbf{Z}_{a,y} \qquad (12)$$

(iv) Correlation between fishing effort and fishing mortality:

$$\mathbf{F}_y = q\, \mathbf{E}_y; \qquad (13)$$

where q is catchability factor.

(v) Catch-at-age and fishing year, $\mathbf{C}_{a,y}$:

$$\mathbf{C}_{a,y} = \mathbf{N}_{a,y}\, \mathbf{S}_{a,y}\, \mathbf{F}_y \left[1 - e^{-\mathbf{Z}_{a,y}}\right] / \mathbf{Z}_{a,y}. \qquad (14)$$

Thus the only element of this model that is subject to random error is recruitment. All other parameters are derived empirically, in contrast to the complete Butterworth (1988) model in which many components are subject to error.

For simulation of population dynamics the following initial data are required:

a_k - number of age groups;

y_k - number of fishing years;

M - natural mortality rate;

$w_{a,y}$ or w_a - mean weight-at-age (and fishing year);

$\mathbf{N}_{a,0}$ - distribution of abundance by age during the zero fishing year;

$\mathbf{C}_y$ - total catch by weight by fishing years;

q - catchability factor;

$\mathbf{S}_a$ - age selectivity factor;

σ_r^2 - the variation of the random component in expression (7) and the parameters of "stock-recruitment" ratio.

The algorithm of simulation involves the following stages:

(i) the abundance of zero group in the first fishing year is estimated from equation (8);

(ii) the abundance values $\mathbf{N}_{a,1}$, $a = 1,2, ...,a_k$ are computed from the formula:

$$\mathbf{N}_{a,1} = \mathbf{N}_{a-1,0}\, e^{-\mathrm{M}};$$

(iii) for each $y, y = 1,2, ...,y_k$:

(a) age selectivity values $S_{a,y}$ are computed from formula (7);

(b) total fishing mortality F_y is estimated from equation (12) with the use of the present value of C_y;

(c) fishing effort E_y is deduced from (13);

(d) "real" catch $C_{a,y}$ is computed for $a = 1,2, ...,a_k$ from (14);

(e) if $y \neq y_k$, $N_{0,y+1}$ is produced from (8) and from (5) $N_{a,y+1}$ is found for $a = 1,2, ...,a_k$.

Thus the major output information for each model run comprises:

- matrix of catch-at-age and fishing year $C_{a,y}$;
- fishing effort by fishing year E_y.

A general procedure for the study of natural mortality rate specification with the use of this simulation is as follows:

(i) the value of **M** for a single simulation of commercial population dynamics is set;

(ii) the number of model runs **P** for the simulation is determined;

(iii) simulation of population dynamics is made in accordance with the above-mentioned model which results in the values of $C_{ay}^{(p)}$, $E_y^{(p)}$ for $\mathbf{p} \in \mathbf{P}$.

(iv) the simulation is run for a number of values of natural mortality M_i, $i = 1,2 ...j$. The result of this algorithm are the intersect values of the regression equation (2).

(v) calculation of final statistics for each assumed **M** rate.

The null hypothesis is that the intercept of equation (2) will equal zero when the value of **M** used is equal to the true value of **M**.

4. DATA USED

For running this simulation model a number of parameters and values are required. It was decided that it was better to use real data from the fishery for this purpose and as an example the *C. gunnari* fishery in Subarea 48.3 was chosen.

The required initial parameters and values were computed from actual data used for stock assessment purposes (Gasyukov, 1990). Corresponding values of catch-at-age and fishing year, and fish mean weight are given in Tables 1 and 2. The catch by weight of *C. gunnari* in Subarea 48.3 and standardised values of fishing effort computed by means of the multiplicative model (Gasyukov, 1990) are presented in Table 3.

The abundance values and fishing mortality rates were estimated by the VPA tuned by the Laurec-Shepherd method (Pope and Shepherd, 1985). The corresponding values are given in Tables 4 and 5.

Thus the following values were taken as initial ones:

$\mathbf{M} = 0.56$;
$a_k = 6$;
$y_k = 8$;
$a_f = 3$;
$a = 36.85$;
$\beta = 0.0113$;
$q = 0.000115$;
$\sigma_r = 0.7008$;
$\mathbf{P} = 1000$ (number of simulation runs).

Age selectivity rates and initial values of abundance during the zero year had the following values:

Age group, a	1	2	3	4	5	6
$\mathbf{S}_a$	0.0215	0.174	0.692	0.568	0.761	0.759
$\mathbf{N}_{a,o}$x10^{-6}	941.8	1216.3	233.2	71.2	25.6	14.6

Thus together with the mean fish weight data from Table 2, the above-stated parameters form the necessary basis for running of simulation model for *C. gunnari* from Subarea 48.3.

5. COMPUTATION RESULTS AND THEIR DISCUSSION

Two variants of the mortality algorithm were used, specified for estimation of the mean fishing mortality for major age groups, by weighting by abundance (equation 3) or by catch (4).

For each value of natural mortality rate out of the set of its assumed values 1 000 runs of the model were made. The results of simulation took the shape of histograms of values of intersect of regression equation with the mean and median values.

Corresponding results are presented in Table 6 and shown in Figure 1.

First of all, similarity of the results obtained from both computation variants are worth noting. If the assumed natural mortality rate values are less than the "ideal" one, then the values of the intersect have a positive shift, whereas if the values are greater than the "ideal" one, this shift is negative. Irrespective of weighting method used for computation of the mean weighted fishing mortality rate, the values of the intersect appeared to be close for the two weighting methods. Although the sign of the shift is the same, its range appears to be greater when weighting by **C** than when weighting by **N**. The difference between zero and the intercept is minimal if the assumed value of **M** is close to the "ideal" one and maximal if the assumed value is much greater than the "ideal" one.

The simulated distribution of values of the intersect has a marked assymetrical pattern with assumed values of **M** which significantly differ from the "ideal" value and is close in its shape to normal distribution of the values close to the "ideal" one.

Two peculiar features of the values were revealed from simulation results. Firstly, if the assumed value of **M** exceeds the "ideal" one, then the shift of the absolute intersect values is very small and markedly unlike the difference between the "ideal" and assumed values of **M**.

For example, with the assumed **M** of 0.72 the value of this shift is not greater than 0.02 to 0.04 and is comparable with the value of shift with the "ideal" value of **M** (Figure 1).

This fact has a theoretical foundation. In his paper, Hilden (1988) showed that if the error $\Delta \mathbf{M}$ is introduced to the natural mortality rate when performing the VPA, then the below is true:

$$exp\left(\mathbf{F}_t^{'} + \Delta \mathbf{M}\right) > exp\left(\mathbf{F}_t\right)$$

where $\mathbf{F}_t^{'}$ is the fishing mortality rate value produced from VPA, with incorrect natural mortality rate $\mathbf{M}+\Delta\mathbf{M}$;

$\mathbf{F}_t$ is "ideal" value of fishing mortality rate. Then if $\Delta \mathbf{M}$ is positive, $\mathbf{F}_t^{'}$ will be closer to $\mathbf{F}_t$ than in case when $\Delta \mathbf{M}$ is negative. This was the feature confirmed by the simulation results.

The second peculiarity of the values lies in the fact that the shift of the value of the regression equation intersect in all cases appeared to be smaller in terms of absolute value than deviation of the assumed **M** from its "ideal" value. No theoretical explanation was found for this case. Evidently this can be hardly done in a general form as fishing mortality rate values produced by the VPA depend not only on ΔM but also on the values of **F** for preceding age groups (Hilden, 1988).

However, in general, the results of simulation showed that the suggested approach (Gasyukov and Dorovskikh, 1990) makes it possible to specify the value of natural mortality rate for commercial fishes.

6. CONCLUSION

The suggested method for deriving natural mortality rate is based on a regression equation between the fishing mortality rate computed from the VPA using an assumed natural mortality rate, and fishing effort. If the selected natural mortality rate is correct, the intersect of this equation will be close to zero. Otherwise its value will be different from zero.

The study carried out with the use of the mathematical simulation by using *C. gunnari* fishing in Subarea 48.3 as an example showed that the suggested approach gives reliable estimates. If there is an error in the natural mortality rate, the absolute intersect (a) in equation (2) is different from zero; the shift has a positive sign if the assumed value of the natural mortality rate is smaller than the "ideal" one, but close to zero or somewhat greater than zero if the assumed value is greater than the "ideal" one.

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Table 1. Age composition of catches of *C. gunnari* (n x 10^6).

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90
1	25.97	98.63	5.28	21.64	6.92	8.60	10.25	1.81
2	162.20	167.08	18.20	39.62	207.12	12.42	128.89	3.13
3	428.08	120.92	47.05	34.01	276.94	70.06	14.47	29.09
4	68.13	76.11	12.71	1.89	19.31	35.51	9.18	3.16
5	24.97	21.54	1.800	0.670	4.210	25.16	11.49	1.83
6	8.55	4.31	0.540	0.130	0.700	6.85	2.31	0.89
Total	717.9	488.6	85.6	98.0	515.2	158.6	176.6	39.9

Table 2. Average fish mass (in grams) for *C. gunnari* in Subarea 48.3

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90
1	29.7	35.8	23.4	29.7	24.9	17.7	23.4	19.2
2	87.8	97.2	79.0	87.8	81.9	70.6	79.0	74.6
3	175.8	189.0	163.3	175.8	167.4	151.0	163.3	160.7
4	291.8	308.0	276.0	291.8	281.2	260.5	276.0	293.0
5	430.2	448.9	411.9	430.2	418.0	393.8	411.9	467.0
6	585.2	605.5	565.2	585.2	571.8	545.3	565.2	615.0

Table 3. Catch in weight and standardised effort.

Year	Total catch	Effort
80/81	29464	14142
81/82	47454	7182
82/83	131576	20420
83/84	80664	15798
84/85	14293	2984
85/86	11368	4483
86/87	71853	20035
87/88	37736	15941
88/89	22213	7972
89/90	7268	1497

Table 4. Population numbers of *C. gunnari* in Subarea 48.3 (x10^6).

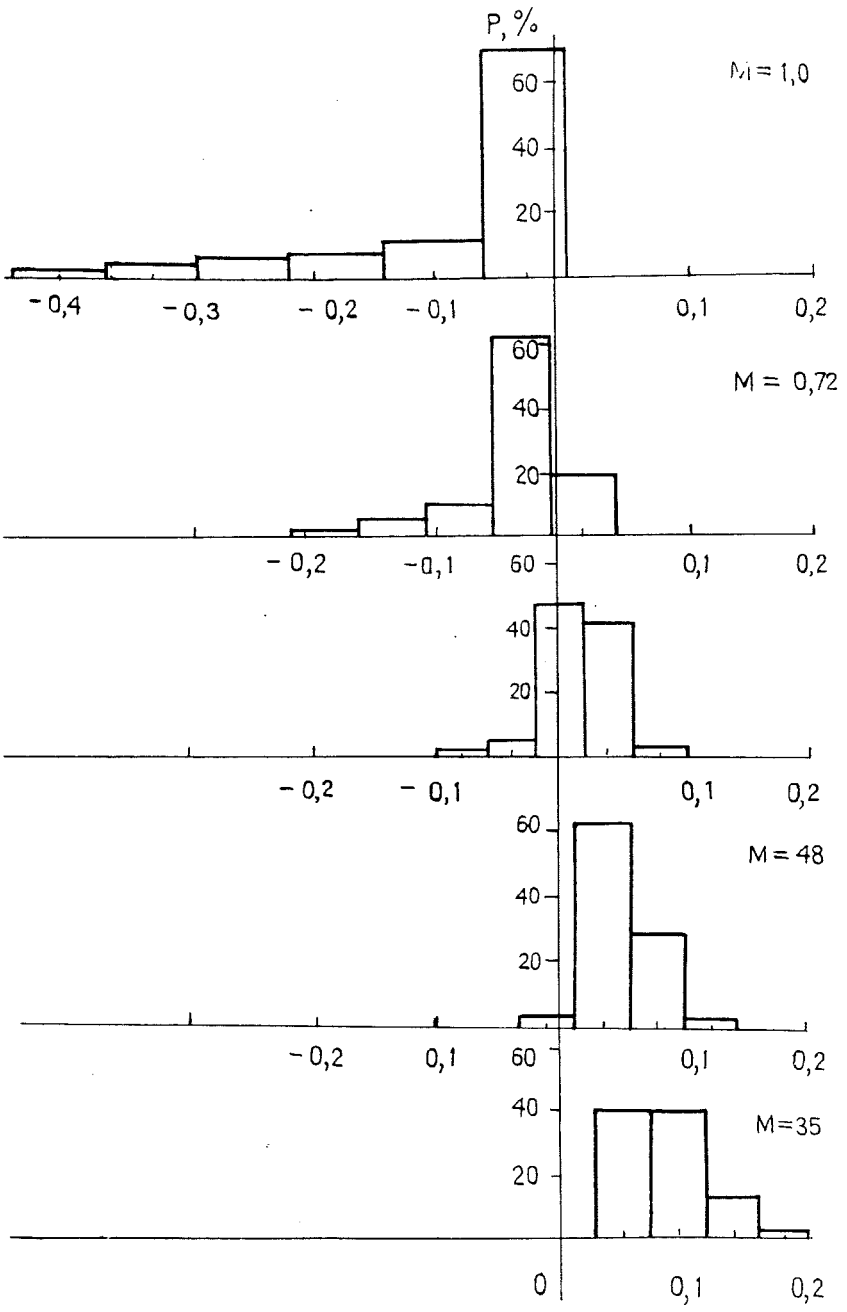
	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90
1	952.2	945.0	1796.2	1091.5	461.3	1803.8	1175.0	1049.7
2	542.3	524.6	466.7	1022.0	607.4	258.3	1023.9	663.5
3	696.5	191.4	178.0	253.0	554.3	196.4	138.3	489.5
4	133.6	97.7	24.8	67.2	119.4	119.0	61.3	68.3
5	40.9	27.8	4.6	5.1	37.0	54.0	42.0	28.3
6	14.7	5.8	1.3	1.3	2.4	18.0	12.8	15.6
Total	2380	1792.2	2471.5	2440.2	1781.7	2449.4	2453.4	2314.9

Table 5. Fishing mortality rate of *C. gunnari* in Subarea 48.3.

	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90
1	0.036	0.145	0.004	0.026	0.020	0.006	0.011	0.002
2	0.481	0.521	0.052	0.052	0.569	0.065	0.178	0.006
3	1.404	1.482	0.414	0.191	0.979	0.604	0.146	0.080
4	1.011	2.504	1.018	0.037	0.234	0.480	0.215	0.062
5	1.389	2.469	0.691	0.185	0.160	0.880	0.431	0.089
6	1.269	2.154	0.710	0.138	0.459	0.658	0.265	0.077

Table 6. Intercept values of regression equation from the results of simulation runs.

	Weighing by **N**			Weighing by **C**		
	Value of **a**		Discard interval	Value of **a**		Discard interval
M	Mean	median	**a** in histogram	Mean	median	**a** in histogram
0.35	0.087	0.082	[0.056 ; 0.177] :	0.102	0.083	[0.045 ; 0.302]
0.48	0.042	0.039	[-0.012 ; 0.115] :	0.065	0.050	[0.019 ; 0.196]
0.56	0.014	0.016	[-0.086 ; 0.082] :	0.038	0.025	[0.005 ; 0.146]
0.72	-0.036	-0.025	[-0.189 ; 0.019] :	-0.012	-0.016	[-0.048 ; 0.058]
1.00	-0.084	-0.051	[-0.414 ; -0.030] :	-0.062	-0.047	[-0.177 ; 0.009]



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BIOLOGIE ET EXPLOITATION DE *DISSOSTICHUS ELEGINOIDES* AUTOUR DES ILES KERGUELEN (DIVISION 58.5.1)

Guy Duhamel*

Abstract

Dissostichus eleginoides is becoming an increasingly important species in the fisheries of the Southern Ocean. In Division 58.5.1, a directed trawl fishery has been in operation since 1984/85 and has expanded in the deep western sector of the Kerguelen Shelf. This fishery harvests the sub-adult/adult part of the stock. Fishing effort and corresponding catches are very variable from year to year and highly dependent on the harvestable resources of *Champsocephalus gunnari*. Vital biological information on population dynamics, as well as demographic structures and trends observed in an abundance index, is provided. Prospects for exploitation are discussed with respect to the development of fishing methods.

Résumé

Dissostichus eleginoides constitue de plus en plus une espèce importante dans les pêcheries de l'océan Austral. Dans la division 58.5.1 une pêche dirigée au chalut existe depuis 1984/85 et s'est développée dans le secteur ouest profond du plateau de Kerguelen. Cette pêcherie exploite la partie sub-adulte et adulte du stock. L'effort de pêche et les captures correspondantes sont très variables d'une année à l'autre et fortement dépendants des ressources exploitables en *Champsocephalus gunnari*. Des informations biologiques indispensables en dynamique des populations, les structures démographiques et les tendances observées à partir d'un indice d'abondance sont fournies. Les perspectives d'exploitation sont discutées en fonction du développement des méthodes de pêche.

Резюме

Dissostichus eleginoides приобретает все большее значение как промысловый вид в Южном океане. Направленный траловый промысел ведется на Участке 58.5.1 с 1984/85 г. и в настоящее время имеет место в глубокой западной части шельфа о-вов Кергелен. Облавливаются неполовозрелые и взрослые особи запаса. Промысловое усилие и соответствующие уловы сильно изменяются из года в год и в значительной мере зависят от эксплуатируемых ресурсов *Champsocephalus gunnari*. В данной работе приводится ключевая информация о динамике популяции, а также о демографических структурах и тенденциях, замеченных в показателе численности. Рассматривается вопрос о перспективах для промысла в зависимости от совершенствования методов его ведения.

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Resumen

Dissostichus eleginoides es una de las especies del Océano austral cuya importancia va en aumento. Desde la temporada 1984/85 existe una pesquería de arrastre en la División 58.5.1, que se ha extendido al sector oriental de la plataforma de la isla Kerguelén. Esta pesquería se concentra en la captura de los peces adultos y subadultos de la población. El esfuerzo pesquero y las capturas varían considerablemente de un año a otro y dependen en gran manera de los recursos explotables de *Champsocephalus gunnari*. Se ofrece información biológica esencial sobre la dinámica de las poblaciones, así como de la estructura demográfica de la población y las tendencias observadas en un índice de abundancia. Se examinan las perspectivas de explotación en función del perfeccionamiento de los métodos de pesca.

1. INTRODUCTION

La pêche dirigée de *Dissostichus eleginoides* est une caractéristique récente de la pêcherie des îles Kerguelen. Elle résulte de la découverte en 1984/85 de fonds de pêche correspondant aux concentrations de sub-adultes/adultes de cette espèce dans le secteur ouest profond du plateau des îles Kerguelen. Auparavant la pêcherie s'intéressait aux trois autres espèces abondantes (*Champsocephalus gunnari*, *Notothenia rossii* et *Notothenia squamifrons*) beaucoup plus facilement exploitables en raison de la connaissance des zones de pêche acquise par les pêcheurs depuis le début des années 1970. La raréfaction de *N. squamifrons*, la limitation de la pêche dirigée sur *N. rossii* et les années creuses dans l'exploitation de *C. gunnari* ont bouleversé les habitudes et obligé les pêcheurs à reprendre la prospection. Une nouvelle orientation de l'effort de pêche sur *D. eleginoides* en a résulté d'autant que cette espèce présente une haute valeur commerciale.

La connaissance de la biologie de cette espèce est cependant encore fort incomplète particulièrement pour la phase adulte. Ces informations sont pourtant indispensables pour l'interprétation des statistiques de pêche qui prouvent que l'on assiste à un développement de pêche dirigée. Il est donc utile de présenter les résultats obtenus à partir des programmes scientifiques confiés aux observateurs embarqués sur les chalutiers et récemment sur un palangrier.

2. MATERIEL ET METHODE

Le programme scientifique développé pour la pêcherie des îles Kerguelen depuis 1979/80 (Duhamel, 1987a) s'applique à l'étude de la biologie et de l'exploitation de *D. eleginoides*. Il est réalisé à bord de tout navire en opération autour des îles Kerguelen.

Des mensurations régulières (échantillonnages aléatoires des captures avec comme unité de mesure retenue : le centimètre inférieur) sont réalisées en individualisant les chalutages. Des prélèvements biologiques concommittants (prélèvements d'écailles et d'otolithes pour la détermination ultérieure de l'âge, analyse et prélèvements de gonades pour l'étude de la maturation sexuelle et de la reproduction, analyse de contenus stomacaux pour l'étude du régime alimentaire) sont effectués régulièrement et suivent les recommandations pour l'étude des espèces de l'océan Austral.

Les carnets de pêche obligatoires permettent de recueillir l'ensemble des statistiques de pêche. Leur exploitation se fait à partir de la banque de données KERPECHE qui regroupe ainsi

quelque 37 000 chalutages depuis 1979/80. Les applications permettent d'obtenir les captures totales et par espèce, les rendements, la localisation géographique et bathymétrique des chalutages. Les données biologiques peuvent ainsi être directement reliées à ces résultats.

3. RESULTATS

3.1 Principaux traits de la biologie de *Dissostichus eleginoides*

D. eleginoides est l'espèce de poisson qui atteint les plus grandes tailles (îles Kerguelen: Lt maximale observée = 215 cm) dans l'océan Austral tout comme son congénère plus antarctique *Dissostichus mawsoni*. Sa distribution géographique est vaste, circumantarctique, et principalement localisée au nord ou en limite (Géorgie du Sud par exemple) du front polaire.

Il a été démontré (Duhamel, 1987a), à partir de l'analyse des captures dans deux secteurs de la partie indienne de l'océan Austral (Crozet: sous-zone 58.6; Kerguelen: division 58.5.1), qu'avec la croissance *D. eleginoides* effectuait une migration bathymétrique. Les analyses des distributions de fréquences de longueurs, stratifiées par profondeur, montrent bien cette migration des poissons les plus âgés vers les grandes profondeurs (Figure 1). Chaque groupe de taille est ainsi représentatif d'un intervalle bathymétrique, ce qui permet indirectement de connaître avec précision l'origine des captures d'un chalutage puisque ce résultat est valable pour tous les secteurs géographiques de la zone concernée. Ainsi, au niveau des îles Kerguelen les juvéniles sont rencontrés au-dessus du vaste plateau péri-insulaire où ils adoptent un comportement alimentaire très similaire à celui de *C. gunnari* (prédation sur les crustacés pélagiques). Avec la croissance une tendance ichtyophage est plutôt constatée (>85% du régime alimentaire) lorsque les individus fréquentent les accores du plateau (proies préférentielles: *C. gunnari* et Myctophidae du genre Gymnoscopelus). Enfin les adultes rencontrés en grande profondeur (talus, au-delà de 400 m) continuent leur modification de régime alimentaire en incluant une forte proportion de céphalopodes (calmars du genre Histiotheuthis) au reste des proies toujours constituées de poissons, en particulier *Paradiplospinus gracilis* (Duhamel, 1981; Chechun, 1984; Duhamel 1987a et b).

Les déterminations de l'âge effectuées à partir des lectures d'écailles (Duhamel, 1987a) indiquent que la croissance en longueur est rapide les premières années et atteint parfois 10 cm annuellement. Certaines classes d'âge (I et II particulièrement) peuvent être ainsi aisément distinguées par des pics d'abondance dans les distributions de fréquences de longueurs. Cette croissance reste toujours conséquente ultérieurement (7 à 10 cm par an). Les individus de 100 cm sont ainsi âgés d'environ 11 ans et les individus de 160 cm dépassent une lecture de 17 ans, ce qui permet d'imaginer l'âge respectable que peuvent atteindre des spécimens de plus de 200 cm. Les groupes de taille les plus fréquemment observés dans les captures au chalut (30-60 à 50-100 cm) appartiennent aux classes d'âge III/V à V/XI respectivement.

La détermination de la taille et de l'âge de première maturité sexuelle a toujours été difficile à obtenir en raison du peu d'individus matures rencontrés dans les captures antérieures à 1984/85 et du peu d'analyses effectuées depuis lors (Duhamel, 1987a et b). Un échantillonnage récent (octobre 1990) permet de déterminer la taille moyenne de première maturité et celle de première reproduction (Figure 2) en utilisant l'échelle de maturité d'Everson (1977). Les valeurs obtenues diffèrent pour les mâles (57 et 65 cm respectivement, ce qui correspond aux classes d'âge VI et VII) et les femelles (70 et 80 cm soit les classes d'âge VII et VIII) et sont très comparables à celles notées pour les individus du secteur des îles Crozet (Duhamel, 1987b). Il est par ailleurs observé une différence constante entre les structures démographiques des individus mâles et femelles. Les mâles ne sont pas représentés dans les tailles les plus élevées, ce qui laisse supposer une croissance et une mortalité différentes des deux sexes une fois la maturité sexuelle dépassée. Les échantillonnages destinés aux lectures d'âge sont cependant encore trop peu importants pour pouvoir vérifier cette hypothèse résultant de l'observation des distributions de fréquences de longueurs.

La période de reproduction de l'espèce se situe en hiver austral (probablement à partir du mois de juin) dans les strates bathymétriques les plus profondes fréquentées par les adultes. En raison de l'inaccessibilité au chalutage des profondeurs supérieures à 550 m environ, la localisation géographique de la (ou des) frayères n'est fondée que sur le modèle observé pour les autres Nototheniidae abondants du plateau de Kerguelen, en l'occurence le rassemblement des individus matures aux abords de l'aire supposée de ponte quelques temps avant la reproduction. Le secteur ouest profond du plateau de Kerguelen représenterait alors cette zone. Cette espèce possède une fécondité absolue très élevée (Chikov et Melnikov, 1990), cependant la fécondité relative reste modeste (Duhamel, 1987b).

Ces informations biologiques recueillies à partir du suivi des chalutages réalisés sur tout le plateau de Kerguelen restent encore incomplètes puisque les chalutiers sont limités par des contraintes de nature de fond tant en zone côtière qu'au-delà de l'isobathe 550 m et que, par ailleurs, peu de chose est connue sur la phase ichtyoplanctonique conduisant à l'implantation des juvéniles en zone peu profonde. Pour les individus fréquentant les grandes profondeurs il faut faire appel à un autre métier pour obtenir des données. Une première campagne exploratoire à la palangre réalisée en 1991 dans le secteur ouest profond (>500 m) permet d'apporter des informations supplémentaires sur la structure démographique observée. La distribution de fréquences de longueurs résultant de cette campagne peut être comparée à celle obtenue lors des chalutages les plus profonds réalisés dans le même secteur par un chalutier (Figure 3). On constate que les distributions sont très comparables avec seulement une légère proportion d'individus plus âgés capturés par la palangre comparativement au chalut. Ce résultat montre qu'au-delà d'une certaine profondeur la structure démographique échantillonnée ne se modifie que très peu et que la proportion d'individus matures est toujours peu élevée.

3.2 La pêcherie

L'évolution de la pêcherie des îles Kerguelen (Table 1) permet de confirmer l'importance croissante de *D. eleginoides* dans le volume de capture réalisé depuis la création de la Zone Economique Exclusive (ZEE). Cette espèce qui ne représentait pas 1% des captures pour la période 1979/80 - 1983/84 représente maintenant plus de 15% du total capturé et les tendances actuelles hisseraient *D. eleginoides* au niveau de la deuxième espèce-cible pour la pêcherie.

Antérieurement à 1984/85 aucune pêche dirigée n'existait sur *D. eleginoides* comme le confirme l'effort de pêche relevé dans le secteur géographique ouest qui allait devenir la zone de pêche privilégiée ultérieurement (Table 2). La capture notée en 1979/80 résultait non d'un effort de pêche dirigé sur *D. eleginoides* mais d'une prise accessoire lors d'une pêche dirigée sur *C. gunnari*. La découverte en 1984/85 de concentrations profondes de *D. eleginoides* dans le secteur ouest a conduit à la mise en exploitation d'un stock vierge et fait immédiatement l'objet d'une pêche dirigée par plusieurs chalutiers. Le niveau de capture et les rendements observés cette année-là sont directement le reflet d'une abondance liée à cette découverte. Depuis cette date le secteur ouest a fait l'objet d'une exploitation systématique tant bathymétrique que géographique comme les cartes de positionnement des chalutages et des captures correspondantes de *D. eleginoides* (Figure 4), ainsi que les distributions de fréquences de longueurs observées simultanément (Figure 5), permettent de le constater. Les tailles des poissons échantillonnés permettent d'affirmer que c'est le stock adulte/sub-adulte de *D. eleginoides* qui est ciblé par la pêcherie.

Depuis la mise en exploitation du secteur ouest les captures s'élèvent à 15 441 tonnes et ce secteur représente à lui seul 87 % du total pêché de *D. eleginoides*. Les fluctuations annuelles des captures sont le reflet d'un effort de pêche très variable sur le stock. En particulier cet effort est très dépendant de celui déployé sur l'espèce-clé de la pêcherie des îles Kerguelen : *C. gunnari*. Les faibles valeurs d'effort de pêche observées en 1985/86, 1988/89 et 1990/91 correspondent en effet aux années de fortes captures de *C. gunnari* (17 054, 23 048 et 12 660 tonnes respectivement). Cette tendance peut être vérifiée par la comparaison de

faible abondance de *C. gunnari* l'effort de pêche sur *D. eleginoides* dépasse toujours 35% de l'effort de pêche total.

Les tendances observées à l'aide d'un indice standardisé basé sur la prise par unité d'effort de pêche (tonnage moyen capturé par heure de chalutage effectif pour un chalutier du type "Atlantic" utilisant un chalut de 41,7 m muni de maillage de 120 mm) permettent de constater une baisse notoire de l'abondance suivant la mise en exploitation du stock vierge puis une diminution plus relative ultérieurement. Les valeurs de cet indice doivent cependant être analysées en tenant compte des gammes de tailles exploitées d'une année à l'autre (Figure 5) et qui peuvent apporter un biais non négligeable à l'indice (nécessité de pondération de ce dernier en utilisant la relation taille/poids). Il en est de même de la localisation géographique de l'exploitation. Il est donc nécessaire de tenir compte de ces remarques pour des analyses plus fines de tendances.

En raison de la découverte récente (1984/85) des fonds de pêche du secteur ouest, dont l'étendue géographique a été confirmée par les prospections scientifiques exhaustives par chalutage de l'ensemble du plateau des îles Kerguelen en 1987 et 1988 (WG/FSA-88/22 Rév. 1), il était logique de s'interroger sur l'existence possible d'autres zones potentielles de pêche profonde de *D. eleginoides* dans d'autres secteurs géographiques du plateau de Kerguelen. En effet de fortes présomptions résultaient de ces prospections dans le secteur nord et secondairement dans le secteur nord-est. De nouveaux chalutages exploratoires ont été menés en 1989/90 (45 traits de chaluts correspondant à 76,3 heures de pêche pour la capture de 93,5 tonnes de *D. eleginoides*) et ont conduit à une mise en exploitation en 1990/91 (196 traits; 398,3 heures de pêche; 1 356 tonnes pêchées) d'un nouveau secteur de pêche pour cette espèce. Des rendements moyens de 3,4 tonnes/heure de chalutage ont été obtenus et cette valeur est assez comparable à celle observée en 1984/85 lors de la découverte des fonds de pêche du secteur ouest (Table 2). Il faut toutefois noter que l'étendue des fonds de pêche de cette nouvelle zone n'est pas comparable avec celle du secteur ouest et ne permettra pas une extension importante de la pêcherie par chalutage. Il s'avère donc que le stock profond de *D. eleginoides* n'est actuellement pas complètement exploité et que les résultats obtenus 5 ans après le début de la pêche dirigée sont encore partiels.

4. CONCLUSION

La division 58.5.1 (îles Kerguelen) constitue la principale zone de pêche au chalut de *D. eleginoides* pour tout l'océan Austral. Le mode de pêche est ainsi très différent de celui utilisé, en l'occurrence la palangre, pour la seconde zone où des captures sont enregistrées : la Géorgie du Sud (sous-zone 48.3). L'effort de pêche porte sur la partie sub-adulte/adulte du stock et est limité bathymétriquement par des fonds inchalutables au-delà des isobathes 500/550 m ce qui correspond aux accores du plateau. Le secteur ouest constitue la zone géographique exploitée depuis la découverte récente (1984/85) du stock; cependant d'autres fonds de pêche, de superficies plus réduites, permettent une certaine extension de la pêcherie. Le niveau de captures annuel et les rendements obtenus montrent que les potentialités d'exploitation de ce stock au chalut sont limitées et ne peuvent excéder quelques centaines de tonnes annuellement. Les premières analyses effectuées sur ce stock (SC-CAMLR-VIII) fournissent une première estimation de captures annuelles de 1 100 tonnes. Il est cependant nécessaire de réviser cette estimation avec des données plus pertinentes. En particulier une meilleure connaissance de la mortalité naturelle est indispensable mais reste cependant difficile à acquérir. En effet seule une partie du stock est exploitée actuellement par la pêche au chalut, ce qui est confirmé par les prospections scientifiques sur le plateau et ses accores et une première campagne exploratoire à la palangre. Si l'on considère l'indice d'abondance utilisé depuis le début de la pêcherie dirigée, les résultats mettent en évidence une diminution du stock exploité. Il faut tenir compte cependant d'un effort de pêche très variable d'une année à l'autre, d'une orientation géographique sectorielle également fluctuante et d'un niveau bathymétrique d'exploitation qui cible différentes classes d'âge. Ces résultats incitent à une certaine prudence dans le développement ultérieur d'une telle pêcherie si l'on ne désire pas qu'elle périclite

dans le développement ultérieur d'une telle pêcherie si l'on ne désire pas qu'elle périclite rapidement tout comme celles des autres Nototheniidae exploités de l'océan Austral depuis le début des années 1970. Une réorientation de l'effort de pêche dirigé sur *D. eleginoides* est envisageable vers d'autres secteurs géographiques de la sous-zone 58.5 après qu'une prospection scientifique coordonnée ait permis d'évaluer les potentiels d'exploitation. D'autres techniques de pêche, telle que la palangre, peuvent, par ailleurs, s'avérer plus appropriées dans le cas d'une pêche spécifique si les problèmes de mortalité accidentelle sont résolus d'une manière efficace après évaluation scientifique de cet impact.

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Table 1: Captures totales et par espèce (en tonnes) enregistrées pour la pêcherie des îles Kerguelen (division 58.5.1) depuis la création d'une ZEE. Les pourcentages de chaque espèce par rapport au total pêché pendant la période considérée sont indiqués entre parenthèses.

	1979/80 à 1983/84 (5 ans)	1984/85 à 1988/89 (5 ans)	1989/90 à 1990/91 (2 ans)
Captures Totales (en tonnes)	102 375	80 301	18 308
dont			
Champsocephalus gunnari	51 748 (50,5%)	51 209 (63,7%)	12 919 (70,6%)
Notothenia squamifrons	27 255 (26,6%)	13 378 (16,7%)	1 200 (6,6%)
Notothenia rossii	22 038 (21,5%)	3 271 (4,1%)	460 (2,5%)
Dissostichus eleginoides	603 (0,6%)	12 421 (15,5%)	2 902 (15,8%)
divers	731 (0,7%)	22	827 (4,5%)

Table 2: Effort de pêche (en nombre de coups de chalut et nombre d'heures de pêche), capture (en tonnes) et rendement pour *Dissostichus eleginoides* (tonnes par heure de pêche) dans le secteur ouest du plateau de Kerguelen (division 58.5.1) obtenus depuis la création d'une ZEE.

Année australe (1 July - 30 June)	Nombre de coups de chalut	Nombre d'heures de pêche	Capture (tonnes)	Rendement (tonnes/heure de pêche)
1979/80	204	495,000	106	0,21
1980/81	69	73,75	25	0,33
1981/82	10	13,08	<1	0,05
1982/83	4	5,42	0	/
1983/84	14	15,17	5	0,33
1984/85	1 571	2 619,00	6 544	2,50
1985/86	162	260,58	370	1,42
1986/87	1 135	1 704,75	3 090	1,81
1987/88	440	632,33	510	0,81
1988/89	561	898,50	1 486	1,65
1989/90	524	783,75	991	1,26
1990/91	154	226,42	311	1,38

Table 3: Effort de pêche total et effort de pêche dirigé (secteur ouest) sur *Dissostichus eleginoides* (en nombre d'heures de pêche) pour la période 1984/85 - 1990/91 au niveau des îles Kerguelen (division 58.5.1). ( ) pourcentage par rapport à l'effort de pêche total. Les années de pêche dirigée sur *Champsocephalus gunnari* sont pointées avec une flèche.

Année australe	Effort de pêche total (heures de pêche)	Effort de pêche dirigé sur *D. eleginoides* (heures de pêche)	
1984/85	6 919	2 619 (37,9%)	
1985/86	4 435	261 (5,9%)	=
1986/87	4 110	1 705 (41,5%)	
1987/88	1 257	632 (50,3%)	
1988/89	7 269	899 (12,4%)	=
1989/90	1 784	784 (43,9%)	
1990/91	4 209	226 (5,4%)	=

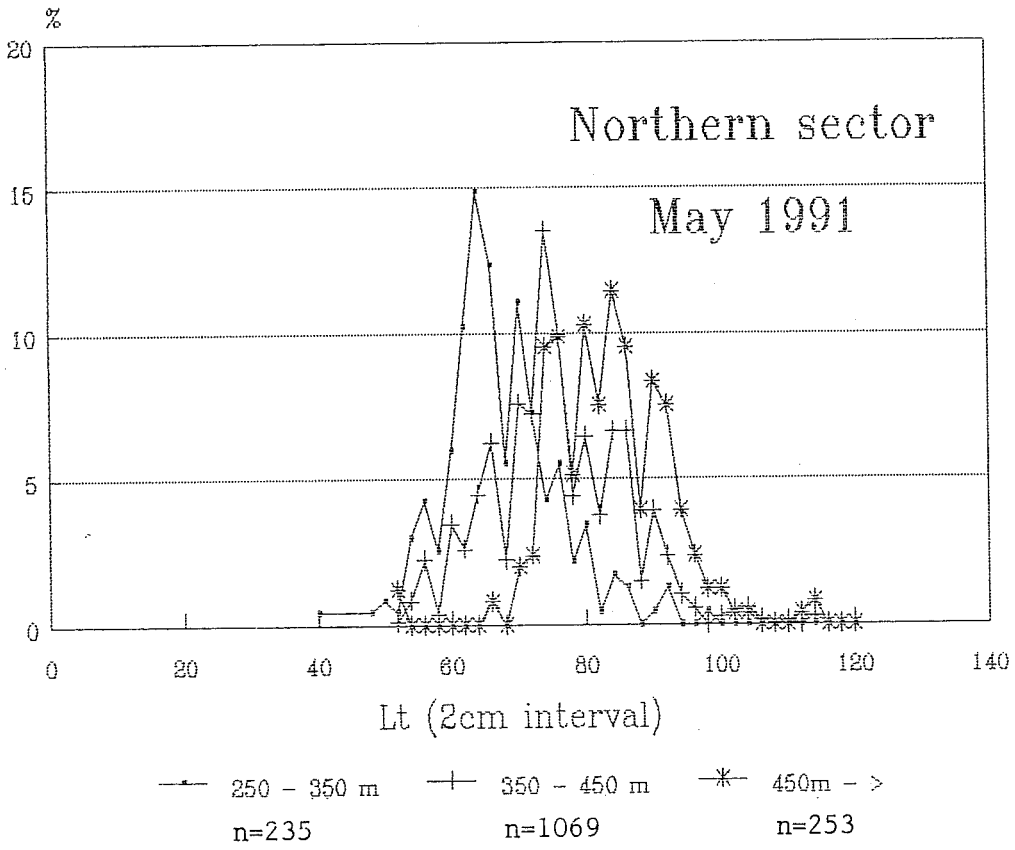


Figure 1: Distributions de fréquences de longueurs de *Dissostichus eleginoides* en fonction de la strate bathymétrique échantillonnée dans le secteur nord du plateau des îles Kerguelen en mai 1991.

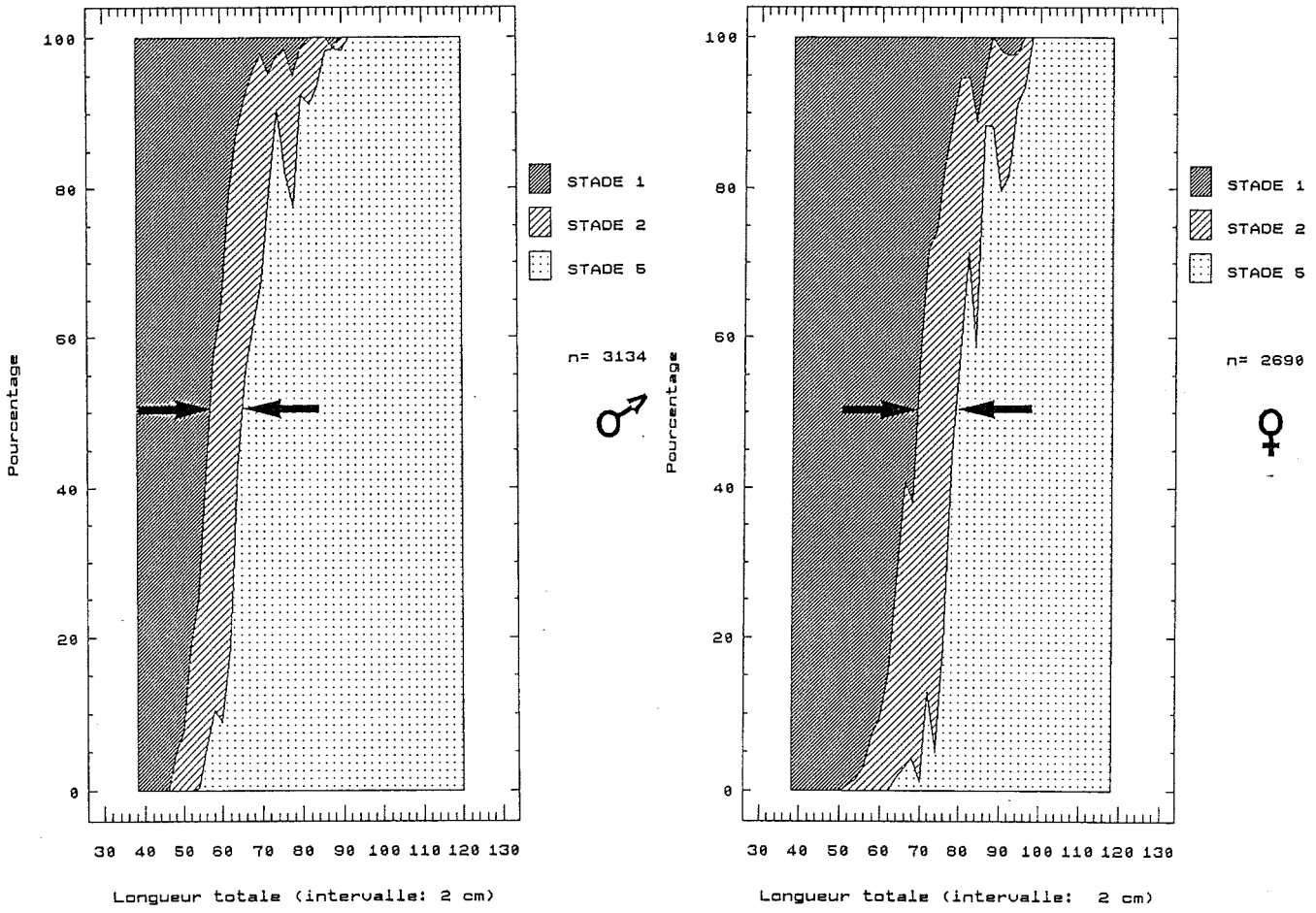


Figure 2 : Longueur moyenne (50% des individus analysés) de première maturité sexuelle (-) et de première reproduction (=) chez les mâles et femelles de *Dissostichus eleginoides* échantillonnés en zone profonde du plateau de Kerguelen (division 58.5.1) en octobre 1990. Stades de maturité selon l'échelle d'Everson (1977).

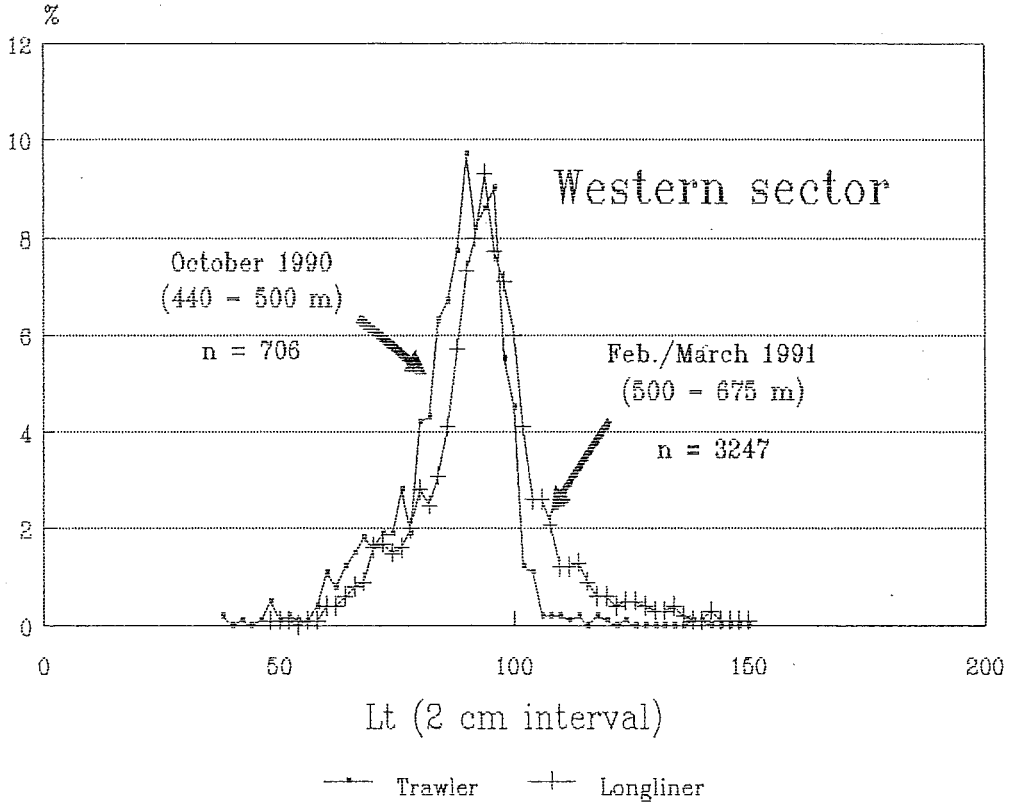


Figure 3 : Distributions de fréquences de longueurs obtenues à partir des captures d'un chalutier et d'un palangrier dans le secteur ouest du plateau de Kerguelen en 1990/91.

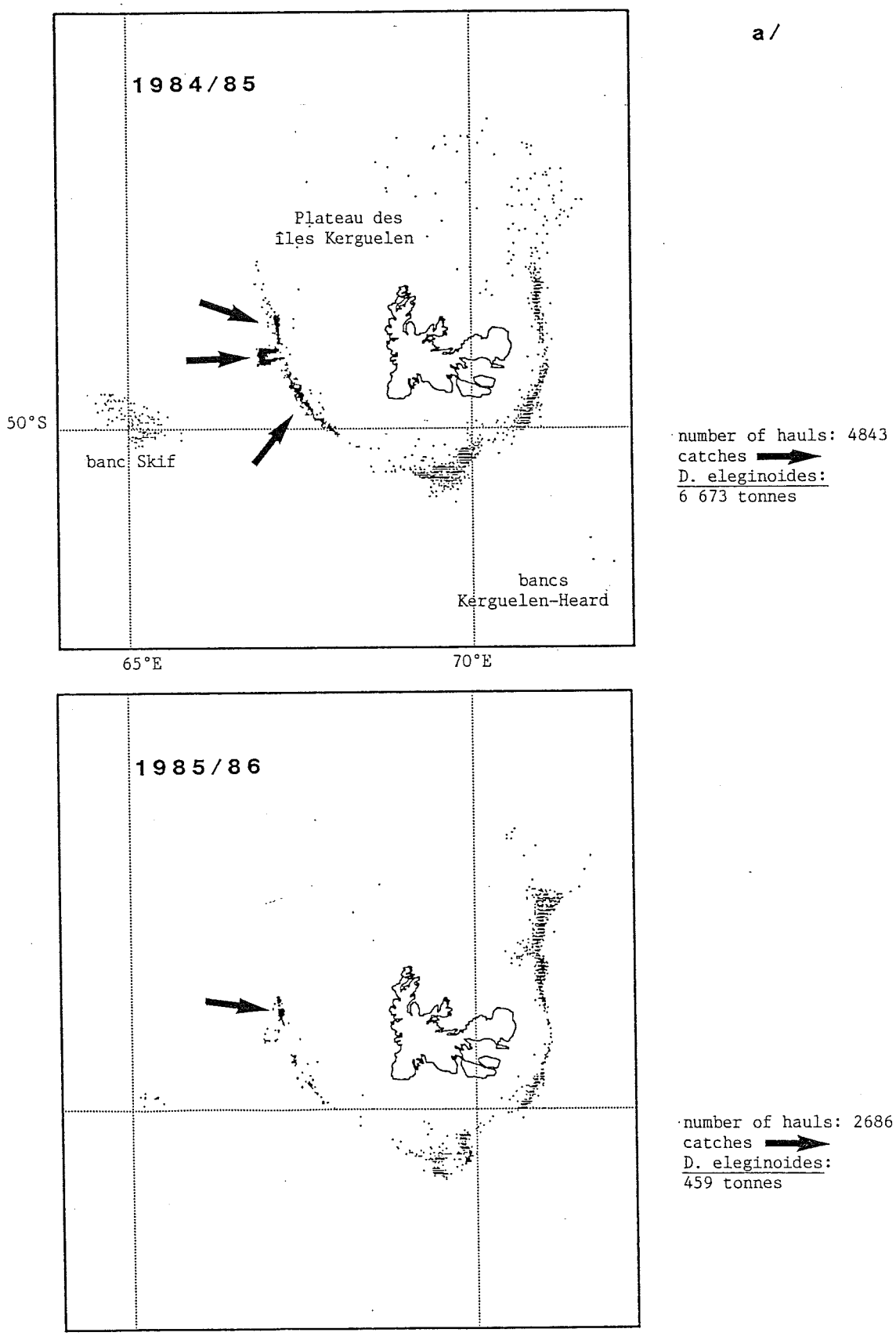
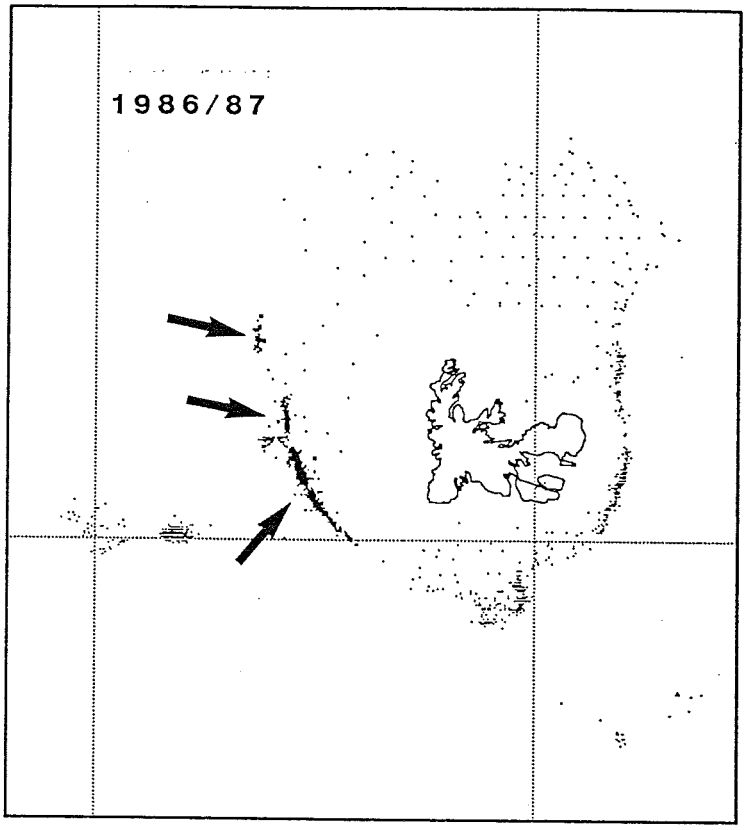
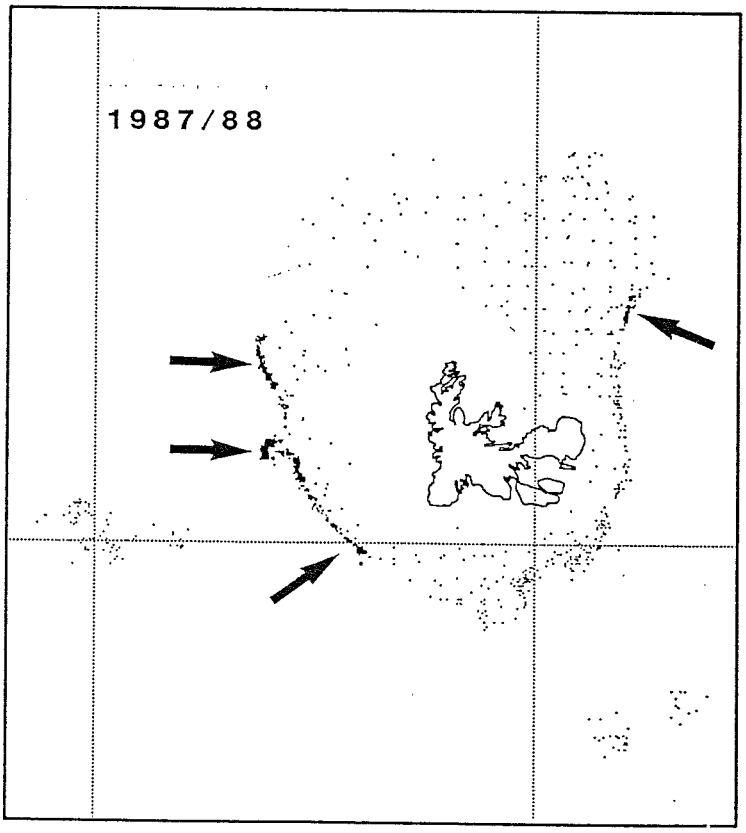


Figure 4: a, b, c, d — Position géographique (points) de tous les chalutages réalisés dans la ZEE des îles Kerguelen (division 58.5.1) par année australe depuis 1984/85. Les chalutages ayant permis la capture de *Dissostichus eleginoides* sont représentés par des carrés proportionnels à la capture réalisée.

b /

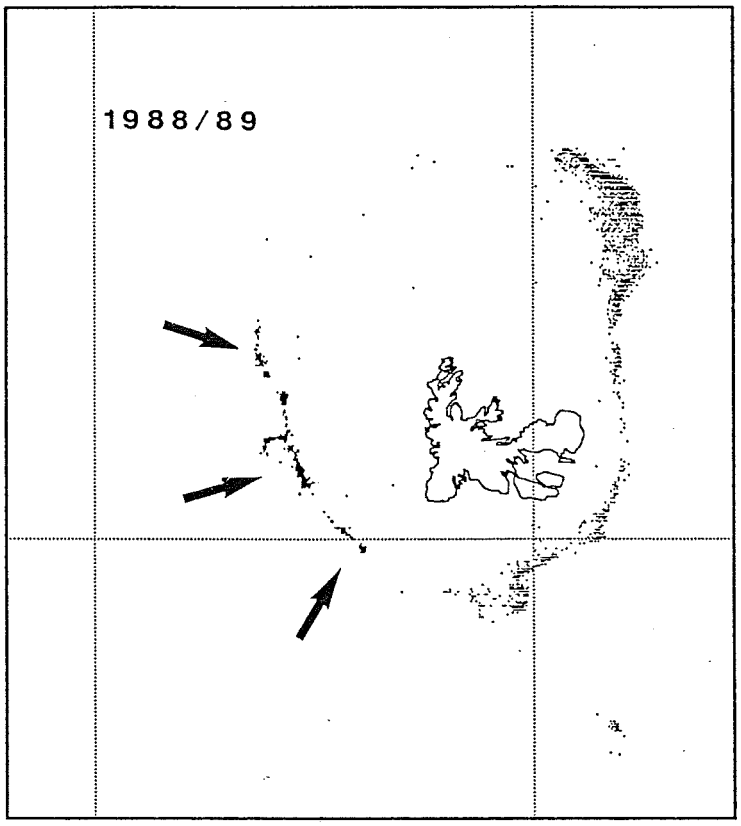


number of hauls: 2712
catches ➡
D. eleginoides:
3 160 tonnes

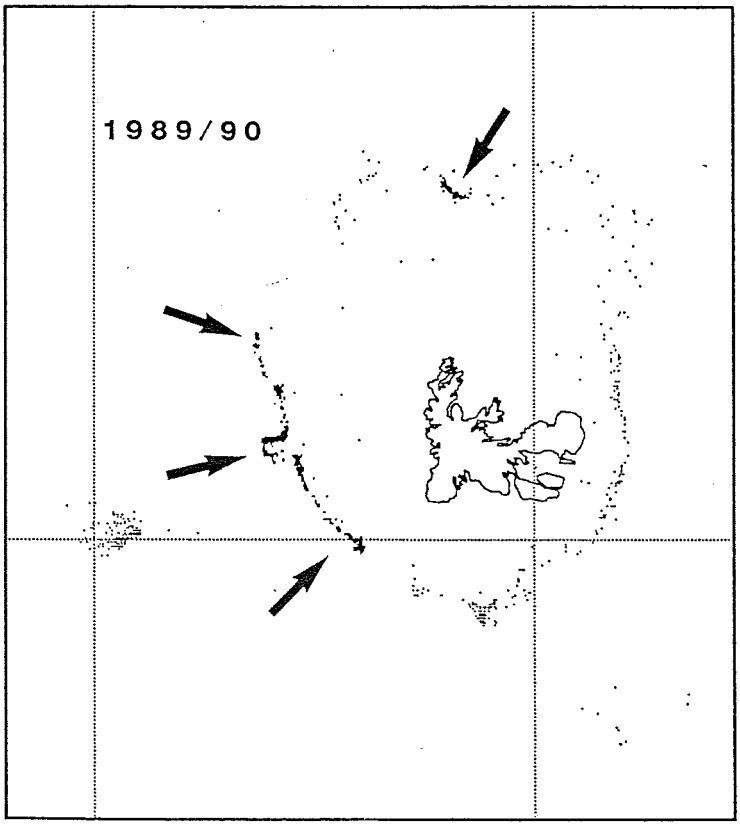


number of hauls: 1050
catches ➡
D. eleginoides
562 tonnes

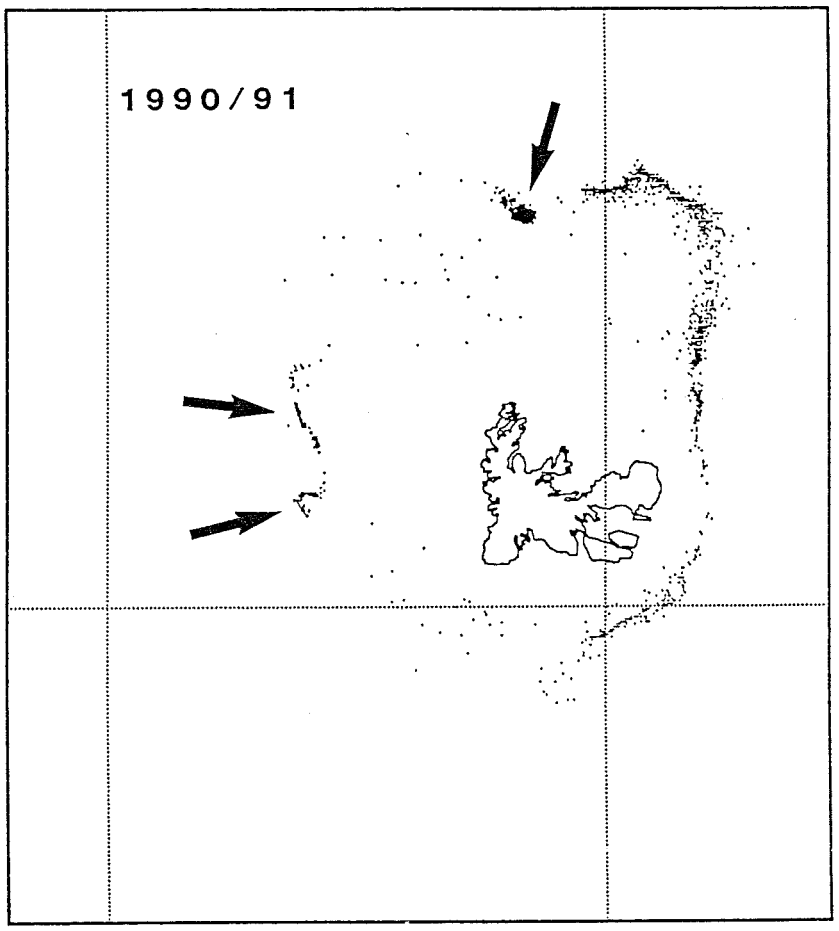
c /



number of hauls: 3601
catches →
D. eleginoides
1 565 tonnes



number of hauls: 1171
catches →
D. eleginoides
1 159 tonnes



d/

number of hauls: 1902
catches
D. eleginoides
1 863 tonnes

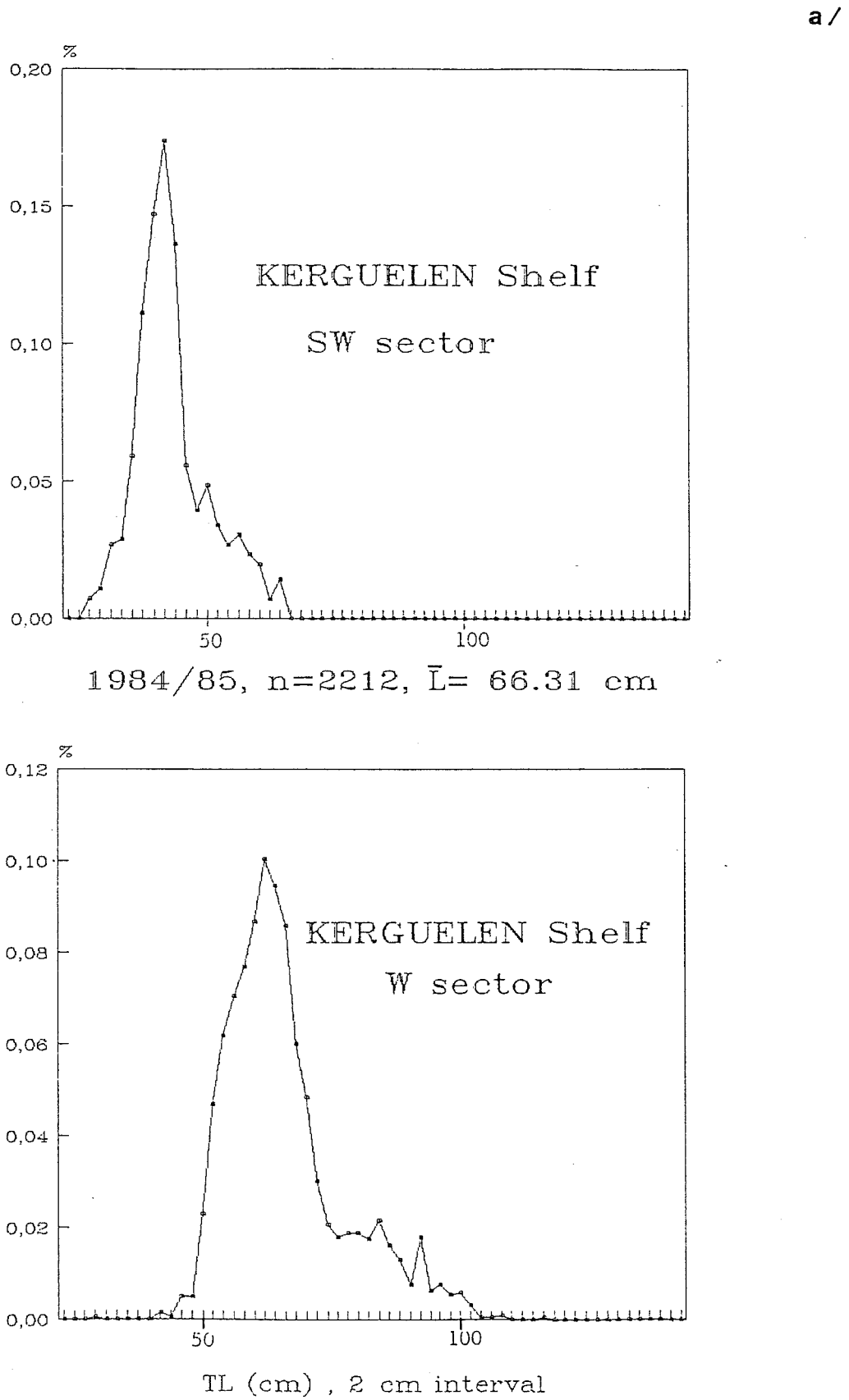
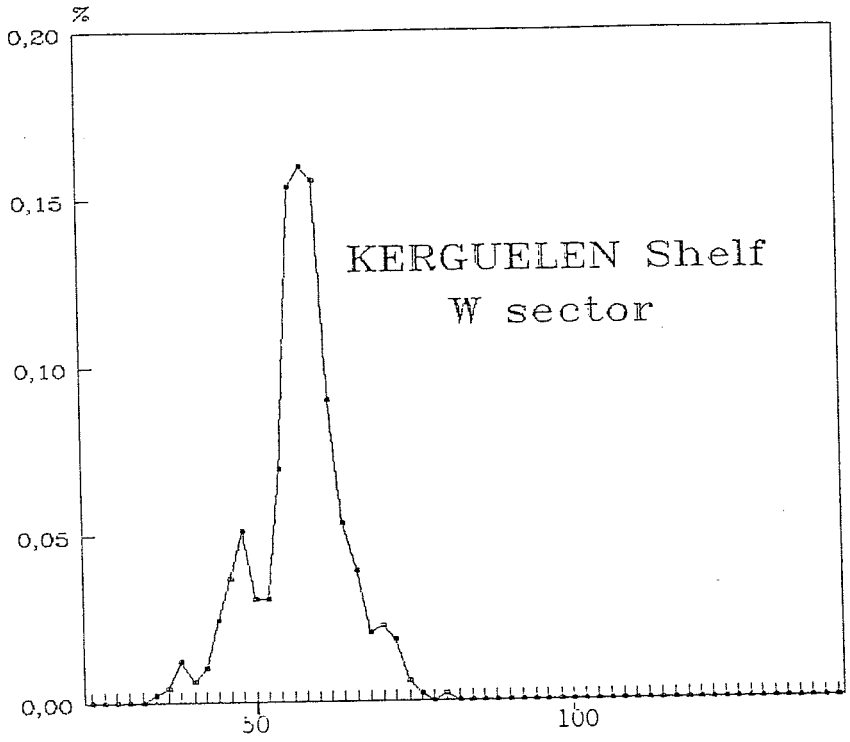


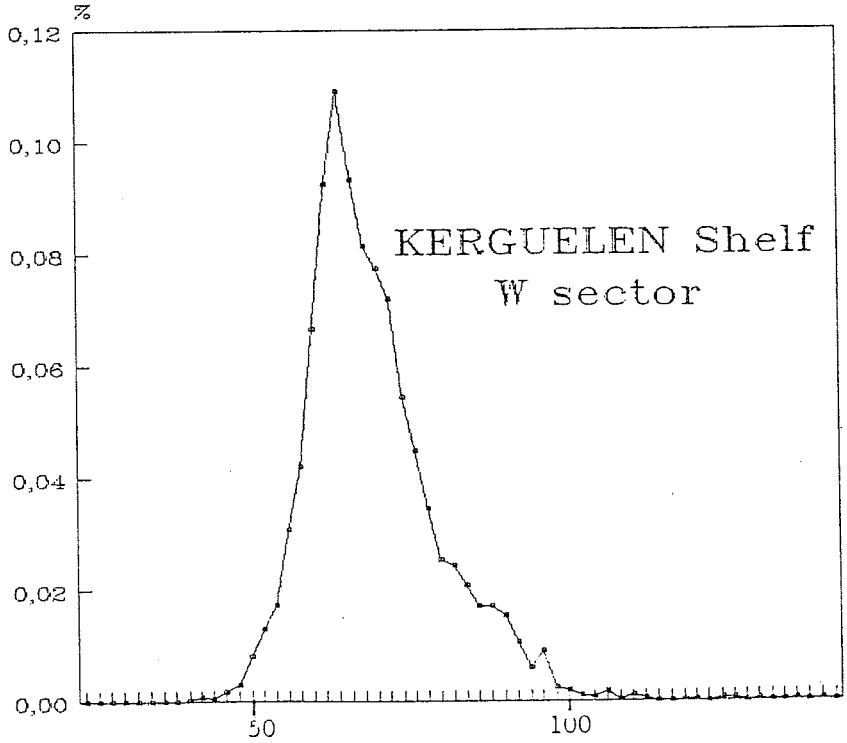
Figure 5 : Distributions de fréquences de longueurs de *Dissostichus eleginoides* résultant des a, b, c, d échantillonnages effectués durant les campagnes de pêche des chalutiers opérant dans le secteur ouest profond du plateau de Kerguelen (division 58.5.1).

DISSOSTICHUS ELEGINOIDES
1985/86, n=499, $\bar{L}$=57.87 cm

b /



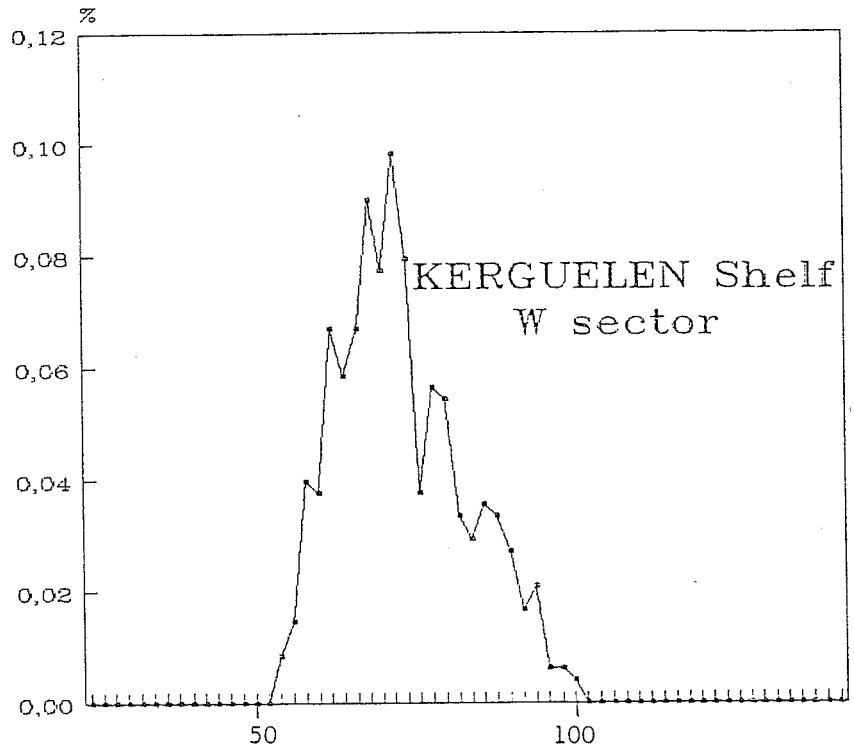
1986/87, n=3711, $\bar{L}$=69.84 cm



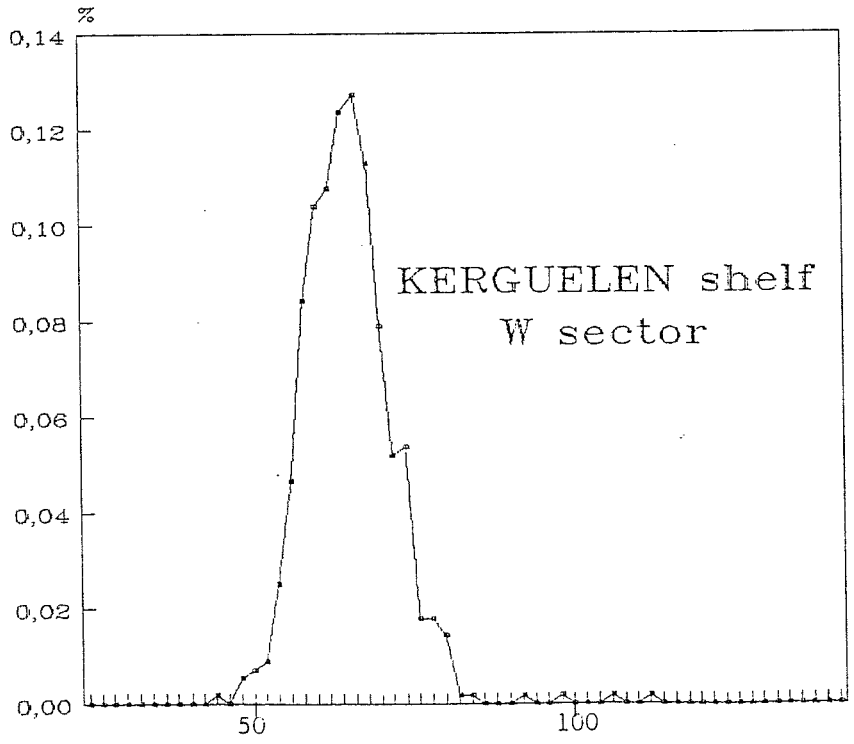
TL (cm) , 2 cm interval

DISSOSTICHUS ELEGINOIDES
1987/88, n=478, $\bar{L}$=73.55 cm

c/



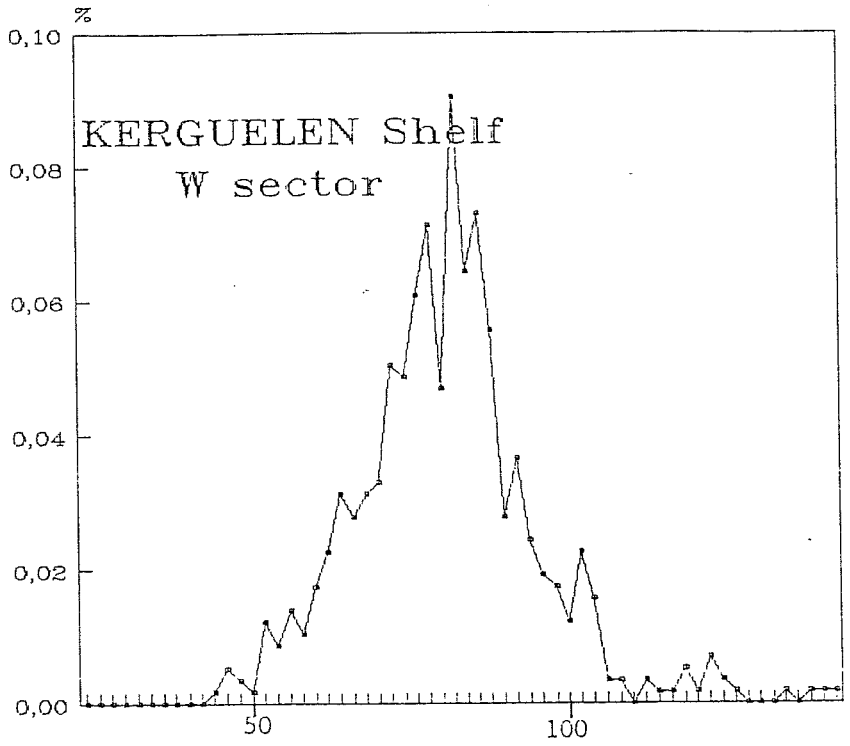
1988/89, n=558, $\bar{L}$=65.54 cm



TL (cm) , 2 cm interval

DISSOSTICHUS ELEGINOIDES
1989/90, n=575, $\bar{L}$=81.59 cm

d/



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общего промыслового усилия. Стрелкой обозначены годы, в которых велся лов *Champsocephalus gunnari*.

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HOOK SELECTIVITY IN THE LONGLINE FISHERY OF *DISSOSTICHUS ELEGINOIDES* (NOTOTHENIIDAE) OFF THE CHILEAN COAST

Carlos A. Moreno*

Abstract

Existing information from technical publications on Chilean fisheries of the Patagonian toothfish, *Dissostichus eleginoides* is reviewed in order to study selectivity of different types and sizes of hooks used in longlines. Original data obtained during 1991 off the coast of Valdivia, South East Pacific, are also taken into consideration. The data show that circle hooks are far more efficient than straight hooks. The length frequency distributions of fish caught with straight hooks Nos 3 and 4 are not significantly different, but hooks No. 3 are nearly 31 % more efficient than hooks No. 4. Using different bait does not result in significant differences. It is worth noting that the ratio of females increases significantly in catches, when the size of straight hooks is increased (e.g., from 4 to 3) or when circle hooks are used instead of straight hooks.

Résumé

L'examen des informations contenues dans les publications techniques sur les pêcheries chiliennes de légine australe, *Dissostichus eleginoides*, a pour but d'étudier la sélectivité des différents types et tailles d'hameçons des palangres. Les données originales obtenues en 1991 au large de la côte de Valdivia, dans le secteur sud-est du Pacifique, sont également prises en considération. Ces données indiquent que l'efficacité des hameçons recourbés est nettement supérieure à celle des hameçons droits. Les distributions de fréquences de longueurs des poissons capturés avec des hameçons droits N°s 3 et 4 ne présentent pas de différence significative, mais les hameçons N° 3 sont de près de 31% plus efficaces que les hameçons N° 4. Le changement d'appâts ne crée pas de différences significatives. Il convient de noter que la proportion des femelles augmente notablement dans les captures lorsqu'on augmente la taille des hameçons droits (de 4 à 3, par ex.) ou lorsqu'on passe d'hameçons droits à des hameçons recourbés.

Резюме

В целях изучения селективности крючков различных типов и размеров, используемых при ярусном промысле, делается обзор существующей информации по промыслу Чили патагонского клыкача, *Dissostichus eleginoides*, взятой из технических публикаций. Также приняты во внимание первоначальные данные, полученные в течение 1991 г. у

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побережья Вальдива, юго-восточная часть Тихого океана. Данные показывают, что закругленные крючки гораздо эффективнее одногибых. Частотное распределение длины рыбы, выловленной одногибыми крючками №3 и №4 не отличается значительно, но крючки №3 почти на 31% эффективнее крючков №4. Использование разной наживки не приводит к большим различиям. Следует отметить, что соотношение самок значительно возрастает при увеличении размера одногибых крючков (например от №4 до №3) или когда вместо одногибых крючков используются закругленные крючки.

Resumen

Se examina nuevamente la información actual procedente de publicaciones técnicas, relacionada con la pesquería chilena de austromerluza negra, *Dissostichus eleginoides*, con el fin de estudiar la selectividad de diferentes tipos y tamaños de anzuelos empleados en la pesquería de palangre. Además se ha tomado en consideración la información original obtenida en 1991 a la altura de Valdivia, Pacífico sudoriental. Los datos muestran que los anzuelos curvos son mucho más efectivos que los anzuelos derechos. Las distribuciones de la frecuencia de tallas de peces capturados con anzuelos derechos No. 3 y 4, no difieren mayormente, pero los anzuelos No. 3 tienen una eficacia de alrededor de un 31% más que los anzuelos No. 4. Empleando diferentes tipos de cebos no causa una notable diferencia. Vale tomar en consideración que la proporción de las hembras aumenta considerablemente en las capturas cuando se aumenta el tamaño de los anzuelos derechos (es decir, de 4 a 3) o cuando se emplean los anzuelos curvos en lugar de los anzuelos derechos.

1. INTRODUCTION

Exploratory fishing for the Patagonian toothfish (*Dissostichus eleginoides*, Smith, 1898) in Chile started as early as 1955, the year in which the exploration of the continental slope began for fishery purposes, mainly searching for pink ling (*Genypterus blacodes*) as the target species (González, 1962). In the late sixties, Pavez *et al.* (1968) designed a special longline gear to be used at depths greater than 1 000 m, and obtained first catches of commercial interest for the fishery. After that, fish pots and gill nets were tested, proving that the longline method was far more efficient than others (Inostroza, 1975). During 1990, catches of *D. eleginoides* with longlines along the Chilean coast reached a record of 9.387 tonnes (SERNAP, 1991).

In accordance with information by DeWitt *et al.* (1990) and data from the actual fishing of *D. eleginoides*, the distribution area of this species includes the South East Pacific Ocean, covers the continental slope of the Chilean-Peruvian trench and reaches the Arica coast in the north of Chile. Besides that, it has also been reported from the Argentinean-Patagonian zone and from the Antarctic (Figure 1). In front of the coast of Chile adult fish mainly inhabit waters between 500 and 2 500 m depth (Salas *et al.*, 1987), living near the bottom and migrating to the upper layers (Oyarzún *et al.*, 1988). Recent developments in this fishery in Chile shows a worrying tendency to deplete stocks and to expand the fishery further south (Lemaitre *et al.*, 1991). It indicates that the moment for establishing fishery regulations is not too distant.

Studies of hook selectivity could result in the development of a conservation measure analogous to the selection of distance between knots in gill nets, which might later be used as an ultimate management measure. Fishery of *D. eleginoides* has been recently introduced in some areas of the CCAMLR Convention Area. Information presented in this paper can, therefore, be used by the CCAMLR Working Group on Fish Stock Assessment for comparative analyses.

2. CHILEAN FISHERY LEGISLATION

The fishery of *D. eleginoides* is regulated in Chile by Decree No. 439 of the Economy Ministry of 1985, which establishes that only vessels of a maximum length of 15 m and operating up to 12 000 hooks each can be used. The length of Chilean vessels was increased to 18 m by Decree No. 43 of 1986 of the same Ministry. This amendment relates to vessels that operate further south of 32°45'40" (Point Liles), and maintains the restriction of hook number. The regulation does not consider types and sizes of hooks utilised.

3. FISHING WITH LONGLINES

The first selectivity study of hooks used in deep-water longlines was performed by Zapata (1976) with different sizes of Mustad Kirby hooks, model 2330. He recommended hooks Nos 4 and 5. He also suggested that a time between setting and hauling of a longline should be 14 to 16 hours.

However, the most complete study of the *D. eleginoides* fishery was carried out by Salas, Robotham and Lizama (1987) (from here on, SRL) in the VIII Region of Chilean waters. They used three horizontal longlines of 1 500 hooks each, with five sections with hooks No. 3 and five sections with hooks No. 4. The hooks used were also of Mustad Kirby, model 2330. The efficiency of the previously described straight hooks with long shank (model 2330) was compared with the efficiency of circle hooks (Mustad Tuna Circle, model 39965 ST, size 14/0) (Figure 2).

Sections of different types of hooks were arranged randomly along the longline according to methodology described by Pope *et al.*, (1983).

Each section comprised of 150 hooks placed 2 m apart on 60 cm branches made of 3 mm diameter polypropylene rope. The length of the longline was 3 080 m. Salted common sardines (*Clupea bentincki*) and mackerel (*Trachurus murphy*) were used as bait. Below we describe recent information obtained off the coast of Valdivia (X Region) on fishing with circle hooks and fresh mackerel bait.

For comparison all data were expressed in CPUE units defined as g/hook in each catch; indicating hook efficiency. Length composition of catches is illustrated in Figures 3 and 4 using the same method as SRL (1987).

4. CATCH EFFICIENCY OF STRAIGHT AND CIRCLE HOOKS

Catch efficiency of straight hooks (No. 4) and circle hooks was expressed in the same units of effort (g/hook) in order to obtain comparable results. Types of hooks used in 1987 in VIII Region do not differ significantly from hooks used in X Region (Valdivia zone). For this reason we consider it possible to pool data from these regions together for the analysis (Table 1, data from SRL, 1987 for VIII Region and original data for X Region combined). The comparison of all data showed that catch efficiency of circle hooks was significantly higher than

that of straight hooks. Circle hooks apparently have better retention rate of captured fish. This analysis agrees with the conclusion of SRL (1987) that circle hooks are significantly more efficient.

5. SELECTION OF BAIT

The question if the type of bait affects fishing efficiency has also been approached in several studies. Table 2 presents the available data on three types of baits used in *D. eleginoides* fishery: salted sardine, salted and fresh mackerel. The first two types of bait are commonly used in longline fishery along the Chilean coast.

The first two sets of data came from the study of SRL (1987). Data of sets 3 to 7 were collected from the X Region during 1991. In July 1991 we also obtained data from fishing operation of a longline vessel which used fresh mackerel bait during five fishing trips. A comparison of CPUEs obtained with different type of bait do not reveal statistically significant differences, although fresh bait data have larger variance (Table 2). The belief that fresh bait is more efficient is therefore based on fishermen tending to recall cases of larger catches than on results of statistical analyses.

6. SIZE SELECTIVITY

In general, catches consisted of fish larger that 50 cm length (total length, TL), both males and females. In my observations the smallest fish caught in 1991 off the coast of Valdivia was a male of 47 cm TL and 800 g weight (gutted). The largest specimen caught during research surveys in Chilean waters was a female of 174 cm TL and 51.4 kg weight (gutted).

Length range of fish caught by different size of straight hooks in the VIII Region is presented in Table 3 together with mean length. Length frequency distribution of catches is shown in Figure 3. The differences observed in length composition of fish caught by straight hooks Nos. 3 and 4 do not seem significant when length distributions are compared for different depth ranges. In accordance with SRL (1987) efficiency of hooks No. 4 was approximately 31% higher than that of hook No. 4. This conclusion is in agreement with Zapata (1976). Figure 3 demonstrates that bigger fish are caught at greater depth and females are, in general, more abundant in catches than males. In studies of SRL (1987), the highest proportion of females was 1:2.4 when using straight hook No.3 and 1:1.56 when using smaller size straight hook No.4. In case of circle hooks the highest proportion of females was 1:3.6.

Figure 4 presents data collected in August 1991 off the coast of Valdivia from longline catches at depth from 500 to 2000 m using circle hooks and similar data for straight hooks from SLR (1987). Statistical comparison of these data by Kolmogorov-Smirnov test (Rohlf, Sokal, 1989) gives D_{max} values for males and females greater than corresponding critical values of D taken from Table 31 of Sokal and Rohlf (1989). Therefore, in both cases there is evidence these length samples are significantly different in their distribution. We observe that circle hooks catch bigger fish than straight hooks. Unfortunately, both data sets are not collected simultaneously and we can not be absolutely sure about the selection effect of hooks of bigger sizes.

7. CONCLUSION

Two types of hooks have been used in deep-water longline fishery for *D. eleginoides*, straight and circle hooks. Circle hooks were found to be significantly more effective than straight hooks, when corresponding values of CPUE (g/hook) are compared. Length distributions of fish caught by straight hooks Nos. 3 and 4 do not differ significantly, although

hooks No. 3 were about 31% more efficient than hooks No. 4. No significant differences are found in the fishing efficiency when different types of bait have been used. We believe that higher efficiency of circle hooks relates to a higher rate of fish retention by this type of hooks.

