SC-CAMLR-SSP/7

SCIENTIFIC COMMITTEE FOR THE CONSERVATION OF ANTARCTIC MARINE LIVING RESOURCES

1990

SELECTED SCIENTIFIC PAPERS

COMMUNICATIONS SCIENTIFIQUES SELECTIONNEES

ИЗБРАННЫЕ НАУЧНЫЕ РАБОТЫ

DOCUMENTOS CIENTIFICOS SELECCIONADOS

CCAMLR
25 Old Wharf
Hobart
Tasmania 7000
AUSTRALIA

Telephone : 61 (02) 31 0366
Facsimile : 61 (02) 23 2714
Telex : AA 57236

September 1991

Copies of this document are available on request to the CCAMLR Secretariat at the above address.

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 1990. The text of the papers is reproduced in the original language of submission; 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 1990. Le texte de ces communications est reproduit dans leur langue d'origine; 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 1990 г. Работы представлены на языке оригинала; их резюме, заголовки таблиц и подписи к рисункам переведены на официальные языки Комиссии (английский, французский, русский и испанский).

Resumen

Este volumen contiene una selección de los documentos científicos presentados en las reuniones del Comité Científico y de los Grupos de Trabajo del Comité Científico en 1990. El texto de estos documentos está reproducido en el idioma original; los resúmenes de éstos y los títulos de los cuadros y figuras están traducidos a los idiomas oficiales de la Comisión (español, francés, inglés y ruso).

TABLE OF CONTENTS

II. ANTARCTIC FISH

III. CEPHALOPODS

IV. ECOSYSTEM MONITORING

TABLE DES MATIERES

II. POISSONS ANTARCTIQUES

СОДЕРЖАНИЕ

III. ГОЛОВОНОГИЕ

IV. МОНИТОРИНГ ЭКОСИСТЕМЫ

INDICE

II. PECES ANTARTICOS

I. ANTARCTIC KRILL

SIZE COMPOSITIONS OF MALES AND FEMALES IN THE COURSE OF THE LIFE CYCLE OF *EUPHAUSIA SUPERBA*

R.R. Makarov*

Abstract

Earlier studies did not pay attention to differences in size composition of *Euphausia superba* populations by sex and its seasonal variability. In this paper variations in size and sex composition of samples from commercial catches are analyzed over the reproductive season, using samples from different years. The observed variations were related to stages of krill maturity during the reproductive cycle. Information on size composition by sex is considered to be vital for an understanding of krill population structure. It is suggested that duties of biologist-observers aboard commercial vessels should include not only measurement but also sex determination of adult krill.

Résumé

Les études antérieures n'ont nullement fait cas des différences de la distribution de fréquences de tailles des populations d'*Euphausia superba* par sexe ou de sa variabilité saisonnière. Dans ce document, les variations de composition par taille et par sexe des échantillons des captures commerciales sont analysées au cours de la saison de reproduction, à l'aide d'échantillons provenant d'années différentes. Les variations observées portaient sur les stades de maturité du krill pendant son cycle reproducteur. Les informations sur la composition en tailles par sexe sont estimées essentielles à la compréhension de la structure démographique du krill. Il est suggéré que les biologistes-observateurs embarqués sur les navires commerciaux aient pour tâche, non seulement de mesurer le krill adulte, mais également d'en déterminer le sexe.

Резюме

Предыдущие исследования не принимали во внимание различия в размерном составе половых групп популяций *Euphausia superba* и его сезонной изменчивости. В данном труде на примере проб, собранных за разные годы, приводится анализ изменений размерного и полового состава проб на протяжении сезона воспроизводства. Отмеченные изменения были связаны со стадиями половозрелости криля в течение цикла воспроизводства. Информация о размерном составе по половым группам считается необходимой для понимания структуры популяции криля. Наблюдателям-биологам на борту коммерческих промысловых судов предлагается выполнять не только измерение половозрелых особей криля, но и определение их половой принадлежности.

* VNIRO, 17a Verkhnaya Krasnoselskaya Street, Moscow, USSR 107140

Resumen

En estudios anteriores no se ha prestado atención a las diferencias debidas a la variabilidad estacional o al sexo en la composición por tallas de las poblaciones de *Euphausia superba*.. A partir de los muestreos realizados durante varios años en las capturas comerciales, se estudian las variaciones de las composiciones por talla y sexo durante el ciclo reproductor completo. Las variaciones observadas están relacionadas con la fases de madurez del krill en su ciclo reproductor. La información sobre la composición por sexos se considera vital para entender la estructura de las poblaciones de krill. Se sugiere que los observadores-biólogos de los buques comerciales, no sólo se encarguen de medir el krill adulto sino también de determinar su sexo.

---

1. INTRODUCTION

Size composition of *Euphausia superba* (as in all other crustaceans) is the only criterion for examining population age structure in the field. Usually, when analyzing size composition, researchers use modal size for comparison. In general, such analyses are carried out for whole samples without subdividing them into males and females. However, it has been observed that modal size of males and females sometimes differs considerably.

Specialized studies of trends in size composition of males and females in the course of the life history of *E. superba* have not yet been carried out. Earlier isolated observations revealed considerable variations in relative size of males and females at different reproductive stages (Makarov, 1983). Recently collected data have made it possible for us to evaluate these variations in detail. In addition to data on adult krill, available data on juvenile krill were used in analyses of size variations.

2. MATERIALS AND METHODS

Samples of *E. superba* taken from commercial catches in different seasons and areas were analyzed for size of males and females at different stages of the active reproduction period - from the beginning of maturation of *E. superba* in spring to the end of spawning and the stage of development in females of "juvenilized" gonads for the next spawning season. Stages of the reproductive cycle are given with reference to developmental stages of females. Specimens were measured to the nearest 1 mm from the tip of rostrum to the end of telson.

An abbreviated scale of maturity stages for females was compiled for the purposes of this study. The following four stages were distinguished (stages of the BIOMASS scale are included in brackets for reference):

A non-mature or at the beginning of maturation (IIB, IIIa-IIIC);

B ready for spawning with developed oocytes (IIID);

C recently spawned (ovaries with residual oocytes), juvenilization of ovaries has not yet started (IIIE);

D post-spawning with juvenilized small ovaries (usually with residual round oocytes surrounded by smaller uniform-sized cells) (IIIC).

The succession of events in the *E. superba* population was considered by observing stages of maturity in males and females as indicators of reproductive cycle stages. Time of sampling was not regarded as of immediate importance for this study. It was considered more important to get results which were not affected by an inter-annual variability caused by differences in dates on which the reproductive cycle stages occurred. For this reason an analysis of the stages of maturity of females has been carried out for all samples combined.

The bulk of the data used are data on adult specimens. However, some data on *E. superba* larvae and juveniles are also used. Specimens were sexed by observing their internal sexual features (petasmas in males were also taken into account). The same procedure was used in sexing larvae. A comprehensive examination of the anatomy of specimens usually made it possible for the sex of larvae at stages Furcilia V and VI to be determined. Larvae were measured up to the nearest 0.1 mm. Ovaries were clearly visible, but observation of sperm glands presented a difficult and time-consuming task. For this reason, if ovaries were not found, the specimen was counted as male. Comprehensive examinations were undertaken periodically after each 8 to 10 specimens analyzed in order to verify sex determination.

3. SIZE COMPOSITION OF MALES AND FEMALES

Larvae. Size composition and sex of larvae in stages Furcilia V to VI are shown in Figure 1. Samples were taken from a "patch" concentration of krill in the Scotia Sea in March 1969. As can be seen, the size of males and females differs considerably. The maximum size of males is generally greater than of females. Males are more abundant at stage VI, females are more abundant at stage V. It is clear that males are larger and in a more advanced stage of development than females.

Juveniles. In general, the size composition of juveniles (i.e., non-mature females with small even-sized oocytes and males with underdeveloped sperm ducts and external sexual features) follows the pattern found in larvae, though not in such an obvious manner (Figure 2). Differences are often observed in frequency distribution and in some cases in modal size. These differences are not always related to absolute size of males and females in any given sample.

Adults. As a rule, only samples with a small range of specimen sizes were selected for the analysis. A small size range was typical for samples taken from the South Orkney Is area. Samples from other areas contained some juveniles and were usually rejected.

In spring, at the beginning of reproduction season, when maturing of gonads takes place (stage of maturity A), the size composition of adult males and females is the same as in juveniles (Figure 3).

The modal size of fully matured females (stage of maturity B) was greater than that of males (Figure 4). Samples collected in 1967 present an exception from this rule. It is noteworthy that other samples taken in 1967 in other areas (South Orkney Is) demonstrate a similar tendency.

If samples consist of specimens at different stages of maturity (A, B, C), females are found to prevail to some extent among larger specimens (excluding 1967 data) (Figure 5).

Towards the end of spawning season (females at stage C are dominant) size composition becomes most diverse (Figure 6).

Soon after spawning (females at stages C and D; later stage D only) the observed size composition returns to that observed prior to spawning (Figure 7). As earlier, males have a greater modal size than females, especially when most of the females are at stage D.

4. DISCUSSIONS

As can be seen, in the usual and initial size ratio between males and females of *E. superba*, the number of larger males is greater (this applies to larvae and juveniles as well as adults). This was observed earlier by H. Bargmann (1945). Variability in the relative size of males and females is observed in mature specimens, especially during peak reproductive season, during spawning. During this period some females might be larger than males.

What is the reason for such variability? The problem is rather complicated and require special attention. Of course, we can suggest only some preliminary considerations.

Firstly, it could be suggested that a spatial segregation of males and females leads to such variability.

The different rhythms of diurnal vertical migration of krill of different sizes and sexes can be also considered as a possible cause. It is important to remember that all catches are taken in the upper 100 m layer. Indeed, one reported catch using a Juday net (36 cm diameter) from 200 to 500 m and deeper consisted exclusively of males (over 200 males) (Makarov, 1981). However, at the same time, the sex ratio in catches from nearby areas was 1:1. For this reason this catch can be considered as a local phenomenon (Elephant Is area).

Another explanation relates to the preponderance of males or females in commercial catch samples taken over a vast area. A paper on this phenomenon is being prepared for publication. The reason for this may be related to seasonal changes in vertical distribution of males and females. However, the phenomenon is not frequently observed.

The observed regular and temporal variations in the size composition ratio of males to females can not, however, be reasonably explained by the above suggestions. Because variations in size composition ratio correlate well with stages in the reproductive cycle, it will be also necessary to discuss the question of the post-spawning mortality rate in *E. superba.*

Maturation occurs in males earlier than in females and mating takes place long before spawning (Bargmann, 1945; Makarov, 1983). For this reason, post-spawning mortality of males should also take place earlier. Moreover, larger males and females do mature faster. It may also be possible that an increase in male mortality begins shortly before the spawning season (Figure 4).

If these suggestions are correct, females should have a higher modal size, particularly during early stages of the spawning season in *E. superba* populations.

It is likely that an increase in post-spawning mortality in females begins at later stages of the spawning season. During that time, due to the earlier onset of mortality in larger females, the size compositions of males and females become more similar (Figures 5 and 6). In addition, soon after the spawning season and with the passage of time, new smaller adult females (with juvenilized ovaries) are recruited to the population and the size composition ratio of males to females reverts to its usual, initial value (Figure 7).

The above explanations are not the only ones possible and some other population characteristics need to be analysed in order to clarify the problem further. For example, a similar analysis of males can be carried out. The sex ratio is of particular importance. Indeed, the observed sex ratio in samples was highly variable. Future studies should seek to find causes of this variability in connection with the size composition ratio between males and females.

Additional information over all seasons of any particular year is required for these purposes. Such information may be gathered aboard a commercial fishing vessel, because numerous repetitive observations are most important in this case. Commercial vessels more or less maintain their position on fishing grounds and with a transfer of observers from vessel to vessel there is a good chance of covering the whole spawning season of *E. superba.*

Sex determination of krill is not a difficult task because these observations deal only with adult krill. Repetitive observations can be also made very easily.

The type of information described above is valuable for assessing size composition of *E. superba.* Variations in size frequency distribution and, in particular, new additional size peaks may be the result not only of a real shift in occurrence of some size (age) groups, but also of the sequence of reproductive cycle stages. The latter relates to considerable variations in the size ratio of specimens from the same size (age) groups of the population. As was observed, spawning aggregations of krill, even within a limited area, may differ considerably in compositions of females in terms of stages of maturity.

Therefore, the duties of biologists-observers aboard commercial vessels (as suggested at CCAMLR-VII) should include not only daily measurements of krill size but also sex determination of adult krill. The latter is important not only for the acquisition of the information discussed here, but will enhance our knowledge of the biological processes involved. Continuing monitoring of krill size and sex composition in trawl catches (the so-called differentiated approach to measurement) will help researchers to develop an optimal sampling strategy for the subsequent thorough analysis of samples ashore.

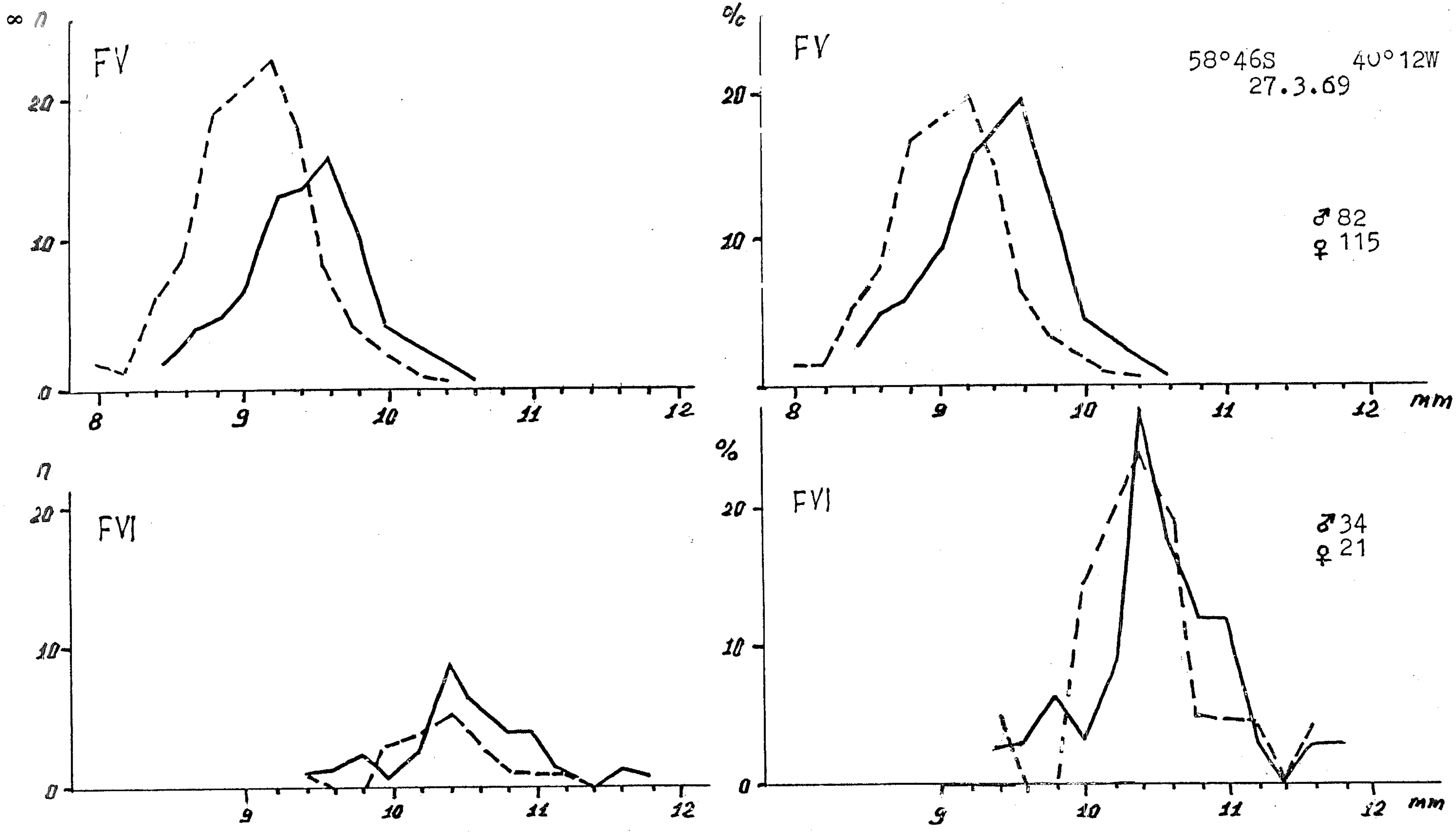


Figure 1: Size composition of *E. superba* males and females, larvae stages Furcilia V and VI. (Males - dotted lines, females - unbroken line).