In spite of the finding that differences in length composition of fish caught at the same depth by straight hooks of different sizes are not significant (when Kolmogorov-Smirnov test is used), it is of interest that a proportion of female is larger when bigger straight hooks or circle hooks are used. Higher fishing mortality of females could endanger the population of *D. eleginoides* because the population recovery rate would be lower than in case when 1:1 sex ratio is maintained.

However, a proportion of females and their length is also increased in catches taken at greater depth. Due to operational constraints vessels smaller than 18 m length rarely fish deeper than 2 000 m thus establishing a sort of a refuge zone for *D. eleginoides* in deeper waters. Therefore, if a decrease in catchability of longlines is required, prohibiting the use of circle hooks could be imposed as a future management measure.

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Table 1: Catch by units of effort (g/hook) for straight and circle hooks in *D. eleginoides* fishing in the VIII Region (data from SRL, 1987) and in the X Region (original data).

A.		Hook	
Data set	Region	Straight	Circle
1	VIII	80	231
2		83	142
3		28	99
4	X	44	99.5
5		45.1	90.4
6		60.8	75.1

B.					
Source	Sum-of-Squares	df	Mean-Square	F-Ratio	P
Region	5129.46	1	5129.46	3.581	0.095
Hook type within region	10374.60	1	13074.6	9.129	0.017
Hook type	2293.56	1	2293.56	1.601	0.241
Error	11458.06	8	1432.25		

Table 2: Catch by units of effort for circle hooks 14/0 with three types of bait in experimental fishing of *D. eleginoides* in the VIII Region (SRL, 1987) and in the X Region (Sardine = *Clupea bentincki*; Mackerel = *Trachurus murphy*).

Data Set	Region	Type of Bait		
		Salted Sardine	Salted Mackerel	Fresh Mackerel
1	VIII	147 (g/hook)	61 (g/hook)	--
2		48	56	--
3	X	68.4	76.1	110.0
4		87.1	101.4	80.3
5		44.7	65.0	40.0
6		--	--	65.1
7		--	--	57.4
Mean:		70.74	71.9	79.04
SD:		26.14	18.1	41.6

(One way ANOVA, F = 0.113; df = 2; P = 0.894)

Table 3: Length range and mean length of *D. eleginoides* by hook sizes and fishing depth.

Fishing Depth (m)	Hook Size (No.)	Fish Length Range (cm)	Fish Mean Length (cm)
500 to 1 000	3	51 - 110	77.1
	4	54 - 95	73.4
1 001 to 2 000	3	53 - 146	82.4
	4	53 - 110	75.9
2 001 to 3 000	3	72 - 131	97.0
	4	75 - 133	95.4

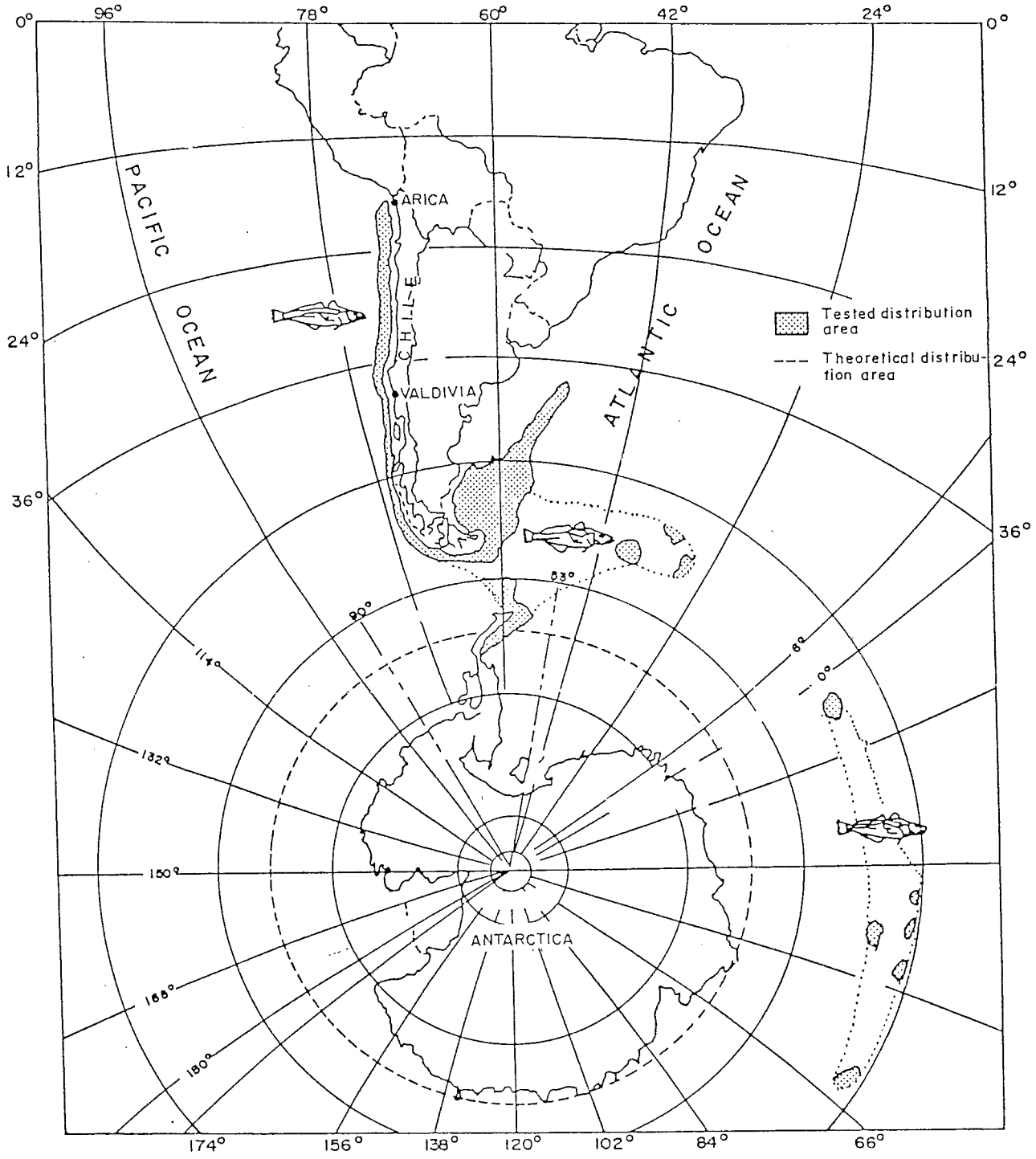

Figure 1: Geographical distribution of *D. eleginoides*.

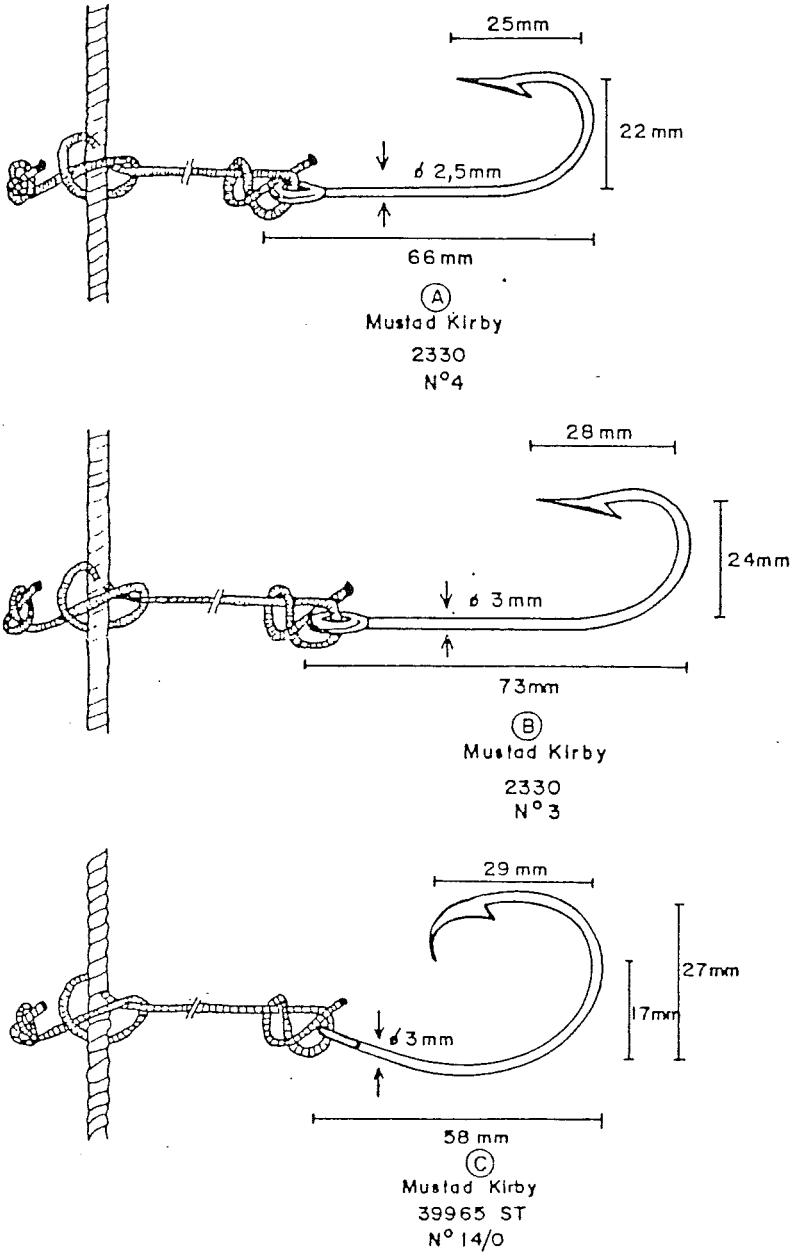

Figure 2: The type of hooks used in the longline fishery of *D. eleginoides* in Chile.

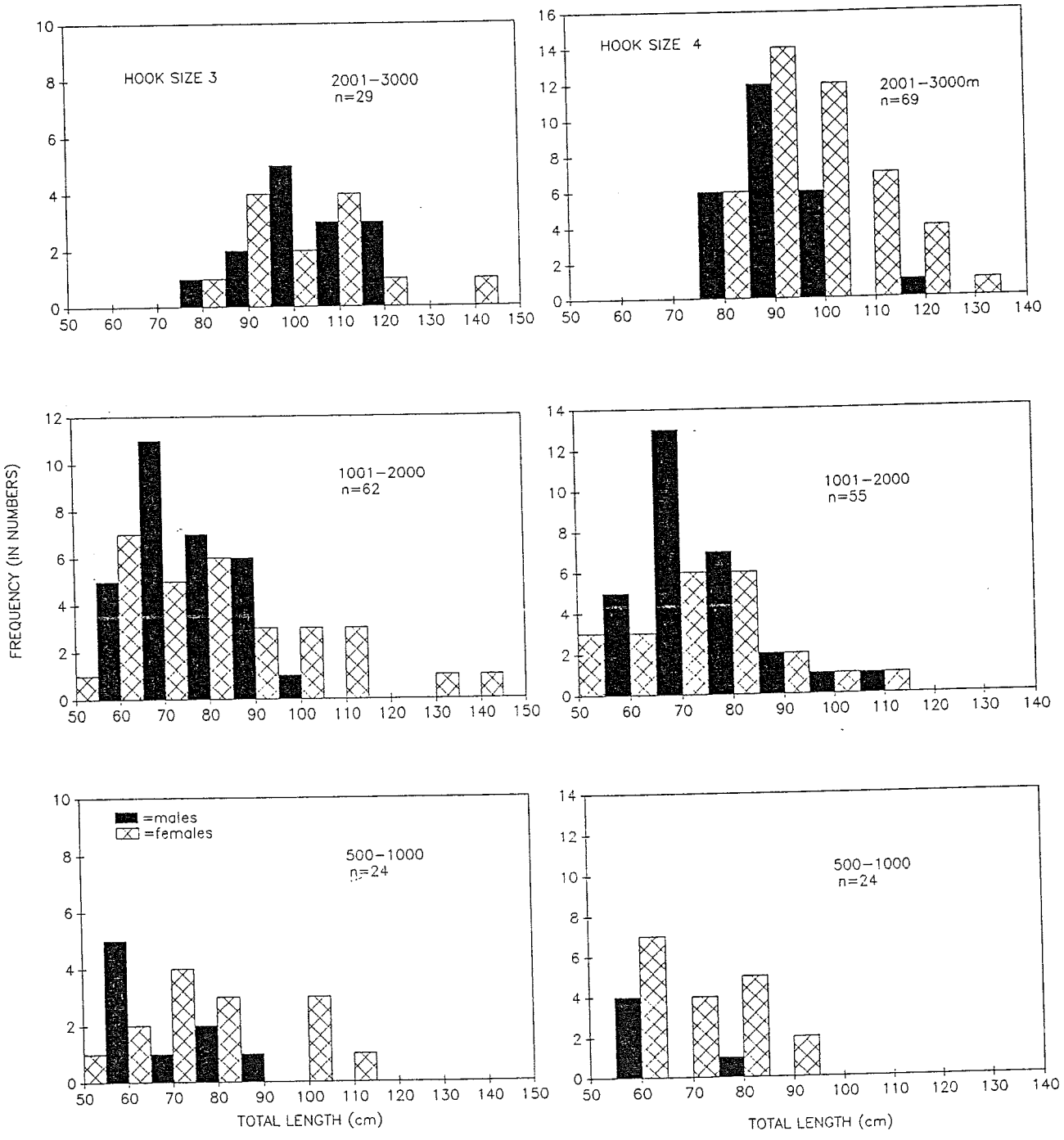

Figure 3: Length composition of *D. eleginoides* fished with straight hooks (Nos. 3 and 4) off the coast of VIII Region of Chile (from SRL 1987).

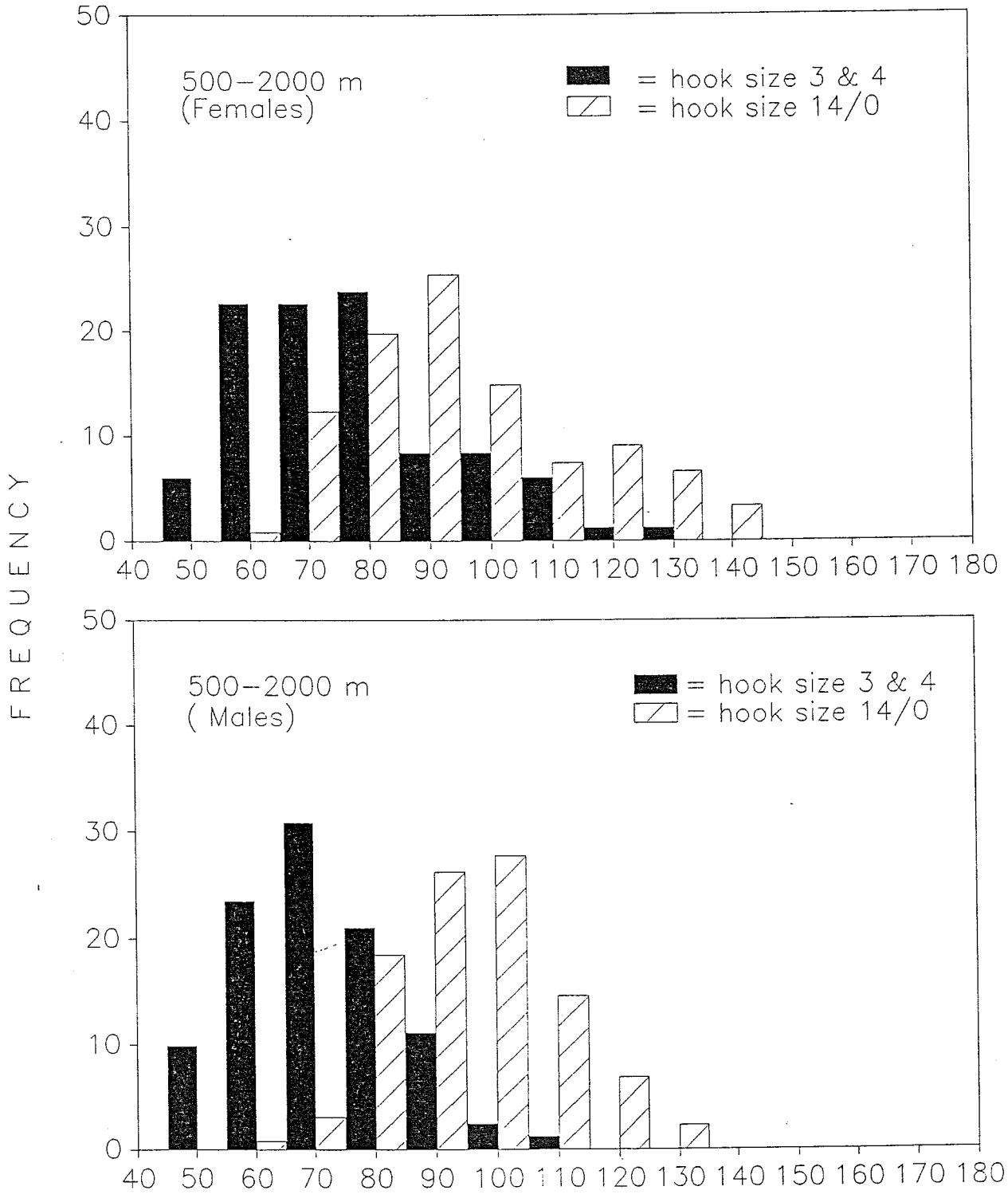

Figure 4: Length composition of *D. eleginoides* caught by straight (Nos 3 and 4) and circle (No. 14/0) hooks off the coast of the VIII and X Regions of Chile. Statistical analysis by using Kolmogorov-Smirnov test show significant differences in both cases (for males and females).

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II. KRILL BIOLOGY AND MANAGEMENT

KRILL (*EUPHAUSIA SUPERBA*) DISTRIBUTION IN RELATION TO WATER MOVEMENT AND PHYTOPLANKTON DISTRIBUTION OFF THE NORTHERN SOUTH SHETLAND ISLANDS

T. Ichii, H. Ishii and M. Naganobu*

Abstract

In December/February 1990/91 a survey was conducted by RV *Kaiyo Maru* in the vicinity of the South Shetland Islands and Elephant Island. The main objective of the survey was to investigate the mechanisms responsible for the concentration of krill and to estimate krill biomass in the area surveyed. Krill biomass estimation was done by means of hydroacoustics. Phytoplankton distribution was assessed by measuring surface concentrations of chlorophyll *a*. Water circulation was studied with satellite-tracked buoys equipped with curtain drogues deployed at a level of 30 m from the surface because at this level krill concentrations are most frequently observed. Main krill concentrations were observed in shelf waters north of the islands as usual. Tracking of buoys demonstrated the existence of convergent complex eddies in shelf waters of these islands. A high concentration of chlorophyll *a* was also recorded in shelf waters. A spatial correlation between distributions of krill and chlorophyll *a* was observed. It is therefore considered that both hydrodynamic and food availability factors may be responsible for krill concentration. On a traditional krill fishing ground north of Livingston Island, krill density had increased 3.4 times over a period of 40 days from late December 1990 to early February 1991. This increased krill density in early February 1991 (157 g/m^2) was 54% lower than that observed in late January 1988. Information from studies of krill predators by US scientists also indicated that krill abundance during the first half of the 1990/91 summer was lower than that in previous seasons. Total biomass of krill in shelf waters of the area surveyed was estimated at 1.78 million tonnes (56 g/m^2) in late January 1991. The obtained estimate of krill biomass should be regarded as the lower level for this time of the season. From mid-February and onwards it was reported that krill abundance had increased to the normal level.

Résumé

En décembre/février 1990/91, les alentours des îles Shetland du Sud et Eléphant ont fait l'objet d'une campagne d'évaluation à bord du RV *Kaiyo Maru*. L'objectif principal de la campagne était l'investigation des mécanismes responsables de la concentration du krill et l'estimation de la biomasse du krill dans la région étudiée. C'est au moyen de méthodes hydroacoustiques qu'a été évaluée la biomasse du krill. La répartition du phytoplancton a été estimée en mesurant les concentrations de surface de chlorophylle *a*. Les mouvements de l'eau ont été étudiés à l'aide de bouées suivies par satellite et équipées d'ancres de cape, déployées à 30 m de profondeur, niveau auquel les concentrations de krill sont le plus fréquemment rencontrées. Comme de coutume, les principales

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concentrations de krill ont été observées dans les eaux du plateau nord des îles. La poursuite de bouées a révélé l'existence de tourbillons complexes d'eaux convergentes sur le plateau de ces îles. Une concentration élevée de chlorophylle *a* a également été relevée dans les eaux du plateau. Une corrélation spatiale a été établie entre la présence du krill et celle de chlorophylle *a*. Il est ainsi possible d'envisager que les facteurs hydrodynamiques et de disponibilité de nourriture soient responsables de la concentration du krill. Dans un lieu de pêche traditionnel de krill, au nord de l'île Livingston, la densité du krill a augmenté de 3,4 fois en une période de 40 jours de fin décembre 1990 à début février 1991. Cette densité accrue de krill (157g/m^2), début février 1991, était de 54% inférieure à celle observée fin janvier 1988. Les informations provenant des études des prédateurs de krill par les scientifiques des USA ont également indiqué que, pendant la première moitié de l'été 1990/91, l'abondance de krill était inférieure à celle des saisons précédentes. La biomasse totale de krill des eaux du plateau de la région étudiée était estimée à 1,78 millions de tonnes (56g/m^2) fin janvier 1991. Cette estimation devrait être considérée comme étant la plus faible pour cette époque de la saison. A partir de mi-février, l'abondance de krill relevée avait augmenté pour rejoindre le niveau normal.

Резюме

В декабре-феврале 1990/91 гг. в районе Южных Шетландских островов и острова Элефант была проведена съемка НИС *Kaiyo Maru*. Главными целями съемки являлись исследование действия механизмов, влияющих на концентрацию криля и оценка биомассы криля в районе съемки. Оценка биомассы криля была осуществлена методом гидроакустики. Распределение фитопланктона исследовалось путем измерения поверхностных концентраций хлорофилла *a*. Циркуляция воды изучалась при помощи спутникового слежения за буями, оснащенными плавучими якорями, которые были размещены на уровне 30 метров от поверхности, поскольку чаще всего концентрации криля наблюдаются на этом уровне. Основные концентрации криля, как обычно, наблюдались в шельфовых водах к северу от островов. Слежение за буями помогло обнаружить присутствие конвергентных сложных водоворотов в шельфовых водах этих островов. Также в шельфовых водах был зарегистрирован высокий уровень концентрации хлорофилла *a*. Наблюдалась пространственная коррелляция между распределениями криля и хлорофиллом *a*. В связи с этим считается, что как гидроакустический фактор, так и фактор присутствия пищи могут влиять на распределение криля. За 40-дневный период, длившийся с конца декабря 1990 г. до начала февраля 1991 г., плотность криля на традиционном участке промысла криля к северу от острова Ливингстон возросла в 3,4 раза. Эта, возросшая в начале февраля 1991 г., плотность, составившая 157 г/м^2, была на 54% ниже, чем наблюденная в конце января 1988 г. Данные исследований по хищникам криля, проведенных американскими учеными также показали, что численность

криля в течение первой половины лета 1990/91 г. была ниже, чем в предыдущие сезоны. Общая биомасса криля в шельфовых водах района съемки в конце января 1991 г. составила 1,78 миллионов тонн (56 г/м^2). Полученная оценка биомассы криля должна считаться низкой для этого времени сезона. С середины февраля и далее начали поступать сведения о восстановлении нормального уровня численности криля.

Resumen

De diciembre a febrero 1990/91, el BI *Kaijo Maru* realizó una prospección alrededor de las islas Shetland del Sur y Elefante. El objetivo principal consistió en investigar los mecanismos responsables de la concentración de krill y estimar la biomasa del krill en el área estudiada que se determinó hidroacústicamente. La distribución del fitoplancton se calculó por la clorofila-*a* superficial. La circulación del agua se estudió mediante el despliegue de boyas rastreadas por satélite, equipadas con unas "pantallas para medir corrientes" a una profundidad de 30 m de la superficie ya que las concentraciones de krill se encuentran más frecuentemente a estas profundidades. Como es lo usual, las concentraciones de krill más importantes se encontraron en la plataforma, al norte de las islas. El rastreo de las boyas demostró la existencia de complicados torbellinos convergentes en las aguas de la plataforma de estas islas. Estas aguas también registraron una alta concentración de clorofila-*a*. Se observó una correspondencia espacial entre las distribuciones de krill y de clorofila-*a*, concluyéndose así que tanto la hidrodinámica como la disponibilidad de alimento son factores que afectan la concentración de krill. En un caladero tradicional de krill situado al norte de la isla Livingston, la densidad de krill ha aumentado 3.4 veces en un período de 40 días, de fines de diciembre de 1990 a principios de febrero de 1991. Este aumento de la densidad del krill a principios de febrero de 1991 (157 g/m^2) representa una reducción de un 54% en comparación con aquella observada a fines de enero de 1988. Las investigaciones de científicos estadounidenses sobre los depredadores de krill, corroboraron el descenso en la abundancia de krill durante la primera mitad de la temporada 1990/91 en comparación con temporadas anteriores. La biomasa total de krill en las aguas de la plataforma de la zona estudiada se calculó en 1.78 millones de toneladas (56 g/m^2) a fines de enero de 1991. Esta cifra de biomasa debiera ser considerada como el nivel inferior de la temporada. Desde mediados de febrero en adelante se informó que la abundancia de krill había aumentado a niveles normales.

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1. INTRODUCTION

Krill concentrations regularly observed in the waters north of the South Shetland Islands and north and west of Elephant Island. Japanese krill fishing trawlers have mainly operated in this region with the yearly catches of 10 000 to 70 000 tonnes for the past eight years. This region, because of the abundance of krill-dependent predators, is also designated as an Integrated Study Region by CCAMLR.

This krill-rich region is, however, only insufficiently known in regard to mechanisms responsible for high abundance of krill and interannual variability in its biomass. As basic information for these matters, this paper will present the distributional pattern of krill biomass in relation to water flow and chlorophyll *a* (Chl-*a*) distribution in 1990/91 austral summer.

2. MATERIALS AND METHODS

The survey conducted in December/February 1990/91 by RV *Kaiyo Maru* was comprised of two legs. The first one covered the South Shetland Islands and Elephant Island regions including waters along the western side of the Antarctic Peninsula (Leg I: 22 to 29 December, 1990, Figure 1), whereas the second one covered thoroughly the waters from north of Elephant Island to north of the South Shetland Islands (Leg II: 18 January to 4 February, 1991, Figure 2).

2.1 Physical Oceanography and Chlorophyll *a* Studies

Oceanographic data were collected using a Sea-Bird SBE-19 CTD probe. CTD stations were taken down to 1 000 m or to the sea bottom in shallow areas. Water samples were obtained from 11 depth levels (0, 10, 20, 30, 40, 50, 75, 100, 125, 150 and 200 m). Chl-*a* concentration was determined by fluorometric method with a Turner Model-III fluorometer after extraction with 90% acetone (Strickland and Parsons, 1972).

2.2 Hydroacoustic Studies

Hydroacoustic studies were carried out in order to determine (i) the overall distribution of krill biomass in the survey area; and (ii) changes in krill abundance which took place in time between Leg I and Leg II on krill fishing grounds north of Livingston Island (shown as shaded areas in Figures 1 and 2). Observations were conducted along closely-spaced transects (4-mile intervals). The fact that Leg II of the survey was carried out almost in the same area as the previous cruise of RV *Kaiyo Maru* in 1988 (Fisheries Agency, 1989), made it possible to observe interannual variability in krill biomass in this area.

The echosounder used was FQ-50 with a digital integrator (Furuno Electric, Japan). Operating frequency was 200 kHz. Operational characteristics of the acoustic system is summarised in Table 1. Throughout the whole survey, excluding time spent for station measurements and net towing, the mean volume back-scattering strength (MVBS) was measured for constant horizontal integration intervals of 1 n mile and the depth range from 10 to 200 m or to the bottom if shallower. The top level of the integration depth, 10 m, was changed sometimes to 20 m in order to avoid impact of the surface noise. The default value of the target strength of krill was -66.1 dB per kilogram wet weight of krill (Shimadzu *et al.*, 1989). This value was obtained by Shimadzu *et al.* (1989) who measured krill of about the same size as observed during the present survey. Before (29 October 1990) and after (26 March 1991) of the cruise, the echo-integrator was calibrated in the port of Tokyo with the help of a hydrophone. Two calibrations showed a little reduction in the source level and receiving sensitivity of the echo-integrator after the cruise.

2.3 Drifting Buoy Studies

For the study of flow patterns around the islands, five drifting buoys (model C-2243, TOKYOCOM, Japan) were released in each Leg (Figures 1 and 2) and tracked using the Argos system carried on TIROS-N and NOAA-A satellites. Typically, twelve locations per day were obtained for each buoy with an accuracy higher than several hundred metres. Since krill in this region tended to be most abundant within the depth range of 30 to 40 m (Fisheries

Agency, 1989; observations of the 1987/88 austral summer), each buoy was equipped with a curtain drogue (4 m x 1 m) deployed at 30 m depth in order to study flow patterns at this depth.

3. RESULTS

3.1 Physical Oceanography

Figure 3 shows the horizontal distribution of salinity at 30 m depth during Leg II. Waters in the study region are divided into three categories, i.e. oceanic, frontal and shelf waters. The frontal waters, which are called CWB (Continental Water Boundary), are characterised by a relatively intense southward increase in salinity (from 33.7 to 34.1 ppt) and are restricted to a narrow band near the continental slope.

3.2 Chlorophyll *a*

High concentration of surface Chl-*a* was observed in the shelf waters with the richest area (higher than 1.0 mg/m^3) located to the north of Livingston Island (Figure 4). High gradients of Chl-*a* concentration were observed over the frontal waters with concentration values decreasing northward. Chl-*a* concentration was very low (0.2 to 0.3 mg/m^3) in the oceanic waters.

3.3 Hydroacoustic Surveys

Mean krill density was calculated for each distance between stations along the cruise track (Figures 5 and 6). In Leg I krill tended to form small or dispersed swarms with the biomass of 22 to 76 g/m^2 along the Antarctic Peninsula and 16 to 123 g/m^2 near Livingston Island. The highest value (123 g/m^2) was observed in the shelf waters north of Livingston Island. Krill were absent from a large part of the survey region. The fact that one krill fishing trawler operated at that time not only to the north of Livingston Island but also to the north of King George Island implies that the acoustic survey failed to detect krill to the north of King George Island, probably because krill occurred in widely spaced small swarms. On the traditional fishing ground on the northern shelf of Livingston Island, where the intensive acoustic survey was undertaken, the average biomass of krill was 46 g/m^2 on 25 December, 1990.

During Leg II the acoustic survey revealed a distinct tendency of high krill abundance observed in shelf waters, low abundance in oceanic waters and intermediate abundance in frontal waters. Higher values of biomass (> 100 g/m^2) were most frequently observed to the north of the South Shetland Islands with the highest biomass of 397 g/m^2. In oceanic waters, where krill were almost absent during Leg I, biomass of approximately 10 g/m^2 was observed during Leg II. On the traditional fishing ground the average biomass was 157 g/m^2 on 3 February, 1991.

To obtain the total biomass throughout the Leg II survey area (defined by broken lines in Figure 6), the area was divided into five subareas according to the regularity in krill density distribution. Krill biomass was calculated for each subarea. The total biomass, the sum of the biomass calculated for each subarea, was 2.11 million tonnes, of which 1.78 million tonnes (157 g/m^2) was concentrated in shelf waters (subareas C, D and E).

3.4 Drifting Buoy Studies

Seven buoys continued to operate for more than 50 days, while the other three failed shortly after deployment. Figure 7 shows tracks of four buoys.

Buoy 1 deployed in oceanic waters moved northeast with meandering and eddying current and arrived at South Georgia region five and a half months after deployment. The buoy appeared to drift in the Weddell-Scotia Confluence from west of Elephant Island onward. It was retrieved west of South Georgia, where Russian and Japanese trawlers were conducting winter krill fishing. Another buoy released in oceanic waters in Leg I (not shown in Figure 7) drifted eastward between Elephant Island and King George Island, and was trapped by erratic oceanic eddies to the east of Elephant Island. This buoy, in the end, became entrained in waters adjacent to Elephant Island.

Buoys 2 and 3 drifted eastward in the northern and southern portions of frontal waters, respectively. The latter one, however, recurved landward, then became entrained within the eddy north of Livingston Island and for a duration of one and half circulations before exiting it. The buoy left the eddy on the day when a furious storm occurred (wind scale was 10 by Beaufort scale). The buoy further travelled round the South Shetland Islands anticlockwise (with smooth current on the southern side of the islands and erratically rotating current on the northern side) and, surprisingly, executed more than one and a half circulations around the islands before ceasing to transmit. The track of this buoy elucidated the occurrence of complex eddies in the waters north of the South Shetland Islands. As for Buoy 2, it continued to drift eastward, then became entrained in the waters adjacent to Elephant Island, and went round the island anticlockwise while moving in loops along both the northern and western sides of the island.

Buoy 4 deployed in the shelf area moved east, then reversed and was trapped in Barclay Bay on the northern side of Livingston Island. It stalled there for more than seven months.

Thus, the buoys exhibited a distinct tendency to be trapped in complex topographical eddies generated in shelf waters.

4. DISCUSSION

Major concentrations of krill were observed in shelf waters north of the South Shetland Islands and Elephant Island, which mainly corresponds with the general pattern of krill distributions expected for the summer season. This study suggests two factors responsible for krill concentration. One is a convergent accumulation of krill by complex topographic eddies. Because of its rather stationary nature, the topographic eddies may provide some spatially-stable sites for retention of krill swarms, leading to the formation of persistent concentrations. Another factor is a behavioural response of krill. High concentration of Chl-*a* was observed in shelf waters. Krill arriving to near the islands would detect and respond to concentration gradient of phytoplankton (Price, 1989) and as the result would congregate actively in shelf waters. It is reasonable to assume that these two factors worked together, and resulted in a marked increase of krill abundance over the period from Leg I to Leg II (Figures 5 and 6).

Buoy 1 travelled all the way to South Georgia and has been trapped on krill winter fishing grounds. This implies that krill can reach their favourable habitats (e.g., island regions) even by passive drifting only. Considering the observed strong current-borne movement of krill (Everson and Murphy, 1987), krill may make much use of these currents for migration.

Krill abundance increased 3.4 times on the traditional fishing ground north of Livingston Island over the 40-day period during 25 December 1990 to 3 February 1991. This increase rate is quite comparable with 5-fold increase observed around Elephant Island over the two-month period from January to February in 1990 (Amos *et al.*, 1990).

The estimate of krill abundance (157 g/m^2) obtained for this traditional fishing ground on 3 February 1991 was approximately half of the estimate (342 g/m^2) obtained there on 20 January 1988 (Fisheries Agency, 1989). The distributional pattern of krill was also different between these seasons: in 1991 'layers' (a form of krill swarm with horizontal length exceeding 1 000 km) were observed only occasionally, whereas in 1988 'layers' were the main feature (Endo and Shimadzu, 1989). Brinton (1987) reported similar differences between March 1981 and March 1984 in biomass (229 g/m^2 vs 134-201 g/m^2) and distributional pattern (large, thick swarms vs smaller, dispersed swarms) of krill near Elephant Island.

The US AMLR report (1991) described the 1990/91 season as characterised by the following features: krill abundance was low (compared with other seasons) during the first half of summer (December to early February), whereas it approximated to the normal level towards the end of summer (mid-February to mid-April). On Seal Island, low krill abundance in the beginning of this summer caused approximately 20% decline (as compared to last year) in numbers of penguins occupying nests, and made feeding trips of fur seals rather long (5 to 9 days compared to 1 to 3 days later in the season) (AMLR, 1991). Krill fishery data from the 1990/91 season have also indicated that density index of krill (catch-per-hour of fishing) remained low in January. Therefore, the estimate of total krill biomass throughout shelf waters in late January 1991, i.e., 1.78 million tonnes (157 g/m^2), should be regarded as the lower level of krill biomass for this region at this time of the season.

ACKNOWLEDGMENTS

We are grateful to Captain Morooka T., officers and crew of RV *Kaiyo Maru* for their assistance during the cruise.

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Table 1: Operational characteristics of the echosounder Furuno FQ-50.

Frequency	200 kHz
Equivalent beam width	0.007 sr
Pulse duration	1.8 ms
Depth range	0 to 200 m
Depth channel	10* to 200 m (9 channels)
Integration interval	1 nautical mile
Attenuator	20 dB
Threshold	15 dB
TVG	20 log R
Gain constant	78.9 dB

* The level of the top depth integration range was changed to 20 m in order to avoid impact of the surface noise when the sea was rough.

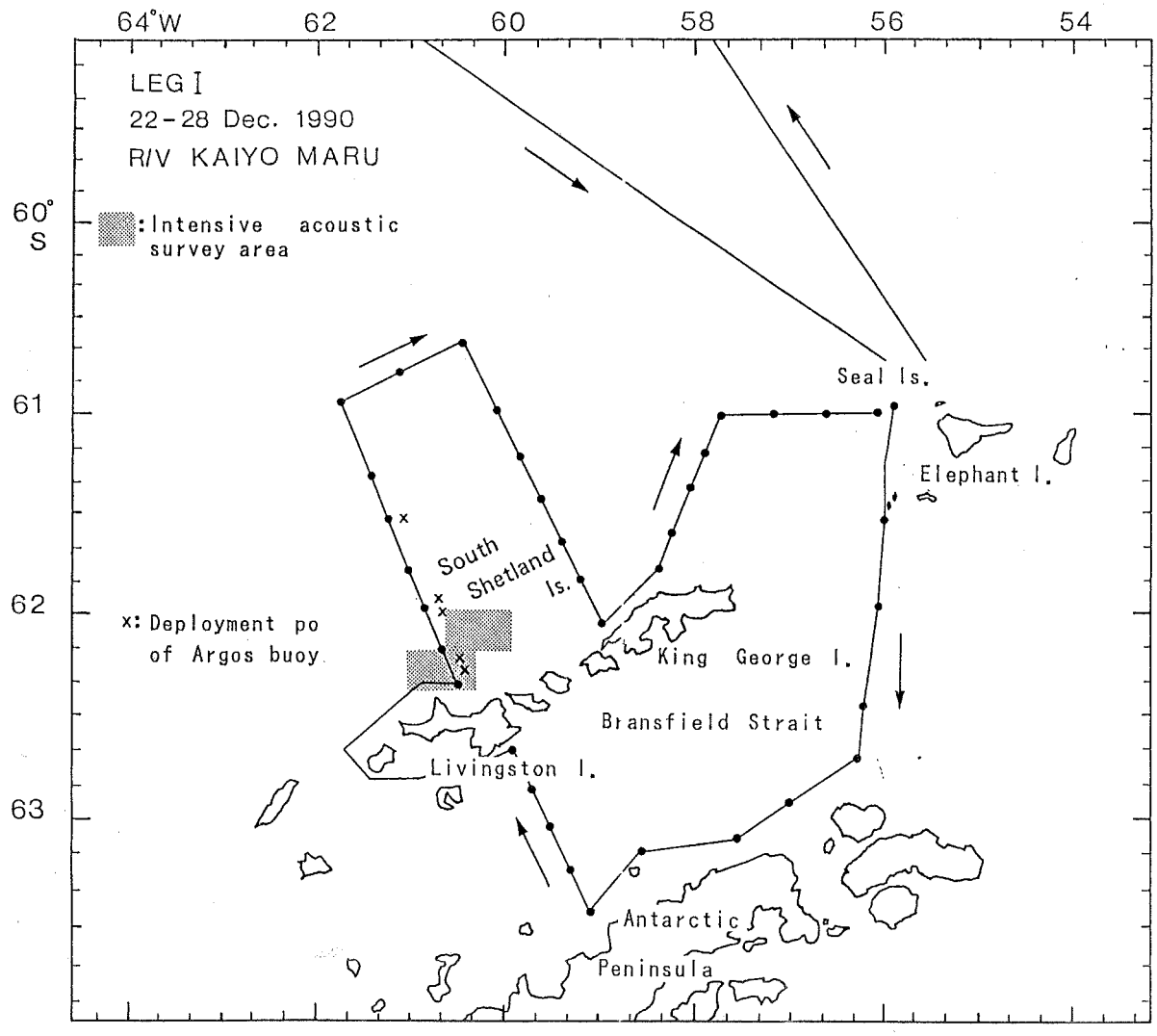


Figure 1: Cruise track and stations in Leg I.

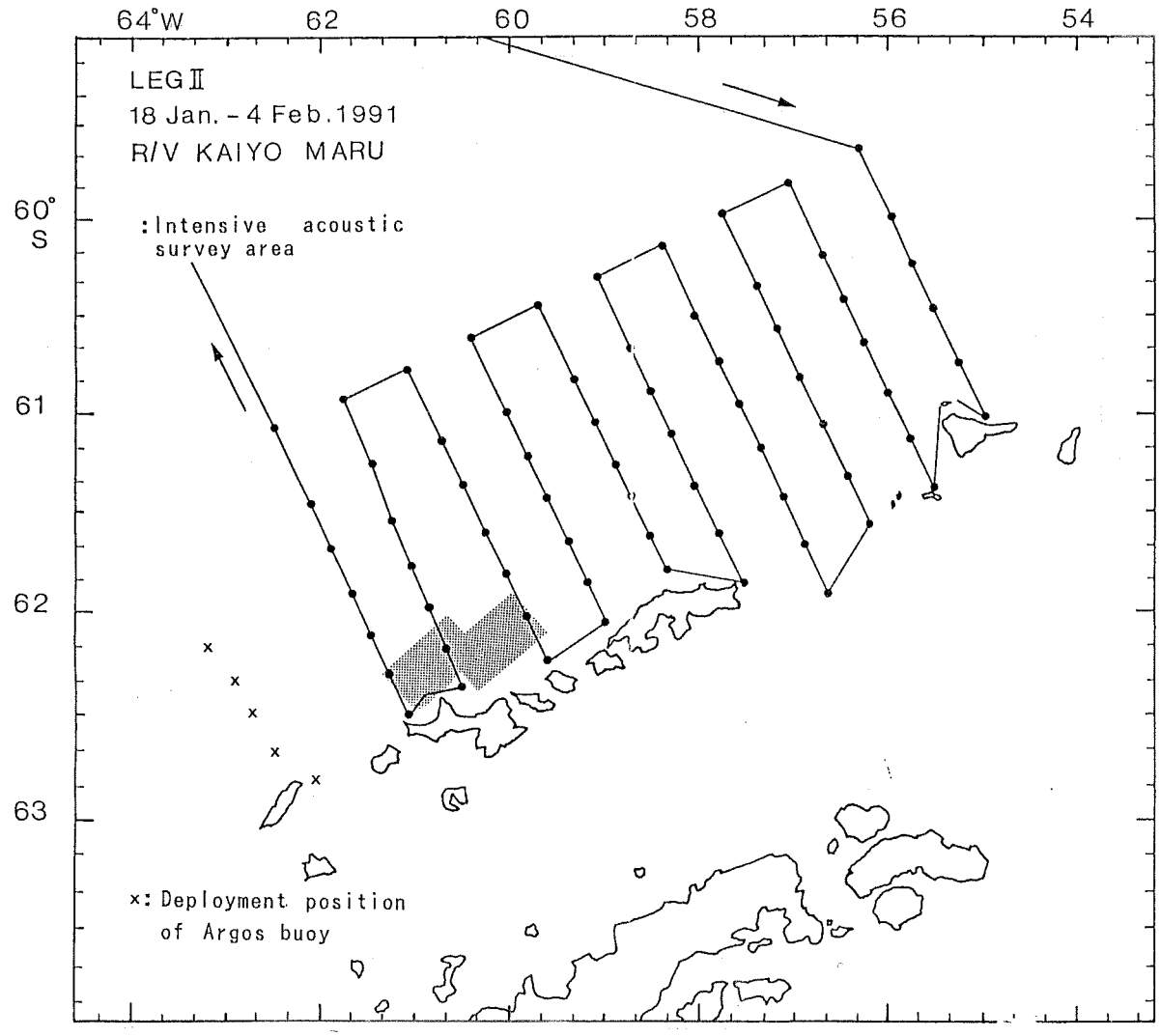


Figure 2: Cruise track and stations in Leg II.

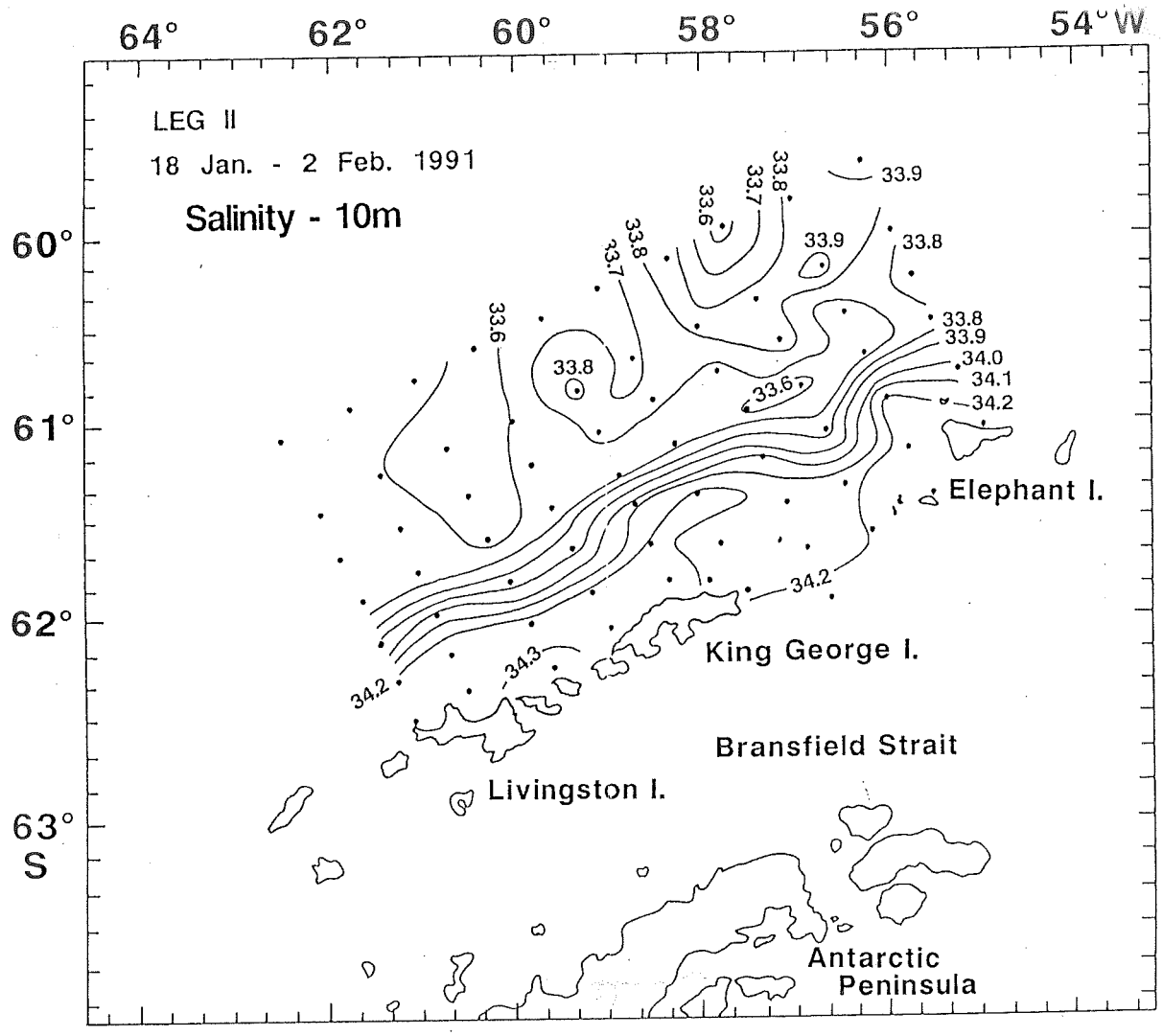


Figure 3: Distribution of salinity at 10 m depth in Leg II.

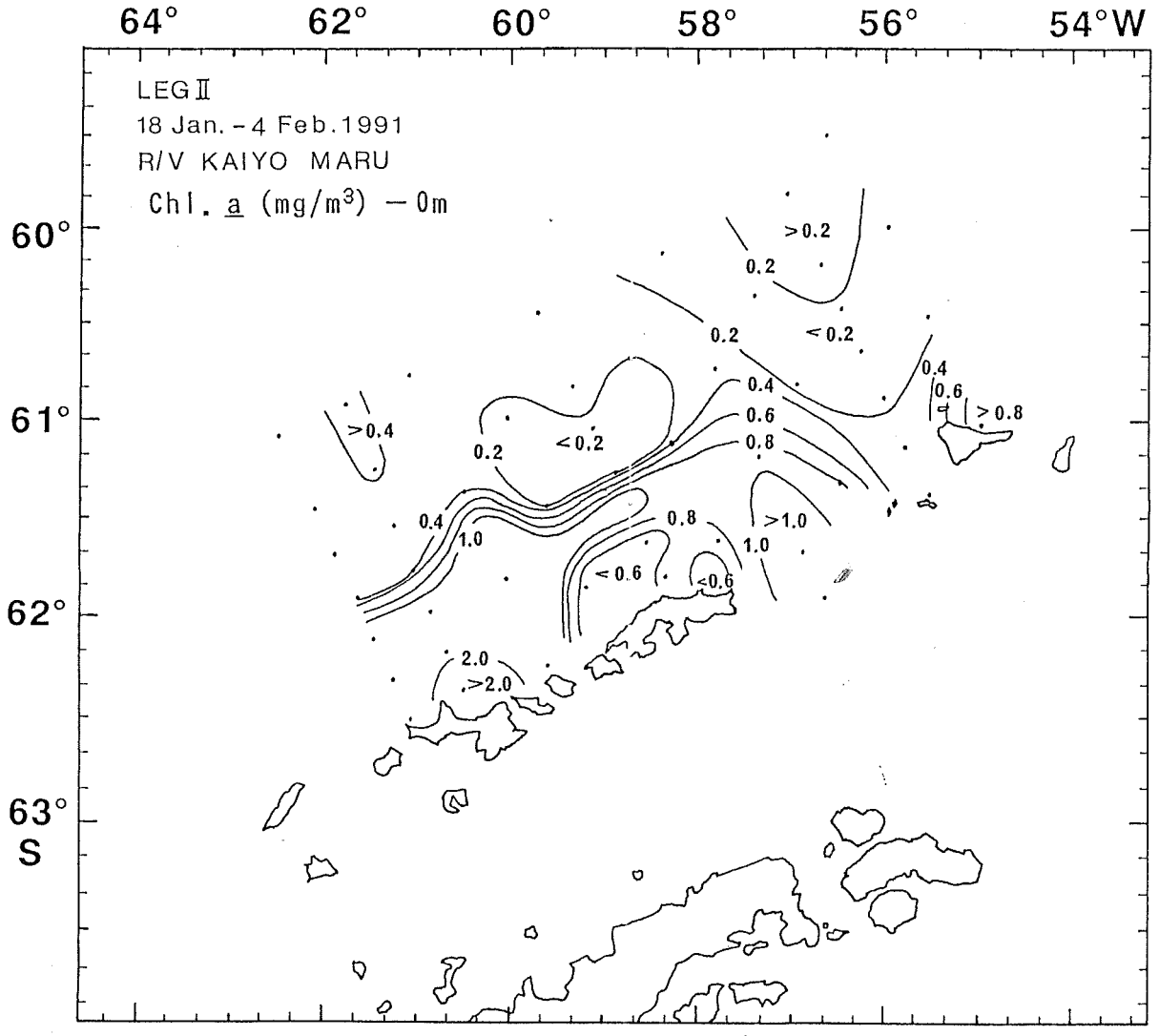


Figure 4: Distribution of chlorophyll *a* (mg/m^3) at the surface in Leg II.

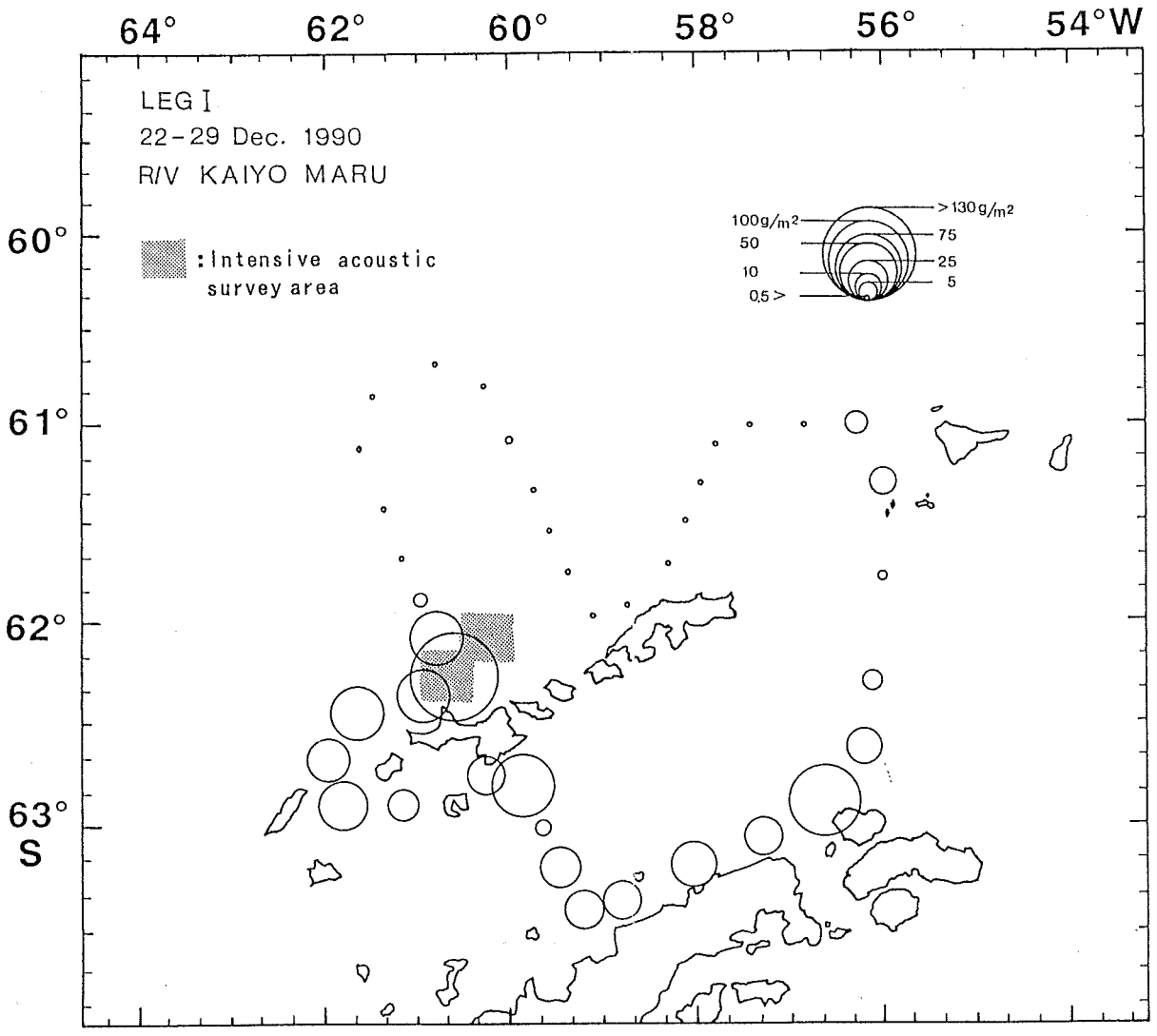


Figure 5: Hydroacoustically detected krill distribution in Leg I.

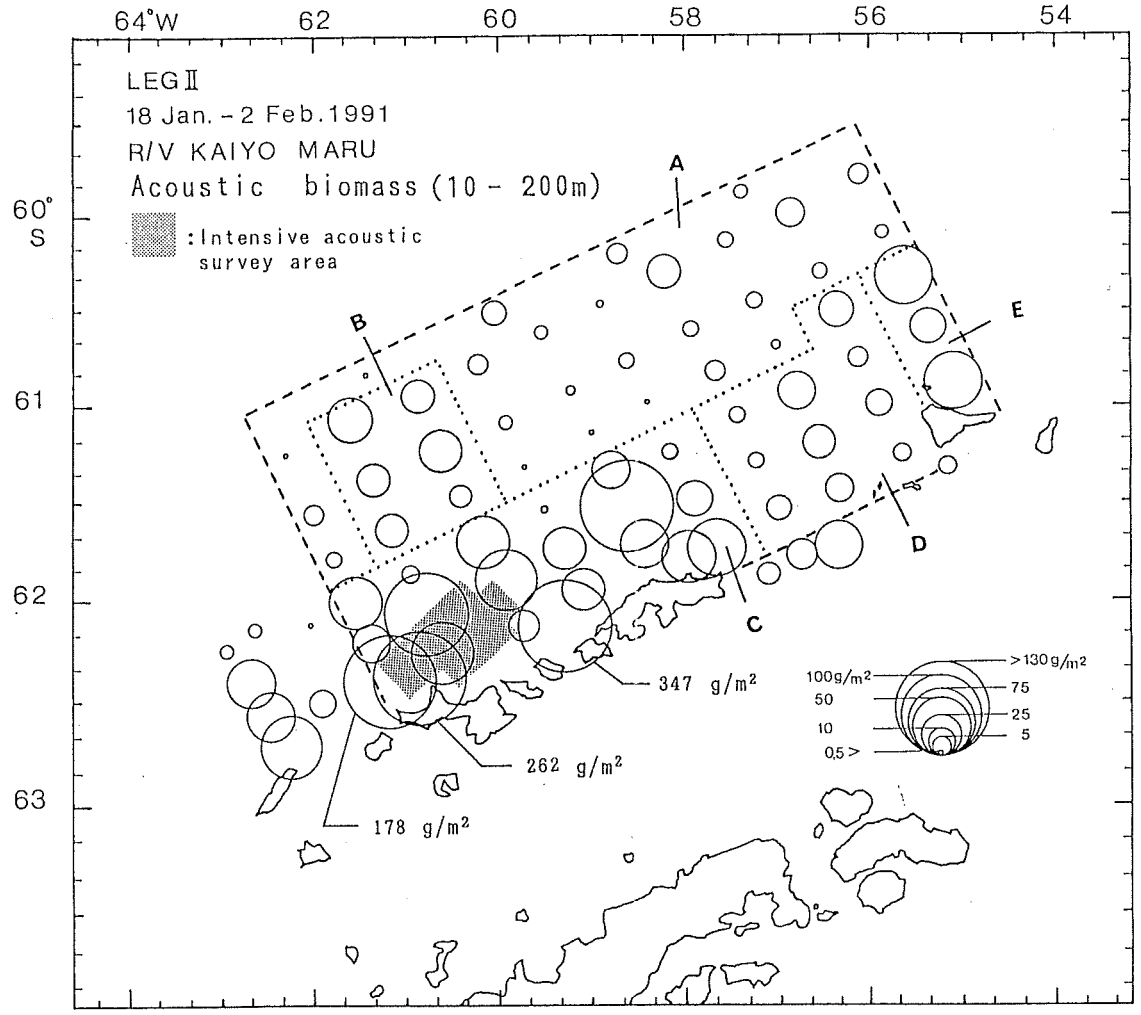
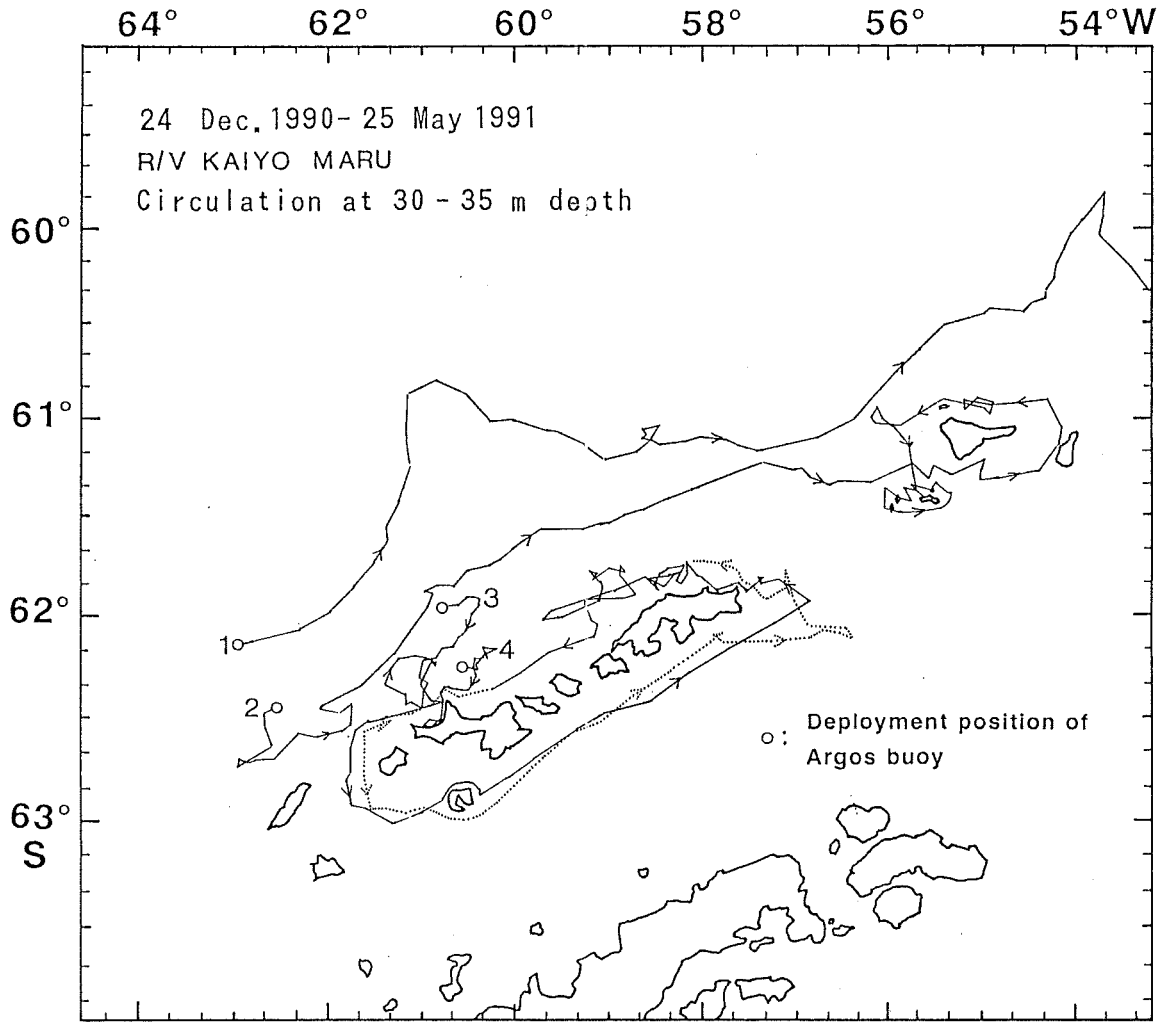


Figure 6: Hydroacoustically detected krill distribution in Leg II.



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TARGET STRENGTHS OF KRILL AT 136 AND 20 KHZ

S.M. Kasatkina*

Abstract

Estimation of krill target strength was made by ensonifying encaged live krill and using trawl hydroacoustic method. Ensonification of encaged live krill. For aggregations with mean lengths from 45 to 50 mm the mean single-krill target strengths range from -68 to -69 dB at 136 kHz. For aggregations with mean lengths from 43 to 47 mm the mean single-krill target strengths range from -71 to -77 dB at 20 kHz. Trawl hydroacoustic method. For aggregations with mean lengths from 47 to 50 mm the mean target strengths ranged from -71 to -75 dB. At the same frequency for aggregations with mean lengths in the range 41 to 47 mm the mean single-krill target strength is in the range -76 to -81 dB.

Résumé

L'estimation de l'intensité de réponse acoustique du krill a été effectuée en ensonifiant le krill vivant en enceinte, par la méthode de chalutage acoustique. Ensonification de krill vivant en enceinte. Pour les concentrations dont les longueurs moyennes varient de 45 à 50 mm, l'intensité de réponse acoustique moyenne d'un individu de krill se situe entre -68 et -69 dB à 136 kHz. Pour celles dont les longueurs moyennes varient de 43 à 47 mm, l'intensité de réponse acoustique moyenne d'un individu de krill s'étale entre -71 et -77 dB à 20 kHz. Méthode de chalutage acoustique. Aux concentrations dont les longueurs moyennes varient de 47 à 50 mm correspond l'intensité de réponse acoustique moyenne située entre -71 et -75 dB. A la même fréquence, les concentrations dont les longueurs moyennes s'étalent de 41 à 47 mm ont pour intensité de réponse acoustique moyenne d'un individu de krill entre -76 et -81 dB.

Резюме

Оценка силы цели криля выполнялась путем облучения живых особей в садке и тралово-акустическим методом. Измерения с помощью садка. Для агрегаций криля со средней длиной рачков в диапазоне 45-50 мм получены средние значения силы цели в диапазоне -68-,-69 дБ на частоте 136 кГц, а для средних длин рачков 43-47 мм - значения силы цели -71,-77 дБ на частоте 20 кГц. Тралово-акустический метод. Для агрегаций криля со средней длиной особей в диапазоне 47,54 мм получены средние значения силы цели в диапазоне -71,-75 дБ, а для средних длин рачков 41- 47 мм - значения силы цели -76,-81 дБ на частоте 20 кГц.

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Resumen

Se calculó la potencia de blanco mediante la insonificación de krill cautivo, con el método de arrastre acústico: Insonificación del krill. Para los grupos de talla media de 45 a 50 mm, la potencia media del blanco de un ejemplar osciló entre -68 y -69 dB a 136 kHz; para las tallas medias de 43 a 47 mm, la potencia del blanco de un ejemplar fue -71 a -77 dB a 20 kHz. Método de arrastre acústico. Para los grupos de talla media de 47 a 50 mm, la potencia del blanco osciló entre -71 a -75 dB. A la misma frecuencia, la potencia media de blanco de un ejemplar de krill de talla media entre 41 y 47 mm fue de -76 a -81dB.

1. INTRODUCTION

Despite the fact that research into the ability of krill to reflect sound ("reflectability") has been going on for more than ten years, this question is still far from fully understood.

The most recent works of Foote *et al.*, 1990 have identified lower target strengths (by almost 10 dB) compared to those values used until now in biomass estimates as recommended by the Post-FIBEX Workshop (Anon., 1986). With this in mind the CCAMLR Working Group on Krill called for a review of all current works on determination of krill target strength (**TS**) (SC-CAMLR, 1990).

Presented below are previously unpublished results of experimental evaluations of krill **TS** carried out by AtlantNIRO from 1980 to 1985. We feel that these may be useful in general discussion on the question of krill acoustic reflectability.

2. METHODS

Evaluation of krill **TS** was carried out using indirect methods, whereby **TS** calculation is based on recorded values of volume back-scattering strength obtained from ensonified aggregations of krill having a known density either by:

- ensonifying a known number of live caged krill, or
- using trawl hydroacoustic methods.

In this case krill **TS** was evaluated on the basis of the algorithm:

$$\mathbf{TS} = \mathbf{SV} - 10\,\ell g\rho \qquad (1)$$

where **SV** - volume back-scattering strength, dB
TS - target strength, dB
ρ - krill mean weight density ($g \cdot m^{-3}$)

2.1 Target Strength Estimation of Encaged Krill

Measurements were taken from a vessel standing at anchor where wave strength did not exceed 2 points on the Beaufort scale. Hydroacoustic equipment included a Soviet echosounder "Sargan-E" (operating frequencies 19.7 kHz and 136 kHz), an echointegrator

QM-MK-II (Simrad, Norway), an interface device between the echosounder and the echointegrator and a calibration device with a hydroacoustic transducer.

Calibration was carried out using a device composed of a metal frame in the shape of a truncated pyramid. The hydroacoustic transducer connected to the impulse generator of the "Sargan-E" echosounder was affixed to the top part of the frame and the cage was affixed to the base. The geometrical dimensions of the structure were determined by calculating the directional diagram of the monostatical transducer being used taking into account the shape of the distant difraction zone in the area being measured and the optimal ratio of target sizes to the transducer size:

Operating frequency 20 kHz
- dimensions of the calibration device: height - 1.9 m, length of the base - 2 m
- hydroacoustic transducer (magnetostrictive)
- width of directional diagram at 3 dB - 11° x 28°.

Operating frequency 136 kHz
- dimensions of the calibration device: height - 3.5 m, length of the base - 2 m
- hydroacoustic transducer (piezoceramic)
- width of directional diagram at 3 dB - 10°.

The cage was cubic in shape and was made of netting with a 5 mm mesh size. It was attached by monofilament kapron line in the base of the calibration device.

Individual krill taken straight from catches were used in the experiments. Hauls were carried out by a commercial trawl and were brief, not exceeding from 5 to 10 minutes. Krill specimens were removed from the catch and placed in a container of sea-water. After sorting, groups of various numbers of live, undamaged krill were transferred into other containers of sea-water. The number of these containers corresponded to the number of experiments to be carried out for each set of measurements. Krill were placed in the cage using a funnel. The length of krill in the cage were then measured at the end of each test.

Hydroacoustic calibration was carried out using a standard sphere attached with a monofilament line to the base of the calibration device along the acoustic axis of the transducer. The calibration device was submerged to a depth of about 10 to 15 m over the side of the vessel using a winch. The following standard spheres were used:

- frequency 20 kHz: aluminium, diameter 120 mm, **TS** = -30.92 dB
- frequency 30 kHz: brass, diameter 100 mm, **TS** = -31.04 dB
- frequency 136 kHz: steel, diameter 76 mm, **TS** = -39.6 dB

Target strength of an empty cage was measured prior to assessing krill target strength. The calibration device was lowered to a depth of 10 to 15 m.

TS values for the empty cage and the cage containing krill were recorded 40 minutes after submersion in order to guarantee that the cage had become completely saturated and that there was no air trapped beneath krill carapaces. Each impulse was 1 ms in duration and the length of the integration period was 60 minutes. Integrated readings were recorded every six minutes, which corresponded to the vessel covering one mile at a speed of 10 knots.

2.2 Trawl Hydroacoustic Method

Assessing krill target strength using the trawl hydroacoustic method is based on the comparison of the catch obtained and volume back-scattering strength (**SV**), determined by integrating acoustic signals from krill within the trawl operating area (beneath the vessel).

If the catchability (**P**) of the trawl is known, and assuming that information on the operating area of the trawl (**B**) is completely accurate, the density of krill biomass can be calculated for the trawl swept volume. The trawl operating area (swept volume) **B** is defined as

$$B = L \cdot h_1 \cdot v \cdot \tau \qquad (2)$$

where L - horizontal opening between trawl doors (in metres)
v - trawling speed (metres/second)
τ - trawling duration (seconds)
h_1 - vertical operating area of the trawl
$h_1 = h_t$ at $h_t \leq H$
$h_1 = H$ at $h_t > H$
h_t - vertical opening of the trawl (metres)
H - depth of water column containing relevant species

Density of krill in the swept volume area is defined as (Kasatkina, 1990)

$$Q = B \cdot \rho \cdot m \cdot P \qquad (3)$$

where Q - catch per haul (kg)
B - trawl operating area (m^3)
m - mean krill weight in the catch (kg)
P - total trawl catchability
ρ - mean density in the swept volume ($1/m^3$)
Equation (1) is the working algorithm for determining krill **TS**.

3. RESULTS

3.1 Target Strength Assessment of Encaged Krill

3.1.1 Krill Target Strength at Frequency 20 kHz

Experiments were conducted in the South Orkney area in May, 1983. Krill swarms were taken by a commercial trawl type 67.5/36 m. Trawling speed was 3.5 knots. Krill used in the experiments were selected from catches not exceeding 2 to 3 tonnes.

Krill ranging in size from 30 to 58 mm in length were caught. The modal group was between 41 and 44 mm. The mean length was $\bar{L}$ = 44.7 mm and the mean weight was $\bar{\rho}$ = 0.55 g. The sex ratio of females to males was 1.56:1. All females had sex organs in the second stage of maturity; the majority of these had been spawn before. Males had also spawn before. Krill intestines contained a very small amount of food.

Seven sets of measurements were made, comprising 19 experiments in which the number of encaged krill varied from 125 to 400 specimens. One trawl sample was taken for each set.

Target strength was only assessed in cases when krill removed from the cage after the test in another container were actively swimming.

3.1.2 Target strength (TS) of the empty cage was -53.06 dB.

Results of krill target strength assessment at a frequency of 20 kHz are presented in Table 1. Cage target strength and the number of specimens in it are abbreviated as **TS** (cage +

number of krill specimens). Table 1 shows the numerical characteristics (assessment of mathematical expectation $\bar{L}$ and standard deviation (**sd**) of length distribution in each experiment. Summary length composition of krill specimens used in the experiment is shown in Figure 1.

3.1.3 Krill Target Strength at Frequency 136 kHz

Experiments were conducted in the Elephant Island area in January, 1985. Krill swarms were taken by a commercial trawl type 72/308m.

Krill length varied from 32 to 59 mm and on average was 47.6 mm. The ratio of females to males was 1.43:1. All males were at the fourth stage of maturity, while females were at Stages III-IV. Krill had been feeding well.

Five sets of measurements were made (15 experiments). Krill target strength was assessed on the results of 11 experiments. The number of encaged krill varied from 76 to 165 specimens.

Target strength (TS) of the empty cage was -51.1 dB.

Results of krill target strength assessment at frequency 136 kHz and parameters $\bar{L}$ and $\bar{\rho}$ for encaged krill are shown in Table 2. Mean lengths of specimens used in the experiment are presented in Figure 2.

3.2 Krill Target Strength Assessment Using the Trawl Hydroacoustic Method

3.2.1 Krill target strength at frequency 30 kHz

Experiments were conducted in the Bouvet Island (December, 1979) and Maude Rise (February, 1980) areas.

In the Bouvet Island area large, mature krill were taken with females predominating over males. The sex ratio was 1:3. Length of specimens varied from 44 to 62 mm, most belonging to size group 50-56 mm (76%). Mean length was 54.6 mm and mean weight was 1.29 g.

Females were at Stage IV of maturity (97.4%). The majority of males (98.7%) were at Stage V.

In the Maude Rise area krill ranging from 30 to 51 mm in length were found in catches. Mean length was 39.55 mm and mean weight was 0.42 g. Sex ratio of females to males was 1:1. Males in catches were mainly immature with 97% being at Stage I. The overwhelming majority of females were immature; 80.4% were at Stage I.

Krill specimens had virtually not been feeding and the intestines were empty.

Krill swarms were fished with a trawl type 67.5/360m. Twenty two hauls were made. Mean values (SV) in the trawl operational area were made using an integrating system composed of an SRM-873 echosounder (Furuno, Japan) and the QM-MK-II echointegrator.

Table 3 shows the results of krill **TS** measurements.

Krill density ρ in the swept volume area is given taking into account trawl catchability. Moreover, results obtained by the author over the period 1983 to 1985 following research into

the catchability of the 67.5/360m trawl over a wide range of patterns of targeted krill swarm distribution were used as a basis for **TS** assessments (Kasatkina, 1990).

Table 3 only gives the results of representative hauls for which:

- trawl catchability (P) was able to be determined (from specific data on krill distribution characteristics and trawling regime);
- trawl catchability (P) did not vary over the trawling period as a result of irregularities in the trawling regime, e.g. change in trawling speed, changes in length of trawl ropes as the vessel changes course or changes in trawling depth;
- size composition analysis of krill from the catch was carried out (Table 3, Figure 3).

3.2.2 Krill target strength assessment at frequency 20 kHz

Experiments were conducted in the South Orkney Islands area in May, 1983 and in the South Georgia area in July, 1983.

A biological description of krill samples from the South Orkney Islands area is given above. Krill varying from 35 to 58 mm in length (modal group 47 to 54 mm) were taken in June in the South Georgia area. Mean length of specimens was 49.9 mm and mean weight was 0.814 g.

Males were dominant in the catches and comprised 60%. All males were at Stage II of maturity. Females comprised 40% and were also at Stage II. Krill had been feeding poorly.

Krill swarms were fished with a trawl type 67.5/360m. Mean values (SV) in the trawl operational area were made using a system comprised of a "Sargan-E" echosounder and the QM-MK-II echointegrator.

Results of krill **TS** assessments are given in Table 4 which gives the numerical distributional characteristics of back-scattering cross section (estimate of mathematical expectation $\overline{L}$, standard deviation - sd) and their corresponding boundary target strength values TS_1 and TS_2 (where $TS_1 = 10 \ell g (\overline{\sigma} - sd)/ 4\pi$; $TS_2 = 10 \ell g (\overline{\sigma} - sd)/ 4\pi$.

Krill size composition is given in Figures 1 to 5.

4. DISCUSSION

As one can see from Tables 1 to 4, the experiments which were conducted have made it possible to assess values of **TS** over a fairly wide range of sizes.

Measurements in a cage. At a frequency of 136 kHz mean **TS** values between -68 and -69 dB were obtained for swarms of krill with an average length of 45 to 50 mm, while at a frequency of 20 kHz target strength values of -71 to -77 dB were obtained for krill with an average length of 43 to 47 mm.

Trawl Hydroacoustic Method. At a frequency of 20 kHz mean **TS** values between -71 and -75 dB were obtained for krill swarms with an average length of 47 to 54 mm, while target strength values of -76 to -81 dB were obtained for krill with an average length of 41 to 47 mm. At a frequency of 30 kHz mean **TS** values between -71 and -82 dB were obtained for krill with

an average length of 36 to 50 mm, while target strength values of -69 to -76 dB were obtained for krill with an average length of 53 to 54 mm.

Regression equations for **TS** and **L**, calculated using data in Tables 1 to 4, are shown in Table 5 and their corresponding regression plots in Figures 5 to 7.

It is well known that until now the majority of **TS** assessments have been carried out at 120 kHz (Anon, 1986; Kalinowski *et al.*, 1980; Yudanov, 1986; Foote *et al.*, 1990). Since **TS** of shrimps (and krill) do not greatly depend on frequency in the 100 to 170 kHz range we can compare the values of krill **TS** at 136 kHz with known **TS** values at 120 kHz.

Values for **TS** obtained at f=136 kHz are much lower (by as much as 4 to 5 dB) than **TS** values recommended by BIOMASS (Anon., 1986). One should expect to obtain **TS** values 3 to 5 dB higher than those obtained by Foote (Foote *et al.*, 1990) for krill 30 to 39 mm in length.

TS values assessed at 20 kHz with the use of a cage were higher than **TS** values obtained using the trawl-acoustic method both at 30 kHz, which is clearly contrary to the character of frequency dependence of krill **TS** (Samovolkin, 1980; Dalen, Kristansen, 1981), and at 20 kHz (Figure 7).

These highlighted differences in krill **TS** assessment may be attributable not only to biases in measurements but also to differences in biological condition and length composition of the ensonified krill swarms.

In our view, the large increase in krill **TS** at 30 kHz where specimens were 53 to 54 mm in length (Bouvet Island area: large mature krill; more females than males; Stages IV and V of maturity) in comparison to **TS** where krill length was from 40 to 50 mm (Maude Rise area: immature krill, sex ratio 1:1, Stage I of maturity) can to a large extent be attributed to the influence of such biological parameters as stage of sexual maturity, sex ratio and degree of stomach/intestinal fullness (Figure 8, Table 3).

It should be recalled that the nature of dependence between **TS** and the parameter L/λ (λ = wave length) excludes the possibility of such a divergence in **TS** values, while at the same time allowing a gradual increase in **TS** in the range $L/\lambda = 7 \div 12$ (Samovolkin, 1980; Andreeva and Samovolkin, 1986).

5. CONCLUSION

Experiments carried out demonstrated the dependence of krill **TS** on frequency of ensonification, length and biological condition of the specimens involved.

In general the assessments obtained for **TS** were lower than those recommended by BIOMASS but higher than those presented by Foote *et al.* (1990).

The low technical level of equipment used in experiments carried out in the period 1979 to 1985 somewhat reduces the reliability of **TS** assessments presented.

Given the current state of knowledge, we believe that the most representative experimental assessments of krill **TS** for small-sided krill are those carried out by Foote (Foote *et al.*, 1990). However, the necessity to apply **TS** data on krill to the calculation of its biomass means that research is still required into target strength in relation to biological condition and length composition of krill aggregations as well as the time of day, in order to take into account possible daily changes in **TS** (e.g. changes in krill's spatial orientation).

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Table 1: Results of krill target strength assessment at 20 kHz. South Orkney Islands area, May 1983.

Experiment No.	No. of Krill in the Cage	TS (cage + krill), dB	Krill TS, dB	Krill Length	
				$\bar{L}$ (mm)	sd
1	288	-52.0	-76.6	43.0	4.1
2	350	-45.1	-71.25	47.1	4.2
3	190	-48.3	-72.86	46.5	4.0
4	285	-48.6	-75.0		
5	400	-49.1	-77.37		
6	220	-48.7	-74.09		
7	400	-49.1	-77.37		
8	115	-49.5	-72.58	47.1	4.2
9	380	-46.6	-73.43		
10	230	-49.3	-75.24	44.7	4.8
11	350	-48.9	-76.36	44.0	4.3
12	300	-49.2	-76.16	43.9	4.1
13	200	-47.8	-72.36	45.3	4.0
14	125	-50.34	-71.3	45.3	4.1

Table 2: Results of krill target strength assessment at 136 kHz. Elephant Island area, January 1985.

Experiment No.	No. of Krill in the Cage	TS (cage + krill), dB	Krill TS, dB	Krill Parameters		
				$\bar{L}$ (mm)	sd	$\bar{\rho}$
1	100	-45.99	-68.10	47.1	4.78	0.762
2	85	-46.63	-68.50	46.5	3.39	0.742
3	80	-48.18	-68.07	47.1	4.77	0.778
4	165	-44.81	-68.50	46.4	4.15	0.726
5	140	-45.57	-68.90	46.3	3.85	0.655
6	76	-46.88	-68.48	47.1	4.78	0.764
7	107	-45.68	-67.91	48.9	3.62	0.846
8	99	-46.84	-68.84	45.9	3.99	0.684
9	105	-45.80	-68.05	47.7	4.86	0.811
10	130	-45.71	-68.81	45.1	3.65	0.600
11	117	-45.80	-68.46	46.2	3.51	0.694

Table 3: Results of krill target strength assessment at 30 kHz. Trawl-acoustic method.

Ship Time at Setting of Trawl	Krill Density in Swept Volume ($\rho \cdot m^{-3}$)	Back-Scattering Strength SV, dB	TS, dB	Krill Parameters		
				$\bar{L}$ (mm)	sd	$\bar{\rho}$
Bouvet Islands area (December 1979)						
8:50	1.43	-69.7	-71.8	53.6	4.8	1.22
11:10	5.6	-67.7	-75.7	53.7	4.9	1.1
16:20	1.3	-74.3	-75.4	53.9	3.9	1.19
20:30	0.14	-77.5	-69.0	54.2	5.7	1.23
Maude Rise area (February 1980)						
7:30	3.6	-72.5	-78.3	47.3	3.9	0.97
8:45	1.24	-70.0	-70.9	50.0	5.1	0.97
10:15	16.2	-70.3	-82.2	46.4	4.1	0.77
17.35	2.4	-71.7	-75.5	47.7	3.9	0.69
5:10	3.49	-74.7	-80.1	38.1	3.1	0.42
10:00	164.6	-60.3	-82.4	36.0	3.1	0.25

Table 4: Results of krill target strength assessment at 20 kHz. Trawl-Acoustic Method.

Area	σ (m^2)	sd (m^2)	TS, dB	TS_1	TS_2	Krill Parameters		
						$\bar{L}$ (mm)	sd	$\bar{\rho}$
May 1983 S. Orkneys	2.08×10^{-7}	1.0×10^{-7}	-77.8	-80.7	-76.1	44.7	3.0	0.56
June 1983 S. Georgia	7.39×10^{-7}	3.25×10^{-7}	-72.3	-74.8	-70.7	49.9	5.0	0.815

Table 5: Regression equations between krill target strength (TS, dB) and krill length (mm), Maude Rise area.

Method	Frequency (kHz)	Regression equation	Correlation coefficient
Encaged krill	136	TS = 0.39L - 86.50 (4)	0.87
Encaged krill	20	TS = 1.27L - 131.30 (5)	0.84
Trawl-Acoustic Method		TS = 1.1L - 127.3 (6)	0.79
Trawl-Acoustic Method		TS = 0.5L - 99.30 (7)	0.72

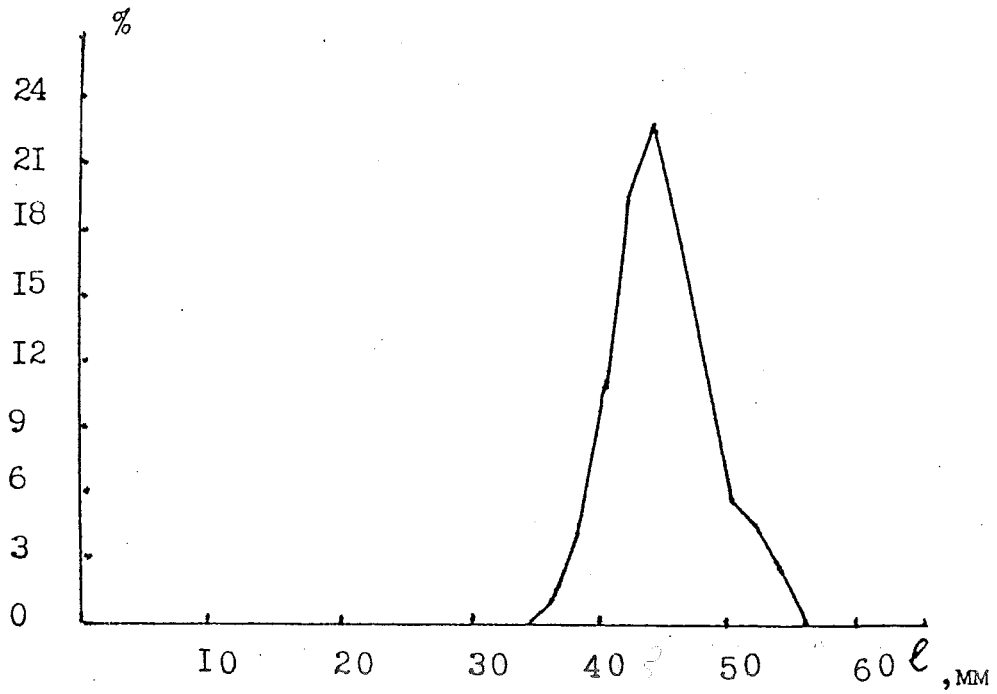


Figure 1. Krill length composition. South Orkney Islands area. May, 1983.