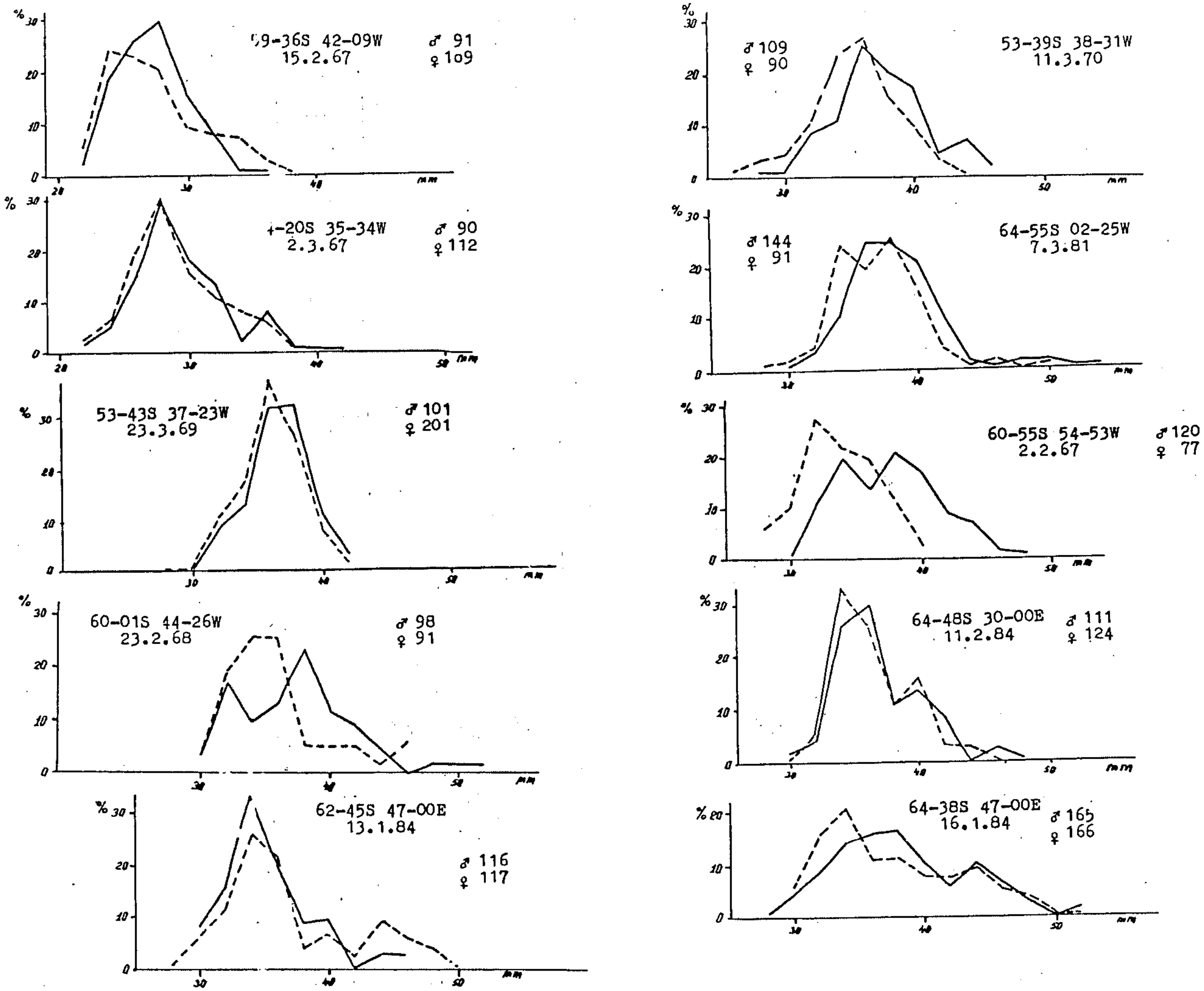


Figure 2: Size composition of juvenile *E. superba*, males and females. (For legend, see Figure 1).

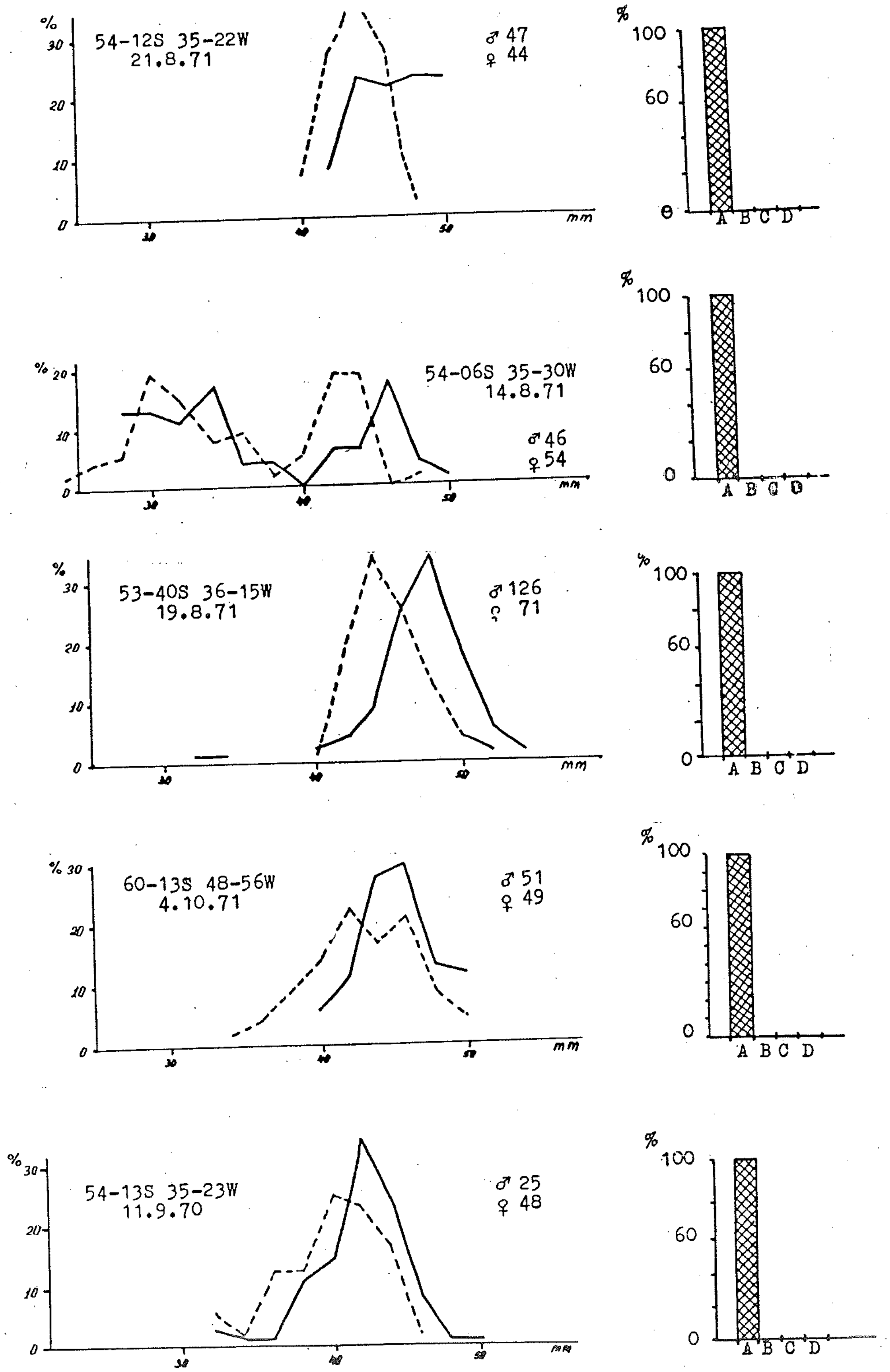


Figure 3: Size composition of *E. superba* males and females in pre-spawning season. (For legend, see Figure 1).

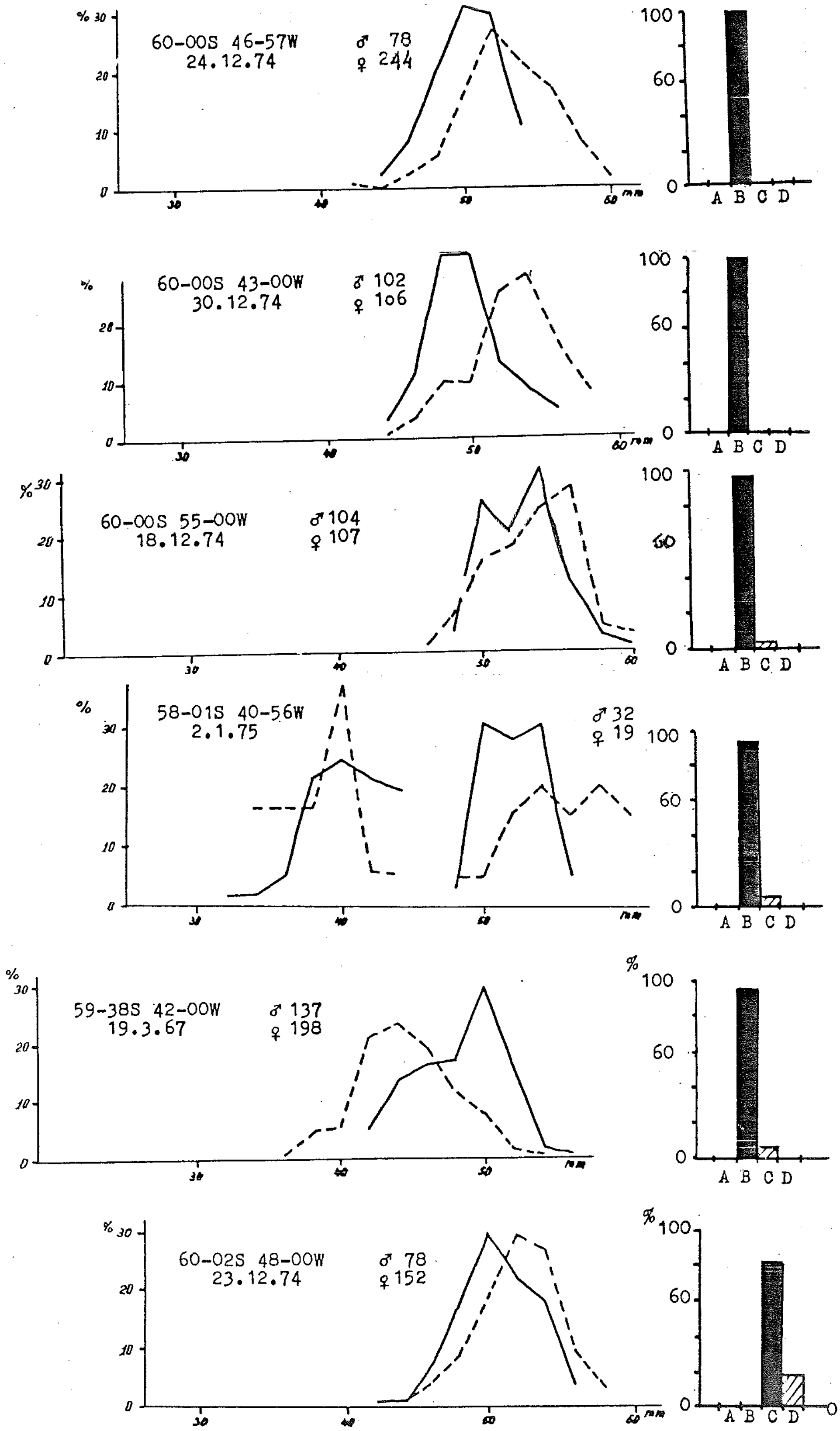


Figure 4: Size composition of *E. superba* males and females at stages of full maturity. (For legend, see Figure 1).

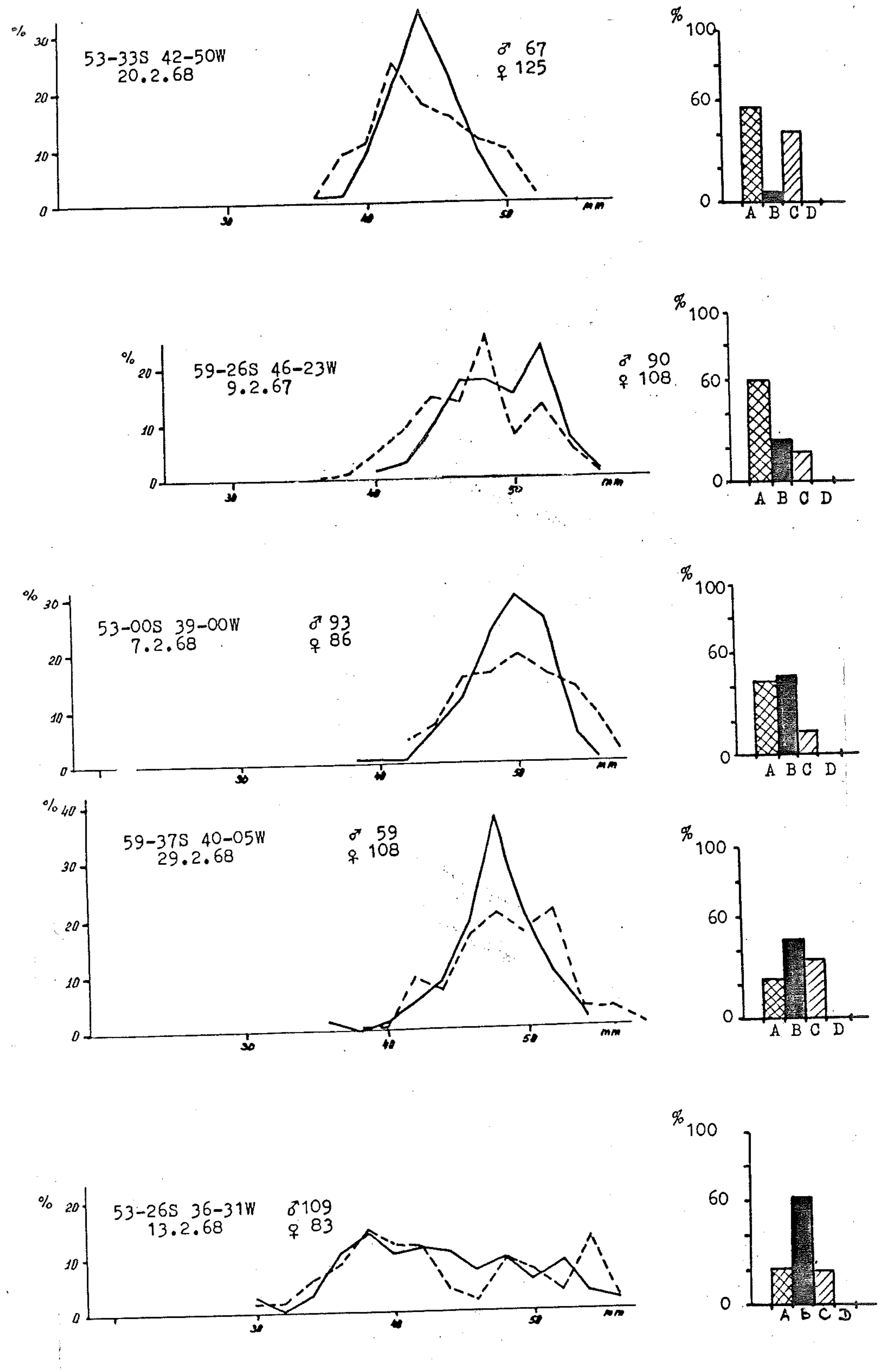


Figure 5: Size composition of *E. superba* males and females in spawning season. (For legend, see Figure 1).

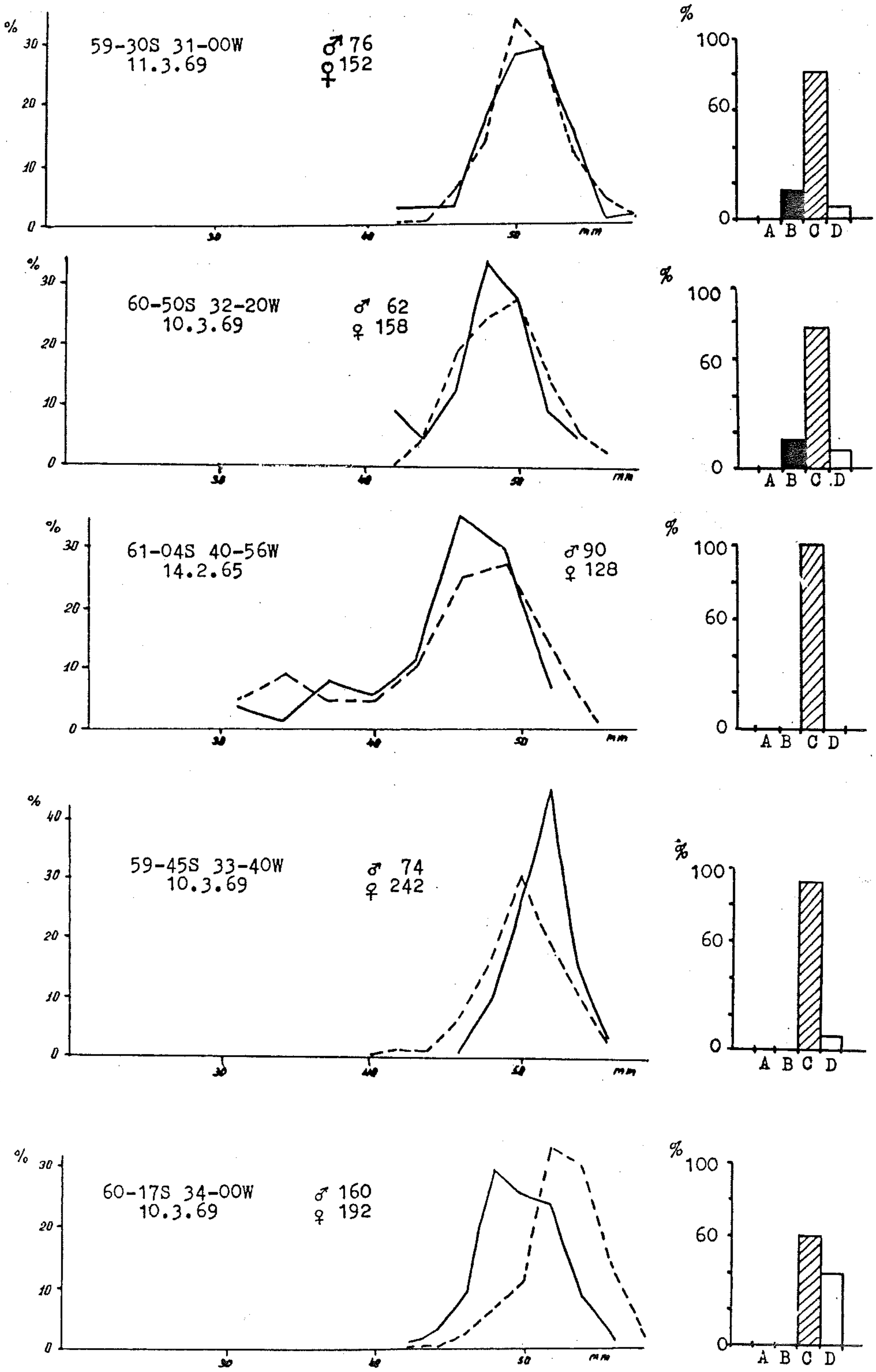


Figure 6: Size composition of *E. superba* males and females towards the end of spawning season. (For legend, see Figure 1).

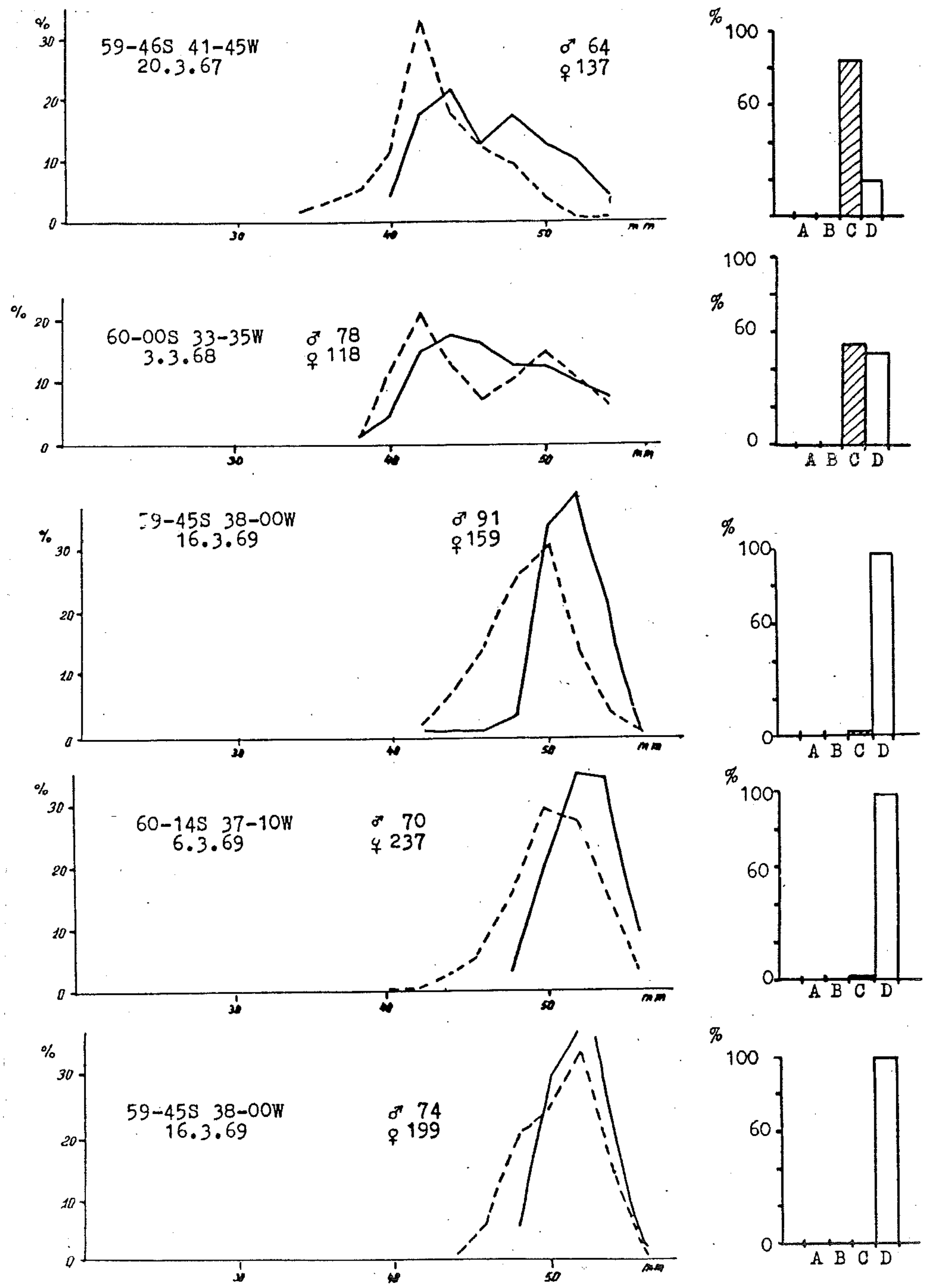


Figure 7: Size composition of *E. superba* males and females in post-spawning season. (For legend, see Figure 1).

Figura 2: Composición por tallas de macho *E. superba* juvenil. (Véase la leyenda de la Figura 1).

Figura 3: Composición por tallas de machos y hembras de *E. superba*, antes del desove. (Véase la leyenda de la Figura 1).

Figura 4: Composición de tallas de machos y hembras de *E. superba*, en la fase de plena madurez reproductora. (Véase la leyenda de la Figura 1).

Figura 5: Composición por tallas de machos y hembras de *E. superba*, en la época de desove. (Véase la leyenda de la Figura 1).

Figura 6: Composición por tallas de machos y hembras de *E. superba*, al final de la época de desove. (Véase la leyenda de la Figura 1).

Figura 7: Composición por tallas de machos y hembras de *E. superba*, en la época posterior al desove. (Véase la leyenda de la Figura 1).

HOMOGENEITY OF BODY LENGTH COMPOSITION OF ANTARCTIC KRILL WITHIN THE COMMERCIAL ZONE

T. Ichii*

Abstract

The homogeneity of krill (*Euphausia superba*) length composition in commercial trawl catches (hauls) was investigated by comparing length compositions from different parts of the same haul. There was no significant difference (***P*>0.05**) in 53 out of 60 hauls. Therefore it is concluded that sampling from one part of the haul provides a reasonable estimate of length composition in the entire haul. In contrast to small variations in length composition within the same haul, variation between different hauls was most noticeable in areas where krill length frequency compositions were bimodal.

Résumé

L'homogénéité de la distribution des fréquences de longueurs du krill (*Euphausia superba*) dans les captures commerciales des chaluts (traits) a été examinée en comparant les compositions en longueurs provenant de différentes parties d'un même chalut. Aucune différence significative (***P*>0.05**) n'a été notée dans 53 des 60 chalutages. Cela a permis de conclure que l'échantillonnage provenant d'une partie du trait offre une estimation raisonnable de la composition en longueurs de tout le trait. Contrairement aux variations minimes dans la distribution en fréquences de longueurs dans un même trait, la variation entre plusieurs traits était la plus claire dans les régions où les distributions de fréquences de longueurs du krill sont bimodales.

Резюме

Степень однородности размерного состава коммерческих уловов (за одно траление) антарктического криля (*Euphausia superba*) была изучена путем сравнения размерного состава проб, взятых из различных частей одного улова. В 53 из 60 уловов различие было незначительным (***P*>0,05**). Следовательно, по пробе, взятой из одной части улова, можно получить приемлемую оценку размерного состава всего улова. По сравнению с незначительной изменчивостью размерного состава различных частей одного улова, различия между различными уловами были наиболее существенны в районах распространения криля, характеризующегося бимодальным размерным составом.

* Far Seas Fisheries Laboratory, 7-1, 5-chome, Orido, Shimizu 424, Japan

Resumen

Se investigó la homogeneidad de la composición de tallas del krill de las capturas realizadas con arrastres comerciales (lances), comparándola en distintas partes del mismo lance. No se encontraron diferencias significativas (*P*>0.05) en 53 de los 60 lances estudiados. Se llega a la conclusión pues, de que el muestreo de una parte del lance ofrece una estimación razonable de la composición por tallas de su totalidad. Por contraste a las pequeñas variaciones encontradas en la composición de tallas de un mismo lance, las variaciones entre distintos lances fue más patente en aquellas zonas donde la composición por tallas del krill era bimodal.

1. INTRODUCTION

In order to accurately estimate length compositions in commercial trawl catches (hauls), it is necessary to take a random sample from the haul. By analyzing length compositions of samples from trawl catches during a survey for blue grenadier (*Macruronus novaezelandiae*), Uozumi and Kawahara (1988) have shown that finfish are not randomly mixed within each haul. They, therefore, recommended the collection of sub-samples from as many different parts of the haul as possible in order to obtain an unbiased estimate of the catch length composition.

In the case of Japanese krill trawlers, krill (*Euphausia superba*) is usually collected only from one part of the haul, on the assumption that the length composition is homogeneous throughout the haul. In order to investigate this assumption, krill length compositions of samples taken from different parts of the same haul were compared.

Variations in length compositions between different hauls are also examined in order to compare within-haul variations.

2. MATERIALS AND METHODS

A total of 60 commercial trawl catches, each containing 7 to 8 tonnes of krill on average, were examined on board FV *Zuiyo Maru No. 2* (3 023 tonnes, Hakodate Kokai Gyogyo Co.) off George V Land in the 1985/86 season. In 58 of these hauls, two krill length composition samples were taken from each haul, one sample being taken from location A and the other from location B in the vessel fish pond (Figure 1). In two hauls, three samples were collected from locations A, B and C, respectively (Figure 1). Each sample contained about 150 krill specimens. Krill body length was measured to the nearest mm from the tip of rostrum to the posterior end of the telson. All length measurements were carried out by one observer to avoid methodological differences in the measurement as described by Watkins *et al.* (1985).

Within-haul length compositions were compared by testing the null hypothesis (H_0) that there was no significant difference in krill length composition within the same haul. This hypothesis was tested using a Chi-square (χ^2) test for a multinomial distribution. The value of the statistic χ^2 was calculated using the following formula;

$$\chi^2 = \Sigma_i \Sigma_j (n_{ij} - n_{i.}n_{.j}/n_{..})^2/(n_{i.}n_{.j}/n_{..})$$

where n_{ij} = the number of krill in the i^{th} (i=1, 2, ..., m) sample in the j^{th} (j=1, 2, ..., k) length class,

$n_{i.}$ = the total number of krill in the i^{th} sample;

$n_{.j}$ = the total number of krill in the j^{th} class,

$n_{..}$ = the total number of krill.

If the calculated value of χ^2 exceeded the critical value of χ^2 with **(m-1) (k-1)** degrees of freedom, H_0 was rejected. This test is not really suitable for n_{ij} smaller than 5. Therefore length classes with $n_{ij}<5$ were lumped with adjacent classes to increases n_{ij} to 5 or larger.

3. RESULTS AND DISCUSSION

Results for each haul are presented in Table 1. The null hypothesis of homogeneity of krill length composition was rejected in only seven out of 60 hauls ($P<0.05$). Of these seven hauls, one had a monomodal length composition, while the remaining six had bimodal length compositions. In the total 23 hauls had monomodal length composition, while 37 had bimodal length compositions. Therefore the rejected hauls were biased heavily towards those showing bimodality. Differences in length compositions for hauls in which H_0 was rejected are shown in Figure 2. Apart from haul number 31, the differences are not too obvious. Thus, it is concluded that krill length compositions are fairly homogeneous within the same haul and that a sample from one part of the haul may be considered as representative of the entire haul.

In contrast to the observed small variations in length compositions within the haul, variations between sequential hauls were most apparent in areas where length compositions were bimodal. As shown in Figure 3, in areas where the overall length composition was monomodal, between-haul length compositions were consistent throughout the area and exhibited similar mean lengths. Whereas in areas where the overall length composition was bimodal, the proportion of large and small size classes often varied between sequential hauls with the length modes being fairly stable (Figure 4). This may indicate that the proportion of various size classes differed from swarm to swarm. Therefore in areas where length compositions have more than two modes, it is recommended that samples should be taken as frequently as possible from different hauls in order to obtain a more representative sample of the whole population of krill in the area.

ACKNOWLEDGEMENTS

I am indebted to Mr K. Hiramatsu of the National Research Institute of Far Seas Fisheries for the helpful discussions and comments on the manuscript. I would also like to express my thanks to Mr D.G.M. Miller of the Sea Fisheries Research Institute in South Africa for correcting English and giving valuable comments. Messrs. S. Kawahara and Y. Uozumi of the former-mentioned Institute kindly provided valuable information.

REFERENCES

UOZUMI, Y and S. KAWAHARA. 1988. Are length composition samples being taken at random? Bulletin of West Japan Groundfish Section. *Fisheries Resource Investigations by Scientists of the Fisheries Agency, Japanese Government, 16*: 13-22. (In Japanese).