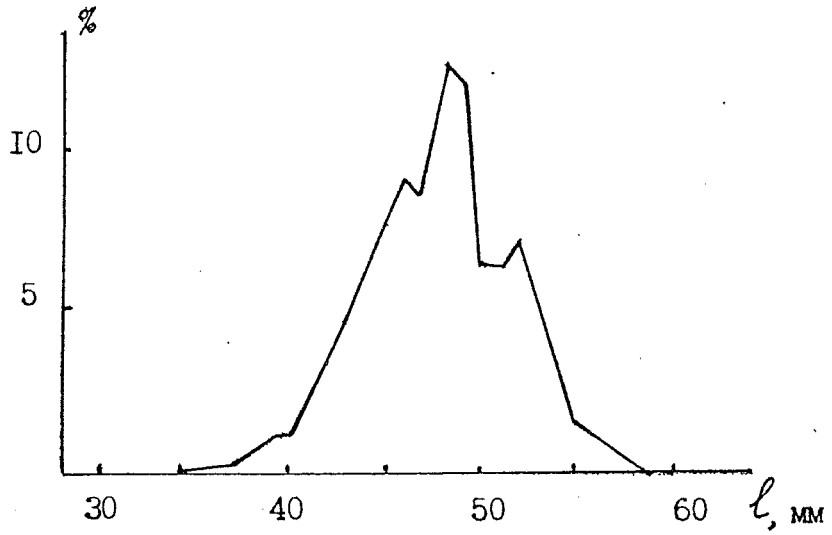


Figure 2. Krill length composition. Elephant Island area. January, 1985.

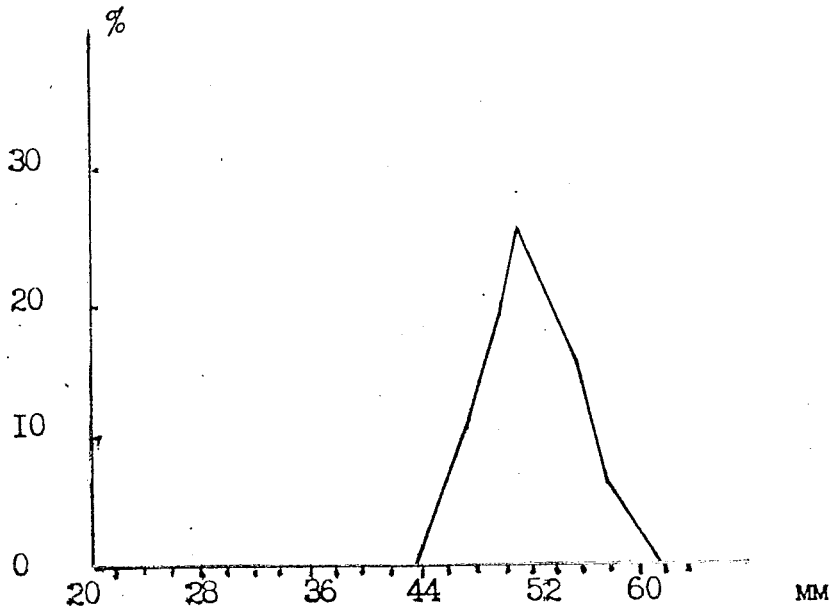


Figure 3. Krill length composition. Bouvet Island area. December, 1979.

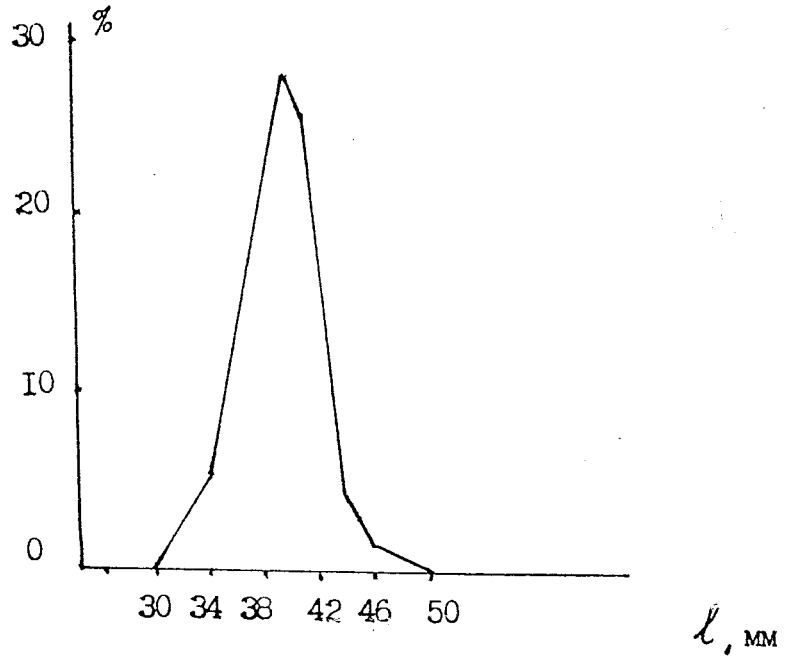


Figure 4. Krill length composition. Maude Rise area. February, 1980.

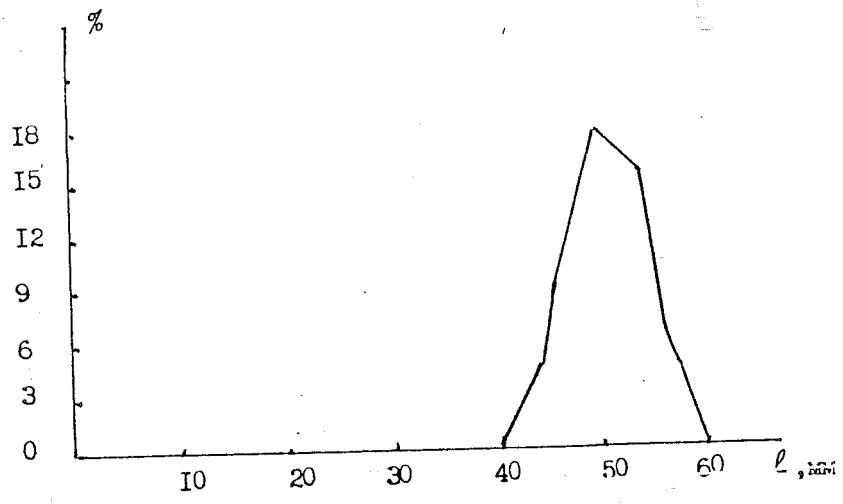
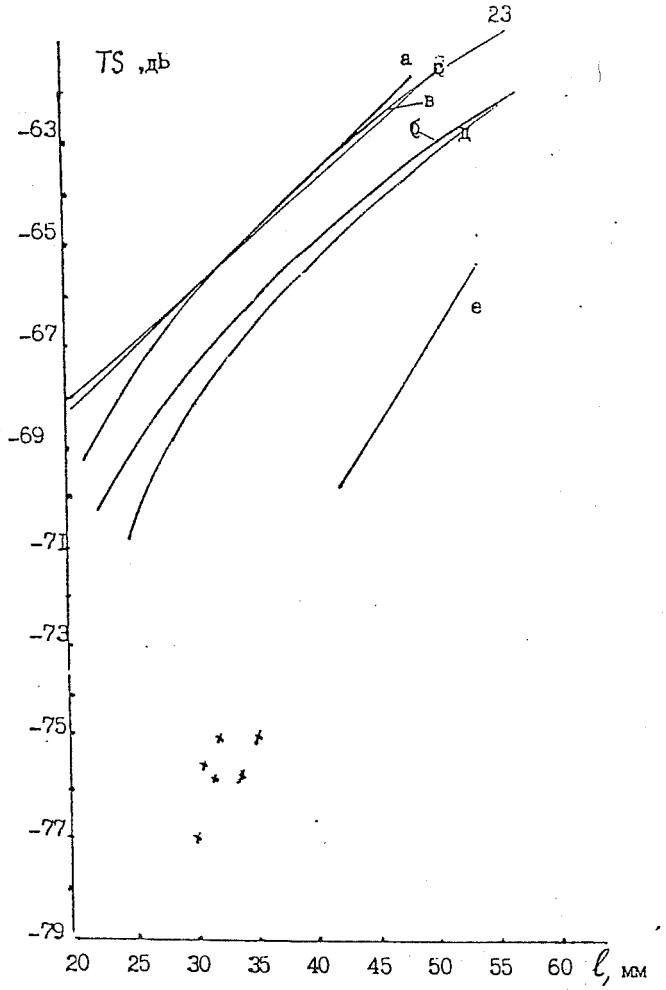


Figure 5. Krill length composition. South Georgia area. June, 1983.



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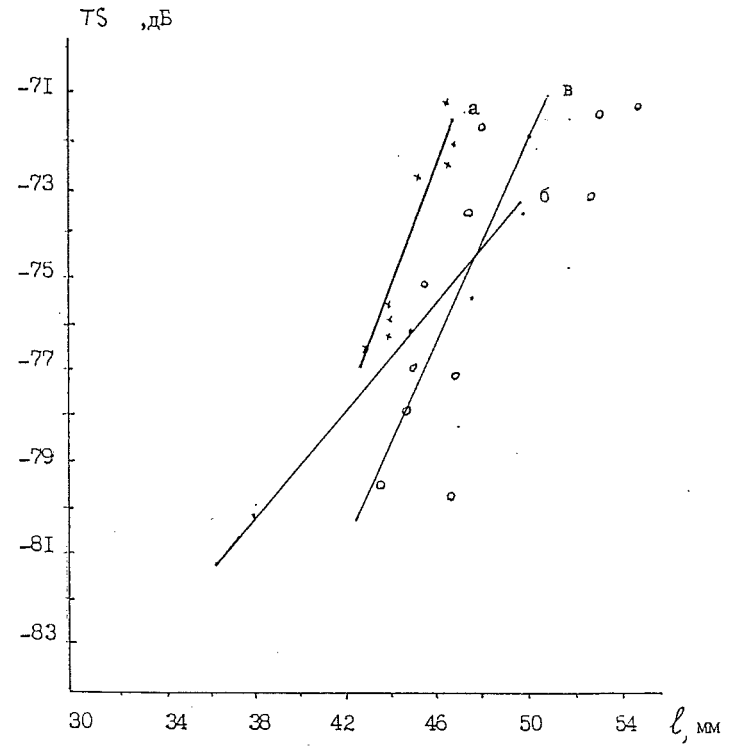
d	-	Anon. (1986)
e	-	Godlewska (1982)
f	-	Kasatkina, 136 kHz
×	-	Foote *et al.* (1990)



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- • - experimental measurements at 30 kHz (trawl-acoustic method)
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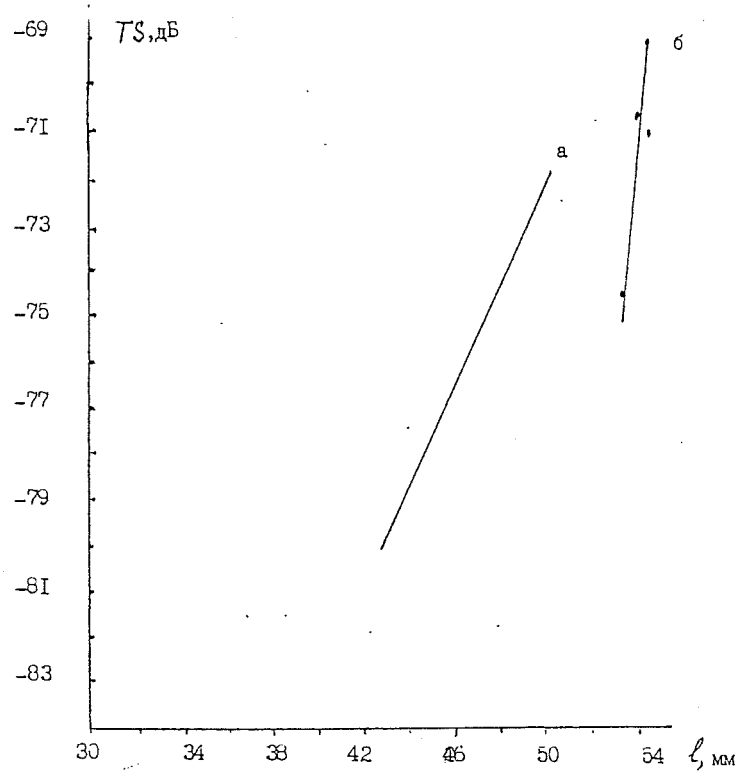

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ESTIMATION OF KRILL (*EUPHAUSIA SUPERBA*) MORTALITY AND PRODUCTION RATE IN THE ANTARCTIC PENINSULA REGION

V. Siegel*

Abstract

A net sampling survey for krill was carried out by RV *Meteor* along the Antarctic Peninsula from 26 December 1989 to 14 January 1990. Results were compared with data of an identical survey with RV *Polarstern* in 1987/88. Seasonal variation between summer and winter abundance/biomass data exceeded a factor of 1:35, while interannual variability between available surveys reached only a factor of 1:1.6. Krill mortality was calculated by linearized catch curve analysis and resulted a rate of Z = 0.88 (1989/90) and Z = 0.96 (1987/88). Production was estimated and resulted a P/B ratio of 0.88 to 0.94 for different years. The exchange rate of water masses and krill biomass within one summer season was roughly estimated as two times from which follows a maximum total effective biomass (including production) of 4.3 and 5.0 x 10^6 tonnes passing through the survey area during the respective summer.

Résumé

Du 26 décembre 1989 au 14 janvier 1990, le RV *Meteor* a effectué une campagne d'évaluation du krill par échantillonnages au filet le long de la péninsule antarctique. Les résultats ont été comparés avec les données d'une campagne identique effectuée par le RV *Polarstern* en 1987/88. La variation saisonnière entre les données d'abondance et de biomasse d'été et d'hiver dépassait un facteur de 1:35, alors que la variabilité interannuelle entre les données de campagnes disponibles n'atteignait qu'un facteur de 1:1,6. La mortalité du krill, calculée par l'analyse de la courbe de capture linéarisée, a produit un taux de Z = 0,88 (1989/90) et Z = 0,96 (1987/88). La production ayant été estimée, on est arrivé à un rapport de P/B de 0,88 à 0,94 selon les années. Le taux d'échange des masses d'eau et de biomasse de krill en une saison d'été était estimé, grosso modo, à deux fois, d'où une biomasse effective totale maximale (production comprise) de 4,3 et 5,0 x 10^6 tonnes traversant l'aire de la campagne pendant les étés respectifs.

Резюме

С 26 декабря 1989 г. по 14 января 1990 г. вдоль Антарктического полуострова НИС *Meteor* была проведена съемка по сбору проб криля сетями. Результаты были сравнены с данными идентичной съемки проведенной НИС *Polastern* в 1987/88 г. В результате сезонной изменчивости данных по численности/биомассе различие между зимними и летними месяцами составило 1:35, тогда как межгодовая

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изменчивость между имеющимися съемками достигла лишь фактора 1:1,6. Смертность криля была подсчитана при помощи анализа линеаризированной кривой улова. Были получены следующие результаты: коэффициент Z = 0,88 (1989/90) и Z = 0,96 (1987/88). Оценка продуктивности составила отношение P/B от 0,88 до 0,94 в разные годы. Коэффициент обмена масс воды и биомассы криля в течение одного лета был приблизительно равен 2, из чего следует, что в течении изученных летних сезонов, мигрирующая через данный участок максимальная общая фактическая биомасса (включая продуктивность) составит 4,3 и 5,0 x 10^6 тонн.

Resumen

El buque de investigación *Meteor* llevó a cabo una prospección con redes a lo largo de la península Antártica del 26 de diciembre de 1989 al 14 de enero de 1990. Se contrastaron los resultados con los datos obtenidos de una prospección idéntica hecha con el BI *Polarstern* en 1987/88. La variación estacional de los datos de abundancia y biomasa entre el verano y el invierno sobrepasó un factor de 1:35, mientras que la variación interanual de las prospecciones disponibles sólo alcanzó un factor de 1:1.6. La mortalidad del krill fue calculada mediante un análisis lineal de la curva de capturas y dio un índice de Z = 0.88 (1989/90) y Z = 0.96 (1987/88). El rendimiento estimado dio una razón P/B de 0.88 a 0.94 para distintos años. El índice de intercambio de las masas de agua y biomasa de krill dentro de una temporada estival se calculó, a *grosso modo*, en dos veces, de lo que se deduce una biomasa total efectiva máxima (incluida producción) de 4.3 y 5.0 x 10^6 toneladas que pasaron por el área prospectada durante los veranos respectivos.

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1. INTRODUCTION

During recent years research on Antarctic krill has led to a deeper understanding of the species life cycle and a more refined knowledge on distribution patterns and the variability with time. First attempts had been carried out to estimate population dynamic parameters as there are age, growth, mortality and production. A comprehensive review of the present state of knowledge was undertaken by Miller and Hampton (1989) who documented the progress since the report by Everson (1977). On the other hand this review also elucidated the problems of diverting published results which are often derived from different methodological approaches.

For a long time krill was thought to live only for two or three years and spawn only once during the life-cycle. Studies on 're-maturation' and 're-juvenation', however, led to the conclusion of a multiple spawning during a longer life span. Meanwhile a longevity of five to seven years (6 to 8 age groups) is accepted in principal (Ettershank, 1984 and 1985; Siegel, 1986 and 1987; Rosenberg *et al.*, 1986; Hosie *et al.*, 1988) which changed the basis for the calculation of basic population dynamic parameters.

Since the establishment of a commercial krill fishery there is an increasing need for reasonable estimates on age, growth, mortality and productivity. The present study intends to

support data from a survey covering the area of the krill distribution range from juvenile to adult stages. A representative sample of all age groups can be expected which overcomes shortcomings of earlier locally restricted investigations. Determination of mortality as well as productivity will support more reliable results than it would be possible from an unknown, smaller part of the population with an unknown age structure.

2. MATERIAL AND METHODS

A net sampling survey for krill was conducted by RV *Meteor* during 26 December 1989 and 14 January 1990. The survey area was located along the Antarctic Peninsula between Elephant Island in the northeast and Adelaide Island in the southwest. The station grid was based on the extended BIOMASS-SIBEX grid, which was already surveyed during previous years, March 1984/85, winter 1986, and November/December 1987/88.

A total of 88 stations were sampled (Figure 1) by a multiple RMT 8 net with a mesh size of 4.5 mm (Roe and Shale, 1979). Flow-meter data, net angle, fishing depth and temperature were monitored continuously and the data stored on a personal computer (Dimmler and Klindt, 1990). Filtered water volumes were calculated from the net parameters applying formulas given by Rose and Shale (1979) and Pommeranz *et al.* (1982).

Plankton samples were preserved in 4% buffered formalin seawater solution. Krill was always sorted completely from the entire sample. Total length (AT) was measured from the anterior margin of the eye to the tip of the telson to the nearest millimetre below. All measurements were carried out by a single observer to avoid methodologically biased differences in length frequency data (Watkins *et al.*,1985). A total of 12 933 krill specimens were measured and their developmental stages determined.

Statistical analyses were carried out using the CSS statistical computer package. Age groups were derived from length frequency data by application of the distribution mixture analysis presented in detail by MacDonald and Pitcher (1979). The MIX computer program was run in an interactive session to estimate, by stepwise optimization, certain variables of single components of the distribution mixture (means, standard deviations and proportions) as well as the chi-square goodness of fit test.

3. RESULTS

The survey covered an area of approximately 93 800 n miles^2. Abundance values were integrated for the 200 m depth zone.

3.1 Stock Composition

The composition of the krill stock and its spatial distribution pattern was investigated applying a cluster analysis to compare similarity between stations. A similarity matrix was computed based on the relative frequency of each krill length class as station parameters as described by Siegel (1986 and 1988). Results of this analysis were plotted as a dendrogram. A similarity level of 70% led to four geographical coherent clusters which were interpreted to be biologically meaningful.

Since number of stations and the abundance of krill were different in these clusters, a simple unweighted mean length frequency distribution calculated from the above relative distribution would bias the absolute abundance and the composition of the overall length composition. Therefore krill density strata were established in each cluster. The stratified mean (Saville, 1977) was then determined for each cluster separately and multiplied by the size of the

respective cluster. The sum of all four clusters finally led to the absolute abundance of size classes within the entire survey area.

The overall length frequency distribution is shown in absolute numbers in Figure 2 for the summer cruise 1989/90. The scarcity of juvenile krill of 23 to 30 mm became quite obvious, while 30 to 44 mm medium sized subadults represented the bulk of the krill stock. Largest adult specimens were 61 mm in size, which is generally the maximum length reached by this species.

The above described procedure was also undertaken for other surveys from different years to detect the degree of interannual variation in krill abundance. The occurrence of different cluster and their related length frequency distributions during various cruises had been published earlier (Siegel, 1988 and 1989). Data and results are summarized in Table 1.

In summer 1989/90 the total amount of krill reached 2 700 x 10^9 individuals in the survey area (Figure 3). Abundance was higher during the post-spawning season 1984/85 with 3 795 x 10^9 krill and highest in early summer pre-spawning season 1987/88 with more than 4 400 x 10^9 krill. During winter 1986 the stock was at its lowest level with 124 x 10^9 individuals. Juvenile krill was scarce in 1984/85 and 1989/90, indicating poor 1^+ age groups. Subadult stages observed in lower numbers during the 1987/88 season indicating a missing of a middle aged class (see below).

3.2 Biomass

Krill biomass was mapped as g/m^2 and contoured and size of biomass density strata were measured. The stratified mean and variance were determined for the area within the krill distribution range using the method described by Saville (1977). Data from earlier surveys were reanalysed in the same manner, because in some cases the area of zero catches beyond the distribution range - but inside the survey area were included for the calculation of the overall stratified mean. This reduces the value of the stratified mean and would not give a real impression on the variability of biomass density within the distribution limits of the species. Results of all estimations are given in Table 2.

During summer the total estimated biomass ranged from about 1 million tonnes to more than 1. 6 million tonnes regarding the fact that the size of the survey area slightly differed from year to year.

3.3 Population Dynamic Parameters

3.3.1 Age Composition

The estimation of population dynamic parameters require a representative sample of the stock. It is important, therefore, to know that during summer krill distribution has its furthest northern extent into oceanic waters along the Peninsula. During this time the stock presents a complete set of developmental stages/age groups (Siegel, 1988). The survey grid considers the distribution pattern and included shelf as well as oceanic waters and covers most of the krill distribution range or even extended beyond this range. The overall length frequency distribution given in Figure 2 was computed by the stratified means and the size of the cluster subareas and thus is representative for the krill stock in the Peninsula area. The data of this length frequency distribution were used to analyse the age class composition and the strength of age classes in the stock. The separation of normal distributions from a distribution mixture was conducted by applying the method described in detail by MacDonald and Pitcher (1979). The basic assumption on normal distribution of size classes for krill age groups had been discussed and analysed by Siegel (1986).

The results with best goodness of fit of observed and expected values for the least number of components are summarized in Table 3 (chi-squared = 11.1, df = 25, P = 0.992). At least five age groups could be distinguished from the distribution mixture. Since age class 0 was only present as recently spawned eggs or hatched nauplii, the smallest group of 26.5 mm size can be regarded as age class 1^+. The largest group of 55.4 mm mean size represented only a small number (3.3%) of individuals and a high degree of overlapping occurred with the preceding group. Since it was not possible to split this group into further components, the largest group is defined as $\geq 5^+$, because this group might include more than one undetected age class - although these would be very rare ones and strongly overlapping in size.

The total number of krill in the survey area (Table 1) and the calculated proportions of the components (Table 3) were used to estimate the number of krill for each of the age classes. The same procedure was undertaken for the data of the 1987/88 summer cruise, which also resulted at least five components. Results on the abundance of each age group are given in Table 4.

In both seasons 1987/88 as well as 1989/90 age group 1^+ was scarce and represented only 1.5% and 2.3% of the krill stock, respectively (Table 4). Age class 2^+ was by far the most abundant group (75.8%) in 1989/90 and showed even higher proportions (78.4%) in summer 1987/88. The results of 1989/90 further showed a steady decline in number of krill for the older age classes. From Table 3, however, it is obvious that in 1987/88 the age group 3^+ with a mean length of 44.7 mm contributed only 4.4% to the stock size which was much less than the proportion of the older 4^+ age group (11.3%).

3.3.2 Mortality

Since data of consecutive years were not available, the static model was taken as an alternative way. This involves examining the age structure of the stock at one period in time. Working with these 'pseudo-cohort' data we can apply the linearized catch curve equation with constant time intervals (Sparre *et al.*, 1989)

$$\ln C_{(t1\,,\,t2)} = g - Zt$$

Figure 4 shows the linearized catch curve analysis for the particular years 1987/88 and 1989/90. As appears from the figure data points from the age group 1^+ and 3^+ (in 1987/88) show a sufficiently large deviation from the straight line to justify the exclusion from the regression analysis (Sparre *et al.*, 1989). The reason is that these age groups can be suspected to be extremely poor year classes most probably due to a failure of spawning in preceding years.

From the 1987/88 age group composition a total mortality of $Z = 0.96$ ($r = -0.999$) was calculated, which corresponds with a survival rate of 38 % from one year to the next. The 1989/90 data resulted a slightly lower mortality of $Z = 0.88$ (survival rate 41%) and a slightly lower correlation coefficient ($r = -0.969$), because the abundance of the age groups varied more and data points deviate more from the theoretical straight line than in 1987/88.

3.3.3 Production

For this analysis production was defined as the sum of growth increments (weight increase of all individuals during a one year period) of all post-larval age groups. The annual

production of a monocyclic species (the population is represented by one age group and the reproductive period is of limited duration) can be calculated by

$$P = B_2 - B_1 + E$$

when the eliminated (E) part of the population is added to the difference in biomass from the starting and the end of the cycle. Elimination is defined as the difference between original and final abundance multiplied by the arithmetic mean of the starting and final individual weight of the respective age group (Winberg, 1971):

$$E = (N_1 - N_2) \cdot 0.5 \cdot (B_1/N_1 + B_2/N_2)$$

The production of a species with a multi-year life-cycle can be obtained by summing up the results for single age groups.

In the present study the results of the age group composition analysis were introduced as parameters in the krill production estimation. Mean size of age classes and their proportion of total abundance are given in Table 3. Table 4 includes the number of individuals and the biomass for each age group. Data indicated by asterisks represent theoretical values derived from the linearized regression in Figure 4, to allow the calculation of the elimination. Elimination and production of biomass within a one year cycle are also given for each age group in Table 4.

Since age class 1^+ was almost completely missing in 1987/88 and 1989/90 seasons, this group was not considered for the total production in either year. Furthermore, the 3^+ age class elimination and production figures were only of theoretical interest in 1987/88, because this group was almost missing in this season. Absolute krill production was 2.522×10^6 tonnes for 1987/88 excluding 3^+ age group, and the relative relationship between production and biomass can be calculated as P/B = 0.94 or 1.1 if the theoretical values for age group 3^+ are considered. In 1989/90 a biomass of 1.159×10^6 tonnes was estimated for the krill stock including age groups older than 1^+. Krill production was calculated as 0.967×10^6 tonnes/year in the survey area, resulting an index of P/B = 0.83.

4. DISCUSSION

The present net sampling surveys as well as the analysis were carried out in a standardized way, which allows a direct comparison of the results. Overall mean biomass in summer ranged from 6.1 g/m² in 1987/88 to less than 4.5 g/m² in 1989/90, but it was at its minimum in winter 1986 (0.55 g/m²). Seasonal variation between summer and winter exceeded a factor of 35 times, i.e. the winter stock was at a minimum level of 2.8% of the maximum observed summer stock. The interannual variability between the krill summer stock was less pronounced, the total number of krill varied by factor 1.6, which means the lowest summer value still reached 61% of the amount observed in a year of maximum abundance. Results from hydroacoustic surveys (summarized by Godlewska and Rakusa-Suszczewski, 1988) indicate differences within the same season (1984/85) of 1.78 to 37.58 tonnes/n miles², which is a factor of at least 21 between spring and late summer. Maximum interannual difference obtained from standardized hydroacoustic surveys was 71.27 tonnes/n miles² (1983/84) and 7.95 tonnes/n miles², which is a factor of 8.9 times.

In general it can be concluded that the seasonal fluctuation in abundance and biomass of the krill stock off the Antarctic Peninsula is several times higher than the interannual variability. The situation might be different in areas like South Georgia, where krill is living close to its northern distribution limits and large-scale ocean atmosphere processes may lead to a dramatic decline in the krill stock of this region from year to year (Bonner *et al.*,1978; Morris and

Priddle, 1984; Heywood *et al.*, 1985; Priddle *et al.*, 1988). The extremely low krill abundance off South Georgia does not necessarily mean a decrease in total abundance in the Atlantic sector, because at the same time abundance may increase further south in the Scotia Sea.

The interannual variation in krill abundance might be explained by oceanographic circumstances besides at least one known biological factor. Recruitment shows a general alternation of good and bad year classes (Siegel, 1989). Data indicated that during the last years several year-classes had been poor or almost missing, e.g. year-class 1983/84 as well as 1986/87 and 1988/89 (present data). This led to variation in the total abundance and biomass of the krill stock. Since mean length-per-age of gravid female indicate that krill becomes mature during 3^+ age group and krill live at least as long as 5^+ age group, several age groups contribute to the spawning success. Therefore a breakdown of the entire spawning stock like for the South Georgia region was never observed.

Information on post-larval krill mortality are rare in the published literature. Estimates obtained by different methods were summarized by Miller and Hampton (1989). In determining natural mortality of krill a critical review of methods and assumptions is required.

Kawakami and Doi (1979) analysed krill mortality by applying Edmondson's method, which considers several parameters like duration of egg development, number of offspring, hatching rates, larval survival and length-at-age (see Miller and Hampton, 1989). For most parameters assumptions had to be made. The natural mortality rate of krill at one year after hatch was estimated as $M = 5.5$. Calculations based on length-at-age data with a two to three year life cycle will, however, strongly affect the results by increasing the mortality rate. Meanwhile studies on longevity suggest a longer life span of krill and 6 to 8 age groups seem to be more realistic, so that the value of Kawakami and Doi (1979) seems to be too high at least for the postlarval age groups (see below).

Brinton and Townsend (1984) tried to avoid the assumption of a constant mortality rate over several years and supported figures for single age groups. They derived estimates for the 1980/81 season of $M = 2.31$ for 1 to 2 year old krill and $M = 0.6$ for 2 to 3 year old animals. The problem arises that Brinton and Townsend (1984) based their calculations on a three year life span of krill. Their age group 1 (20 to 43 mm) included the two age groups 1^+ and 2^+. Age group 2^+ was represented at that time by the poor 1978/79 year class (Witek *et al.*, 1980), which disappeared in the chosen log-transformed length frequency distribution given by these authors. Furthermore the spawning season 1980/81 was extremely successful (Rakusa-Suszczewski, 1984; Hempel, 1985) so that larval age group 0 was abundant above average. From this it has to be assumed the first mortality rate of $M = 2.31$ is too high. Age group 3 (44 to 58 mm) of Brinton and Townsend (1984) also included more than one age group, which would lead to an overestimation of the abundance in this group and consequently underestimate the annual mortality rate.

Siegel (1986) estimated total mortality rates by regression analysis based on age composition data from various years (linearized catch curve method). Results varied from $Z = M = 0.78$ to 1.17. One disadvantage was the fact that calculations were based on data from limited areas. Abundance data from the Bransfield Strait might be problematic, because the concept on spatial succession of krill stages/age groups (Siegel, 1988 and present data) showed that older stages are under-represented inside Bransfield Strait. Other data were available from one transect off Anvers Island which covered the distribution range from juvenile to adult krill and thus included all age groups, but abundance data from a single transect might be arbitrary and not representative for the composition of the whole stock along the Peninsula.

The present analysis circumvents the problem by considering weighted data from the entire survey area. Average mortality rates were obtained by deleting age groups which were

known to be under-represented in the stock. Results varied between Z = 0.88 and 0.96 for data from two different years.

Natural mortality and the growth constant **K** of the von Bertalanffy growth curve are closely related. Priddle *et al.* (1988) estimated the instantaneous rate of natural mortality from growth parameters obtained by Rosenberg *et al.* (1986) for a six to seven year life-span of krill. Under the assumption that **M** is about two times greater than **K**, the values would range from M = 0.8 to 1.35. Siegel (1986) also calculated natural mortality rates from Bertalanffy growth curve parameters which was based on six age groups and resulted M = 0.94 to 0.99. This method is of course highly dependent on the validity of the age determination. The conversion factor 2 for **K** to **M** used by Priddle *et al.* (1988) was taken from clupeoid fish. Beverton and Holt (1959) found values of the ratio **M/K** mainly ranging between 1.5 and 2.5. Siegel (1986) determined the growth parameter **K** for krill by different methods and his results ranged from K = 0.4018 to 0.4728 which would result a factor of M/K = 1.86 to 2.39. Therefore results obtained by this method have to be considered as rough estimates of the natural mortality rate.

Basson and Beddington (1989) estimated krill mortality by different approaches. They considered the length specific aspect of mortality and transformed *Discovery* data to cumulative length frequency distribution and from this modelled curve they derived a relatively low average mortality rate of M = 0.5. This value is almost identical with the growth rate (K = 0.52) estimated from the same data. Basson and Beddington (1989) further tried to estimate krill mortality including length specific aspects of predation with the assumption that predators mainly feed on larger krill. They established a simple length dependent predation curve and estimated average mortality rates for simulated and observed length frequency data. Total mortality was Z = 0.65 for the time before and Z = 0.45 for the period after the reduction of the whale stock. The authors stated, however, that there was no indication of a continued trend for the decrease in krill mortality rate.

Naturally small specimens are exposed to a larger predation than larger ones, simply because small animals have more predators (Sparre *et al.*, 1989). Peters (1955), for example, supported data on length frequencies from whale stomachs and found high abundances of 20 to 30 mm juvenile krill. These size groups represented age class 1^+ and indicate that these length classes are also heavily exploited by whales when they are most abundant in early summer. Furthermore, other carnivorous zooplankton seem to feed heavily on younger krill life stages (Hosie, 1988). In general the simple predation model is a valid alternative method, but the hypothetical curve of length-specific predation rates possibly needs further improvement, because data on krill predation are still insufficient or even missing for many components of the related food web.

In principal longevity is more closely related to mortality than to **K** and $\mathbf{L}_\infty$ (Sparre *et al.*, 1989). Following Alagaraja (1984) the life span of a species is the age at which 99% of a cohort had died and it had been exposed to natural mortality only:

$$M_{1\%} = - \ln (0.01)/Tm \qquad \text{(Tm as longevity in years)}$$

Recently published results on number of krill age groups range from six groups including larval 0 group which means a life span of at least five years (Siegel, 1987) up to six to seven year life span (Rosenberg *et al.*, 1986) or eight age groups and a maximum longevity of seven years (Ettershank, 1984 and 1985). Based on this maximum range krill mortality rate then would be expected as M = 0.92 for a five year life span or M = 0.66 for a seven year life span. This general approach once again demonstrates that some of the results mentioned above deviate considerably from the expected level.

Total production can be calculated from the standing stock over a given time and the growth rate of the species. In the season 1987/88 total abundance, biomass and production were higher than in 1989/90, although two age groups (1^+ and 3^+) were almost missing in this

season instead of only one (1+) in 1989/90. The amount of krill listed in Table 4 support estimates of instantaneous biomass and abundance. Since the area off the Antarctic Peninsula is not static but highly dynamic, the potential or effective total biomass within one season will be higher than reflected by the present results.

Several basic parameters are available in the literature to come at least to a rough idea of the krill fluxes through the area. It is known that krill occurrence is extremely low in the entire area during the whole winter season and that the increase in abundance and biomass is commencing not before late October, while the stock declines rapidly during March (Stepnik, 1982; Siegel, 1988). This gives a maximum time span of 150 days while krill is immigrating in considerable numbers to maintain the high level of the summer stock. The main currents run from the southwest to the northeast. Current speed measurements for the upper 400 m water column show a maximum range between 6.5 and 32 cm/sec (Stein, 1979; Wittstock and Zenk, 1983; Nowlin and Zenk, 1988). An average velocity of 20 cm/sec for the near-surface layer obtained from tracking the drift of FGGE buoys seems to be more realistic to follow the drift of krill, because this layer is more strongly influenced by wind than the deeper layers where current meter measurements had been carried out.

The survey area extended over approximately 650 nautical miles. Let us assume that krill is continually drifting in from the southwest and transported with the mean current speed and no retention occurs by meanders or eddies. Under these circumstances a minimum time interval of 70 days is necessary for a complete exchange of the water masses and the krill standing stock along the Peninsula. This means that during an entire summer season the krill stock could be exchanged about two times at a maximum. The instantaneous biomass was estimated as 1.65×10^6 tonnes (for all age groups) in 1987/88 and 1.16×10^6 tonnes in 1989/90. The biomass including the krill production would amount to 2.52×10^6 tonnes and 2.13×10^6 tonnes, respectively. Considering an exchange rate of 2.0 a maximum effective total stock size of 5.0×10^6 and 4.3×10^6 tonnes, respectively, would have passed the survey area during the seasons under consideration. Taking into account the meandering of the current system and the occurrence of eddies with accumulating and retention of krill this is included in the estimation of the instantaneous biomass - then the exchange rate is obviously too high and the potential or effective total biomass and production represent the extreme upper limit of the krill stock passing the survey area within one season.

Several attempts had been made to estimate the ratio of production to biomass (P/B) and were discussed by Miller and Hampton (1989). Allen (1971) was the first to calculate a ratio of P/B = 1.8 to 2.3 and stated the lower end of the range being more likely. Yamanaka (1983) estimated a ratio of P/B = 1.19, which was at least partly based on the assumptions made by Kawakami and Doi (1979) for the calculation of the natural mortality rate as described above. Miller *et al.* (1985) obtained different values ranging from P/B = 1.19 to 2.77. Siegel (1986) calculated production from age group composition analysis and found smaller P/B ratios ranging from 0.8 to 1.1. Almost identical results (P/B = 0.83 to 0.94) were obtained in the present study applying the same method for different and more comprehensive survey data sets. A more theoretical value of 1.1 was derived from the same analysis by substituting some data of strongly under-represented age groups with expected abundances.

The P/B estimations of Allen (1971) were carried out for various growth and mortality models and showed that longevity and mortality rates as well as growth rates are fundamentally important to obtain reasonable estimates of the P/B ratio.

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Table 1: Stratified mean and total abundance of krill for different years and site clusters (cluster numbers of earlier years refer to results given by Siegel (1987 and 1989)).

Year/Cluster	Str. Mean ($n \times 1\,000\ m^{-3}$)	Approx. Cluster Size ($n\ miles^2$)	Absoulte Abundance ($n \times 10^9$)
85/1	225.30	1 300	205
85/2	165.59	30 000	3 450
85/3	6.25	31 000	141
86/1	9.51	7 800	51
86/2	5.55	19 400	74
87/1	93.71	2 100	140
87/2	118.99	30 000	2 553
87/3	49.76	49 000	1 735
90/1	217.13	6 900	1 021
90/2	77.46	9 900	527
90/3	36.51	40 000	1 028
90/4	9.84	20 000	140

Table 2: Statistical table of krill biomass calculations for different surveys in the region of the Antarctic Peninsula (the stratified mean is calculated for the area of krill occurrence).

	February 1982	March 1985	May/June 1986	Nov/Dec 1987	Dec/Jan 1989/90
Number of Stations	21	59	59	74	69
Strat. Mean (g/m^2)	4.90	4.23	0.55	6.13	4.50
90% Confidence Limits (%)	± 79	± 102	± 85	± 108	± 60
Tonnes/n $miles^2$	16.8	14.5	1.9	21.0	15.43
Size of Survey Area ($n\ miles^2$)	14 300	97 200	78 940	88 230	93 800
Size of Krill Area (%)		64	35	89	80
Total Biomass (10^6 tonnes)		0.905	0.053	1.651	1.160

Table 3: Results of distribution mixture analysis for age group composition of the krill stock during summer 1987/88 and 1989/90.

	Age Groups 1+	2+	3+	4+	5+
1987/88					
Proportion %	1.5	78.4	4.4	11.3	4.3
Mean Length	15.4	29.6	44.7	51.6	55.3
σ	1.4	3.7	2.5	2.6	1.1
1989/90					
Proportion %	2.34	51.20	27.97	15.18	3.31
Mean Length	26.5	35.9	44.3	50.8	55.4
σ	1.3	3.3	2.7	2.8	1.9

Table 4: Estimated total abundance of krill age groups, biomass and production from 1987/88 and 1989/90 survey data (* indicate theoretical values obtained from regression analysis in Figure 11.

		Season			
		1987/88		1989/90	
ln N	1^+	24.92	(29.84)*	24.88	(29.02)*
	2^+	28.87		27.96	
	3^+	23.42	(27.92)*	27.36	
	4^+	26.94		26.75	
	$\geq 5^+$	25.97		25.22	
N x 10^9	1^+	66.4	(9 106)*	63.7	(4 011)*
	2^+	3472.1		1391.8	
	3^+	194.9	(1 362)*	760.4	
	4^+	500.5		412.6	
	$\geq 5^+$	190.4		90.1	
W (10^3tonnes)	1^+	1.4	(192)	5.3	(335)
	2^+	543		339	
	3^+	109	(764)	384	
	4^+	439		336	
	$\geq 5^+$	209		100	
E (10^3tonnes/year)					
	2^+	500		429	
	3^+	(757)		236	
	4^+	619		229	
	$\geq 5^+$	306		308	
P (10^3tonnes/year)					
	2^+	851		434	
	3^+	(978)		281	
	4^+	293		181	
	$\geq 5^+$	77		71	
$B = \Sigma W_{(2-5)}$ (10^3tonnes) (instantaneous biomass)		1300	(1 956)	1159	
$\Sigma P_{(2-5)}$ (10^3tonnes)		1221	(2199)	967	
$P+B_{(1-5)}$ (10^3tonnes)		2522		2131	
P/B		0.94	(1.1)	0.83	

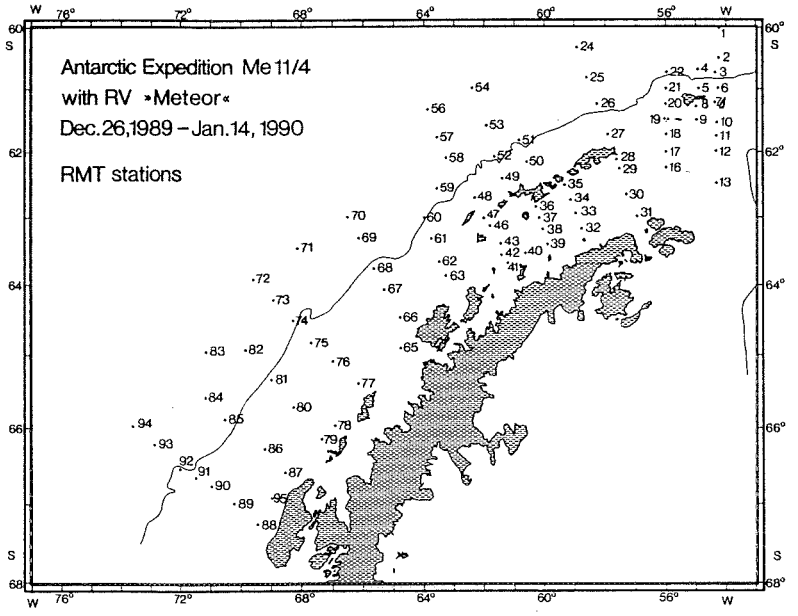


Figure 1: Station grid for RMT net sampling survey during *Meteor* cruise ME11/4, 26 December 1989 to 13 January 1990.

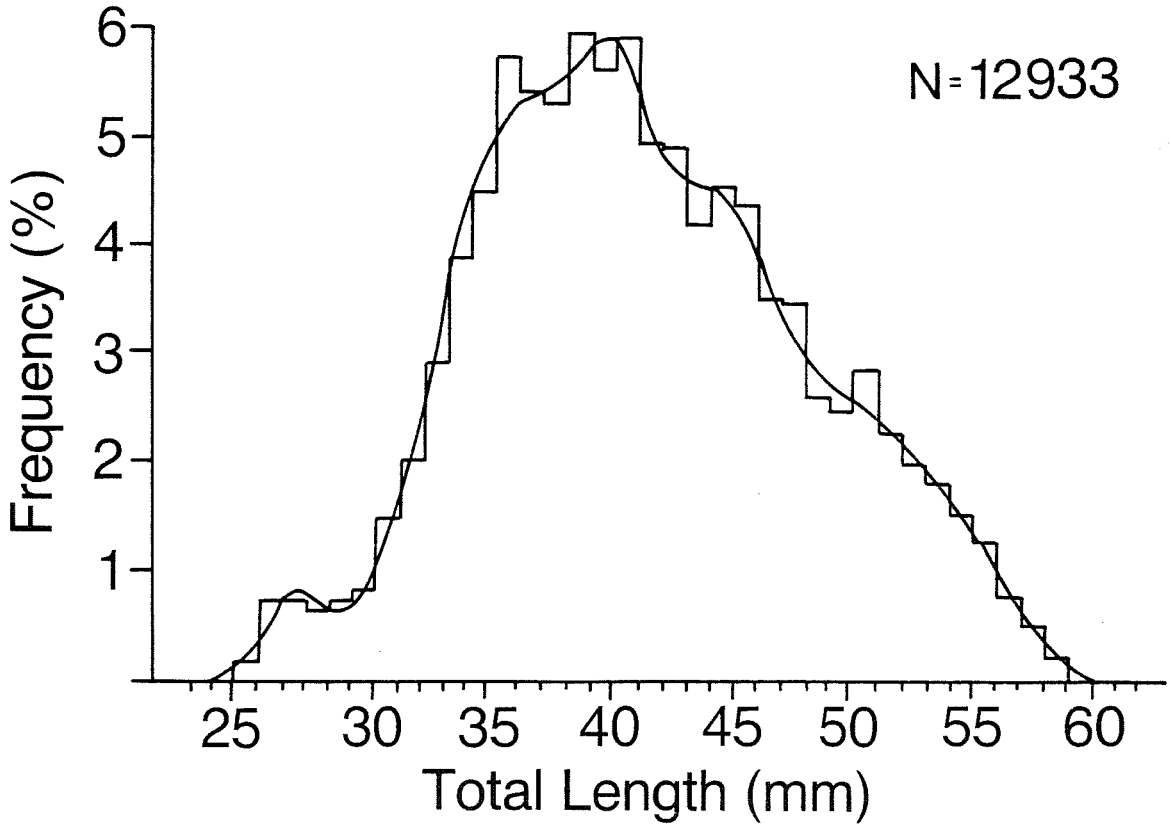


Figure 2: Composite krill length frequency distribution for the survey area in 1989/90 season and fitted line from distribution mixture analysis (see text).

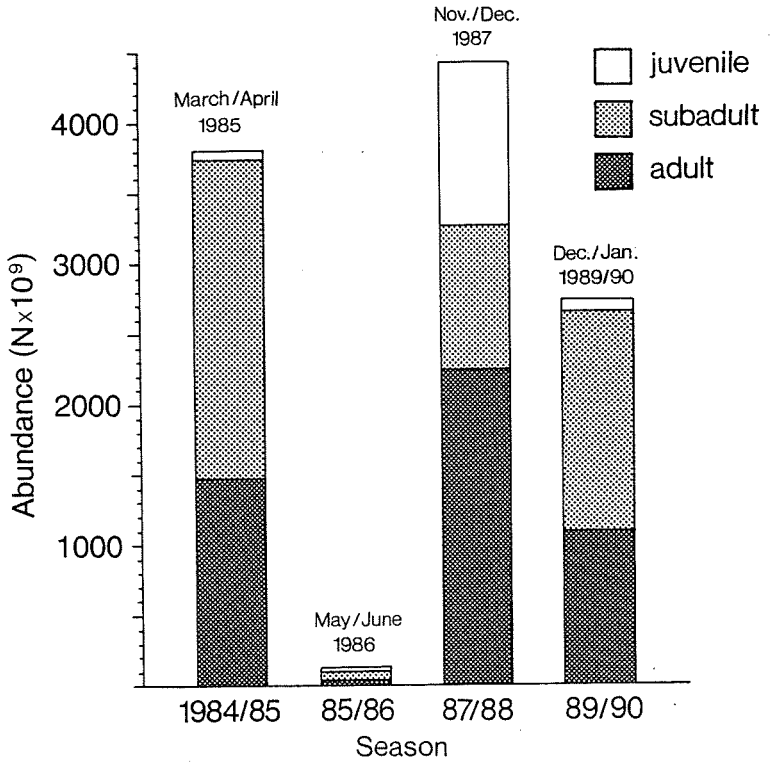
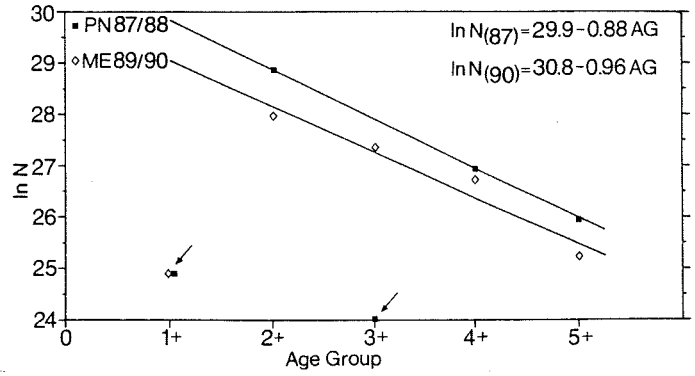


Figure 3: Absolute krill abundance in the Antarctic Peninsula survey area for different years.



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CHARACTERISTICS OF KRILL SWARMS FROM PRYDZ BAY

D.J. Agnew* and I.R. Higginbottom**

Abstract

The CCAMLR.AUS dataset available to the Subgroup on Survey Design was derived from a survey of Prydz Bay, Antarctica, in December 1990. Swarm length, depth, thickness, Mean Volume Backscattering Strength (MVBS) and interswarm length were calculated for swarms of euphausiids encountered along a 78 km transect over the continental shelf close to the CEMP study site at Magnetic Island. The euphausiid species was probably *Euphausia crystallorophias*. An increase in swarm length was seen with increasing distance from the coast.

Résumé

Le jeu de données CCAMLR.AUS dont disposait le sous-groupe sur la conception des campagnes d'évaluation était dérivé d'une campagne d'évaluation de la baie Prydz, en Antarctique, en décembre 1990. Pour les essaims d'euphausiacés rencontrés le long d'un transect de 78 km sur le plateau continental à proximité du site d'étude du CEMP à l'île Magnetic, on a calculé la longueur, la profondeur, l'épaisseur, l'intensité moyenne de rétrodiffusion par volume (MVBS), ainsi que la distance entre les essaims. Les euphausiacés concernés appartenaient vraisemblablement à l'espèce *Euphausia crystallorophias*. Une augmentation de la longueur des essaims a été remarquée à mesure que l'on s'éloigne de la côte.

Резюме

Набор данных "CCAMLR. AUS", имевшийся у Подгруппы по схеме съемки, был получен в результате съемки в заливе Прюдз, Антарктика, в декабре 1990 г. Были вычислены длина, глубина и плотность скопления, средняя сила объема обратного акустического рассеивания (MVBS) и расстояние между скоплениями эвфаузиид, обнаруженными вдоль 78-километрового разреза над континентальным шельфом вблизи участка исследования по Программе CEMP на острове Магнетик. Имеется предположение, что встреченные эвфаузииды относились к виду *Euphausia crystallorophias*. По мере удаления от побережья наблюдалось увеличение длины скоплений.

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Resumen

El fichero CCAMLR.AUS utilizado por el "Subgrupo para el Diseño de Prospecciones" contenía los datos de la prospección realizada en la bahía de Prydz, Antártida, en diciembre de 1990. Se calcularon el tamaño, profundidad y espesor de los cardúmenes, la reverberación media volúmetrica (MVBS) y la distancia entre cardúmenes, de los cardúmenes de eufáusidos encontrados a lo largo de un transecto de 78 km, efectuado en la plataforma continental cercana a la localidad del CEMP de la isla Magnética. La especie de euphausido era posiblemente *Euhausia crystallorophias*. Se constató un aumento del tamaño de los cardúmenes a medida que aumentaba su distancia de la costa.

1. INTRODUCTION

This paper explains the derivation of the CCAMLR.AUS dataset available to the Subgroup on Survey Design. The subgroup was set up by the CCAMLR Working Group on Krill (WG-Krill) and was directed "to establish:

(i) a set of initial parameters pertaining to the distribution of krill;

(ii) a set of options for the design of surveys; and

(iii) a set of methodologies for the determination of variances and other data required from these surveys."

The CCAMLR.AUS dataset is intended to complement similar data from the South African and FRG FIBEX cruises at 20°E and 55°W (Miller and Hampton, 1989a). This paper describes the methods used to produce the dataset and presents an initial analysis of the swarm characteristics it describes.

The dataset used in this analysis is relatively short (78 km transect length). However, it is believed to be representative of the swarm characteristics seen over the continental shelf in Prydz Bay in December 1990. The placement of the transect, close to a designated predator parameter monitoring site at Magnetic Island (CCAMLR, 1991), has direct relevance to the area that would have to be surveyed during the Ecosystem Monitoring Program, defined as within a radius of 100 km of a monitoring site (SC-CAMLR-IX, Annex 6, paragraph 101).

2. METHODS

Data were analysed from a single transect undertaken by Australian Antarctic Division using the RV *Aurora Australis* over the continental shelf in Prydz Bay, Antarctica. The transect was run due north from Davis Station on 18 December 1990 along 74°30'E longitude (Figure 1). Conditions were calm and ice free from 1200 hours until 2300 hours GMT when the ship encountered a band of pack-ice just before reaching the edge of the continental shelf.

Data were collected with a Simrad EK500 echosounder at a frequency of 120 kHz using a hull mounted transducer. The echosounder was fully calibrated prior to the survey. Data for single pings were stored as Mean Volume Backscattering Strength (MVBS) integrated in 25 m depth intervals over a 225 m range. The raw data were submitted to CCAMLR for the use of the Subgroup on Survey Design.

Unfortunately, no ground truthing was performed during this time. It is most likely however, that the swarms this far into Prydz Bay were predominantly *E. crystallorophias*. Surveys carried out in February showed that most of the euphausiids over the shelf (south of 67°S) were *E. crystallorophias* although there was some *E. superba* in the samples (S. Nicol and G. Hosie, pers. com.).

Analysis was performed at the CCAMLR Secretariat using a VAX minicomputer. The first depth layer, 0 to 25 m, was subject to a great deal of noise and was excluded from the analysis. Pings were designated as krill bearing if a single depth range had an MVBS value exceeding a threshold of -95 dB. Noisy pings were identified by having a krill thickness of greater than 125 m, and a characteristic pattern of increasing dB with depth (because of the Time Varied Gain correction), and were excluded from the analysis.

Once pings containing krill had been identified the characteristics of swarms were determined. Two key variables used were:

(i) the Intercepted Swarm Length (ISL), defined as the distance between the first ping encountering a swarm and the first ping to lose the swarm; and

(ii) the Between Swarm Distance (BSD), the distance from the last ping encounter with the swarm and the first encounter with the next swarm.

The latter is particularly important in determining the end or the continuation of a swarm if the ping sequence of a swarm has breaks in it where no krill are present, either because of breaks in the swarm structure or because of noise.

In the analysis the minimum BSD was set to 10 m and the minimum ISL to 2 m, to ensure that the shortest 'swarms', single ping encounters, were included, although these may not be considered true swarms in the classification of Miller and Hampton (1989b).

The time of each ping was available in the original data file, and distance was calculated using mean speeds derived from the ship's positional data. The ping data was analysed in five sections, each with slightly different ship speeds. Integrated MVBS* and mean swarm thickness were also calculated for each swarm, although swarm thickness calculated from these data will lack accuracy due to the EK500 integration interval of 25 m.

For the purposes of comparison, a biomass index was calculated using an assumed mean *E. crystallorophias* length of 27.5 mm, weight 200 mg (G. Hosie, pers. comm.), and the equations

$$TS = -127.45 + 34.85 \log10 \text{ (length in mm)}$$

(TS relationship for *E. superba* given by SC-CAMLR (1991), at 120kHz, extrapolated for *E. crystallorophias*).

$$\text{swarm radius (m)} = \lambda\,(2/\pi) \qquad \text{(Butterworth, 1988)}$$

$$\text{mean number density (individuals.m}^{-3}) \quad \sigma_V = 10^{0.1(s_v - TS)}$$

---

* Calculated using $MVBS_{swarm} = 10 \log_{10}\left(\frac{\sum_{i=1}^{n} 10^{0.1 svi}}{n}\right)$,

where **n** = number of ping/depth intervals in the swarm, **svi** is the MVBS for a single ping depth interval.

swarm biomass index (kg) = $p.\ \lambda^2.\ (4/\pi).w.\sigma_v$

where λ = intercepted swarm length (m)
p = swarm thickness (m)
TS = target strength
s_v = observed MVBS
w = weight (kg)

3. RESULTS

The data sequence started at 1558 hours on 18 December and continued until 2213 hours when the data became very noisy as the ship started encountering ice. The ping rate was about one every second until 1808 hours (approximately 30 km from the start) when it dropped to one every six seconds. This leads to a somewhat distorted dataset, with minimum swarm length of about 18 m (1 ping) after 1808 hours compared with about 3.5 m before this time. Figures 2a and b show this clearly. The change in ping rate also effects the calculated BSD, which has a minimum value corresponding to 2 pings (about 36 m) after 1808 hours.

Intercepted swarm length, observed between swarm distance, swarm thickness, integrated MVBS and swarm biomass index are shown in Figures 3a to 3e. Length, BSD and biomass are approximately log normally distributed. The bars marked '*' in Figures 2a and b are distortions introduced by the decreased ping rate after 1800 hours discussed above, and the true modes lie at 3-3.5 and 4.4-4.6 for ln(length) and ln(BSD) respectively. Basic statistics for these parameters are given in Table 1. The mean swarm length of 24 m and BSD of 83 m indicate that the pattern of krill aggregations was one of many small swarms with a few much larger ones (more than 50% of total biomass index is contributed by a single large swarm).

There were no significant correlations between any of the independent swarm parameters (length, MVBS, depth, thickness or mean between swarm distance). Plots of swarm length and swarm biomass index with distance, however, show that maximum length and biomass both increased with distance from the shore; ln(swarm length) is positively correlated with distance (correlation coefficient = 0.472 n = 477). This effect is influenced by the change in ping rate after 30 km, but Figure 4 clearly shows that mean swarm biomass index started increasing before the 30 km point.

4. DISCUSSION

The analysis was hampered by the change in ping rate after 1808 hours (north of 67°51'38"S) and the loss of resolution that this resulted in. Resolution is also lost by the pre-integrations into 25 m depth intervals which results in the artificial lower limit of swarm thickness. These problems may be overcome in future but the difficulties encountered in interpreting these data highlights the importance of recording acoustic data with the highest resolution available. The loss of data on krill swarms shallower than 25 m is also a problem, particularly as many of the swarms in this transect were encountered between 25 and 50 m depth, as is the uncertainty about species composition and biological characteristics (length and weight).

Even though the distance of this transect is relatively small, there is a significant change in swarm length and estimated swarm biomass with distance from the shore, despite the high variances associated with the data (Anova result, $P < 0.001$). These are real changes in the quantity of prey available to predators within 100 km radius of a predator monitoring site at Magnetic Island, even though they relate to *E. crystallorophias* rather than *E. superba*. The fact that these characteristics change relatively fast within the ranges identified by CEMP as being important for prey surveys around predator monitoring sites has important consequences for survey design.

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Table 1. Krill swarm parameters. Intercepted length, between swarm distance and biomass have been log transformed; their corresponding exponential values are given in parentheses (n = 475).

	ln(Length) (m)	ln(BSD) (m)	MVBS (dB)	Depth (m)	Thickness (m)	ln(Biomass) (kg)
Min	1.194 (3.3)	2.754 (15.7)	-94.9	25	25	-6.956 (0.001)
Max	6.465 (642.3)	7.154 (1279.2)	-56.3	200	62.5	12.354 (232 tonnes)
Mean	3.184 (24.1)	4.417 (82.8)	-77.6 (0.171[1])	57.684	28.104	1.263 (3.54)
St Dev.	0.983	0.861	8.723 (0.034[1])	38.069	6.909	3.584

[1] Mean and standard deviation of $\log_{10}$(0.01 Sv)

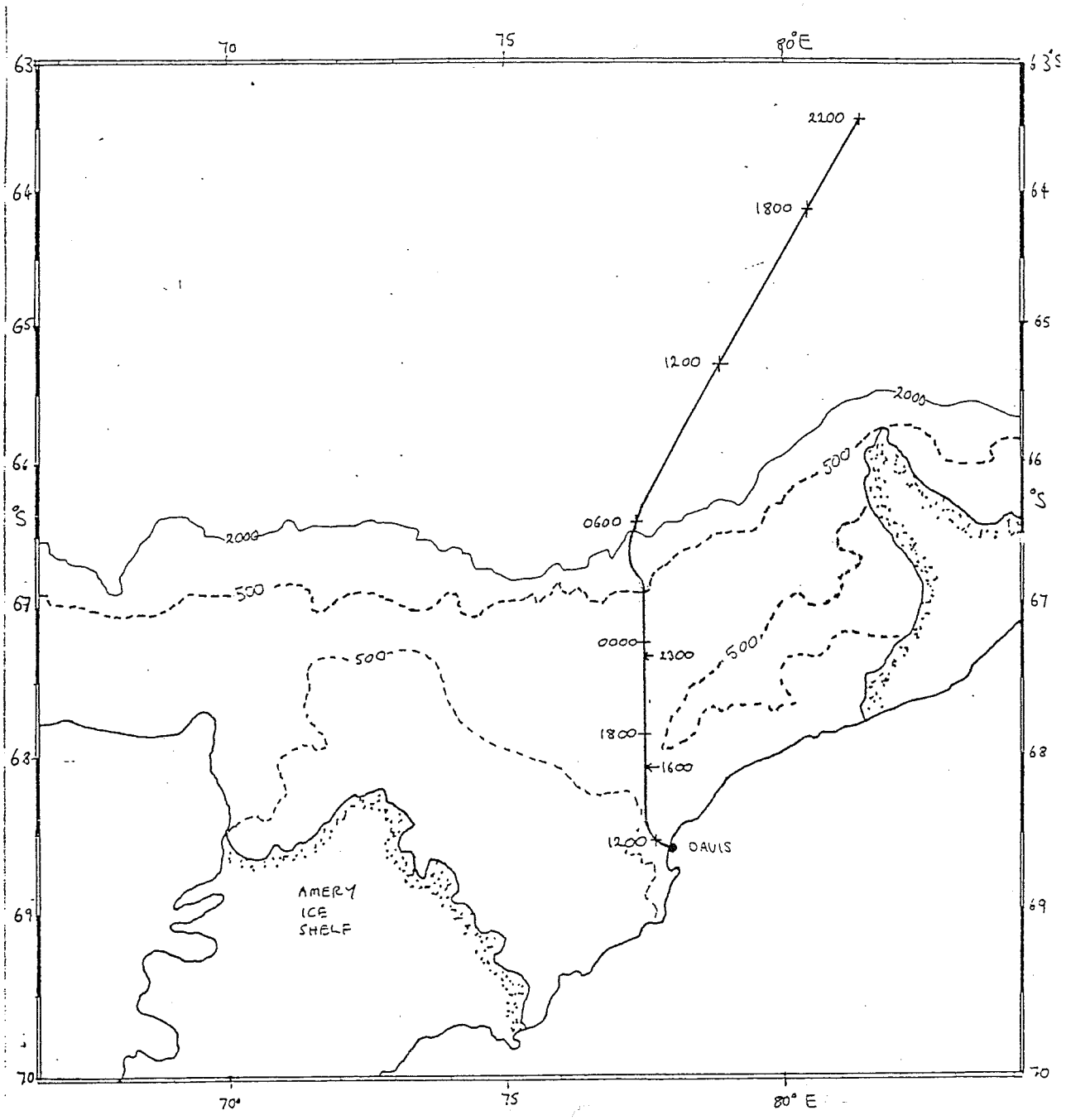


Figure 1: RV *Aurora Australis* cruise track 18 to 19 December 1990.

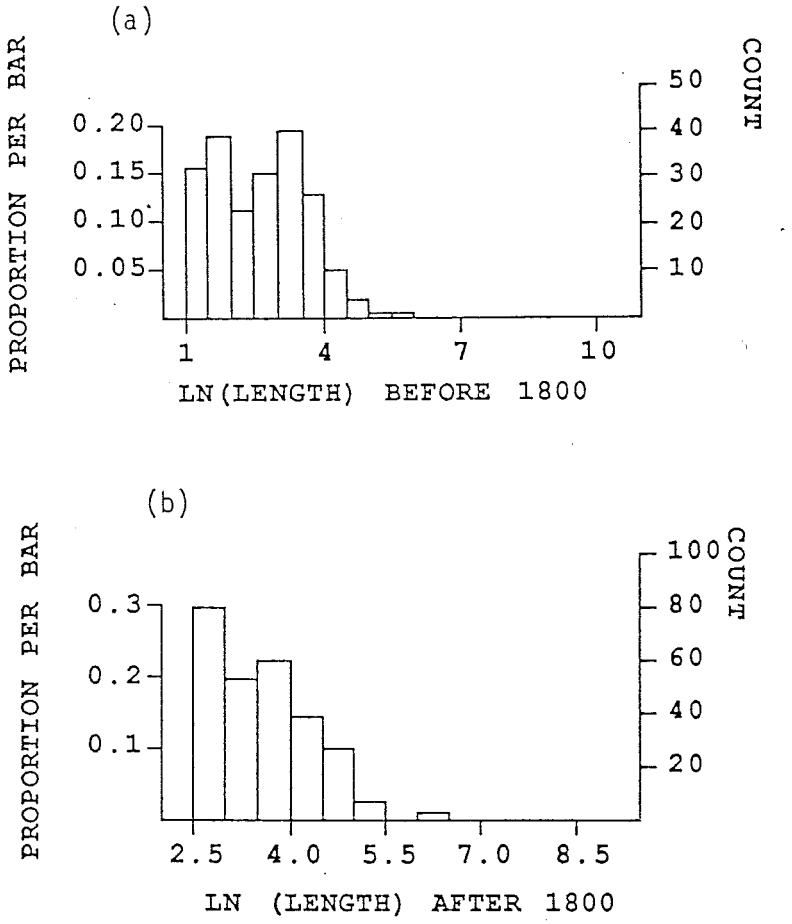


Figure 2: Log transformed intercepted swarm length before (a) and after (b) the change in ping rate at 1808 hours GMT.

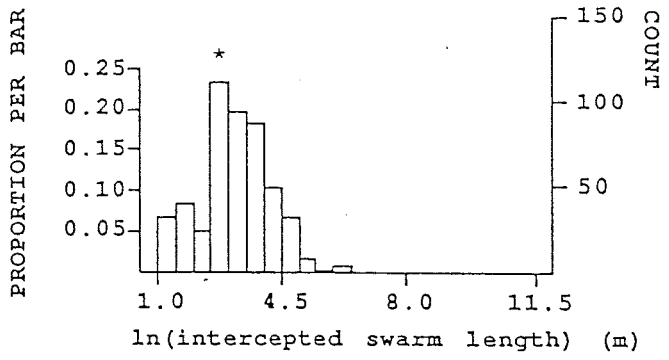


Figure 3(a): Log transformed swarm length.

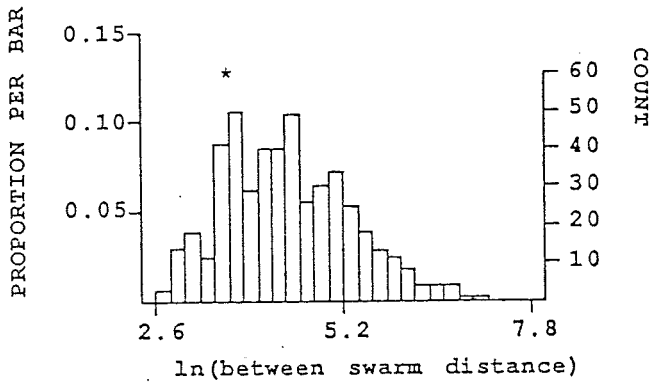


Figure 3(b): Log transformed between swarm distance.

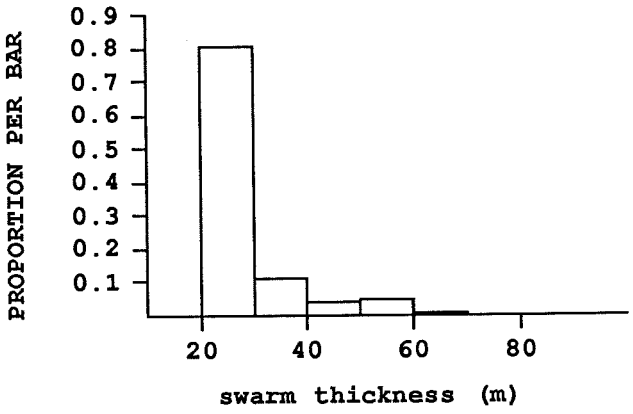


Figure 3(c): Swarm thickness.

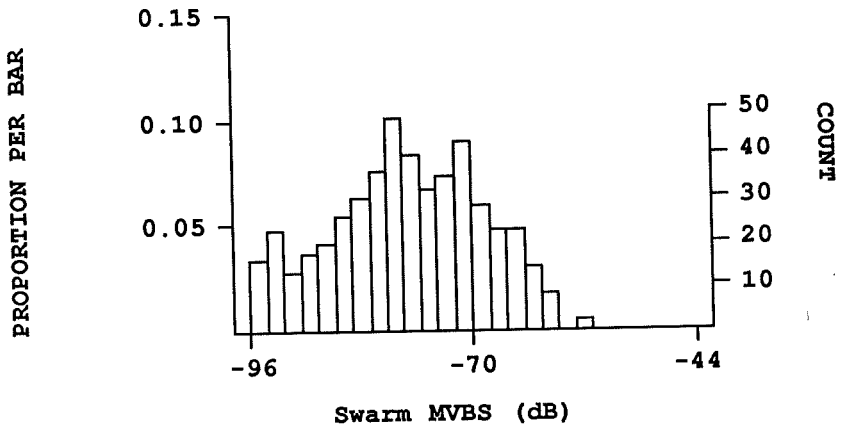


Figure 3(d): Swarm MVBS.

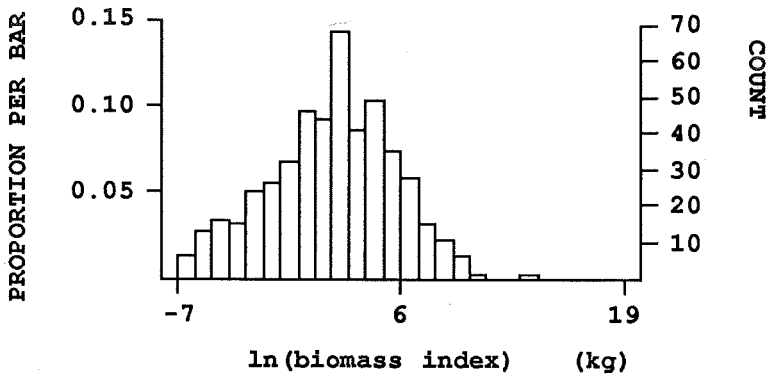


Figure 3(e): Log transformed swarm biomass index.

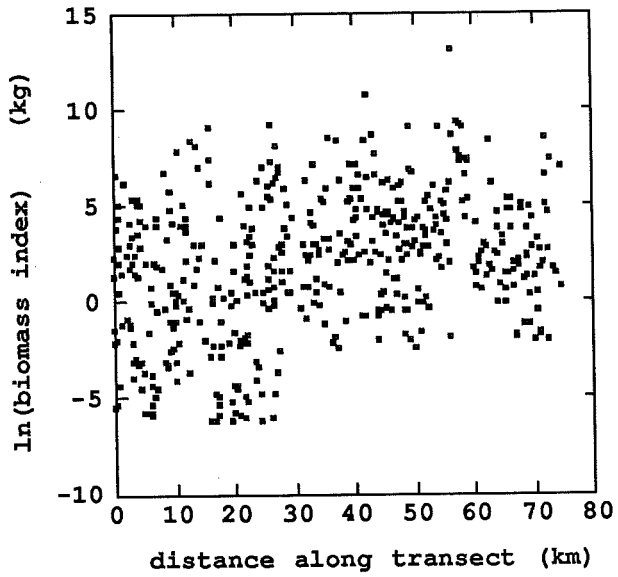
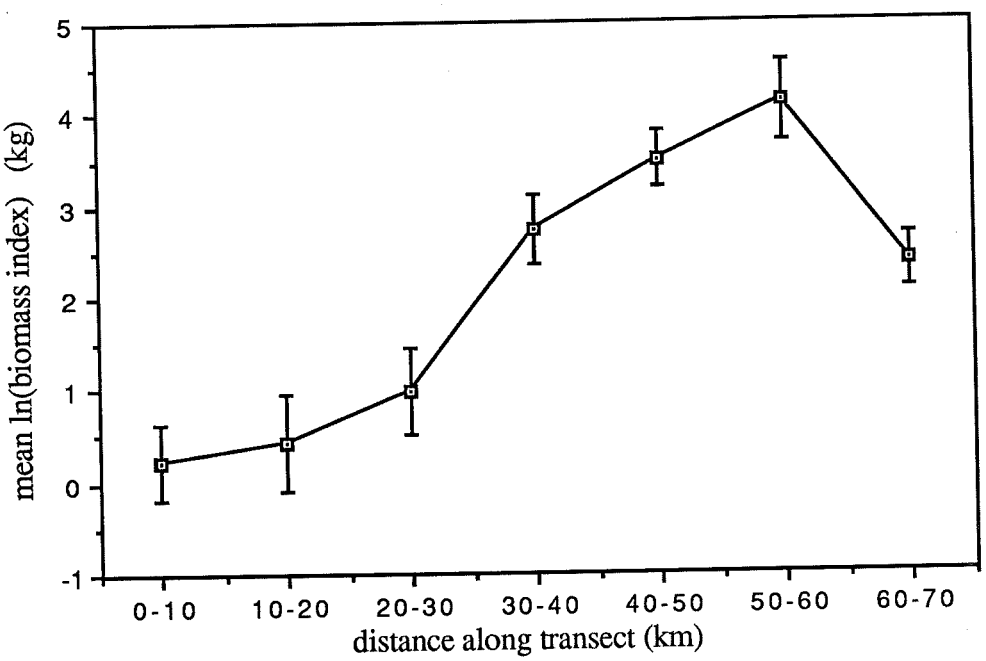


Figure 4(a): Change in swarm biomass with distance.



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SOME COMMENTS ON THE PROCEDURE FOR TESTING ESTIMATORS OF KRILL ABUNDANCE WHICH UTILISE SURVEY DATA

D.S. Butterworth*, D.L. Borchers* and D.G.M. Miller**

Abstract

Since krill distributional data do show evidence of spatial correlation, estimators of abundance which attempt to model such effects (such as those based on Kriging techniques) may provide improved abundance estimates from survey data. However, computer simulation studies are first required to test whether such estimators, and alternative possible survey designs, are indeed likely to provide improved performance in practice. Such studies require a simple method for computer generation of krill distribution patterns, which are compatible with existing information on the distributions from surveys. "Two-level" models of krill distribution are considered. These achieve overall spatial correlation by placing krill swarms at random within larger aggregation features termed concentrations; these concentrations are then located at random within the survey area. These "two-level" models provide an encouraging improvement in fits to the distribution of inter-swarm distances observed on the 1981 FIBEX survey by MV *SA Agulhas*. However, evidence of model misspecification remains. Further work is needed before such models can be used as the basis for the simulation studies required - some suggestions are made in this regard.

Résumé

Vu que les données sur la distribution mettent bien en évidence une corrélation spatiale, les paramètres d'estimation d'abondance tentant de modéliser ces effets (tels que ceux fondés sur les techniques de Kriging) pourraient fournir de meilleures estimations d'abondance à partir des données des campagnes d'évaluation. Cependant, en premier lieu, des études par simulation informatisée sont nécessaires pour vérifier si ces paramètres d'estimation, et d'autres modèles de campagne possibles, sont bien susceptibles, sur le plan pratique, d'offrir de meilleurs résultats. Ces études nécessitent une méthode simple de production informatisée de schémas de répartition du krill qui soient compatibles avec les informations actuelles, fournies par les campagnes d'évaluation, sur les répartitions. Des modèles "à deux niveaux" de répartition du krill sont considérés. Ils réalisent la corrélation spatiale globale en plaçant les essaims de krill au hasard, à l'intérieur de grands rassemblements de krill nommés concentrations; ces concentrations sont ensuite situées au hasard dans l'aire étudiée. Ces modèles "à deux niveaux" sont prometteurs quant à une amélioration des ajustements à la distribution des distances entre les essaims observées par la campagne FIBEX 1981 du MV *SA Agulhas*. Quelques traces d'erreurs de spécification du modèle subsistent toutefois. Avant de pouvoir utiliser ces modèles comme bases des études par simulation, il importe de poursuivre les travaux - quelques suggestions sont avancées à ce sujet.

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Резюме

В связи с тем, что данные по распределению криля действительно указывают на пространственную взаимосвязь, показатели численности (например основанные на методе Крайга), направленные на моделирование подобных эффектов могут представить более точные оценки численности на основе съемочных данных. Тем не менее, первой целью исследований по компьютерному моделированию является проверка вероятности действительного улучшения эффективности на практике подобных показателей и возможных альтернативных схем съемок. Такие исследования требуют внедрения простого метода компьютерного производства моделей распределения криля, которые совместимы с существующими съемочными данными по распределению. Рассматриваются "двухступенчатые" модели распределения криля. С помощью этих моделей можно получить общее пространственное соотношение, произвольно поместив скопления криля в пределах бльших агрегаций, называемых концентрациями; затем эти концентрации произвольно помещаются в пределах района съемки. Использование этих "двухступенчатых" моделей обеспечвает получение более точных подгонок к распределению расстояний между скоплениями, зарегистрированными в ходе съемки FIBEX, проведенной судном *SA Agulhas* в 1981 г. Тем не менее, имеется доказательство неправильного построения модели. Прежде чем эти модели могут быть использованы в качестве основы для требуемых исследований по моделированию, необходимо продолжить работу в этой области - в этой связи в данном труде приводится несколько предложений.

Resumen

Debido a que los datos de distribución del krill presentan evidencia de una correlación espacial, los estimadores de abundancia que intentan modelar tales efectos (como aquellos basados en las técnicas Kriging) podrían proporcionar estimaciones de abundancia mejoradas utilizando los datos de prospección. Sin embargo, se necesita primero hacer estudios de simulación computerizada para investigar si en efecto, tales estimadores, y posibles diseños alternativos de prospección, podrían proporcionar un mejor rendimiento. Tales estudios requieren un método simple para generar patrones de distribución de krill por medios computerizados, que sean compatibles con la información actual obtenida de las prospecciones. En este documento se consideran modelos de distribución de krill de "dos niveles". Estos logran una correlación espacial global mediante la posición aleatoria de las agrupaciones de krill dentro de mayores agregaciones denominadas concentraciones; estas concentraciones a su vez, son localizadas aleatoriamente dentro del área de prospección. Estos modelos de "dos niveles" proporcionan un alentador avance en los ajustes de la distribución de las distancias entre agregaciones observadas durante la

prospección FIBEX de 1981, realizada por el buque *SA Agulhas*. Sin embargo, aún existe evidencia de errores de especificación en los modelos. Se necesita llevar a cabo más investigación antes de que se puedan utilizar tales modelos como la base para los estudios de simulación requeridos - se plantean algunas sugerencias a este respecto.

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1. INTRODUCTION

A "straightforward" approach to abundance estimation from surveys of marine resources is to place a set of transects at random in the area of interest. The density estimate from each transect is then treated as an independent estimate of the density in the area, and the mean and associated standard error of the set of estimates from each transect (weighted appropriately in relation to transect length if necessary) immediately provide an estimate of overall abundance and of its variance. For the best possible precision (given a constraint on the survey effort available), the area should be pre-stratified on the basis of *a priori* expectations of density variations, with effort allocated so as to minimise the anticipated variance. Further, within any stratum, the directions of the transects should be chosen to lie parallel to any *a priori* expectation of density trend. Substitution of a fully random survey design by a systematic one would be a satisfactory procedure in most circumstances.

An objection that has been raised to this approach is that it is discarding the information on the spatial variation of density along a transect which is obtained during the survey. In the case of krill, it has been suggested (Foote and Stefansson, 1991) that estimation procedures such as Kriging, which model spatial correlation effects, could be used to produce improved estimates of abundance and its variance by making use of these within-transect data.

Incorporating spatial correlation in the estimation procedure requires that the values of additional parameters be estimated from the data. If krill swarms are in fact located at random within the stratum concerned, such an exercise can lead only to a reduction in the precision of the abundance estimate eventually obtained. Accordingly, the first question which needs to be addressed is whether there are data that do indeed show that krill swarm distributions exhibit spatial correlation. An answer is provided by the analysis by Miller and Hampton (1989a) of the distribution patterns of the swarms encountered during the 1981 FIBEX survey of an area of the south-west Indian Ocean by MV *SA Agulhas*. This demonstrates that that distribution was definitely non-random at the scale of the whole area surveyed, although there were indications of randomness at a smaller scale.

Accepting therefore that krill distributions do exhibit spatial correlation, the next question is whether estimators which attempt to model such effects will provide improved estimates of overall abundance from survey data than those, such as the "straightforward" approach above, which do not. This may also have implications for survey design, as different designs may provide improved estimates if a technique such as Kriging, for example, is used for estimation purposes. This question cannot be answered immediately, because the benefits of basing estimation on a model which better reflects the real situation, may nevertheless still be outweighed by the costs arising from the estimation of additional model parameters which may increase the variance of the abundance estimate.

The answer is therefore case dependent, and can only be obtained by computer simulation studies. Essentially these involve four steps:

(i) setting up a "real" krill distribution on the computer;

(ii) carrying out a "survey" of this distribution, to provide data of the kind which would be obtained from an actual survey;

(iii) analysing the data provided using the estimation procedure proposed, to obtain an abundance estimate; and

(iv) comparing that abundance estimate with the abundance of the "real" krill distribution (which is known to the computer), to ascertain how well the estimation procedure has performed.

Since stochastic factors are involved in these steps (both in generating the distribution, and in the sampling process effected by the survey), the procedure has to be repeated many times on the computer to ascertain the statistical properties (such as bias and variance) of the combination of survey design and estimation procedure proposed.

The "real" distribution set up in step (i) should reflect the known characteristics of krill distributions as closely as possible. Generating such distributions on the computer is simple if they are required to be random representations of an underlying average density, which is either constant or follows a given trend in space. However, once spatial correlation effects need to be introduced, this exercise becomes distinctly non-trivial. Ideally one would wish to generate the simulated distributions from empirical observations, but the essential difficulty is that the data are collected along one-dimensional transects, whereas it is a two-dimensional structure which has to be generated. Techniques are available which can generate spatially correlated data using the correlation model underlying the Kriging technique [decomposition of covariance matrix, see Fishman (1973)]. However, a possible objection to using these is that the true potential of a Kriging-based estimation procedure may be inflated if the "real" distributions are generated in this way, because this approach cannot make allowance for model misspecification (i.e., differences between the process actually governing the "real" distribution, and that assumed for the purposes of estimation from the data collected).

One simple approach to generating spatially correlated data is to use a two stage process. Thus, the krill distribution is envisaged to be comprised of larger scale concentrations distributed at random through the area; then, within each concentration, the krill swarms themselves are distributed at random. The simulated krill distributions generated by Butterworth (1989) and Mangel (1989) in their studies of the potential utility of krill fishery CPUE data to index abundance had this two-level structure. Generation of such data again becomes straightforward, because of the random nature of the placement of concentration centres and swarms within concentrations. However, viewed overall, the distribution of the krill swarms generated will exhibit positive spatial correlation.

This is an attractive basis upon which to proceed, but the final question which remains is whether the spatial correlation patterns exhibited by actual krill distributions are compatible with a simple two-level structure. This paper makes an initial attempt to address this question but reanalysing the data considered by Miller and Hampton (1989a) using simple two-level models.

2. DATA AND METHODS

The krill data analysed by Miller and Hampton (1989a) are shown in Figure 1, which is a reproduction of Figure 1 of their paper. There are significant differences between day- and night-time distribution patterns; further, an underlying density trend could be argued from inspection of this plot. However, for the purposes of the simple analyses of this paper, these complications will be overlooked.

If the krill swarms detected were randomly distributed over the area surveyed, the distances between successive swarms encountered should follow an exponential distribution.

Miller and Hampton (1989a) showed that the data exhibit significant deviations from such a distribution, so that the hypothesis that the overall distribution is random can be rejected.

Instead, we model a two-level distribution structure of concentrations and swarms-within-concentrations (as discussed above, and in line with the hierarchy of structure discussed in Miller and Hampton, 1989b) under the assumption of a random distribution at each level. Two models are considered. The first (A) is based on the relationship:

$P_A(y)$ = Prob[encounter swarm]

= Prob[encounter swarm if within concentration] x Prob[within concentration] + Prob[encounter swarm (i.e., next concentration) if outside concentration] x Prob[outside concentration]

$$= \lambda_1 e^{-\lambda_1 y} w + \lambda_2 e^{-\lambda_2 y} (1 - w) \qquad (1)$$

where **y** is the distance travelled since the last swarm was encountered,

λ_1 is proportional to the number of swarms per unit area within a concentration,

λ_2 is proportional to the number of concentrations-per-unit area, and

w is the fraction of the survey area covered by concentrations.

Model (B) is less formally motivated, and has the form:

$P_B(y)$ = Prob[encounter swarm]

$$= \alpha e^{-\lambda_1 y} \qquad y \le Y \qquad (2)$$
$$= \alpha e^{-\lambda_1 Y} e^{-\lambda_2 (y-Y)} \qquad y > Y$$

where $\alpha = [\lambda_1^{-1}\{1 - e^{-\lambda_1 Y}\} + \lambda_2^{-1} e^{-\lambda_1 Y}]^{-1}$, and

Y is related to the (typical) radius of the concentration.

The basic assumption underlying this approach is that once a distance greater than **Y** has been travelled without encountering a swarm, the vessel has passed outside the concentration boundary so that the probability-per-unit distance (**g**) of encountering a swarm drops to a lower value. In principle, the constants of proportionality for the two expressions of equation (2) could differ, but in the interests of parsimonious parametrization, continuity (though, of course, not derivative continuity) of probability as a function of **y** (and therefore continuity at **Y**) is assumed. In reality, concentrations would have different radii, so that the true probability function would be some weighted average of equation (2) over different values of **Y**, which would then smooth out any discontinuity. Equation (2) may thus still remain a reasonable empirical representation of such a function.