WATKINS, J.L., D.J. MORRIS and C. RICKETTS. 1985. Nocturnal changes in the mean length of a euphausiid population: vertical migration, net avoidance, or experimental error? *Mar. Biol., 86*: 123-127.

Table 1: Comparisons of within-haul krill length compositions.

Data Set Set	Type of Length Composition	Number of Samples	DF	χ^2	*P*
-1-	-2-	-3-	-4-	-5-	-6-
1	b	3	26	13.091	0.9831
2	m	3	12	26.091	0.0104*
3	m	2	12	16.767	0.1586
4	b	2	18	15.523	0.6258
5	b	2	16	21.605	0.1564
6	b	2	16	11.721	0.7630
7	b	2	14	7.747	0.9021
8	b	2	12	11.807	0.4613
9	b	2	14	9.738	0.7811
10	b	2	13	19.619	0.1051
11	m	2	12	11.273	0.5057
12	m	2	11	14.702	0.1976
13	b	2	14	24.603	0.0387*
14	m	2	11	11.809	0.3782
15	m	2	11	10.615	0.4761
16	m	2	9	10.069	0.3449
17	m	2	12	10.334	0.5867
18	m	2	13	6.582	0.9224
19	m	2	10	13.961	0.1748
20	b	2	11	13.399	0.2680
21	b	2	14	12.040	0.6031
22	b	2	12	11.484	0.4880
23	b	2	15	10.535	0.7848
24	b	2	14	6.216	0.9608
25	b	2	13	10.099	0.6858
26	b	2	15	13.732	0.5459
27	b	2	13	9.622	0.7245
28	m	2	11	11.409	0.4097
29	m	2	11	13.275	0.2757
30	m	2	12	11.741	0.4667
31	b	2	9	28.563	0.0008**
32	b	2	12	20.588	0.0567
33	m	2	11	6.650	0.8267
34	m	2	10	5.695	0.8402
35	b	2	12	16.321	0.1770
36	b	2	15	9.467	0.8519
37	b	2	10	7.054	0.7203
38	b	2	16	7.137	0.9705
39	b	2	14	10.283	0.7412
40	m	2	11	7.908	0.7215
41	b	2	17	11.517	0.8285
42	b	2	16	11.456	0.7805
43	b	2	17	11.226	0.8446
44	b	2	14	15.696	0.3323
45	b	2	18	15.060	0.6578
46	b	2	14	24.702	0.0376*
47	m	2	9	11.670	0.2326
48	b	2	20	23.546	0.2628
49	b	2	16	35.975	0.0029**

Table 1 (continued)

-1-	-2-	-3-	-4-	-5-	-6-
50	b	2	15	8.134	0.9183
51	b	2	14	53.427	0.0000**
52	b	2	18	8.444	0.9713
53	b	2	15	26.912	0.0295*
54	m	2	14	12.340	0.5790
55	b	2	15	9.995	0.8201
56	m	2	10	4.514	0.9212
57	m	2	10	5.837	0.8288
58	m	2	8	4.096	0.8484
59	m	2	9	3.813	0.9233
60	m	2	8	8.570	0.3799

b bimodal length composition
m monomodal length composition
DF degrees of freedom
* $P<0.05$
** $P<0.01$

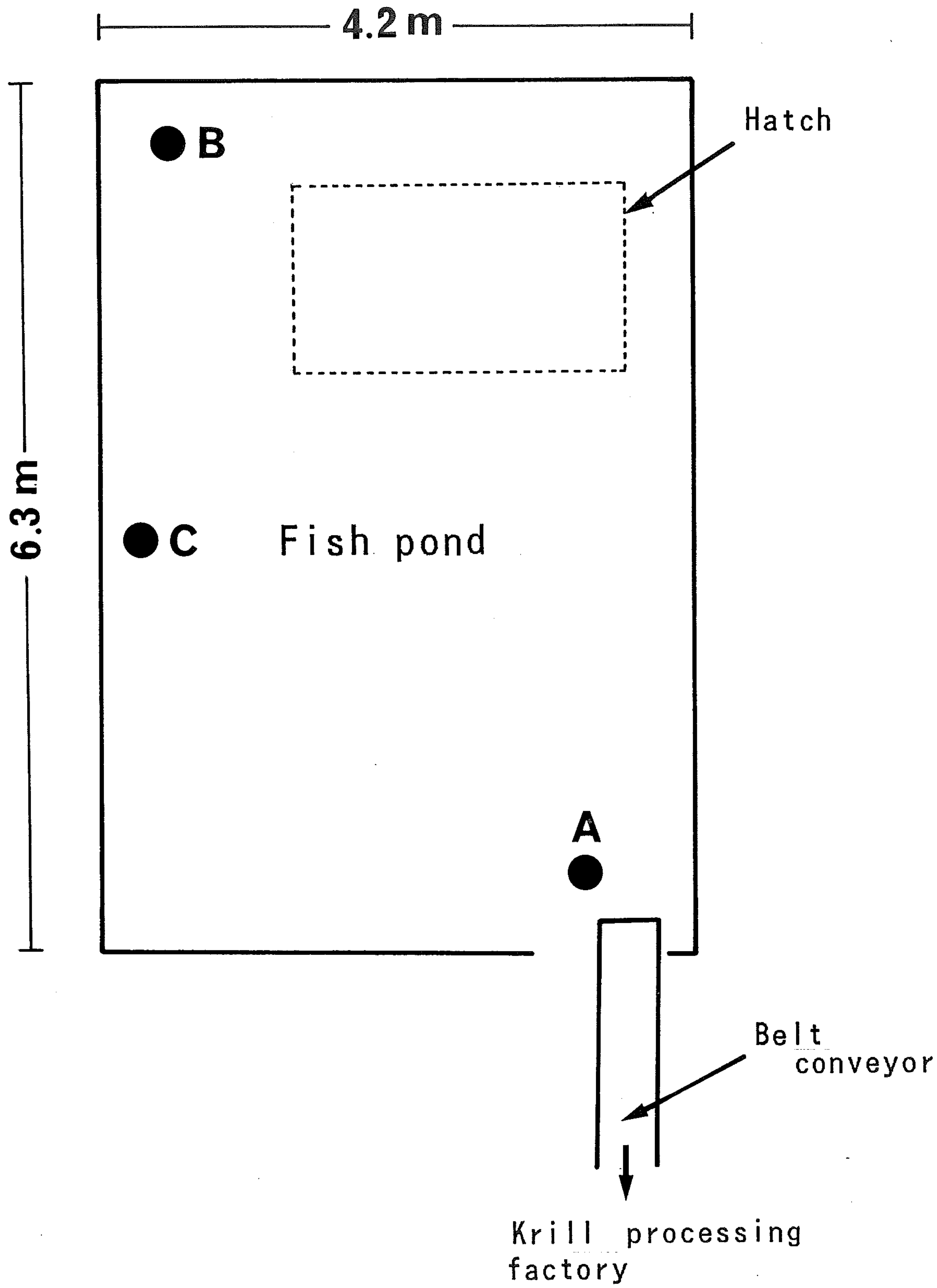


Figure 1: Sampling locations for krill length composition samples in the vessel fish pond. Locations are shown in closed circles.

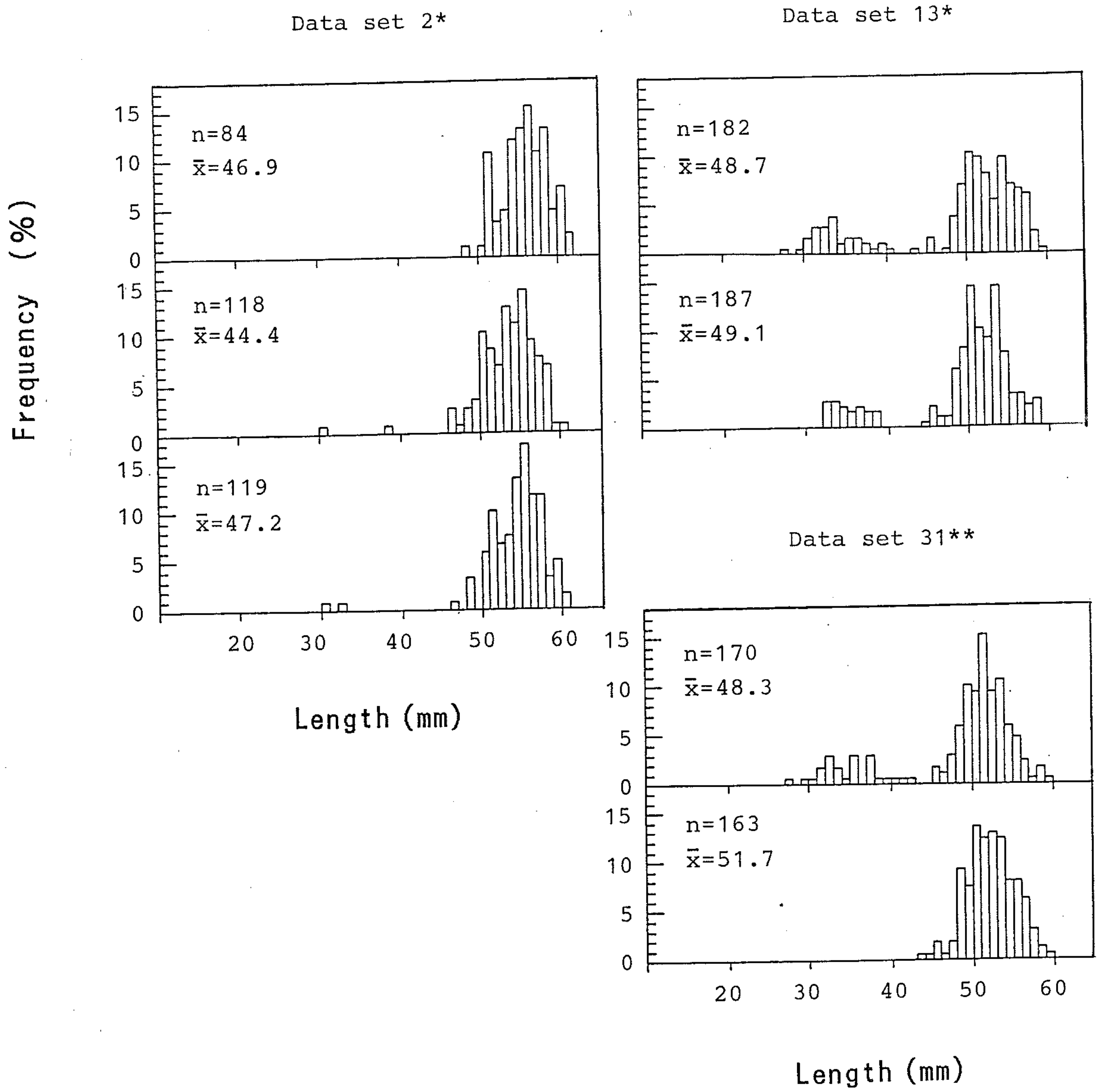


Figure 2: Comparisons of krill length compositions for which significant differences were observed.
* ***P*<0.05**
** ***P*<0.01**

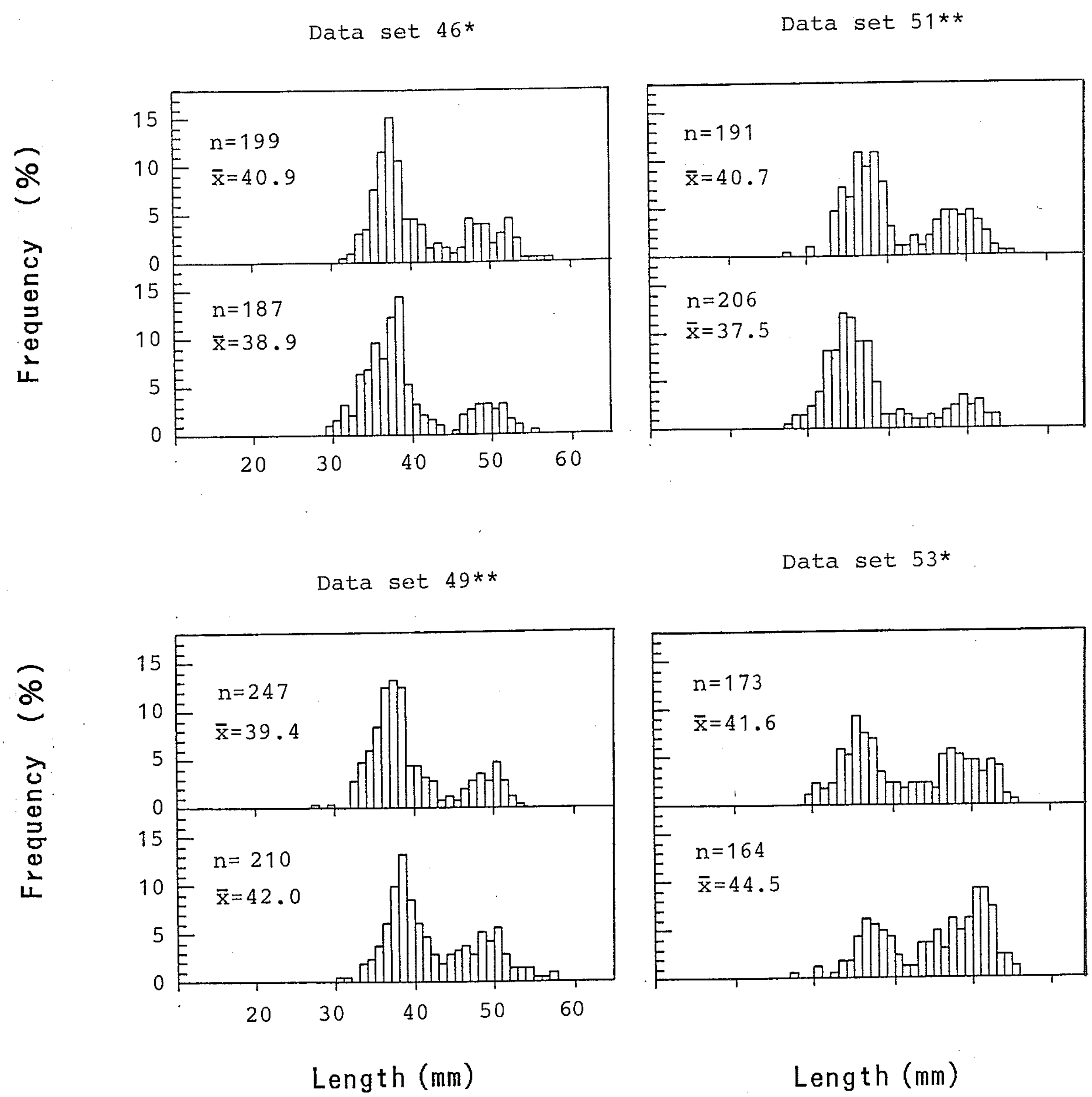


Figure 2 (continued)