Both models have three parameters to be estimated from the data:

(A): λ_1, λ_2, w

(B): λ_1, λ_2, Y

The parameters were estimated by numerical maximization of the respective likelihood functions $\prod_{i=1}^{n} P_A(y_i)$ and $\prod_{i=1}^{n} P_B(y_i)$. The data to which these models were then applied comprises $n = 1\,566$ successive inter swarm distances (y_i), where these distances were measured from centre-to-centre of each intercept of a krill swarm (see Miller and Hampton, 1989a, for the definition of this measure, which they name BSWC). [Note: Not all the krill aggregations encountered were necessarily "swarms" as conventionally defined, but this level of detail is ignored for this analysis, so that the term "swarm" is used throughout for convenience.]

3. RESULTS AND DISCUSSION

The results of the fits of models (A) and (B) to the data are given in Table 1 and Figure 2. This table also includes the fit for an assumed random distribution, i.e. the negative exponential:

$$P_{NE}(y) = \lambda_1 e^{-\lambda_1 y} \tag{3}$$

Though this is the same form as fitted by Miller and Hampton (1989a) to these data, the results are different. This is because the maximum likelihood estimator:

$$\hat{\lambda}_1 = n \Big/ \left(\sum_{i=1}^{n} y_i \right) \tag{4}$$

was used here, while Miller and Hampton used the estimator:

$$\hat{\lambda}_1 = (\ell n\ 2)/y_{median} \tag{5}$$

These two estimators are deterministically identical (if the model assumed is correct). The estimator of equation (5) has the advantage of being more robust to occasional outliers at large y, and is more appropriate if fitting the data at smaller y is of the greatest concern. However, in the context of modelling the distribution at <u>all</u> scales (not just the smaller scale), the numerous large inter-swarm distances cannot all be dismissed as outliers, so that use of this estimator becomes questionable given the obvious model misspecification. The maximum likelihood estimator of equation (4) has therefore been used instead, and provides comparability with the fitting procedures used for the other models.

The x^2 values in Table 1 and Figure 2 show that the two-level models (A) and (B) achieve fits to the data which are much improved to that of the negative exponential. The fits of the two-level models are very similar, both indicating a change in the pattern of the distribution (to a much slower decline with y) at a scale of some 5 to 7 km. However, both fits show the same systematic deviations from the data, with predictions that are somewhat too low between [0, 0.5] and [2, 20] km, and too high in the complementary ranges. The fact that the x^2 values still indicate statistically significant lack of fit in both cases, means that model misspecification does remain to some extent.

It is appropriate to consider whether the estimates of the model parameter values are meaningful, given other data available from the survey. Attention is confined to model (A), which (on a minimum x^2 basis) provides a better fit than model (B) for the same number of estimable parameters. Consider a simple situation where all swarms are circular with the same radius **r**, and all concentrations also circular with identical radii **R**. If there are d swarms per unit area within a concentration, and the density of concentrations in the survey region is **D** per-unit area, then the following relationships hold:

$$\lambda_1 = 2rd$$
$$\lambda_2 = 2RD$$
$$w = \pi R^2 D \qquad (6)$$

The mean intercepted swarm length (ℓ) in such a model is given by:

$$\ell = \pi r/2 \qquad (7)$$

Data from the survey gives a value for **P** of (26.786/1567), which yields:

$$r = 0.0109 \text{ km} \qquad (8)$$

Substituting this and the parameter estimates of Table 1 into equations (6) gives the values:

$$d = 54.6 \quad \text{swarms/km}^2$$
$$R = 13.7 \quad \text{km}$$
$$D = 0.00146 \text{ concentrations/km}^2 \qquad (9)$$

This simple model makes a prediction for the fraction (**f**) of the survey area covered by krill, viz:

$$\hat{f} = d\pi r^2 \,.\, D\pi R^2$$
$$= 0.0175 \qquad (10)$$

The corresponding observed value is:

$$f_{obs} = 26.786 \text{ km covered by krill} / 6579.654 \text{ km surveyed}$$
$$= 0.00407 \qquad (11)$$

i.e. a some four-fold discrepancy.

This discrepancy is not that discouraging, given the oversimplification of calculations which were performed on the assumptions that all swarms and concentrations are circular and have fixed sizes, and further the model misspecification evident for model (A) [and (B)]. The "problem" seems to be the "high" estimate for **w**, which implies that concentrations covered as much of 86% as the survey area - seemingly an unrealistically high proportion?

Model (A) can be constrained to be consistent with the observed value for **f**. This requires that:

$$\pi r \lambda_1 w/2 = f_{obs}$$

$$\text{i.e. } w = 2 f_{obs}/(\pi r \lambda_1) = 0.238/\lambda_1 \quad (12)$$

so that model (A) becomes:

$$P_A^*(y) = 0.238\, e^{-\lambda_1 y} + (1 - 0.238/\lambda_1)\, \lambda_2\, e^{-\lambda_2 y} \quad (13)$$

The results for this two-parameter version of the model can be found in the column headed: ' Model (A) "constrained" ' in Table 1. Clearly the quality of fit has deteriorated substantially, indicating that the discrepancy between the values of $\hat{f}$ and $\mathbf{f_{obs}}$ in equations (10) and (11) above is not trivially resolvable.

4. CONCLUDING REMARKS

The ability of the two-level models considered to mimic an observed spatial distribution pattern for krill swarms is encouraging. Nevertheless, evidence of model misspecification remains, and the ability of more complex models to provide improved fits to data needs to be investigated. This should be done before such models are used to provide simulated krill distributions for tests of alternative survey strategies and krill abundance estimators, because realistic distributions are required if the tests are to give reliable results.

One immediate priority for future work would seem to be the application of the models developed here to other krill data sets, to see whether similar estimates of parameter values are obtained. Another would be the extension of the models to allow the λ values to vary with position in a simple way, so as to reflect overall spatial trends in krill density.

ACKNOWLEDGEMENTS

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Table 1: Fits to the frequency distribution of inter-swarm distances by the various models considered. Full descriptions of the models and definitions of their parameters are provided in the text.

Distance Interval	Observed	Negative Exponential	Model (A)	Model (B)	Model (A) "constrained"
0 - 0.2	328	73	287	318	79
0.2 - 0.4	277	70	227	254	74
0.4 - 0.6	162	66	179	202	69
0.6 - 0.8	122	63	141	161	64
0.8 - 1.0	86	60	112	128	60
1.0 - 1.2	69	58	88	102	56
1.2 - 1.4	49	55	70	81	52
1.4 - 1.6	42	52	55	65	49
1.6 - 1.8	26	50	44	52	46
1.8 - 2.0	35	48	35	41	43
2.0 - 3.0	101	206	94	108	177
3.0 - 4.0	54	163	34	34	129
4.0 - 5.0	28	128	16	8	96
5.0 +	187	474	184	192	572
x^2	-	2107	69	141	1929
d.f.	-	13	10	10	11
Parameters					
λ_1 (km^{-1})	-	0.238	1.19	1.14	0.39
λ_2 (km^{-1})	-	-	0.04	0.04	0.06
w	-	-	0.86	-	(0.61)
Y (km)	-	-	-	4.57	-

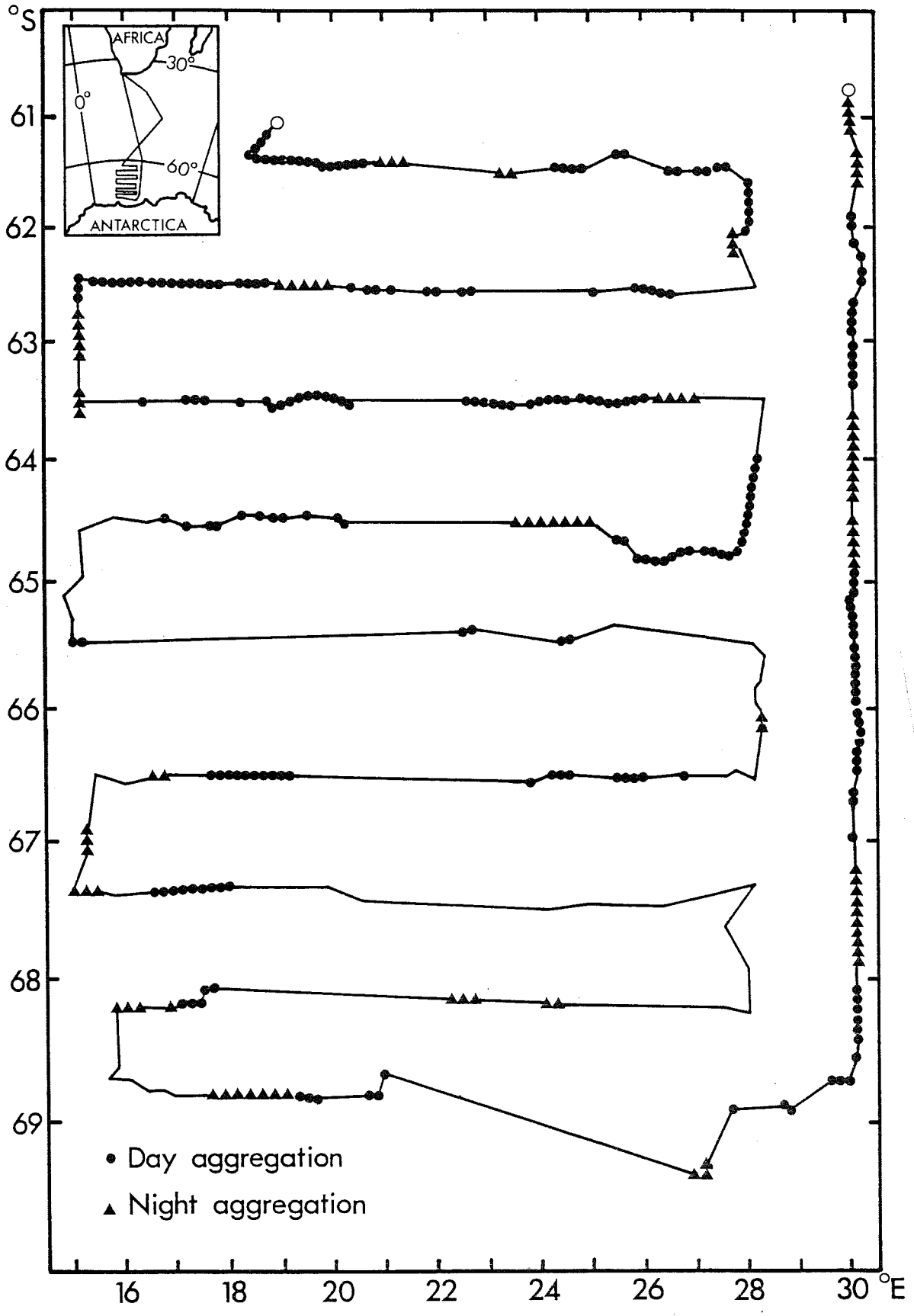


Figure 1 : Krill aggregations detected in the south-west Indian Ocean during FIBEX, February to March, 1981. The cruise track of MV *SA Agulhas* is also shown.

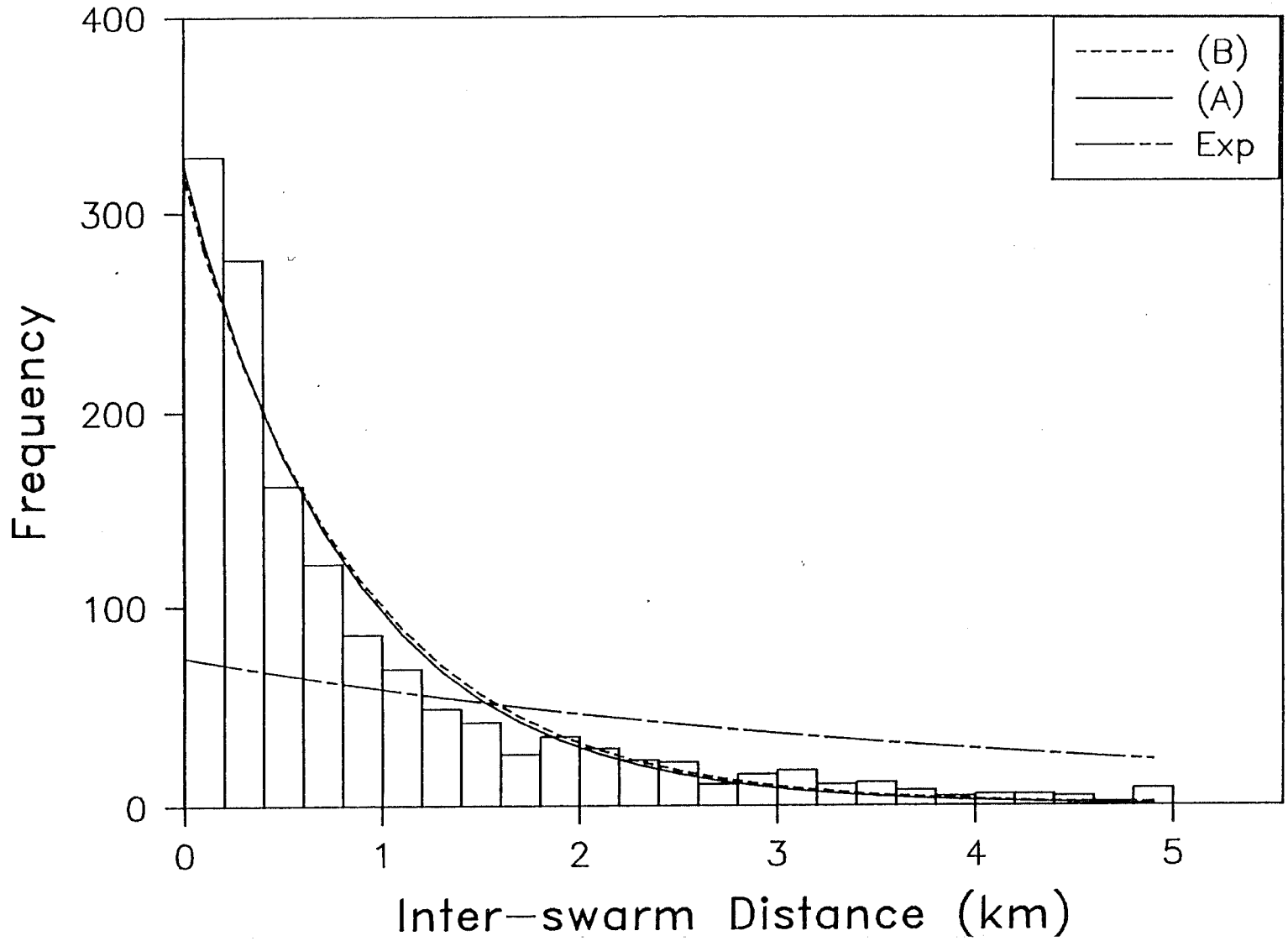
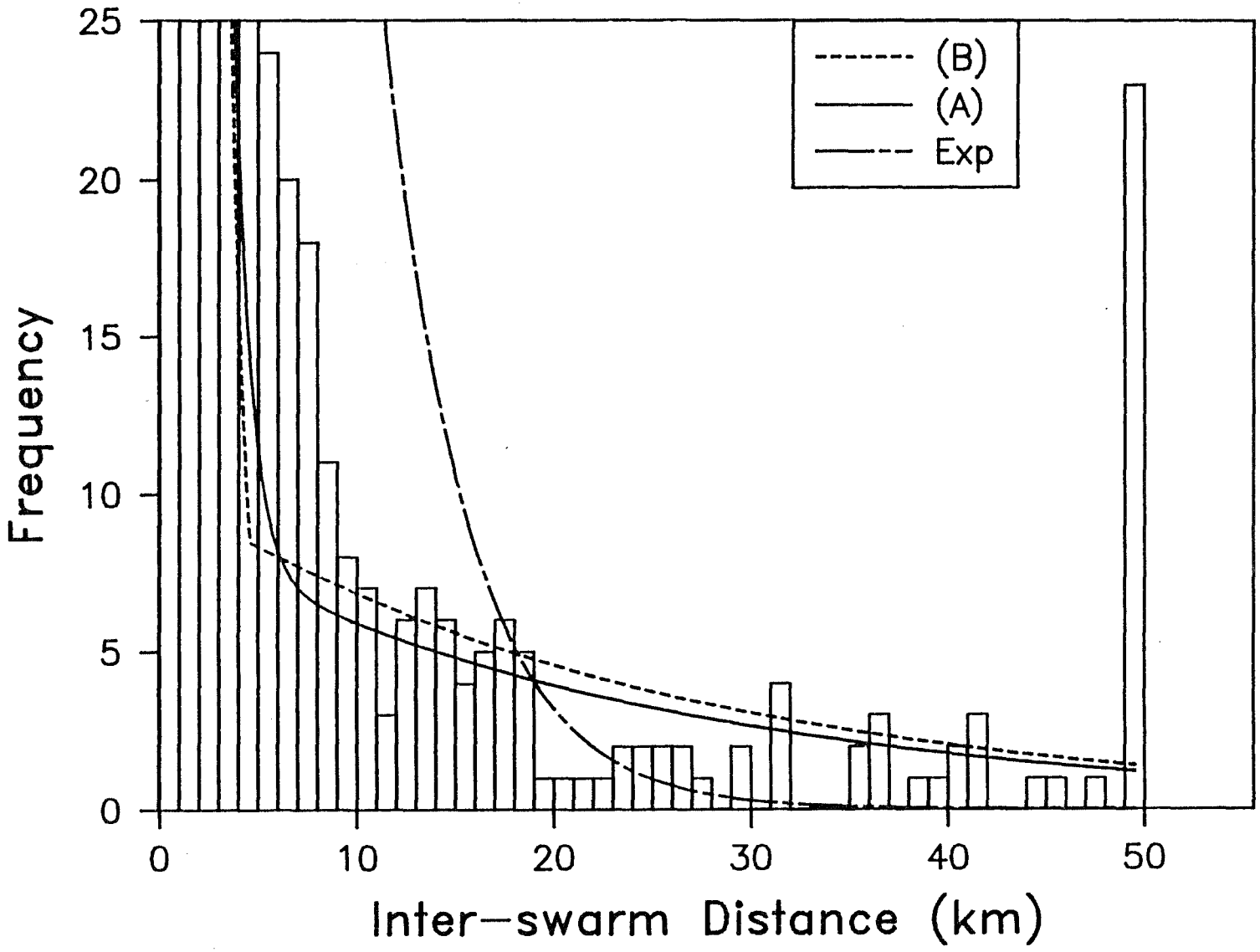


Figure 2 : Comparison of the observed frequency distribution of inter-swarm distance (y) with the fits to these data by the negative exponential model, and by the two-level models (A) and (B). The same plot is shown at two different scales to better indicate the behaviour of the fits at small and at large values of y.


25
20
15
10
5
0
Frequency
0
10
20
30
40
50
Inter–swarm Distance (km)
(B)
(A)
Exp

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A SIMPLE APPROACH FOR CALCULATING THE POTENTIAL YIELD OF KRILL FROM BIOMASS SURVEY RESULTS

D.S. Butterworth*, A.E. Punt* and M. Basson**

Abstract

Estimates are calculated for the parameter λ in the yield equation $\mathbf{Y} = \lambda \mathbf{M} \mathbf{B}_0$ for a krill fishery in which both the fishery and krill growth are seasonal. The criterion used for the calculations is that the probability that the krill spawning biomass drops below 20% of its median pre-exploitation level over a 20 year period of harvesting should equal 10%. The value of λ depends strongly on the value of **M** (natural mortality) and σ_R(recruitment variability), and also on the relative values of the ages at maturity and first-capture. Seasonal effects seem to be of lesser importance.

Résumé

Calculs d'estimations du paramètre λ dans l'équation de rendement $\mathbf{Y} = \lambda \mathbf{M} \mathbf{B}_0$ pour une pêcherie de krill dans laquelle l'intensité de la pêche et la croissance du krill sont saisonnières. Pour les calculs, le critère utilisé est le suivant : la probabilité qu'en une période d'exploitation de 20 ans, la biomasse reproductrice du krill chute en dessous de 20% de son niveau moyen d'avant l'exploitation, devrait être égale à 10%. La valeur de λ est fortement dépendante de la valeur de **M** (mortalité naturelle) et de σ_R (variabilité du recrutement) ainsi que des valeurs relatives des âges de maturité et de première capture. Les effets saisonniers semblent être de moindre importance.

Резюме

Вычислены оценки параметра λ в уравнении вылова $\mathbf{Y} = \lambda \mathbf{M} \mathbf{B}_0$ в промысле криля, при котором как промысел, так и рост криля носят сезонный характер. Критерием вычислений являлось то, что вероятность спада биомассы нерестующего криля ниже 20% его медианного доэксплуатационного уровня за 20-летний период промысла, должна равняться 10%. Значение λ существенно зависит от значения **M** (естественная смертность) и σ_R (изменчивость пополнения), а также от относительных значений возраста при половозрелости и первом вылове. Сезонные воздействия, по-видимому, представляют меньшую важность.

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Resumen

Se calculan las estimaciones del parámetro λ en la ecuación de rendimiento $\mathbf{Y} = \lambda \mathbf{M} \mathbf{B}_0$ para la pesquería de krill, en la cual la pesquería y el crecimiento del krill son estacionales. El criterio empleado para los cálculos es que la probabilidad de que la biomasa de desove del krill descienda a menos del 20% de su nivel mediano de pre-explotación, sobre un período de captura de 20 años, deberá ser igual a un 10%. El valor de λ está estrechamente ligado al valor de **M** (mortalidad natural) y de σ_R (variabilidad de reclutamiento), y también a los valores relativos de las edades de madurez y de primera captura. Se considera que los efectos estacionales tienen menos importancia.

1. INTRODUCTION

One of the topics considered by the Second Meeting of the Working Group on Krill was the estimation of potential yield (SC-CAMLR, 1990). Some members suggested that a possible approach to the determination of appropriate yields might be to use the formula:

$$Y = \lambda M B_0 \qquad (1)$$

where **Y** is the annual yield,
M is the natural mortality in yr^{-1},
$\mathbf{B_0}$ is an estimate of the effective total biomass of the population prior to exploitation,
λ is a numerical factor which is typically less than 0.5.

A basis for calculating an appropriate value for λ is set out in Beddington and Cooke (1983). The criterion which they use is that the probability that the spawning stock size drops below 20% of its average value prior to exploitation, over a 20 year period of harvesting, is equal to 10%. Clearly the value of λ is dependent on biological parameters such as growth rates and the extent of recruitment variability, as well as on the age-at-first capture, and Beddington and Cooke (op.cit.) provide tables giving the value of λ for various combinations of these parameters.

However, Beddington and Cooke's calculation is based on a von Bertalanffy growth curve, which reflects steady growth throughout the year. In contrast, krill exhibits growth which varies systematically over the year (Miller and Hampton, 1989). The Second Meeting of the Working Group on Krill (SC-CAMLR, 1990) therefore suggested that, rather than use values given in Beddington and Cooke's tabulations, their calculations should be repeated for krill in a manner which takes account of seasonal growth variation, for a range of plausible values for pertinent parameters.

This paper reports the results of calculations along these lines.

2. METHODS

The mathematical detail of the calculations carried out is given in Appendix 1. This section comments only on the assumptions upon which those calculations are based.

The model of Rosenberg, Beddington and Basson (1986) is used to describe the seasonal growth of krill. This model for the length of krill of age (a+t) years may be written:

$$\ell(a+t)=\begin{cases}\ell_\infty\left[1-e^{-\beta(a+\delta t)}\right] & 0\le t\le 1/\delta \\ \ell_\infty\left[1-e^{-\beta(a+1)}\right] & 1/\delta\le t\le 1\end{cases} \qquad (2)$$

Rosenberg *et al.*'s (op.cit.) fit to data yields an estimate of $\delta = 4$, which corresponds to a three month growth period, followed by nine months of zero growth.

Much of the fishing of krill off Antarctica is concentrated in the three summer months December to February (Miller, 1990), so that it is convenient for these calculations to assume that the three-month growth and fishing seasons coincide exactly, even though results in Rosenberg *et al.* (op. cit.) suggest that the krill growth season is a little earlier than this. The start of this season is taken to be the appropriate time to reflect a measure of spawning biomass.

The biomass estimate $\mathbf{B_0}$ which is to be used in equation (1) is considered to be made in the middle of the season (i.e. mid-January). This is an estimate of the biomass prior to any harvesting taking place, but the analysis takes account of the fact that unexploited biomass will fluctuate from year to year because of recruitment variability. Beddington and Cooke (1983) assume that the estimate is exact, but allowance for (survey sampling) estimation error has been made in this analysis [the η term in equation (A.9) of Appendix 1]. In other respects, the method of analysis is identical to that of Beddington and Cooke (op.cit.), except that only a constant catch harvesting strategy has been considered. Beddington and Cooke also considered a constant fishing mortality strategy, but this seems inappropriate for krill. The reason is that, in practice, such a strategy could only be implemented in the form of fixed fishing effort, but for krill any simple (e.g. linear proportionality) relationship of CPUE to abundance (or equivalently fishing effort to fishing mortality) is questionable, particularly for the crude measures of effort (such as vessel-days) in terms of which regulations would have to be framed (Butterworth, 1989).

It is important to appreciate that the computations are of a "Myopic Bayes" nature (Walters, 1986). They assume that the only information available upon which to regulate the fishery for the following 20 years, is that from a single pre-exploitation biomass survey. No account is taken of the likelihood that further surveys will take place, and that their results could also be incorporated in some more complex feedback control management procedure.

The basic krill dynamics model used (see Appendix 1) assumes that natural mortality, unlike fishing mortality, has no seasonal component and takes place uniformly throughout the year. This assumption could be questioned, as krill predator abundance around Antarctica also fluctuates seasonally, because baleen whales (for example) are present primarily in the late spring to early summer months. To ascertain whether this might have a marked effect on results, some of the calculations have been repeated for the extreme assumption that all natural mortality also takes place during the three-month growth/fishing season. The appropriate equations for this alternative model (equivalent to one with no seasonal component, as investigated by Beddington and Cooke) are also given in Appendix 1.

3. CHOICE OF PARAMETER VALUES

The model developed in Appendix 1 has nine parameters: $\mathbf{M}$, $\mathbf{a_r}$, $\mathbf{R}$, σ_R, α, β, $\mathbf{a_m}$, $\mathbf{a+}$ and σ_s. As the results of interest concern only biomass ratios [$\mathbf{D(y)}$ - see Appendix 1], they are unaffected by the values chosen for R and α, so that these two parameters can both be set equal to 1 for convenience.

Rosenberg *et al.* (1986) estimate ℓ_∞ = 60 mm and β = 0.45 yr^{-1}. The values of length-at-age at the start of the season corresponding to these estimates are shown in Table 1.

Acoustic surveys of krill biomass would probably be most sensitive to krill of length 20 mm and above (D. Miller, pers. comm.), so that the lengths listed in Table 1 suggest that $a^+ = 1^+$ would be an appropriate choice. [Given a value for **M**, the multiplicative factors required to modify the values of λ reported below can be found by a simple deterministic calculation.]

It would be inappropriate to consider every possible combination of the remaining five parameters: **M**, $\mathbf{a_r}$, σ_R, $\mathbf{a_m}$ and σ_s. The greatest uncertainty would seem to exist regarding appropriate values for **M** and σ_R, so that a "base case" has been chosen which includes all nine combinations of the choices:

$M = 0.3;\ 0.6;\ 1.0\ \ yr^{-1}$
$\sigma_R = 0.2;\ 0.4;\ 1.0$

Fixed values $a_r = 3$, $a_m = 3$ and $\sigma_s = 0.3$ have been chosen to complete this "base case". [Some data-based case could be made for each of these choices; for example, the choice for σ_s seems typical of coefficients of variation reported in Anon. (1986).] The sensitivity of results to variations of these choices has been investigated only for the central element of the (**M**, σ_R) combinations considered, viz. ($M = 0.6\ yr^{-1}$, $\sigma_R = 0.4$). The different choices explored are:

$a_r = 2;\ 4$
$a_m = 2;\ 4$
$\sigma_s = 0;\ 0.5$

A value $\sigma_s = 0$ is, of course, unattainable. It was selected to correspond to the calculation procedure of Beddington and Cooke (1983).

For the alternative model (**M** concentrated in the three-month growth/fishing season), calculations have been carried out for the "base case" set of parameter value choices.

4. RESULTS AND DISCUSSION

Table 2 shows the estimates of λ for the "base case" set of parameter values for the (seasonal) krill dynamics model of Appendix 1. Certain of the entries in this Table are shown as "(1.00)". For the "base case" choice of identical ages at maturity and first-capture ($a_m = a_r = 3$), the 2-year-olds of the preceding year contribute to the spawning biomass (calculated at the start of the season) before the year-class concerned is affected in any way by fishing. In certain circumstances then (high **M** and low σ_R), it becomes possible to catch effectively all krill older than the age-at-first-capture, because the recruiting cohort is always large enough to satisfy the criterion that $B_{sp}/K_{sp} > 0.2$. It is for such circumstances that the λ estimate is shown as "(1.00)".

Table 3 reports estimates of λ for the tests of sensitivity to the values chosen for $\mathbf{a_r}$, $\mathbf{a_m}$ and σ_s. The sensitivity does not seem to be particularly marked, unless circumstances become such as lead to a "(1.00)" estimate situation.

Finally, Table 4 gives the results of assuming that **M** is concentrated in the three-month growth/fishing season (effectively equivalent to a no-seasonality situation). They show very little change from the results in Table 2.

The primary implications of these calculations are that the value of λ is strongly dependent on the values of the **M** (natural mortality) and σ_R (recruitment variability) parameters, and also on the relative values of the ages at maturity and first-capture.

The seasonality of the krill fishery seems a matter of lesser importance at this stage. The calculations of this paper have assumed krill fishing over the summer season. In certain statistical areas (specifically Subarea 48.3), krill fishing actually peaks in winter (Miller, 1989). The values of λ would obviously change for this situation. However, given the smallness of the seasonality effects evident in the Table 2 - Table 4 comparison, one would not anticipate the change in λ for a winter fishery to be large compared to the differences in λ evident for alternative choices for **M** and σ_R. Clearly, efforts to narrow the range of likely values for **M** and σ_R merit the greatest attention at this time.

The growth equation used for krill in these calculations indicates a fairly long-lived animal. If this is correct, one would not expect a value of **M** that is very high (or too few krill would survive to the older ages indicated). Appropriate ranges for **M** for calculations such as these must therefore be correlated to some extent with the growth curve assumed.

Finally, it must be pointed out that equation (1) applies to a situation where $\mathbf{B_0}$ represents the total biomass of the stock concerned. In cases where a biomass survey does not cover the full range of the stock, including those where there is net transport of krill through the area surveyed, yield estimates from equation (1) will obviously contain an element of negative bias.

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Table 1: Values of krill length-at-age [$\ell(\mathbf{a})$] at the start of the season corresponding to the parameter estimates obtained by Rosenberg *et al.* (1986) for the growth model of equation (2).

Age **a** (years)	Length $\ell(\mathbf{a})$ (mm)
0	0
1	22
2	36
3	44
4	50
5	54
6	56
7	57

Table 2: Estimates of the harvesting fraction parameter λ (where $Y = \lambda MB_{obs}$) for the krill dynamics model of Appendix 1 with the "base case" set of parameter value choices: $a_r = 3$; $a_m = 3$ and $\sigma_s = 0.3$.

	$M = 0.3\ yr^{-1}$	$M = 0.6\ yr^{-1}$	$M = 1.0\ yr^{-1}$
$\sigma_P = 0.2$	0.43	(1.00)	(1.00)
$\sigma_P = 0.4$	0.39	0.23	0.21
$\sigma_P = 1.0$	0.20	0.08	0.04

Table 3: Tests of the sensitivity of estimates of λ for the case ($M = 0.6\ yr^{-1}$, $\sigma_R = 0.4$) to variations in the "base case" (BC) choices for parameters $\mathbf{a_r}$, $\mathbf{a_m}$ and σ_s.

Parameter Change	λ
BC	0.23
$a_r = 2$	0.18
$a_r = 4$	(1.00)
$a_m = 2$	(1.00)
$a_m = 4$	0.15
$\sigma_s = 0$	0.25
$\sigma_s = 0.5$	0.20

Table 4: Estimates of λ for the alternative krill dynamics model (**M** concentrated in the three-month growth and fishing season) for the "base case" set of parameter value choices.

	$M = 0.3\ yr^{-1}$	$M = 0.6\ yr^{-1}$	$M = 1.0\ yr^{-1}$
$\sigma_P = 0.2$	0.44	(1.00)	(1.00)
$\sigma_P = 0.4$	0.40	0.24	0.25
$\sigma_P = 1.0$	0.20	0.08	0.04

APPENDIX 1

MATHEMATICAL DETAILS OF PROCEDURE USED TO CALCULATE λ

1. KRILL DYNAMICS MODEL

The numbers of krill of age a years at the start of "year" y ($N_{y,a}$) are governed by the equations:

$$N_{y+1,a+1} = \begin{cases} N_{y,a} e^{-M} & 0 \le a < a_r \\ N_{y,a} e^{-[M+F(y)]} & a_r \le a \le 7 \end{cases} \qquad \text{(A.1)}$$

where "year" is a 12-month period whose commencement coincides with the start of the season during which krill grow,
M is the natural mortality rate (effective throughout the year),
F(y) is an effective annual fishing mortality rate in year **y**, and
$\mathbf{a_r}$ is the (knife-edge) age-at-first-capture.

These equations assume that the number of krill 8 years of age and older is relatively small and so can be neglected.

The number of krill recruits at the start of each year ($N_{y,0}$) is given by:

$$N_{y,0} = R \exp\left(\varepsilon_y - \sigma_R^2 / 2\right) \quad \varepsilon_y \text{ from } N\left(0; \sigma_R^2\right) \qquad \text{(A.2)}$$

where **R** is the mean recruitment, and
N(0; σ^2) is a normal distribution with zero mean and variance σ^2.

Mass-at-age is obtained from the growth curve form used by Rosenberg *et al.* (1986), together with the assumption that mass is proportional to length cubed. Thus the mass of krill of age **a** at the start of the "year" (w_a) is given by:

$$w_a = \alpha [1 - e^{-\beta a}]^3 \qquad \text{(A.3)}$$

In the middle of the season during which the krill grow, their mass-at-age ($\overline{w}_a$) is then:

$$\overline{w}_a = \alpha \left[1 - e^{-\beta(a+0.5)}\right]^3 \qquad \text{(A.4)}$$

The spawning biomass of krill (taken to correspond to the start of the "year") is accordingly:

$$B_{sp}(y) = \sum_{a=a_m}^{7} w_a N_{y,a} \qquad \text{(A.5)}$$

where $\mathbf{a_m}$ is the age-at-maturity for krill.

The median spawning biomass prior to any exploitation ($\mathbf{K_{sp}}$) is therefore:

$$K_{sp} = \sum_{a=a_m}^{7} w_a \, R \exp\left(-\sigma_R^2 / 2\right) e^{-Ma} = R \exp\left(-\sigma_R^2 / 2\right) \alpha \sum_{a=a_m}^{7} e^{-Ma}\left[1-e^{-\beta a}\right]^3 \quad \text{(A.6)}$$

Assuming further that the growth and fishing seasons coincide, and are of three months duration, the mid-season biomass of krill aged a years and above ($\mathbf{B_{a+}}$) is given by:

$$B_{a+}(y) = \sum_{a=a+}^{7} \overline{w}_a \, N_{y,a} \exp\left[-\left\{1.5\, M/12 + F(y)/2\right\}\right] \quad \text{(A.7)}$$

The catch in number of krill over a season from a single cohort of size $\mathbf{N_0}$ at the start of the "year" will be given by an equation of the form:

$$\int_0^{0.25} 4F \bullet N(t)dt = \int_0^{0.25} 4F \bullet N_0 \, e^{-(M+4F)t} \, dt$$

Making allowance for krill mass and its growth during the season, the annual catch in mass [**C(y)**] is therefore given by:

$$\begin{aligned} C(y) &= \sum_{a=a_r}^{7} \int_0^{0.25} 4F(y) \bullet N_{y,a} \, e^{-[M+4F(y)]t} \; \alpha\left[1-e^{-\beta(a+4t)}\right]^3 dt = \\ &= 4F(y) \, \alpha \sum_{a=a_r}^{7} N_{y,a} \sum_{\mu=0}^{3} \gamma(\mu) \, e^{-\mu\beta a} \left[1-e^{-\{M+4F(y)\,+\,4\mu\beta\}/4}\right] / \left[M+4F(y)+4\mu\beta\right] \end{aligned} \quad \text{(A.8)}$$

where $\gamma(0) = 1$; $\gamma(1) = -3$; $\gamma(2) = 3$ and $\gamma(3) = -1$.

2. THE ALGORITHIM FOR THE COMPUTATIONS

The results required are computed using the following algorithm.

(i) For given values of biological parameters and the age-at-first-capture, choose a value for λ.

(ii) For "year" y=1, set up deterministic equilibrium age-structure for F=0, i.e.:

$$N_{1,a} = R \exp\left(-\sigma_R^2 / 2\right) e^{-Ma} \qquad a = 0,1,...,7$$

Note that since results are required for biomass <u>ratios</u> only, **R** can be set equal to 1.

(iii) Project the numbers-at-age forward in the absence of exploitation [F(y) = 0] using equations (A.1), with stochastic recruitment given by equation (A.2), for "years" y = 2 to 11. Thus, by "year" y = 10, all memory of the initial deterministic age-structure has been lost.

(iv) In year y = 10 (the year before fishing commences), the **a+** biomass is "measured" in mid-season, yielding a result $\mathbf{B_{obs}}$ where:

$$B_{obs} = \sum_{a=a^+}^{7} \overline{w}_a N_{10,a} \exp[-1.5M/12] \exp[\eta - \sigma_s^2/2] \qquad (A.9)$$

where η from $N(0; \sigma_s^2)$ is the log normal variation associated with the biomass survey.

(v) Fix a constant catch $C = \lambda MB_{obs}$.

(vi) For year y = 11, find the fishing mortality **F(y)** which satisfies equation (A.8) for the catch computed in v). [To speed computations, in instances where **F(y)** exceeds 5, it is set to ∞, i.e. <u>all</u> the krill above the age-at-first-capture are harvested.] Project the age-structure forward to y = 12 using that value of **F(y)** in equations (A.1). Calculate the ratio of the spawning biomass to its median pre-exploitation level, $D(y) = B_{sp}(y)/K_{sp}$ for y = 12. [Note that y = 12 is the first year for which the spawning biomass has been influenced by the effects of fishing.]

(vii) Repeat step (vi) for y = 12 to 30, thereby obtaining values of **D(y)** for y = 13 to 31.

(viii) Ascertain whether any elements of the set {**D(y)** : y = 12, ... 31} are less than 0.2.

(ix) Repeat steps (iii) to (viii) a large number of times (1 000 simulations was found to provide adequate precision for this study), to estimate the probability **P** that a value of **D(y)** less than 0.2 occurs during the 20 year harvesting period.

(x) Repeat steps (ii)) to (ix) for different values of λ until one is found which yields the result P = 0.1. This λ value is the result required. [For reasons explained in the text, an upper bound of 1.0 is set for λ in this exercise.]

Note that to ensure a smoother relationship between λ and **P** so that computations [specifically step (x)] are eased, the same set of random numbers [η and $\varepsilon(\mathbf{y})$] are used for different values of λ.

3. ALTERNATIVE DYNAMICS MODEL

Under the extreme assumption that all natural mortality also takes place during the three-month growth and fishing season, the problem becomes equivalent to the standard form where seasonality has no effect. The consequent modifications to equations (A.6), (A.8) and (A.9) involve effectively the replacement $M \rightarrow 4M$, which yields respectively:

$$B_{a^+}(y) = \sum_{a=a^+}^{7} \overline{w}_a N_{y,a} \exp[-\{M + F(y)\}/2] \qquad (A.10)$$

$$C(y) = F(y)\, \alpha \sum_{a=a_r}^{7} N_{y,a} \sum_{\mu=0}^{3} \gamma(\mu)\, e^{-\mu\beta_a} \left[1 - e^{\{M+F(y)+\mu\beta\}}\right] / [M + F(y) + \mu\beta] \qquad (A.11)$$

$$B_{obs} = \sum_{a=a^+}^{7} \overline{w}_a N_{10,a} \exp[-M/2] \exp[\eta - \sigma_s^2/2] \qquad (A.12)$$

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Таблица 3: Чувствительность оценок λ, когда (M = 0.6 yr^{-1}, σ_R = 0.4), к изменениям исходного набора (BC) альтернативных параметров $\mathbf{a}_r$, $\mathbf{a}_m$ и σ_S.

Таблица 4: Оценки λ для альтернативной модели динамики криля (**M** сосредоточено в трехмесячном сезоне роста и промысла) для исходного набора альтернативных параметров.

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NOTE ON ESTIMATING KRILL ABUNDANCE FROM ACOUSTIC DATA ON INDIVIDUAL AGGREGATIONS

I. Hampton and D.G.M. Miller*

Abstract

The fundamental equations and assumptions underlying estimation of krill abundance using echo-integration information and aggregation parameters are briefly described. The chief differences of the two approaches are highlighted. It is concluded that the echo-integration approach is superior for the estimation of regional krill abundance and its variance since it is easier to apply, requires less data analysis and does not require any assumptions concerning aggregation distribution or conformation.

Résumé

Le présent document est une brève description des équations et des hypothèses fondamentales, à la base de l'estimation de l'abondance du krill à partir d'informations obtenues par écho-intégration et de paramètres de concentrations. Il souligne les principales différences entre les deux méthodes. Il y est conclu que l'approche de l'écho-intégration est supérieure pour l'estimation de l'abondance régionale du krill et de sa variance : d'application plus aisée, elle ne nécessite ni le même degré d'analyse des données, ni des hypothèses sur la répartition ou la conformation des concentrations.

Резюме

Кратко описаны фундаментальные уравнения и предположения об оценке распределения криля с использованием эхоинтегральной информации и параметров агрегаций. Выделены главные различия этих двух подходов. В итоге признано превосходство эхоинтегрального подхода для оценки регионального распределения криля и его изменчивости, поскольку он удобнее в применении, требует меньшего анализа данных и не требует никаких допущений в отношении распределения или структуры агрегаций.

Resumen

Se describen brevemente las ecuaciones e hipótesis fundamentales en que se basa la estimacion de la abundancia del krill, a partir de datos de ecointegración y de parámetros de concentraciones. Se destacan las diferencias más notables de ambos enfoques. Se llega a la conclusión de que, para estimar el krill de una zona dada y su variancia, es mejor el enfoque de ecointegración, ya que es más fácil de aplicar, requiere menos análisis de datos, y no es necesario establecer hipótesis con respecto a la distribución o estructura de la concentración.

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1. INTRODUCTION

At its Second Meeting in Leningrad, the CCAMLR Working Group on Krill (WG-Krill) emphasised the importance of acoustic techniques in the determination of krill abundance and distribution (SC-CAMLR, 1990). To date, the most commonly employed method to estimate krill abundance has been echo-integration (cf. Forbes and Nakken, 1972; Johannesson and Mitson, 1983; Maclennan and Simmonds, 1992). This method provides a cumulative measure of the acoustic backscatter received from krill encountered during a survey. The resultant information is used to calculate the average krill density for each Elementary Sampling Distance Unit (ESDU). Finally, the density information is combined in some way to estimate total krill abundance in the area under consideration. The major advantage of the echo-integration technique is that it is relatively simple and efficient when used to estimate krill abundance over large areas (Miller and Hampton, 1989a).

In recent years, advances in acoustic hardware and software have enabled fine resolution (i.e., ping-by-ping) information on the density and size of individual krill aggregations to be collected. Some workers (see discussion in Butterworth and Miller, 1987) have suggested that this information could be used to estimate krill abundance over large geographical areas. The approach differs from echo-integration in that use is made of information on the spatial variation of density along-transect (see also Butterworth *et al.* - this volume). Foote and Stefánsson (this volume) have suggested that improved estimates of biomass and variance may be obtained by using such information. Although the principles underlying such an approach are essentially similar to those of echo-integration, a number of additional factors need to be taken into account when the data are used in this way. The chief differences and other considerations are outlined here.

2. ABUNDANCE ESTIMATION BY ECHO-INTEGRATION

The primary equation for estimating $\bar{\rho}_j$, the mean surface density for the jth echo-integration interval (or ESDU) from a single-channel echo-integrator is:

$$\bar{\rho}_j = \frac{C\,(R_2 - R_1)}{n_j} \sum_{i=1}^{n_j} (\bar{I}j)_i$$

$$= C\,(R_2 - R_1)\ (\bar{\bar{I}})_j \qquad (1)$$

where $(\bar{I}j)_i$ = mean echo-intensity (proportional to mean squared voltage) between depths $\mathbf{R_1}$ and $\mathbf{R_2}$ (the integration channel) for the ith ping within the jth ESDU;

$(\bar{\bar{I}})_j$ = mean echo-intensity between $\mathbf{R_1}$ and $\mathbf{R_2}$ for all pings within ESDU j;

$\mathbf{n_j}$ = number of pings in ESDU j;

$\mathbf{C}$ = system constant, incorporating equipment parameters and mean target strength.

This equation holds irrespective of the vertical or horizontal distribution of the echo-signal, provided that **I** falls within the linear region of the detector, and that the integration channel completely encompasses the vertical extent of the targets of interest. Areal biomass is estimated by multiplying the survey area by the weighted (according to ESDU length) average of the $\bar{\rho}_j$ values. Variance can be estimated formally from the variation in density transects provided they are randomly selected (see, for example, Anon., 1986 and Jolly and Hampton, 1990).

3. ABUNDANCE ESTIMATION FROM AGGREGATION DENSITY

In some cases the integrator output for each ESDU is not available, but there is information on the mean intensity of echoes returned by individual aggregations intercepted along the transect. Suppose that there are m_j aggregations within the analysis channel for the jth ESDU, that the mean intensity returned from the kth aggregation, averaged between $\mathbf{R}_1$ and $\mathbf{R}_2$, is $\bar{\mathrm{I}}_k$, and that its intercepted length is l_k. Then,

$$\left(\bar{\bar{\mathrm{I}}}\right)_j = \left(\bar{\mathrm{I}}\right)_{Ag} \mathrm{I}_j \ ,$$

where $\left(\bar{\mathrm{I}}\right)_{Ag}$ is the mean intensity of the echo from all the individual aggregations encountered, averaged between $\mathbf{R}_1$ and $\mathbf{R}_2$, and f_j is the fractional cover of aggregations intercepted along ESDU j. $\left(\bar{\mathrm{I}}\right)_{Ag}$ and f_j are given by:

$$\left(\bar{\mathrm{I}}\right)_{Ag} = \sum_{k=1}^{m_j} \bar{\mathrm{I}}_k \, l_k \Big/ \sum_{k=1}^{m_j} l_k, \tag{2}$$

and

$$f_j = \sum_{k=1}^{m_j} l_k / L_j$$

respectively, where L_j is the length of ESDU j. Hence $\bar{\rho}_j$, and therefore biomass, can be estimated from Equation 1 as before. If the aggregation data is available in terms of density rather than echo-intensity, Equation 1 simply becomes:

$$\bar{\rho}_j = \bar{\rho}_{Ag} \, f_j$$

where $\bar{\rho}_{Ag}$ is the mean within-aggregation surface density, averaged as before over the analysis channel.

If within-aggregation intensities have been averaged over the vertical limits of the swarm instead of the analysis channel, $\bar{\mathrm{I}}_k$ is given by:

$$\bar{\mathrm{I}}_k = \sum_{i=1}^{n_k} \frac{\left(\bar{\mathrm{I}}'_k\right)_1 (h_k)_1}{(R_2 - \mathrm{R}_1)}$$

where $(\bar{I}'_k)_I$ is the average intensity for ping i from aggregation k, averaged over $(h_k)_i$, the vertical limits of the aggregation at that point, and n_k is the number of pings received from aggregation k. Substitution of $\bar{I}_k$ in Equation 2 gives $(\bar{I})_j$, and hence $\bar{\rho}_j$ from Equation 1.

It is important to note that the above estimators will only be valid if all the krill encountered is in the form of aggregations. Dispersed krill, and krill in aggregations too small or large to be classified as aggregations according to whatever classification scheme is in use, will be omitted from the estimate, thereby causing $\bar{\rho}_j$ to be under-estimated. This is a real danger, since most automated swarm-identification algorithms require the echo to exceed a pre-selected value for a number of pings in succession to be classified as having originated from a swarm. In contrast, an echo-integrator will only lose pings which fall below whatever level has been set to exclude background noise.

Estimation of variance in $\bar{\rho}_j$, and hence in the biomass estimate requires, *inter alia*, knowledge of the variance in f_j. An estimator is available for randomly distributed aggregations (Lucas and Seber, 1977), but in general, estimating this variance is a complex problem.

4. ABUNDANCE ESTIMATION FROM AGGREGATION BIOMASS

Another way to estimate areal biomass (B) from echosounder data would be from $\bar{B}_{Ag}$, the mean biomass of individual aggregations intercepted on the line transects. The appropriate expression is:

$$B = \frac{A f \bar{B}_{Ag}}{\bar{S}_{Ag}}$$

where $\bar{S}_{Ag}$ is the mean surface area of the aggregations intercepted, f the fractional cover taken over all transects , and A the area surveyed. The problem with this estimator is that neither $\bar{B}_{Ag}$ nor $\bar{S}_{Ag}$, nor their variances (which are needed in estimating the variance of B) can be estimated from intercepted lengths without assumptions about aggregation shape. $\bar{B}_{Ag}$ and $\bar{S}_{Ag}$ are in any event biased estimators because of the disproportionate probability of intercepting larger aggregations (see discussion in Hampton, 1985). Corrections can be made for the latter effect if the cross-track width of each intercepted aggregation can be estimated (e.g., Hampton, 1981), but otherwise only if the aggregations are known to be circular in horizontal cross-section. The method is therefore not recommended for krill aggregations which are often very irregularly shaped (see, for example, Miller and Hampton, 1989a).

5. CONCLUSION

We conclude, therefore, that for estimating regional krill abundance, the echo-integration method is superior to methods based on the physical parameters of intercepted aggregations, since it - (a) is simpler to apply; (b) involves the handling of much smaller volumes of data; (c) requires no assumptions regarding aggregation size and shape, or judgements on whether or not intercepted targets should be classified as aggregations; and (d) requires no assumptions regarding aggregation shape, size or distribution in estimating variance.

For the purposes of straightforward abundance estimation, therefore, there seems to be little sense in collecting acoustic data on individual aggregations, although naturally, for studies on spatial distribution and related topics, such data are often essential (see discussion in Miller and Hampton, 1989a and 1989b).

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ANALYSES OF ACOUSTIC LINE-TRANSECT DATA FROM THE WATERS AROUND SOUTH GEORGIA: ESTIMATION OF KRILL (*EUPHAUSIA SUPERBA* DANA) - BIOMASS

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Abstract

A large-scale acoustic survey of zooplankton stocks in the waters around South Georgia was carried out during November and December 1981. The data have been analysed using various definitions of strata. The total biomass in the area of 155 786 km^2 was estimated to be 1.8225 x 10^6 tonnes (Coefficient of Variation = 9.5%). This gives an estimate of mean density throughout the region of 11.7 tonnes km^{-2}. Although the estimate of the mean is not sensitive to the definition of strata, the variance of the estimate is sensitive. The analyses highlight the importance of careful planning of acoustic surveys.

Résumé

Une campagne d'évaluation acoustique à grande échelle des stocks de zooplancton s'est déroulée dans les eaux adjacentes à la Géorgie du Sud en novembre et décembre 1981. Les données ont été analysées pour diverses stratifications. La biomasse totale de l'aire de 155 786 km^2 a été estimée à 1,8225 x 10^6 tonnes (coefficient de variation = 9,5%). Ceci donne une estimation de densité moyenne pour toute la région de 11,7 tonnes km^{-2}. Bien que l'estimation de la moyenne ne soit pas sensible à la définition de la strate, la variance de l'estimation, elle, l'est. Les analyses soulignent l'importance de la conception minutieuse des campagnes acoustiques.

Резюме

В течение ноября и декабря 1981 г. в водах Южной Георгии была проведена крупномасштабная акустическая съемка запасов зоопланктона. Полученные данные анализировались с использованием различных определений страт. Общая биомасса в районе площадью 155 786 км^2 составила 1,8225 ч 10^6 тонн (коэффициент изменчивости = 9,5%). Средняя плотность во всем районе составила таким образом 11,7 тонн км$^{-2}$. Хотя оценка средней величины не зависит от определения страт, изменчивость самой оценки чувствительна к ним. Этот анализ подчеркивает важность тщательного планирования акустических съемок.

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Resumen

Durante noviembre y diciembre de 1981 se realizó una prospección acústica a gran escala de las poblaciones de zooplancton que existen en las aguas alrededor de Georgia del Sur. Esta información se ha analizado empleando varias definiciones de estratos. La biomasa total de esta área que cubre 155 786 km^2, se estimó en 1.8225 x 10^6 toneladas (coeficiente de variación = 9.5%), que implica una estimación de la densidad media de la región de 11.7 toneladas•km^{-2}. Aunque la estimación de la media no es susceptible a la definición de los estratos, es el caso contrario con la varianza de la estimación. Los análisis demuestran la gran importancia que tiene la planificación minuciosa de las prospecciones acústicas.

1. INTRODUCTION

Acoustic surveys have become a standard technique in the study of the distribution and abundance of Antarctic krill *(Euphausia superba* Dana). There are, however, a number of problems in the application of these techniques for the routine surveying of krill populations in the Southern Ocean. In particular, the design of field surveys presents various logistical and analytical problems. Many of these design problems are similar to those encountered in the development of acoustic survey programs of fish populations. The ICES Acoustic Working Group has produced a draft report on current acoustic survey design practices (ICES, unpublished manuscript) which forms a good starting point for considering many of these problems. However, the highly heterogeneous nature and scale-related patchiness of krill distributions produce some particular problems which have not been adequately addressed to date.

In this paper we report on a major acoustic survey of krill abundance and distribution in the South Georgia region. The data have been analysed using a number of different approaches to illustrate the effect of the estimation technique on the final results. This emphasises the importance of careful pre-survey planning and post-survey analyses.

2. METHODS

2.1 The Survey Design

The survey was designed to investigate some of the interactions taking place in the South Georgia marine ecosystem and involved a major interdisciplinary program of data collection, various aspects of which have been discussed by Priddle *et al.* (1986) and Atkinson and Peck (1988). The survey region was a 180 by 240 n mile box centred on the island of South Georgia (Figure 1). There was no information available at the planning stage to produce a stratified sampling design based on the biomass distribution. The large size of the area prohibited the execution of a suitable pilot study in the time available. The chosen design was systematic parallel transects with the direction of the transect perpendicular to the long-axis of the island. Nine major transects were traversed over the period from 24 November to 19 December 1981. The survey start was chosen at random to reduce the possibility of systematic errors. Each transect was divided into six sections approximately 30 n miles in length. Each section was further divided into 1 n mile integration intervals (ESDU). Density was estimated from the acoustic parameter mean volume backscattering strength (MVBS).

At the end of each section various 'station' activities were carried out as part of the interdisciplinary program. This included deployment of a CTD system to produce temperature and salinity profiles.

2.2 The Acoustic Methods

A Simrad EKS 120 echosounder connected to a Simrad QM Analogue echo-integrator was used for the study. The echosounder was calibrated on 22 November and 23 December 1981 and the following values obtained.

Constant	Date	
	22 November 1981	23 December 1981
Source Level [dB//1 μPa ref. 1 metre]	218.3	218.9
Voltage Response [dB//1 volt/μPa]	-108.9	-107.8

Pulse duration was measured at 0.6 msec.

Not all of the acoustic targets will have been krill. However, krill are likely to be the major zooplankton target in this area so in this study we assume all target are krill for the purpose of the analyses of the dataset. The length distribution of all krill taken during the survey period is shown in Figure 2. Most of the krill were small, with a mean length of 29.73 mm. This mean size is similar to that of the krill used by Everson *et al.* (1990) to estimate the target strength of krill. Based on that study we have used a mean target strength of -75 dB to estimate the biomass of krill in this region. The mean weight of the sampled krill was 0.18 g.

An estimate of the mean bottom depth was available for each section. The CTD profiles collected at either end of a section allowed an estimate of the mean temperature minimum to be obtained and used to characterise water mass (Atkinson *et al.*, 1990).

3. RESULTS AND ANALYSIS

3.1 Analytical Techniques

The notation of Jolly and Hampton (1990) is followed throughout. There are j = 1, .., n_i sample units and i = 1, .. ,N strata. The density of a sample unit is then given by:

$$\hat{\rho}_{ij} = \frac{b_{ij}}{L_{ij}} \tag{1}$$

$\mathbf{b_{ij}}$ is the biomass recorded over the j_{th} sample unit in the i_{th} stratum
$\mathbf{L_{ij}}$ is the length of j_{th} sample unit in the i_{th} stratum

The mean density in the strata is given by:

$$\hat{\bar{\rho}} = \frac{1}{n_i} \sum_{j=1}^{n_i} w_{ij} \hat{\rho}_{ij} \tag{2}$$

where the weights are based on the sample unit length:

$$w_{ij} = \frac{L_{ij}}{\bar{L}_i} \tag{3}$$

and the mean sample unit length is:

$$\bar{L}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} L_{ij} \tag{4}$$

The estimated mean density for the whole region is then:

$$\hat{\bar{\rho}} = \frac{\sum_{i=1}^{N} A_i \, \hat{\bar{\rho}}_i}{\sum_{i=1}^{N} A_i} \tag{5}$$

where A_i = Area of stratum **i**.

The variance is:

$$Var\left(\hat{\bar{\rho}}\right) = \frac{\sum_i A_i^2 \, Var\left(\hat{\bar{\rho}}_i\right)}{\left(\sum_i A_i\right)^2} \tag{6}$$

where

$$Var\left(\hat{\bar{\rho}}_i\right) = \frac{\sum_{j=1}^{n_i} w^2_{ij} \left(\hat{\bar{\rho}}_{ij} - \hat{\bar{\rho}}_i\right)^2}{n_i(n_i - 1)} \tag{7}$$

The assumption underlying such analyses is of random sampling within a stratum. In the survey reported here it was assumed that the between-transect distance is sufficiently large to remove any systematic error; that is at a scale at which the krill distribution can be considered random with respect to the transects.

The equations can be applied to the data for any size of sample unit. However, the problem of non-random sampling within a stratum can invalidate the basic assumptions of the statistical methods. The simplest case would be to consider each ESDU to be a sample. However, the inherent serial correlation in the datasets makes the estimation of variance on this basis meaningless.

For the variance of the final estimate to be a minimum the sampling units should be chosen to give low within-stratum variability. The definitions of strata are given in Table 1. The results of the analyses of the data using various sampling units and strata definitions are shown in Table 2. Those estimates in which the ESDU are taken as the basic sampling unit (Table 2, lines 1 to 6) suffer from serial correlation problems. A possible breakdown of the data (Table 2, line 7) is to produce 18 transects by splitting the transects into two transects

either side of the shelf region (Figure 4), and taking a section as the basic sampling unit. This is not unreasonable as the transecting was delayed for station sampling at the end of each section. The next three estimators (8 to 10) consider the six strata shown in Figure 5. These strata split the sample region on the basis of the bathymetric contours. Each of these estimators takes a different basic sampling unit: transects, sections or ESDU.

The different estimators are presented here to highlight that the estimate of mean density and total biomass is not sensitive to the analytical breakdown used. However, the variance of the estimates can change markedly. The variance of the mean density estimate from the Jolly method (Jolly and Hampton, 1990) is a weighted sum of the within-stratum variances. Thus, the stratification at the large-scale is aimed at the removal of the largest element of the variance. The sampling units within the strata should then be chosen to produce least variance within strata. The between-stratum variance does not enter into the overall calculation of the variance. An analysis of variance (Table 3) shows that most of the variation is explained by the chosen strata and that sections within strata are more variable than the transects. This indicates that the strategy of running transects perpendicular to the shelf produced runs which crossed the steepest gradient in the krill density distribution, and consequently lower variation between transects. The best combination of sampling unit and strata in this case is six strata and transects as sample units (Table 2, line 10), producing an estimate of the mean density of 11.7 tonnes km^{-2} and total biomass for the region of 1.8225×10^6 tonnes (CV = 9.5%). Statistics for the 18 transect breakdown (Figure 4) and the six strata breakdown (Figure 5) are given in Tables 4 and 5 respectively. These estimates are based on the assumption of random sampling within strata which is not the case. However, the conclusion that there were generally higher densities of krill in the north east region around South Georgia is reasonable.

Further stratifications were made by water mass, characterised by contiguous regions of similar minimum temperature (Table 2, lines 11 and 12). These do not simply describe strata in the distribution of krill in the region so do not give particularly useful biomass estimates. Bathymetry and temperature are aliased in this region (correlation coefficient, r = -0.428). Analyses of the data to produce estimates of mean density classified by bathymetric region and minimum temperature range are shown in Tables 6 to 8. In all depth regions the highest krill densities were found in the colder, less than zero degree minimum temperature water mass. The highest densities were found in the shelf slope regions of 250 to 1 000 m in depth. The greatest biomass is found offshore and is associated with the colder water regions to the east.

3.2 Kriging Analysis

A simple Kriging analysis was performed using the UNIMAP (1990) software system. A biomass estimate was obtained for an area approximately 1.63×10^5 km^2, which compares with the 1.56×10^5 km^2 used in the above analyses. Blanking regions were defined to set similar boundaries to the area of interpolation to these used in the above estimates. The semivariogram was fitted by eye at an angle to the vertical of 150°; settings used were: range = 1, sill = 650, nugget = 0. No trend corrections were made. This produced the map of krill density shown in Figure 7. The volume of the integrated surface gives an estimate of the total biomass in the region. This was 2.13×10^6 tonnes giving a mean krill density estimate of 13.07 tonnes km^{-2}. Reasonable changes in the parameter settings used in the semivariogram model produced changes in the density estimate of approximately $\pm$ 3 tonnes km^{-2}.

4. DISCUSSION

The target strength value we have used produces larger values for a given MVBS than those used in earlier studies (BIOMASS, 1984). Few data are available to cross reference to this analyses carried out in this study. The density estimated for the West Atlantic section of the Southern Ocean from the BIOMASS cruises (February, 1981) was 4.46 tonnes km^{-2} which is lower than the 11.7 tonnes km^{-2} obtained in the present study. The USSR vessel *Odyssey*

surveyed part of the north side of the South Georgia area during February, 1981 and these results gave a density estimate of 15.63 tonnes km^{-2} (BIOMASS, 1984). In this study the same region produced some of the highest density estimates with stratum values of 13.08 and 23.59 tonnes km^{-2} (Table.5). The BIOMASS analyses used a much higher target strength value so this suggests there was a higher krill biomass in the BIOMASS sampled regions during the early part of 1981 than was observed in this study in the latter part of 1981.

Other estimates of krill density in the South Georgia region are those from trawl based studies (Latogursky *et al.*, 1990). The values for the early part of 1981 are of the same order as those obtained in this study, 37.4 and 5.4 tonnes km^{-2} and are consistent with the *Odyssey* data These values are low compared to other trawl estimates obtained for the region in other years.

The above analyses have highlighted that the various estimation methods based on classical statistical techniques produce little difference in the estimate of mean density but they do affect the variance. Careful design is the only way that a valid estimate of mean density can be obtained. There is little that can be done at the post-processing stage except to consider the precision of the estimate. The underlying estimate may be wrong but there is nothing that can be done about this at this stage. This highlights the importance of careful pre-planning of the survey. Assumptions of randomness at the wrong scale will give incorrect variance results for krill biomass.

The use of Kriging or other spatial statistical techniques clearly requires far more investigation but holds some promise (Foote and Stefansson, 1991). However, we can say at this stage that the simple application of bilinear interpolation techniques is incorrect and is likely to produce erroneous results. The distribution of krill is extremely patchy and the variability of the distribution must be taken into account using an approach such as Kriging. The spatial techniques must be rigorously applied and all of the interpolated estimates should be reported with details of the fits and confidence in the estimates. The development of spatial statistical analytical methods is a continually evolving field of study (Ripley, 1988).

Croxall *et al.* (1985) produced a value of 16 x 10^6 tonnes as an estimate of the consumption of krill by seabirds and seals in Scotia Sea area. Approximately 42% were taken by South Georgia based predators (approximately 6.7 x 10^6 tonnes). The estimate of the standing stock is low compared to the predator consumption figure for the South Georgia area. This predator consumption rate is spread throughout the year and should not be compared directly with standing stock estimates. The Antarctic Circumpolar Current is a potential source of replenishment of the krill stocks in the South Georgia area (Everson, 1984). This is likely to mean that several times the standing stock may be available in the region in any year.

For 6.7 x 10^6 tonnes to be available in a year and assuming no local production then a crude estimate of input rate may be calculated. Assuming the standing stock remains constant and that demand is constant throughout the year, then the estimated demand is 18 356 tonnes day^{-1}. If the krill enter the region only through the eastern side of the box (Figure 1, this dimension is approximately 333 km in length) then 55.1 tonnes are brought in each day along each kilometre of the side of the box. If the density outside the area in the Scotia Sea is in the range 4.5 to 11.7 tonnes km^{-2} then the required flow rates are 0.28 to 0.11 knots respectively. These values are well within the expected current speeds for the region (Foster, 1984).

In this study we have assumed all detected targets in this area are krill, this is unlikely to be the case and will have produced an overestimate of krill biomass. However, some of the krill were much larger than the mean length and use of a mean target strength will have caused underestimation of the biomass. The distribution of the krill within the area is consistent with the suggestion of the occurrence of the Antarctic Surface Water in the region (Everson, 1984; Atkinson and Peck, 1988). This water mass was the cooler water region to the east where the higher densities of krill were recorded during this study. The higher densities of krill in the shelf regions support suggestions that these areas are important in the development of krill aggregations (see Miller and Hampton, 1989 for a discussion).

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Table 1: Definitions of strata used in the analyses of the transect data.

Strata	Description of Stratification
9 transects	Each of the long transects treated as a contiguous sample region (Figure 3).
18 transects	Each of the nine long transects split in the middle (Figure 4).
6 strata	Each set of three half transects were grouped together on the basis of geographic region (Figure 5).
6 strips	Each of the sections running west to east were considered as a single stratum (Figure 6).
3 depth bands	The data were analysed according to bathymetric region. These regions are not necessarily contiguous.
3 temperature bands	The data were analysed according to minimum temperature region. These regions are not necessarily contiguous.
3 temperature regions	Stratum boundaries were set on the basis of contiguous regions of similar temperature.

Table 2: Mean density and total biomass estimates produced by the application of different stratification criteria (Table 1) to the transect data.

	Method of Estimation	Mean Density (tonnes km^{-2})	Variance	Total Biomass (tonnes x 10^6)	Variance
1	Stratified by 18 transects (resets as units)	11.44	0.410	1.8225	0.00950
2	Stratified by 9 transects (resets as units)	11.48	0.419	1.8225	0.01017
3	Stratified by 6 strips (resets as units)	11.86	0.437	1.8225	0.01060
4	Stratified by 54 sections (resets as units)	11.61	0.373	1.8225	0.00906
5	Stratified by 3 depths (resets as units)	11.30	0.438	1.8225	0.01063
6	Stratified by 3 temperature bands (resets as units)	12.11	0.436	1.8225	0.01059
7	Jolly 18 transects (sections as units)	11.70	2.070	1.8225	0.05024
8	Stratified by 6 strata (resets as units)	11.59	0.416	1.8225	0.01011
9	Jolly 6 strata (sections as units)	11.70	1.816	1.8225	0.04408
10	Jolly 6 strata (transects as units)	11.70	1.228	1.8225	0.02980
11	Jolly 3 temp/geographic (transects as units)	11.70	2.969	1.8225	0.07205
12	3 temp/geographic strata (resets as units)	11.27	0.437	1.8225	0.01060

Table 3: Accumulated analysis of variance based on the six regional strata shown in Figure 5.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio
Stratum	5	58306.6	11661.3	20.62
Stratum / Transect	12	21686.3	1807.2	3.20
Stratum / Section	33	101585.0	3078.3	5.44
Residual	1463	827425.3	565.5	
Total		1009003.2	666.9	

Table 4: Mean density and biomass estimates based on the 18 transects defined in Figure 4. Sampling units are transect sections.

Transect	No. of Observations	Density (tonnes km^{-2})	Variance	Area (km^2)	Biomass (tonnes)
1	3	9.13	5.066	9260.7	84566.0
2	2	1.82	0.043	6173.8	11238.4
3	3	6.89	8.282	9260.7	63845.6
4	3	8.61	42.361	8849.2	79772.0
5	3	7.28	1.310	6070.9	67413.0
6	3	1.83	1.215	8231.8	16962.6
7	3	9.42	38.131	6173.8	83401.2
8	2	8.10	37.424	9157.8	49174.5
9	3	6.75	1.702	9260.7	55548.0
10	2	13.29	176.730	9260.7	82074.8
11	3	9.21	20.941	9260.7	84388.0
12	3	16.19	4.319	9260.7	149973.6
13	3	7.32	34.743	9260.7	67834.9
14	3	15.93	48.701	9260.7	147548.3
15	3	16.96	186.101	9260.7	157057.0
16	3	32.16	18.742	9260.7	297800.8
17	3	12.29	49.713	9260.7	113809.4
18	3	22.69	33.960	9260.7	210129.3

Table 5: Mean density and biomass estimates based on the six regional strata (Figure 5). Transects are taken as the basic sample unit.

Stratum	No. of Observations	Density (tonnes km^{-2})	Variance	Area (km^2)	Biomass (tonnes)
1	3	7.77	0.477	27782.2	215824.2
2	3	4.37	5.398	24695.3	107972.9
3	3	8.51	8.510	26238.7	223336.9
4	3	13.08	13.08	21505.5	281222.9
5	3	12.19	12.19	27782.2	338700.6
6	3	23.59	23.59	27782.2	655477.0

Table 6: Classification of the acoustic density data by three water depth ranges.

Depth Region	No. of Records	Min.	Mean (tonnes km^{-2})	Max.	Median	Variance	Area (km^2)	Biomass (tonnes)
< 250 m	170	0.0	6.61	41.63	0.0	83.156	17492.5	115627.7
250 - 1000 m	176	0.0	15.40	341.98	10.16	943.473	18109.9	278926.5
>1000 m	1168	0.0	11.88	336.14	1.52	705.221	120184.9	1427996.6
Total	1514	0.0	11.70	341.98	1.52	666.879	155787.3	1.8225×10^6

Table 7: Classification of the acoustic density data by three classes of the mean minimum temperature of the vertical CTD profiles.

Temp. Region (°C)	No. of Records	Min.	Mean (tonnes km^{-2})	Max.	Median	Variance	Area (km^2)	Biomass (tonnes)
< 0.0	479	0.0	15.30	173.99	3.12	764.854	49287.9	754207.1
0 - 0.5	689	0.0	9.07	336.14	0.00	567.964	70896.5	643017.3
> 0.5	346	0.0	11.95	341.98	2.24	700.396	35602.4	425318.4
Total	1514	0.0	11.70	341.98	1.52	666.879	155786.8	1.8225x10^6

Table 8: Classification of the acoustic density data by water depth and mean minimum temperature.

Temperature Region	Bathymetric Region					
	< 250 m		250 - 1000 m		> 1000 m	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
< 0.0	11.90	2.53	20.28	2.58	15.29	1.17
0 - 0.5	5.70	2.14	14.08	2.27	9.09	1.05
> 0.5	7.66	2.19	16.03	2.03	11.05	1.72

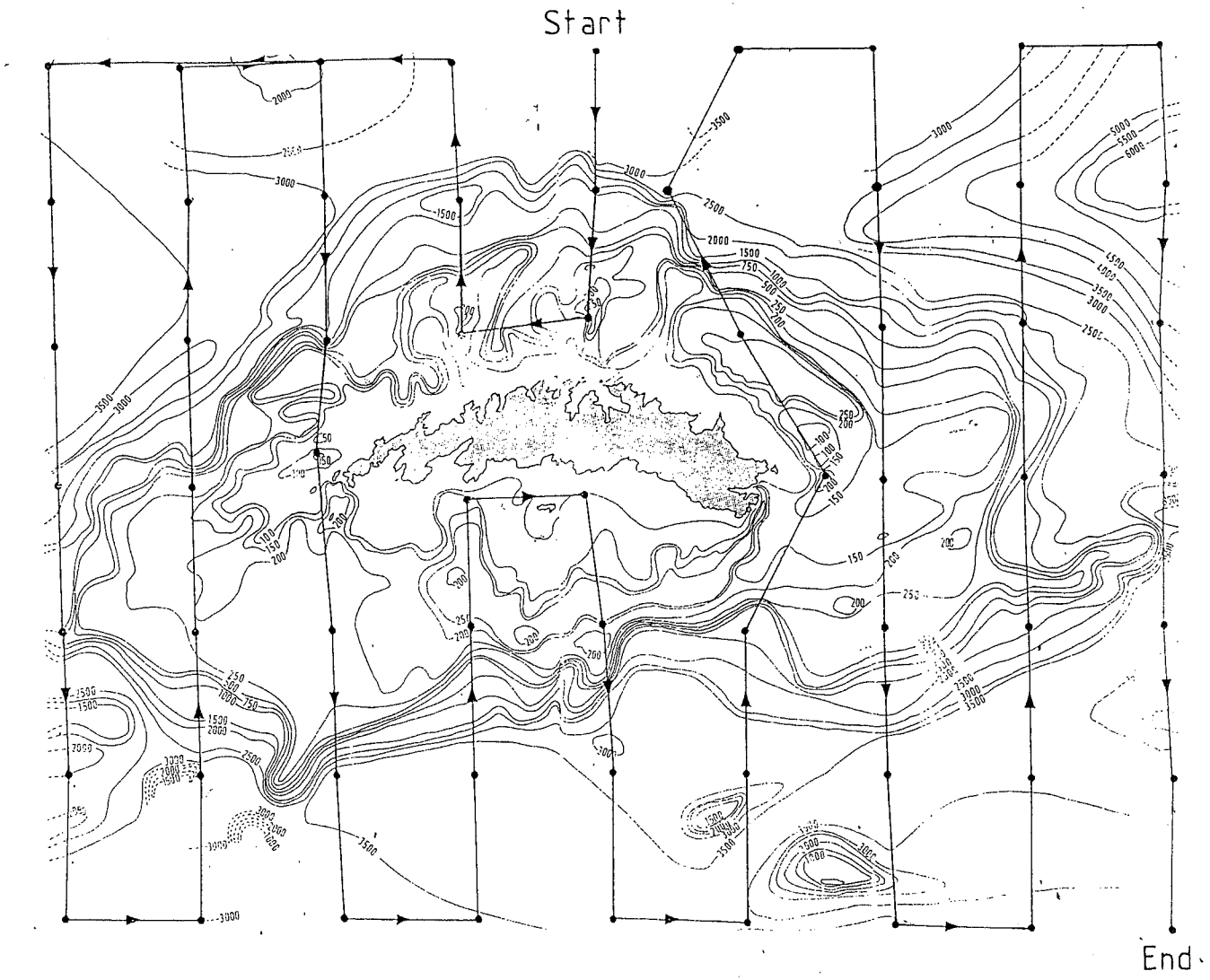


Figure 1: The realised survey track around the island of South Georgia. The survey tracks are approximately 30 n miles apart. The survey box was approximately 240 n miles x 180 n miles. The transecting started on the north side of the box and ended in the southeast corner.

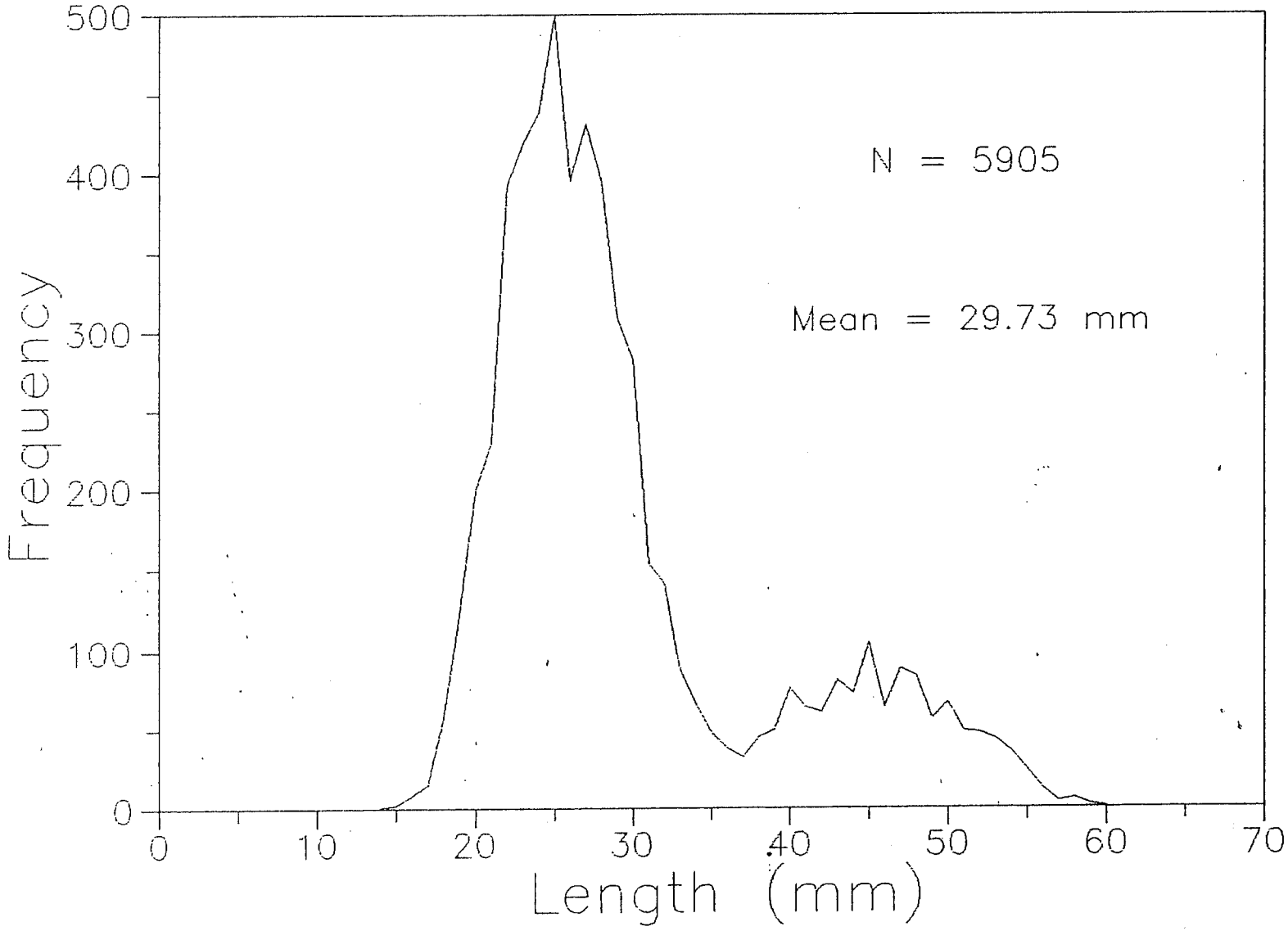


Figure 2: The length of frequency distribution of all krill measured during the survey period, 24 November 1981 to 19 December 1981.

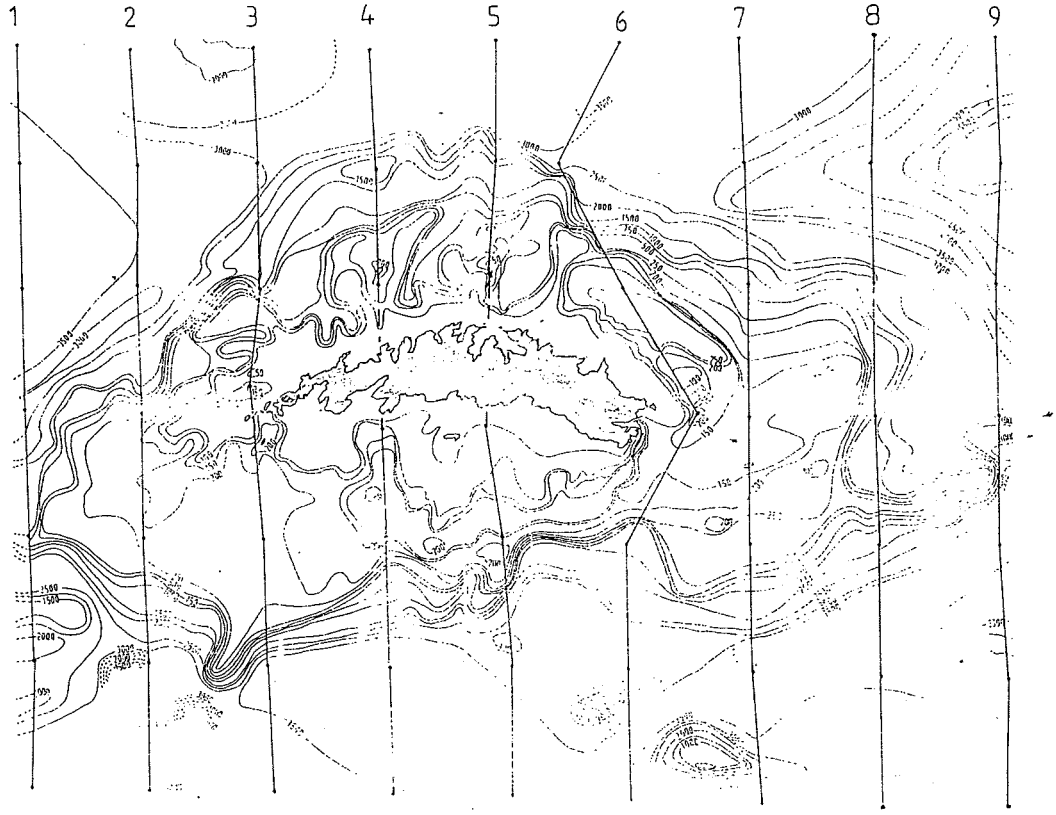


Figure 3: Nine parallel transects.

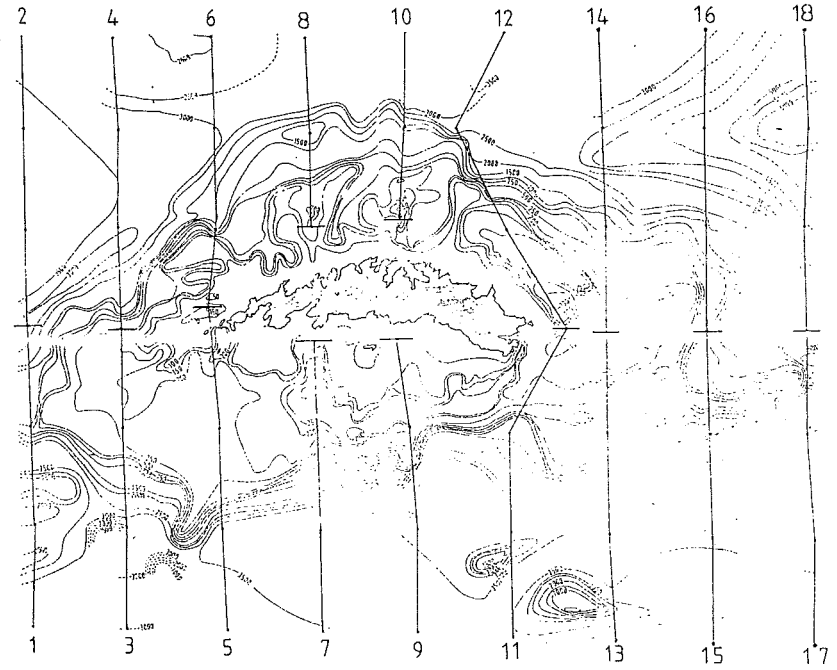


Figure 4: Eighteen transects obtained by splitting the nine transects along the long axis of the island.

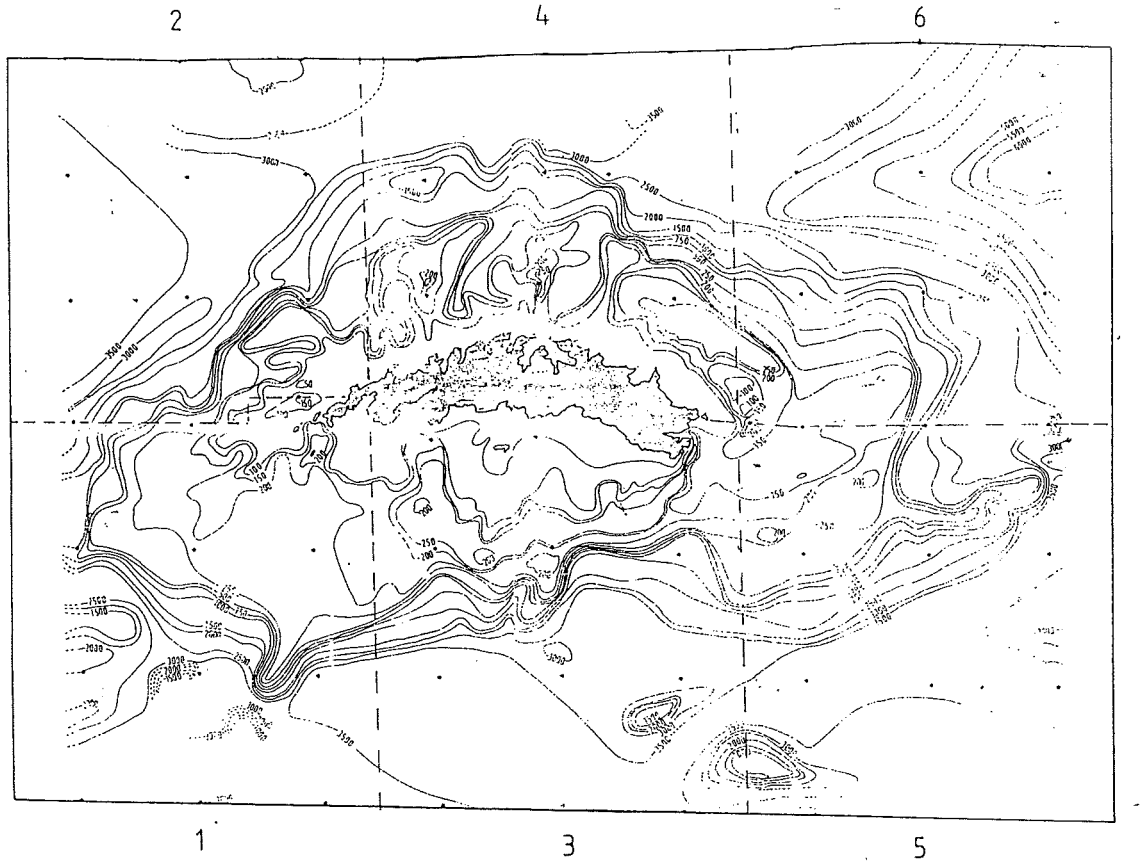


Figure 5: Six regional strata covering on-shelf regions around South Georgia.

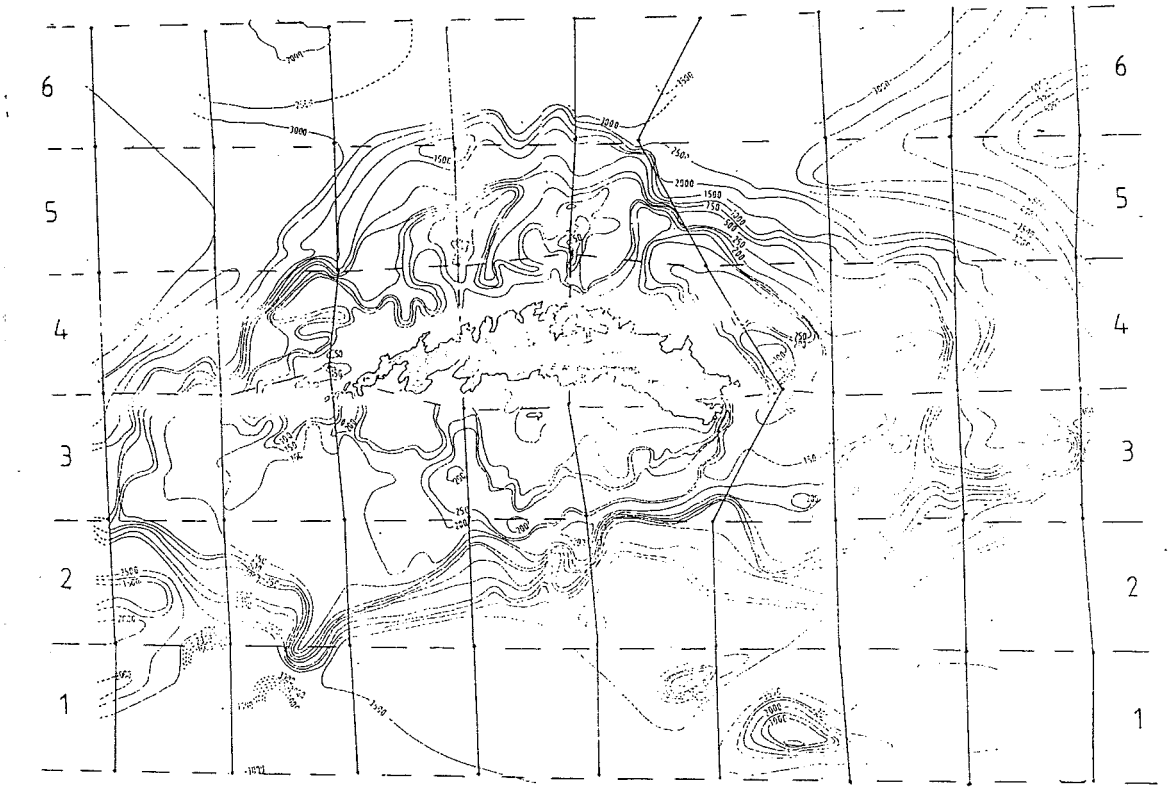
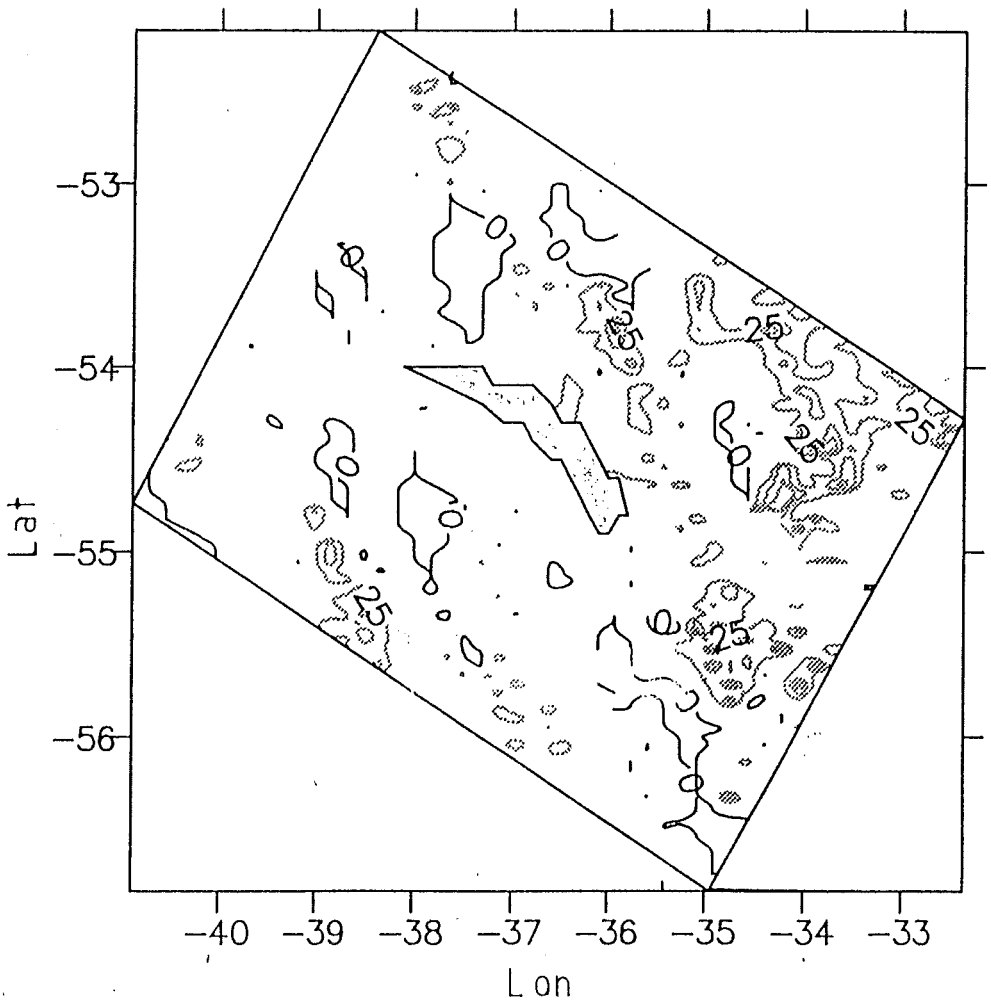


Figure 6: Six strip regions running parallel to the long axis of the island. These are based on the transect sections.



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SMALL SCALE KRILL SURVEYS: SIMULATIONS BASED ON OBSERVED EUPHAUSIID DISTRIBUTIONS

D.J. Agnew*, S. Nicol**

Abstract

An observed distribution of aggregations of the euphausiid, *Meganyctiphanes norvegica* is used to model the effects of krill swarm orientation and shape on the success of two proposed survey designs. The simulation involves a number of random paths of parallel or radially arranged transects passing through three distributions each of which is given four rotations. The results indicate that the coefficient of variation (CV) of mean krill density varies inversely with mean density, and is lowest for the survey design utilising parallel transects set at right angles to the long axis of the aggregations. Calculations based on the power of surveys to reliably detect changes in mean density indicate that with probability of Type I and Type II errors 0.1 and 0.2 respectively, about 100 transects would be required to detect changes of 40% in the mean if CVs are as high as those obtained in the simulations.

Résumé

L'observation d'une répartition de concentrations de l'euphausiacé *Meganyctiphanes norvegica* est utilisée pour la modélisation des effets de l'orientation et de la forme des essaims de krill sur le succès de deux propositions de modèles de campagnes d'évaluation. La simulation met en jeu un certain nombre de voies aléatoires de transects parallèles ou radiaux traversant trois concentrations, chacune d'elle subissant quatre rotations. Les résultats indiquent que le coefficient de variation (CV) de la densité moyenne du krill varie inversement à la densité moyenne et qu'il atteint le taux le plus faible lorsque le modèle d'évaluation utilise les transects parallèles perpendiculaires à la longueur des concentrations. Les calculs, fondés sur la capacité qu'ont les évaluations de déceler les changements de densité moyenne d'une manière fiable, révèlent qu'avec une probabilité d'erreurs de Type I et II de 0,1 et 0,2 respectivement, et pour des CV aussi élevés que ceux obtenus lors des simulations, une centaine de transects seraient nécessaires pour déceler des changements de 40%.

Резюме

Наблюденное распределение агрегаций эвфаузиид, *Meganyctiphanes norvegica* использовано в целях моделирования влияния ориентации и формы скоплений криля на успех двух предложенных схем съемок. Моделирование предполагает несколько произвольных курсов параллельно или радиально организованных разрезов, проходящих через три распределения, каждое из

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которых вращают четыре раза. Результаты показывают, что коэффициент изменчивости (CV) средней плотности криля изменяется обратно пропорционально средней плотности, и является наименьшим, когда схема съемки использует параллельные разрезы, установленные на прямых по отношению к длинной оси агрегаций углах. Вычисления, основанные на способности съемок надежно выявлять изменения в средней плотности, показывают, что при вероятности ошибок Типа I (0,1) и Типа II (0,2), для выявления изменений в среднем на 40%, потребуется около 100 разрезов, если значения CV окажутся такими же, что и при моделировании.

Resumen

A partir de una concentración de distribución conocida del eufausido *Meganyctiphanes norvegica,* se modelan los efectos de la orientación y de la forma de los cardúmenes en el logro de dos diseños de prospección propuestos. La simulación comprende varias rutas aleatorias, en transectos paralelos o radiales, que atraviesan las tres distribuciones y en las que se hacen cuatro giros en cada una. Los resultados indican que el coeficiente de variación (CV) de la densidad media del krill varía inversamente a la densidad media, y que es menor en el diseño de prospección basado en transectos paralelos dispuestos en ángulos rectos al eje longitudinal de la concentración. Los cálculos basados en la potencia de prospección para conocer las variaciones en la densidad media indican que, con la probabilidad de errores de tipo I y tipo II de 0.1 y 0.2 respectivamente, haría falta realizar unos 100 transectos para poder detectar cambios del 40%, siempre que los CV fueran tan altos como los que se obtuvieron en las simulaciones.

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1. INTRODUCTION

During the FIBEX and SIBEX krill biomass surveys various systems of survey design and analysis were considered in order to produce reliable estimates of krill biomass and variance within particular regions around the Antarctic continent. BIOMASS (1980 and 1981) generally recommended that randomly placed transects should run across contour lines in krill abundance, and this meant across the mean direction of ocean currents. Some of the earlier surveys, however, were run with the main transects running east-west. This survey design was used with some success during the BIOMASS experiments (Miller and Hampton, 1989) on areas with diameters up to 500 n miles.

The requirements of prey monitoring for CEMP are, for more localised surveys, directed at regions around CEMP sites for the duration of CEMP predator parameter monitoring; these may be described as having a radius of 50 to 100 km (27 to 50 n miles) (SC-CAMLR-IX, Annex 4, Table 3) and the same criteria as for the BIOMASS surveys (contours of krill abundance) are unlikely to apply. Everson (1987) has considered the requirements of these types of surveys and concluded that a radial transect design may be more suitable and easier to perform than parallel transects.

The analysis suggested for both these designs is that recommended by BIOMASS (1986) and consists of obtaining mean density estimates for krill for a number of transects and

combining these using ratio estimator techniques within strata. This assumes that transects are independent (co-variance is not included) and that variance increases with transect length.

The areal shape of euphausiid aggregations has been reviewed by Miller and Hampton (1989) but information on the spatial relationships of aggregations within known distributions is rare. To our knowledge the only studies of this type are those of Hampton (1985), using side-scan sonar on *Euphausia superba* swarms, and aerial photographs of surface swarms of another euphausiid, *Meganyctiphanes norvegica* (Nicol, 1986). These data show that swarms are predominantly elongated along one axis, and do not generally have shapes that can be approximated by circles, the case that is usually assumed for simulation studies (Butterworth, 1988 has considered some of the consequences of elongated swarms). Furthermore, Nicol (1986) shows that aggregations within an area may be elongated in one direction, presumably in response to current structures in the area.

This paper considers the effect of krill swarm orientation on survey design using real data on the distribution of euphausiid swarms collected by Nicol (1986). We examine the behaviour of random parallel transect and radial transect designs under a number of scenarios, and discuss the implications for the extent and frequency of transects required for the purposes of the CEMP program.

2. METHODS

Two maps of euphausiid distributions are shown in Figures 1(a) and 1(b). Although these are not *E. superba* (being *Meganyctiphanes*) and are on a very small scale (60 m diameter) they are used here to model the types of distributions shown by krill on larger scales. The most important feature of these distributions is that the swarms were observed to be moving and are orientated in a particular direction.

These krill distributions were coded into two areas, divided by 100 x 100 grids (distributions A and B, Figure 1a,). An additional distribution (C) was constructed from distribution A with the addition of two swarms duplicated within distribution A (Figure 1(c)). Each occurrence of krill in a grid square was taken to represent a unit krill density. Random transects were taken over the area and the proportion of krill encountered was expressed as a percentage and taken to represent mean krill density for the transect. This is an equivalent process to that used to calculate mean krill density in $g \cdot m^{-2}$ over a single transect in previous studies (BIOMASS, 1986).

Figures 2(a) and (b) give examples of random transects overlying krill distributions. The parallel transects were overlaid vertically on the grid, and calculation of percentage cover involved searching each pass for krill occurrence. Radial transects were designed on a 90° arc from the origin at the bottom left hand corner with a constant radius of 100 units, but they had a gap close to the origin to simulate the sort of pattern suggested by Everson (1987). Because transects estimate krill density over a larger arc the further they are from the origin, estimates of percentage cover were weighted by the distance from the origin.

Mean density and variance for the whole area was calculated from a number of transects (equation 4 of BIOMASS (1986) simplifies to a standard calculation of variance when transects are all the same length). For comparison, the actual mean density of krill in the area was calculated by taking the total possible area that the transects covered (the total survey area) and calculating the known percentage cover of krill in this area.

For each survey pattern, a number of rotations of the distributions were used to investigate the effects of starting surveys at different positions with regard to the swarms.

3. RESULTS

The results of 10 000 transects on each of the distributions rotated sequentially through 90° intervals is shown in Table 1. It is apparent that the coefficient of variation is usually very high (between 100% and 160%), a result of the high number of passes encountering no krill. Larger surveys are unlikely to have so severe a problem of zero encounters. Krill densities were log normally distributed apart from the zero values. Despite this, the calculated mean density, taken as the mean of all untransformed transect densities, converged on the known mean (Table 1). Figure 3 shows that there was a relationship between the means and the standard deviations. There was a great deal of variation in coefficient of variation (CV) (calculated as standard deviation divided by the mean) using the radial design, in general more so than using the parallel design. The lowest CVs were obtained using the parallel designs with the transects going across the axis of movement of the swarms.

4. DISCUSSION

The coefficients of variation seen in Figure 3(b) are very high, but are similar to those obtained by Higginbottom *et al.* (1988) from 1 n mile integration intervals along transects taken for FIBEX, ADBEX-II and SIBEX-II (mean CV = 1.6). Most reported density and biomass estimates and variances are not directly comparable to those calculated here because following the procedures suggested in BIOMASS (1986) they are variances of the mean densities within a transect $\overline{\rho_k}$, where that transect is typically several hundreds of nautical miles long. Because of the scale used in this study the more appropriate estimates of variance are those of the variance of integration intervals within a transect.

It is not appropriate here to comment on the magnitude of variances that are likely to be obtained in whole surveys of this nature, because of the very small scale of our distributions. However, it is apparent that:

(i) parallel survey designs that travel at right angles to the orientation of krill swarms have lower variances than either parallel designs parallel to their orientation or radial designs. The former is predictable but the latter somewhat surprising - radial designs appear to exacerbate the effect of swarm orientation; and

(ii) with greater mean density of krill the CV obtained by either survey declines.

For the purposes of monitoring krill biomass for CEMP the magnitude of the CV is extremely important. The effect of CV on the power of a survey to detect changes in mean biomass is dependent on the number of transects used. Figure 4 shows the relationship between CV and number of transects required to confidently detect changes in mean densities of 20 to 50% (probability of Type I error = 0.1, probability of Type II error = 0.2) (Sokal and Rohlf, 1981). The number of transects required to reliably detect changes of 20%, for instance, is 28 when the CV is 0.3 and 310 when it is 1.0. Everson (1987) estimates that 10 transects in a CEMP survey could be completed in 10 days. Thus even under favourable conditions, when the CV is close to 0.3, prey surveys may take 30 or more days to complete if sufficient power for inter-annual comparisons is required by the CEMP program.

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Table 1: Mean and standard deviation of krill density calculated from 10 000 random transects on four separate orientations of three krill distributions shown in Figure 1. Direction of rotation is anticlockwise. With this number of transects the standard deviation is taken to approximate σ.

Dataset and Method Used	Real density of Krill in Surveyed Area	Calculated Mean Krill Density After 10 000 Transects	Standard Deviation of Density (σ)
Parallel Survey:			
Area A	4.6	4.59	5.18
Area A rotated 90°	4.6	4.46	6.17
Area B	2.24	2.21	2.87
Area B rotated 90°	2.24	2.19	3.18
Area C	7.85	7.78	6.86
Area C rotated 90°	7.85	7.88	7.04
Radial Survey:			
Area A	5.92	5.89	7.74
Area A rotated 90°	2.28	2.41	3.9
Area A rotated 180°	5.71	5.6	7.49
Area A rotated 270°	5.09	5.04	6.16
Area B	2.56	2.51	3.81
Area B rotated 90°	2.08	2.01	3.17
Area B rotated 180°	2.68	2.59	3.21
Area B rotated 270°	2.86	2.81	3.21
Area C	9.85	9.67	8.18
Area C rotated 90°	6.5	6.64	8.25
Area C rotated 180°	9.94	9.9	8.27
Area C rotated 270°	8.48	8.54	10.58

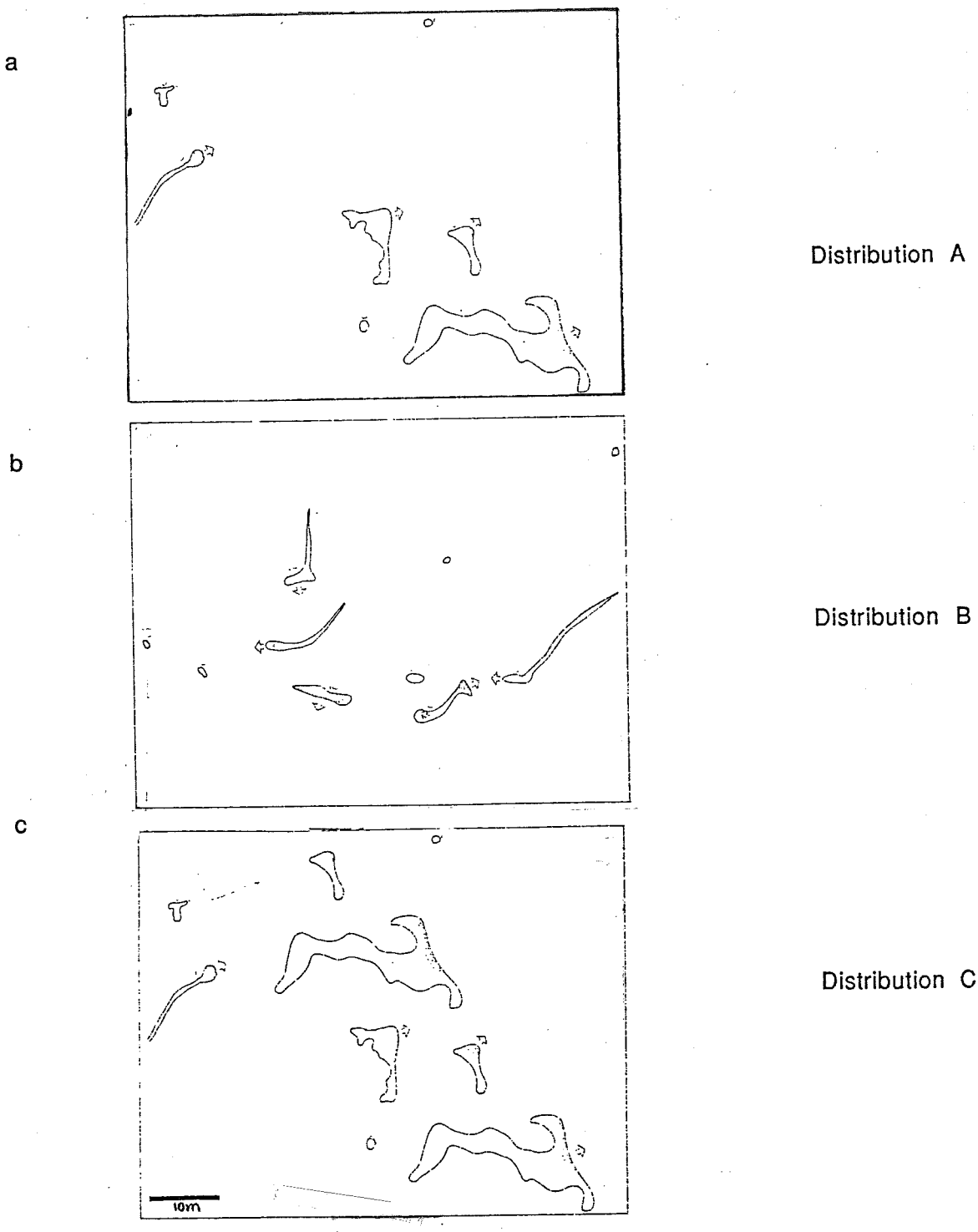


Figure 1: Krill distribution patterns used in the study. Direction of movement of individual swarms is shown by arrows and in general is east-west. The distributions are shown in their unrotated states, and rotation proceeded anticlockwise.

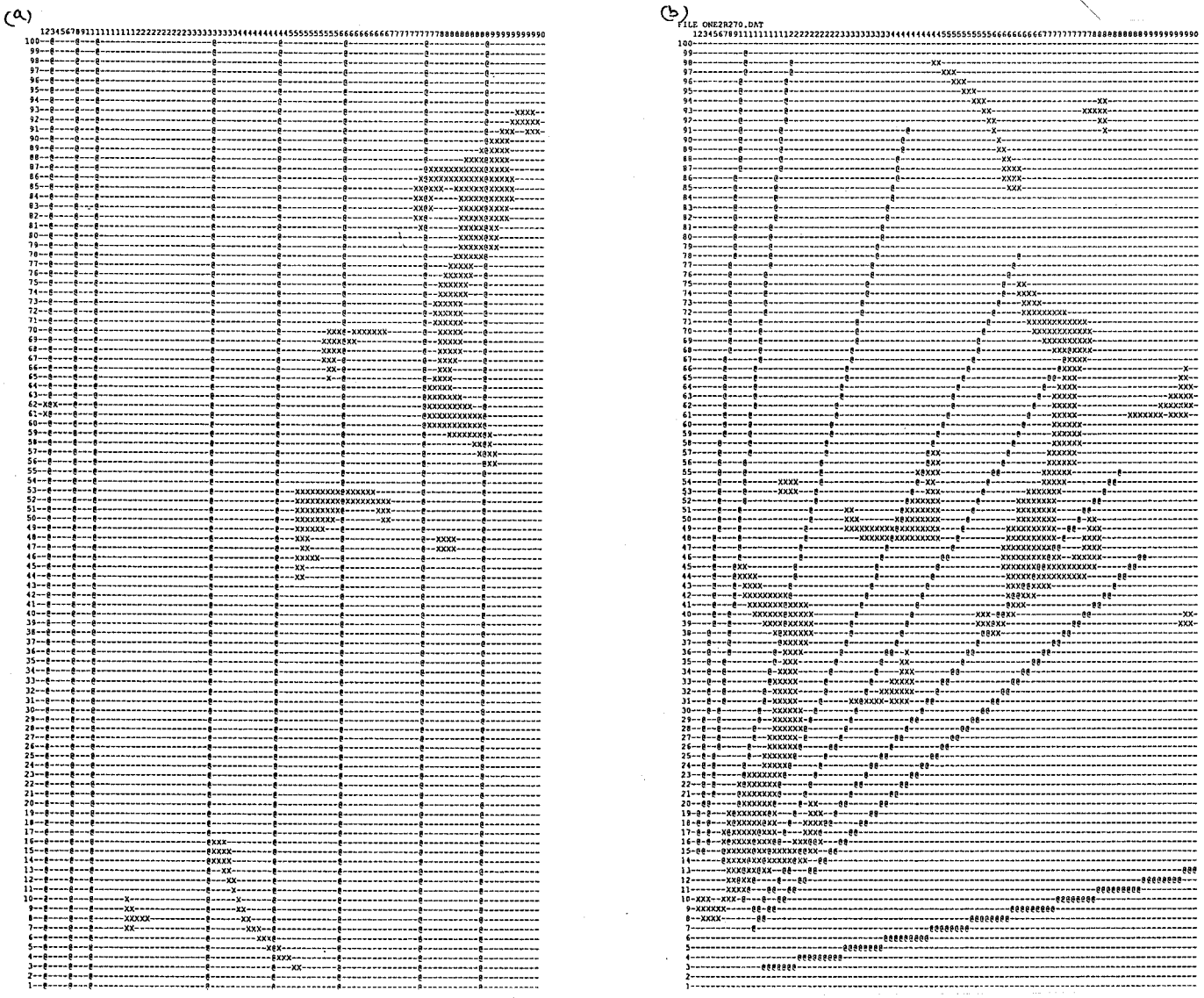


Figure 2: Random parallel (a) and radial (b) transects overlaid on distribution A (90° rotation) and B (270° rotation) respectively.

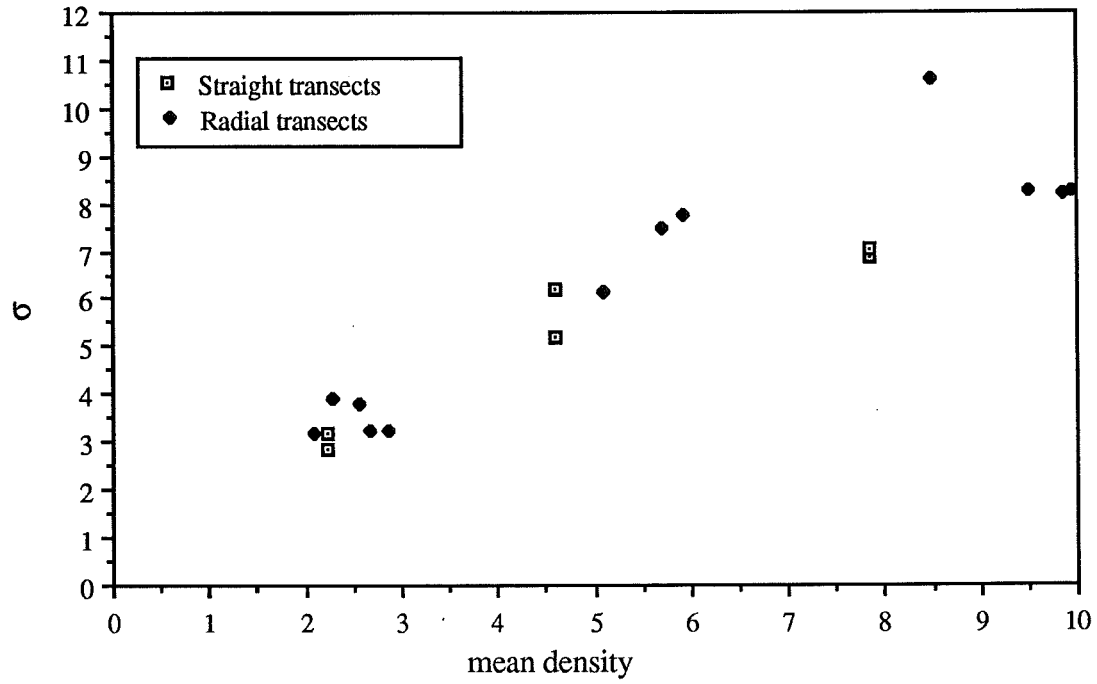


Figure 3(a): Expected mean density versus standard deviation of 10 000 random transects for all three areas in four rotated states. For more explanation of the rotations applied see Table 1.

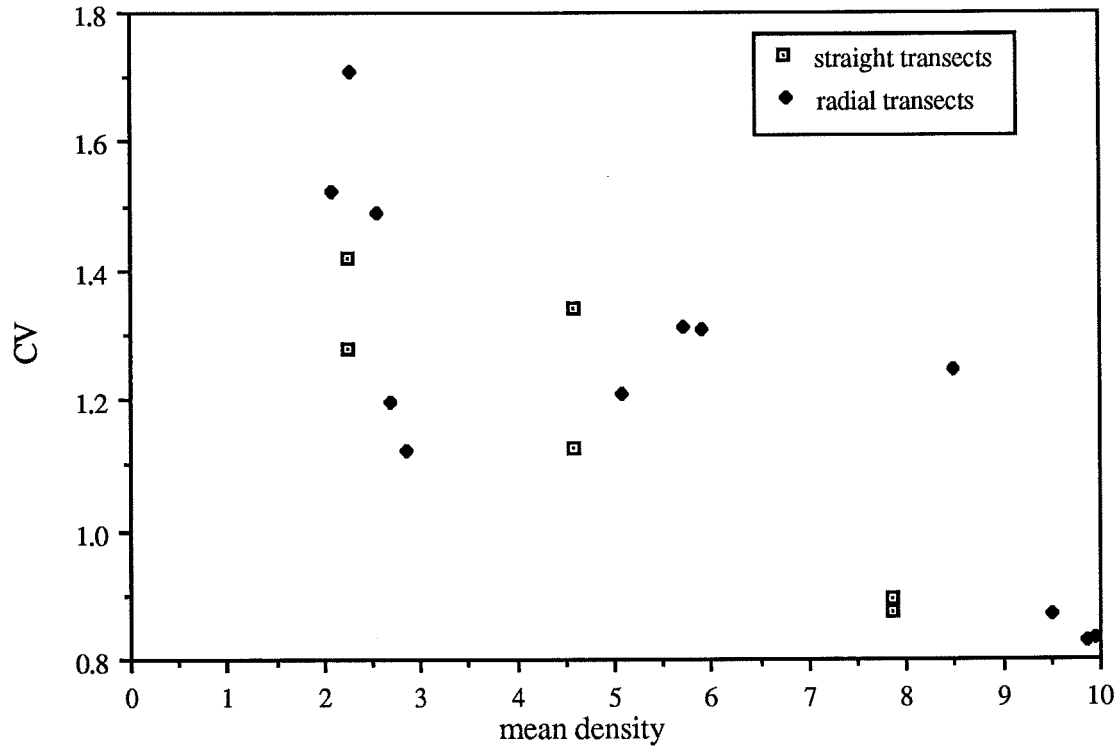
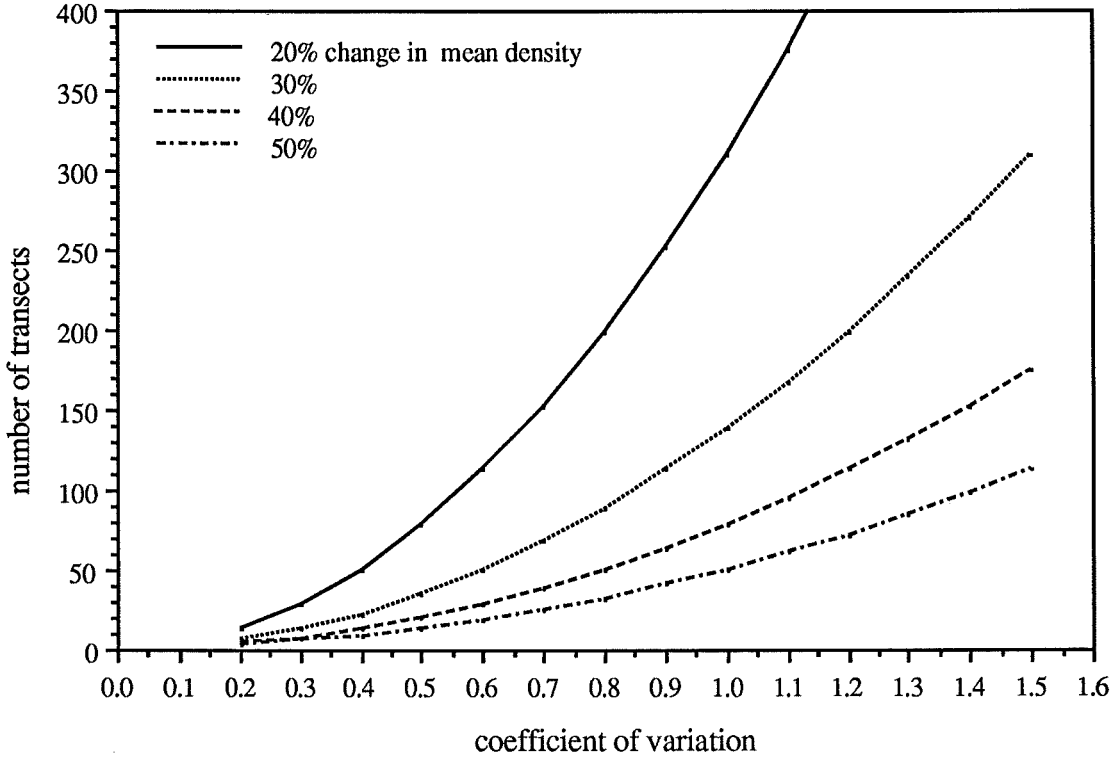


Figure 3(b): Expected mean density versus coefficient of variation of 10 000 random straight and radial transects of four rotations of three krill distributions.



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MIDWATER TRAWL CATCHABILITY AS AN ASPECT OF A QUANTITATIVE ASSESSMENT OF KRILL BIOMASS CONDUCTED USING A TRAWL CENSUS SURVEY

S.M. Kasatkina*

Abstract

Midwater trawl catchability is a variable which depends on both the behavioural and distributional characteristics of the target species and trawl parameters. Reliability of biomass assessments will improve with better knowledge of trawl catchability and krill distribution patterns. A comparative analysis of trawl catchability for commercial midwater trawls and small research trawls, in this case using an Isaacs-Kidd trawl, demonstrated the futility of using the latter for trawl census survey biomass assessments due to their highly variable catchability over the survey area and also because the biomass estimates thus obtained were characterised by high relative error. A standard method for conducting krill trawl census surveys needs to be developed. Mathematical modelling fishing trawls as well as hydroacoustic research on catchability properties of trawls can facilitate selecting the optimal construction of commercial midwater trawls. Assessments of the total amount of krill entering the trawl should be carried out when selecting trawl construction.

Résumé

La capturabilité des chaluts pélagiques est une variable qui dépend des caractéristiques de comportement et de répartition de l'espèce visée ainsi que des paramètres des chaluts. Une connaissance plus approfondie de la capturabilité des chaluts et de la manière dont se répartit le krill entraînera une plus grande fiabilité des évaluations de la biomasse. Une analyse comparative de la capturabilité des chaluts pour les chaluts pélagiques industriels et les petits chaluts de recherche - un chalut Isaacs-Kid étant dans ce cas utilisé -, a démontré combien l'utilisation de ce dernier était futile en ce qui concerne les évaluations de la biomasse provenant des campagnes de recensement par chalutage, du fait de leur capturabilité extrêmement variable sur la zone prospectée et également parce que les estimations ainsi obtenues étaient caractérisées par une erreur relative importante. Il est nécessaire d'élaborer une méthode standard de conduite des campagnes de recensement du krill par chalutage. Une modélisation mathématique liée à des études hydroacoustiques des propriétés de capturabilité des chaluts peut faciliter la sélection du modèle de chalut pélagique industriel le plus favorable. La quantité totale de krill pénétrant dans le chalut devrait être évaluée lors de la sélection du modèle de chalut.

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Резюме

Уловистость разноглубинного трала является переменной величиной, зависящей как от характеристик поведения и распределения облавливаемого объекта так и параметров трала. Улучшенное знание об уловистости трала и характеристик распределения криля в районе съемки позволят повысить надежность получаемых оценок биомассы. Сравнительный анализ уловистостей промысловых разноглубинных тралов и малых исследовательских тралов на примере трала Айзекса-Кидда показал, что последние нецелесообразно использовать для оценок биомассы методом учетных съемок, поскольку они обладают высокими вариациями уловистости на полигоне съемки, а получаемые оценки биомассы характеризуются высокими относительными погрешностями. Необходима разработка стандартной методики учетной траловой съемки криля. Выбор оптимальной конструкции разноглубинного промыслового трала может быть выполнен на основе математического моделирования по моделям статистической теории рыболовных тралов и путем гидроакустических исследований его улавливающих качеств. Выбор конструкции трала должен включать исследования по оценке брутто-изъятия криля.

Resumen

La capturabilidad de las redes de arrastre pelágicas es una variable que depende de las características de distribución y comportamiento de las especies buscadas y de los parámetros del arrastre. La fiabilidad de las evaluaciones de biomasa mejorará al contar con un mejor conocimiento de la capacidad de captura de la red y de la forma de distribución del krill. Un análisis comparativo de la capturabilidad de los arrastres comerciales y la de los pequeños arrastres de investigación, en este caso una red de arrastre Isaacs-Kidd, demostraron que éstos últimos no sirven para hacer censos de evaluación de biomasa debido a la gran variabilidad de la capturabilidad en la zona prospeccionada, y al importante error relativo de las estimaciones de biomasa obtenidas. Es preciso elaborar un método estándar para realizar prospecciones de censo. El modelado matemático de las redes de arrastres, junto con estudios hidroacústicos de las características de capturabilidad, facilitarán la selección óptima del modelo de red de arrastre comercial pelágica. En su selección debería tenerse en cuenta el volumen de krill retenido en el interior de la red.

1. INTRODUCTION

Direct census surveys using midwater trawls as well as scientific research fishing remain part of an integrated approach to krill studies. Various types of midwater research (e.g. RTM-1, RTM-8, MOCNESS, Isaacs-Kidd) and commercial trawls have been used for this purpose.

However fundamental questions such as trawl catchability, the choice of trawl type and the procedure of its exploitation, factors determining the reliability of krill density and biomass estimates, have yet to be fully resolved.

The author has attempted to address the abovementioned problems using hydroacoustics and simulation studies of fishing trawls.

2. METHODOLOGY

It is well known that for trawl census surveys, specific biomass (density) of krill in the catch is expressed in g/m^2 or g/m^3 at the point of trawling (converted to unit of swept volume or unit of total area). Specific krill biomasses are plotted on the survey chart and depth contours are drawn corresponding to the areas fished. Then krill biomass over all depth strata is determined according to mean specific biomass for each stratum. Finally, total krill biomass for the entire survey area is calculated by adding the values for each layer.

Yu.V. Kadilnikov (1988) demonstrated that the following formula is the basis for estimating biomass from trawl surveys:

$$w = \frac{S_o}{S} \cdot \frac{\overline{m}q}{P} \tag{1}$$

$$\text{or } w = \frac{B_o}{B} \cdot \frac{\overline{m}q}{P} \tag{2}$$

where S_o, B_o - area and volume of the study area;

S, B - area and volume fished by the trawl over a standard hauling period;

$\overline{m}q$ - mean catch per standard hauling period **T**;

P - trawl catchability.

Assuming that information on values S_o S, B, B_o contains no errors, the relative error in the biomass estimate from formulas 1 and 2 will be calculated as:

$$\xi(w) = \pm\left[\xi(\overline{m}q) + \xi(P)\right] \tag{3}$$

$$\xi(w) = \pm\left[\xi(\overline{m}\rho) + \xi(P)\right] \tag{4}$$

where ρ - specific biomass

$\xi(\overline{m}q)$ - relative error in estimate of mean catch per standard hauling period T;

$\xi(P)$ - relative error in estimate of trawl catchability;

$\xi(\overline{m}\rho)$ - relative error in specific krill biomass estimate in the swept volume:

$$\xi(\overline{m}q) = \pm\frac{t_\varepsilon}{\sqrt{N}} \cdot \frac{\sigma q}{\overline{m}q} \tag{5}$$

$$\xi(\overline{m}\rho) = \pm\frac{t_\varepsilon}{\sqrt{N}} \cdot \frac{\sigma \rho}{\overline{m}\rho} \tag{6}$$

$$\xi(P) = \pm \frac{t_\varepsilon}{\sqrt{N}} \cdot \frac{\sigma p}{P} \qquad (7)$$

where t_ε - confidence coefficient corresponding to the accepted confidence probability ε

N - number of hauls

$\sigma q, \sigma p, \sigma \rho$ - mean standard deviations in the catch per haul, catchability and specific biomass.

As can be seen from formulas 3 to 7, the error in biomass assessment from trawl survey data is determined by statistical variation coefficients of catchability ($K_p = \sigma_p$/P) and specific biomass density ($K_\rho = \sigma_\rho / \overline{m}\rho$) or by the coefficient of variation of the catch per haul ($K_q = \sigma_q / \overline{m}q$).

Difficulties in estimating the trawl catchability coefficient led to the following assumption: the biomass value obtained using formulas 1 and 2 will be minimal if the catchability coefficient is equal to 1.0.

Moreover, the catchability of research trawls such as the Isaacs-Kidd is generally known to be equal to 1.0, while in the case of a commercial trawl catchability $P = 1.0$ is applied to the fine-meshed attachment in the trawl mouth. Specific krill biomass over the study area are calculated on the basis of this section of the trawl.

In practice, there was a large dispersion of catches per haul during trawl surveys. This necessitated dividing the large amount of catch (or specific biomass) data into several strata over which the coefficients of variation K_q (or $K\rho$) were not high. This made it possible to lower the relative error $\xi(w)$.

The above approach to krill biomass estimation using trawl census surveys is essentially based on the suppositon that the catchability of this type of trawl is a constant value independent of both the distributional patterns of the target object and trawling procedure. The following assumptions can be made in this regard:

- specific biomass densities are determined practically with the same degree of accuracy over the entire survey area;
- biomass estimates obtained in different seasons in a particular area or various areas may be subjected to comparative analysis.

Therefore, the accuracy of krill biomass estimates using trawl census surveys above all depends on the soundness of the assumption regarding consistent catchability of the particular trawl being used.

This paper will not examine matters such as selecting the optimal set of trawl stations or how to process trawl survey data, both of which significantly affect the accuracy of biomass estimates.

An assessment of midwater trawl catchability depending on the main parameters of the trawl and target species distribution, as well as a comparative analysis of the retaining qualities of various midwater trawl designs from the point of view of improving the reliability of krill biomass estimates, were carried out on the basis of experimental and theoretical research.

The main models of the statistical probability theory of fishing trawls were used in theoretical research. This theory allows one to calculate fairly accurately trawl catchability and

catch per ship/day of fishing using information on distributional patterns of target objects and the technichal parameters of the trawl unit (trawl and vessel) (Anon.,1985a). Experiments have proven the applicability of this theory to assessing the retaining qualities of krill trawls (Kasatkina, 1989).

Distributional patterns were assessed in accordance with a set of standard methods (Anon., 1985b).

The hydroacoustic method of determining the retaining qualities of a trawl is based on a comparison of the actual catch with krill biomass estimates obtained using echo integrators located in the effective trawling area and other sections of the trawl (Kasatkina, 1985).

Experiments were conducted using a hydroacoustic unit comprised of two echo integrators, allowing the estimation krill swarm biomass in the effective trawling area as well as in the trawl mouth. This arrangement also enabled an assessment of total catchability ***P*** as a multiple factor event expressed as the following equation (Kadilnikov, 1985):

$$P = P_1 . P_2$$

where P - total catchability
P_1 - the likelihood of krill entering the trawl mouth from the effective trawling area.
P_2 - the likelihood of krill entering the codend from the trawl mouth.

3. RESULTS

Studies of the retaining qualities of midwater trawls were carried out using data from multidisciplinary research by AtlantNIRO in the Scotia Sea from 1983 to 1990.

4. CATCHABILITY OF COMMERCIAL MIDWATER TRAWLS

The catching qualities are discussed following an analysis of the process of krill fishing by several types of trawls. Trawl parameters are given in Table 1.

Experiments were carried out in the fishing areas of the South Sandwhich, South Orkney, South Shetland and South Georgia islands. The dependency of trawl catchability on its working parameters (trawling speed, angle of attack of the net) and distributional patterns of the targetted krill swarms were studied.

Tables 2 to 4 give mean statistical data for estimates of midwater trawl catchability on a number of fishing grounds in the Scotia Sea (Kasatkina, 1990; Kastakina and Latogursky, 1990). Midwater trawl catchability varies considerably within these fishing grounds as the spatial distribution of targetted krill swarms changes.

Analysis of the hydroacoustic assessment of commercial midwater trawl catchability over a wide range of distributional characteristics of targetted krill showed a correlation between catchability and distributional patterns. For example, the correlation coefficient between density of krill swarms and total catchability P for the 72/308 trawl was 0.65.

Moreover, if catchability P_1 (the likelihood of the target entering the trawl mouth from the effective trawling area) greatly depends on such krill distribution characteristics as the depth of the top edge of the krill swarm in relation to trawling depth, then trawling speed and the angle of attack of the net (i.e., the correlation between the trawl mouth and the codend

opening) will have a telling effect on catchability P_2 (the likelihood of the target entering the codend from the trawl mouth area) and the escape coefficient (K_B) for the target passing through trawl netting.

By increasing trawling speed and the angle of attack, krill escapement increases significantly and, consequently, catchability P_2 decreases (Kasatkina, 1988).

Simulation studies were used to analyse the retaining qualities of various types of trawls employed in krill fishing. Calculations were made for several types of krill distributional characteristics and demonstrated that the most effective trawl in terms of krill behaviour is the 74/416 trawl (Zimarev *et al.*, 1990).

5. CATCHABILITY OF RESEARCH TRAWLS USING THE ISAACS-KIDD TRAWL AS AN EXAMPLE

The Isaacs-Kidd research trawl as modified by Samyshev and Aseev, is a midwater weighted trawl operating with one towing rope. The length of the trawl along the topenant is 26.8 metres. Total trawl mouth area is about 7 m^2 and remains constant throught all stages of operation. The trawl is made from 5 mm netting, which is in turn covered by a trawl bag of 20 mm twine. This protects the trawl bag from mechanical damage.

Features of this particular trawl include fast submersion and ease of lowering and raising, which saves time during trawl stations. In addition, trawl catchability is generally accepted as being a constant value equal to 1.0.

We will compare the choice of the Issacs-Kidd trawl for carrying out trawl surveys with a commercial trawl in terms of obtaining reliable krill biomass estimates.

From the description of the Isaacs-Kidd trawl it is clear that this type of trawl does not have a rope section and the guaranteed catch zone begins at the trawl mouth. In accordance with the multiplicitive catchability equation:

$$P = P_1 \times 1 \qquad (13)$$

In other words, catchability of the Isaacs-Kidd trawl will be determined by the likelihood of krill entering the trawl mouth from the catching area.

A comparative analysis of the catching qualities of a commercial trawl and the Isaacs-Kidd trawl was of necessity carried out using mathematical modelling since census surveys were not carried out simultaneously by these trawls in the same study area (Kasatkina, 1990).

Calculations were based on data from a census survey using an Isaacs-Kidd trawl over a small area of 3 270 km^2 near the South Orkney Islands. A 72/308 trawl was used for the sake of comparison. The krill distribution pattern in this area is shown in Figure 1. After the survey this area was stratified by specific biomass.

An assessment of catchability for the Isaacs-Kidd trawl operating between 0 and 100 metres at five depth levels (100, 75, 50, 25, 0 metres) showed that catchability differed significantly from a value of 1.0. There was also substantial variation when trawling depth was changed during each haul. At some trawl stations the coefficient of variation of catchability (Kp) reached 3.50. Mean catchability per haul also varied considerably depending on krill distribution patterns in the study area (Kp = 3.64, Table 5).

At some stations trawl catchability reached $P = 0.2$ at various depths. On the whole, however, the mean statistical value of catchability for the Isaacs-Kidd trawl is lower than the commercial trawl both in relation to individual depth strata and the entire study area (Tables 6 and 7). Also the coefficients of variation of catchability (Kp) for the Isaacs-Kidd trawl were much higher than in the case of the commercial trawl (Tables 6 and 7).

High Kp coefficients for the Issacs-Kidd trawl caused high relative errors ξ(w) in the biomass estimate. Table 5 shows the errors $\xi(w)$ are different over the depth layers. It would therefore be incorrect to summarise the biomass estimates made with different relative errors.

6. DISCUSSION

It has been demonstrated that midwater trawl catchability depends on the trawl's parameters and the behaviour and spatial distribution of the target species. Moreover, the heterogeneous nature of krill swarm distribution over the study area and the variability of this distribution in time substantially contribute to changes in the trawl's catchability. As a consequence of this, each trawl census survey will have its own distribution of catchability, characterised by mean statistical parameters, for the particular trawl used.

The assumption that midwater trawl catchability is a constant value during trawl surveys does not correspond to reality.

Therefore, census surveys used to obtain a quantitative estimate of krill biomass must be accompanied by an assessment of mean statistical parameters of the trawl used.

Since midwater trawls are used to conduct census surveys, the choice of which one to use must be made with a view to obtaining reliable assessments of krill biomass.

A comparative analysis of the catchability of midwater trawl and the Isaacs-Kidd trawl demonstrated that the latter should not be used to assess krill biomass since its catchability CVs are high over the survey area and the biomass estimates obtained are characterised by a high degree of relative error.

Calculations showed that in order to guarantee a relative error of catchability no less than ξ x(P) = 0.1, it would be necessary to carry out over the study area 20 hauls with a commercial trawl and by almost an order of two more than that with an Isaacs-Kidd trawl.

The catch per haul coefficient of variation (Kq) of the Isaacs-Kidd trawl used in krill fishing is significant (see Table 5), which is caused by a small effective trawling area (30 minutes trawling with the Isaacs-Kidd, $B = 2\text{x}10^4\text{m}^3$; the same time trawling with the 72/308, $B = 11.34\text{x}106\text{m}^3$) and a high coefficient of variation Kp. It could be proven that with two trawls operating in the same area, one could expect the coefficient Kq for the Isaacs-Kidd to be greater by almost an order of magnitude than the commercial 72/308 trawl, thanks only to their different trawl operational areas (Kadilnikov, 1988).

The Isaacs-Kidd trawl has an advantage over the commercial trawl in that it allows one to save time during trawl stations. On the other hand, it gives less accurate biomass estimates.

Small research trawls (e.g. Isaacs-Kidd, RMT-8 etc.) have one more disadvantage. Krill is able to avoid these trawls. Moreover, krill's reaction to them manifests itself in various ways during the day and at night (Everson, 1986). We recall that the vertical opening of the Isaacs-Kidd trawl is only 2.3 metres, while krill can attain a "burst" speed of 60 cm per second (Kils, 1981). In particular, when fishing krill with the RMT-8 trawl, the latter travelled a distance of 10 metres away from the trawl in 8 seconds (Everson, 1986). Since krill speed

depends on its length, size composition of catches landed by commercial and research trawls will be different. A histogram has shown that, compared with a commercial trawl, krill length distribution of catches made by a small research trawl tends significantly towards smaller sized individuals (Siegel, 1982).

In our opinion, therefore, the Isaacs-Kidd trawl cannot replace commercial trawls for krill census surveys both in terms of accuracy of biomass estimates and qualitative assessment of krill swarms.

It would seem appropriate to conduct fishing with two types of trawl (commercial and small research) simultaneously to obtain a qualitative assessment of krill swarms.

For estimating krill biomass density during trawl census surveys commercial trawls are recommended. Coefficients of variation for catch per haul and trawl catchability may be substantially decreased if a rational trawl design is chosen.

Choosing the best trawl design may be facilitated by simulation studies and hydroacoustic research into its catching capabilities. Also, assessments of the total amount of krill entering the trawl should be carried out when selecting trawl design (Zimarev, Kasatkina and Frolov, 1990).

As mentioned above, census surveys should be conducted together with catchability assessments of the midwater trawl used. This may be done using hydroacoustic methods or by calculations based on information about krill distribution patterns in the survey area. In this regard, it would be a good idea to use during census surveys automatic data recording and processing systems for data on spatial distribution of the target species.

It should be noted that planning the network of trawl stations and processing trawl survey data should be based on knowledge of krill distributional patterns in the study area.

7. CONCLUSIONS

Midwater trawl catchability is a variable depending on the behavioural and distributional patterns of the target species, as well as on trawl parameters.

Reliability of biomass estimates can be improved by knowledge of trawl catchability and krill distribution in the survey area.

In terms of accuracy of biomass estimates, commercial trawls are preferable to the Isaacs-Kidd and similar small research trawls.

A standard method for conducting krill trawl census surveys needs to be developed, including the selection of an optimal midwater trawl construction and operating procedure.

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Table 1: Principal parameters of midwater krill trawls.

Parameter	Trawl type			
	72/308	74/416	76/400	67.5/336
Vertical opening from the headline to the footrope (metres)	35	40	43	43
Horizontal and vertical mouth opening in the fine-mesh section (metres)	9.8	11.0	17	13
Horizontal opening between trawl boards (metres)	100	60	70	110
Horizontal opening between wings (metres)	40	35	37	35
Trawl length along the topenant - from wingtips to the fine-mesh section (metres)	115	141	138	115
Length of cables (metres)	150	100	100	150
Angle of attack - cables (degrees)	11.5	7.2	9.5	16.1
Angle of attack - trawl netting in horizontal aspect (degrees)	7.5	4.9	4.2	6
Angle of attack - trawl netting in vertical aspect (degrees)	6.3	5.9	5.4	8.3
Trawling speed (knots)	3.5	3.5	3.5	3.5
Length of trawl board rib (metres)	4	4	4	4
Mesh size in trawl bag (mm)	6.5	10	12	12

Table 2: Mean statistical data on krill swarm distribution patterns and midwater trawl catchability in various fishing areas (Kasatkina, 1990).

Parameter	Sandwich Is.	South Orkney Islands				Elephant Island		
	March 1983	April 1983	May 1983	Dec 1984	Jan 1985	Nov 1984	Dec 1985	Jan 1985
	Trawl 67.5/336	Trawl 67.5/336		Trawl 72/308		Trawl 72/308		
Mean thickness of layer over which swarms are distributed (metres)	62	35	50	33	44	52	57	39
Mean swarm depth (metres)	42	29	41	24	29	25	30	21
σ, swarm depth	13	20	13	8	10	14	16	8
Mean swarm thickness	9	8	15.6	6	9	6	7	3
σ, swarm thickness (metres)	2	4	6	2	6	2	4	1
Mean swarm length (metres)	37	47	59	30	23	20	29	17
σ, mean swarm length (metres)	15	16	19	7	10	7	20	4
Swarm density field in 2-dimensions, λ_s m^{-2}	1.65×10^{4}	4.95×10^{5}	1.96×10^{5}	1.94×10^{3}	8.3×10^{4}	1.94×10^{3}	1.95×10^{3}	6.19×10^{3}
β	0.0393	0.067	0.188	0.1266	0.1165	0.0667	0.2670	0.1211
Estimate of mathematical expectation of total catchability, P	0.0353	0.0457	0.063	0.0453	0.0439	0.0353	0.0530	0.0582
σ, total catchability	0.0081	0.0053	0.017	0.0109	0.0304	0.0106	0.0201	0.0231

Table 3: Mean krill distribution characteristics and catchability of trawl 74/416 in the Coronation Island area (Kasatkina, Latogursky, 1990).

Parameter	Period				
	4.12-18.12.1989	19.12.89-7.1.90	8.1-28.1.1990	29.1-18.2.1990	19.2-27.2.1990
Mean thickness of layer over which swarms are distributed (metres)	100	99	100	86	105
Mean swarm thickness (metres)	15	18	5	17	19
σ, swarm thickness (metres)	4	7	2	6	8
Mean swarm length (metres)	72	89	28	89	65
σ, swarm length (metres)	21	25	12	23	18
Mean swarm diameter (assuming that swarms are cylindrical) (metres)	92	120	36	120	84
Mean swarm volume (m^3)	9.97×10^4	2.03×10^5	5.09×10^3	1.92×10^5	1.05×10^5
Mean swarm density in 3-dimensions	0.0298	0.0982	0.2796	0.188	0.168
Swarm density field in 2-dimensions, λ_s m^{-2}	2.98×10^5	4.78×10^5	5.4×10^3	7.52×10^5	1.11×10^4
Mean krill concentration density (g/m^3) - calculated estimate	4.49	4.07	2.20	5.88	9.46
Calculated estimate of total catchability *P* for a 74/416 trawl	0.0605	0.068	0.1253	0.0807	0.101

Table 4: Total catchability estimates for the 72/308 trawl in various areas of the Scotia Sea (Kasatkina, 1990).

Area	Estimate of mathematical expectation of total catchability P	Total catchability σ_p
Elephant Island, Jan 1985		
Fishing grounds	0.0582	0.0231
Remaining waters	0.0341	0.0078
South Orkney Islands		
Fishing grounds	0.0439	0.304
Remaining waters	0.0291	0.019

Table 5: Summary data on the Isaacs-Kidd trawl catchability and relative error in biomass estimate over the survey period (Kasatkina, 1990).

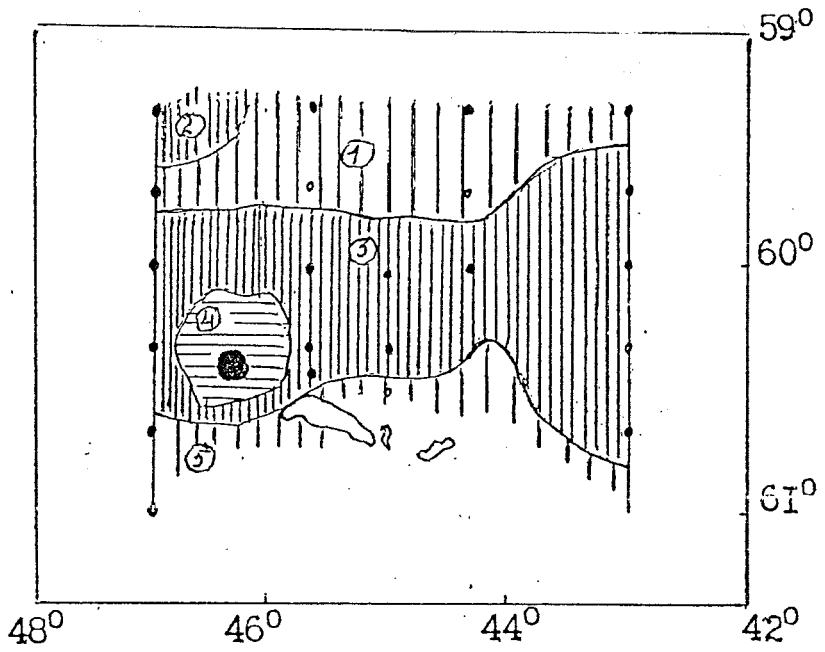
Strata	Total catchability			Relative error in estimate		
	Estimate of mathematical expectation P	σ_p	Coefficient of variation K_p	Specific biomass ξ (m_p)	Catchability ξ (P)	Biomass ξ (w)
1	0.0191	0.0601	3.15	0.935	1.3	2.235
3, 2	0.0177	0.0611	3.45	0.26	1.04	1.30
5	0.0035	0.0088	2.5	1.032	0.927	1.959

Table 6: Summary catchability estimates for the 72/308 trawl used in krill census surveys (Kasatkina, 1990).

Strata	Total catchability			Relative error in catchability estimate ξ (P)
	Mathematical expectation, P	σ_p	Coefficient of variation - K_p	
1	0.054	0.0044	0.081	0.10
3 and 2	0.048	0.00456	0.095	0.08
5	0.0288	0.00428	0.15	0.158

Table 7: Statistical estimates of midwater trawl catchability over the survey area (Kasatkina, 1990).

Type of trawl	Total catchability		
	Mathematical expectation, P	σ_p	Coefficient of variation - K_p
Commercial trawl	0.0435	0.00989	0.207
Isaacs-Kidd	0.0127	0.0462	3.64



Specific biomass density (mg/m^3)

10-100

100-500

500-1000

1000

① - stratum number

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CHILEAN KRILL FISHERY: ANALYSIS OF THE 1991 SEASON

Victor H. Marín*, Armando Mujica** and Patricio Eberhard***

Abstract

This paper summarises Chilean catch data for 1991. Special emphasis is given to the analysis of haul-by-haul data and its use in studying small-scale spatial distribution of catches. The results show that krill fishing in Subarea 48.1 is particularly intense near CEMP sites. Other ways of using of haul-by-haul data are suggested.

Résumé

Le présent document récapitule les données de capture chiliennes de 1991. Il met l'accent sur l'analyse des données par trait et son utilisation dans l'étude de la distribution spatiale à petite échelle des captures. Les résultats mettent en évidence l'intensité particulière de la pêche de krill à proximité des sites du CEMP de la sous-zone 48.1. Quelques suggestions sont avancées sur les autres utilisations possibles des données par trait.

Резюме

В настоящей работе суммируются данные по промыслу Чили за 1991 г. Особое внимание уделено анализу данных за каждое отдельное траление и их использование в изучении мелкомасштабного пространственного распределения уловов. Результаты показывают на то, что промысел криля в Подрайоне 48.1 особенно интенсивен вблизи участков CEMP. Также предложены другие способы использования данных за каждое отдельное траление.

Resumen

Este documento resume la información de las capturas de krill en 1991 realizadas por Chile. Se destaca la importancia del análisis de información de lances individuales y su utilidad en el estudio de la distribución espacial de las capturas a escala fina. Los resultados muestran que la pesca de krill en la Subárea 48.1 es intensa cerca de las localidades del CEMP. También se sugieren otras formas de utilizar los datos de lance por lance.

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1. INTRODUCTION

The main objective of CCAMLR, by definition, is the conservation of the Antarctic marine living resources. Krill is by far the most abundant resource. The analysis of the krill fishery is the major task of the Working Group of Krill (WG-Krill) including among other jobs to review and evaluate information concerning the size, distribution and composition of commercial krill catches, including likely future trends in these catches (SC-CAMLR 1988, paragraph 2.26). At its 1989 meeting, WG-Krill agreed that analyses of haul-by-haul data should commence as soon as possible (SC-CAMLR 1989, Annex 5, paragraph 78). During the second meeting of WG-Krill in 1990 there was some discussion on the use of haul-by-haul data (SC-CAMLR 1990, Annex 4, paragraphs 114 and 115) and WG-Krill felt that some preliminary analyses are needed. Accordingly, the Chilean National Fisheries Service (CNFS) produced a form to collect haul-by-haul information. The main objective of this article is to present a preliminary analyses of the haul-by-haul data.

2. GENERAL CHARACTERISTICS OF THE CHILEAN FISHERY

The Chilean krill fishery has operated, except for the year 1983, only in the Subarea 48.1, comprising from 5% to 100% of the krill fishery in that subarea (Figure 1). The catch is used in the production of feed either as frozen krill or meal. For that reason, quality is a substantial component in the fishing operation. The personnel operating the vessels recognise three categories of krill with respect to colour: red, pink and white. Their target is the red krill, since the product is sold, among others, to the salmon industry. In this regard the product being sold is the carotenoid of either the frozen krill or the krill meal. For the same reason, green feeding krill and gravid females are avoided by the fishery.

In producing frozen krill, the whole animal is frozen without any additional processing. The size of the catch (haul-by-haul) is regulated by the processing capability of the vessel and as a rule does not exceed 10 tonnes at the time. The total catch is regulated by the capacity of the freezers.

3. CHILEAN KRILL FISHERY DURING 1991

3.1 General Overview

During the 1991 fishing season Chile sent one factory vessel to fish for krill in Antarctic waters. The total catch for the season was 3 679 tonnes. This catch level is about 19% lower than the 1990 level when two vessels were fishing. The products from 1991 were 251 tonnes of krill meal and 1 265 tonnes of frozen krill. These quantities correspond to the maximum transportation capacity of the vessel.

Figure 2 shows the total catch-per-day during the season. The average total catch-per-day was 108 tonnes, a maximum of 160 tonnes was obtained at the end of the season. A total of 419 hauls were taken. The number of hauls-per-day remained between 12 and 14 for the whole season except for three days (Figure 3). The total effort-per-day, measured as total towing time, ranged between 3 and 14 hours (Figure 4). During the first 20 days the effort ranged between 6 and 12 hours, decreasing to a lower level during the last 14 days. This shift in effort had a major effect, as it is shown below, in the CPUE values. The reason for this is that due to processing constraints the catch (haul-by-haul) is maintained at relatively low values (9 000 tonnes on average), adjusting the effort accordingly.

The fact that the Chilean krill fishery operates only in Subarea 48.1 and takes a consistent portion of the total catch in the subarea, allowed us to study interannual changes in CPUE from 1987 to 1991. Average and maximum (haul-by-haul) CPUE values, expressed as catch-per towing time were calculated and are shown in Figure 5. Both the average value and

the maximum show the same trend: an increase from 1987 to 1988, followed by a decrease during 1989-1990 and a further increase in 1991. The increase during 1987-1988 agrees with data from Miller (1989).

3.2 Spatial Distribution of Hauls

In 1991, fishing took place in the northern shelf of the South Shetlands. The season started 20 February near Livingston Is. and ended 25 March near Elephant Is. (Figure 6). This pattern of movement is similar to that described by Endo and Ichii (1989) for Japanese trawlers in the same area.

The analyses of the distribution of hauls in space showed three major fishing sectors (Figure 6): sector (1), the northern shelf of Livingston Is.; sector (2), the area north of Robert Is. and Nelson Is.; and (3) the northern shelf of Elephant Is. Fishing in sector (1) lasted for 19 days, 4 days in sector (2) and 11 days in sector (3). The three sectors had bottom depths shallower than 300 m. Figure 7 shows the depth of the hauls. The maximum daily average trawling depth was approximately 85 m, however, most of the time trawling depth was between 44 and 60 m.

Our data together with the data presented in Endo and Ichii (1989) and the CCAMLR fine-scale data information (SC-CAMLR, 1991) show that there are two consistent fishing grounds in Subarea 48.1: north of Livingston Is. and north of Elephant Is. Both areas correspond to shallow shelf waters. It is important to note that in both areas there are large colonies of land-based krill predators. In fact during 1990 Chile and USA submitted proposals for CEMP sites at Cape Shirreff (Livingston Is.) and Seal Is. (Elephant Is. sector) respectively (CCAMLR 1990, paragraph 6.3). Feeding grounds for land-based predators may extend 100 km from the colony. Thus, the most important fishing grounds in Subarea 48.1 occur well within feeding areas of these predators.

3.3 Haul-by-Haul CPUE Data

We have attempted a preliminary analysis of haul-by-haul data collected during 1991. The objective of this analysis was a comparison between Livingston Is. and Elephant Is. fishing grounds. We envisage that this preliminary treatment of haul-by-haul data will promote further analysis and discussions on the use of this data.

All analyses were conducted in terms of catch-per-unit-effort, using towing time as effort. Figure 8 shows the daily average and range of CPUE values during 1991. CPUE remained stable during the first 23 days increasing in the last 11 days. Haul-by-haul data were plotted against haul number in order to study CPUE changes in detail. Figure 9 shows the data for areas (1) and (2), Figure 10 shows the data for area (3).

In areas (1) + (2) only 0.8% of the hauls exceeded 1 tonne min^{-1}, in area (3) all hauls exceeded that level (ANOVA). We conducted a correlation analysis to study the spatial dimensions of the "krill patches" in terms of number of hauls-per-patch. An autocorrelation function was calculated for both the total catch-per-haul and CPUE (Figures 11 and 12). The point of interest in this analysis is the position of the first zero crossing. This point gives some idea on the spatial structure of the hauls. The results show that the autocorrelation function for both variables "dies out" after five hauls, suggesting that on average the vessel move away from a patch after five hauls. This result was independent of the area fished, suggesting that although there were differences in CPUE, the spatial structure did not change significantly.

Finally we analysed the detailed movement of the vessel in an attempt to study the advection of krill patches into the whole area. The vessel move to area (2) on 21 February finding a patch centre at around 62°10'S, 60°W. This patch was fished for two days (21 to

23 February) yielding 260 tonnes (CPUE = 12.9 tonnes hr $^{-1}$). Later in the season, on 10 March the vessel returned to area (2). This time finding a patch at about 62°S, 59°13'W. This patch was fished for another two days yielding 264 tonnes (CPUE = 9.3 tonnes hr $^{-1}$).

If we assume that the two patches in area (2) were the same, we could calculate the advection of krill into this area. Under this assumption the patch moved about 40 miles in 17 days which gives a drift speed of 5 cm s^{-1}. If we use that figure, we could then calculate the time that it would take for a patch to move from Livingston Is. to Elephant Is. (distance near 420 n. miles). According to our estimate it would take 179 days or six months for a patch to passively drift from one fishing area to another. Even if we consider doubling the drifting speed it would take about three months to move between these two areas. Fishing season lasted 34 days. Thus for a given season, both areas would be treated as independent fishing grounds. This analysis does not allow that krill could swim actively from area to area.

3.4 Scientific Observers and By-Catch

Scientific observers went on board the commercial vessel during 1991. Sampling comprised of two litre samples from each haul to analyse krill and a by-catch of fish. These data are currently being analysed. A total of 169 hauls were analysed for by-catch. Adult fishes of 13 species belonging to five families were found in 42 hauls (Table 1). Myctophids were the most abundant, especially in the area near Elephant Is. Juveniles were more abundant than adults, however, no species identification was possible at this time. This work is currently underway.

4. CONCLUSIONS

Analyses of haul-by-haul CPUE data could be an important tool in the study of small scale spatial distribution of fishing grounds. In this regard the results of such an analysis may be very applicable to CEMP studies. Here we have shown that fishing grounds and potential feeding grounds of land-based predators coincide in space. Furthermore, our data show that in Subarea 48.1 the largest fishing grounds are near CEMP sites. A study of ecological consequences of this type of fishing activity (shallow water) is a primary task for both WG-Krill and WG-CEMP. Haul-by-haul CPUE data from other fishing areas will be necessary in order to continue this analysis.

Haul-by-haul data are also valuable if they are combined with scientific observations on board commercial vessels. They can help in identifying "stocks" and also in providing a first insight on the advection of krill in some areas. All these studies require detailed data on vessel position for each haul; ie., latitude and longitude in degrees and minutes. In summary, analysis of haul-by-haul CPUE data may be an important way of analysing the potential impact of krill fishing on other components of the Antarctic ecosystem. For the review, a submission of haul-by-haul data to CCAMLR should be continued.

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SC-CAMLR. 1991. Fine-scale catches of krill reported to CCAMLR. 1988-1990. Document *WG-Krill-91/9*. CCAMLR, Hobart, Australia.

Table 1: Species of fish found as by-catch during krill fishing in Subarea 48.1 (1991 season). Data from scientific observers on board of a Chilean commercial vessel.

Family:	Species:
Nototheniidae	*Notothenia gibberifrons* *Notothenia squamifrons* *Pleuragramma antarcticum*
Channichthyidae	*Neopagetopsis ionah* *Chaenocephalus aceratus* *Champsocephalus gunnari* *Chionodraco rastrospinosus*
Bathydraconidae	*Parachaenichthys charcoti*
Paralepididae	*Notolepis coatsi*
Myctophidae	(two unidentified species)

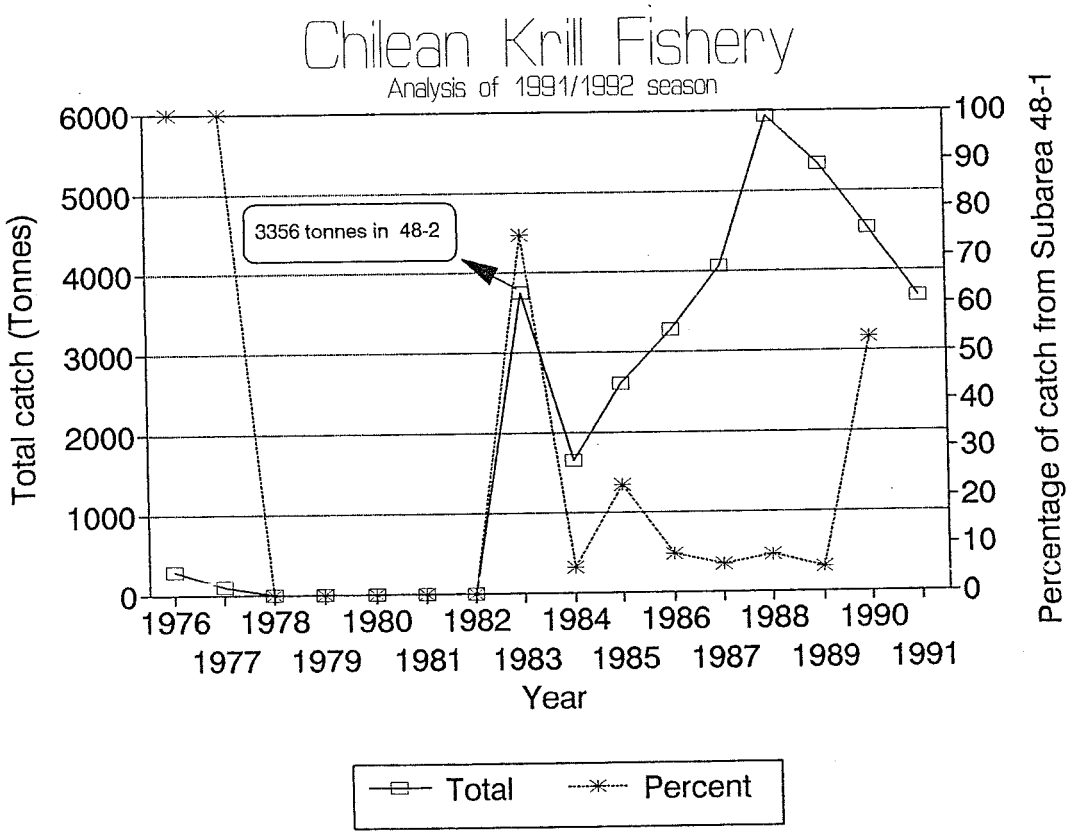


Figure 1: Total catch by Chilean trawlers in Subarea 48.1 from 1976 to 1991. The percentage of the Chilean catch with respect to total catch is also shown.

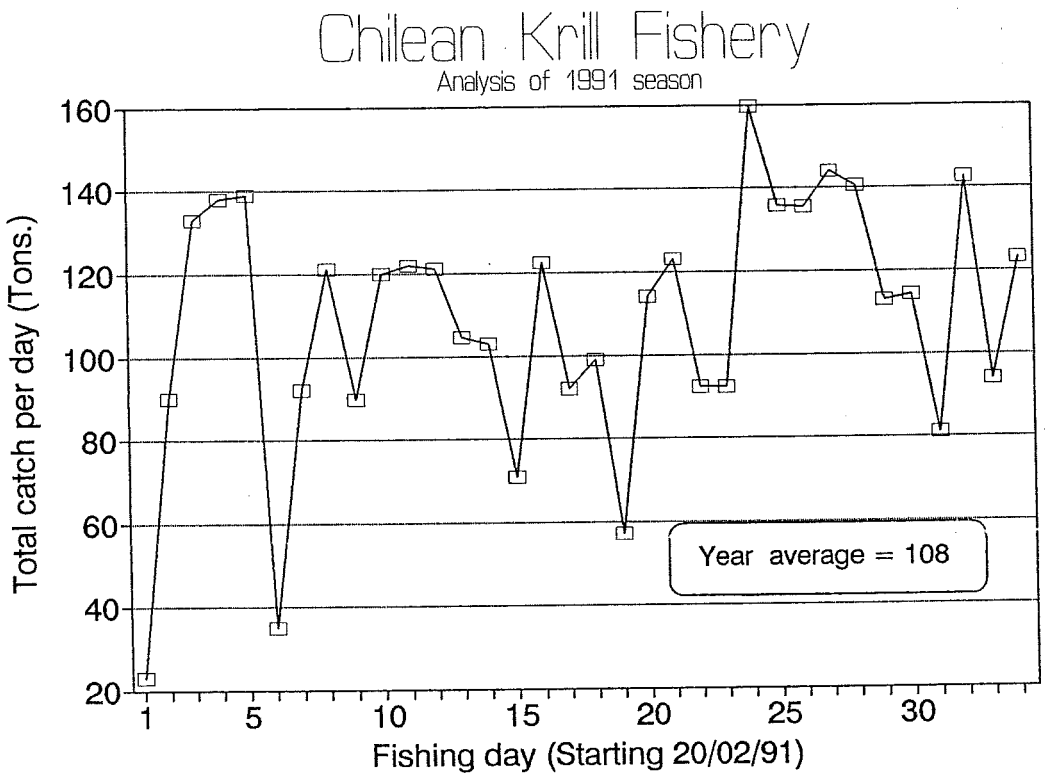


Figure 2: Total catch-per-day during 1991.

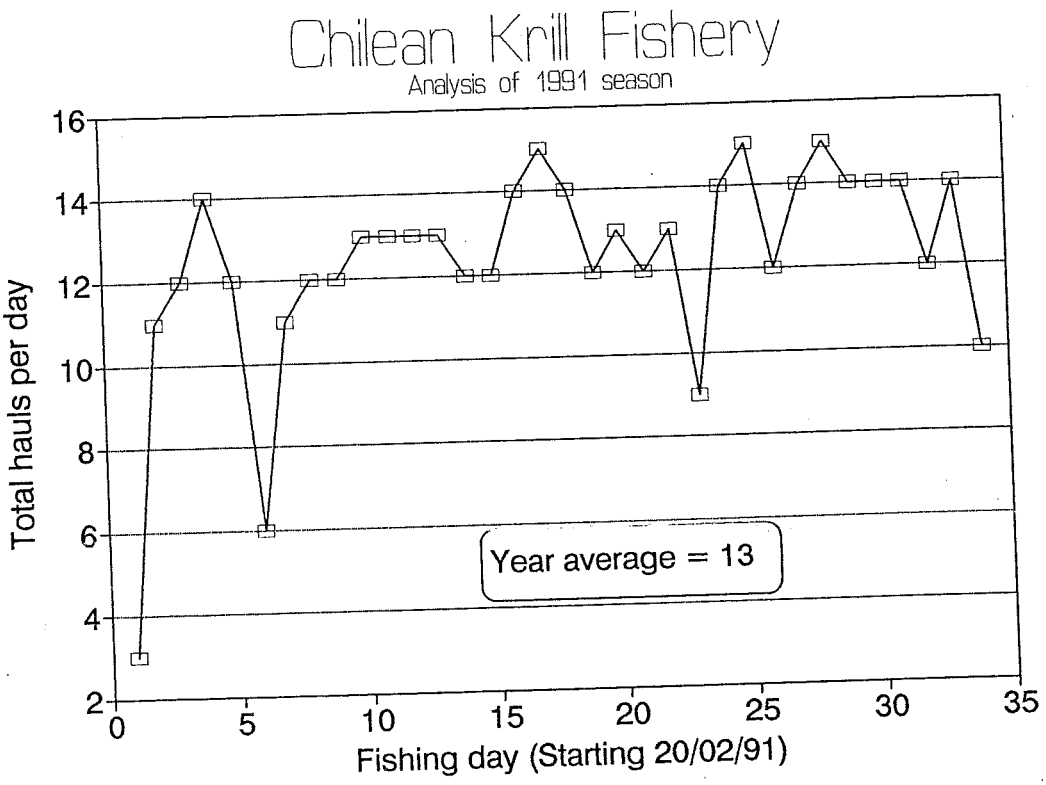


Figure 3: Total number of hauls-per-day during 1991.

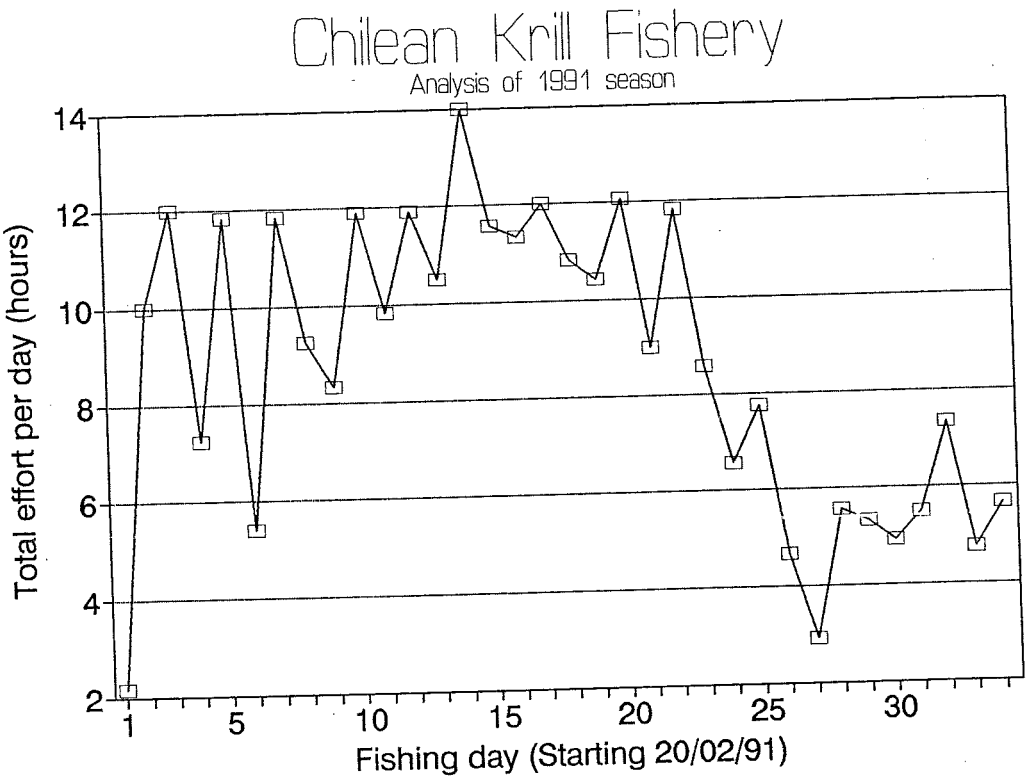


Figure 4: Total effort (measured as total towing time)-per-day during 1991.

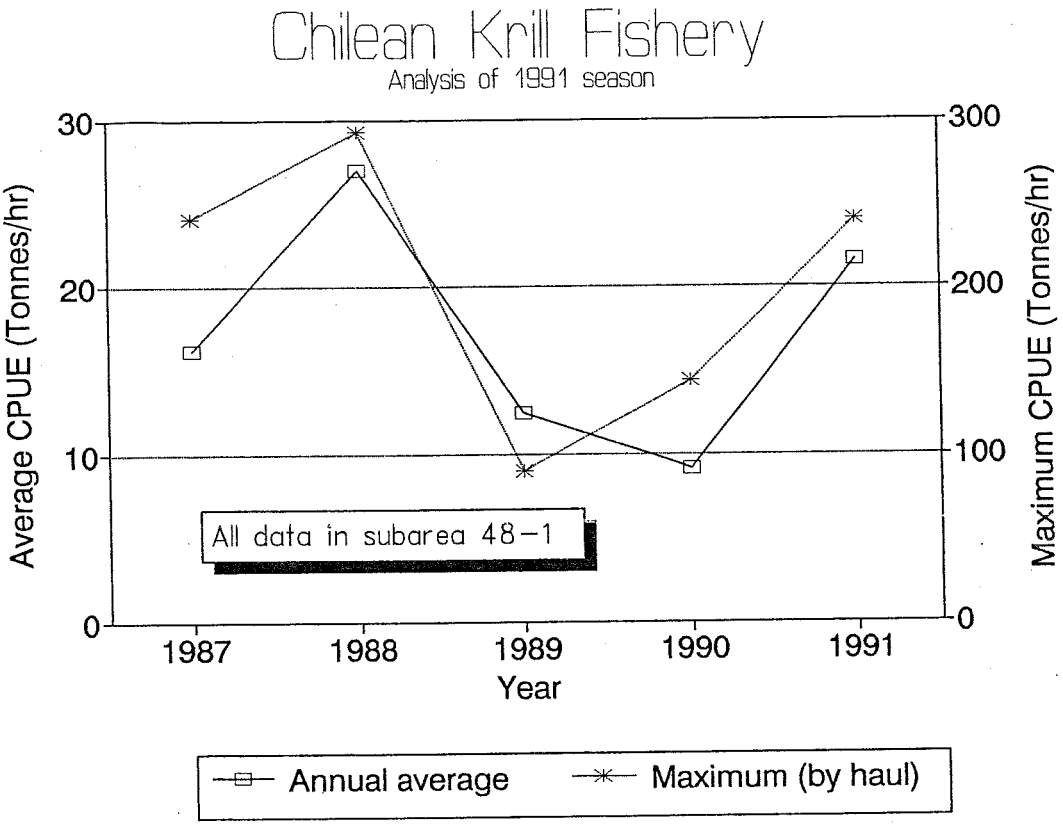


Figure 5: Mean CPUE for the Chilean krill fishery from 1987 to 1991. Data is presented by split-years and shown under the calendar year in which the split-year ends.