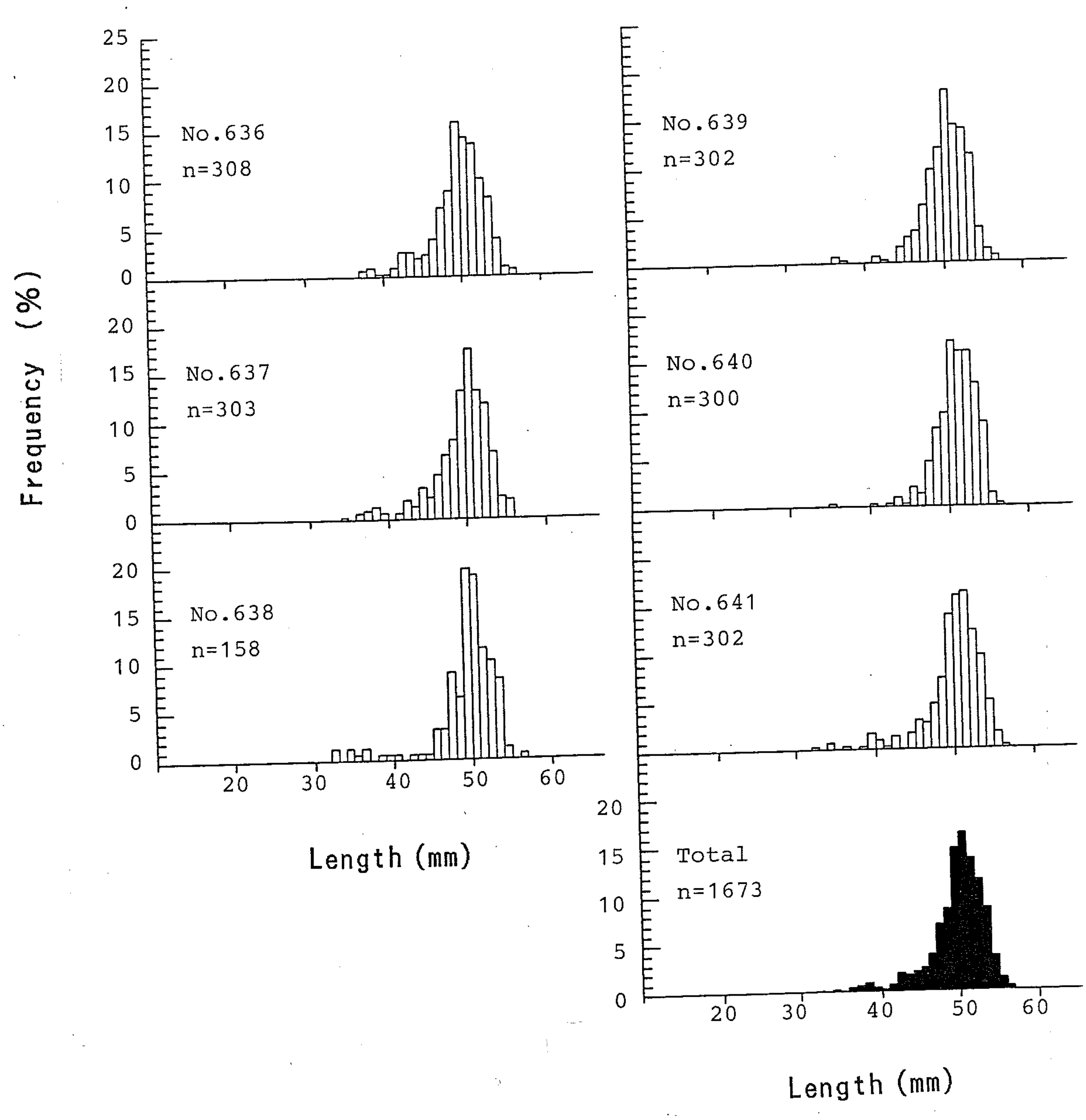


Figure 3: Variations in krill length compositions between sequential hauls in area X. The black-filled length composition picture is the accumulated composition for six sequential hauls (from haul 636 to 641).

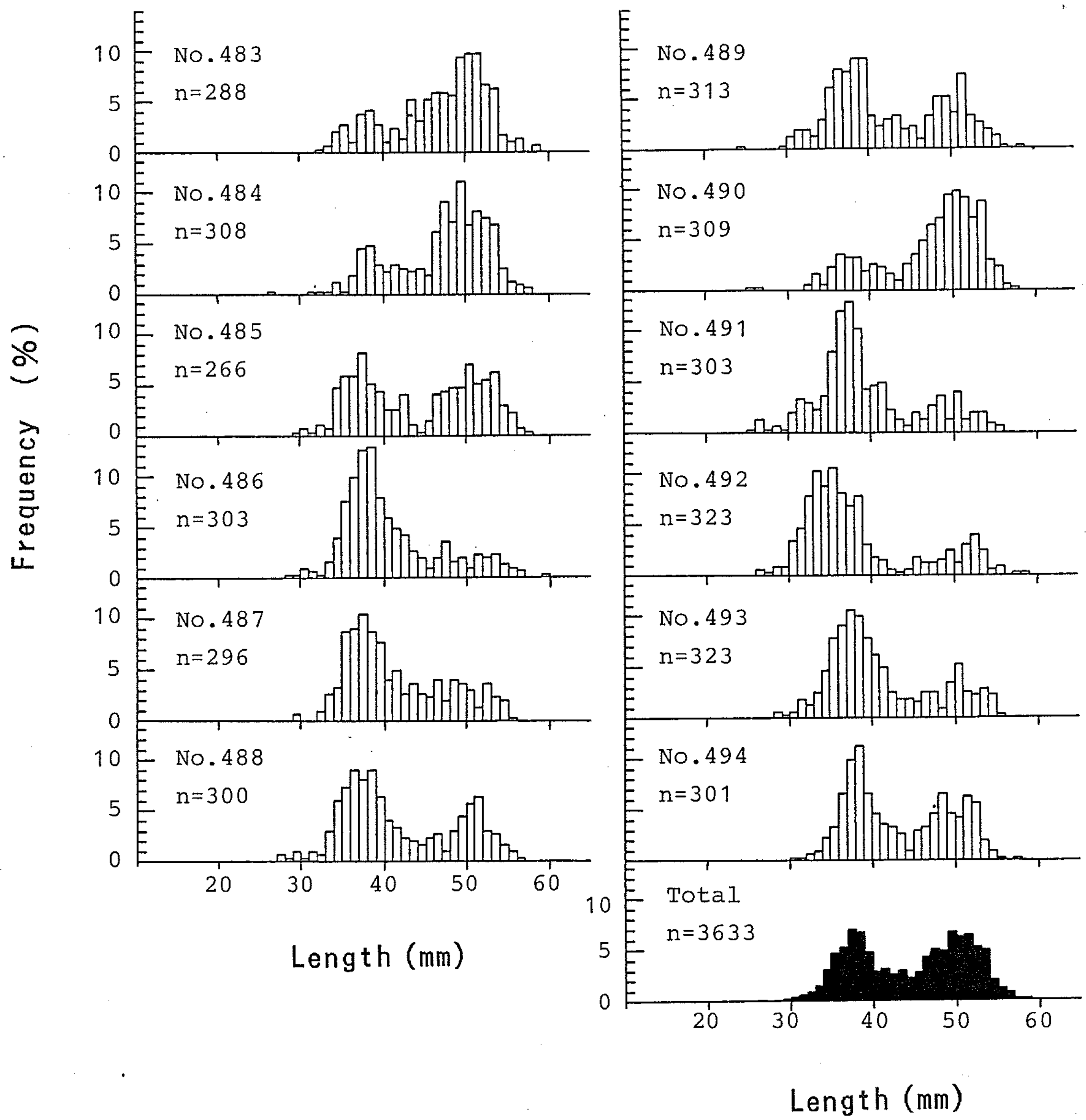


Figure 4: Variations in krill length compositions between sequential hauls in area Y. The black-filled length composition picture is the accumulated composition for 12 sequential hauls (from haul 483 to 494).

Lista de las tablas

Lista de las figuras

ON THE INTENSITY OF SAMPLING KRILL TRAWL CATCHES

D.G.M. Miller*

Abstract

This paper uses actual krill length-frequency data in an attempt to address the problem of the determination of adequate sample size to obtain representative krill length-frequency distributions from commercial catches. The possible effect of two other factors (within-trawl variability and sample decomposition) which may influence length-frequency data quality is also considered. Attention is drawn to the following:

- all measurements of length from commercial krill catches should be made, as far as possible, by a single observer/vessel;

- consideration still has to be given to the minimum length differences which should be detectable between catches. Account must be also taken of the desired biological characteristics which are to be discerned (e.g., length-with-age). At present, and in the interests of both statistical rigour and efficiency of measurement, it is proposed that length measurements made on commercial krill catches should be grouped into 2 mm size classes;

- biological implications associated with the detection of specific differences in length should be considered in conjunction with the need to collect information on maturity stages;

- for most purposes a minimum sample size of at least 100 animals/trawl is necessary to obtain statistically meaningful differences between samples; and

- the problem of how frequently commercial krill catches should be sampled still requires consideration.

Résumé

C'est en utilisant les données actuelles de fréquence de longueurs de krill que ce document tente de résoudre le problème de la détermination de la taille de l'échantillon qui permettrait d'obtenir de manière adéquate les distributions de fréquence de longueurs de krill des captures commerciales. Les conséquences possibles de deux autres facteurs (variabilité dans un même trait et décomposition des échantillons) d'influence potentielle sur la qualité des données de fréquence de longueurs sont également étudiées. Il convient de souligner les points suivants:

- toutes les mesures de longueurs du krill provenant de captures commerciales devraient (si possible) être effectuées par un seul observateur/navire;

* Sea Fisheries Research Institute, Private Bag X2, Roggebaai 8012, South Africa

- l'examen des différences minimales de longueurs décelables d'une capture à l'autre reste à faire. Il faut dûment prendre en considération le choix des caractéristiques biologiques à discerner (par ex. longueur-avec-âge). A présent, et dans l'intérêt de la rigueur statistique et de l'efficacité de la prise de mesures, il est suggéré de grouper les mesures de longueurs provenant des captures commerciales de krill en classes de tailles de 2 mm;

- les implications biologiques associées à la détection des différences spécifiques de longueurs devraient être étudiées conjointement à la nécessité de recueillir des informations sur le stade de maturité;

- dans la plupart des cas, une taille d'échantillon d'un minimum de 100 individus par chalut est nécessaire pour obtenir des différences significatives sur le plan statistique entre les échantillons; et

- le problème de la détermination de la fréquence à laquelle il faut échantillonner les captures commerciales de krill reste à examiner.

Резюме

В данном труде делается попытка рассмотреть проблему определения размера проб, необходимого для получения репрезентативных данных по распределению частоты длины криля в коммерческих уловах, с помощью анализа фактических данных по частоте длины криля. Кроме того, рассматривается вероятное воздействие двух других факторов (изменчивость в улове за одно траление и разложение проб) на качество данных по частоте длины. Внимание обращается на следующее:

- все замеры длины особей криля в коммерческих уловах должны (по возможности) проводится одним наблюдателем и/или судном;

- остается открытым вопрос об определении минимального различия в длине криля между уловами, которое должно быть измеримо. Необходимо уделить должное внимание идентификации желательных биологических характеристик, напр. - соотношение длина-возраст. В настоящее время в интересах как статистической точности, так и эффективности измере-ния, предлагается сгруппировать данные по длине, полученные по коммерческим уловам криля, по 2-миллиметровым размерным классам;

- при рассмотрении вопросов биологического характера, связанных с выявлением конкретных размерных различий, следует учитывать необходимость сбора данных по стадиям половозрелости; для определения статистически значимой разницы между пробами, в большинстве случаев минимальная проба должна включать по меньшей мере 100 особей за траление; и

- дальнейшему рассмотрению подлежит вопрос частоты сбора проб из коммерческих уловов криля.

Resumen

Este documento utiliza la información actual sobre frecuencia de tallas del krill, en un esfuerzo por estudiar el problema asociado con la determinación del tamaño de muestra de las capturas comerciales que permitirá obtener distribuciones representativas de las frecuencias de tallas del krill. También se considera el posible efecto de otros dos factores (variabilidad en el arrastre y estado de descomposición de la muestra) que pueden afectar la calidad de los datos de frecuencia de tallas. Se destacan los siguietes aspectos:

- todas las mediciones de talla de krill de las capturas comerciales deberán efectuarse, en lo posible, por un sólo observador/buque;
- se deben tomar en cuenta también las diferencias mínimas detectables en las tallas entre capturas. También se deberán examinar las características biológicas que son de interés (por ejemplo, talla por edad). Actualmente, para lograr una precisión estadística y mejorar la eficacia de la medición, se propone que las mediciones efectuadas en las capturas comerciales de krill sean agrupadas en intervalos de tallas de 2mm;
- se deberán considerar las consecuencias biológicas asociadas con la detección de diferencias específicas en tallas, junto con la necesidad de obtener información de las fases de madurez;
- en general, se necesita un tamaño de muestra mínimo de por lo menos 100 especímenes por arrastre, de modo que las diferencias estadísticas entre muestras sean coherentes;
- queda todavía por considerarse más a fondo la cuestión de ¿cuán frecuentemente se deben muestrear las capturas comerciales de krill?

---

1. INTRODUCTION

At its first meeting in June 1989, the CCAMLR Working Group on Krill (WG-Krill) recommended:

- the development of sampling procedures to take account of how many samples and how frequently samples of krill length distributions in commercial catches should be taken; and
- an interim measure whereby sampling of at least 50 krill from one haul per fishing day should be undertaken by all vessels other than those of the Japanese fishing fleet, which already carry out such sampling.

This recommendation was subsequently endorsed by the Scientific Committee (SC-CAMLR-VIII, paragraph 2.44). In the process of receiving the necessary consensus for this endorsement, SC-CAMLR requested that (a) studies should be undertaken to develop standardized sampling procedures for krill catches, (b) due account should be taken of the number and frequency at which krill length-frequency samples in commercial catches should be collected, and (c) procedures should be developed by which within-catch variances in the sampling of length-frequency distributions in addition to between-catch and vessel variability could be assessed (SC-CAMLR-VIII, paragraph 2.43). The Scientific Committee also urged Members to report any difficulties experienced with the interim sampling procedure outlined above as well as the procedures they are currently using or intend to use to sample krill length distributions (SC-CAMLR-VIII, paragraph 2.44).

Considering the above sampling procedures, it should be noted that Watkins *et al.* (1986) have emphasized that the high level of heterogeneity in many krill populations necessitates implementation of sampling procedures which take account of the extent of such heterogeneity. Not only does this directly influence the extent of sampling, in the case of sampling commercial catches it requires that an appropriate balance between the minimum levels of sampling desired and the cost of sampling be found.

This paper therefore uses actual krill length-frequency data to address the problem of determining adequate sample size as part of the ongoing effort within WG-Krill to obtain representative krill length-frequency distributions from commercial catches. In addition, the possible effect of two other factors which may influence length-frequency data quality are also considered. These are the effect of elapsed time after capture (i.e., decomposition of samples) on measurements of length and within-catch sample variability as related to the position within a trawl from which a particular length sample is taken.

2. MATERIALS AND METHODS

Krill were sampled at 22 localities close to Coronation (South Orkneys) (**n**=13) and Elephant (South Shetlands) (**n**=19) Islands during an acoustic survey by RS *Africana* in March 1990. A Polish commercial krill trawl (16/41) was used for all sampling and reference should be made to Slosarczyk (1986) and Miller (1987) for details of its construction and operation.

Routinely, krill samples were collected from the aft-quarter of the trawl codend and the lengths of 50, 100 and 150 animals were measured. A variable number of animals per sample were also measured until 50 animals in a single 1 mm size class were obtained. The length measurement used was that recommended by SC-CAMLR - namely, from the front of the eye to the tip of the telson, excluding the terminal setae - and to avoid problems of sampling error alluded to by Watkins *et al.* (1985) all measurements were made by a single observer. Analyses of Variance (ANOVA) were undertaken using the Statistical Analysis Software (SAS 1985) package to compute length statistics and to investigate differences in mean length between stations and between areas. Additional statistical procedures described in Zar (1984) were used to estimate projected sample sizes, based on variances in mean length between areas, and minimum detectable length differences independent of, and relative to, projected sample sizes. The formulae for these various procedures are given in Appendix 1.

The length measurement procedure and statistical analyses outlined above were repeated for samples collected from 10 different localities within a single trawl, proportionately increasing in distance from the codend mouth. Similarly, a single sample of 50 animals was measured repeatedly at various times (up to 46 hours) after collection.

3. RESULTS

3.1 Analysis of Length by Station and Area

Length-frequency distributions for animals collected at the South Orkneys and Elephant Island respectively are given in Figure 1. The data in this figure are based on measurements until 50 animals in each single 1 mm length size class were collected. The ANOVA of mean length by area indicated a significant difference between the two areas (F_{ratio}=8476.21,

α=0.05). Mean lengths and standard deviations by station in the two areas are shown in Figures 2 and 3. Again significant differences were found between mean lengths by station at both the South Orkneys (F=120.38, α=0.05) and Elephant Island (F=86.46, α=0.05).