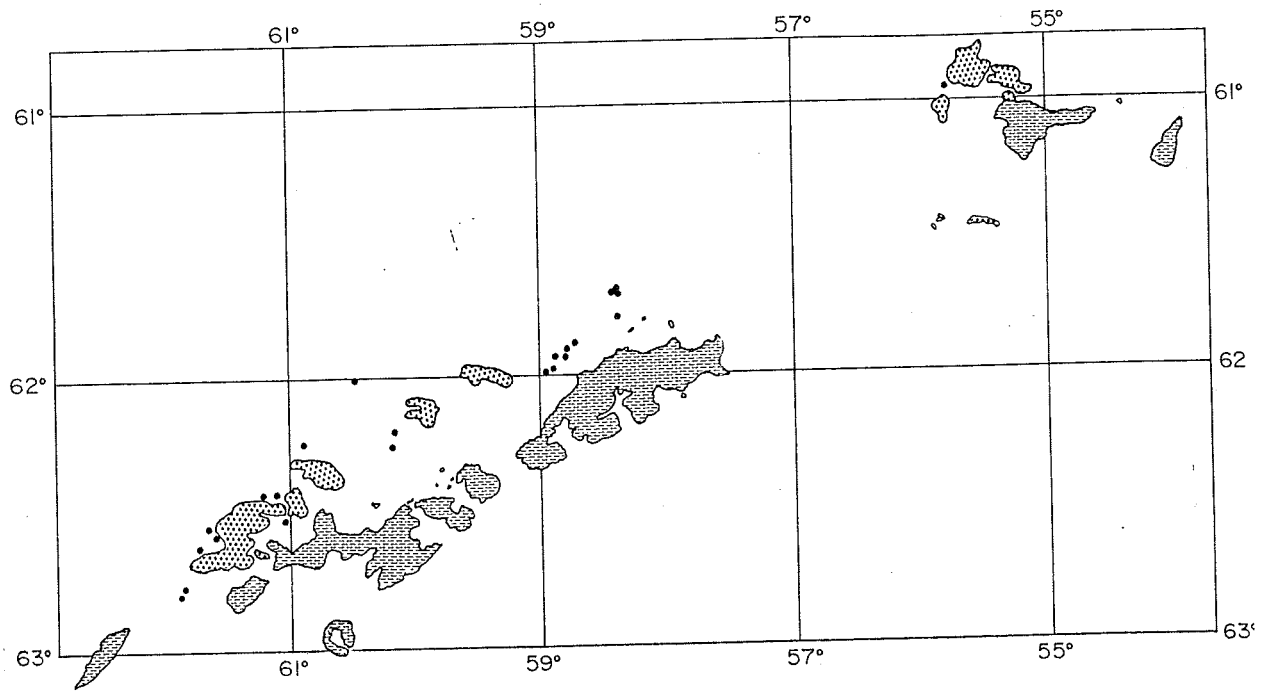
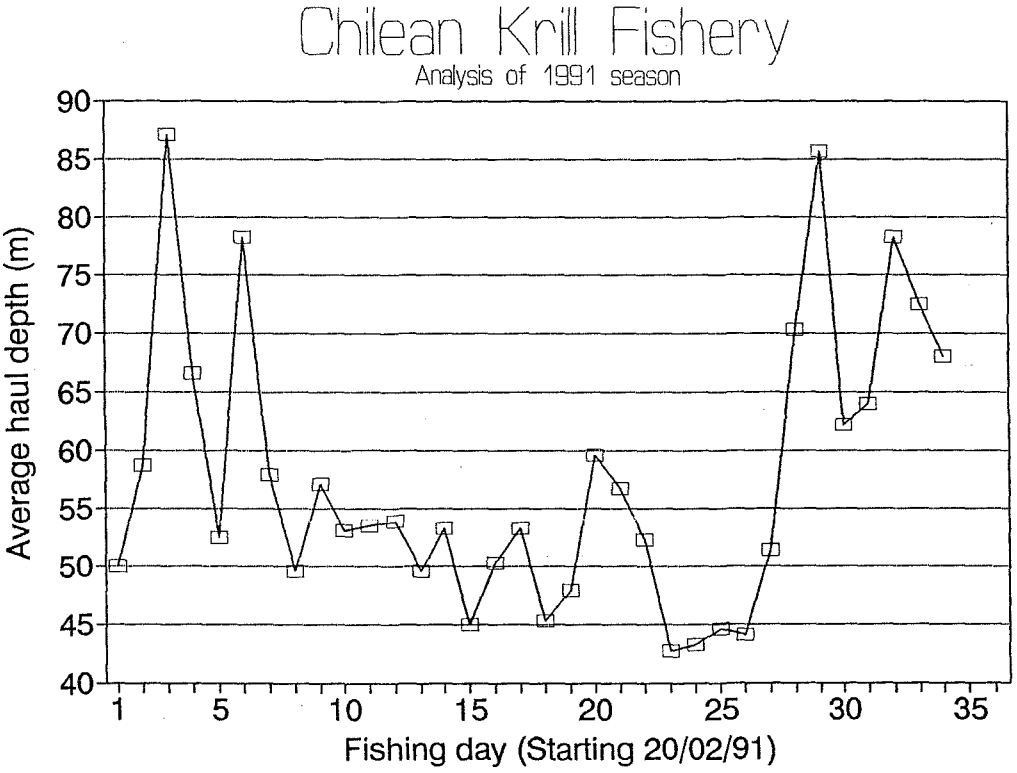


Figure 6: Spatial distribution of hauls during the 1991 season. Areas of high density of hauls have been encircled.



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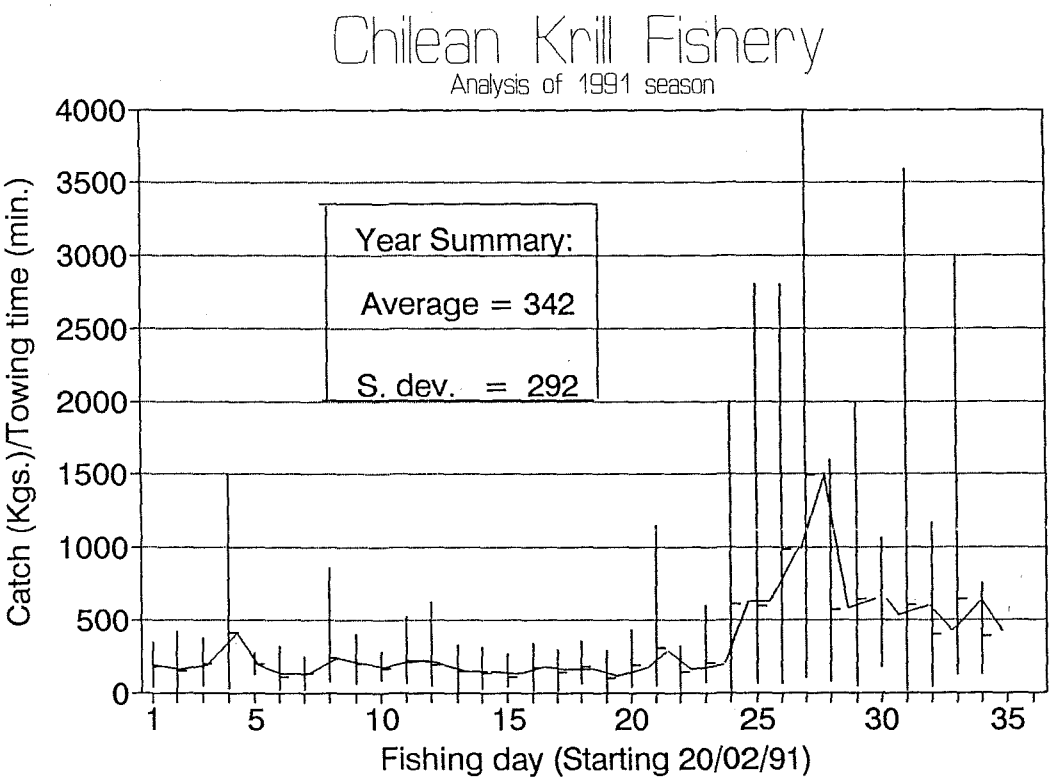

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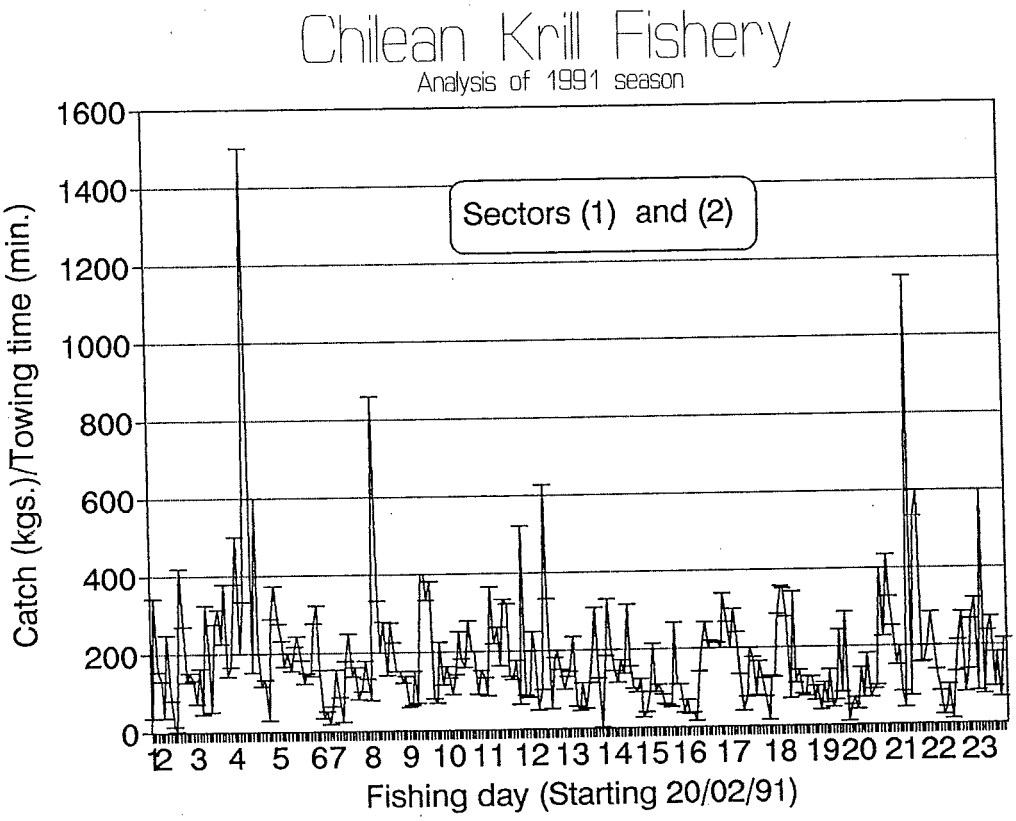


Figure 9: Haul-by-haul CPUE data for areas (1) and (2). Each small horizontal line corresponds to a haul.

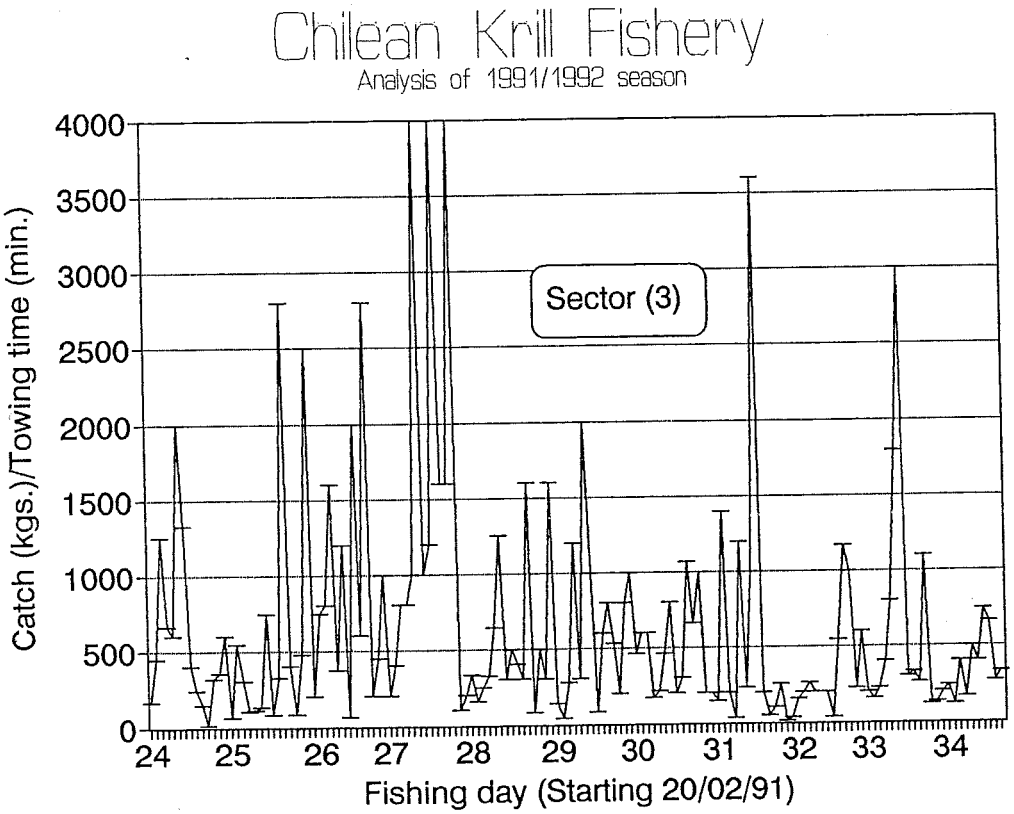
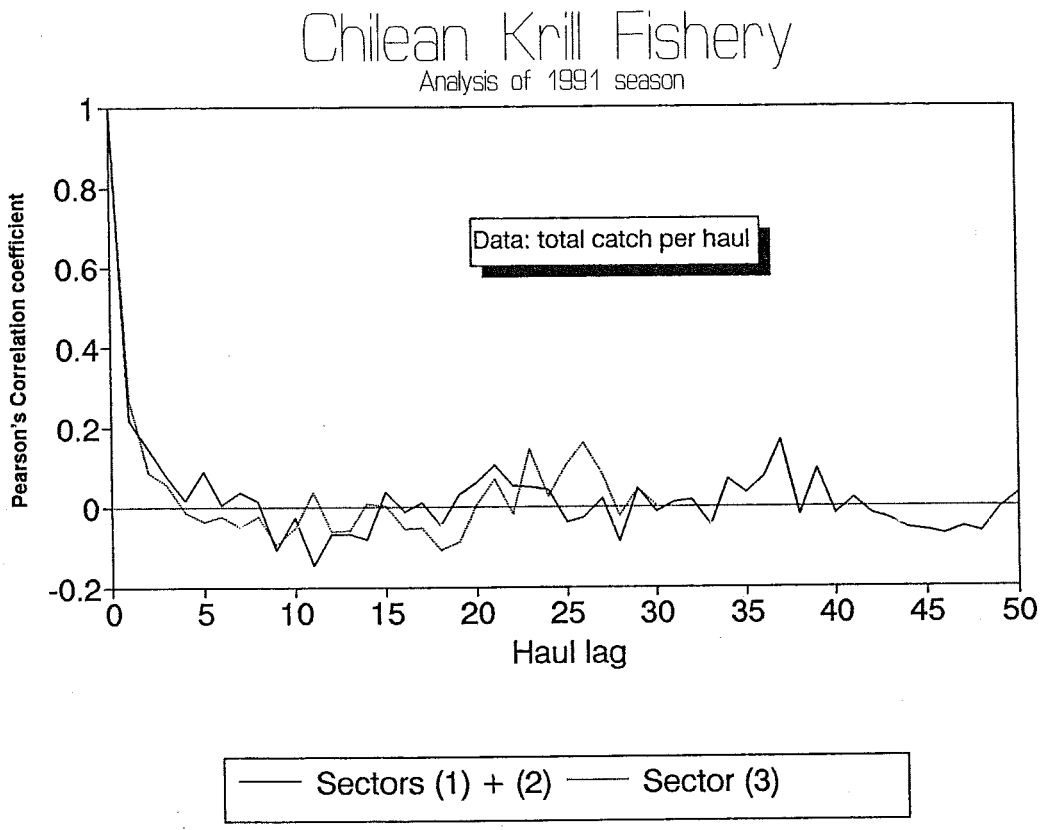


Figure 10: Haul-by-haul CPUE data for areas (1) and (2). Each small horizontal line corresponds to a haul.



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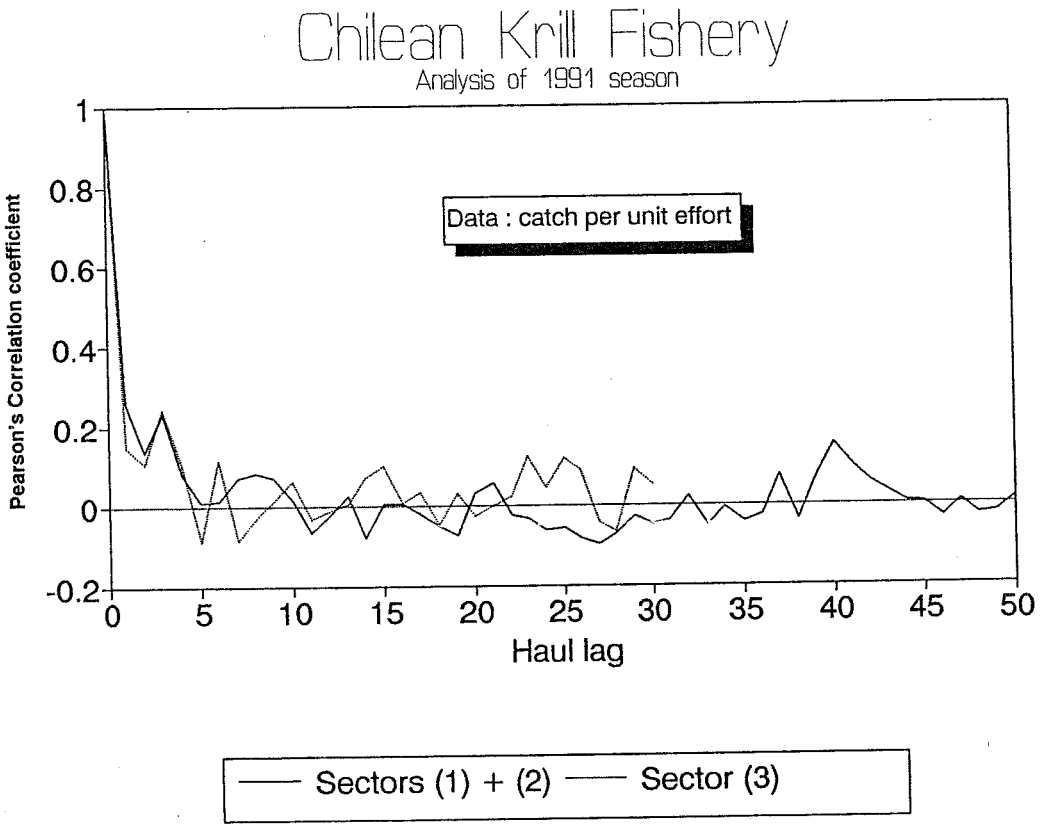

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III. SPECIES INTERACTIONS AND CONSERVATION

FORAGING BEHAVIOUR AND REPRODUCTIVE SUCCESS IN CHINSTRAP PENGUINS: THE EFFECTS OF TRANSMITTER ATTACHMENT

D.A. Croll, J.L. Bengtson, P.L. Boveng, M.E. Goebel and J.K. Jansen*

Abstract

The use of radio telemetry has been accepted as a standard method with which to monitor foraging trip duration in penguins by the CCAMLR (Commission for the Conservation of the Antarctic Marine Living Resources) Ecosystem Monitoring Program (CEMP). This paper reports on: (i) the effects of radio transmitter attachment on nest attendance, foraging trip duration, nest failure, and reproductive success in chinstrap penguins; (ii) differences in these parameters when transmitters are applied to one or both members of a breeding pair; and (iii) variability in foraging patterns of penguins unencumbered by transmitters within the brood period. This study was conducted from December 1990 to January 1991 in a discrete chinstrap penguin colony composed of 666 nests on Seal Island, South Shetland Islands. In total, one member of each pair at 20 nests and both members of each pair at 10 nests were equipped with a radio transmitter, 120 nests were used as a control group. The results of this study demonstrate that, for the size of transmitter used (1.4 cm^2 front section area), there may be no difference between trip durations obtained by applying the transmitters to one or both members of a breeding pair. However, when all parameters of reproductive success were measured, it was revealed that nests with both members equipped with a transmitter fared worse than both the control group and the group with only one member equipped with a transmitter. Several of the differences in those parameters were shown to be statistically significant. It is therefore recommended to use instruments on only one member of each breeding pair in studies utilising CEMP Standard Methods.

Résumé

L'utilisation de la radio télémétrie a été acceptée comme méthode standard applicable au contrôle de la durée des sorties d'approvisonnnement chez les manchots par le Programme de contrôle de l'écosystème de la CCAMLR (Commission pour la conservation de la faune et la flore marines de l'Antarctique) (CEMP). Cette communication porte sur : i) les effets de la fixation d'émetteurs radio sur la présence au nid, la durée des sorties alimentaires, l'échec des nids et la réussite de la reproduction chez le manchot à jugulaire; ii) les différences dans ces paramètres quand les émetteurs sont fixés sur un seul individu d'un couple reproducteur, ou sur les deux; et iii) la variabilité des rythmes de l'approvisionnement des manchots non encombrés d'émetteurs pendant la période de couvaison. Cette étude a été menée de décembre 1990 à janvier 1991 à l'île Seal, dans les îles Shetland du Sud, dans une colonie isolée de manchots à jugulaire composée de 666 nids. En tout, on a posé des émetteurs radio sur un

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seul membre par couple dans 20 nids, et sur les deux membres des couples de 10 nids; 120 nids ont constitué le groupe témoin. Les résultats de cette étude mettent en évidence le fait que, pour la taille de l'émetteur utilisé (1,4 cm^2 de surface de la section de face), l'application d'émetteurs sur l'un ou sur les deux membres d'un couple reproducteur ne semble pas causer de différence apparente dans la durée de leurs sorties. Cependant, quand tous les paramètres de la réussite de la reproduction ont été mesurés, il s'est révélé que les nids dont les deux partenaires étaient munis d'émetteurs n'obtenaient pas d'aussi bons résultats que ceux du groupe témoin ou ceux dont un seul partenaire portait un émetteur. Plusieurs des différences dans ces paramètres se montraient significatives sur le plan statistique. Il est de ce fait recommandé de n'utiliser d'instruments que sur un partenaire par couple reproducteur dans les études utilisant les méthodes standard du CEMP.

Резюме

В рамках программы АНТКОМ по мониторингу экосистемы (СЕМР), использование радиотелеметрии признано стандартным методом мониторинга продолжительности поиска пищи у пингвинов. Настоящая работа касается таких тем, как: (i) последствия прикрепления радиопередатчиков на пребывание у гнезда , продолжительность поиска пищи, неудачу кладки и репродуктивный успех пингвинов чинстрап; (ii) различия в этих параметрах, в случае прикрепления передатчиков к одному или к обоим членам родительской пары; (iii) разнообразие способов поиска пищи пингвинов, не стесненных передатчиками во время периода высиживания. Это исследование проводилось на острове Сил, Южные Шетландские о-ва, с декабря 1990 г. по январь 1991 г. в дискретной колонии пингвина чинстрап, состоящей из 666 гнезд. В общей сложности передатчики были прикреплены к одному из членов каждой пары в 20 гнездах и обоим членам каждой пары в 10 гнездах, 120 гнезд подвергались наблюдению в качестве контрольной группы. Результаты этого исследования показывают, что при данном размере использованного передатчика (площадь фронтального сечения 1.4 $см^2$), различия между продолжительностью поиска пищи, полученной в результате прикрепления передатчиков к одному или к обоим членам родительской пары, может и не существовать. Тем не менее, когда были подсчитаны все параметры репродуктивного успеха, было обнаружено, что в гнездах, в которых передатчики были прикреплены к обоим членам, результаты оказались хуже, чем в контрольной группе или группе, в которой передатчики были прикреплены только к одному из членов пары. В связи с тем, что некоторые различия в этих параметрах являются важными со статистической точки зрения, в исследованиях, использующих Стандарные методы СЕМР, инструменты рекомендуется использовать только на одном из членов каждой родительской пары.

Resumen

El Programa de Seguimiento del Ecosistema de la CCRVMA (CEMP) ha aceptado el uso de la radio telemetría como un método estándar para el seguimiento de los viajes de alimentación de pingüinos. Este documento muestra los resultados de: (i) los efectos de los transmisores en la presencia en el nido, en la duración de los viajes de alimentación, en el fracaso de nidos, y en el éxito de la reproducción de pingüinos de barbijo; (ii) las diferencias entre estos parámetros cuando se adosan transmisores a un miembro de la pareja reproductora y a ambos; y (iii) la variabilidad en los hábitos de alimentación de pingüinos libres de transmisores durante la época de cría. Este estudio se llevó a cabo de diciembre 1990 a enero 1991 en una colonia discreta de pingüinos de barbijo compuesta de 666 nidos, en la isla Foca, archipiélago de las Shetlands del Sur. En un total de veinte nidos se marcó a un miembro de la pareja y en 10 nidos se marcaron a ambos, se usaron 120 nidos como grupo de control. Los resultados de este estudio demostraron que, para el porte de transmisor utilizado (1.4 cm^2 corte frontal), no parece haber diferencia entre las duraciones de los viajes cuando un miembro de la pareja fue marcado y cuando ambos miembros de la pareja fueron marcados. Sin embargo, al medirse todos los parámetros para determinar el éxito de la reproducción, se vio que los nidos en que ambos miembros tenían transmisores corrieron menos suerte que los nidos del grupo de control o aquellos en que un sólo miembro tenía transmisor. Muchas de las diferencias de esos parámetros mostraron tener un peso estadístico. Se recomienda por lo tanto usar instrumentos en un solo miembro de la pareja reproductora cuando se utilicen los métodos estándar del CEMP.

1. INTRODUCTION

The use of radio telemetry has permitted the measurement of behaviour in a manner not previously possible, often eliminating the need for long hours of vigil. It has been demonstrated, however, that attaching such devices to marine animals may significantly alter their behaviour, leading to biased parameter estimates (e.g., Wilson *et al.*, 1986; Wanless *et al.*, 1988; Wilson *et al.*, 1989). The attachment of devices may lead to changes in behaviour of the study animal through the effects of increased drag (Wilson *et al.*, 1986) or the discomfort of instrument package attachment (Wilson *et al.*, 1990). Croll, Osmek and Bengtson (in press) reported that attaching radio transmitters led to a significant increase in the duration of foraging trips of chinstrap penguins *(Pygoscelis antarctica)*. It is important to understand the possible biases that may result from the use of animal-borne devices to collect behavioural information. Unfortunately, in many instances (e.g., diving behaviour), it is difficult to accurately assess the potential impact of the attached device because comparable dive data from non-instrumented animals are rarely available. However, some parameters, such as foraging trip duration and reproductive success, can be measured for birds with and without attached devices in order to assess instrument effects.

The use of radio transmitters has been accepted as a standard method with which to monitor foraging trip duration in penguins by the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) Ecosystem Monitoring Program (CEMP) (SC-CAMLR, 1991). In accepting this method, it was acknowledged that biases may potentially result from the effects of transmitter attachment on foraging trip duration, and that differences in foraging patterns may result from the attachment of transmitters to one or both members of a breeding

pair. It was also noted that factors affecting variability in foraging trip duration should be examined to evaluate the utility of this method for monitoring ecosystem variability. This paper reports on: (i) the effects of radio transmitter attachment on nest attendance, foraging trip duration, nest failure, and reproductive success in chinstrap penguins; (ii) differences in these parameters when transmitters are applied to one or both members of a nest; and (iii) variability in foraging patterns of penguins unencumbered by transmitters within the brood period. The present study extends the study of Croll, Osmek and Bengtson (in press).

2. METHODS

A total of approximately 20 000 pairs of chinstrap penguins nest on Seal Island, South Shetland Islands, Antarctica (60°59.2'S, 55°23.1'W). This study was conducted from December 1990 to January 1991 in a discrete chinstrap penguin colony composed of 666 nests (colony 25) on Seal Island.

The methods used in this study were similar to those used by Croll, Osmek and Bengtson (in press). Nests were individually identified by examining their relative location using Polaroid photographs (reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA). Attendance patterns of adult penguins at those nests were followed during three observation periods: early-brooding (1800, 31 December 1990 to 2300, 4 January 1991), mid-brooding (2200, 13 January 1991 to 2200, 15 January 1991), and late-brooding (2200, 25 January 1991 to 2200, 27 January 1991). Three experimental groups were examined during each period:

No instrument group (control): 102 nests that were active (eggs and/or chicks present) at the beginning of the observation period were used as a control group. No transmitters were attached to adults in this group. One member of each pair was marked on the breast with a spot of nyanzol-D dye (a black, waterproof dye) while the bird was incubating its egg(s);

One adult with transmitter group: One member of each pair at 20 nests was equipped with a radio transmitter and marked with picric dye (a yellow, waterproof dye); and

Both adults with transmitter group: Both members of each pair at 10 nests were equipped with a radio transmitter. One member was marked with yellow picric dye, the other with black nyanzol-D dye.

Radio transmitters (1.35 cm diameter x 6.8 cm length, 20 g weight, 1.4 cm^2 frontal cross sectional area, 28.5 cm whip antenna) were attached to the middle of the back using two cable ties and a small spot (approximately 3 g) of Devcon 5-minute epoxy to the contour feathers. The transmitters (Advanced Telemetry Systems, Model 2) were attached to the birds on 28 and 29 December.

A random sample of 50 nests was chosen from the 102 control nests prior to the first observation period for monitoring nest attendance patterns. Nest attendance patterns for the control and treatment birds were recorded from an observation blind located within 50 m of all study nests. During each observation period, nests in all three groups were visually checked every hour, and the individual in attendance was identified and recorded. It was noted whether both members of a pair were present, and if so, the identity of the adult brooding the chick was recorded.

The survival of chicks and nests in the control group was followed from 29 December 1990 until 30 January 1991 (12 nest-check dates) and in the treatment groups from 30 December 1990 until 30 January 1991 (eight nest-check dates). During each nest check, the number of eggs and/or chicks present in the nest was recorded. Nest failure dates were recorded as the first day that a nest was observed with no chicks. A failure date of 13 January

(last date of first-chick hatching interval) was ascribed to four control nests that incubated but did not hatch eggs during the study. Chick survival was calculated for each of the three observation periods as the number of chicks present in nests on the last date of observations, divided by the number of chicks (and/or eggs) present in nests on the first date of observations. The number of chicks per active nest was calculated as the total number of chicks present divided by the number of nests in each group that contained chicks (i.e., nests that failed were excluded) for the beginning and conclusion of observations. Nest failure rate was calculated as the number of nests which had failed by the end of observations divided by the number of nests active at the start of observations.

To compare durations of feeding trips, attendance visits, and overlap (both adults at the nest), the mean duration of each parameter was calculated for each individual. The mean and variance among these individuals were then calculated and used in comparisons among treatments and time periods. This method eliminated possible bias resulting from over-representation of individuals that make a large number of short duration trips, visits, or overlaps. The mean number of trips day^{-1} was calculated for each nest, using the total number of trips for both members of the nest. Statistical tests were conducted using the SYSTAT statistical package. Times are given as hours in local time (UTC minus 3 hours).

3. RESULTS

The average foraging trip and visit durations of each treatment group during each observation period are shown in Table 1 and Figures 1 and 2. One-way analysis of variance tests performed within each period comparing the groups demonstrated that neither the foraging trip durations nor visit durations of the treatment groups within each period were significantly different from the control group. Comparison of the foraging trip duration and visit duration of the control group by period showed that both trip and visit durations were significantly different among the three periods (ANOVA, $P < 0.01$, $P < 0.01$ for durations of trips and visits, respectively). Multiple comparisons revealed that trip durations decreased significantly through the chick brooding period while visit durations during early-brooding were significantly longer than those during mid- and late-brooding, which in turn were not different. Comparison of the number of trips/nest/day between the three groups within each period revealed that there was no significant effect of transmitters (either on one or both members of the pair) (Figure 3). However, the numbers of trips/nest/day in the control nests were significantly different among the three observation periods (ANOVA, $P < 0.01$). Multiple comparisons (Tukey HSD test) showed that fewer trips were made during the early brood period than both the mid- and late-brooding periods, which were not different. The mean durations of overlap (both members of pair at nest) (Figure 3) were also not significantly different among the three groups within each period. Comparison of the amount of overlap in the control group indicated significant differences among the early-, mid-, and late-brooding periods (ANOVA, $P < 0.01$). Significantly more time was spent in overlap during the early-brooding period compared to the mid- and late-brooding periods (which were not different) (Tukey HSD test).

Results of treatment and control groups' reproductive success are shown in Table 2. Significantly fewer chicks survived the study period in both groups in which transmitters were attached (either one or both members of each pair) when compared with the control group (Chi-squared test, $P < 0.05$ and $P < 0.05$ in one adult and both adults equipped with transmitter groups, respectively). Examination of the number of chicks per active nest and the nest failure rate revealed that while the decrease in number of chicks per active nest was not different between control and treatments (Table 2), there were significant differences among the control and treatment groups in the rate of nest failures (Chi-squared test, $P = 0.006$). Furthermore, a test for a gradient in proportions (Bartholomew, 1959a and 1959b; Fleiss, 1981) indicated that there was a significant increase in the proportions of nest failures as the number of transmitters per nest increased from zero, to one, to two ($P < 0.005$).

Of the 12 nest failures in the control group, 50% occurred prior to 9 January; in the treatment groups, 91% of the failures occurred prior to 10 January. Three of the 20 nests with one mate instrumented failed before the first nest check on 30 December (the instrumented birds could not be located visually, although one was regularly detected on the radio-telemetry data logger). A test for whether the proportion of early failures was significantly higher in the treatment groups (indicating a possible handling effect) has not yet been completed.

4. DISCUSSION

4.1 Durations of Foraging Trips, Visits, and Overlap

In contrast to the study of Croll, Osmek and Bengtson (in press), the radio transmitters attached to chinstrap penguins in the present study had no significant effect on foraging trip duration. This contrast may have resulted from: (i) differences in prey availability or environmental conditions that allowed the instrumented birds to forage more effectively in the present study than in the former study; or (ii) differences in the sizes of instruments used in the two studies. Comparisons of chick growth rates, fledging weights, and survival from hatching to creching on Seal Island indicated that overall conditions for rearing chicks during the brood period in 1990/91 were similar to those found during the 1989/90 season (Croll, Jansen and Bengtson, in press). Therefore, and because the transmitters used in 1990/91 were smaller than those used in 1989/90, we favour the latter explanation.

The transmitters used in 1990/91 had a frontal cross sectional area that was 40% of the frontal area used in 1989/90 (1.43 cm^2 vs 3.5 cm^2). Because hydrodynamic drag is directly proportional to frontal area (Vogel, 1981), the transmitters used in this study should have created much less drag in the water and therefore should have had less effect on swimming efficiency than the larger transmitters used previously. In addition, less epoxy was applied to the contour feathers when attaching the transmitters in 1990/91, which may have further reduced drag and/or other burdens caused by the instrument.

The radio transmitters used in a study of gentoo penguins (Williams and Rothery, 1990) were similar in size to those used in the study by Croll, Osmek and Bengtson (in press) (18 mm diameter by 80 mm length, 35 g, and 20 mm diameter by 55 mm length, 25 g, respectively). It is possible that the increase in foraging trip duration observed by Williams and Rothery (1990) between brooding and creching may have been due to the chronic effect of transmitter attachment rather than changes in foraging patterns. In order to properly evaluate the results of any study of this type, however, it is important to assess the effect of the instrument(s) deployed. We feel that the cross sectional area of the transmitters used in the present study may serve as a "maximum" guideline for future studies, because the effects on foraging behaviour observed for the larger transmitters by Croll, Osmek and Bengtson (in press) were not observed in the smaller transmitters.

Although neither the foraging trip durations nor the visit durations of either group equipped with transmitters were different from the control group, examination of Figures 1 and 2 shows that foraging trips appear to be slightly longer and visit durations slightly shorter in nests of birds equipped with transmitters. This leads to the question of whether the failure to detect statistically significant differences was due to a genuine lack of an instrument effect or to high inter-individual variability of trip/visit durations and to small sample sizes. Further analysis of the statistical power expected for the design of the present study may indicate whether the experiment would be worthwhile repeating with larger sample sizes.

4.2 Reproductive Success

Although no significant effects on foraging patterns were observed, the transmitters did affect reproductive success. It seems likely, therefore, that the instruments have an effect on

some component of the process of providing chicks with food. Gales *et al.* (1990) made similar observations in a study of the foraging behaviour and instrument effects in the little penguin *(Eudyptula minor).* They found that although foraging trip duration was unaffected by instrument attachment, the efficiency of foraging was significantly decreased, as measured using water turnover. It is unclear, however, whether the effect observed in chinstrap penguins derives from some chronic effect on energetics and/or behaviour, or the handling and attachment process. Because penguins in the control group were not handled in the same manner as those in the instrumented groups, any chronic effect of carrying the transmitters would be confounded with any handling effects that may have occurred (e.g., Culik *et al.*, 1990). Further analyses of the dates of nest failure may indicate whether a significant handling effect was present in this study.

One of the recommendations of CEMP in adopting the use of transmitters in measuring foraging trip durations was that an assessment of the attachment of transmitters on one or both members of a pair should be undertaken (CCAMLR 1991). The results of this study demonstrate that, for the size of transmitter used in this study, there may be no difference between trip durations obtained by applying the transmitters to one or both members of nesting pairs. However, examination of Table 2 reveals that in all parameters of reproductive success that were measured, nests with both members instrumented fared worse than both the control group and the group with only one member instrumented. Several of the differences in those parameters were shown to be statistically significant. We therefore recommend using instruments on only one member of each nesting pair in studies utilising CEMP Standard Methods.

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Table 1: Mean foraging trip and visit durations, measured by visual observation during three periods, for chinstrap penguins instrumented with radio transmitters on Seal Island, South Shetland Islands, Antarctica during the 1990/91 breeding season. Values in parenthesis indicate standard deviation and the number of penguins from which statistics were derived.

	Control	One Member with Transmitter		Both Members with Transmitters
		Bird with Transmitter	Bird without Transmitter	
Early Brooding:				
Trip	13.4 (6.0, 99)	14.7 (4.7, 16)	14.6 (6.0, 16)	17.1 (9.6, 15)
Visit	20.7 (7.2, 97)	20.8 (6.3, 16)	22.0 (6.6, 16)	17.5 (6.1, 15)
Mid Brooding:				
Trip	9.6 (2.7, 99)	11.5 (7.0, 10)	9.1 (2.7, 14)	11.1 (4.3, 12)
Visit	13.6 (3.5, 99)	12.3 (4.5, 11)	17.0 (5.5, 13)	11.8 (4.1, 12)
Late Brooding:				
Trip	7.8 (2.2, 89)	7.9 (1.7, 6)	7.6 (1.1, 5)	8.4 (2.0, 11)
Visit	13.2 (5.6, 88)	9.3 (1.9, 5)	14.3 (5.7, 5)	10.6 (4.0, 11)

Table 2: Chick survival, individual nest production, and nest failure for chinstrap penguins instrumented with radio transmitters on Seal Island, South Shetland Island, Antarctica during the 1990/91 breeding season.

	Control (No Transmitter)	Treatment	
		One Member with Transmitter	Both Members with Transmitters
Chick Survival	76%	57%	47%
Chicks/Nest:			
Start	1.74	1.4	1.70
End	1.43	1.23	1.33
% Change	-18%	-12%	-22%
Nest Failure Rate	12%	35%	40%

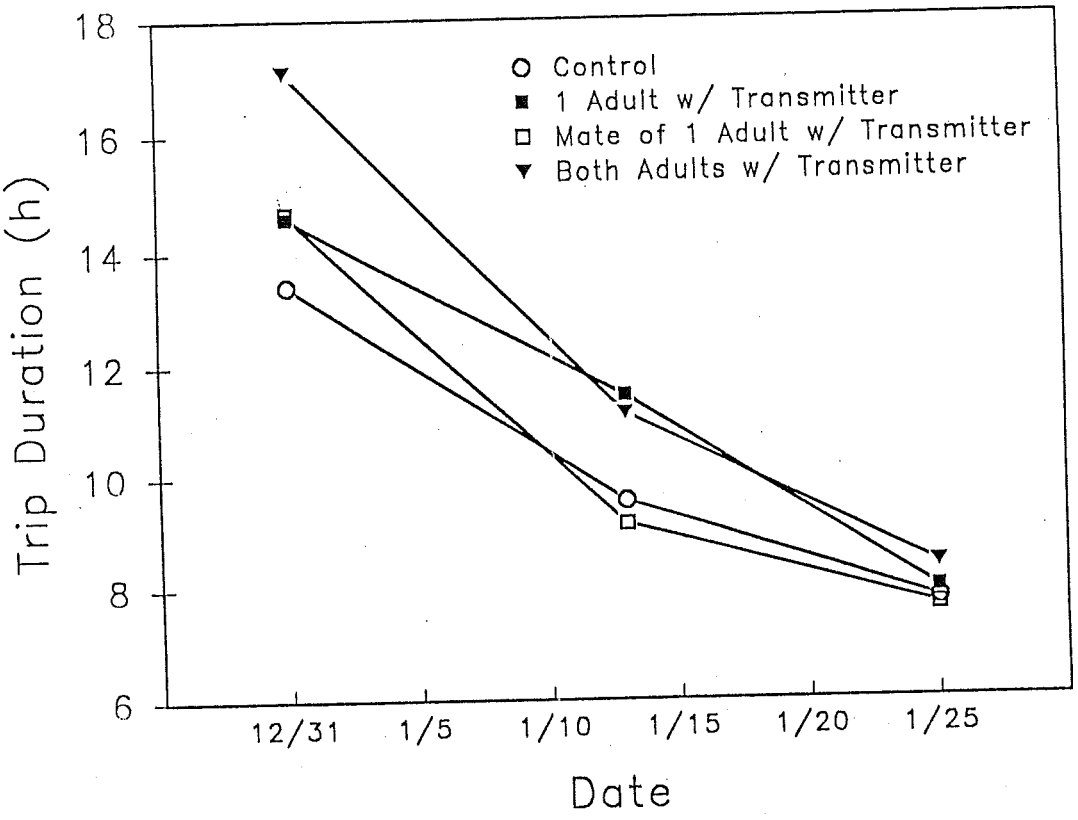


Figure 1: Mean foraging trip durations, measured by visual observations, of chinstrap penguins instrumented with radio transmitters on Seal Island, Antarctica, during the 1990/91 breeding season.

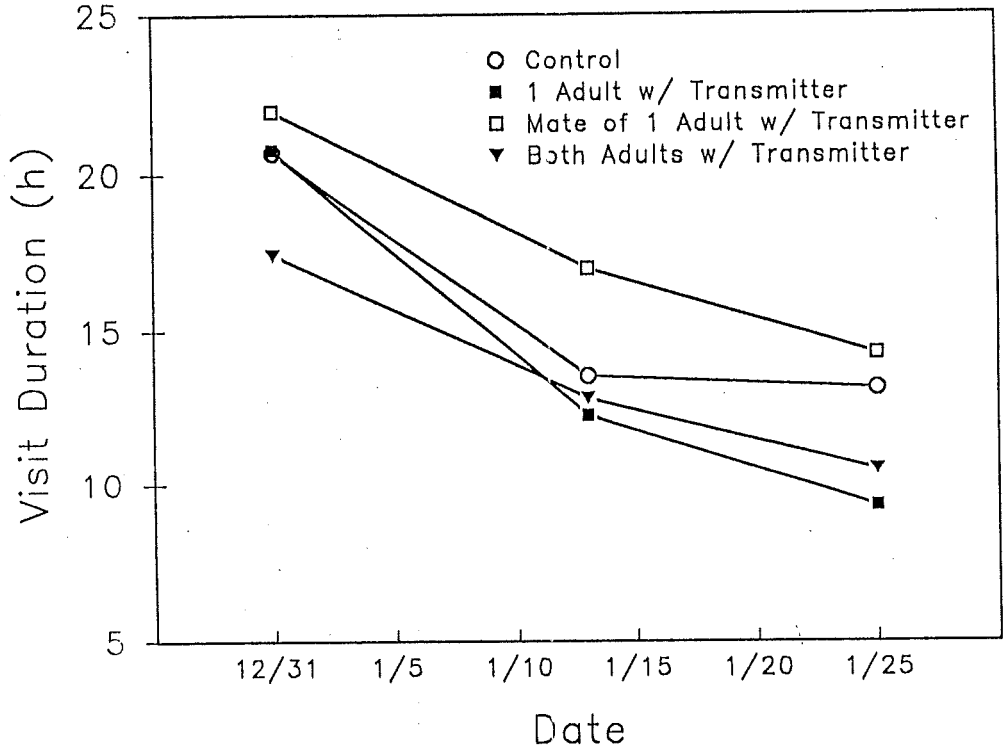
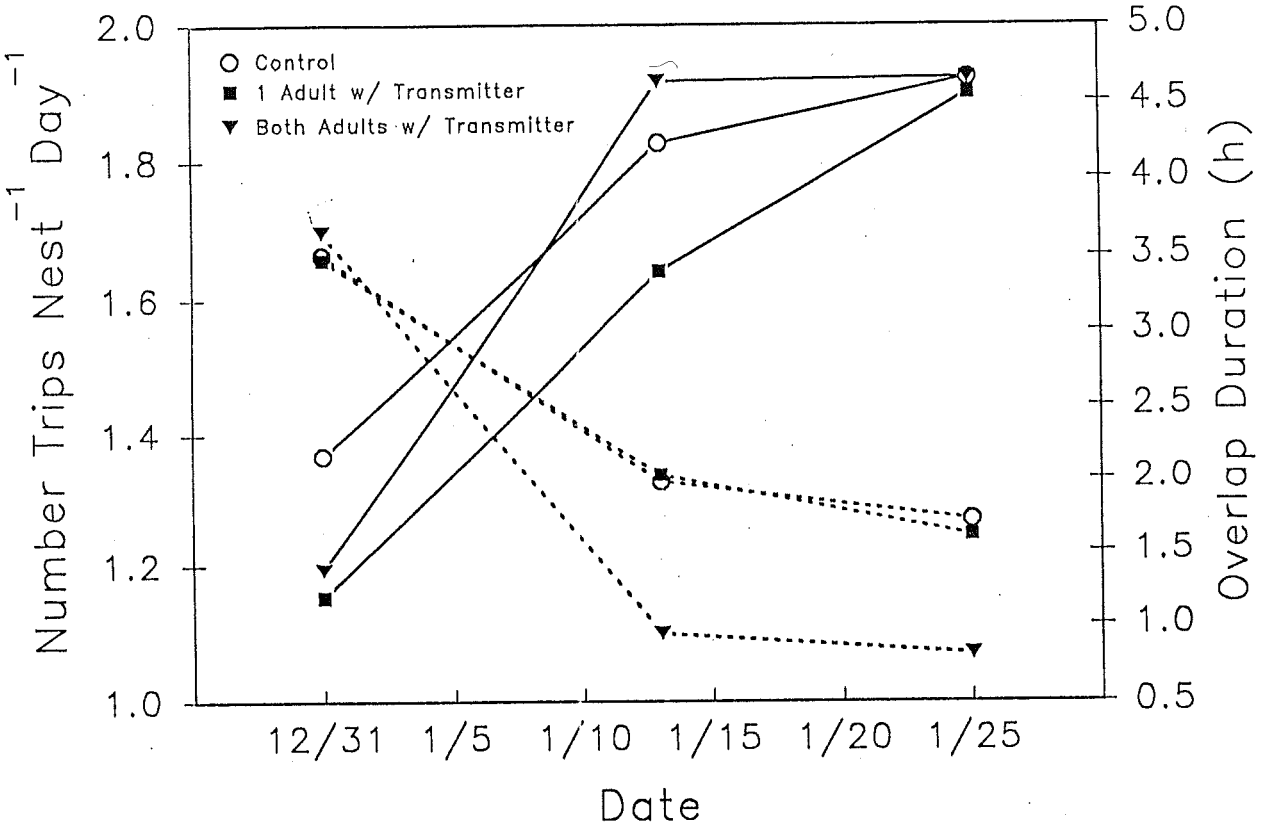


Figure 2: Mean visit durations, measured by visual observations, of chinstrap penguins instrumented with radio transmitters on Seal Island, South Shetland Islands, Antarctica, during the 1990/91 breeding season.



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DATA ON KRILL (*EUPHAUSIA SUPERBA* DANA) CONSUMPTION BY COASTAL FISHES IN DIVISION 58.4.2 (KOSMONAVTOV AND SODRUZHESTVA SEAS)

Ye.A. Pakhomov, V.A. Bibik and V.V. Gerasimchuk*

Abstract

Current estimates of the level of krill consumption (*Euphausia superba*) are based on data obtained from the Atlantic sector which have then been extrapolated over all of Antarctica. According to these calculations the entire amount of krill consumed is between 166 and 450 million tonnes; of this amount fish consume from 30 to 32 million tonnes (Lubimova, Shust, 1980 and Shust, 1987). However these extrapolated values of krill consumption by fish and other species may differ significantly from those for specific areas. Localised assessments of krill consumption have thus far only been carried out for the Scotia and Lazarev Seas (Kock, 1985; Miller *et al.*, 1985). Assessments contained in this paper are based on results of research conducted in the Sodruzhestva and Kosmonavtov Seas over many years by the YugNIRO institute. Data obtained from trawl and acoustic surveys as well as on fish feeding patterns and krill production were used in the calculations. Assessments of krill consumption are based on calculations made for individual fish species taking into account their distribution in the particular study area of Antarctica. Total fish stock was calculated for a depth range of 100 to 500 metres in waters between 30 and 80°E. Krill consumption was estimated for summer only (December to April). The assessments obtained indicate that if total fish biomass is 551 300 tonnes, fish will consume 960 000 tonnes of krill. Given the total krill biomass in the study area it is concluded that fish consume from 9 to 18% of annual krill production.

Résumé

Les estimations actuelles du niveau de consommation de krill (*Euphausia superba*) sont fondées sur des données provenant du secteur atlantique, qui ont ensuite été extrapolées sur la totalité de l'Antarctique. Ces calculs nous portent à croire que la quantité totale de krill consommée se situe entre 166 et 450 millions de tonnes, dont 30 à 32 sont consommées par des poissons (Lubimova and Shust, 1980; Shust, 1987). Cependant, il est possible que ces valeurs extrapolées de la consommation de krill par des poissons ou d'autres espèces diffèrent grandement de celles des zones spécifiques. Les évaluations localisées de la consommation de krill n'ont été effectuées, jusqu'à maintenant, que pour les mers de la Scotia et de Lazerev (Kock, 1985; Miller et al., 1985). Les évaluations de cette communication sont tirées des résultats de recherches menées par l'institut YugNIRO dans les mers Sodruzhestva et Kosmonavtov sur plusieurs années. Les données provenant des campagnes par chalutages et acoustiques, de même que les données sur les rythmes alimentaires des poissons et la production de krill ont servi aux calculs. Les évaluations de la

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espèces de poissons individuelles, en tenant compte de leur répartition dans la zone d'étude donnée en Antarctique. Le stock total de poissons a été calculé pour une échelle de profondeur de 100 à 500 mètres dans les eaux situées entre 30 et 80°E. La consommation de krill n'a été évaluée que pour l'été (de décembre à avril). D'après les évaluations, si la biomasse totale de poisson s'élève à 551 300 tonnes, les poissons consommeront 960 000 tonnes de krill. Vu la biomasse totale de krill dans la zone d'étude, nous pouvons conclure que le poisson consomme 9 à 18% de la production annuelle de krill.

Резюме

Имеющиеся до настоящего времени оценки потребления Антарктического криля, *Euphausia superba,* различными видами-консументами были основаны на данных, полученных для Атлантического сектора и экстраполированных на всю акваторию Антарктики. По этим расчетам общее количество потребляемого криля находится на уровне 166-450 млн тонн, а на долю рыб приходится до 30-32 млн тонн криля от этого количества (Любимова, Шуст, 1980 и Шуст, 1987). Однако для конкретных регионов Антарктики действительные величины потребления криля рыбами и другими видами-консументами могут значительно отличаться от этих экстраполированных величин. Региональные оценки потребления криля были выполнены до сих пор только для морей Скотия и Лазарева (Kock, 1985, Miller *et al.*, 1985). Изложенные в настоящей работе оценки потребления криля рыбами основаны на результатах многолетних исследований, проведенных институтом ЮгНИРО в морях Содружества и Космонавтов. В расчетах использовались данные траловых и акустических съемок и материалы по питанию рыб и продукции криля. Оценка потребления криля основана на расчетах по отдельным видам рыб с учетом их распространения в исследуемом районе Атнарктики. Общий запас рыб был расчитан для диапазона глубин 100-500 м в водах между 30° и 80°в.д. Оценка потребления криля была произведена только для летнего сезона (декабрь-апрель). Полученные оценки показывают, что при общей биомассе рыб равной 551 300 тонн они потребляют 960 000 тонн криля. Принимая во внимание общую биомассу криля в исследуемом районе, делается вывод, что рыбы могут потреблять до 9-18% от его годовой продукции.

Resumen

Los cálculos actuales del nivel de consumo de krill (*Euphausia superba*) se basan en los datos obtenidos del sector Atlántico que han sido extrapolados sobre toda la Antártida. De acuerdo con estos cálculos, la cantidad total de krill consumido es entre 166 y 450 millones de toneladas; de esta cantidad, los peces consumen entre 30 y 32 millones de toneladas (Lubimova, Shust, 1980 y Shust, 1987). Sin embargo, estos valores extrapolados del consumo de krill por los peces y otras especies, podrían ser considerablemente distintos a aquellos de áreas

especies, podrían ser considerablemente distintos a aquellos de áreas específicas. Hasta ahora se han realizado evaluaciones locales del consumo de krill para los mares de Scotia y Lazarev solamente (Kock, 1985, Miller *et al.*, 1985). Las evaluaciones que aparecen en este documento se basan en los resultados obtenidos de investigaciones realizadas durante muchos años por el instituto YugNIRO en los mares de Sodruzhestva y Kosmonavtov. En los cálculos se ha utilizado la información obtenida de las prospecciones acústicas y de arrastre, así como de los patrones de alimentación de peces y de la reproducción del krill. Las evaluaciones del consumo de krill se basan en los cálculos hechos para especies individuales de peces, tomando en cuenta su distribución en el área de estudio de la Antártida. Se calculó la población total de peces para el rango de profundidad de 100 a 500 metros en las aguas entre 30 y 80°E. Solamente se calculó el consumo de krill durante el verano (diciembre a abril). Las evaluaciones obtenidas indican que si la biomasa total de peces es de 551 300 toneladas, los peces consumirán 960 000 toneladas de krill. Se concluye que, dada la biomasa total del krill en el área de estudio, los peces consumen de un 9 al 18% de la producción anual de krill.

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1. INTRODUCTION

In order to understand properly the fundamental patterns of the unique pelagic ecosystems in some Antarctic regions and to implement a rational regime of harvesting bio-resources, it is important to determine the level of krill consumption by its various predators. Previous assessments (Lubimova, Shust 1980; Laws 1985) gave values from 166 to 450 million tonnes for krill consumption, assuming that of this amount fish consumed 30 to 32 million tonnes. For the most part these figures are based on data obtained from the Atlantic sector of the Southern Ocean. In our view, for specific areas the ratio of krill consumption by fish and other consumers may be widely divergent from those values obtained by extrapolation for all Antarctic waters. Localised assessments have only been carried out for the Scotia (Kock, 1985) and Lazarev (Miller *et al.*, 1985) Seas. Such attempts have not been made for the Indian Ocean sector, more importantly for such locations as the Sodruzhestva and Kosmonavtov Seas. Moreover, Russian scientists have pointed out the possibility of the formation of various biotopes whose organisms (fish) have different levels of krill consumption (Trotsenko *et al.*, 1990) and the existence of independent faunistic macroplankton complexes in different parts of continental seas (Pakhomov, 1991).

This work is founded on the results of many years' research by YugNIRO in the Sodruzhestva and Kosmonavtov Seas and is perhaps the first attempt to assess the amount of krill consumed by fish in that area.

2. MATERIALS AND METHODS

Data on krill and fish stocks and biomass, diet composition, fish feeding rates and trophic relationships are used in this work. The mean krill stock size in the Sodruzhestva Sea (to the south of 65°30'S, between 60 and 80°E, area approximately 10^7 km^2) was calculated from census trawl and acoustic surveys from 1978 to 1990. Mean biomasses in certain areas, where fish biomass was observed to be high, were determined for 1978 to 1990. It should be noted that acoustic surveys in these areas were carried out over one to three days and, as a rule, where krill swarms were of a high density. Therefore the biomass values obtained are "instantaneous" and high in relation to the real average.

Information on biomass assessment methods used, survey designs, confidence intervals and krill trawls used is contained in the works of Bibik and Yakovlev (1990) and Bibik and Yakovlev (1991). These works also contain data on krill stocks in the Sodruzhestva Sea and biomass in the continental slope area 65 to 66°E. Krill biomass in the area 61 to 63° was calculated for the first time.

Mean krill stock size (biomass) in the Kosmonavtov Sea (area 8 x 10^4 km^2) was determined by averaging trawl-acoustic data for the three years from 1988 to 1990.

Data obtained by YugNIRO following experimental work on daily krill growth rates (0.0033 mm) were used to determine krill production (Samyshev 1986). Therefore the P/B coefficient for summer (December-April), when the amount of krill eaten by fish was calculated, equals 0.5. Given this coefficient and the long term average biomass for the Sodruzhestva and Kosmonavtov Seas (8 x 10^6 tonnes) seasonal krill production is 4 x 10^6 tonnes; 2.5 x 10^6 tonnes for the Sodruzhestva Sea and 1.5 x 10^6 tonnes for the Kosmonavtov Sea.

Serious difficulties arose during calculation of yearly krill production. The majority of scientists assume that an animal's growth ceases during winter (Aseev, 1983; Siegel, 1987 and Hosie *et al.*, 1988). In this case the seasonal coefficient and seasonal production may be proportional to their annual values. Using simulation methods, V.B. Tseitlin calculated the annual P/B coefficient to be 0.52 (Tseitlin, 1989), in other words close to the seasonal value determined from experiments.

There is also a theory that krill does not stop growing entirely in winter (Samyshev, 1991). According to this view, growth occurs not only from December to April, but also in the months leading up to this period (at least from October) when the days become lighter and krill can feed on algae in large polynyas as well as on cryophyte phytoplankton. Taking this into account, E.Z. Samyshev calculated the annual P/B coefficient to be 1.0 (Samyshev, 1991). In this case, yearly krill production in the study area would be 8 x 10^6 tonnes; 5 x 10^6 tonnes for the Sodruzhestva Sea and 3 x 10^6 tonnes for the Kosmonavtov Sea. Therefore, we assume that the minimum value of P/B coefficient should be 0.5 (seasonal production) and the maximum value 1.0 (yearly production).

Fish biomass on the outer shelf and the upper part of the continental slope was determined using the swept area method based on results of bottom and mid-water trawl hauls as well as acoustically, whereby swarm density has already been calculated using data from control hauls.

Stocks of Antarctic silverfish *Pleuragramma antarcticum* were assessed using the swept area method and only for pelagic aggregations. Standard commercial mid-water trawls 99.4m, 86.0m, 78/520m, 110/560 and 110/600m with fine-meshed nets were used (minimum mesh size in the codend - 20 mm). Trawl mouth openings ranged from 800 to 2 338 m^2; trawling speed was from 2.5 to 5 knots (3.5 knots on average). Overall, the results of more than 300 hauls were used. It should be noted that commercial fishing of *P. antarcticum* in Subarea 58.4 did not take place.

The biomass of bottom-dwelling fish on the banks of the Sodruzhestva and Kosmonavtov Seas was determined using trawl-acoustic survey data in swarms and bottom haul data for fish beyond these swarms. Trawls 33/64m, 45/48.4m, 41.7/39.6m had 80 mm mesh-size in the codend. The horizontal trawl opening was 21 to 24 metres and the trawling speed was 2.5 to 4.0 knots (an average of 3 knots).

The biomass of bottom-dwelling fish was calculated by stratum (Table 1). Data on area were kindly supplied to us by Dr Trofimov. In calculating biomass, note was taken of the

particular biotopes formed in various areas of the shelf and the different proportionality of species therein. Therefore the areas under study were divided into subareas with different biotopes of major species, largely for the sake of convenience (Trotsenko *et al.*, 1990). We tried to avoid averaging the available data which could have disguised or even led to the "disappearance" of some fish species and, consequently, their role in the functioning of the ecosystem.

Data on fish feeding were gathered during YugNIRO expeditions from 1983 to 1990. In total, the contents of 12 500 stomachs of 27 fish species were analysed. Fish were sampled from catches of commercial mid-water and bottom trawls operating at depths of 100 to 600 m, mainly from 200 to 400 m. These data are presented in Pakhomov (1989).

In order to assess fish diet, stations lasting from one to several days were carried out in the Kosmonavtov Sea above the Gunnerus Ridge from 7 to 10 February 1983; near Prince Olaf Land from 19 to 20 March 1987; at 67°50'S - 41°25'E from 23 to 24 March 1988 and at the bank located at 62°30'E in the Sodruzhestva Sea (Storegg Beach) from 4 to 10 March 1989, 8 to 10 February 1990 and 11 to 13 March 1990. Analysis of data and calculations of daily diets are presented in Pakhomov (1989) and Pakhomov and Tseitlin (1992). Other reference material on the daily food ration of *P. antarcticum* was also used (Gorelova and Gerasimchuk, 1981).

Calculation of krill consumption was carried out for summer only (five months from December to April). The values of mean daily diet of all fish species were taken from Pakhomov and Tseitlin (1992), except in the case of *Chaenodraco wilsoni*, in respect of which a slackening off in feeding was observed during spawning in December and January (Gerasimchuk and Trotsenko, 1988). Therefore, in calculating the seasonal diet of this species it was assumed that the average daily ration in December-January was 0.6% of body weight (Pakhomov and Tseitlin, 1991) and 2.5% of body weight in February-April (Pakhomov, 1989).

3. RESULTS

3.1 Kosmonavtov Sea

Food requirements of various species are given in Table 2 and in Table 3 for *C. wilsoni* on various banks. According to Table 2, total fish stocks are 295.6 $x10^3$ tonnes and the total consumption of krill over the summer is estimated at 515.4 x 10^3 tonnes. The main consumers of krill are *C. wilsoni* (62%) and *P. antarcticum* (33.5%). Moreover, according to Table 3, *C. wilsoni* primarily consumes krill where dense swarms form over localised banks (52%).

The total mean stock size of krill in the Kosmonavtov Sea is estimated at 3.0 x 10^6 tonnes. Applying the values for P/B coefficients presented above gives a minimum seasonal production of 1.5 x 10^6 tonnes and a maximum value of 3.0 x 10^6 tonnes. In this case the total value of krill consumption by fish comprises 34% of seasonal production and 17% of yearly production.

3.2 Sodruzhestva Sea

Over the period December to April, assessment of krill consumption by fish was carried out both for the entire sea as well as individual areas (underwater rises) with high ichthyomass levels, where krill was the main component of fish diets.

3.3 Bank "62°30'E"

Of the 30 000 tonne fish stock in this area (Zaitsev *et al.*, 1990) 79% comprised *C. wilsoni* and 20% were *Trematomus eulepidotus*. The amount of krill consumed from January to April 1990 was calculated using data on the daily ration of the larger fish species inhabiting this area as well as the contents of their stomachs. According to these calculations the amount of krill consumed over the summer period in this area was 109.03 x 10^3 tonnes.

Instantaneous krill biomass in the bank area (between 61° and 63°E) was 0.65 ± 0.12 x 10^6 tonnes in February and 0.13 ± 0.03 x 10^6 tonnes in March. Daily production for the two months was 2.1 and 0.4 x 10^3 tonnes respectively.

Daily krill requirements for fish were 1.5 x 10^3 tonnes at the beginning of the season and 0.36 x 10^3 tonnes at the end. Thus in January-February, fish consumed in one day up to 68% of daily krill production in this localised area. The index of stomach fullness for fish (6.8 to 7.5% of body mass) indicates that krill had been feeding intensely during the same period. Krill comprised 81 to 83% of stomach contents. The daily krill requirement for fish in March was 90% of daily krill production. This would seem to explain the drop in feeding rates (mean index of stomach fullness was from 2.0 to 6.9%) and a switch from *E. superba* to *E. crystallorophias* as the main dietary component (up to 65% body weight).

3.4 Bank "65°10'E" (Table 4)

Total fish stock size was 4.6 x 10^3 tonnes, 99% of which was comprised of *T. eulepidotus*. Preliminary calculations indicate that from January to April fish consumed 10.6 x 10^3 tonnes of krill on this rise. Krill biomass in this area (between 65° and 66°) varied from 0.2 to 0.3 x 10^6 tonnes. Total daily krill production was 0.8 x 10^3 tonnes. The daily krill requirements for fish was calculated to be 0.09 x 10^3 tonnes (about 11% of daily production).

Favourable oceanic conditions were reflected by a high degree of stomach fullness (4.2 to 7.6% body weight).

3.5 Prydz Bay (Table 5)

P. antarcticum stocks in Prydz Bay have varied over the years from 17.5 to 85 x 10^3 tonnes. Seasonal consumption of krill by this species ranges from 26 to 128 x 10^3 tonnes and it is able to consume from one to 13% of yearly krill production. Data contained in Table 5 indicate that, in addition to several other key factors, the *P. antarcticum* population contributed significantly to the decrease of krill biomass in 1986 when it consumed more than a tenth of yearly krill production.

3.6 Sodruzhestva Sea in General (Table 6)

The total fish stock in the Sodruzhestva Sea is estimated at 255.7 x 10^3 tonnes and seasonal krill consumption at 444.7 x 10^3 tonnes. Approximately 18% of seasonal or 9% of yearly krill production is consumed by all fish over the summer season.

4. DISCUSSION AND CONCLUSIONS

We have obtained a value of approximately one 1 x 10^6 tonnes, or 25% of seasonal and 12% of yearly production, for the amount of krill consumed by coastal fishes in the Kosmonavtov and Sodruzhestva Seas during summer (December to April).

Our estimate for krill consumption is quite high when one considers that it was calculated for the summer season alone and only for coastal fishes of a commercial size. Assuming that these fish continue to feed in the winter, the actual level of consumption will obviously be much higher.

In conclusion, we would like to emphasise strongly the regional nature of the estimates presented. For this reason we believe it would be absolutely improper to link our results to other areas of Antarctica. It must also be pointed out that in some areas of the Antarctic, various groups of organisms could be the primary consumers of *E. superba.* It is entirely possible that in Prydz Bay (Sodruzhestva Sea), the main krill consumers are *P. antarcticum, T. eulepidotus* and whales (or seals), while they might be penguins in areas adjacent to the Antarctic Peninsula and crab-eater seals in the Ross Sea. The environment of the Antarctic is highly diverse. Therefore a great deal remains to be done in order to obtain a realistic value for the amount of krill eaten by all possible groups of consumers. Solving this problem would be greatly assisted by the combined efforts of Russian, Australian, South African and Japanese scientists in carrying out, under the aegis of CCAMLR, regular ecosystem monitoring in the Sodruzhestva Sea and adjacent areas.

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Table 1: Area of depth strata between 30° and 80° and the number of hauls used to estimate the biomass of bottom-dwelling fish.

Depth Range (metres)	100 to 200	200 to 300	300 to 500
	Kosmonavtov Sea		
Number of Hauls	2	250	22
Area (miles^2)	2774	4020	3777
	Sodruzhestva Sea		
Number of Hauls	10	88	52
Area (miles^2)	6654	5162	12061

Table 2: Consumption of Antarctic krill by coastal fishes in the Kosmonavtov Sea (30°-50°E) from December to April. Calculated for the depth range 100 to 500 metres.

Species	Stock Size (tonnes)	Seasonal Diet (body mass)	Percentage of Krill by Weight in Stomach	Krill Consumption
Chaenodraco wilsoni	137090	2.61	90	322024
Trematomus eulepidotus	1028.5	3.0	50	1543
Pleuragramma antarcticum	128046	1.5	90	172862
Trematomus hansoni	7593.5	5.25	12	4784
Chionodraco hamatus	3200	2.4	3	230
Cryodraco antarcticus	1143	3.3	1	1
Lepidonotothenia kempi	9987	5.25	20	10486
Dissostichus mawsoni	711	5.25	2	75
Cygnodraco mawsoni	700	1.5	5	53
Trematomus centronotus	522	3.0	20	313
Gymnodraco acuticeps	277	6.0	3.5	58
Others: *Neopagetopsis ionah, T. nicolai, Histiodraco velifer, Pogonophrine scotti, Bathyraja* sp. *et al.*	5279	3.75	2-50, on average 15	2969
Total	295577	2.32	82.2	515398

Table 3: Krill consumption by *Chaenodraco wilsoni* on various banks in the Kosmonavtov Sea.

Bank Longitude	Fish Stock (x 10^3 tonnes)	Krill Consumption by Periods (x 10^3 tonnes)	Total Krill Consumption over Summer (x 10^3 tonnes)
40°40'E	9	21.2	21.2
	9.4(XII-I)*	3.0	
41°10'E	30(II-III)*	40.5	52.3
	13(IV)*	8.8	
41°40'E	9	21.2	21.2
42°10'E	4.6	10.8	10.8
42°50'E	22	51.7	51.7
43°10'E	10.5	24.7	24.7
44°30'E	30	70.5	70.5
45°30'E	7	16.4	16.4
Total krill consumption			268.8

* months

Table 4: Antarctic krill consumption by fish on banks 62°30'E and 65°10'E in the Sodruzhestva Sea during January to April 1990.

Fish Species	Bank '62°30'E'				Bank '65°10'E'			
	Stock (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in Food	Krill Consumption (tonnes)	Stock (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in Food	Krill Consumption (tonnes)
C. wilsoni	23730	3.438* / 2.76	81* / 34	67236* / 22268; 89504	-	-	-	-
C. hamatus	90	1.8	48	78	-	-	-	-
C. antarcticus	30	2.04	1	1	-	-	-	-
N. ionah	90	3.0	40	108	-	-	-	-
T. eulepidotus	5910	3.82 / 0.89	83 / 16	18738 / 842; 19580	4573	3.0	77	10564
T. hansoni	90	4.2	12	45	5	4.2	12	2
D. mawsoni	60	4.2	3	8	-	-	-	-
Total	3000			109324	4578			10566

* Nominator - data for January-February; denominator - data for March-April.

Table 5: Krill consumption by *Pleuragramma antarcticum* in Prydz Bay (seasonal diet was 1.5 of body mass; krill comprised 90% of food)

Year	*P. antarcticum* Stock (x 10^3 tonnes)		Antarctic Krill Biomass between 68°-78°E and to the South of 65°30'S (x 10^6 tonnes)	Seasonal Krill Consumption (x 10^6 tonnes)	Percentage of Yearly Krill Production Consumed
	Min-Max	Median			
1978	50 - 83	62	2.5 - 3.0	0.093	3.4
1982	14 - 23	17.5	2.5 - 2.8	0.026	1.0
1984	41.5 - 69	52	2.5 - 3.0	0.078	2.8
1986	68 - 113.5	85	1.0	0.128	12.8
1987*	-	22	0.3	0.033	11.0

* *P. antarcticum* stock calculated over a very small area.

Table 6: Antarctic krill consumption by coastal-dwelling fishes in the Sodruzhestva Sea (55 to 80°E) from December to April. Fish stock size calculated for a depth range of 100 to 500 m.

Species	Stock Size (tonnes)	Seasonal Diet (body mass)	Percentage of Krill in the Stomach	Krill Consumption (tonnes)
Chaenodraco wilsoni	45305	3.64	64	105543
Trematomus eulepidotus	67946	4.965	53	178797
Pleuragramma antarcticum	89411	1.5	90	120705
T. hansoni	6068	5.25	12	3823
Chionodraco hamatus	19665	2.4	48	22654
C. mayersi	10156	2.4	10	2437
Cryodraco antarcticus	2435	3.3	0.2	16
Lepidonotothen kempi	1930	5.25	1	101
T. centronotus	649	3.0	8.5	166
Dissostichus mawsoni	1128	5.25	3	178
Cygnodraco mawsoni	765	1.5	18	207
Neopagetopsis ionah	6880	3.3	40	9082
Pogonophrine sp.	173	3.0	5	26
Bathyraja sp.	1798	1.5	20	539
T. nicolai	925	3.75	4	139
Notothenia coriiceps	214	5.25	0	0
Other: *P. macropterus, T. bernachii, G. acuticeps, T. scotti, H. velifer, P. borchgrevinki, T. lepidorchinus,* and *M. whitsoni*	267	3.75	0-85 (on average 25)	250
Total	255715	3.12	62.2	444663

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FEEDING PATTERNS OF NINE SPECIES OF ANTARCTIC FISH AND ASSESSMENT OF THEIR DAILY FOOD CONSUMPTION

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Abstract

Little is known about the feeding patterns of non-commercial fish species in Antarctic waters. The aim of this study is to collect information on the feeding patterns of several commercially non-targetted species in the Indian Ocean sector of the Southern Ocean: Nototheniidae (four species), Channichthyidae (three species) and Bathydraconidae (two species). The study concentrated on analysing the food composition of these species to find out their daily diet. One 36-hour station was carried out in the Kosmonavtov Sea (67°50'S; 41°24'E) in March 1988. All samples were taken from the depth range 300 to 350 m and a total of 1 165 stomachs were collected and analysed. The species studied were classified into the four following categories: (i) *Chaenodraco wilsoni* and *Trematomus eulepidotus* - planktivorous species with euphausiids, mainly *Euphausia superba*, being the staple food; (ii) *Trematomus centronotus* - a benthophage feeding mainly on amphipods, mobile and sedentary forms of polychaetes, with *Euphausia superba* also comprising a considerable portion of its diet; (iii) *Trematomus hansoni* - a euryphage; (iv) *Dissostichus mawsoni, Cygnodraco mawsoni, Gymnodraco acuticeps, Chionodraco hamatus* and *Cryodraco antarcticus* - predators feeding mainly on fish. The daily diet of these species was from 1 to 4% of their body weight. Annual food consumption by these species was calculated to be about five times their body weight.

Résumé

Les habitudes alimentaires des espèces de poissons non commerciales dans les eaux de l'Antarctique sont très peu connues. Cette étude a pour but de rassembler des informations sur les habitudes alimentaires de plusieurs espèces non visées commercialement dans le secteur Indien de l'océan Austral, notamment : Nototheniidae (quatre espèces), Channichthyidae (trois espèces) et Bathydraconidae (deux espèces). L'étude est axée sur l'analyse de la composition de l'alimentation de ces espèces pour découvrir leur régime alimentaire quotidien. Une station de 36 heures a été effectuée dans la mer Kosmonavtov (67°50'S; 41°24'E) en mars 1988. Tous les échantillons ont été prélevés de la zone de profondeur 300 - 350 m. Un total de 1 165 estomacs ont été recueillis puis analysés. Les espèces étudiées ont été classifiées en quatre catégories : i) *Chaenodraco wilsoni* et *Trematomus eulepidotus* - des espèces planctonophages dont l'aliment de base est l'euphausiidé, notamment *Euphausia superba*; ii) *Trematomus centronotus* - une espèce benthophage qui se nourrit principalement d'amphipodes, de différentes sortes de polychètes mobiles ou sédentaires, et dont une grande partie du régime se compose

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d'*Euphausia superba*; iii) *Trematomus hansoni* - une espèce euryphage; iv) *Dissostichus mawsoni, Cygnodraco mawsoni, Gymnodraco acuticeps, Chionodraco hamatus* et *Cryodraco antarcticus* - des prédateurs se nourrissant principalement de poissons. La quantité de nourriture absorbée quotidiennement par ces espèces variait entre 1 à 4% de leur poids corporel. Il a été calculé que leur consommation annuelle de nourriture correspond à environ 5 fois le poids de leur corps.

Резюме

До сих пор еще недостаточно известно о питании антарктических рыб, на которые не ведется коммерческого промысла. Целью настоящего исследования является сбор информации о питании нескольких коммерчески не эксплуатируемых видов в индийском секторе Южного океана: Nototheniidae (четыре вида), Channichthyidae (три вида) и Bathydraconidae (два вида). Это исследование направлено на анализ состава пищи этих видов в целях изучения их суточного рациона. Одна суточная станция была выполнена в море Космонавтов (67°50'ю. ш.; 41°24'в. д.) в марте 1988 г. Все пробы были собраны на глубине 300-350 м. В общей сложности было собрано и проанализировано 1 165 желудков. Изученные виды были подразделены на следующие четыре категории: (i) *Chaenodraco wilsoni* и *Trematomus eulepidotus* -планктофаги, в питании которых преобладали эвфаузииды, преимущественно *Euphausia superba;* (ii) *Trematomus centronotus* - бентофаг, потребляющий главным образом амфиподы, подвижные и оседлые формы полихет; *Euphausia superba* также составляет большую часть рациона; (iii) *Trematomus hansoni* -эврифаг; (iv) *Dissostichus mawsoni, Cygnodraco mawsoni, Gymnodraco acuticeps, Chionodraco hamatus* и*Cryodraco antarcticus* - хищники, питающиеся, в основном, рыбой. Суточный рацион этих видов колебался в пределах 1-4% от массы тела. Годовое потребление пищи составило около 5 масс тела.

Resumen

Se sabe muy poco del tipo de alimentación de las especies no explotadas comercialmente en aguas antárticas. El objetivo de este estudio es reunir información sobre el tipo de alimentación de varias especies que no han sido objeto de pesca comercial en el sector Indico del océano Austral: Nototheniidae (cuatro especies), Channichthydae (tres especies) Bathydraconidae (dos especies). El estudio se concentró en el estudio de la dieta diaria de estas tres especies mediante el análisis de la composición de alimentos. Se realizó una estación de 36 horas de duración en el mar de Kosmonavtov (67°50'S; 41°24'E) en marzo de 1988. Todas las muestras se tomaron entre los 300 - 350 m de profundidad, recogiéndose unos 1 165 estómagos para su posterior análisis. Las especies estudiadas se clasificaron en cuatro categorías:

(i) *Chaenodraco wilsoni* y *Trematomus eulepidotus* - son especies planctófagas, que se alimentan de eufáusidos, siendo *Euphausia superba*, el componente habitual; (ii) *Trematomus centronotus* - es una especie bentófaga que se alimenta principalmente de anfípodos y de poliquetos móviles y sedentarios, además de *Euphausia superba*, que forma una parte importante en su dieta; (iii) *Trematomus hansoni* - es una especie eurífaga; (iv) *Dissostichus mawsoni, Cygnodraco mawsoni, Gymnodraco acuticeps, Chionodraco hamatus* y *Cryodraco antarcticus* - son especies depredadoras que se alimentan básicamente de pescado. La dieta diaria de estas especies oscilaba entre el 1 y el 4% de su peso corporal. El consumo anual de estas especies se calculó en cinco veces el peso corporal de la especie.

1. INTRODUCTION

Our knowledge of the feeding behaviour of Antarctic fish is very limited despite the existence of numerous publications on the subject. Feeding patterns of commercial fish has usually been studied in order to evaluate annual consumption of krill, and more often than not in the Atlantic sector of the Southern Ocean (Permitin, 1970; Kock, 1985). There is only scant information on the feeding patterns of non-commercial fish species, but the level of krill consumption by these species might be substantial. This study was aimed at collecting information on the food composition of several commercially non-targeted species in the Indian Ocean sector of the Southern Ocean: Nototheniidae (four species), Channichthyidae (three species) and Bathydraconidae (two species). Another aim was to discover their daily level of food consumption.

One 36-hour station was carried out in the Kosmonavtov Sea (67°50' S; 41°25'E) on 23 to 24 March 1988. Adult specimens were taken from the depth range 300 to 350 m at a rate of one sample each 4 hours. Biological analyses of fish were carried out according to standard procedures (Anon., 1974). Food boluses were collected from fish stomachs and analysed. Food items were identified by species and also ranged according to their level of digestion (fresh, half-digested, completely digested). A total of 1 165 stomachs of nine fish species were processed in this way.

In calculating daily consumption it was assumed that food evacuation from fish stomachs corresponds to an exponential function (Tyler, 1970 and Montgomery *et al.*, 1989). In this case, food evacuation rate is:

$$\frac{dS}{dt} = -AS \qquad (1)$$

where S - amount of food at a given time,
t - time,
A - constant.

From equation (1) it follows that the amount of food in a particular stomach varies according to the equation:

$$S(t) = S\,(0) \exp(-At) \qquad (2)$$

where $S\,(0)$ - amount of food at time $t = 0$.

Equation (2) clearly shows that 90% of food is evacuated over a time of T_{90} (evacuation time):

$$T_{90} = \frac{\ln 0.1}{A} \cong \frac{2.3}{A} \tag{3}$$

Evacuation time is from two to five days for Antarctic fish (Grawford, McLeave as cited in Targett, 1981; Montgomery *et al.*, 1989). In accordance with equation (3) the constant value A = 0.048 - 0.019 when T_{90} is within the above-mentioned range. The mean specific daily consumption (C_W) was calculated according to Pennington's equation (Krasnoper, 1988):

$$C_W = [yAT - y(0) + y(T)] \frac{24}{T} \bullet 100 \tag{4}$$

where C_W is expressed in percent of body mass,
y - mean index of stomach fullness,
A - constant from (3) corresponding to the particular evacuation time,
T - duration of observations (36 hours),
$y(0)$ and $y(T)$ mean indices of stomach fullness at the beginning and end of observations respectively.

Daily food consumption for each fish species was calculated for two values of T_{90}: 48 and 72 hours. The corresponding values of A are 0.048 and 0.032.

In order to compare consumption rates we also calculated approximate daily consumption according to metabolic rate and the index

$$K_2 = \frac{P}{P+R}$$

where P - production
R - metabolic rate.

The parameter K_2 was taken to be 0.2. Therefore, $\frac{P}{R} = 0.25$. Since the amount of consumption $C_w = \frac{P+R}{U}$, where the assimilation index, U, is taken to be 0.8, we obtain the value $C_W = 1.56R$. In order to calculate R, we used the following equations for the basal metabolic rates for cold-water fish (Chekunova, 1983): $R_{st1} = 0.187\ W^{0.783}$ ml O_2 hr^{-1} for most species and $R_{st2} = 0.039W^{0.891}$ ml O_2 hr^{-1} for *Chionodraco hamatus* and *Cryodraco antarcticus*.

If under normal environmental conditions $R=2Rst$ (Vinberg, 1956), then specific daily consumption would be:

$$C_{w_1} = \frac{6.8 \bullet W^{-0.2}}{q} \tag{5}$$

$$C_{w_2} = \frac{1.42 \bullet W^{-0.2}}{q} \tag{6}$$

where: C_W is expressed in percent of body mass;
W - mean body mass (g);
q - food calorific content, assumed to be 1 kcal g^{-1}.

Information on food composition of fish species studied is presented in Table 1. According to this table all species may be classified in the following way:

(i) *Chaenodraco wilsoni* and *Trematomus eulepidotus* - planktophagic species with euphausiids, mainly *Euphausia superba*, being the staple food. *T. eulepidotus* also consumes a substantial amount of myctophids (*Electrona antarctica*) and juvenile nototheniids (mainly *Pleuragramma antarcticum*);

(ii) *Trematomus centronotus* - benthophagic species, feeding mainly on amphipods, mobile and sedentary forms of polychaetes (Table 1). *Euphausia superba* also comprises a considerable portion of the diet of *T. centronotus*;

(iii) *Trematomus hansoni* - euryphagic species. However, food scraps from vessels comprised almost half of sampled stomach contents (Table 1) which significantly distorted the results for this species;

(iv) *Dissostichus mawsoni, Cygnodraco mawsoni, Gymnodraco acuticeps, Chionodraco hamatus* and *Cryodraco antarcticus* - predators, feeding mainly on fish (Table 1). The diet of *D. mawsoni* contained *T. eulepidotus* (38% by weight), *T. hansoni* (6%), *Chaenodraco wilsoni* (13%), myctophids (12%) and juvenile *P. antarcticum* (9%). The diet of *C. mawsoni* and *G. acuticeps* comprised of juvenile fish of almost all species inhabiting the survey area, including their own juveniles. However, the major food items of *G. acuticeps* were the myctophids, *E. antarctica* (21%) and *Gymnoscopelus spp* (25%), and for *C. antarctica* - the fairly uncommon species *Aethotaxis mytopteris* (25%). The main food items for *Chionodraco hamatus* and *Cryodraco antarcticus* were first-year matured *C. wilsoni* (SL=17-20 cm) (37% each), *P. antarcticum* (15 and 22% respectively) and *T. eulepidotus* (17 and 19%).

All fish sampled had been intensively feeding, with *C. wilsoni* and perhaps *G. mawsoni* being the exceptions. The mean index of stomach fullness ranged from 2.2 to 3.9% of body mass (Table 2). It is impossible to be specific about feeding intensity in relation to *D. mawsoni* due to a lack of data. The feeding behaviour of *C. wilsoni* at the time of the survey may have been affected by a range of oceanological conditions (Gerasimchuk and Trotsenko, 1988). This is quite likely since samples collected on the same day some 4 to 5 n. miles from the station position showed a high rate of feeding for *C. wilsoni* (index of stomach fullness was 2 to 4% of body mass).

Following analysis of stomach contents and comparing food at various stages of digestion, we concluded that the actual digestion time for plankton-eaters and benthophages is no less than two or three days, while for predatory and euryphages digestion takes no less than three or four days. This is in total agreement with the experimental data presented earlier.

Some scientists (Novikova, 1949; Kogan *et al.*, 1963) believe that changes in the stomach fullness index over time can be viewed as an indicator of processes occurring within the targetted population, i.e. falls in the index are interpreted as food digestion while increases are seen as consumption. Differences between consecutive values of the index are used to estimate digestion rates which in turn are used to calculate consumption. In our opinion this approach is unsuitable for sea fishes. Populations of sea fishes consist of many schools, each containing several dozen or a few hundred individuals. There is a much greater degree of uniformity of behaviour of specimens within a particular group (school) compared with other groups. Each group behaves as a unit and its members feed simultaneously. However, there is obviously some correlation of behaviour among groups which have certain similarities as species. On average, such groups might consume the same amount of food over several days but the amount of food in their stomachs at any given moment can vary significantly. Each

population sample is obtained after trawling three miles for one hour and, since we do not know why fish tend to group together, we cannot say how many groups make up the catch. Figure 1 shows the weight distribution of *T. hansoni* in two consecutive samples. If one assumes that schooling patterns are determined by age or size, then the first sample is formed by one group and the second one by at least two. Figure 2 shows consecutive changes in the mean stomach fullness index, mean body weight and the amount of fresh food recorded over the observation period in respect of *T. hansoni*. The data in Figures 1 and 2 indicate that changes in the index are not indicative of the process of the stomach becoming full or of food evacuation. Rather, these changes are brought about by size differences among specimens and decreases in the amount of fresh food as the overall stomach fullness index increases.

The case of *C. wilsoni* is somewhat different. Body weight for this species in consecutive samples did not differ significantly and the population was of one age class. However here we came across an increase in the index of stomach fullness over four hours due to heavily digested food which had been in the fishes' stomachs more than one day. Obviously in this case different groups of fish were analysed separately.

Modelling was used to study fish feeding patterns and to check the methods used in this field of study. Parameters studied within the fish population were specific body weight and food evacuation rate. Both of these indices displayed a degree of inconsistency which is characteristic of a real population. At random times (but at a specific part of the day) fish received portions of food corresponding to the weight of prey they would consume in the wild. The likelihood of food portions being taken was fitted so that over three days they received an amount of food corresponding to their normal consumption. Levels of stomach fullness were studied for a random group of 25 specimens (i.e. observation was simulated). Results of modelling indicated that such random feeding is sufficient to obtain a clear picture of changes in the stomach fullness index such as occur in natural conditions. Changes in the fullness index over time were caused by random sampling and not by consumption and food evacuation patterns themselves.

Calculated daily and yearly consumption turned out to be small (Table 2) and for the following species were: *Chaenodraco wilsoni** - 2.5% and 5.8%; *Trematomus eulepidotus* and *T. centronotus*- 2.0% and 4.6%; *Dissostichus mawsoni* and *T. hansoni* - 3.5% and 8.1%; *Gymnodraco acuticeps* 4.0% and 9.2%; *Cygnodraco mawsoni* - 1.0% and 3.0%; *Chionodraco hamatus* - 1.6% and 3.5% and *Cryodraco antarcticus* - 2.2% and 4.0%. The mean annual rate of consumption for these fish is about five times their body weight. The average amount of consumption for the waters of eastern Antarctica, which has a mean biomass density in the order of 4.6 to 5.1 thousand km^2 can be calculated using Shust's data. An annual food base production of no less than 20 to 25 thousand km^2, is required for a biomass of this size. If one assumes that the mean biomass of bottom and near-bottom dwelling fish is 12 to 13 million tonnes (Lubimova and Shust, 1980) then the yearly consumption rate of Antarctic fish is between 60 and 65 million tonnes.

* Consumption for *C. wilsoni* was minimal (about 0.6% of body weight) due to inactive feeding. Such a low value is uncharacteristic for this species. According to data obtained from the Kosmonavtov Sea, daily consumption by this species is usually about 2.5% of body weight (Pakhomov and Shumatova, 1988). This is the value we took for our estimate of annual consumption by *C. wilsoni*.