The procedures outlined in Appendix 1 (A) were then used to compute the required sample size to detect various differences (1, 2 and 5 mm) in mean length at a 0.05 level of significance with a 90% chance of detecting a true difference. As explained in Appendix 1 (A), a simple two-sample ***t*** test was used and the between-population variance was calculated from the combined error mean squares for length at the two islands derived by the ANOVA procedure. From Figure 3 it can be seen that the maximum benefit in terms of detecting real differences in mean length with area as a function of sample size is to be derived by increasing the length class intervals being used in the sample analyses. In this connection it is apparent that the greatest impact on the required sample size occurs when the length class difference being assessed is increased from 1 to 2 mm. This trend is also apparent in the computed minimum detectable differences in mean length in relation to projected sample size for various functions of the pooled variance obtained from the analyses between areas (Figure 1). In both cases, a sample size of at least 100 animals appeared most suited for the detection of a 2 mm difference in mean length between the two areas.

A similar picture to that obtained from between area analyses is apparent when between-station differences in mean length are analyzed (see Appendix 1 (B) for details of analytical procedures) for the two areas separately. Figure 5 shows the minimum detectable differences in mean length in relation to various functions of the between station variance in length encountered. Table 1, on the other hand, illustrates the projected sample sizes required for the detection of specific differences in mean length between stations. Once again a sample size of approximately 100 animals appears best suited for detecting a 2 mm difference in mean length between stations at both islands. It would be logical to assume, however, that this picture would change with the extent of the underlying variance encountered between stations.

The ANOVA for between station differences in length indicates that for sample sizes of 100 animals or less, no significant differences in between-station lengths were detectable (F=1.967 and 1.187 and F=2.14 and 1.295 [α=0.05] for measured sample sizes of 50 and 100 animals at the two islands respectively). This would imply that such samples were too small to detect differences in length between stations, a conclusion supported by the results of the projected sample size-detectable length difference analysis reported above.

3.2 Analysis of Samples by Locality Within a Single Catch

Mean lengths for different sample sizes taken from 10 localities within a single trawl are shown in Figure 6. Both a nested ANOVA for all localities as well as a comparison-of-means test between localities indicate that there were no significant differences (F=8.75, α=0.10 to 0.05) between mean lengths or the number of animals measured/location (i.e., 50, 150 or 50 in one size class).

3.3 Analysis of Samples With Time

The mean lengths of a sample of 50 animals measured at various times up to 46 hours after collection are shown in Figure 7. Results from the ANOVA (F=0.31, α=0.10 to 0.05) indicate no significant changes in mean length with time thereby implying that sample length measurements are not affected by decomposition, at least over the period considered.

4. DISCUSSION

From the current results, the sample size of 50 animals/trawl/vessel/day recommended by SC-CAMLR appears insufficient to detect even quite large differences in mean length between areas and between samples in one area unless a large number of vessels are operating (i.e., a large number of samples are measured) in one locality. In this connection, some consideration needs to be given to precisely how large detected differences in mean length should be in order to provide meaningful insights into the underlying biological characteristics and/or differences of commercial krill catches.

Both the projected sample size and minimum detectable length difference analyses suggest that in the interests of minimizing underlying measurement effort whilst still maintaining the ability to detect meaningful length differences, the most cost effective grouping of length is into 2 mm size classes. Furthermore, from both a statistical and practical point of view, it would appear that measurement of about 100 animals/sample is sufficient to obtain an adequate representation of the length structure. The number of animals to be measured, however, is obviously a function of the underlying variance in length of the population(s) being considered and similarly so is the minimum detectable difference in length. In this paper, therefore, some attempt has also been made to illustrate how both these parameters may change with underlying variance in length of the population concerned (see Figures 4 and 5).

From the above results it is also interesting to note that observed trends in the minimum detectable differences in length as a function of between-station variance are essentially similar to those between areas. This suggests that even length samples from a relatively small area may yield quite high variances thereby necessitating the collection of a larger number of samples in order to quantify such variance more adequately (cf. Watkins *et al.*, 1986). This would in turn imply that once again the standard of only length sample/fishing day recommended by SC-CAMLR is probably insufficient to detect real changes in length, especially in the presence of marked small-scale (say between-swarm) variability in the length composition of the population(s) being sampled and when the number of catches sampled is small (i.e., only a small number of vessels is operating in the area concerned).

From the analyses of samples taken from different localities in the trawl, it would appear that mean length and length-frequency distribution are not affected by spatial differences within-trawl. This conclusion is substantiated by similar results reported by Ichii (1990) from his sampling of Japanese commercial catches. It is also apparent that there are no significant differences between length data obtained via various sample sizes (i.e., 100, 150 and 50 animals in one size class). Given that the trawl catch used in this particular experiment was "aimed" into a single krill swarm, then it would be reasonable to assume that the sample length variance would be low. It is interesting to note, however, that comparison of length between stations in relation to sample size indicates that small samples (i.e., <100 animals) also did not indicate any significant differences in length. This result is in accordance with the estimated minimum sample size (≥ 100) required to detect specific length differences between stations reported above.

Surprisingly, length did not appear to vary significantly with time post-capture. This was despite the fact that the condition of individual animals being measured noticeably deteriorated. Fluctuations in measured length were observed, however, as can be seen from minor differences in mean length with time as shown in Figure 7. No consistent trend was observable and it can only be assumed that such fluctuations fell within the limits of normal measurement error as highlighted by Watkins *et al.* (1985).

In conclusion, therefore, the following points are offered for consideration:

- All measurements of length from commercial krill <u>catches should be made, as far as possible, by a single observer/vessel</u>. As proposed by Watkins *et al.* (1985)

further studies of between-observer variances in the measurement of length should be encouraged so as to improve quantification of this effect.

- Consideration must be given to the minimum length differences between-catches which are to be detected. As far as possible, account should be taken of the particular biological characteristics which the measurements are aimed at best discerning (e.g. length-with-age). At present, and in the interest of both statistical rigour and the efficiency of measurement, it is proposed that length measurements from commercial catches should be grouped into 2 mm size classes.

- In addition to the biological implications of detecting specific length differences, there seems to be little doubt that if current knowledge of the fishery's operational characteristics is to be improved then attention should be given as to whether, and how, maturity stage information could be collected. The recommendations put forward by Morris *et al.* (1988) therefore need to be noted and critically reviewed.

- From the present analyses, and for most purposes, a minimum sample size of at least 100 animals/trawl appears necessary in order to obtain statistically meaningful differences between samples.

- The problem of the frequency of sampling still has not been satisfactorily resolved other than that a single length sample/trawling day does not appear sufficient to obtain even a representative approximation of the length-frequency distributions in an area(s) where the between-sample variance is quite low (as was the case in this study) and where the number of fishing vessels is likely to be sparse. The issue of sampling frequency thus obviously requires further consideration.

ACKNOWLEDGEMENTS

I would like to express my thanks to Mr R. Leslie and Ms J. Nelson and D. Merkle for their assistance in both the data collection and analyses. Financial support from the Sea Fisheries Research Institute is also gratefully acknowledged.

REFERENCES

ICHII, T. 1990. *Homogeneity of Body Length Composition of Antarctic Krill Within the Commercial Haul.* WG-Krill-90/11. Hobart, Australia: CCAMLR. p. 10.

MILLER, D.G.M 1987. The South African SIBEX II cruise to the Prydz Bay region. *S. Afr. J. Antarct. Res. 17*(2): 101-107.

MORRIS, D.J., J.L. WATKINS, C. RICKETTS, F. BUCHOLZ and J. PRIDDLE. 1988. An assessment of the merits of length and weight measurements of Antarctic krill *Euphausia superba. Br. Antarct. Surv. Bull., 79*: 27-50.

SAS. 1985. *SAS User's Guide: Statistics, Version 5 Edition.* Cary, NC: SAS Institute Inc. p. 956.

SLOSARCZYK, W. 1986. Attempts at quantitative estimate by trawl sampling of distribution of postlarval and juvenile nototheniids (Pisces, Perciformes) in relation to environmental conditions in the Antarctic Peninsula region during SIBEX, 1983-1984. *Mem. Natl Inst. Polar Res., Spec Issue No. 40*: 299-315.

WATKINS, J.L., D.J. MORRIS and C. RICKETTS. 1985. Nocturnal changes in the mean length of a euphausiids population: vertical migration, net avoidance or experimental error? *Mar. Biol. 86*: 123-127.

WATKINS, J.L., D.J. MORRIS, C. RICKETTS and J. PRIDDLE. 1986. Differences between swarms of Antarctic krill and some implications for sampling populations. *Mar. Biol.*: 137-146.

ZAR, J.H. 1984. *Biostatistical analysis, Second Edition.* Englewood Cliffs, New Jersey: Prentice-Hall. p. 718.

Table 1: Projected minimum sample sizes for the detection of specific differences in mean length between-stations at the South Orkneys and Elephant Island. Significance level α=0.05 and confidence limit of 90%.

Minimum Detectable Length Difference	Projected Sample Size	
	South Orkneys	Elephant Island
1 mm	750	500
2 mm	200	150
5 mm	30	25

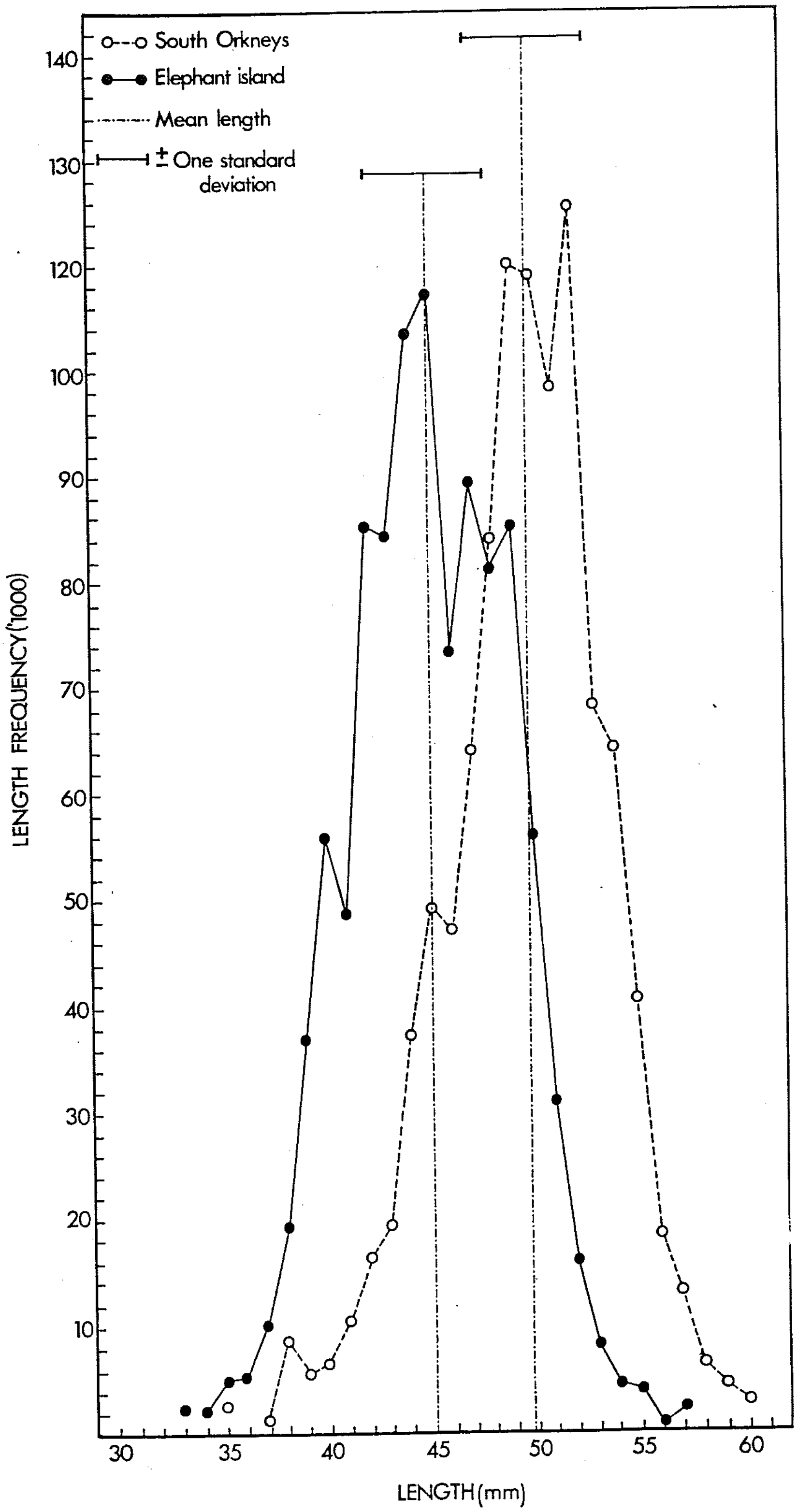


Figure 1: Length-frequency distributions for krill collected with a Polish commercial krill trawl at the South Orkneys and Elephant Island. Mean lengths for each area (±1 S.D.) are also shown.

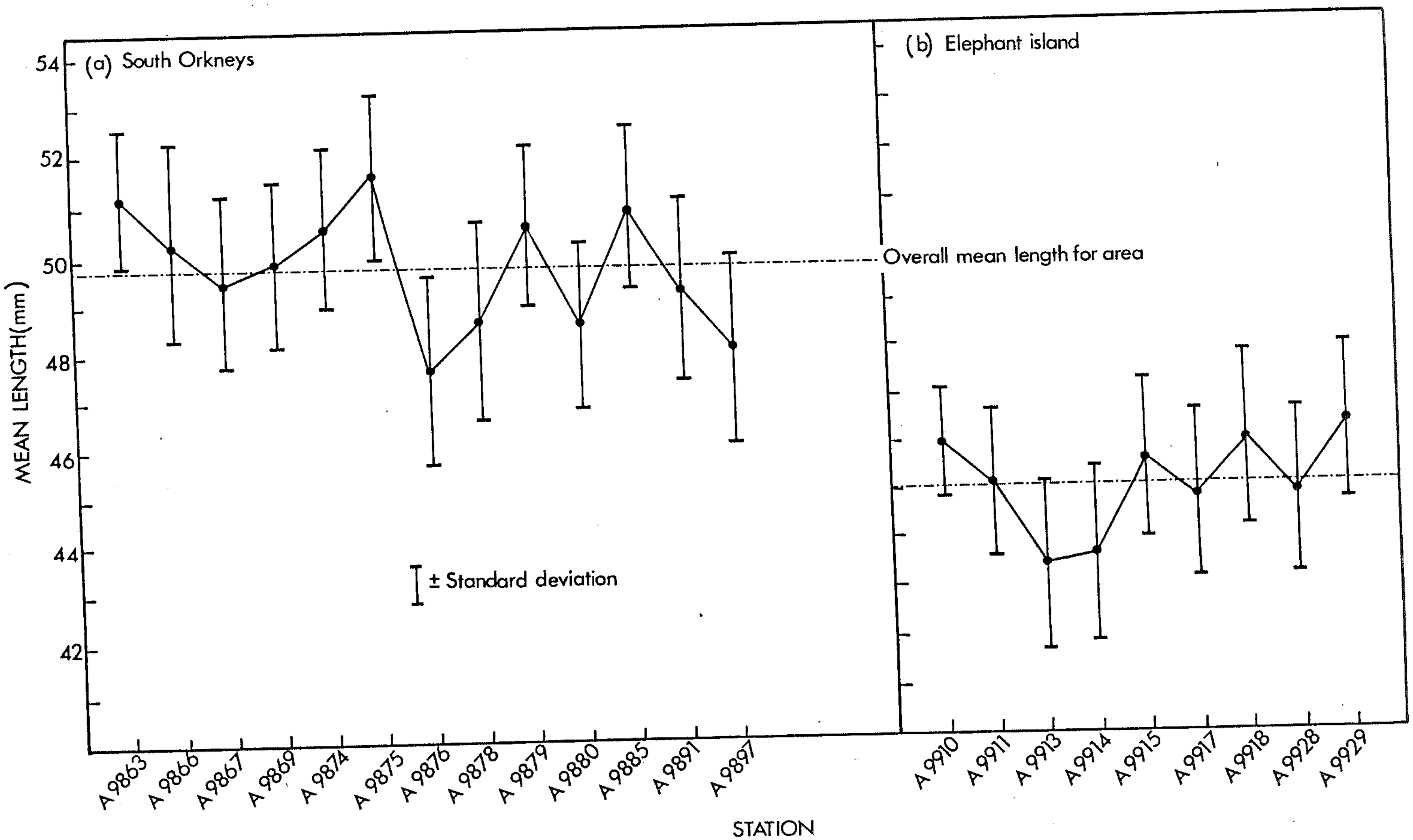


Figure 2: Mean Length (± 1 S.D.) by station for krill collected at (a) the South Orkneys, and (b) Elephant Island.