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Table 1: Food composition in fish (percentage of food by weight) sampled at a 36-hour station in the Kosmonavtov Sea - 23 to 24 March, 1988.

Food Items	*C. wilsoni*	*T. eulepidotus*	*T. hansoni*	*T. centronotus*	*D. mawsoni*	*C. mawsoni*	*G. acuticeps*	*C. hamatus*	*C. antarcticus*
E. superba	84.6	52.2	1.97	32.9	2.0	1.1	2.3	1.9	0.1
Other	5.8	10.2	0.03	0.8	1.0	0.4	0.05	0.6	+
Euphausiids									
Mysidacea	-	-	0.1	0.2	0.7	1.6	0.02	0.1	-
Amphypoda	0.03	0.8	0.7	12.6	+	3.8	0.03	-	-
Isopoda	-	-	0.2	1.0	-	0.03	-	-	-
Decapoda	-	-	-	0.8	-	0.4	0.05	-	0.2
Gastropoda	-	-	2.6	0.1	-	-	-	-	-
Teuthida	-	-	1.4	3.7	2.1	-	0.3	-	-
Pteropoda	-	0.2	-	-	-	-	-	-	-
Polychaeta	-	0.05	6.5	41.4	-	1.7	0.07	-	-
Tunicata	-	1.2	0.1	2.7	0.1	-	-	-	-
Fish eggs	-	-	29.5	1.1	-	-	0.07	-	-
Myctophidae	5.1	23.5	0.4	0.3	12.0	1.4	52.3	14.5	-
Nototheniidae	4.5	11.4	10.4	2.1	82.1	89.1	44.8	82.9	99.7
Vessel waste	-	-	45.6	-	-	-	-	-	-
Other food	-	0.4	0.54	0.3	-	0.1	-	-	-
Soil elements	-	-	0.1	0.01	-	0.4	0.02	-	-
Number of stomachs examined	250	219	243	43	52	197	84	58	21

Table 2: Percentage of daily food consumption of the examined fish at a 36-hour station in the Kosmonavtov Sea - March 1988.

Species	Number of Specimens	Mean Body Weight $\omega \pm \sigma$ (g)	Mean Index of Stomach Fullness	Food Evacuation Rate	Daily Food Consumption as % of Body Weight	Daily Food Consumption as per Vinberg's Formula
Chaendraco wilsoni	250	180 ± 2[1] (104 - 288)[2]	0.009 ± 0.001 (0 - 0.1)	48 72	0.9 0.6	2.4
Trematomus eulepidotus	219	118 ± 6 (50 - 650)	0.022 ± 0.001 (0 - 0.094)	48 72	2.8 1.9	2.6
Trematomus hansoni	243	380 ± 20 (100 - 1350)	0.038 ± 0.002 (0 - 0.157)	48 72	5.2 3.7	2.1
Trematomus centronotus	43	97 ± 10 (48 - 433)	0.036 ± 0.004 (0 - 0.109)	48 72	3.4 2.0	2.7
Dissostichus mawsoni	52	1033 ± 100 (214 - 4450)	0.040 ± 0.005 (0 - 0.245)	48 72	5.4 3.9	1.7
Cygnodraco mawsoni	197	299 ± 9 (25 - 1020)	0.019 ± 0.002 (0 - 0.245)	48 72	1.7 1.0	2.1
Gymnodraco acuticeps	84	413 ± 45 (160 - 780)	0.034 ± 0.004 (0 - 0.196)	48 72	5.7 4.4	2.0
Chionodraco hamatus	58	437 ± 38 (300 - 940)	0.021 ± 0.005 (0 - 0.11)	48 72	2.4 1.6	0.72
Cryodraco antarcticus	21	604 ± 85 (79 - 1300)	0.051 ± 0.01 (0 - 0.2)	48 72	4.2 2.25	0.7

[1] the value following ± is the mean square error (σ)
[2] minimum and maximam values

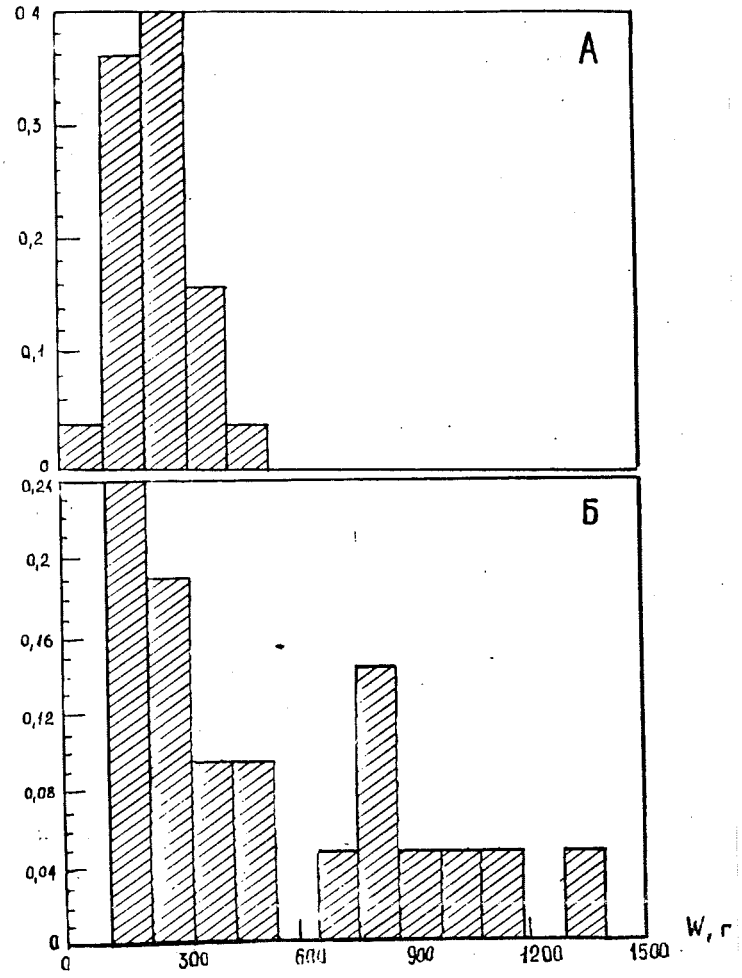
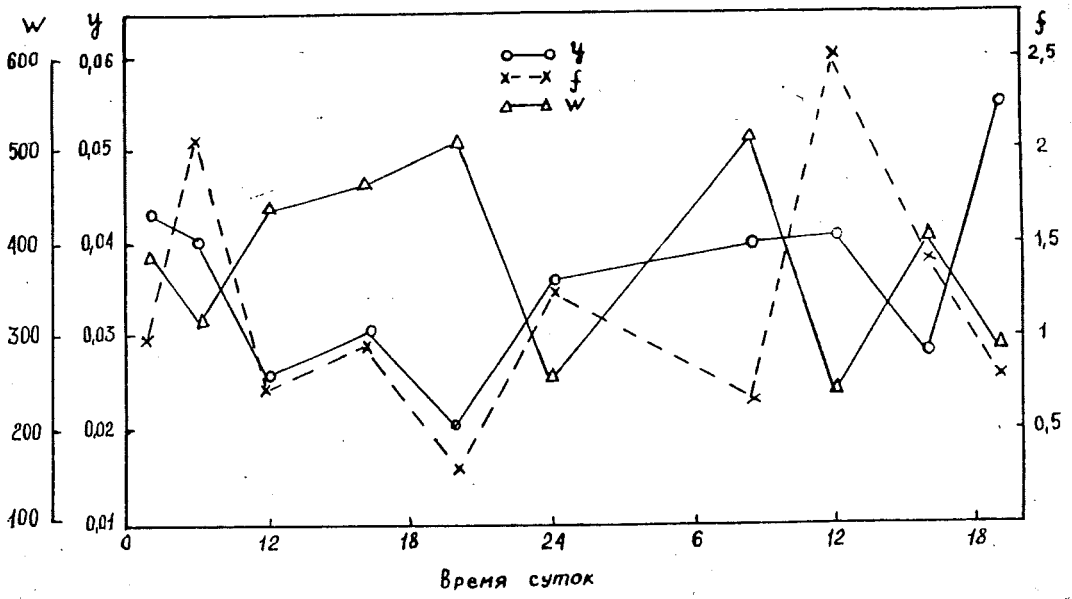


Figure 1: Weight frequency distribution of *Trematomus hansoni* in two consecutive samples: Sample A - mean weight 236 g; sample B - mean weight 524 g.



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MYCTOPHIDS IN THE DIET OF ANTARCTIC PREDATORS

E. Sabourenkov*

Abstract

The aim of the present study is to review published data on the diet of various top predators (birds, seals, whales, fish and squids) in order to help evaluate the importance of myctophids in their diets. This review covers publications for the period since 1984-85 to the present. In total, over 50 publications contained some information on the myctophid component of the diet of Antarctic predators. Myctophids were found in the diet of one species of squid, 18 species of fish (*Nototheniidae* - eight, *Channichthyidae* - seven, *Bathydraconidae* - two and *Rajidae* - one), 18 species of birds (penguins - seven, albatrosses - four, petrels - five, prions - one and cormorants - one) and two species of seals. Myctophids in the diet of predatory species are represented by 16 species of genera *Krefftichthys* (one species), *Protomyctophum* (four species), *Electrona* (five species), *Metelectrona* (one species) and *Gymnoscopelus* (four species). However, the total number of species may be underestimated because identification of myctophids in predator food samples is still difficult. Many species of fish, birds and seals take myctophids opportunistically in addition to their staple diet. Penguins have the largest proportion of myctophids in their diet. The king penguin in the Antarctic Polar Front area of the Indian Ocean is the only one specialist predator on myctophids. The *Bathydraconidae* fish, *Gynmodraco acuticeps,* from the Kosmonavtov Sea (Indian Ocean sector) may be the second most important predator of myctophids. The occurrence of myctophids in the diet of predatory species appears to be highly variable though there are insufficient data to evaluate this. It is obvious that myctophids are widespread in diets of many Antarctic predators. More quantitative studies on as many as possible species of predators are required in order to assess the role of myctophids in the Antarctic ecosystem. Information on the diet of myctophids themselves is also important. These studies should use standardised methods, be carried out in different seasons and have a wide geographical coverage.

Résumé

La présente étude a pour objectif d'examiner des données publiées sur le régime alimentaire de divers prédateurs supérieurs (oiseaux, phoques, baleines, poissons et calmars) dans le but de faciliter l'évaluation de l'importance des Myctophidae dans leur régime alimentaire. Cet examen couvre les publications de 1984/85 à nos jours. En tout, plus de 50 publications contenaient des informations sur la composition du régime alimentaire des prédateurs antarctiques. Des Myctophidae ont été trouvés dans le régime alimentaire des espèces suivantes : une espèce de calmar, 18 espèces de poissons (*Nototheniidae* - huit, *Channichthyidae* - sept, *Bathydraconidae* - deux et *Rajidae* - une), 18 espèces d'oiseaux (manchots - sept, albatros - quatre, pétrels - cinq, prions - une et cormorans - une) ainsi que dans

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deux espèces de phoques. Dans le régime alimentaire des espèces prédatrices, les Myctophidae sont représentés par 16 espèces des genres suivants : *Krefftichthys* (une espèce), *Protomyctophum* (quatre), *Electrona* (cinq), *Metelectrona* (une) et *Gymnoscopelus* (quatre). Toutefois, vu la difficulté que présente toujours l'identification des Myctophidae dans les échantillons alimentaires des prédateurs, il se pourrait que le nombre des espèces soit sous-estimé. De nombreuses espèces de poissons, d'oiseaux et de phoques ajoutent, à l'occasion, des Myctophidae à leur régime alimentaire ordinaire. C'est dans le régime alimentaire des manchots que se trouve la proportion la plus élevée de Myctophidae. Le manchot royal de la région du front polaire antarctique de l'océan Indien est le seul prédateur qui se nourrisse spécialement de Myctophidae. Le poisson Bathydraconidae, *Gynmodraco acuticeps*, de la mer Kosmonavtov (secteur de l'océan Indien) pourrait être le deuxième prédateur de Myctophidae par ordre d'importance. La présence de Myctophidae dans le régime alimentaire des espèces prédatrices semble être des plus variables, quoique le nombre insuffisant des données ne permette pas une telle évaluation. De toute évidence, les Myctophidae sont très répandus dans le régime alimentaire de nombreux prédateurs antarctiques. Il conviendrait d'entreprendre de nouvelles études quantitatives sur un maximum d'espèces prédatrices pour pouvoir estimer le rôle des Myctophidae dans l'écosystème antarctique, et également d'élargir nos connaissances du régime alimentaire des Myctophidae mêmes. Ces études devraient être effectuées par des méthodes standard, en différentes saisons, et couvrir une aire géographique étendue.

Резюме

Целью настоящего исследования является обзор опубликованных данных по рациону различных хищников (птиц, тюленей, китов, рыб и кальмаров), что будет способствовать оценке значения миктофид в их рационе. Этот обзор охватывает работы, публиковавшиеся с 1984-85 г. до настоящего времени. В общей сложности, более 50 публикаций имело некоторую информацию по содержанию миктофид в рационе хищников Антарктики. Миктофиды были обнаружены в рационах одного из видов кальмара, 18 видов рыб (*Nototheniidae* - восемь, *Channichthydae* - семь, *Bathydraconidae* - два, *Rajidae* - один), 18 видов птиц (пингвинов- семь, альбатросов- четыре, буревестников - пять, китовых птиц - один и бакланов - один) и двух видов тюленей. Миктофиды в рационе хищников представлены 16 видами рода *Krefftichthys* (один вид), *Protomyctophum* (четыре вида), *Electrona* (пять видов), *Metelectrona* (один вид), *Gymnoscopelus* (четыре вида). Тем не менее, существует опасность недооценки общего количества видов в связи с тем, что идентификация миктофид в пробах пищи хищников до сих пор представляет собой сложный процесс. Многие виды рыб, птиц и тюленей питаются миктофидами только при случае, в дополнение к их основному рациону. Наибольшая пропорция миктофид обнаружена в рационе пингвинов. Королевский пингвин, обитающий в районе Антарктического полярного фронта Индийского океана,

является единственным хищником, основной пищей которого являются миктофиды. Вид *Bathydraconidae, Gymnodraco acuticeps*, обитающий в море Космонавтов (индоокеанский сектор), возможно является вторым по важности хищником миктофид. Присутствие миктофид в рационе хищников - явление весьма переменное, хотя по этому вопросу еще недостаточно данных. Очевидно, что миктофиды широко распространены в рационе многих хищников Антарктики. В целях оценки роли миктофид в антарктической экосистеме необходимо проводить больше количественных исследований всех возможных видов хищников. Данные по рациону самих миктофид также важны. Такие исследования должны использовать стандартизированные методы, проводиться в разные сезоны и иметь широкий географический охват.

Resumen

El objetivo de este estudio es revisar los datos publicados sobre la dieta de algunos depredadores principales (aves, focas, ballenas, peces y calamares) para poder evaluar la importancia de los mictofidos en su dieta. Esta revisión comprende las publicaciones del período 1984-85 hasta la actualidad. En total, más de 50 trabajos contenían información sobre la composición de mictófidos en la dieta de los depredadores antárticos. Se encontraron restos de mictófidos en la dieta de una especie de calamar, 18 especies de peces (ocho de Nototheniidae - siete de Channichthydae - dos de Bathydraconidae y una de Rajidae), 18 especies de aves (siete pingüinos, cuatro albatros, cinco petreles, un prión y un cormorán), además de dos especies de focas. Los mictófidos que forman parte de la dieta de los depredadores comprenden 16 especies del género *Krefftichthys* (una especie) *Protomyctophum* (cuatro especies), *Electrona* (cinco especies), *Metelectrona* (una especie) y *Gymnoscopelus* (cuatro especies). Sin embargo, el número total de especies puede haberse subestimado por la dificultad que entraña su identificación en las muestras tomadas de la dieta de los depredadores. Algunas especies de peces, aves y focas consumen mictofidos esporádicamente si están a su alcance, además de su dieta acostumbrada. Los pingüinos son quienes consumen el mayor porcentaje de mictofidos. El pingüino real, de la zona del Frente Polar Antártico del Océano Indico, es el único depredador que se limita a los mictófidos. El pez Bathydraconidae, *Gymnodraco acuticeps* del mar de Kosmonavtov (sector del Océano Indico) puede ser el segundo depredador más importante de mictófidos. La presencia de éstos en la dieta de las especies depredadoras parece estar sujeta a grandes variaciones, aunque no se tienen datos suficientes para hacer una evaluación. Es obvio que los mictófidos son muy comunes en la alimentación de muchos depredadores antárticos. Es preciso realizar más estudios del mayor número de especies depredadoras posibles para valorar su función dentro del ecosistema antártico. Es igualmente importante que se obtenga información sobre la dieta de los mictófidos. Estos estudios deberían seguir métodos estándar que cubran diferentes temporadas y zonas geográficas extensas.

1. INTRODUCTION

Myctophids or lanternfish, species of the family *Myctophidae,* are widely distributed in the mesopelagic and bathypelagic waters of the World's oceans. In the Antarctic waters to the south of the Antarctic Convergence 35 species of myctophids are found, i.e. within the CCAMLR Convention Area (Hulley, 1990). Of these 35 species, 11 have circumpolar distributions and are mainly widespread from the Antarctic Polar Front zone (APF) to the edge of the Antarctic continental slope. Other species have more restricted distribution and are found in localised areas in APF waters (eight species in the Atlantic sector of the Southern Ocean, 13 species in the Indian Ocean sector and four species in the Pacific sector). The total biomass of myctophids in Antarctic waters is estimated to be 70-200 x 10^6 tonnes (Lubimova, Shust and Popkov, 1987). Myctophids apparently represent the second largest (after krill) and most widely distributed biological resource in Antarctic waters. Four species of myctophids (*Krefftichthys anderssoni, Electrona antarctica, Electrona carlsbergi* and *Gymnoscopelus nicholsi*), all of which are distributed circumpolarly, contribute the bulk of the biomass (over 80%). The position of myctophids in the Antarctic food web is not adequately understood. It was suggested that myctophids might be a part of a separate food chain from krill, e.g. phytoplankton -> copepods -> myctophids -> predatory fish and squids -> toothed whales (Lubimova, Shust and Popkov, 1987). However, it is also known that diets of many other species of top-level predators, such as marine mammals and birds, contain some myctophids (Croxall, 1984; Laws, 1984; Bengtson, 1985). In addition several species of myctophids consume krill (see Sabourenkov, 1991). The aim of the present study is to review published data on the diet of various top predators (birds, seals, whales, fish and squids) in order to help evaluate the importance of myctophids in their diets.

Early studies on food and feeding ecology of Antarctic top predators were summarised in several detailed reviews (e.g., Everson, 1984; Croxall, 1984 and Laws, 1984). These studies were chiefly based on observed contents of animals faeces, stomachs or regurgitations analysed on the basis of frequency of occurrence of main prey items. Very few studies provided a fully quantitative analysis of stomach contents or provided information on numbers of individuals or total weight of each prey class. Such information is essential for assessing trophic interactions between species, particularly if calculations of prey consumption by populations of predators are desired.

Since the time of these reviews more quantitative studies on food of the Antarctic predators were carried out. Methods have become more standardised, particularly because of the effort of such international organisations as SCAR[1] and SC-CAMLR[2].

This review covers publications for the period since the reviews of 1984 to 1985 mentioned above. In total, over 50 publications contained some information on the myctophid component of the diet of Antarctic predators. Many publications report only descriptive information and refer to myctophids only as a group of species. Quite a few publications, however, provide various quantitative estimates on the proportion and species composition of myctophids in the diet of particular predators.

All available information on myctophids was compiled in order to evaluate the number of predator species which have myctophids in their diet and the number of myctophid species found in the diet of each predator. The available quantitative results of stomach analyses were then combined and discussed for each major group of predator species. Several of the most detailed sets of results were summarised and are presented in tabular form in the Annex.

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1 Scientific Committee on Antarctic Research and, in particular, its Group of Specialists on Seals and Bird Biology Subcommittee.

2 Scientific Committee of the Convention on the Conservation of Antarctic Marine Living Resources

2. MYCTOPHID COMPONENT OF THE DIET OF PREDATORS

Recent studies found myctophids in the diet of one species of squid, 18 species of fish (eight *Nototheniidae,* seven *Channichthyidae,* two *Bathydraconidae* and one *Rajidae),* 18 species of birds (penguins - seven, albatrosses - four, petrels - five, prions - one and cormorants - one) and two species of seals (Table 1). No myctophids were reported from studies of whale diets in the Antarctic waters[3]. Two species of myctophids, *E. antarctica* and *G. nicholsi* were found to eat some juvenile myctophids as a part of their diets (Williams, 1985; Takahashi, 1983).

In total, 16 species of myctophids have been identified so far in the diets of Antarctic top predators. They belong to the following five genera: *Krefftichthys* (one species), *Protomyctophum* (four species), *Electrona* (four species), *Metelectrona* (one species) and *Gymnoscopelus* (six species). Identification of myctophid species in food samples is rather difficult and some fish remnants and otoliths remain unidentified or identified only to genus level. For this reason the actual number of species may be presently underestimated.

Species composition of myctophids consumed by Antarctic predators is given in Table 2. Six species of myctophids have been identified to date in the diet of fish, 10 species in the diet of penguins, nine species in the diet of flying birds and 13 species in the diet of seals.

Myctophids were found in the diet of predators in several localities in the Antarctic along the APF area and the Antarctic coast (Figure 1). In the APF area data on myctophids came from sub-Antarctic islands and two shallow banks (Ob and Lena Bank). On the Antarctic coast myctophids were reported from samples taken in the Prydz Bay area, Budd Coast and the east coast of the Weddell sea.

3. QUANTITATIVE AND OTHER DETAILED DATA ON MYCTOPHIDS EATEN BY PREDATORS

3.1 Fish

Three studies from the Indian Ocean sector and the South Shetland Islands area report quantitative data (Takahashi, 1983; Chechun, 1984; Pakhomov and Tseitlin, 1992) (Annex, Table 1) but do not distinguish the species of myctophids involved, treating them as a group.

In the APF area of the Indian Ocean the data come from four different localities: Kerguelen Islands, Crozet Islands, Lena and Ob Banks (Chechun, 1984). The food of 11 species of fish was studied. Myctophids were found in the diet of three species of nototheniids and two species of channichthyids. Myctophids do not comprise a staple food item in the diet of these fish in the area.

The diet of *Notothenia rossii* by percentage of weight contains 3.6% of myctophids in the Ob Bank area; in the other three areas it varies from 0.9 to 2.7%. Species of *Scyphozoa, Ctenophora* and *Tunicata* (salps) comprise the bulk of *N. rossii* diet (over 30%). Fish comprise from 16.1 to 24 % of *N. rossii* diet.

The diet of *Notothenia squamifrons* contains the largest proportion of myctophids (13.5% by weight in the Crozet Islands area) in comparison with other fish. Myctophids of the genus *Gymnoscopelus* were identified as a separate group. They comprise from 1.6 to 3.4% by weight. In other areas (Kerguelen Islands, Lena and Ob Banks) myctophids represent from 1.8 to 7.6% (salps, hyperiids and polychaetes comprise the bulk of food of *N. squamifrons*). In total, fish comprise from 11.6 to 13.8% (by weight).

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[3] Finding of two specimens of *E. antarctica* from stomachs of minke whale sampled in 1982/83 was recently reported (Bushuev, 1991).

The diet of *Dissostichus eleginoides* in the areas surveyed contained 3.3 to 8.4% by weight of myctophids. Fish comprised at about 75% (73.3 to 77.9%) of its diet.

The diet of *Champsocephalus gunnari* and *Chaenichthys rhinoceratus* was studied only in the Kerguelen Islands area. For *C. gunnari* the proportion of myctophids by weight was 2.4% and for *C. rhinoceratus* it was 3.4%. Fish comprised only 7.9% of the diet of *C. gunnari* (the bulk of food was copepods, hyperiids and euphausiids) but 84.3% of the diet of *C. rhinoceratus*.

The data from the South Shetland Islands area give only frequency of occurrence of myctophids in the diet of three species of nototheniids, one species of channichthyid and also of *G. nicholsi* and unidentified *Rajidae* spp. (Takahashi, 1983). Only *Notothenia kempi* has a high frequency of occurrence of myctophids (33.3%); for the other species it is 1.2 to 3.4%. The presence of myctophids in the diet of bottom-dwelling fish such as Rajidae spp. suggested the possibility of migrations of myctophids into benthic habitats.

In the Kosmonavtov Sea, myctophids were found in diets of eight species of fish (Pakhomov and Tseitlin, 1992). The myctophid component in the diet of *Gymnodraco acuticeps* (*Bathydraconidae*) is more than 50% (by weight). This species feeds mainly on fish which constitute 97.1% of its food (other fish food in the diet of the species was *Notothenioidei*). Of three studies species of *Trematomus* (*Nototheniidae*), only one *Trematomus eulepidotus,* has myctophids (23.5%) in its diet. The remaining food items were mainly euphausiids, with *E. superba* comprising 52.2%. *D. eleginoides,* the species which primarily feeds on fish, has 12.0% of myctophids in its diet in Kosmonavtov Sea with the remaining fish food being mainly *Notothenioidei* (82.1%). Myctophids are reported only as a species-group in this study.

In the Atlantic sector, earlier studies in the South Georgia area also found myctophids in the diet of *C. gunnari, Pseudochaenichthys georgianus* (Kock, 1981) and *D. eleginoides* (K.-H. Kock, personal communication). During these studies only the frequency of occurrence of myctophids was determined. The results indicated that myctophids did not comprise a frequent food item of these fish in the South Georgia area.

3.2 Birds

The most complete set of quantitative data on myctophids in the diet of Antarctic predators come from this group of predators, mainly from studies of Antarctic and sub-Antarctic penguins. Summaries of available data are given below by major groups of predators.

3.2.1 Penguins

King penguin *(Aptenodytes patagonicus)*

Information on myctophids in the diet of king penguins came from the APF area of the Indian and Pacific Oceans (Marion, Heard and Macquarie Islands) (Annex, Table 2). The king penguin feeds mainly on fish in all of these three localities. The proportion of fish is about 94% by number and by food weight. A small proportion of squid is also taken. Almost all of the fish taken by king penguin is myctophids with *K. anderssoni* and *E. carlsbergi* being the principal prey items. *Protomyctophum* spp. and *Gymnoscopelus* spp. are also taken but in much smaller quantities. Some variation, however, exists between three localities (Marion, Heard and Macquarie Islands) in species composition of myctophids and their proportions in the diet (see Table 3).

The proportion of *K. anderssoni* in the diet is largest on Heard and Macquarie Islands. On Marion Island an unknown amount of *P. tenisoni is* included in the reported 31.8% of *K. anderssoni* because otoliths of these two species are very difficult to distinguish. All these species of myctophids have circumpolar distribution at least in the APF area with only one exception - *P. normani* which is found to the south of APF only in the Indian Ocean sector. The next most abundant food item in the diet on Marion Island (13.4%) and Macquarie Island (48.5%) is *E. carlsbergi*. This species did not comprise any substantial proportion in the diet on Heard Island, but this might reflect differences in the timing and duration of field studies.

Observations at Marion and Macquarie Islands were carried out for a whole year. Authors noted very distinct seasonal changes in maximum and minimum proportions of *K. anderssoni* and *E. carlsbergi*. The observed seasonal variations are summarised in Table 4. A very close similarity in the distribution of these species in the diet of king penguins is observed on Marion and Macquarie Islands. Observations on Heard Island were conducted in November/December when *E. carlsbergi* is absent in the diet of king penguins at two other surveyed islands. These changes in species composition of the diet may reflect seasonal changes in distribution of *K. anderssoni* and *E. carlsbergi* in the APF area of the Indian Ocean as well as seasonal changes in feeding patterns of king penguins.

Gentoo penguin (*Pygoscelis papua*)

Observations have been conducted at four different localities: South Georgia, Marion, Heard and Macquarie Islands (Annex, Table 3).

On South Georgia observations were conducted during winter (May to September) in 1987 and 1988. Diet composition by sexes was different (Williams, 1991). The diet of females in July/August, 1987 consisted mainly of crustaceans (87% by weight) with *E. superba* being a staple food. The diet of males in the same period consisted mainly of fish (83% by weight). Gentoo penguins show sexual dimorphism in bill size, and males are larger and may be better adapted to catch fish prey. It may also suggest different foraging areas with males feeding close to the shore on fish and females feeding off-shore of krill. Three species of myctophids were identified in food samples: *E. carlsbergi, P. choriodon* and *G. braueri*. However, their total number was only 4.3 to 6.2% of the total number of otoliths in samples. Diet studies in summer (Croxall and Prince, 1980; Croxall, personal communication) have failed to detect myctophids.

On Marion Island the winter diet (September) comprised 70% fish by weight and 30% crustaceans (La Cock, Hecht and Klages, 1984). Three specimens of myctophids belonging to the genera *Electrona, Protomyctophum* and *Gymnoscopelus* (<1.0% of all otoliths) were found. A second study gave results of 86.5% fish, <1.0% of crustaceans and 13.5% of squid (Adams and Klages, 1987).

On Heard Island the diet from November 1986 to January 1987 comprised mainly of crustaceans (75.2% by number) and fish (22.2% by number and 90.5% by weight). Myctophids, mainly *K. anderssoni*, comprised about 12% by number.

On Macquarie Island the diet of gentoo penguin was exclusively fish with 58.3% of myctophids (by weight). Three species of myctophids were observed: *K. anderssoni, E. carlsbergi* and *Gymnoscopelus* spp. A proportion of *E. carlsbergi* was the highest among myctophids (27.5% by weight).

Royal/macaroni penguin (*Eudyptes chrysolophus*)

Two papers were recently published on the diet of royal/macaroni penguins (Annex, Table 4). However, only the data for Macquarie Island contain quantitative details (Hindell, 1988c). Myctophids in the diet comprised 2.2% by number and 41.2% by weight (out of 45.6% of all fish). Four species of myctophids were found: *K. anderssoni, E. carlsbergi* and two species of genus *Protomyctophum* and *Gymnoscopelus*. Other components of the diet were crustaceans (51.3% by weight) and small amount of squids.

On Crozet Islands 35.4 % (by volume) of the diet of royal/macaroni penguins consists of myctophids; *K. anderssoni* (17.2%), *E. carlsbergi (9.0%)* and *P. tenisoni* (6.7%) (Ridoux, 1987).

Results of several studies have been published recently but quantitative data on the diet of this species of penguin is available only for Macquarie Island (Annex, Table 5, Hindell 1988a). The diet of this species contained only a small proportion of fish (1.2% by number and 28.3% by weight). Myctophids comprised only about 0.7% in number and 23.1% by weight. Other food items were crustaceans (69.4% by weight) and a small amount of squids.

3.3 Flying Birds

Quantitative data on myctophids in the diet of flying birds had been obtained for the Wilson's storm petrel from South Georgia and for the blue-eyed cormorant at Macquarie Island (Annex, Table 6). The diet of Wilson's storm petrel contain only 1.0% of fish (by number) forming 28% of the diet by weight. Fish was only myctophids: *P. normani* and *P. bolini*. *G. nicholsi* was found in the diet of the cormorant. It represented 0.2% (by number) of all fish.

Fish form 24% by weight of the diet of white-chinned petrels (Croxall and Prince, 1987). Myctophids comprise 81% by number and about 75% by weight of the fish portion of the diet (Croxall and North, personal communication). Seven species of myctophid were identified (see Table 2) of which *E. antarctica, E. carlsbergi* and *G. nicholsi* were the most common species (contributing 77% by number and 78% by weight of all myctophids).

3.4 Seals

3.4.1 Antarctic fur seal (*Arctocephalus gazella*)

Results of four recent studies on the diet of the Antarctic fur seal contain some quantitative assessments (Annex, Table 7). Myctophids comprised the bulk of all otoliths found in scats of the Antarctic fur seal in the Heard and Macquarie Islands: 60.4 to 85.0% and 88.3%, respectively. Myctophids of the following species were most frequent:

Heard Island - *E. antarctica, E. subaspera* and G. *nicholsi*;
Macquarie Island - *E. subaspera* and one unidentified species of genus *Electrona.*

On South Georgia myctophids (*G. nicholsi)* comprised 10.9% of otoliths in scat samples but by weight this represented only about 2% of the diet (Doidge and Croxall, 1985). Other food items were several species of nototheniids and channichthyids and also some squids with the main diet being Antarctic krill.

4. DISCUSSION

Since the reviews of 1984 and 1985 many quantitative assessments of the diet of the Antarctic predators have been undertaken. Most studies had been carried out on sub-Antarctic islands, on the Antarctic coast and in adjacent waters.

The importance of myctophids as food for other fish is still poorly known. Though myctophids were recently reported from diet studies of 18 species of fish, the number of quantitative studies and their geographical coverage is very limited.

With several exceptions, studies on the diet of birds and seals were generally conducted ashore during their breeding season. Less is known of the diet composition of these predators during winter when most of them feed at sea and do not return ashore. Geographical distribution of sites where myctophids were found in the diet of predators, reflect this situation (Figure 1, Tables 1 and 3). All myctophids were encountered in the two narrow zones: the APF area from the Antarctic Peninsula east to Macquarie Island (nine localities) and the Antarctic coast (four neighbouring localities). Recent studies in the Weddell Sea have shown that outside of breeding seasons in winter myctophids are very significant by mass in diets of Adelie penguins (17%), Antarctic petrel (64%) and snow petrel (87%) (D.G. Ainley, personal communication).

Most quantitative information of myctophids came from studies of diets of penguins. Studies of the diet of king penguin represent the best set of data available. Apparently this species of penguin is the only specialist predator on myctophids at least in the APF area of the Indian Ocean. Unfortunately no quantitative data are available on the diet of king penguins on South Georgia where the bulk of the diet of many predatory species consists of krill, *E. superba*. However, Croxall (1991) lists this species as feeding on myctophids at South Georgia as well. Myctophids were found also in diets of three other species of penguins: gentoo, macaroni and rockhopper. However, the level of quantitative details on myctophids in these studies was not sufficient to make any conclusion on consumption of myctophids or to compare diets in different geographical areas.

Limited quantitative description of myctophids in the diet of two species of flying birds, Wilson's storm petrel and blue-eyed cormorant, is available.

Myctophids in the diet of Antarctic seals in recent studies are reported only for the Antarctic fur seal from South Georgia, Heard and Macquarie Islands. Unfortunately the data basically give only frequency of occurrence of myctophids by species found in collected scats. In 1988 Soviet researchers took more than 200 stomach samples of crabeater, leopard, Weddell, Ross and elephant seals. Preliminary results contained no information on myctophids (Vagin and Shust, 1989).

The diet of Antarctic predators is highly variable temporally and geographically. For many breeding areas information on the diet composition of many predators is not yet available. Table 3 summarises by breeding areas the available information for birds and seals the diet of which, at least at some areas, contain myctophids. This summary table allows a very rough assessment of the extent to which dietary studies have been undertaken at predators' breeding areas. The table also illustrates geographical variations in the diet of some species in relation to myctophids.

The diet of the Antarctic predators in relation to myctophids varies seasonally and annually depending on a stage of the predator life cycle and food availability in the area. Present data on myctophids are insufficient for any sort of quantitative assessment of this variability. Only for the king penguin are data available from year-round studies.

Most of earlier studies which reported myctophids in the diet of predators, contain only one quantitative parameter, frequency of occurrence of food items in samples. Very often

myctophids were reported as a group of fish without species identification. Several recent studies, however, are based on quantitative analysis of dietary components with most fish species identified. Although these studies involve different types of analysis and use different parameters in order to describe the observed diet composition, some of them contain various quantitative characteristics which may enable comparison of the myctophid component of the diet of various predators. However, noting the paucity of available data for some predators and the fact that data come from different geographical localities, conclusions on the diversity of myctophid species in the diet of predators are not possible (Table 2). It appears, however, that myctophids of genus *Electrona* are common in the diet of all predators and, in terms of myctophid component, the diet of birds and seals is more diverse than the diet of fish.

5. CONCLUSION

(i) Most of the data on myctophids in the diet of Antarctic predators came from studies conducted in the following two zones:

- Antarctic Polar Front area between the Antarctic Peninsula and Macquarie Island; and
- Antarctic coast.

(ii) Myctophids were found in the diet of one species of squid, 18 species of fish (eight of *Nototheniidae,* seven - *Channichthyidae,* two - *Bathydraconidae* and one -*Rajidae*), 18 species of birds (penguins - seven, albatrosses - four, petrels - five, prions - one and cormorants - one) and two species of seals (Table 1). No myctophids were reported from studies of whale diets in the Antarctic waters. Two species of myctophids, *E. antarctica* and *G. nicholsi* were found to eat some juvenile myctophids.

(iii) Myctophids in the diet of predatory species are represented by 16 species of genera *Krefftichthys (*one species), *Protomyctophum* (four species), *Electrona (*five species), *Metelectrona (*one species) and *Gymnoscopelus* (four species). However, the total number of species may be underestimated because identification of myctophids in predator food samples is still difficult.

(iv) Many species of fish, birds and seals take myctophids opportunistically in addition to their staple diet. Penguins have the largest proportion of myctophids in their diet. The king penguin in the APF area of the Indian Ocean is the only one specialist predator on myctophids. The *Bathydraconidae* fish, *Gynmodraco acuticeps,* from the Kosmonavtov Sea (Indian Ocean sector) may be the second most important predator of myctophids.

(v) The occurrence of myctophids in the diet of predatory species appears to be highly variable though there are insufficient data to evaluate this. Apart from the obvious variability of the diet composition in different geographical areas, the myctophid diet is subject to seasonal and inter-annual variability.

(vi) It is obvious that myctophids are widespread in diets of many Antarctic predators. However, the available information is mostly descriptive and lacks quantitative assessments. It is clear that more quantitative studies on as many as possible species of predators are required in order to assess the role of myctophids in the Antarctic ecosystem. Information on the diet of myctophids themselves is also important. These studies should use standardised methods, be carried out in different seasons and have a wide geographical coverage.

(vii) Any research in the Antarctic, and in particular on such a widespread and abundant resource as myctophids, will benefit from international cooperation. The CCAMLR Scientific Committee may wish to play an important role in coordinating future international research on Antarctic myctophids.

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Table 1: Known predators of myctophids in Antarctic waters.

++++ Major diet component
+++ Common, although usually not a major diet component
++ Minor diet component
+ Occasional diet component
- Rare diet component

Species	Known Predators	Importance	Area	Reference
***Myctophidae* spp.**	**Squids:**			
	Species not specified	++++	Antarctic open waters	Lubimova 1985
	Moroteuthis knipovitchi	++++	Not specified	Nemoto *et al.* 1985
	Fish:			
	***Nototheniidae*:**			
	N. kempi	+++	South Shetlands	Takahashi 1983
	N. rossii, *N. squamifrons* and *D. eleginoides*	++	Kerguelen Is, Crozet Is, Lena and Ob Banks	Chechun 1984 Duhamel, Hureau 1985
	D. Mawsoni	++	Kosmonavtov Sea	Pakhomov, Tseitlin 1992
	T. eulepidotus	++		
	T. (Pagothenia) hansoni	-		
	T. centronotus	-		
	T. (Pagothenia) hansoni	-	Lützow-Holm Bay	Naito, Iwami 1982
	Channichthyidae:			
	C. gunnari and *Ch. rhinoceratus*	++	Kerguelen Is, Crozet Is Lena and Ob Banks	Chechun 1984 Duhamel, Hureau 1985
	C. gunnari, *P. georgianus* and *C. aceratus*	++	South Georgia	Kozlov *et al.* 1988
	C. rastrospinosus, *C. gunnari* and *P. georgianus*	+	South Shetlands	Takahashi 1983
	C. wilsoni	+	Kosmonavtov Sea	Pakhomov, Tseitlin 1992
	C. hamatus	++		
	***Bathydraconidae*:**			
	Cygnograco mawsoni	+	Kosmonavtov Sea	Pakhomov, Tseitlin 1992
	Gymnodraco acuticeps	+++		
	***Rajidae* spp.**	+	South Shetlands	Takahashi 1983
	***Myctophidae*:**			
	E. antarctica	-	Not specified	Williams 1985
	G. nicholsi	-	South Shetlands	Takahashi 1983
	Birds:			
	Adélie penguin	-	Magnetic Is, Davis	Puddicombe, Johnstone 1988
	Adélie penguin	++++	Weddell Sea	Ainley (pers. comm.)
	Antarctic petrel, storm petrel	++++	Weddell Sea	Ainley (pers. comm.)
	Light-mantled sooty albtrs	++	South Georgia	Thomas 1982
	Black-browed albatross	+	South Georgia	Prince 1980
	Grey-headed albatross	+	South Georgia	Prince 1980
	King penguin, dove prion, blue petrel, black-bellied storm petrel	++	South Georgia	Croxall 1990

Table 1 (continued)

Species	Known Predators	Importance	Area	Reference
	Seals:			
	Ross seal	+	Not specified	As cited by Laws 1984
Krefftichthys anderssoni	King penguin	++++	Marion Is	Adams, Klages 1987; Cooper, Brown 1990
	King, royal/macaroni, rockhopper and gentoo penguins	+++	Macquarie, Heard Is	Williams 1988, 1989; Klages *et al.* 1989; Hindell 1988; Cooper, Brown 1990
	Royal/macaroni penguin	++	Macquarie Is	Horne 1985
		+++	Crozet Is	Ridoux 1987, Ridoux *et al.* 1988
	Antarctic fur seal	++++	Heard Is	Green *et al.* 1989
Protomyctophum bolini	King penguin	+	Marion Is	Adams, Klages 1987; Cooper, Brown 1990
	Royal/macaroni, rockhopper and gentoo penguins	++	Macquarie, Heard Is	Williams 1989, Klages *et al.* 1989; Cooper, Brown 1990
	Antarctic fur seal	+++	Heard Is	Green *et al.* 1989
	Wilson's storm petrel	+	South Georgia	Croxall *et al* 1988a; Croxall, North 1988b
Protomyctophum normani	King penguin	+++	Marion Is	Adams, Klages 1987; Cooper, Brown 1990
	Wilson's storm petrel	+	South Georgia	Croxall *et al* 1988a; Croxall, North 1988b
	White-chinned petrel	+	South Georgia	Croxall, North (pers. comm.)
Protomyctophum choriodon	Gentoo penguin	++	South Georgia	T. Williams 1990
	C. gunnari	-	Kerguelen	Hull, Camus, Hureau 1989
	White-chinned petrel	++	South Georgia	Croxall, North (pers. comm.)
Protomyctophum tenisoni	King, Royal/macaroni, rockhopper, gentoo penguin	+++	Marion Is	Adams, Klages 1987; Cooper,Brown 1990
	Royal/macaroni	+++	Crozet Is	Ridoux 1987, Ridoux *et al.* 1988
	Salvin's prion	++	Marion Is	Cooper, Brown 1990
Protomyctophum	*C. gunnari*	++	South Georgia	Kozlov *et al.* 1988
	C. aceratus	+++		
	P. georgianus	+++		
	Gentoo penguin	+	Marion Is	La Cock *et al.* 1984
	Rockhopper penguin	-	Macquarie Is	Hindell 1988
Electrona antarctica	Adélie penguin	+	Béchervaise Is, Mawson	Kerry (pers. comm.)
	Emperor penguin	+++	Mawson coast	As cited by Williams 1990
	King penguin	+++	Heard Is	Klages *et al.* 1989
	Snow petrel	+++	Budd coast	As cited by Williams 1990

Table 1 (continued)

Species	Known Predators	Importance	Area	Reference
	White-chinned petrel	+++	South Georgia	Croxall, North (pers. comm.)
	Antarctic fur seal	++++	Macquarie Is	Green *et al.* 1989
	Elephant seal	-	Heard, Macquarie Is	Green (pers. comm.)
Electrona carlsbergi	Squids	Not specified	Not specified	Zasel'skiy *et al.* 1985
	Notolepis spp.			
	Chaenichthyidae spp.			
	Adélie penguin	+	Magnetic Is, Davis	R. Williams (pers.comm.)
	King penguin	++++	Macquarie Is	Hindell 1988a, Williams 1988
		+++	Marion Is	Adams, Klages 1987; Cooper, Brown 1990
		++++	Heard Is	Klages *et al.* 1989
	Gentoo penguin	++++	Macquarie Is	Williams 1988
			Heard Is	Hindell 1989
				Klages *et al.* 1989
		++	South Georgia	T. Williams 1990
	Chinstrap penguin	++	Bouvet Is	Cooper *et al.* 1984
	Royal/macaroni penguin	++	Heard, Macquarie Is	Williams 1988, 1989
		++	Crozet Is	Ridoux 1987, Ridoux *et al.* 1988
	Rockhopper penguin	-	Macquarie Is	Hindell 1988c
	King, Royal/macaroni, gentoo, rockhopper penguin	++/+++	Marion Is	Cooper, Brown 1990
	Sooty albatross	+++	Marion Is	Cooper, Klages (in press)
	Light mantled sooty albtrs			
	White-chinned petrel	+++	South Georgia	Croxall, North (pers. comm.)
	Blue petrel, Salvin's prion	++/+	Marion Is	Cooper, Brown 1990
	Antarctic fur seal	++	Macquarie Is	Green *et al.* 1990
		++	Heard Is	Green *et al.* 1989
	C. gunnari	-	Kerguelen	Hulley, Camus, Hureau 1989
Electrona paucirastra	Antarctic fur seal	-	Macquarie Is	Green *et al.* 1990
	C. gunnari	-	Kerguelen Is	Hulley, Camus, Hureau 1989
Electrona subaspera	Gentoo penguin	++++	Macquarie Is	Green *et al* 1990
	Macaroni penguin	+	Marion Is	Cooper, Brown 1990
	Antarctic fur seal	++++	Macquarie Is	Green *et al* 1990
		++	Heard Is	Green *et al.* 1989
	Great-winged petrel, Soft-plumaged petrel	+	Marion Is	Cooper, Brown 1990
	Elephant seal	-	Heard, Macquarie Is	Green (pers. comm.)
***Electrona* spp.**	*C. gunnari*	++	South Georgia	Kozlov *et al.* 1988
	C. aceratus	+++		
	P. georgianus	+++		
	Gentoo penguin	+	Marion Is	La Cock *et al.* 1984

Table 1 (continued)

Species	Known Predators	Importance	Area	Reference
Metelectrona ventralis	*D. elegionoides*	-	Kerguelen Is	Hulley, Camus, Duhamel 1989
	D. eleginoides	-	Heard Is	Williams 1990
	C. gunnari		Kerguelen Is	Hully, Camus, Duhamel 1989
Gymnoscopelus	Gentoo penguin	+	South Georgia	T. Williams 1990
	White-chinned petrel	+	South Georgia	Croxall, North (pers. comm.)
	Antarctic fur seal	+	Heard Is	Green *et al.* 1989
	New Zealand fur seal	+	Macquarie Is	Green *et al.* 1990
	Elephant seal	-	Heard, Macquarie Is	Green (pers. comm.)
Gymnoscopelus bolini	Antarctic fur seal	+	Heard Is	Green *et al.* 1989
		+	Macquarie Is	Green *et al.* 1990
	D. elegionoides		Kerguelen Is	Hulley, Camus, Duhamel 1989
Gymnoscopelus fraseri	Antarctic fur seal	-	Heard, Macquarie Is	Green (pers. comm.)
Gymnoscopelus* nicholsi	Gentoo penguin	+++	Macquarie Is	Hindell 1989
		++	Marion Is	Cooper, Brown 1990
	King penguin	+++	Heard Is	Klages *et al.* 1989
	Rockhopper penguin	+	Marion Is	Cooper, Brown 1990
	White-chinned petrel	+++	South Georgia	Croxall, North (pers. comm.)
	Blue-eyed Cormorant	++++	Macquarie Is	Green *et al.* 1990
	Antarctic fur seal	+++	Macquarie Is	Green *et al.* 1990
		+++	Heard Is	Green *et al.* 1989
		++++	South Georgia	North *et al.* 1983
	Elephant seal	-	Heard, Macquarie Is	Green (pers. comm.)
G. piabilis	Sooty albatross	++	Marion Is	Cooper, Klages (in press)
G. macrolampas	White-chinned petrel	++	South Georgia	Croxall, North (pers. comm.)
***Gymnoscopelus* spp.**	King penguin	+	Marion Is	Adams, Klages 1987
	Gentoo penguin	++	Macquarie Is	Williams 1988
	Gentoo penguin	+	Marion Is	La Cock *et al.* 1984
	Rockhopper penguin	-	Macquarie Is	Hindell 1988
	Sooty albatross	++	Marion Is	Cooper, Klages (in press)
	C. gunnari	++	South Georgia	Kozlov *et al.* 1988
	C. aceratus	+++		
	P. georgianus	+++		
***Diaphus* sp.**	Great- winged petrel	+	Marion Is	Cooper, Brown 1990
	Kerguelen petrel			

* It is possible that *G. piabilis* makes most of the contribution in the predators' diets at Macquarie Is because otoliths of these two species are very hard to distinguish (Williams, 1990).

Table 2: Occurrence of myctophids in the diet of Antarctic predators (for references see Table 1).

* Distribution of myctophids to the south of the Antarctic Convergence:
⊕ Distributed circumpolar between ACC and the Antarctic coast
∅ Distributed circumpolar in the ACC waters
× Localised distribution in the ACC waters

	Myctophidae spp.	*K. andersoni*	*P. bolini*	*P. tenisoni*	*P. normani*	*P. choriodon*	*Protomyctophum* spp.	*E. antarctic*	*E. carlsbergi*	*E. subaspera*	*E. paucirastra*	*Electrona* spp.	*M. ventralis*	*G. nicholsi*	*G. braueri*	*G. bolini*	*G. frazeri*	*G. piabilis*	*G. microlampas*	*Gymnoscopelus* spp.	Total number of spp.
Distribution of myctophids*		⊕	⊕	∅	×	×		⊕	⊕	∅	×		×	⊕	⊕	∅	∅	×	×		
Squids	+							+													1
***Nototheniidae*:**																					
N. rossii	+																				
N. kempi	+																				
N. squamifrons	+												+			+					2
D. eleginoides	+							+													1
D. mawsoni	+																				
T. (Pagathonei) hansoni	+																				
T. eulepidotus	+																				
T. centronotus	+																				
***Channichthyidae*:**																					
P. georgianus	+																				
Ch. rhinoceratus	+					+			+		+		+								4
C. gunnari	+																				
C. aceratus	+																				
C. rastrospinosus	+																				
C. wilsoni	+																				
C. hamatus	+																				
***Bathydraconidae*:**																					
C. mawsoni	+																				
C. acuticeps	+																				
***Rajidae* spp.**	+																				
***Myctophidae*:**																					
E. antarctica	+																				
G. nicholsi	+																				

Table 2 (continued)

	Myctophidae spp.	*K. andersoni*	*P. bolini*	*P. tenisoni*	*P. normani*	*P. choriodon*	*Protomyctophum* spp.	*E. antarctic*	*E. carlsbergi*	*E. subaspera*	*E. paucirastra*	*Electrona* spp.	*M. ventralis*	*G. nicholsi*	*G. braueri*	*G. bolini*	*G. frazeri*	*G. piabilis*	*G. microlampas*	*Gymnoscopelus* spp.	Total number of spp.
Distribution of myctophids*		⊕	⊕	∅	×	×		⊕	⊕	∅	×		×	⊕	⊕	∅	∅	×	×		
Penguins:																					
Emperor	+							+													1
King	+	+	+	+	+			+	+					+							7
Adélie	+							+	+												2
Chinstrap	+								+												1
Gentoo	+	+	+		+	+		+	+	+				+	+						9
Rockhopper	+	+	+						+												3
Macaroni	+	+	+	+					+												4
Flying Birds:																					
Sooty albatross	+								+									+			2
Light-mantled sooty albtrs	+							+	+												2
Black-browed albatross	+																				
Grey-headed albatross	+																				
Snow petrel	+																				
Dove prion	+																				
Salvin's prion									+												1
Blue petrel	+								+												1
White-chinned petrel	+				+	+			+	+			+	+					+		7
Wilson's storm petrel	+		+		+																2
Black-bellied storm petrel	+																				
Great-winged petrel										+											1
Soft-plumaged petrel										+											1
Blue-eyed Cormorant	+													+							1
Seals:																					
Fur seal	+	+	+	+	+			+	+	+	+		+	+	+	+	+				13
Elephant seal	+							+		+				+	+						4

Table 3: Myctophids in the diet of Antarctic birds and marine mammals in breeding areas. (Information on breeding areas is adopted from Bengtson (1985) and publications listed in Table 1).

\+ Species present but no information on the diet available
⊕ Myctophids found in the diet
∅ Myctophids not found in the diet

Predators	Breeding Areas										References to ∅ = No myctophids in the diet (for references to ⊕ = yes, see Table 1)
	Marion Is	Crozet Is	Kerguelen Is	Macquarie Is	Heard Is	South Georgia	South Shetlands, South Orkney, South Sandwich Is	Antarctic Peninsula	Bouvet Is	Antarctic Coast	
Emperor penguin								+		∅ ⊕	Klages 1989; Gales *et al.* 1990; Offredo, Ridoux 1985
King penguin	⊕	+	+	⊕	⊕	⊕					
Adélie penguin							∅	+	+	∅ ⊕	Ridoux, Offredo 1989; Lishman 1985
Chinstrap penguin						+	∅	+	⊕	+	Croxall, Furse 1980; Lishman 1985
Gentoo penguin	⊕	+	+	⊕	⊕	∅ ⊕	+	+			Croxall, Prince 1980
Rockhopper penguin	+	+	+	⊕	⊕						
Macaroni penguin	+	⊕	+	⊕	⊕	∅	∅		+		Croxall, Prince 1980; Croxall, Furse 1980
Sooty albatross	⊕										
Light-mantled sooty albatross	⊕	+	+	+	+	⊕	+	+	+	+	
Grey-headed albatross	+	+	+	+		⊕					
Black-browed albatross		+	+	+	+	⊕					
Snow petrel						+	+	+	+	∅ ⊕	Ridoux, Offredo 1989
Blue petrel	⊕	+	+	+		⊕					Cooper, Brown 1990
Great winged petrel	⊕	+	+								Cooper, Brown 1990
Kerguelen petrel	⊕	+	+								Cooper, Brown 1990
Soft plumaged petrel	⊕	+									Cooper, Brown 1990
Dove prion		+	+	+	+	⊕	+				
Salvin's prion	⊕	+									Cooper, Brown 1990
White-chinned petrel;	+	+	+	+		⊕					
Wilson's storm petrel		+	+		+	⊕	+	+	+	∅	Ridoux, Offredo 1989
Black-bellied storm petrel						⊕					
Cormorant (*P. atriceps)*				⊕	+	∅	+	+			Croxall *et al.* 1991
Fur seal	+	+	+	⊕	⊕	⊕	+	+	+		
Elephant seal	+	+	+	⊕	⊕	∅	+	+	+		Rodhouse *et al* (in press)

Table 4: Myctophids in the diet of king penguins on Marion, Heard and Macquarie Islands in percentage by numbers of food items (adopted from Adams and Klages, 1987; Hindell, 1988b; Klages *et al.*, 1980).

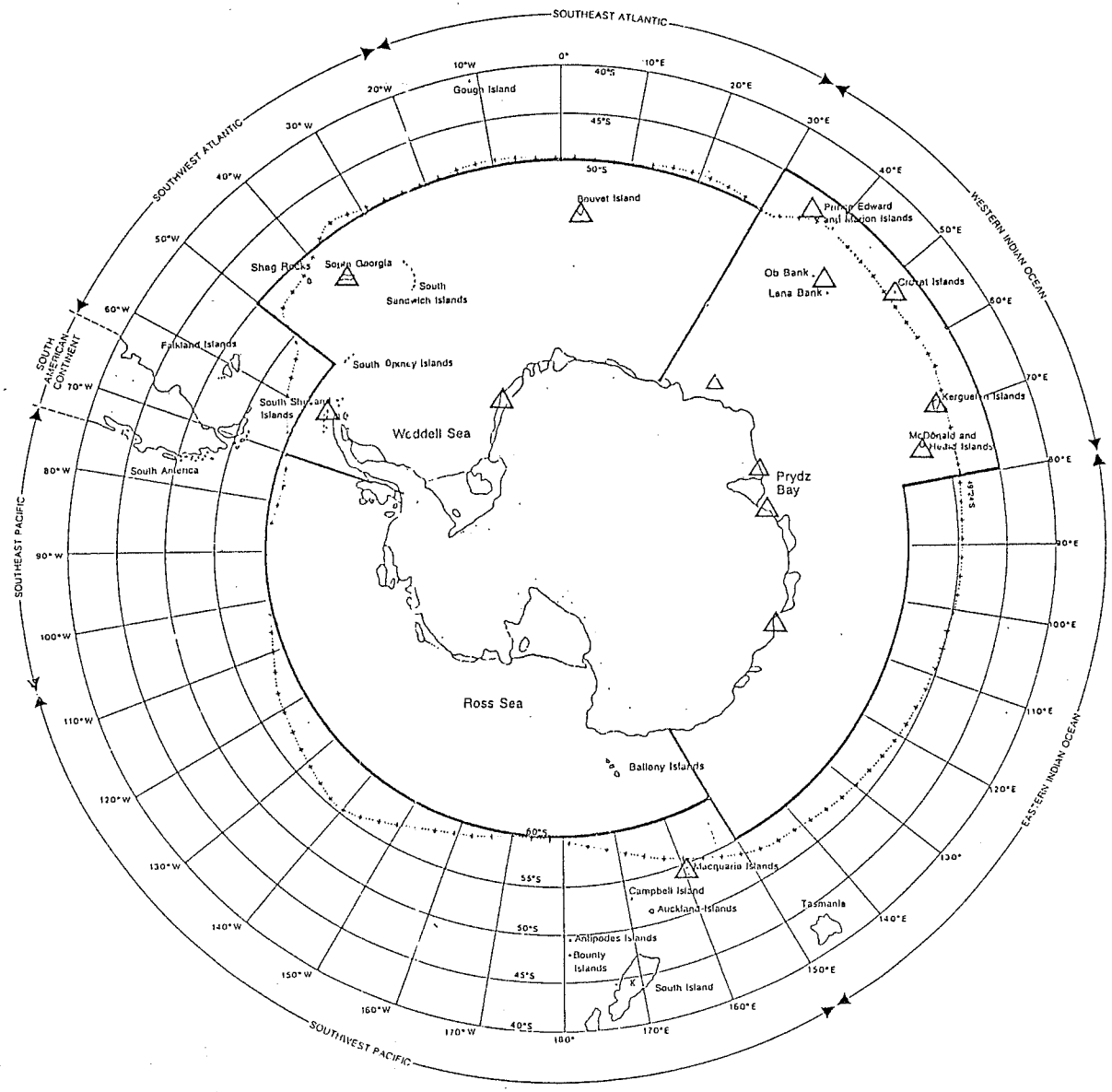
Myctophidae Species	Marion Is	Heard Is	Macquarie Is
K. anderssoni	**31.76**	**96.5**	**48.1**
P. bolini	0.12	+	-
P. normani	0.98	-	-
Protomyctophum spp.	-	-	1.0
E. antarctica	-	+	-
E. carlsbergi	**13.16**	+	**48.5**
G. nicholsi	-	+	-
Gymnoscopelus spp.	0.23	-	0.3
Unidentified	34.75	-	-
Fish total	82.8	99.7	99.1
Myctophids total	81.0	≈99.7	97.9
Squid	17.01	0.15	1.0

Table 5: Seasonal variability in occurrence of *K. anderssoni* and *E. carlsbergi* in the diet of king penguins on Marion, Heard and Macquarie Islands (adopted from Adams and Klages; 1987; Hindell, 1988b; Klages *et al.* 1980).

× observed in the diet
o not observed in the diet

Locality	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Marion Is	*K. anderssoni*	o	o	o	o	o	o	o	o	×	×	×	×
	E. carlsbergi	o	o	o	o	o	o	×	×	o	o	o	o
Macquarie Is	*K. anderssoni*	o	×	×	×	×	o	o	o	o	×	×	×
	E. carlsbergi	o	o	o	o	o	×	×	×	×	o	o	o
Heard Is	*K. anderssoni*											×	×
	E. carlsbergi											o	o

CCAMLR



LEGEND
- STATISTICAL AREA
  ZONE STATISTIQUE
  СТАТИСТИЧЕСКИЙ РАЙОН
  AREA ESTADISTICA
- ANTARCTIC CONVERGENCE
  CONVERGENCE ANTARCTIQUE
  АНТАРКТИЧЕСКАЯ КОНВЕРГЕНЦИЯ
  CONVERGENCIA ANTARTICA
- CONTINENT, ISLAND
  CONTINENT, ILE
  МАТЕРИК, ОСТРОВ
  CONTINENTE, ISLA

Figure 1: Localities (Δ) where myctophids were found in the diet of Antarctic predators.

Liste des tableaux

Tableau 1: Prédateurs connus de Myctophidae dans les eaux antarctiques.

++++ Elément majeur du régime alimentaire
+++ Elément commun mais rarement majeur du régime alimentaire
++ Elément secondaire du régime alimentaire
+ Elément se trouvant parfois dans le régime alimentaire
- Elément rare du régime alimentaire

Tableau 2: Présence de Myctophidae dans le régime alimentaire des prédateurs antarctiques (cf. tableau 1 pour les légendes).

* Répartition des Myctophidae au sud de la Convergence antarctique;
⊕ Réparti entre le courant circumpolaire antarctique (ACC) et la côte de l'Antarctique
∅ Réparti dans les eaux de l'ACC
× Répartition localisée dans les eaux de l'ACC

Tableau 3: Les Myctophidae dans le régime alimentaire des oiseaux et mammifères marins de l'Antarctique dans les lieux de reproduction (les informations sur les lieux de reproduction proviennent de Bengtson (1985) et des publications citées au tableau 1).

\+ Espèce présente mais pour laquelle on ne dispose d'aucune information sur le régime alimentaire
⊕ Myctophidae présents dans le régime alimentaire
∅ Myctophidae absents du régime alimentaire

Tableau 4: Myctophidae dans le régime alimentaire des manchots royaux des îles Marion, Heard et Macquarie en pourcentage du nombre de spécimens d'aliments (d'après Adams et Klages, 1987; Hindell, 1988b et Klages *et al.*, 1980).

Tableau 5: Variabilité saisonnière de la présence de *K. anderssoni* et *E. carlsbergi* dans le régime alimentaire des manchots royaux des îles Marion, Heard et Macquarie (d'après Adams et Klages, 1987; Hindell, 1988b et Klages *et al.*, 1980).

× Observé dans le régime alimentaire
o Pas observé dans le régime alimentaire

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Figure 1: Emplacements (Δ) où ont été trouvés des Myctophidae dans le régime alimentaire des prédateurs antarctiques.

Список таблиц

Таблица 1: Известные хищники миктофид в акватории Антарктики.

++++ Основной компонент рациона
+++ Часто встречающийся, хотя обычно не основной компонент рациона
++ Второстепенный компонент рациона

+ Случайный компонент рациона
- Редкий компонент рациона

Таблица 2: Присутствие миктофид в рационе Антарктических хищников (для справок см. Таблицу 1).

* Распределение миктофид к югу от Антарктической конвергенции
⊕ Распределенные между АЦТ (Антарктическое циркумполярное течение) и Антарктическим побережьем
∅ Распределенные в водах АЦТ
× Локализированное распределение в водах АЦТ

Таблица 3: Миктофиды в рационе Антарктических птиц и морских млекопитающих в районах размножения (Информация по районам размножения была заимствована из Бенгстона (1985) и публикаций, указанных в Таблице 1).

+ Виды присутствуют, но нет информации о рационе
⊕ Миктофиды обнаружены в рационе
∅ Миктофиды не обнаружены в рационе

Таблица 4: Миктофиды в рационе королевского пингвина на островах Марион, Херд и Макуори в процентном содержании по количеству объектов пищи (взято из Адамс и Клейджес, 1987; Хиндель, 1988 и и Клейджес и др., 1980).

Таблица 5: Сезонное разнообразие присутствия *K. anderssoni* и *E. carlsbergi* в рационе королевского пингвина на островах Марион, Херд и Макуори (взято из Адамс и Клейджес, 1987; Хиндель, 1988и и Клейджес и др., 1980).

× наблюдались в рационе
o не наблюдались в рационе

Список рисунков

Рисунок 1: Участки (B), на которых были обнаружены миктофиды в рационе Антарктических хищников.

Lista de las tablas

Tabla 1: Depredadores de mictófidos de las aguas antárticas.

++++ Componente principal de la dieta
+++ Componente común, aunque no es el principal
++ Componente de segundo orden de la dieta
+ Componente poco común de la dieta
- Componente excepcional de la dieta

Tabla 2: Presencia de mictofidos en la dieta de los depredadores antárticos (véase tabla 1 para referencia).

*	Distribución de mictófidos al sur de la Convergencia Antártica
⊕	Distribución circumpolar entre la CCA (Convergencia Circumpolar Antártica) y la costa antártica
∅	Distribución circumpolar en las aguas de la CCA.
x	Distribución localizada en las aguas de la CCA.

Tabla 3: Mictófidos en la dieta de las aves y mamíferos marinos antárticos en las zonas de cría (la información sobre las zonas de cría es de Bengtson (1985) y de las publicaciones que figuran en la tabla 1).

+	Especies encontradas, pero no hay datos sobre la dieta.
⊕	Mictófidos encontrados en la dieta
∅	Mictófidos inexistentes en la dieta

Tabla 4: Mictofidos en la dieta de los pingüinos reales de las islas Marion, Herad y Macquarie, en relación a los distintos alimentos consumidos (según Adam y Klages, 1987; Hindell, 1988 y Klages *et al.* 1980).

Tabla 5: Variabilidad estacional de *K. anderssoni* y *E. carlsbergi* en la dieta de los pingüinos reales de las islas Marion, Heard y Macquarie, (según Adam y Klages, 1987; Hindell, 1988 y Klages *et al.* 1980).

x	presente en la dieta
o	ausente de la dieta

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Figura 1: Localidades (Δ) en donde se encontraron mictófidos en la dieta de los depredadores antárticos

ANNEX, TABLES 1 TO 7

Table 1: Myctophids in the diet of Antarctic fish (Chechun, 1984 and Takahashi, 1983).

Fish Species	Area											
	Kerguelen Is			Crozet Is			Lena Bank			Ob Bank		
	%F	%Wt	Sample Size (n)	%F	%Wt	Sample Size (n)	%F	%Wt	Sample Size (n)	%F	%Wt	Sample Size (n)
N. rossii	8.6	2.7	787	6.7	0.9	165	6.7	2.3	318	8.3	3.6	269
N. squamifrons	3.6	3.4	671	14.5	13.5	216	8.4	8.1	123	17.1	10.7	636
D. eleginoides	8.8	5.7	217	12.9	7.7	103	4.8	3.3	69	11.2	8.4	96
C. gunnari	14.2	2.4	1296	-	-		-	-		-	-	
C. rhinoceratus	2.4	3.4	490	-	-		-	-		-	-	

Fish Species	Area		
	South Shetland Is		
	%F	%Wt	Sample Size (n)
P. georgianus	3.4	-	47
C. rastrospinosus	1.2	-	185
N. kempi	33.3	-	10
C. gunnari	1.4	-	89
Rajidae spp.	1.4	-	85
G. nicholsi	3.1	-	39

Table 2: Myctophids in the diet of king penguins.

Myctophidae Species	%F	%N	%W	Prey Size/Mass (*mm/g*)	Stomachs *n*
Macquarie Is, November 1984 to November 1985, seasonal changes in the diet exist (Hindell, 1988b)					
K. anderssoni	68	48.1	37.7	SL55/2.5	80
Protomyctophum spp.	22	1.0	0.9	-	26
E. carlsbergi	71	48.5	53.2	SL76/6.5	84
Gymnoscopelus spp.	3	0.3	0.3	-	3
Unidentified	3	<0.1	<0.1	-	3
Total fish		99.1	97.8		
Heard Is, November 1986 to January 1987 (Klages *et al.*, 1990)					
K. anderssoni	95.8	96.5		SL48.5/1.9	
P. bolini	4.2				
E. antarctica	4.2				
E. carlsbergi	25.0			ST81/8.1	
G. nicholsi	4.2				
Unidentified	20.8				
Total fish		99.7	99.4		18
Marion Is, March 1984 to March 1985 (Adams and Klages, 1987)					
Myctophidae total	83.3	34.75			
K. anderssoni	85.0	31.76		48.3/1.9	
P. bolini	9.2	0.12			
P. normani	28.3	0.98		79.7/6.4	
E. carlsbergi	70.0	13.16		82.3/8.7	
Gymnoscopelus spp.	3.3	0.23			
Total fish		82.8	86.5		120

Table 3: Myctophids in the diet of gentoo penguins.

Myctophidae Species	%F	%N	%W	Prey Size/Mass (*mm/g*)	Stomachs *n*
Heard Is, November 1986 to January 1987 (Klages *et al.*, 1990)					
K. anderssoni	65.5			SL43.1/1.5	
P. bolini	5.5				
E. antarctica	-				
E. carlsbergi	7.7			TL86.0/9.8	
G. nicholsi	-				
Unidentified	1.8				
Total fish		22.2	90.5		54
Macquarie Is, April to November 1985 (Hindell, 1989)					
					96
K. anderssoni			15.1	37.5/1.3	
E. carlsbergi			27.5	45.9/2.4	
Gymnoscopelus spp.			15.7	88.2/6.7	
Total fish		100	100		96
Marion Is, September 1982 (La Cock, Hecht and Klages, 1991)					
Electrona spp., *Protomyctophum* spp. *Gymnoscopelus* spp.		<1.0*			
Total fish	70		72		64
South Georgia, September 1987 and May to September 1988 (T. Williams, 1991)					
E. carlsbergi		3.6-1.7*		79.2/5.0 103.3/8.9	
G. braueri		0.6*		66.3/2.3	
P. choriodon		0.3*		101.5/-	
Unidentified		1.7*		-	
Total fish		4.3-6.2*			10.9

* of all otoliths

Table 4: Myctophids in the diet of royal/macaroni penguins.

Myctophidae Species	%F	%N	%W	Prey Size/Mass (*mm/g*)	Stomachs *n*
Macquarie Is, November 1984 to February 1985 and September to November 1985 (Hindell, 1988c)					
K. anderssoni	48	1.25	23.69	25.1/2.1	
E. carlsbergi	30	0.76	9.64	23.6/1.6	
Protomyctophum spp.	14	0.14	3.84		
Gymnoscopelus spp.	6	0.02	4.03		
Total fish			45.67		182
Heard Is, December 1986 to January 1987 (Klages *et al.*, 1989)					
K. anderssoni	75.0			46.7/1.7	
P. bolini	8.33			55.7/1.5	
E. carlsbergi	6.25			80.2/7.7	
Total fish		0.7	23.2		48

Table 5: Myctophids in the diet of rockhopper penguins.

Myctophidae Species	%F	%N	%W	Prey Size/Mass (*mm/g*)	Stomachs *n*
Heard Is, December 1986 to January 1987 (Klages *et al.*, 1989)					
K. anderssoni	46.2			40.9/1.2	
P. bolini	3.9			60.4/1.7	
Total fish		0.3	8.0		26
Macquarie Is, November 1984 to October 1985 (Hindell, 1988a)					
K. anderssoni	23	0.4	16.0	54.5/3.4	
Protomyctophum spp.	4	<0.1	0.3	53.0/2.8	
E. carlsbergi	5	0.1	2.2		
Gymnoscopelus spp.	5	<0.1	4.6		
Total fish		1.2	28.3		77

Table 6: Myctophids in the diet of flying birds.

Myctophidae Species	%F	%N	%W	Prey Size/Mass (*mm/g*)	Stomachs *n*
Wilson's storm petrel, South Georgia, March 1987 (Croxall and North, 1988)					
P. normani *P. bolini*		83*	87*	TL90.3/4.2 TL67.5/2.25	
Total fish	41	1.0	28.3		51
Macquarie Island cormorant (*Phalacrocorax atriceps purpurascense*), Macquarie Is, March, 1989 (K. Green *et al.*, 1990)					
G. nicholsi		0.2**			
Total fish	100				64
Sooty albatross (*Phoebetria fusca*), Marion Is, February to May 1990 (Cooper and Klages, in press)					
E. carlsbergi *G. piabilis* *Gymnoscopelus* spp. Myctophids total	8.1 2.7 5.4	26.7** 6.7** 13.3** 53.4**			
Total fish	6.8		33.1		37
Light-mantled sooty albatross (*Phoebetria palpebrata*), Marion Is, February to May 1990 (Cooper and Klages, in press)					
E. carlsbergi *Gymnoscopelus* spp. Myctophids total	3.1 6.3	6.7** 13.3** 20.0**			
Total fish	65.6		45.7		32

* of fish only
** of all fish

Table 7: Myctophids in the diet of Antarctic fur seals. Number of myctophids are in percentage to all otoliths found in scat samples and calculated as weighted mean for the period of observation.

Date	Site			
	Heard Is		Macquarie Is	S. Georgia Is
	November 1987-February 1988	May-June 1990	December 1988-March 1989	January-March 1983
Species:				
K. anderssoni	0.8	0.8		-
E. antarctica	9.9	39.6	0.9	-
E. carlsbergi	6.2	0.5	1.9	-
E. subaspera	3.0	30.2	38.0	-
E. paucirastra	-	-	0.2	-
Electrona spp.	-	-	42.5	-
G. bolini	4.3		0.2	-
G. braueri	3.5	0.6		-
G. fraseri	-	0.2		-
G. nicholsi	28.6	7.5	1.9	10.9
Gymnoscopelus spp.	-	1.6	10.9	-
M. ventralis	-	0.7		-
P. bolini	0.1	0.2		-
P. normani	-	2.4	0.2	-
P. tenisoni	-	0.5		-
Unidentified	4.0	0.2	0.6	-
Number of scats analysed	500	374	374	8
Comments	Fish were found in an average of 95.2% of scats	Fish were found in an average of 93.4% of scats	Fish were found in an average of 99.2% of scats	
Reference	Green *et al.*, 1989	Green *et al.*, in press	Green *et al.*, 1990	North *et al.*, 1983

POTENTIAL NURSERY AREAS FOR FISH IN THE PRYDZ BAY REGION

R. Williams*

Abstract

A survey with a fine-meshed midwater trawl in Prydz Bay in January/February 1991 indicated the potential for the shelf area of the Bay to be a nursery ground for nototheniid and channichthyid fish. Nearly all juvenile fish were caught in the top 50 m over the shelf, and more than 95% were *Pleuragramma antarcticum*. This species was abundant (up to 9 100 were caught in a 30 minute haul) especially near the shelf break. The dominant size class was of 45 mm standard length, which corresponds to an age of 1^+. Nototheniids and channichthyid juveniles were much less common, and were found in the central and western parts of the shelf. Although no specific nursery grounds were identified, the whole of the Prydz Bay shelf area could be considered a nursery area.

Résumé

Une campagne d'évaluation effectuée dans la baie Prydz en janvier/février 1991 avec un chalut pélagique à maillage fin a indiqué la possibilité que la région du plateau de la baie soit une nurserie de poissons notothéniidés et channichthyidés. Presque tous les juvéniles de poissons, composés de plus de 95% de *Pleuragramma antarcticum*, ont été capturés dans les 50 m supérieurs, au-dessus du plateau. Cette espèce était abondante (un trait de 30 minutes a capturé jusqu'à 9 100 poissons), notamment à proximité de la bordure du plateau. La classe de taille dominante était celle de 45 mm de longueur standard, correspondant à un âge de 1^+. Les juvéniles de notothéniidés et de channichthyidés étaient beaucoup moins souvent présents, sauf dans les secteurs central et occidental du plateau. Bien qu'aucune nurserie spécifique n'ait été identifiée, l'ensemble du plateau de la baie Prydz pourrait être considéré comme une zone de nurseries.

Резюме

Съемка мелкоячейным разноглубинным тралом в заливе Прюдз в январе-феврале 1991 г. указала на то, что в шельфовом районе залива имеются условия для откорма семейств нототениевых и белокровных рыб. Почти все неполовозрелые особи были выловлены в верхних 50метрах над шельфом, и более чем 95% являлись *Pleuragramma antarcticum*. Рыбы этого вида преобладали в особенности вблизи границы шельфа (около 9 100 было выловлено за 30 минутное траление). Доминирующий размерный класс составлял 45 мм. стандартной длины, что соответствует возрасту 1^+. Неполовозрелые нототениевые и белокровные встречались гораздо реже, и были обнаружены в

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центральной и западной частях шельфа. Несмотря на то, что специфические участки откорма не были идентифицированы, вся шельфовая площадь залива Прюдз может считаться участком откорма.

Resumen

De un estudio realizado con una red de arrastre pelágico con una luz de malla muy fina en la zona de la plataforma de la bahía de Prydz, en enero/febrero de 1991, se desprende el potencial de la bahía para constituírse en una zona de cría para nototénidos y caeníctidos. Casi todos los juveniles fueron pescados en los 50 m superiores de la plataforma y más del 95% fue *Pleuragramma antarcticum*. Esta especie fue muy abundante (se pescaron hasta 9 100 ejemplares en un arrastre de 30 minutos), especialmente cerca del borde de la plataforma. La clase dominante fue de 45 mm de talla, lo que corresponde a la edad 1^+. Mucho menos comunes resultaron los nototénidos y caeníctidos juveniles en la zona central y occidental de la plataforma. Aunque no se identificaron zonas específicas de cría, toda la zona de la plataforma de la bahía de Prydz se podría considerar como una zona de cría.

1. INTRODUCTION

As a result of debate on the potential of a significant by-catch of juvenile fish in krill fishing operations, the Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR, 1990) agreed that nursery grounds for fish should be identified as a matter of priority and the topic discussed by the Working Group on Fish Stock Assessment.

In the 1990/91 season, Australia conducted a survey of the pelagic fishes of the Prydz Bay region using equipment with sufficiently fine meshes to sample larval and juvenile fish. While not sufficient unequivocally to identify nursery areas as such, the results of this survey do indicate the areas of highest young fish abundance and thus those to be avoided by krill fishing operations if fish by-catch is to be minimised.

2. MATERIALS AND METHODS

The Prydz Bay region was surveyed in using and International Young Gadoid Pelagic Trawl (IYGPT). This has a headline length of 20 m, and a mesh size of 15 cm in the wings and mouth area and 2 mm in the codend. Behaviour of the net while fishing was monitored with a SIMRAD trawl surveillance sonar, allowing real time measurement of the effective mouth area, and hence volume filtered. Mouth opening averaged 11 to 12 m wide by 7 to 8 m high, and nets were towed at fishing depth for a standard haul duration of 30 minutes at 3 knots, giving a volume of water filtered per haul in the vicinity of 233 000 m^3. Stations were planned at 30 mile intervals covering the entire shelf area of Prydz Bay, the banks to the west as far as Scullin Monolith, and along some transects offshore from the shelf break. Most stations were successfully sampled (Figure 1), with the exception of a few in the southeast and east side of the Bay, where ice prevented fishing, and a western transect had to be slightly displaced to avoid ice. At each station, hauls were made at three depths: at 30 to 50 m depth, approximately midway between surface and bottom, and at approximately 30 m above the bottom. Figure 1 shows the sampling sites.

3. RESULTS

Nearly all the juvenile fish were caught in the near surface trawls (30 to 50 m depth), so these trawls alone will be analysed. *Pleuragramma antarcticum* constituted the great majority of the catch, with various channichthyid and nototheniid species making up the rest. Because of some difficulties in identification of small larvae and the low numbers of Channichthyidae and Nototheniidae (excluding *P. antarcticum),* these families are treated as a whole and not subdivided into species.

Figure 2 shows the catches of *P. antarcticum* in the near surface hauls. Large numbers (up to 9100/30 min haul) occur in the central part of the bay, especially near the shelf break and some distance offshore from it, but the southern, eastern and western margins had low or zero catches. The length frequency distribution (Figure 3) shows a major mode at 45 mm, with subsidiary modes at 15 mm and 70 mm. These size modes correspond reasonably well with the 0^+, 1^+ and 2^+ year groups established by Hubold and Ekau (1986) for *P. antarcticum* in the Weddell Sea.

Other Nototheniidae (mainly comprising *Trematomus* spp.*)* were widespread but not numerous, except in one station near the shelf edge at the eastern side of the bay (Figure 4). A wide range of lengths were caught, mostly between 35 mm and 100 mm SL (Figure 5).

Channichthyid juveniles were more abundant than nototheniids, but still far less numerous than *P. antarcticum* (Figure 6). They were mostly found in the central and western parts of the bay, but rarely near the edge of the continental shelf or beyond it. A wide range of sizes up to 120 mm SL were caught (Figure 7), and surprisingly for a mixed group of species there are two distinct size groups.

4. DISCUSSION

It is clear that nearly all juvenile fish caught in the Prydz Bay region are associated with the continental shelf zone. These fish belong to the typically shelf dwelling families Nototheniidae and Channichthyidae. Extremely few larvae or juveniles were caught of the typically oceanic families Myctophidae and Paralepididae, although adults and subadults were common, especially in the deeper hauls beyond the continental shelf edge.

Between the three major groups, the whole of the shelf zone is utilised, with *P. antarcticum* mostly in the region of the shelf break, which includes a zone to seaward of the continental slope, and channichthyids being more confined to the central part of the shelf, away from the shelf edge. The single significant occurrence of nototheniid larvae was in the region of the shelf break.

Although these data do not identify nursery areas in the strict sense of the word, i.e. a discrete where fish are spawned or where young fish congregate to feed, there is some justification for considering the whole shelf region in the area studied as a nursery area. Catches of *P. antarcticum* are high in the shelf break area, and while channichthyid catches are much lower, it should be remembered that channichthyids are larger, probably slower to mature and less fecund than *P. antarcticum,* and so a lower juvenile mortality could still have a significant effect on the population. The Prydz Bay shelf is much wider than in most Antarctic localities, and the concentration of channichthyid larvae further south than the coastline allows in most places may imply that this area is a breeding ground from which fish ultimately disperse to neighbouring shelf areas.

There are no fine-scale data for the krill fishery that took place in the Prydz Bay area in the early 1980s, but if it followed apparent normal practice elsewhere, it probably concentrated

on the region on both sides of the shelf break. Krill fisheries almost exclusively exploit the upper 100 m of the water column, so these fish data are relevant to the potential impact of a krill fishery.

Such a krill fishery would be likely to have a large by-catch of *P. antarcticum,* as it would almost exactly overlap the main area of this species' abundance. There is likely also to be a significant effect on the juvenile channichthyids, especially if the fishery extended further on to the shelf.

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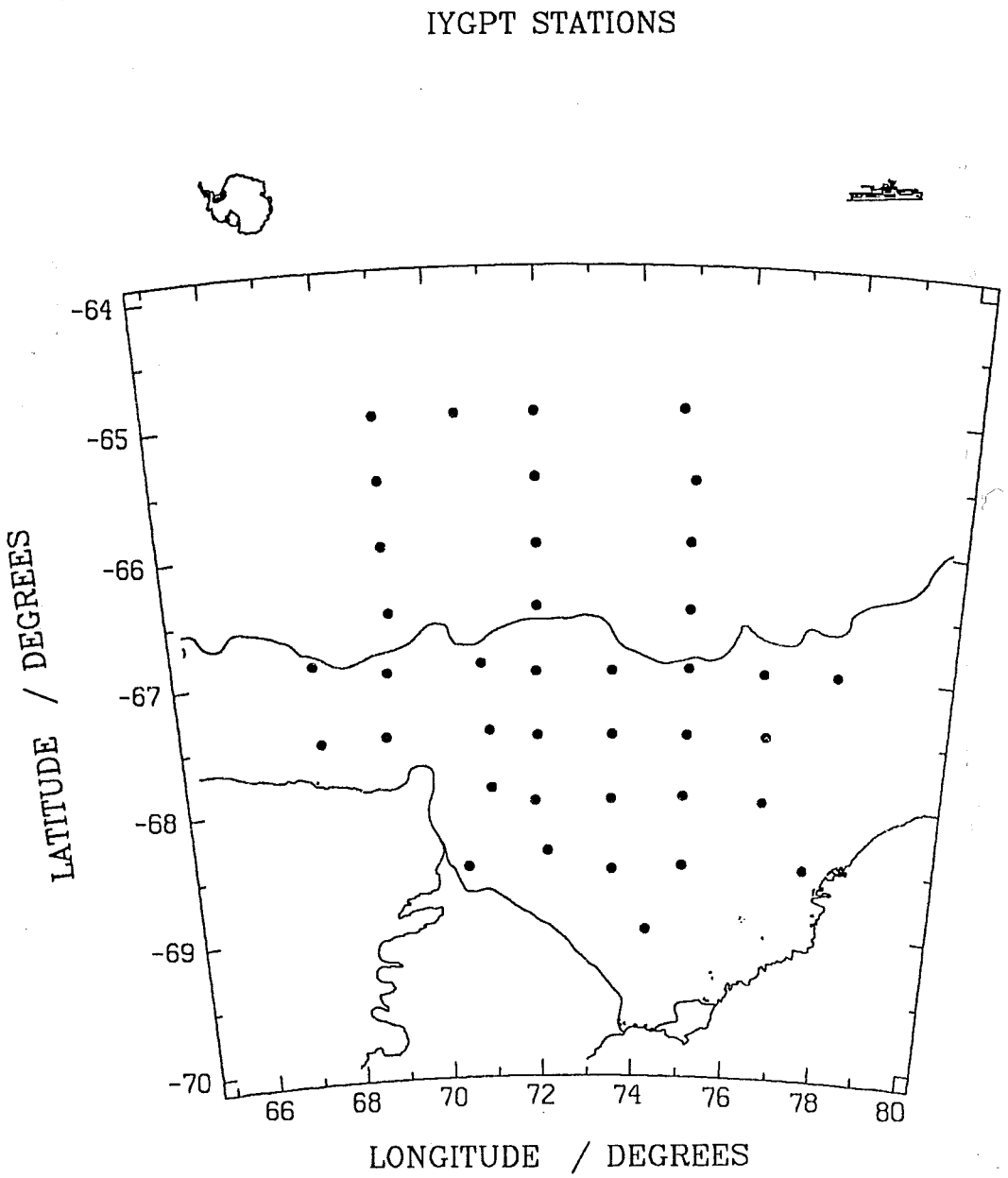

Figure 1: Map of sampling localities in Prydz Bay.

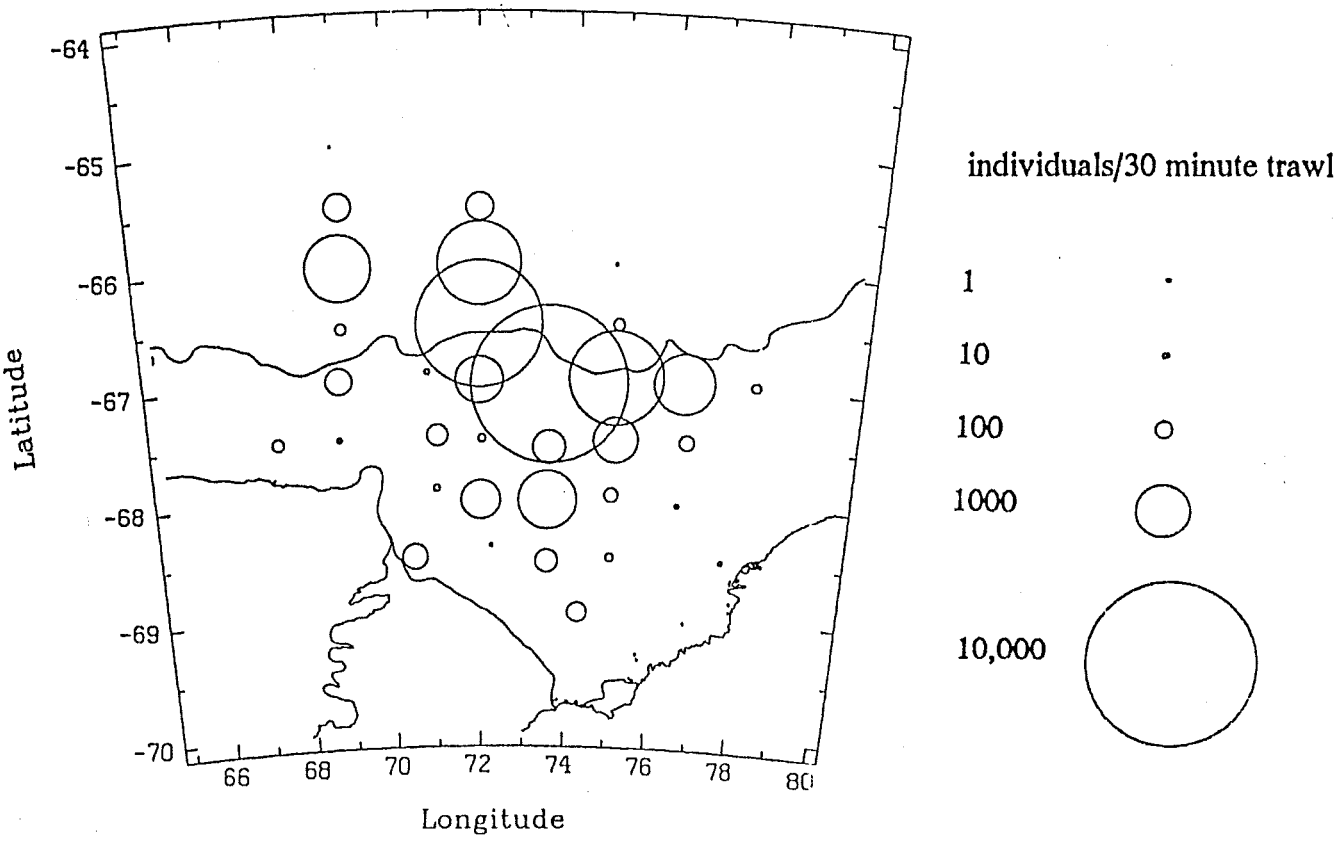

Figure 2: Catches of *P. antarcticum* juveniles.

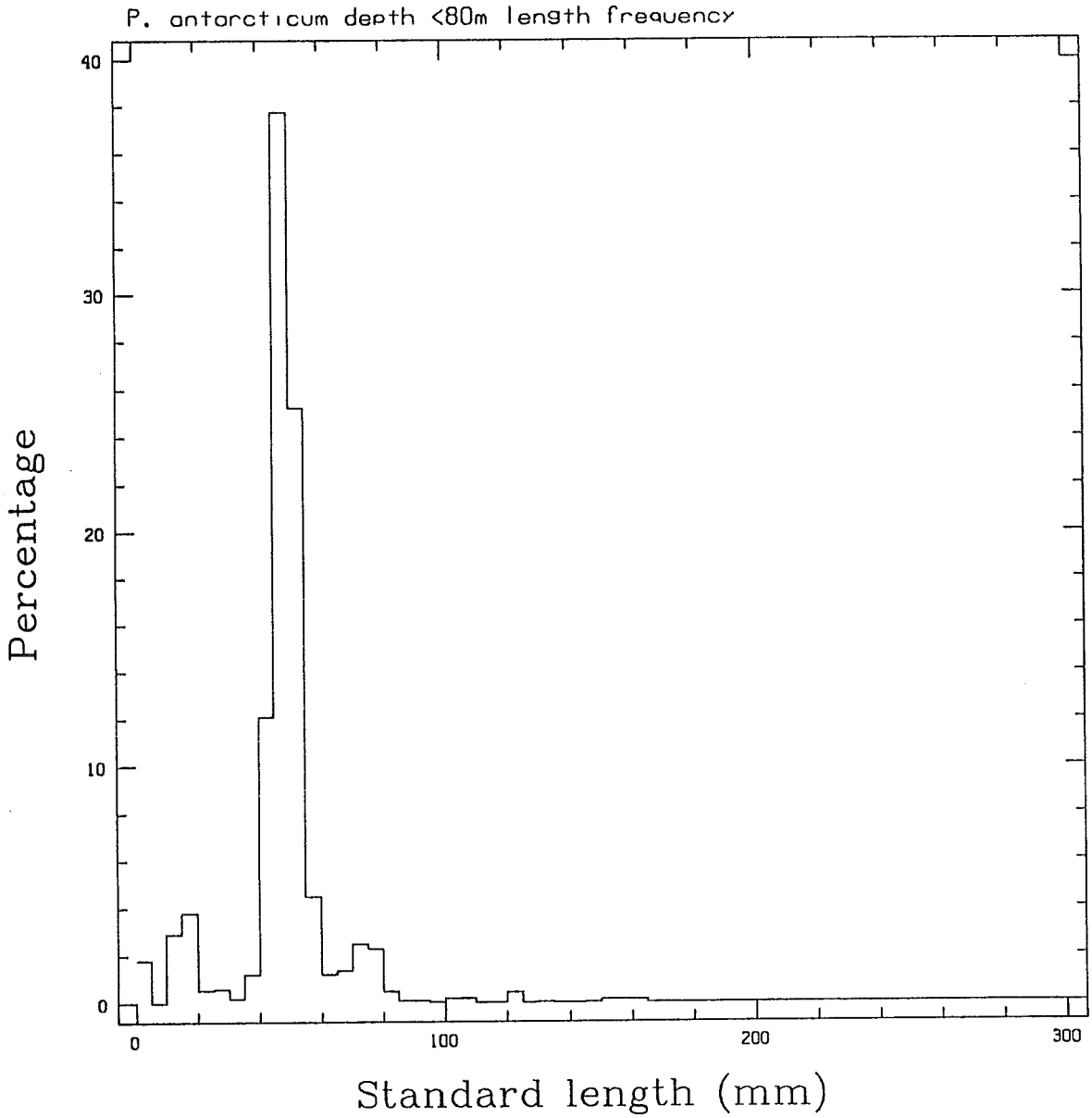

Figure 3: Length frequency of *P. antarcticum* catches.

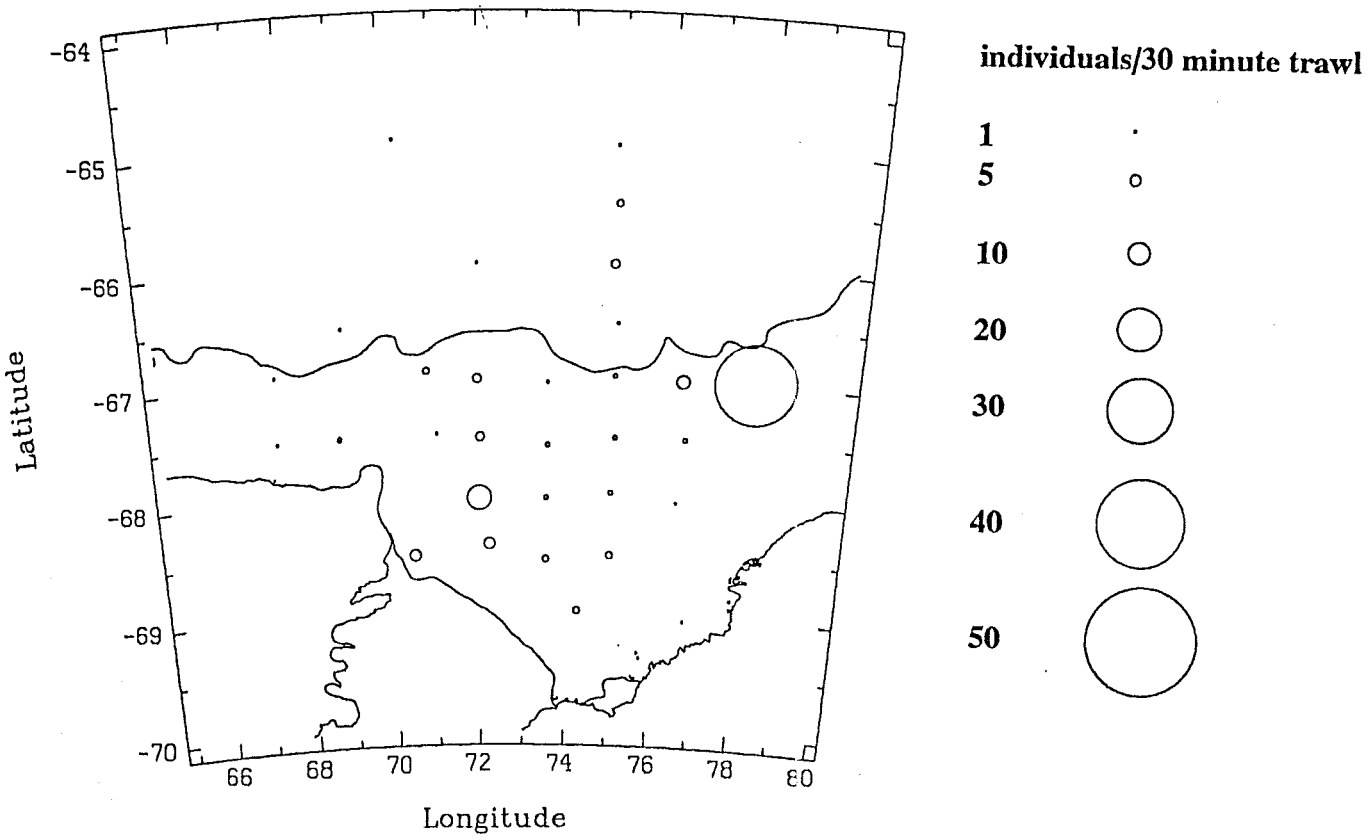

Figure 4: Catches of Nototheniidae (excluding *P. antarcticum)* juveniles.

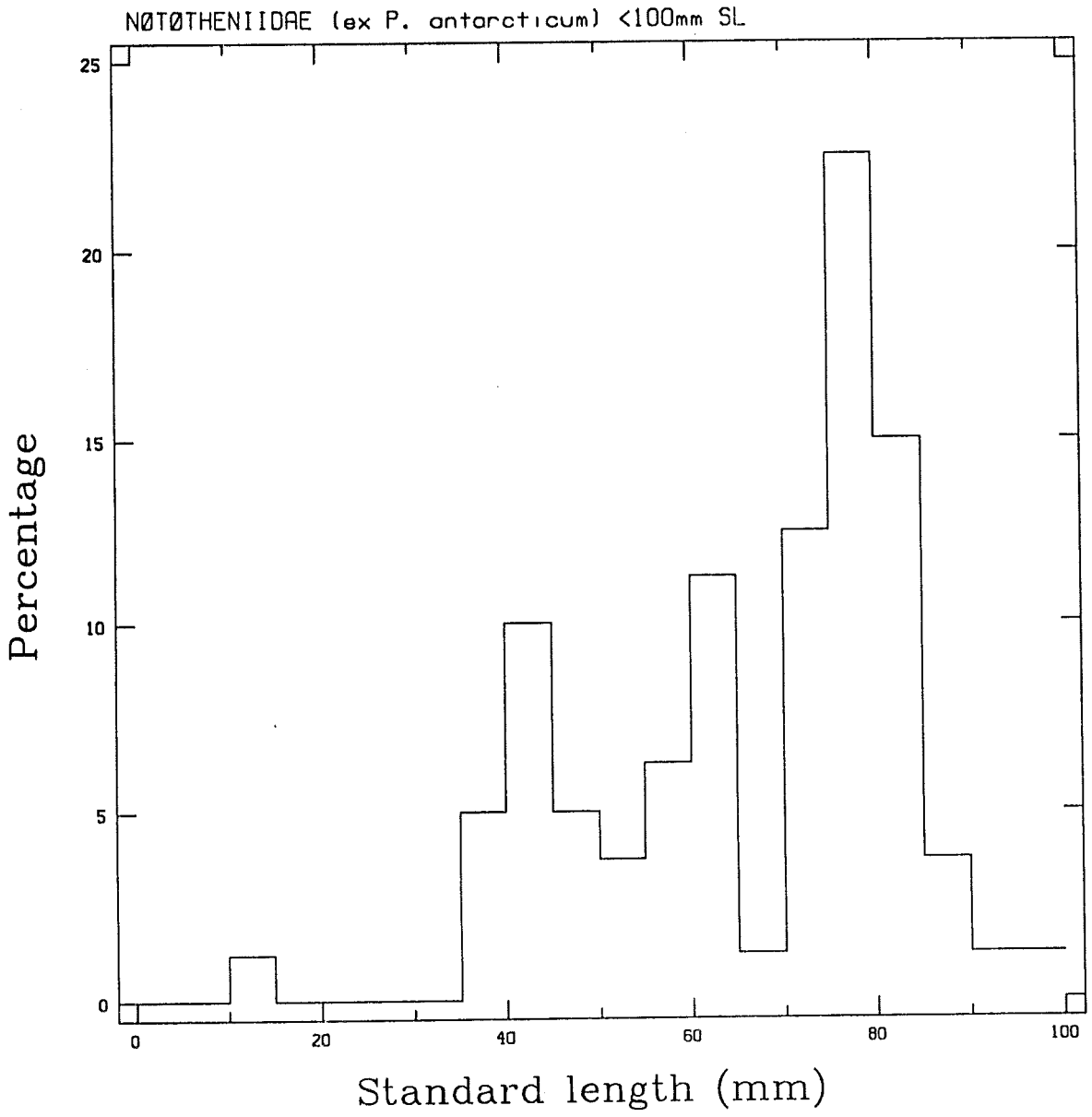

Figure 5: Length frequency of Nototheniidae (excluding *P. antarcticum)* catches.

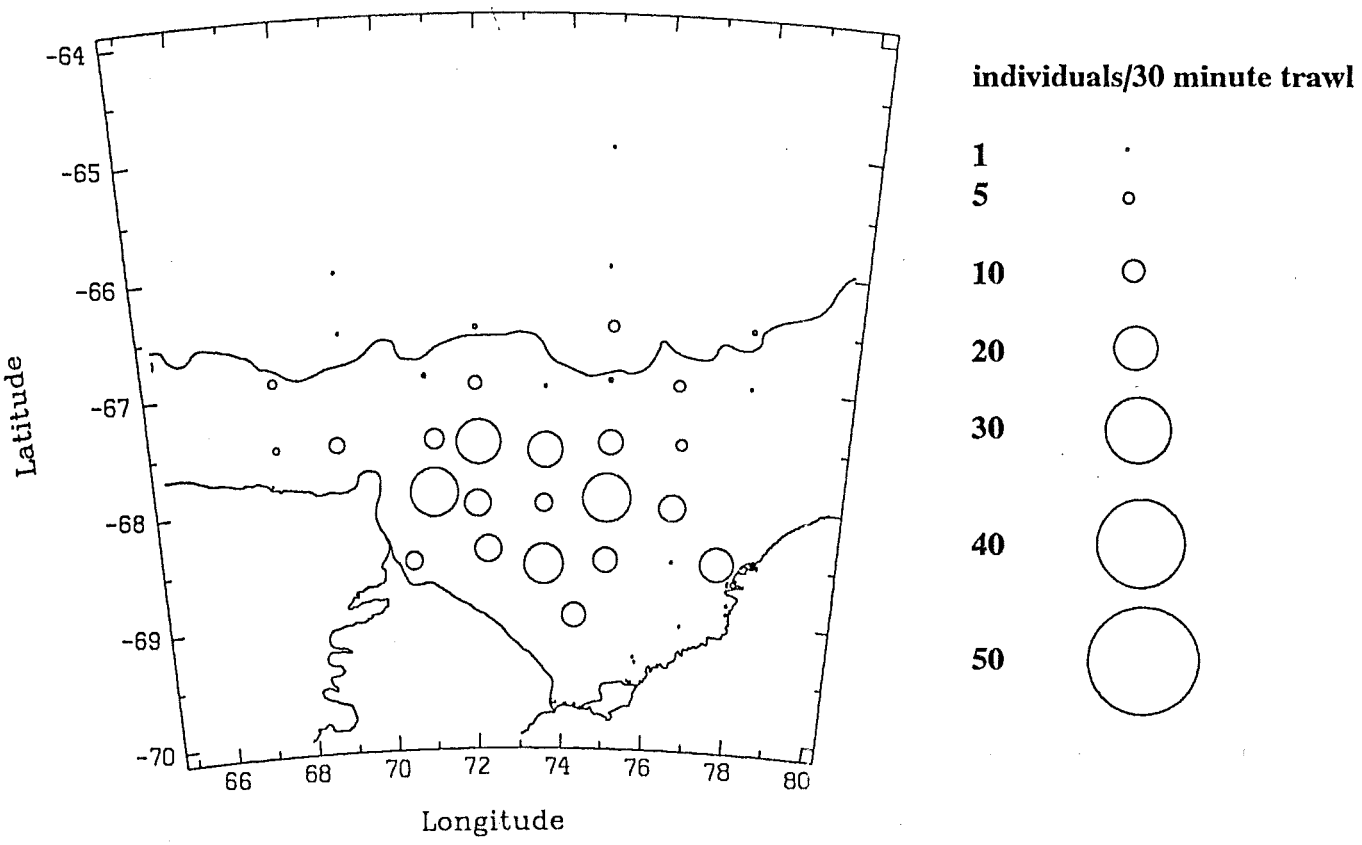

Figure 6: Catches of Channichthyidae juveniles.

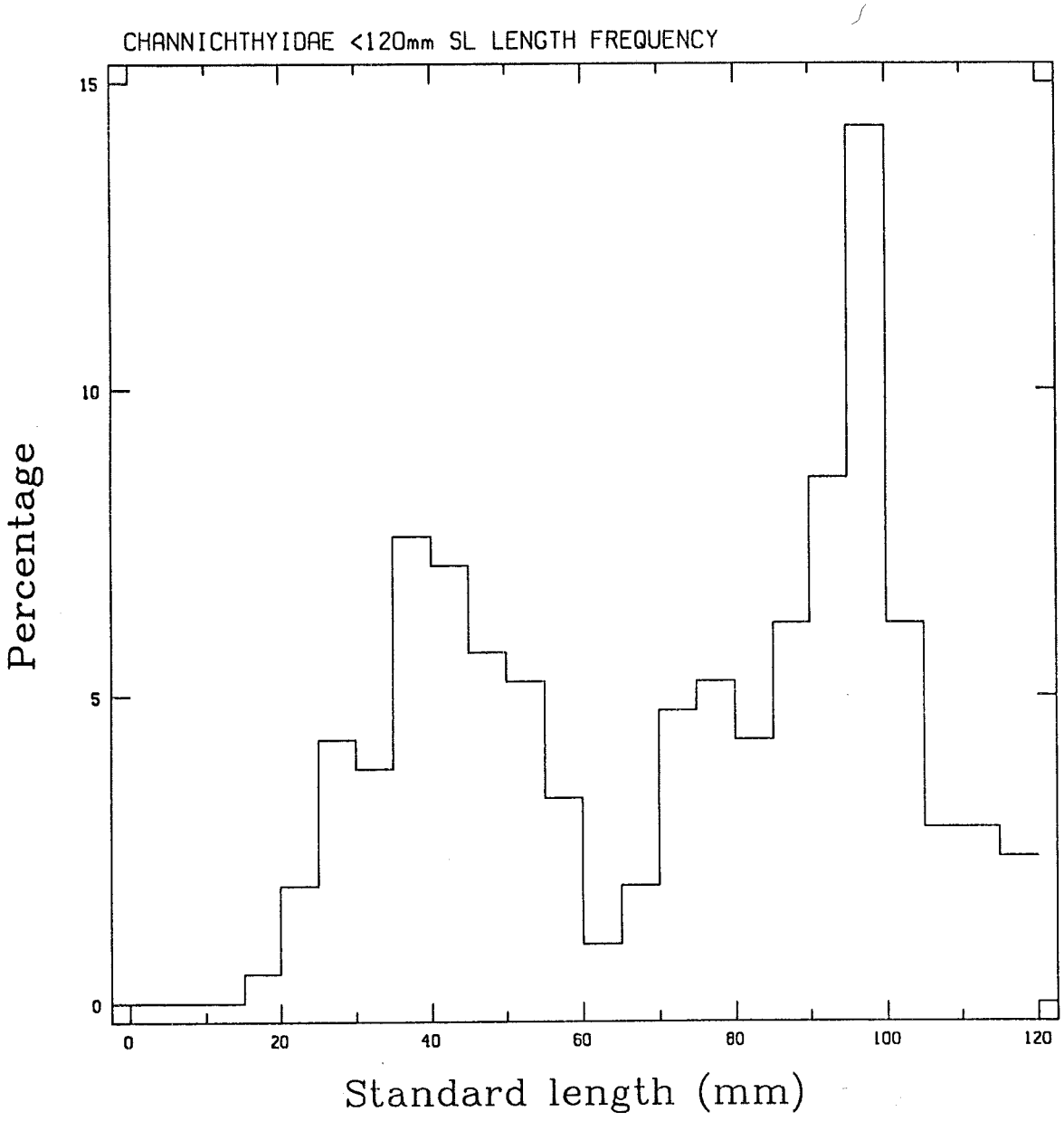

Figure 7: Length frequency of Channichthyidae catches.

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BY-CATCH OF FISH IN THE KRILL FISHERY

I. Everson[1], A. Neyelov[2] and Y.E. Permitin[3]

Abstract

Observations are reported of icefish being taken as by-catch during krill fishing operations from a research vessel. The results indicate that the by-catch of fish in the commercial krill fishery may be significant in some areas of the South Georgia shelf. The problem is thought to be least in open ocean krill fishing.

Résumé

Observations fournies par un navire de recherche sur le poisson des glaces présent dans les captures accessoires des opérations de pêche de krill. Les résultats indiquent que la capture accessoire de poisson dans la pêcherie commerciale de krill pourrait être significative dans certaines régions du plateau de Géorgie du Sud. Il semblerait que le problème soit de moindre importance dans les opérations de pêche en plein océan.

Резюме

С научно-исследовательского судна была получена информация о наблюдении прилова ледяной рыбы при промысле криля. Результаты показывают, что прилов рыбы при коммерческом промысле криля может быть значительным в некоторых районах шельфа Южной Георгии. Предполагается, что проблема менее серьезна при промысле криля в открытом океане.

Resumen

Se han observado capturas accidentales de draco rayado durante la pesca de krill realizada por un buque de investigación. Las conclusiones indican que la pesca íctica accidental que ocurre en la pesquería comercial de krill puede ser considerable en algunas zonas de la plataforma del archipiélago de las Georgias del Sur. Se cree que este problema se da en menor magnitud en la pesca de krill en alta mar.

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1. INTRODUCTION

During the past 20 years a major krill fishery has become established in the Southern Ocean. Nearly all of the catches have been made using midwater trawls, which, because krill (*Euphausia superba*) only grow to a maximum size of about 6 cm, are made of fine mesh netting. The fishery operates by aimed tows at krill swarms which have been located using echosounders.

Recently concern has been expressed that the fishery may be taking a significant by-catch of fish with the result that it may be responsible for significant levels of mortality in other harvested species (SC-CAMLR, 1989). We have analysed results from research vessel catches, using commercial krill trawls, in order to quantify the by-catch of fish in the krill fishery.

2. MATERIAL AND METHODS

Observations were made on catches from the research vessels *Akademik Knipovich* between January and July 1981 (Anon., 1981), and *Evrika* during January 1987. Both cruises were undertaken in the Atlantic sector of the Southern Ocean. Part of the time the research vessels were operating in conjunction with krill fishing fleets. Precise details of the locations and numbers of commercial fishing vessels are not available to us, were are unable, therefore, to relate these results directly to the total krill catch during the two seasons under consideration. Information is available, however, on the general disposition of the commercial fleet in the area.

Position at the end of each haul was recorded along with maximum and minimum water depth, time and duration of tow. The depth of the footrope of the net and the vertical opening of the net were also recorded.

The constraints of the sampling program meant that not all catches could be sampled but wherever possible representative samples were taken to look for fish. In most cases fish were counted, measured and weighed. When this was not possible qualitative observations were recorded in the field logbooks. When large krill catches were made a subsample of the catch was taken for analysis. Numbers and weights of fish in these subsamples have been increased *pro rata* to give an estimated total number or weight for the haul.

3. RESULTS

Information on individual net hauls from both cruises is set out in Tables 3 to 4 for Subareas 48.3, 48.2 and 48.6 respectively. Estimated numbers of the icefish, *Champsocephalus gunnari*, taken in each tow at South Georgia are set out in Table 4. Numbers of other fish species taken in each tow are set out in Tables 5 to 7.

Several size classes were present in many of the catches. The breakdown of size classes in haul 53 is given in Table 8. Reference to Folkina (1989) suggests all the modal values do not correspond with year classes. Based on the result of Frolkina, we suggest that our class (iv) is probably age two or three, our size classes (ii) and (iii) are age 1 and our size class (i) is age 0. *C. gunnari* occurred frequently in the catches of Subarea 48.3 but only in shallow water. This species was never found in hauls where the net had been in water deeper than 500 m throughout the haul. It did not figure in the catches from the other subareas. Moderate numbers of another icefish, *Chaenocephalus aceratus*, were also present in some hauls although the numbers never approached those of *C. gunnari*.

In contrast to the icefish, Myctophidae species were only present in deep water catches.

All other species were only ever present in small numbers.

4. DISCUSSION

4.1 General Considerations

The two icefish species *C. gunnari* and *C. aceratus*, and the Myctophidae were the only species that occurred in large numbers in the catches. The situations under which the large catches occurred are discussed further. The other species were taken in such small quantities that their presence in the by-catch of the krill fishery is unlikely to affect significantly their recruitment.

4.2 *Chaenocephalus aceratus*

The largest by-catches of this species, in common with *C. gunnari*, were made around South Georgia but they were only present when the krill catch was very small, less than would be required by a commercial fishing fleet. Our results suggest that large-scale krill harvesting is probably having little effect on the stocks of *C. aceratus*.

4.3 Myctophidae

Catches of Myctophidae tended to occur over deep water, in some instances at a great distance from the shelf. These species are themselves the subject of directed fishery in deep water in Subarea 48.3 (SC-CAMLR, 1989, Annex 6, paragraph 7). Everson and Goss (in press) showed that the distribution of krill fishing was concentrated close to or on the shelf and so there is likely to be some geographical separation between fleets harvesting these two resources.

4.4 Seasonal Variation

The results that we have reported here were obtained during the first few months of the year. Krill fishing at South Georgia is at its peak during the winter months and our results give no information for that period.

Krill fishing only takes place during the summer in Subarea 48.2 and our results for that area may therefore provide a reasonable indicator of the situation within the commercial fleets.

5. CONCLUSIONS

Our results from research vessel surveys demonstrate that, under certain circumstances at South Georgia, large numbers of fish are likely to be taken in the course of the directed fishery for krill. The problem appears to be greatest in the vicinity of Clerke Rocks where a commercial fleet was operating in an area where significant numbers of the icefish *C. gunnari* were present. This is the same area that Slosarczyk (1983) noted large numbers of Nototheniidae and Channichthyidae being taken in experimental trawls. Both Slosarczyk and Rembiszewski (1982) and Rembiszewski *et al.* (1978) concluded that although the amounts of fish were likely to cause little contamination to the krill catches they were sufficiently large to have a detrimental effect on the abundance of young fish.

From the limited observations we have recorded in this paper we are unable to indicate whether this effect is present during the winter months when the South Georgia krill fishery is at its seasonal peak (Everson and Goss, in press).

We suggest two ways of researching this topic further. Firstly, we would recommend rigorous monitoring of the krill fishery in order to determine the magnitude of the problem in

the field. Secondly, we consider it important to determine the locations and times of year when the demersal fish are at greatest risk. At South Georgia this would mean that results from young fish surveys in winter would be of particular importance. Examination of data from such research cruises would provide guidance to help krill fishermen avoid catching young fish.

The largest by-catches of *C. gunnari* were associated with moderate or low catch rates of krill. The highest catch rates of krill contained a small proportion of by-catch species. This tends to indicate that commercial fishing on dense krill swarms may have only a minor effect on the icefish. Approximately one haul in 20 was however taking large amounts of krill and fish. There is clearly a need for further information on the relationship between the krill swarms and associated demersal fish species.

C. gunnari was not present in the by-catches from Subareas 48.2 or 48.6 and so from this information we would conclude that there is only a very small by-catch of this species in the krill fishery in these areas.

Our results also indicate that other demersal species are probably not present in great quantity in the by-catch in these areas.

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Table 1: Information on trawls in Subarea 48.3 (South Georgia).

Column headings are as follows: a-Haul number, b-Day, c-Month, d-Latitude (degrees south), e-Latitude (minutes), f-Longitude (degrees west), g-Longitude (minutes), h-Water Depth at Start of Trawling, i-Water Depth at End of Trawling, j-Minimum Depth of Footrope of Net, k-Maximum Depth of Footrope of Net, l-Vertical Opening of Net, m-Time, n-Duration of Tow (hours).

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Akademik Knipovich* in 1981													
47	10	4	54	54	34	50	230	255	45	40	30	845	2.00
48	10	4	54	56	34	51	230	130	30	40	24	1640	0.92
49	11	4	54	55	35	2	220	155	40	31	27	225	1.58
50	11	4	54	49	34	49	240	580	35	35	27	600	1.33
51		4	54	55	34	50	500	185	40	35	27	850	1.00
52		4	54	56	34	46	260	145	35	35	26	1645	1.17
53	12	4	54	52	34	51	225	300	35	35	24	650	2.25
54		4	54	46	34	59	250	257	55	42	32	1130	0.92
55		4	54	53	35	3	280	180	32	50	24	1705	2.25
56	14	4	54	57	35	4	170	170	50	50	24	540	2.50
57		4	54	52	35	8	165	165	40	50	27	945	2.25
58		4	54	47	35	16	110	350	75	250	25	1650	3.83
59	15	4	54	44	34	55	450	295	40	45	30	1055	1.66
60		4	54	40	34	50	350	305	40	40	29	1520	2.33
61	16	4	54	41	34	51	360	500	40	50	30	715	1.08
62		4	54	43	34	57	260	290	50	50	33	1015	1.75
63		4	54	45	35	1	255	250				1325	1.75
64	17	4	54	39	35	32	120	120	60	50	30	2115	2.75
65	18	4	54	38	35	14	225	205				235	1.42
66	18	4	54	31	35	19	160	160	50	40	30	725	1.83
67	18	4	54	30	35	10	300	300	50	50	30	1550	2.67
68	19	4	54	29	35	15	300	1160	40	50	30	630	1.50
69	19	4	54	28	35	13	500	600	50	60	25	1025	1.08
70	19	4	54	29	35	7	400	500	40	40	30	1745	1.83
71	20	4	54	14	35	18	250	470				545	2.25
86	10	5	55	0	33	47	3000	3000	70	150		1430	
87	11	5	54	57	31	34	4700	4700	65	150		315	0.50
88	11	5	54	34	32	11	5120	5120	35	55	30	1100	0.50
89	12	5	54	33	34	53	700	700	35	110	30	905	0.58
90	12	5	54	55	34	55	125	180	35	50	27	1700	0.50
91	12	5	54	51	34	42	130	130	37	55	27	1945	1.00
92	12	5	54	49	34	49	320	320	35	110	30	2210	0.67
93	13	5	54	16	35	26	230	120	32	55	30	600	0.50
94	13	5	54	10	35	36	200	200	45	65	30	825	2.08
95	13	5	53	55	34	40	3310	3310	37	53	30	1810	0.50
96	15	5	54	6	35	43	240	240	45	60	30	750	1.42
97	15	5	54	13	35	16	700	690	65	150		1210	0.50
98	15	5	53	51	35	10	3200	3200	42	54	30	1620	0.58
99	16	5	53	58	35	33	980	980	42	54	30	700	0.67
100	16	5	54	3	35	34	230	130	45	65	30	955	1.83
101	16	5	54	13	35	59	215	215	37	54	30	1650	0.50
106	18	5	54	0	35	58	270	300	100	100		1210	0.58
107	19	5	53	47	35	52	630	780	37	54	30	1720	0.50
109	19	5	52	5	36	25	3700	3700	37	54	30	1625	0.50

Table 1 (continued)

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Akademik Knipovich* in 1981 (continued)													
110	20	5	53	10	36	13	3000	3000	100	100		245	0.70
111	20	5	53	37	36	30	620	620	37	54	30	730	0.50
112	20	5	53	45	36	35	180	180	35	60	30	940	0.50
113	20	5	53	41	37	31	320	315	65	150		1535	0.50
114	23	5	53	35	38	20	2550	2550	37	54	30	630	0.50
Cruise of RV *Evrika* in 1987													
6	6	1	56	23	27	29	180	150	40	40		2140	0.92
7	7	1	56	17	26	33	3000	3000				220	0.50
30	18	1	55	28	35	36	250	310	95	150		1655	1.17
31	19	1	54	53	34	43	128	300	20	50		135	1.25
32	19	1	54	53	34	38	200	300	30	130		440	0.92
122	27	2	54	54	34	31	275	270	50	50		2150	0.50
145	4	4	54	40	35	26	150	150	0	35		1400	0.42

Table 2: Information on trawl in Subarea 48.2, South Orkney Island. (Column headings are the same as for Table 1.)

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Akademik Knipovich* in 1981													
74	27	4	60	39	50	57	420	420	35	35	25	1300	0.50
75	27	4	60	59	53	5	1500	1500	37	55	30	2255	0.50
76	28	4	60	30	53	52	3000	3000	37	55	30	550	0.50
77	28	4	60	58	53	48	1760	1760				1215	
78	29	4	62	9	55	27	330	330	35	60	30	1025	0.50
81	30	4	62	34	56	5	205	205	37	40	30	1635	1.25
82	1	5	62	36	35	34	320	320	50	50	30	950	0.75
Cruise of RV *Evrika* in 1987													
9	8	1	57	15	26	31						656	0.58
12	10	1	58	53	26	41	1000	990				1850	0.50
13	10	1	58	56	26	38						2200	0.50
14	11	1	58	16	26	38						120	0.42
17	12	1	59	59	28	9	2000	2000	45	45		2235	0.58
18	13	1	60	3	30	20	2000	2000	30	30		1240	0.58
19	13	1	59	59	30	20	2000	2000	30	20		1500	1.00
20	13	1	59	59	30	28	1000	1000	25	25		1755	1.00
21	13	1	60	3	30	28	2700	2700	25	25		2045	1.00
29	17	1	60	14	60	15	1400	500	15	45		1100	0.83
35	23	1	61	41	27	59	4000	4000	5	125		2215	2.50
36	23	1	63	3	27	57	4000	4000	30	35		1315	1.16
51	30	1	62	36	41	48	3000	3000	0	50		1110	2.50
52	30	1	62	35	41	50	3000	3000	20	50		1625	2.50
53	30	1	62	5	42	30	3000	3000	20	50		2300	2.00
54	31	1	60	44	44	12	150	125	0	65		1150	1.16

Table 2 (continued)

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Evrika* in 1987 (continued)													
55	31	1	60	29	45	2	580	638	30	140		1650	0.92
56	31	1	60	30	44	51	650	400	0	35		2030	2.00
57	1	2	60	25	46	20	125	130	20	50		230	0.75
58	1	2	60	23	45	59	150	600	30	110			
61	3	2	60	28	47	2	250	200	40	70		1310	0.42
62	4	2	60	31	46	13	100	230	0	30		50	0.66
63	4	2	60	26	45	59	130	120	70	120		1000	0.33
64	5	2	60	26	46	11	215	600	30	80		400	1.00
65	5	2	60	26	46	18	100	120	0	50		1600	0.42
66	6	2	60	25	46	6	318	320	30	20		725	0.75
67	6	2	60	27	45	47	150	240	5	110		1930	2.33
68	7	2	60	25	45	48	250	210	20	70		440	2.84
69	7	2	60	25	46	28	180	200	20	70		1315	0.50
70	7	2	60	26	46	25	250	300	20	800		2050	1.67
71	8	2	60	23	46	16	1500	1500				1125	0.33
72	8	2	60	26	46	11	150	1500	10	50		2300	1.00
73	9	2	60	26	45	59	150	150	0	30		245	0.50
74	9	2	60	27	45	51	180	220	25	55		1335	1.16
75	9	2	60	23	46	18	780	600	70	100		1650	1.16
76	10	2	60	26	46	20	230	460	30	90		730	1.50
77	10	2	60	25	46	28	140	210	40	100		1250	2.16
78	11	2	60	24	46	23	131	400	30	90		700	2.42
79	11	2	60	26	46	43	170	550	25	90		1230	2.00
80	12	2	60	25	46	15	100	600	0	40		15	4.00
81	12	2	60	25	46	19	250	300	120	210		950	2.42
82	13	2	60	26	48	30			140	120		1535	0.16
83	13	2	60	27	46	28	600	700	30	150		1720	3.16
104	13	2	60	27	46	11	360	600	70	90		1835	2.25
111	23	2	60	36	45	36	360	305	0	40			

Table 3: Information on trawl in Subarea 48.6. (Column headings are the same as for Table 1.)

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Akademik Knipovich* in 1981													
5	5	3	63	44	9	39	5100	5100	48	85	28	1245	0.50
6	6	3	64	22	6	1	5200	5200	48	67	30	925	0.50
7	7	3	64	54	2	25	5000	5000	48	67	30	545	0.50
8	8	3	66	37	2	18	4500	4500	40	70	28	30	0.58
9	8	3	67	57	2	19	3700	3700	60	70	30	950	0.50
10	8	3	68	37	2	6	3500	3500	31	65	28	1715	0.50
11	9	3	69	35	1	14	2000	2000	53	80	28	1030	1.17
12	10	3	69	23	3	8	2100	2100	50	50	30	100	0.50
13	10	3	69	10	4	57	2180	2180	38	38	28	1915	0.75
14	12	3	69	51	10	14	340	345	48	135	32	1615	0.83
17	14	3	69	35	12	32	220	220	38	55	24	715	0.75

Table 3 (continued)

a	b	c	d	e	f	g	h	i	j	k	l	m	n
Cruise of RV *Akademik Knipovich* in 1981 (continued)													
18	14	3	69	2	12	49	1800	1800	45	45	27	1610	0.83
19	15	3	68	49	13	22	2700	2700	26	57	25	355	0.58
20	15	3	68	55	12	39	2050	2050	62	62	28	1245	1.33
21	15	3	69	17	11	50	760	740	33	53	23	1850	0.50
22	16	3	69	9	10	55	1800	1800	35	60	25	915	0.58
23	16	3	69	31	10	52	750	750	40	35	30	1405	0.50
24	17	3	69	7	10	3	2400	2400	50	50	30	1440	1.08
25	18	3	67	11	9	40	3100	3100	35	50	24	1735	0.58
26	20	3	63	12	5	14	5220	5220	32	68	24	1750	0.83
27	21	3	63	20	1	25	4500	4500	40	95	30	1125	0.67
28	22	3	64	4	3	25	2730	2730	28	40		1200	0.50
29	23	3	64	38	7	14	4000	4000	35	48	27	710	0.58
30	24	3	64	36	3	18	2270	2270	30	50	26	740	0.50
32	25	3	65	15	1	15	3000	3000	37	60	24	810	0.58
34	26	3	65	20	6	60	4600	4600	40	40	30	1110	0.50
35	27	3	65	52	3	31	4500	4500	35	35	30	1435	0.50
36	28	3	66	30	2	30	3850	3850	35	35	30	425	0.50
37	28	3	67	8	3	13	4000	4000	35	60	30	1115	0.50
38	29	3	68	39	6	5	3200	3200	40	68	30	1545	1.41
39	30	3	69	7	1	45	3460	3460	40	40	22	1655	1.33
Cruise of RV *Evrika* in 1987													
37	24	1	64	12	28		4000	4000	5	35		2400	1.75
38	25	1	65	28	27	59	4000	4000	200	245		1200	1.00
48	25	1	68	13	29	60	4000	4000	100	130		2350	0.50

Table 4: Estimated total numbers of *C. gunnari* in hauls at South Georgia using a krill trawl. NQ = Present but not quantified.

Haul	Catch Krill (tonnes)	Sample Size (kg)	Size Classes (i)	(ii)	(iii)	(iv)	Total
RV *Akademik Knipovich*							
47	0.20	all					NQ
48	0.10	all	0	0	0	69	69
49	0.00	all	0	9	11	0	20
50	0.55	10.15	3901	0	0	0	3901
51	13.00						NQ
52	16.00						NQ
53	0.30	21.16	3162	170	128	170	3629
54	17.00	all	0	0	0	0	0
55	1.00	all					NQ
56	1.00	all	0	0	110	0	110
57	10.00	all	0	0	0	1033	1033

Table 4 (continued)

Haul	Catch Krill (tonnes)	Sample Size (kg)	Size Classes (i)	(ii)	(iii)	(iv)	Total
RV *Akademik Knipovich* (continued)							
58	1.70	all	0	0	0	24577	24577*
59	10.00	all	0	0	0	0	0
60	2.50	all					NQ
61	0.30	all	0	0	0	0	0
62	6.00	all	0	0	0	0	0
63	15.00	22.00	682	0	0	0	682
64	1.60	all					NQ
65	0.00	all					0
66	8.00	all	0	0	0	0	0
67	7.00	all	0	0	0	0	0
68	4.00	10.00	800	0	0	0	800
69	18.00	all	0	0	0	0	0
70	5.00	all	0	0	0	0	0
71	9.00	all	0	0	0	0	0
86	0.00	all					0
87	0.00	all	0	0	0	0	0
88	0.00	all					0
89	0.00	all					0
90	few	all	3	2	2	0	7
91	0.00	all					0
92	0.00	all	3	2			5
93	0.50	all	2	0	0	0	2
94	0.15	all	4	1	0	0	5
95	0.00	all					0
96	12.00	all					NQ
97	0.10	all	0	0	0	0	0
98	0.04	all	0	0	0	0	0
99	0.00	all	0	0	0	0	0
100	15.00	all					NQ
101	few	all					0
106	0.00	all	0	0	0	0	NQ
107	0.00	all					1
109	0.00	all					0
110	0.00	all	0	0	0	0	0
111	0.00	all					NQ
112	few	all					NQ
113		all					NQ
114	few	all					
RV *Evrika*							
6	few		0	0	0	0	
7	0.00	all	0	0	0	0	
30	0.00	all	0	0	0	0	
31	0.50	all	0	0	0	0	
32	2.00	all	0	0	0	0	
122	20.00	all	0	0	0	0	
145	20.00	all	0	0	0	0	

* Haul 58, *Champsocephalus gunnari* was estimated to make up 70% of the catch. The size range was 16 to 22 cm which by analogy to Table 8 would have had a mean weight of 48.4 g.

Table 5: Catches of fish other than *Champsocephalus gunnari* at South Georgia.

ACER = *C. aceratus*, PSEU = *Pseudochaenichthys georgianus*, LARS = *Nototheniops larseni*, MYCT = Myctophidae, NQ is the same as in Table 4.

Haul	Krill Catch (tonnes)	Sub-Sample (kg)	ACER	PSEU	LARS	MYCT (n)	MYCT (kg)
RV *Akademik Knipovich*							
47	0.2000		NQ	0	NQ	0	
48	0.1000		162	0	0	0	
49	0.0050		62	1	60	0	
50	0.5500	10.15	2	1	1	0	
51	13.0000		NQ	0	0	0	
52	16.0000		NQ	0	0	0	
53	0.3000	0.0212	83	0	0	0	
54	17.0000		0	0	0	0	
55	1.0000		NQ	0	0	0	
56	1.0000		NQ	1	2	2	
57	10.0000		NQ	0	0	0	
58	1.7000		0	0	0	0	
59	10.0000		0	0	0	0	
60	2.5000		NQ	0	0		8.0
61	0.3000		0	0	0	0	
62	6.0000		0	0	0	0	
63	15.0000		0	0	0	0	
64	1.6000		0	0	0	0	
65	0.0000		0	0	0	0	
66	8.0000		0	0	0	0	
67	7.0000		0	0	0	0	
68	4.0000		0	0	0	0	
69	18.0000		0	0	0		NQ
70	5.0000		0	0	0	0	
71	9.0000		0	0	0	0	
86	0.0000		0	0	0	0	
87	0.0001		0	0	0	46	
88	0.0000		0	0		0	
89	0.0000		0	0	0	0	
90	few		NQ	1	NQ	0	
91	0.0000		590	0	4	0	
92	0.0000		17	0	2	9	
93	0.5000		NQ	0	0	0	
94	0.1500		NQ	0	0	0	
95	0.0000		0	0	0	40	0.5
96	12.0000		0	0	0	0	
97	0.1000		0	0	0	0	
98	0.0400		0	0	0	0	1.5
99	0.0001		0	0	0	1	
100	15.0000		1	0	0	0	
101	few		0	0	2	0	
106	0.0020		0	0	0	0	
107	0.0000		0	0	0		NQ
109	0.0000		0	0	0		15.0
110	0.0000		0	0	0		0.7

Table 5 (continued)

Haul	Krill Catch (tonnes)	Sub-Sample (kg)	ACER	PSEU	LARS	MYCT (n)	MYCT (kg)
RV *Akademik Knipovich* (continued)							
111	0.0000		0	0	0	0	
112	few		1	0	0	0	
113			0	1	0	0	
114	few					NQ	
RV *Evrika*							
6	few		0	0	0	2	
7	0.0000		0	0	0	0	
30	0.0000		0	0	0		1.5
31	0.5000		0	0	0	0	
32	2.0000		0	0	0	0	
122	20.0000		0	0	0	0	
145	20.0000		0	0	0	0	

Table 6: South Orkney data for fish in krill catches.

The species are: A = *C. aceratus*, B = *Chionodraco sp.*, C = other Channichthyidae, D = Myctophidae, E = *Notolepis coatsi*, F = *Pleuragramma antarcticum*, G = Other species, NQ as Table 4.

Haul	Krill Catch (tonnes)	Sub-Sample (kg)	Species A	B	C	D (n)	D (kg)	E	F	G
RV *Akademik Knipovich*										
74	0.0000		0	0	0	0		0	0	0
75	0.0000		0	0	0		3	0	0	0
76	0.0000		0	0	0		2	0	0	0
77	0.0000		0	1	0	0	0	0	0	3
78	0.0005		0	2	5	0	0	0	2	
81	0.1000		0	NQ	NQ	0		0	NQ	NQ
82	9.0000	0.0360	0	2	3	0	0	0	4	1
RV *Evrika*										
9	0.0000		0	0	0	0	0	0	0	0
12	0.0000		0	0	0	0	0	0	0	0
13	few		NQ	0	0	NQ		0	0	0
14	0.0500		2	0	0	0	0	0	0	2
17	few									NQ
18	5.0000		0	0	0	0	0	2	0	0
19	0.0000		0	0	0	0	0	0	0	0
20	8.0000		0	0	0	0	0	0	0	2
21	0.1000		0	0	0	0	0	0	0	1
29	0.0000									NQ

Table 6 (continued)

Haul	Krill Catch (tonnes)	Sub-Sample (kg)	Species A	B	C	D (n)	D (kg)	E	F	G
RV *Evrika* (continued)										
35	0.0400		0	0	0	0	10	0	0	0
36	0.5000		0	0	0	0	0	1	0	0
51	8.0000									NQ
52	2.0000									NQ
53	0.1000			2		NQ				
54	0.0000		0	0	2	0	0	1	0	
55	15.0000		0	0	0	0	0	0	0	0
56	0.0000		0	0	0	0	0	0	0	0
57	25.0000		0	0	1	0	0	0	0	0
58	20.0000									
61	15.0000		0	0	0	0	0	0	1	2
62	15.0000		0	0	0	0	0	0	0	1
63	20.0000		4	0	0	0	0	0	0	10
64	15.0000		1	0	0	0	0	0	0	1
65	15.0000		3	0	0	0	0	0	0	0
66	25.0000		0	0	0	0	0	0	0	0
67	15.0000		0	0	0	0	0	0	0	0
68	0.0000		0	0	0	0	0	0	0	0
69	20.0000		0	0	0	0	0	0	0	1
70	25.0000		0	0	0	0	0	0	0	0
71	20.0000		0	0	0	0	0	0	0	0
72	3.0000		0	0	0	4	0	0	0	1
73	25.0000		0	0	0	0	0	1	0	0
74	0.0000		0	0	0	0	0	0	0	0
75	25.0000		0	0	0	0	0	0	0	2
76	15.0000		0	0	0	0	0	0	0	0
77	30.0000		0	0	0	0	0	0	0	4
78	10.0000		2	0	0	0	0	0	0	
79	30.0000		1	0	0	0	0	0	0	0
80	5.0000		0	0	0	27	1	1	0	5
81	30.0000		0	0	0	0	0	0	0	0
82	0.0000									
83	15.0000		0	0	0	0	0	0		0
104										
111	10.0000		0	0	0	0	0	0	0	0

Table 7: Fish catches in krill trawls from Subarea 48.6.

Species codes are the same as for Table 6 with the addition of I = *Pagothenia brachysoma*, J = *Chionobathyscus dewitti*.

Haul	Krill Catch (tonnes)	Species I	B	C	J	D (n)	D (kg)	E	F	G
RV *Akademik Knipovich*										
5	0.0100	0	0	0	0	0	0	0	0	
6	0.5000	1	0	0	0	0	0	0	0	
7	1.0000	0	0	0	0	0	0	0	0	
8	few	0	0	0	0		5	0	0	
9	0.3000	0	0	0	2	0	0	0	0	
10	few		14					0	0	
11	2.5000	4	15	2	0	0	0	1	0	7
12	0.0010	0	0	1	0	0	3	0	0	
13	few	0	0	0	0	0	0	3	0	1
14	0.0010	0	NQ	0	0	0	0	0	2	
17	0.1000	0	NQ	0	0	0	0	0	0	
18	5.0000	0	NQ	NQ	0			0	NQ	
19	few	0	0	4	0	0	0	0	0	
20	0.0100	0	2	269	0	0	0	0	0	
21	0.0100	0	0	0	0		20	0	0	
22	4.0000	0	NQ	NQ	0	0	0	0	0	
23	0.0020	0	2	70	0	0	0	0	0	
24	3.0000	0	0	3	0	0	0	0	0	2
25	0.0001	0	0	0	0	0	0	0	0	0
26	few	0	0	0	0	0	0	0	0	0
27	0.5000	0	0	0	0	0	0	5	0	0
28	few	0	0	0	0	0	0	NQ	0	
29	0.0000	0	0	0	0	0	0	0	0	0
30	0.0050	0	0	0	0	0	0	0	0	0
32	few	0	0	0	0	0	0	0	0	0
34	few	0	0	0	0	0	0	0	0	0
35	0.0100	0	0	0	0	0	0	0	0	2
36	0.0000	0	0	0	0	0	10	0	0	0
37	few	0	0	0	0	0	0	0	0	0
38	2.5000	0	1	0	0	0	0	1	0	0
39	4.0000	0	0	0	0	0	0	1	0	1
RV *Evrika*										
37	few	0	0	0	0	0	0	0	0	0
38	0.0000	0	0	0	0	0	0	1	0	0

Table 8: Comparison of size classes of *Champsocephalus gunnari* with published information.

Data from Haul 53, *Akademik Knipovich*				
Size Class (Table 4)	n	Length Range (mm)	Total Weight (g)	Mean Weight (g)
(i)	223	26-46	31.9	0.143
(ii)	12	76-97	24.6	2.05
(iii)	9	106-119	51.2	5.69
(iv)	12	194-226	581	48.42
Size-at-age from Frolkina (1989) and Frolkina and Dorovskikh (1989)				
Age	Mean Length	Length Range (mm)	Mean Weight (g)	
1	108	70-130	2.7	
2	181	140-240	24.8	
3	245	200-300	77.6	

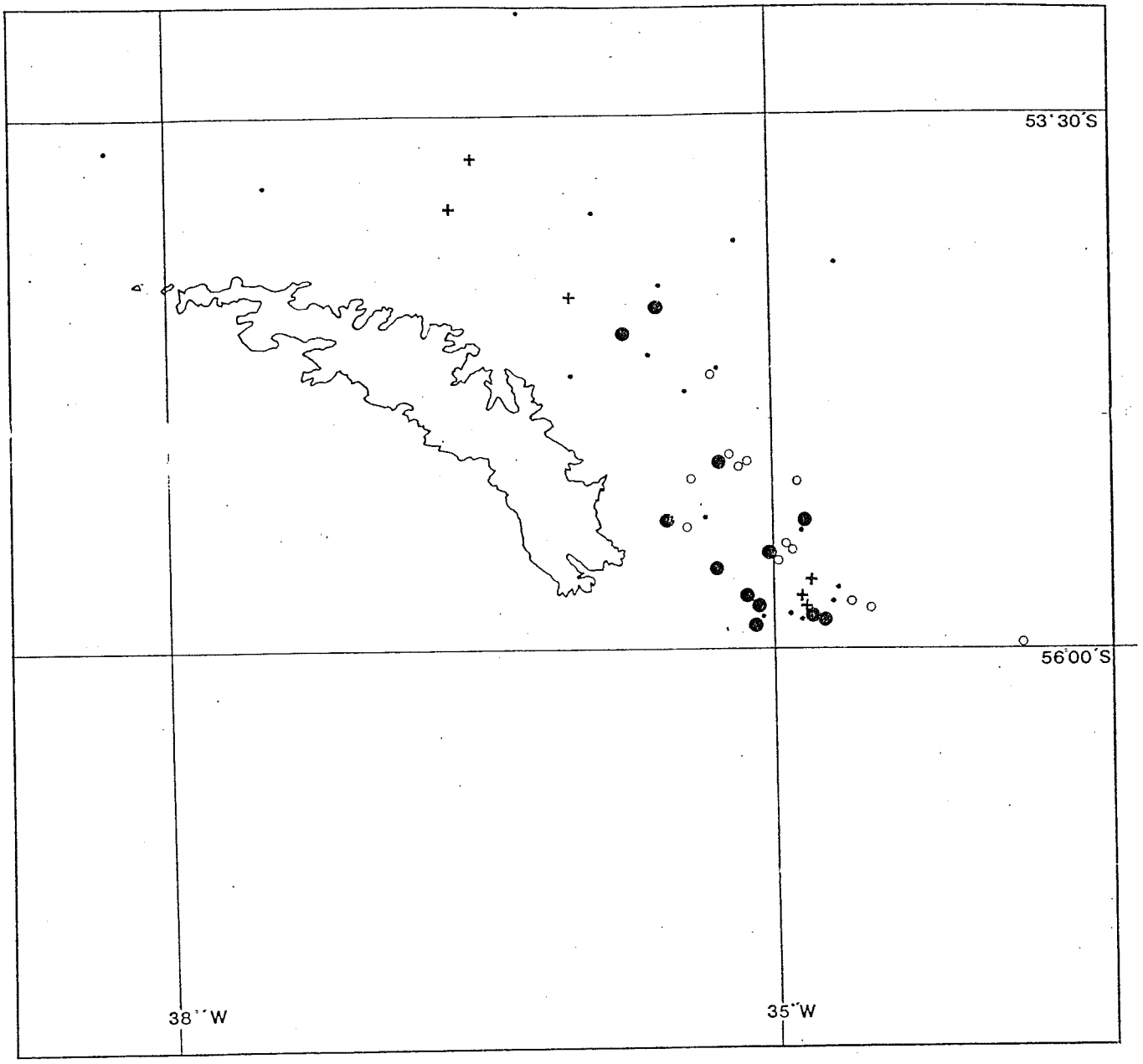

Figure 1: Locations of hauls around South Georgia in Subarea 48.3. Five hauls in deep water beyond the limits of this map and where no fish were caught have been excluded.

Key:

- • = < 1 tonne krill, < 100 *Champsocephalus gunnari*
- \+ = < 1 tonne krill, > 100 *Champsocephalus gunnari*
- o = > 1 tonne krill, < 100 *Champsocephalus gunnari*
- ● = > 1 tonne krill, > 100 *Champsocephalus gunnari*

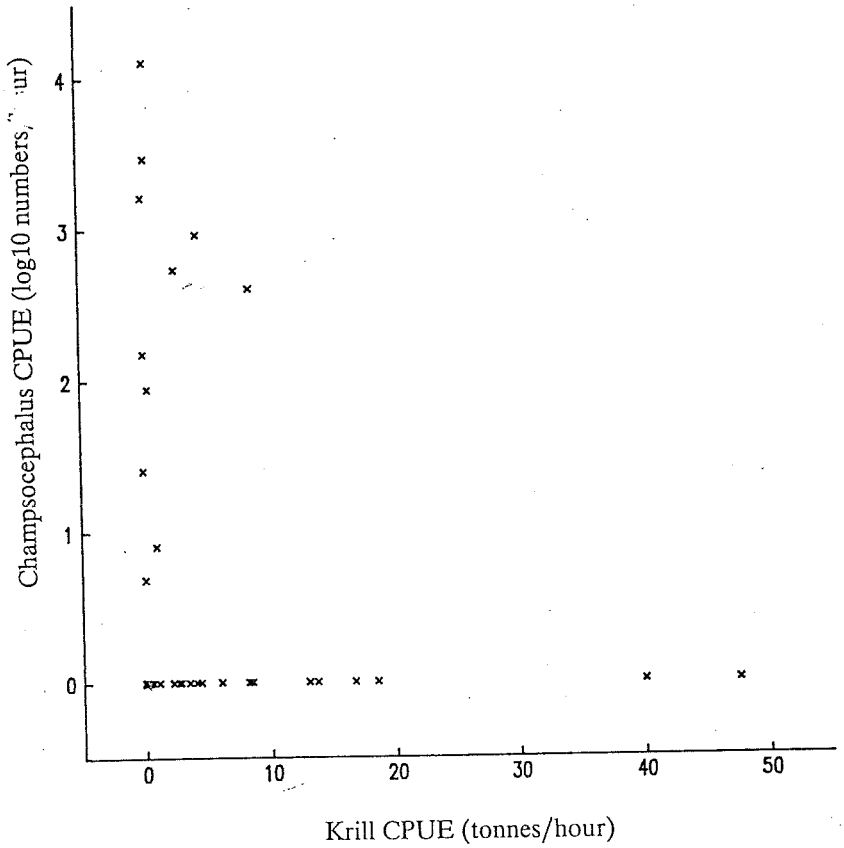

Figure 2: *Champsocephalus gunnari* CPUE in $\log_{10}$ numbers/hour vs krill CPUE in tonnes/hour.

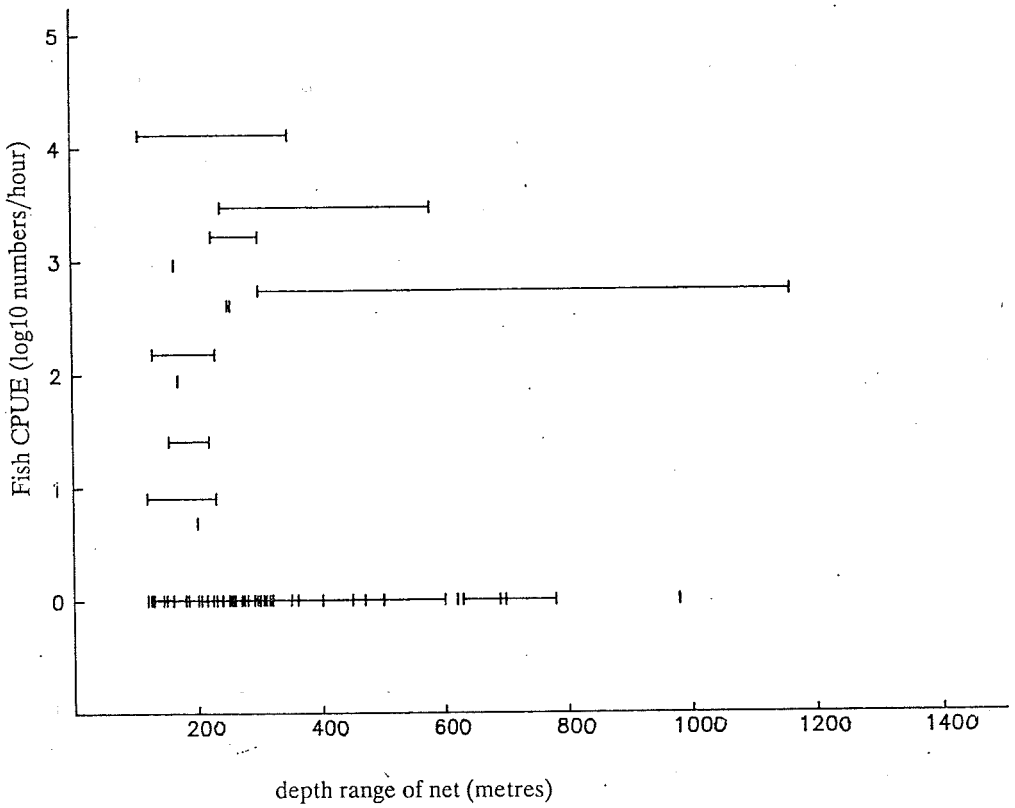

Figure 3: Fish CPUE in $\log_{10}$ numbers/hour vs depth range of net in metres.

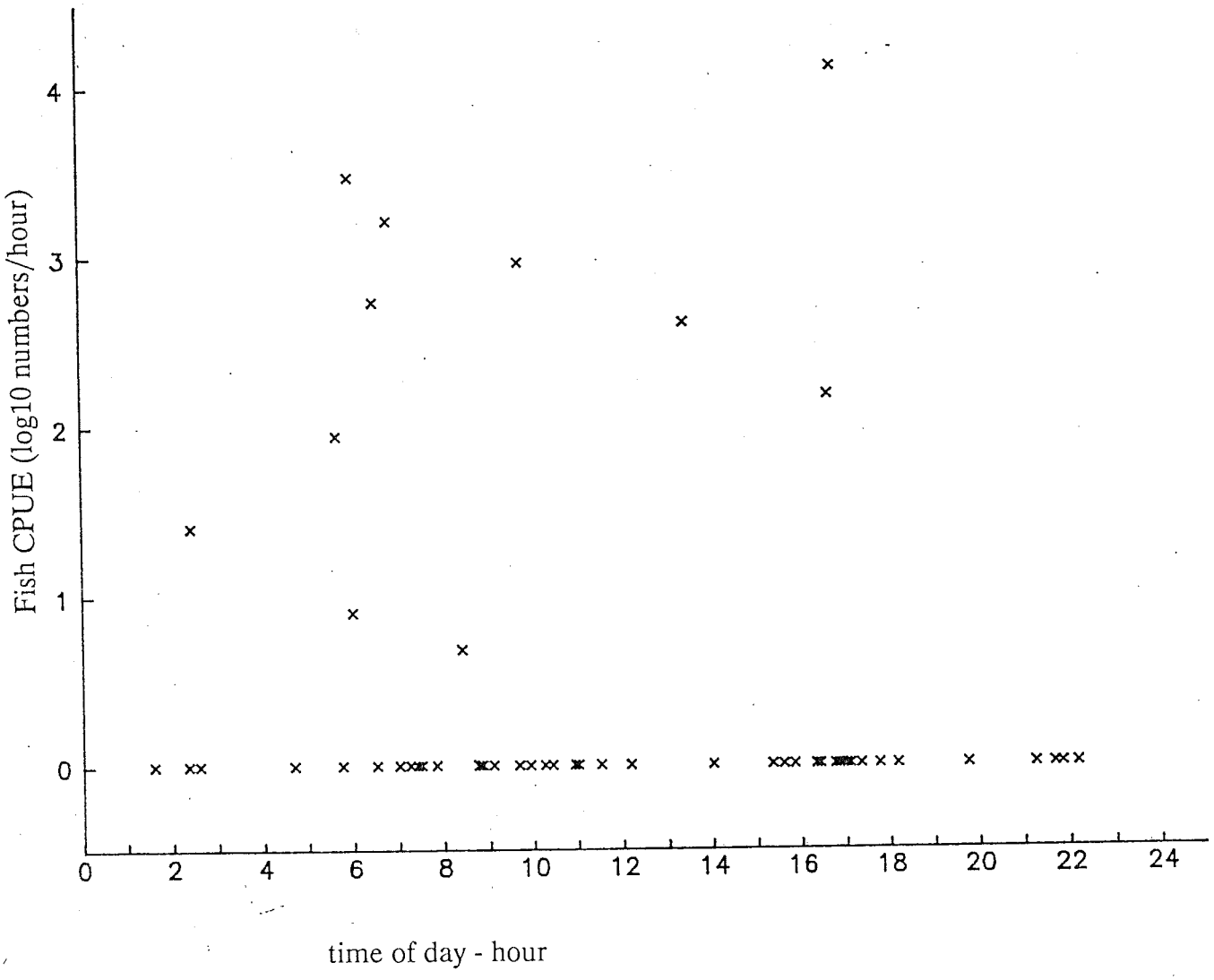

Figure 4: Fish CPUE in $\log_{10}$ numbers/hour vs time of day.

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Tableau 1: Informations sur les chalutages dans la sous-zone 48.3 (Géorgie du Sud).

Les titres des colonnes sont les suivants : a-numéro du chalutage, b-jour, c-mois, d-latitude (degrés sud), e-latitude (minutes), f-longitude (degrés ouest), g-longitude (minutes), h-profondeur totale au début du chalutage, i-profondeur totale à la fin du chalutage, j-profondeur minimale de la ralingue inférieure du filet, k-profondeur maximale de la ralingue inférieure du filet, l-ouverture verticale du filet, m-heure, n-durée du chalutage (heures).

Tableau 2: Informations sur les chalutages dans la sous-zone 48.2 (îles Orcades du Sud). Les titres des colonnes sont ceux du tableau 1.

Tableau 3: Informations sur les chalutages dans la sous-zone 48.6. Les titres des colonnes sont ceux du tableau 1.

Tableau 4: Estimation du nombre total de spécimens de *C. gunnari* dans les chaluts à krill en Géorgie du Sud. NQ = Présents mais en quantité indéterminée.

Tableau 5: Captures de poissons autres que *Champsocephalus gunnari* en Géorgie du Sud.

ACER = *C. aceratus*, PSEU = *Pseudochaenichthys georgianus*, LARS = *Nototheniops larseni*, MYCT = Myctophidae; NQ, voir tableau 4.

Tableau 6: Données sur les poissons dans les captures de krill aux îles Orcades du Sud.

Les différentes espèces sont : A = *C. aceratus*, B = *Chionodraco sp.*, C = autres Channichthyidae, D = Myctophidae, E = *Notolepis coatsi*, F = *Pleuragramma antarcticum*, G = autres espèces; NQ, voir tableau 4.

Tableau 7: Captures de poissons dans les chalutages de krill de la sous-zone 48.6.

Les codes des espèces sont les mêmes qu'au tableau 6, avec, en sus, I = *Pagothenia brachysoma*, J= *Chionobathyscus dewitti*.

Tableau 8: Comparaison des classes de taille de *Champsocephalus gunnari* avec les informations publiées.

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Figure 1: Position des traits autour de la Géorgie du Sud dans la sous-zone 48.3. Cinq traits effectués en eaux profondes, au-delà des limites de cette carte, et s'étant soldés par une capture de poissons nulle, ont été exclus.

Clé :
• = < 1 tonne de krill, < 100 *Champsocephalus gunnari*
+ = < 1 tonne de krill, > 100 *Champsocephalus gunnari*
o = > 1 tonne de krill, < 100 *Champsocephalus gunnari*
• = > 1 tonne de krill, > 100 *Champsocephalus gunnari*

Figure 2: CPUE de *Champsocephalus gunnari* en nombres $\log_{10}$/heure en fonction de la CPUE de krill en tonnes/heure.

Figure 3: CPUE de poissons en nombres log_{10}/heure en fonction de l'intervalle de profondeur du filet en mètres.

Figure 4: CPUE de poissons en nombres log_{10}/heure en fonction de l'heure du jour.

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Таблица 2: Информация по тралениям в Подрайоне 48.2, Южные Оркнейские острова. (Заголовки колонок те же, что в Таблице 1.).

Таблица 3: Информация по тралениям в Подрайоне 48.6. (Заголовки колонок те же, что в Таблице 1.).

Таблица 4: Оценки общего количества *C. gunnari* в тралениях в районе Южной Георгии с использованием крилевого трала. NQ = присутствует, но не подсчитана.

Таблица 5: Прилов других видов рыб кроме *Champsocephalus gunnari* в районе Южной Георгии.
ACER = *C. aceratus*, PSEU = *Pseudochaenichthys georgianus*, LARS = *Nototheniops larseni*, MYCT = Myctophidae, NQ то же, что в Таблице 4.

Таблица 6: Прилов рыбы при промысле криля в районе Южных Оркнейских островов. Обозначения видов: A = *C. aceratus*, B = *Chinodraco sp.*, C = другие белокровные, D = Ьнсещзршвфуб E = *Notolepis coatsi*, F = *Pleuragramma antarcticum*, G = прочие виды, NQ что и в Таблице 4.

Таблица 7: Прилов рыбы в тралах криля в Подрайоне 48.6. Обозначения видов те же, что и в Таблице 6 с добавлением I = *Pagothenia brachysoma*, J = *Chionobathyscus dewitti*.

Таблица 8: Сравнение размерных классов *Champsocephalus gunnari* с опубликованной информацией.

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Ключ:
• = < 1 тонны криля, < 100 *Champsocephalus gunnari*
+ = < 1 тонны криля, > 100 *Champsocephalus gunnari*
o = > 1 тонны криля, < 100 *Champsocephalus gunnari*
● = > 1 тонны криля, > 100 *Champsocephalus gunnari*

Рисунок 2: CPUE *Champsocephalus gunnari* в $\log_{10}$ количество/час в сравнении с CPUE криля в тонны/час.

Рисунок 3: CPUE рыбы в $\log_{10}$ количество/час в сравнении с диапазоном глубин сети в метрах.

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Tabla 1: Datos de arrastres efectuados en la Subárea 48.3 (Georgia del Sur).

Los encabezamientos de las columnas corresponden a: a-número de arrastre, b-día, c-mes, d-latitud (grados sur), e-latitud (minutos), f-longitud (grados oeste), g-longitud (minutos), h-profundidad del agua al inicio del arrastre, i-profundidad del agua al término del arrastre, j-profundidad mínima de la relinga inferior de la red, k-profundidad máxima de la relinga inferior de la red, l-abertura vertical de la red, m-hora, n-duración de los arrastres (horas).

Tabla 2: Datos de arrastres efectuados en la Subárea 48.2, isla Orcadas del Sur. (Los encabezamientos de las columnas corresponden a la tabla 1.)

Tabla 3: Datos de arrastres efectuados en la Subárea 48.6. (Los encabezamientos de las columnas corresponden a la tabla 1.)

Tabla 4: Cálculo del número total de *C. gunnari* en arrastres de krill efectuados en Georgia del Sur. NQ = Captura no cuantificada.

Tabla 5: Capturas de peces distintos de *C. gunnari* en Georgia del Sur.
ACER = *C. aceratus*, PSEU = *Pseudochaenichthys georgianus*,
LARS = *Nototheniops larseni*, MYCT = Myctophidae, NQ según tabla 4.

Tabla 6: Datos de peces extraídos del archipiélago de las Orcadas del Sur en las capturas de krill.
Las especies son: A = *C. aceratus*, B = *Chionodraco* sp., C = otros caenictidos, D = mictófidos, E = *Notolepis coatsi*, F = *Pleuragramma antarcticum*, G = otras especies, NQ igual que en tabla 4.

Tabla 7: Capturas de peces en arrastres de krill en la Subárea 48.6.
Los códigos de especies son los mismos que para la tabla 6 con la adición de I = *Pagothenia brachysoma*, J = *Chionobathyscus dewitti*.

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Clave:

• = < 1 tonelada de krill, < 100 *Champocephalus gunnari*
+ = < 1 tonelada de krill, > 100 *Champocephalus gunnari*
o = > 1 tonelada de krill, < 100 *Champocephalus gunnari*
● = < 1 tonelada de krill, > 100 *Champocephalus gunnari*

Figura 2: CPUE de *Champsocephalus gunnari* expresada en $\log_{10}$ número/horas *versus* la CPUE del krill en toneladas/hora.

Figura 3: CPUE de peces expresada en $\log_{10}$ número/horas *versus* el rango de profundidad de la red en metros.

Figura 4: CPUE de peces expresada en $\log_{10}$ número/horas *versus* la hora del día.

POTENTIAL IMPACTS OF BOTTOM TRAWLING ON BENTHIC COMMUNITIES IN PRYDZ BAY, ANTARCTICA

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Abstract

This paper presents data on benthos retrieved in bottom trawls during a survey of demersal finfish species in Prydz Bay by Australia in the 1990/91 season. The data collected are used to examine a potential impact of bottom trawling on benthic communities in this region. The benthos was examined in trawls at 14 of the 22 random stations providing representative samples from different areas in the Prydz Bay. All benthos in the codend was sorted into major taxa and wet-weighed. The composition of the benthos retained was primarily sponges and ascidians. Holothurians and crinoids were the next most abundant taxa in terms of biomass. The wet-weighed ratio of benthos to finfish in the codend was greater than 1 at 12 out of the 14 stations and was mostly greater than 10. The results of this study demonstrate that the biomass of benthos that could be disturbed by commercial bottom trawling could be high in Prydz Bay. Also, the results indicate that there is a need to examine the nature of benthic communities in areas in which commercial bottom trawling may occur so that measures can be taken to ensure the integrity of these communities are maintained.

Résumé

Ce document présente des données sur le benthos prélevé des chaluts de fond lors d'une campagne d'évaluation des espèces de poissons démersaux dans la baie Prydz effectuée par l'Australie pendant la saison 1990/91. Les données collectées servent à l'examen des effets potentiels des chalutages de fond sur les communautés benthiques de la région. Le benthos examiné dans les chalutages de 14 des 22 stations aléatoires fournit des échantillons représentatifs des différentes zones de la baie Prydz. Tout le benthos du cul de chalut a été trié en taxons dominants et pesé humide. Le benthos prélevé était composé principalement d'éponges et d'ascidiens. Les holothuriens et les crinoïdes formaient ensuite les taxons les plus abondants en matière de biomasse. En poids humide, le rapport benthos/poisson dans le cul de chalut était supérieur à 1 dans 12 des 14 stations et, dans la plupart des cas, supérieur à 10. Les résultats de cette étude révèlent l'importance quantitative potentielle de la biomasse du benthos qui pourrait être dérangé par les chalutages de fond commerciaux dans la baie Prydz. De plus, les résultats mettent en évidence la nécessité d'examiner la nature des communautés benthiques dans les zones potentielles de chalutage de fond commercial afin que soient prises des mesures qui préservent l'intégrité de ces communautés.

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Резюме

В настоящей работе представлены данные по бентосу, удержанному при донном тралении во время австралийской съемки демерсальных плавниковых рыб в заливе Прюдз в 1990/91 г. Собранные данные использовались в изучении потенциального воздействия донного траления на бентические сообщества в этом районе. Бентос был исследован в тралах на 14 из 22 произвольных станций, что обеспечило образцы с разных участков залива Прюдз. Все бентические виды в кутке были рассортированы на основные таксономические категории и взвешенные. В составе удержанных бентических видов в основном находились губки и оболочники. Голотурии и морские лилии были следующими из самых многочисленных таксономических категорий в отношении биомассы. Соотношение взвешенного бентоса к плавниковым рыбам в кутке было больше 1 на 12 из 14 станций, и в основном было больше 10. Результаты этого исследования показывают, что биомасса бентоса, который может быть выведен из состояния покоя коммерческими донными тралениями, может быть высокой в заливе Прюдз. Результаты также указывают на то, что необходимо исследовать природу бентических сообществ в районах, в которых может осуществляться коммерческое донное траление, в целях принятия мер по обеспечению сохранения целостности этих сообществ.

Resumen

Este trabajo presenta la información sobre el bentos recogida durante una prospección de peces demersales realizada por Australia en la temporada 1990/91 en la bahía de Prydz, en la que se utilizaron arrastres de fondo. Los datos recogidos servirán para estudiar los posibles efectos de los arrastres de fondo en las especies bénticas de la zona. Se estudió el bentos en los arrastres realizados en 14 de las 22 estaciones aleatorias, los cuales proporcionaron muestras representativas de diferentes zonas de la bahía de Prydz. El bentos retenido en el copo se clasificó en los grupos taxonómicos principales y se determinó su peso húmedo, que en su mayoría estaba compuesto por esponjas y ascidios. En cuanto a la biomasa, los grupos taxonómicos más abundantes lo constituyeron los holotúridos y los crinoideos. La razón en peso humedo entre bentos y peces en el copo fue superior a 1 en 12 de las 14 estaciones realizadas, siendo en su mayoría superior a 10. Los resultados de este estudio demuestran que una parte importante de la biomasa del bentos podría sufrir daños a resultas de la pesca comercial de arrastre de fondo de la bahía de Prydz. Asimismo, los resultados indican que es necesario estudiar la naturaleza de las comunidades bénticas en las zonas de pesca comercial con arrastres de fondo, para poder tomar medidas que salvaguarden su integridad.

1. INTRODUCTION

In the last 10 years, a number of studies have highlighted the impacts of bottom trawling on benthic communities in heavily fished areas (e.g., De Groot, 1984; Hutchings 1990). On the basis of published data on benthos in the Antarctic, Kock (1990) examined the differences in the characteristics of benthos between commercially fished and unfished areas in the South Atlantic and suggested that bottom trawling in the past 20 years has had a considerable effect on the community structure in the fished areas. He proposed that bottom trawling in this region may have had similar effects on benthic communities as those found in the North Sea and elsewhere.

This paper presents data on benthos retrieved in bottom trawls during a survey of demersal finfish species in Prydz Bay by Australia in the 1990/91 season. The results are used to examine the potential impacts of bottom trawling on benthic communities in this region.

2. METHODS

The survey of demersal finfish in Prydz Bay was conducted at 22 random stations in the bay using a bottom trawl. The headline length was 35 m. Mesh size was 15 cm in the front panels and 5 cm in the codend liner. Ground rope was equipped with a 40 cm diameter bobbin gear. The mouth opening was, on average, 12 to 13 m wide with a headline height of 4 to 5 m. Nets were towed for a standard haul duration on the bottom of 30 minutes at 3 knots. The sweeps (25 mm diameter combination rope) were 25 m long. The length of the bottom bridle was 10 m. Disturbance of the benthos was caused by the bobbin gear, bridle and sweeps. Disturbance also resulted from the dragging of the steel 'V' doors (2 x 1. 3 m) along the bottom.

The benthos was examined in the trawls at 14 of the 22 stations (see Table 1, Figure 1) providing representative samples from the different regions in Prydz Bay. All benthos in the codend was sorted into major taxa and wet-weighed. Benthos entangled in the wings of the net was not retrieved.

3. RESULTS

The wet biomass of the major taxa at each station are illustrated in Figure 1.

Catches of fish only exceeded 50 kg at two stations near the shelf break (stations G and H). The remaining catches of fish were mostly less than 20 kg. Catches in the centre of the bay (stations L, M and N) were very low with little benthos in the net.

Of the benthos, sponges were usually the most abundant taxon in the codend. At four stations, the biomass of sponges exceeded 100 kg with the maximum being 202 kg at station B. Occasionally, ascidians formed a considerable portion of the biomass (stations A, B and H). Echinoderms were the most prominent taxon of the remaining benthos, of which holothurians were the most abundant (Table 2).

The wet-weight ratio of benthos to finfish in the codend was greater than 1 at 12 out of the 14 stations and mostly was greater than 10 (Table 3).

4. DISCUSSION

Nets used in bottom trawls for finfish are designed to minimise the catch of benthos. Nonetheless, bottom trawling in Prydz Bay in February 1991 showed that on most occasions the biomass of benthos in the codend after a 30 minute trawl was greater than the biomass of

finfish caught and often greater than 10 times the biomass of fish. The composition of the benthos retained in the codend was primarily sponges and ascidians. Holuthurians and crinoids were the next most abundant taxa in terms of biomass.

The magnitude of the disturbance and displacement of species through bottom trawling is underestimated in these analyses as a considerable biomass of crinoids and other species were entangled in the wings of the net. Also, the total number and biomass of species that will have been disturbed by the action of the doors and the other bottom gear but not caught in the net could not be detected with this method. Thus, the ratios presented in Table 3 are likely to be underestimates of the mass of benthos disturbed per unit mass of finfish caught.

Kock (1990) has highlighted the need to examine the potential impacts of bottom trawling on benthic communities in the Antarctic. The results of this study demonstrate that the biomass of benthos that could be disturbed by commercial bottom trawling could be high in Prydz Bay. Also, the results indicate that there is a need to examine the nature of benthic communities in areas in which commercial bottom trawling may occur so that measures can be taken to ensure the integrity of these communities are maintained. Given the low resilience, low reproductive rates and the comparatively sessile nature of many Antarctic benthic species (Clarke, 1979 and 1983), a suitable approach to the conservation of these communities would be to have areas within trawling grounds set aside to aid the re-establishment of disturbed species in trawled areas.

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Table 1: Co-ordinates of stations for bottom trawls in Prydz Bay, February 1991. Symbols for stations are the same as those used in Figure 1.

Station	Latitude (S)	Longitude (E)
A	67° 26.54'	70° 20.24'
B	67° 27.35'	68° 50.34'
C	67° 16.35'	68° 57.68'
D	67° 16.66'	70° 05.05'
E	67° 02.37'	70° 18.83'
F	66° 53.36'	70° 40.54'
G	66° 59.98'	74° 18.71'
H	66° 59.68'	75° 06.11'
I	66° 59.47'	76° 26.65'
J	67° 20.64'	77° 14.33'
K	67° 34.17'	77° 32.92'
L	68° 03.77'	73° 09.33'
M	68° 27.91'	75° 26.60'
N	68° 31.73'	73° 13.00'

Table 2: Mean biomass of echinoderms retrieved in bottom trawls in Prydz Bay in February 1991 (n = 14).

Echinoderm Class	Mean (g)	Standard Deviation
Echinoidea	311	736
Asteroidea	1 809	2 511
Crinoidea	1 506	4 615
Ophiuroidea	74	95
Holothuroidea	4 041	6 482

Table 3: Frequency of trawls within each group of ratios of benthos to finfish (by mass) retrieved in bottom trawls in Prydz Bay in February 1991 (n = 14).

Ratio of Benthos/Finfish	Number of Trawls
0 - 1.0	2
1.1 - 10.0	4
10.1 - 50.0	5
> 50.0	3

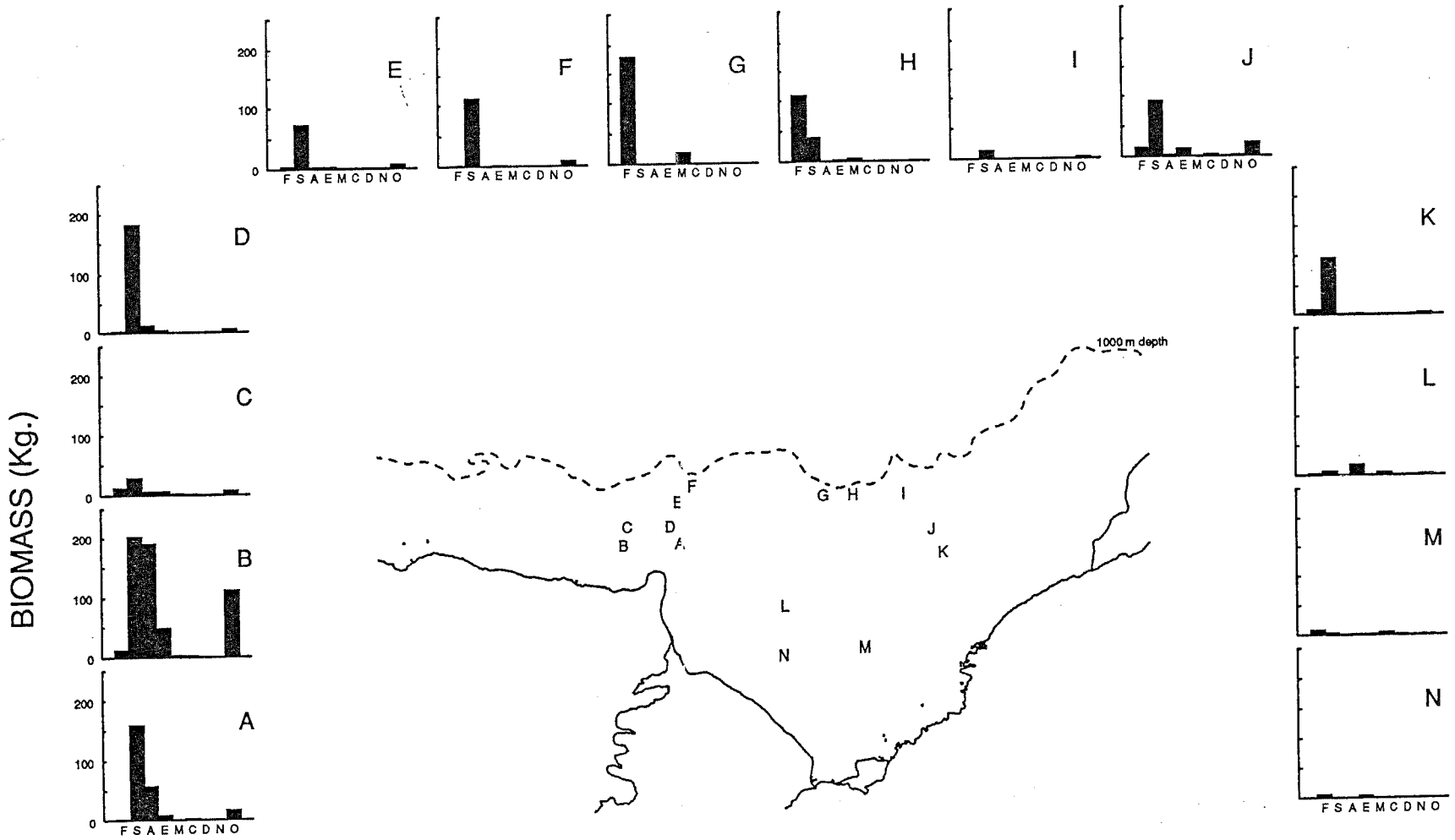

Figure 1: Biomass of major fauna taxa retrieved in bottom trawls in Prydz Bay, February 1991. Each graph shows the catch from stations marked with corresponding letters. Station coordinates are in Table 1. Legend for bars on each graph: F = fish; S = sponges; A = ascidians; E = echinoderms; M = molluscs; C = coelenterates; D = decapods; N = nereids; O = other.

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