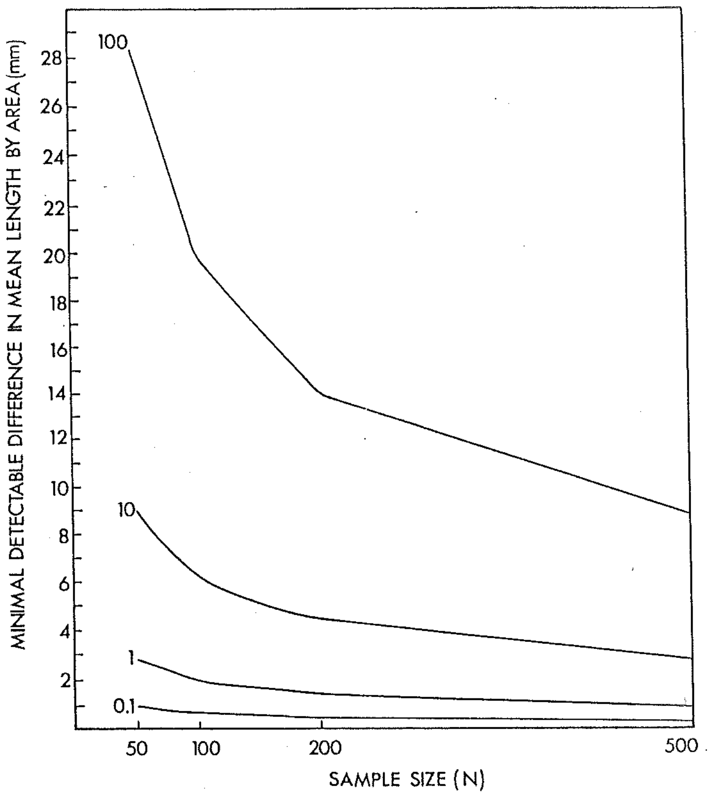


Figure 3: Detectable differences in length as a function of sample size. Data for analyses derived from data for the South Orkneys and Elephant Island together (i.e., between areas - see text for explanation).

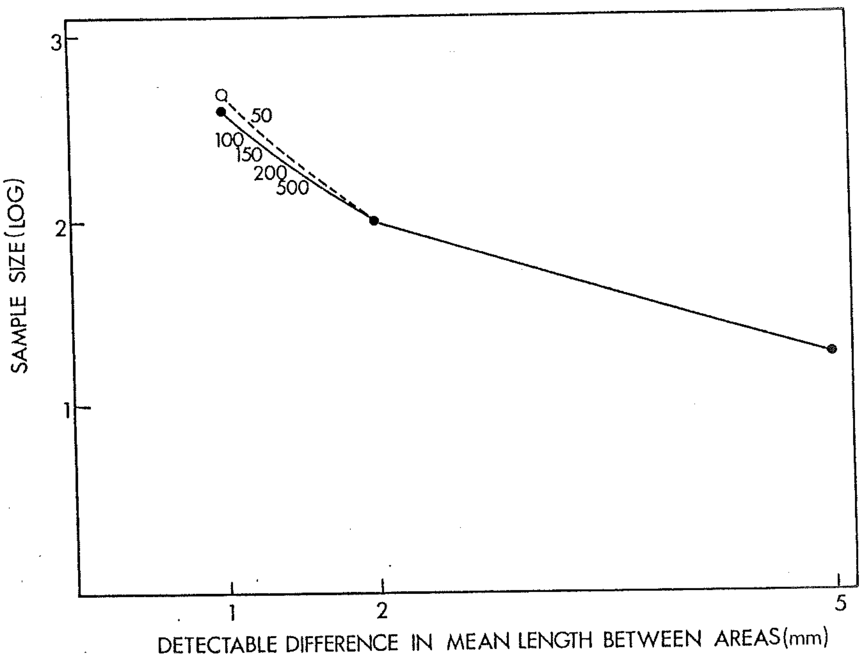


Figure 4: Projected minimum detectable differences in length as a function of sample size (*n*) and in relation to various functions of the between-area variance (s^2 - see Appendix 1 (A) for explanation) in length obtained during the present study.

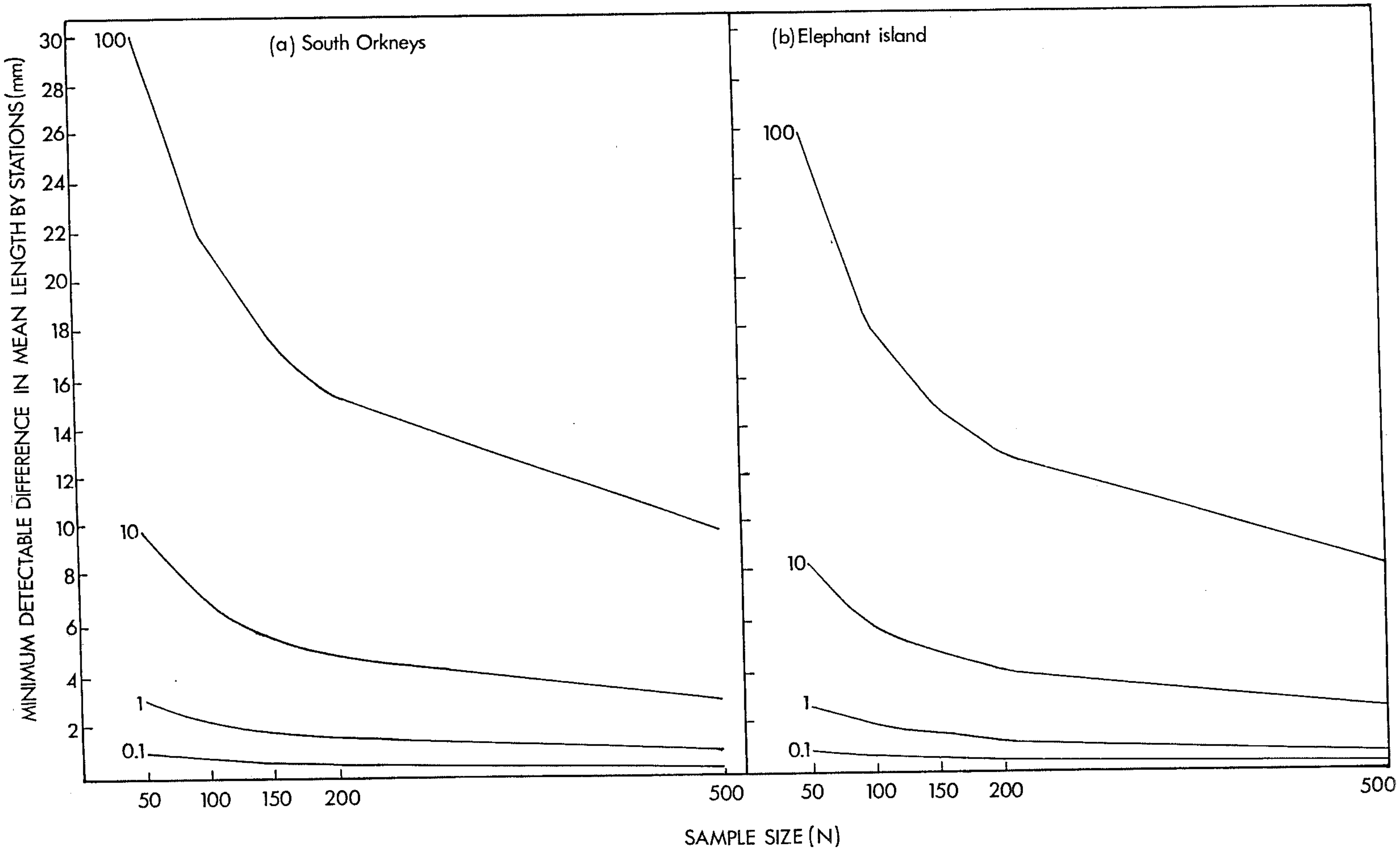


Figure 5: Projected minimum detectable differences in length as a function of sample size (*n*) and in relation to various functions of the between-station variance (s^2 - see Appendix 1 (B) for explanation) in length obtained during the present study at (a) the South Orkneys and (b) Elephant Island.

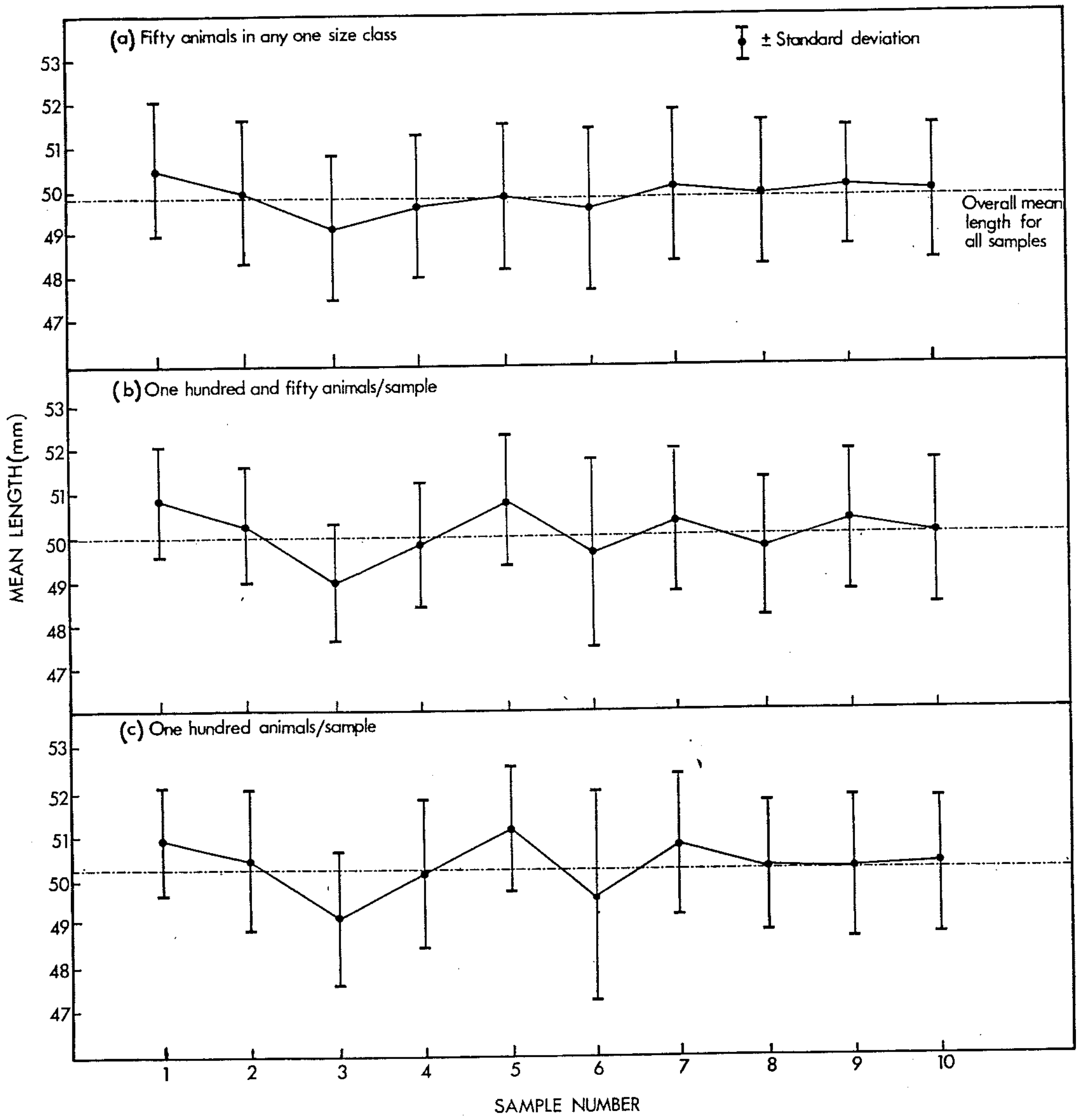


Figure 6: Mean lengths (±1 S.D.) of animals collected from various localities within a single trawl. The number of animals measured was (a) up to 50 in a single 1 mm size class, (b) 150 and (c) 100.

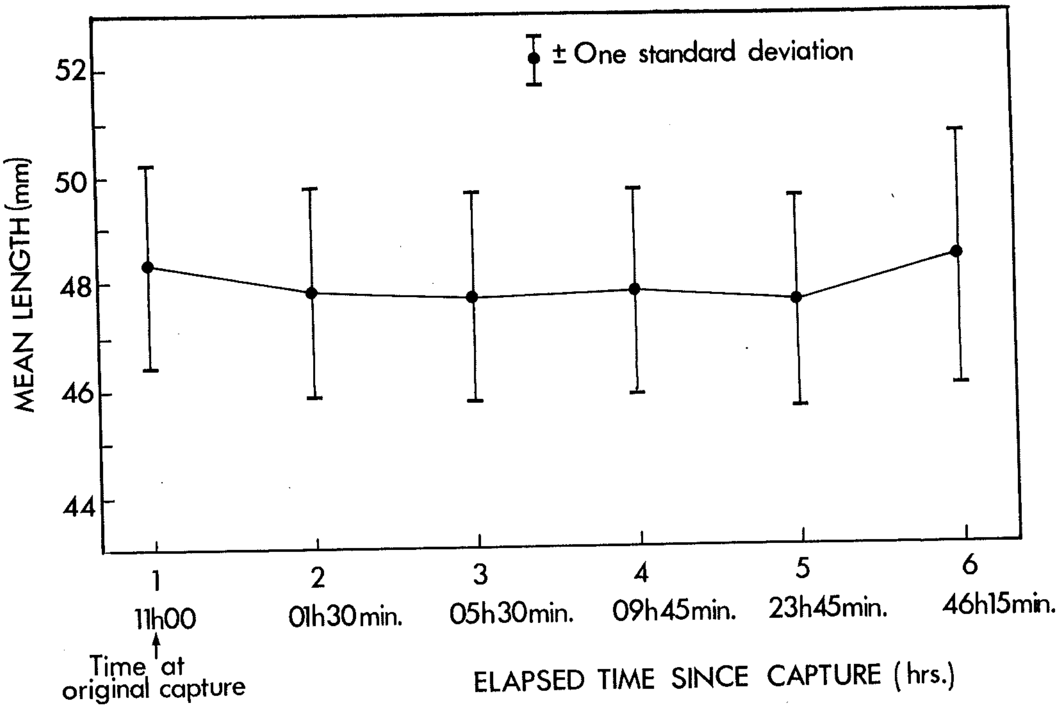


Figure 7: Mean lengths (±1 S.D.) of 50 animals measured at various times after capture.

Lista de las tablas

Lista de las figuras

Figura 5: Diferencias de longitud mínimas perceptibles en función del tamaño de la muestra (n) y en relación a varias funciones de la varianza entre áreas (s^2, véase apéndice 1 (B)) en las tallas obtenidas en el presente estudio en (a) Orcadas del Sur y (b) isla Elefante.

Figura 6: Tallas medias (±1 S.D.) de individuos capturados en distintas localidades dentro de un mismo arrastre. La cantidad de individuos medidos fue de (a) hasta alcanzar los 50 ejemplares de clase de 1 mm, (b) 150 y (c) 100.

Figure 7: Tallas medias (±1 S.D.) de 50 individuos medidos en distintos intervalos después de la captura.

FORMULAE AND PROCEDURES FOR SPECIFIC STATISTICAL ANALYSES

(A). Projected Sample Size Required for and Minimum Detectable Difference in Mean Length Between Areas

This procedure may be considered as an estimation of the minimum sample size required to detect differences between two sample means (i.e., a two-sample *t* test is used). The appropriate formula is given below and the estimation procedure followed can be found in Chapter 9.7 of Zar (1984). The formula used was:

$$n \geq \frac{2s^2p}{\delta^2}(t_{\alpha,\nu} + t_{\beta(1),\nu})^2 \tag{1}$$

where δ = minimum detectable difference between population means,
s^2 = the pooled variance, assuming that the populations sampled have the same variance. (In fact the individual areal sample variances were remarkably similar - 13.45 and 13.73 for Elephant Island and the South Orkneys respectively). The variances used were calculated from the Analysis of Variance (ANOVA) results for between area mean lengths using the sum of squares and necessary degrees of freedom from the relevant variables (see Zar, 1984, p. 134),
α = significance of level where ν equals **2(n-1)**. The level of significance employed in the performance of the necessary *t*-test was 0.05,
1-β = the power of the test. Since a 90% chance of detecting a true population difference in mean length was chosen, then the value of β equals 0.10.

Equation 1 above can be rearranged to determine how small a population difference (δ, defined above) is detectable for a given sample size:

$$\delta \geq \frac{2s^2p}{\delta^2}(t_{\alpha,\nu} + t_{\beta(1),\nu}) \tag{2}$$

(B). Projected Sample Size Required for and Minimum Detectable Difference in Mean Length Between Stations

The procedures used to analyze mean length differences in the two areas separately were based on the between-station variances in the two areas and required the computation of the non-centrality parameter ϕ (see Zar, 1984, Chapter 11.3 for procedural details). In order to determine the projected sample size required to detect a specific change in mean length between stations, the following formula was used:

$$\phi = \frac{n\delta^2}{2ks^2} \tag{3}$$

where ϕ = noncentrality parameter,
n = number of length measurements per station,
δ = minimum detectable difference in mean length;
k = number of stations, and
s^2 = variability (i.e., error MS from ANOVA) within k.

Having estimated ϕ for a desired value of δ, the power and sample size analysis of variance curves developed by Pearson and Hartley (1951) (cf. Zar, 1984) were used to determine the sample size, n (by iteration) required to detect δ at the stipulated significance level (α=0.050 and within the chosen confidence limits (90%).

To estimate the minimum detectable difference in length for a given sample size in relation to various functions of the between-station variances obtained during the current study, Equation 3 was rearranged such that:

$$\delta = \frac{2s^2\phi^2}{n} \tag{4}$$

The Pearson and Hartley tables were then used to estimate ϕ at the desired significance level (α=0.05) and within the stipulated confidence limits (90%).

DISTRIBUTION CHARACTERISTICS OF KRILL AGGREGATIONS IN THE FISHING GROUND OFF CORONATION ISLAND IN THE 1989/90 SEASON

S.M. Kasatkina and V.I. Latogursky*

Abstract

Distributional characteristics of krill aggregations in the Coronation Island fishing ground were examined in relation to environmental factors, the biological condition of krill and the performance of the fishery. Investigations were carried out from October 1989 to February 1990. An echosounder was used to assess the characteristics of krill aggregations. Krill was harvested by standard midwater trawls with a horizontal mouth opening of 33 m. All common types of krill aggregations were recorded in the Coronation Island area over the observation period. From November to February scattered forms of krill tended to combine into larger aggregations. Wind force had no direct or indirect influence on the types of krill aggregations or their density. The increased temperature towards the end of the season, however, assisted the development of phytoplankton which in turn led to an increase in krill concentration. The biological parameters of krill examined (stages of maturity, sex ratio and krill size) varied according to aggregation type. The results obtained should be regarded as preliminary since they were based on data from one season only. Distributional characteristics of krill aggregations varied significantly over time. It was therefore recommended that CPUE simulation studies take into account the actual distributional features of targetted aggregations and the catchability rates of the trawls used at different times in the life of the fishery.

Résumé

Les caractéristiques de la répartition des concentrations de krill dans le lieu de pêche proche de l'île du Couronnement ont été examinées par rapport aux facteurs de l'environnement, à la condition biologique du krill et à la performance de la pêcherie. Les recherches ont été menées d'octobre 1989 à février 1990. Un écho-sondeur a servi à l'évaluation des caractéristiques des concentrations de krill. Le krill a été pêché par des chaluts pélagiques standard d'une ouverture horizontale de 33 m. Tous les types courants de concentrations de krill ont été signalés dans la région de l'île du Couronnement au cours de la période d'observation. De novembre à février, le krill dispersé a eu tendance à se grouper en concentrations plus larges. La vitesse du vent n'a eu aucune influence directe ou indirecte sur les types de concentrations de krill ou sur leur densité. Par contre, vers la fin de la saison, la hausse de la température a favorisé le développement du phytoplancton, ce qui a alors provoqué une augmentation des concentrations de krill. Les paramètres biologiques du krill examiné (stades de maturité, sex ratio et taille du krill) ont varié selon les type de concentrations. Les résultats obtenus devraient être considérés comme étant préliminaires, vu qu'ils sont basés sur les données d'une seule saison. Les caractéristiques de répartition des concentrations de krill ont varié considérablement au

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236999, USSR

cours du temps. Il a de ce fait été recommandé que les études par simulation de la CPUE tiennent compte des caractéristiques mêmes de la répartition des concentrations visées et des taux de capturabilité des chaluts utilisés à différentes époques de l'historique de la pêcherie.

Резюме

Характеристики распределения агрегаций криля в промысловом районе у о. Коронейшн были рассмотрены в связи с факторами окружающей среды, биологическим состоянием криля и результатами промысла. Работы проводились в период с октября 1989 г. по февраль 1990 г. Оценка характеристик агрегаций криля проводилась с помощью эхолота. Промысел криля велся стандартным разноглубинным тралом с горизонтальным раскрытием между крыльями в 33 м. За период наблюдения в районе о. Коронейшн были зарегистрированы все известные типы агрегаций криля. С ноября по февраль была отмечена тенденция увеличения концентрации криля от разрозненных скоплений до крупных агрегаций. Сила ветра не оказывала ни прямого ни косвенного влияния на типы скоплений криля и их плотность. Однако, повышение температуры к концу сезона способствовало развитию фитопланктона и, как результат этого, повышению концентрации криля. Биологические параметры криля - стадии зрелости, соотношение полов и размер - различались в зависимости от типа концентраций. Полученные выводы следует считать предварительными, поскольку они были получены на материалах только одного сезона. Характеристики распределения агрегаций криля на промысловом участке существенно менялись во времени. В результате этого было рекомендовано при расчете величины CPUE методом математического моделирования принимать во внимание реальные характеристики распределения криля в облавливаемых агрегациях и уловистость используемых тралов в различные периоды промысла.

Resumen

Se estudian las características de distribución de las concentraciones de krill en los caladeros de la isla Coronación en relación a los factores del entorno físico, la condición biológica del krill y la actuación de la pesquería. Los trabajos de investigación se llevaron a cabo desde octubre 1989 a febrero 1990; empleándose un ecosondas para evaluar las características de las concentraciones. Las pescas de krill se realizaron con un arrastre pelágico estándar cuya abertura horizontal de la boca era de 33 m. Durante el período de observación de la zona de la isla Coronación, se registraron todos los tipos comunes de concentración. De noviembre a febrero las formaciones dispersas de krill tendían a formar agrupaciones más amplias. La fuerza del viento no influyó en la forma de las concentraciones ni en su densidad. Sin embargo, el aumento de la temperatura hacia el final de la temporada provocó la formación de fitoplancton lo que a su vez originó el crecimiento de la concentración de krill. Los parámetros biológicos del krill examinados (fases de madurez, proporción de sexo y tallas) variaron según el tipo de concentración. Los resultados obtenidos deben considerarse preliminares ya que se han basado únicamente en los datos de una sola temporada. Las características de distribución de las concentraciones de krill variaron considerablemente según la época. Se recomienda por lo tanto que los estudios de simulación de la CPUE tengan en cuenta las características reales de distribución de las concentraciones escogidas, así como los índices de capturabilidad de los arrastres utilizados en las distintas épocas de la pesquería.

---

1. INTRODUCTION

The characteristics of krill distribution have been the subject of a series of scientific works (Kalinowski and Witek 1982, 1985; Anon., 1986; Godlewska and Kluzek, 1988; Miller and Hampton, 1989; William and Hamner, 1984).

The data used in most of these papers have been obtained as a result of scientific programs such as FIBEX and BIOMASS. The study of krill CPUE also requires knowledge of its distributional characteristics in fishing grounds (Endo and Ichii, 1989). These characteristics are determined by environmental factors as well as the biological condition of krill.

The authors have attempted to examine changes in distributional characteristics of krill aggregations in fishing grounds as they relate to krill biology and the performance of the fishery.

2. MATERIALS AND METHODS

Investigations were carried out on board a fishing vessel which did not have echo-integrating equipment, a fact which severely limited the amount of hydroacoustic information obtained. Distributional characteristics of krill aggregations were assessed on the basis of echogram recordings according to a methodology developed by AtlantNIRO (1985).

Since a hydroacoustic assessment of the effectiveness of the midwater trawl type 74/416 used for taking krill was not carried out, catchability was calculated on the basis of statistical probability models used for fishing trawls. This method is quite accurate when used to assess trawl catchability and is an acceptable alternative to hydroacoustic methods (Kasatkina, 1989; Kadilnikov *et al.*). Maximum krill speed in the calculations was taken to be $\mathbf{V}_{max}$=0.23 m/s (Kasatkina and Myskov, 1986; Hamner, 1984). Trawl specifications for the type 74/416 are given in Table 1.

CPUE (Catch-per-unit-effort) was assessed as catch per hour of trawling because expended fishing effort can be expressed as trawling time for a standard trawl. Since we are examining the performance of a single vessel, the 74/416 type trawl is taken as standard.

A well-grounded estimate of mean catch per hour of trawling, **Q/hr**, (Ivanova, 1988; Smith, 1980) was calculated in the following manner:

$$\bar{m}(Q/hr) = \frac{\sum_{i=1}^{n} Q_i}{\sum_{i=1}^{n} T_{tp.i}}$$

where Q_i = catch in haul i;
$T_{tp.i}$ = duration of haul i ;
n = number of hauls over the study period.

Relative error of mean catch per hour of trawling is

$$\xi\,(\bar{m}Q/hr) = \pm\frac{t_\varepsilon}{\sqrt{n}}\left(\frac{\sigma_Q}{\bar{m}_Q} + \frac{\sigma_t}{\bar{m}_t}\right)$$

where t_e = confidence coefficient according to confidence probability ε;

σ_Q = standard deviation of catch per haul;

$\bar{m}_Q$ = mathematical expectation of catch per haul;

σ_t = standard deviation of the duration of one haul;

$\bar{m}_t$ = mathematical expectation of the duration of one haul.

Krill biological condition was determined according to "Methodical Instructions on Sampling and Primary Treatment of Biological Material and Data on Antarctic Krill *in situ*" (Moscow, VNIRO, 1982).

Sea surface temperature was measured to within 0.2°C of accuracy.

3. RESULTS

The entire period of investigations (18 November 1989 to 27 February 1990) may be divided into six smaller periods during which fairly similar krill aggregations were recorded.

The distribution of krill and the catchability coefficient of the 74/416 midwater trawl were evaluated for each of these time intervals (Table 2). Data on catch per hour trawling are given in Table 3; daily catch and fishing effort expended are shown in Table 4.

(Period I) 18 November to 3 December 1989

Observations were carried out over two fishing grounds during this period: north-east (50°10'S to 59°30'S and 43°30'W to 44°W) and south-west (Figure 1).

In the daytime, krill was recorded as a scattered layer in the 10 to 140 m depth range with interrupted, short tracks formed by poorly defined swarms. In periods of darkness (between dusk and dawn), krill was located above depths of 40 m, forming a dispersed sub-surface layer. Daily vertical migration was indistinct (Figure 2).

Mean catch per hour of trawling was $\bar{m}(Q/hr)$ = 2.15 tonnes (Table 3). Commercial catches ($\bar{m}(Q/hr)$ = 13.4 tonnes, σ_Q = 6 tonnes) were obtained due to prolonged periods of trawling: $\bar{m}_t$ = 5.8 hrs, σ_t = 2.5 hours.

Wind force over this period dropped from 3.5 to 2 on the Richter scale while water temperature was between 0° and 0.5° (Figure 4a).

In the north-east fishing ground, mean krill length was 47.8 mm and 45.4 mm in the south-west. The sex-ratio was 0.67 for males and 1.08 for females. A sharp drop in the proportion of post-spawning males and a significant increase in the number of females with a normal thorax were noted in the south-west towards the end of the study period (Figures 3b and 3c). The maturity stages of female ovaries were from 1 to 3 (Figure 3g) and 60% of females had spermatophores. Krill feeding intensity increased somewhat throughout the study period (Figure 3e).

(Period II) 4 December to 18 December 1989

The fishing ground was located to the north-west of Coronation Island (Figure 1).

Krill aggregations were recorded as fields of swarms dispersed in the depth layer of approximately 70 m. Towards nightfall these swarms ascended to the surface and dispersed, forming a rather uniform and sparse layer or separate sparse patches after 11 p.m. Swarming occurred with the onset of dawn (2:30 to 3:00 a.m.) and after five a.m. these swarms migrated downwards (Figure 2b).

Mean catch per hour of trawling was $\bar{m}(Q/hr)$ = 3.9 tonnes (Table 3). Catchability coefficient when targetting such aggregations was calculated to be **P** = 0.0605 (see Table 2).

It should be noted that a temporary redistribution of krill took place from 7 to 8 December. In daylight hours, krill adhered to depths less than 90 m and formed swarms of higher density:

$$\lambda_s = 1.38.10^{-4}\ m^{-2},\ \beta = 0.2089.$$

Catchability coefficient was calculated at **P** = 0.116. Catch per hour of trawling increased to $\bar{m}(Q/hr)$ = 7.5 tonnes. Catch per haul was $\bar{m}(Q)$ = 24.7 tonnes; σ_Q = 5.4 tonnes and trawling duration: $\bar{m}_t$ = 3.3 hours, σ_t = 1.0 hrs. Wind force rose to 4 and temperature dropped to below 0°C towards the end of the period (Figure 3a).

In Period II, mean krill length was from 44 to 47 mm and the sex-ratio of males and females was 0.99. The proportion of post-spawning males notably increased due to those maturing for the first and repeat times and also specimens at the "rest" stage (Figure 3b). A rise in the number of females with enlarged thoraxes due to maturation of eggs was observed. Krill feeding intensity reached its highest level (Figure 3d). Up to 80% of females had spermatophores.

The temporary redistribution of krill on 8 December, which changed the nature of the aggregation, coincides with a transition period in mating and feeding (see Figures 3b and 3f from 1-7 December to 8-15 December 1989).

(Period III) 9 December 1989 to 7 January 1990

The fishing ground shifted somewhat towards the west (Figure 1). Swarms were distributed over a wide range of depths and vertical migration was quite distinct (Figure 4). At night-time (23:00 to 2:00), krill formed sub-surface, sparse patches. In daylight hours column-shaped swarms having a vertical extent of up to 70 m were recorded.

Tables 2 and 3 show that the density of the targetted concentration was somewhat lower compared to the previous period. However, due to the increased catchability of the trawl, the value $\bar{\mathbf{m}}(\mathbf{Q/hr})$ practically remained the same and was equal to 3.99 tonnes.

Wind force for this period decreased to 2-3 on the Richter scale while water temperature ranged from 0° to +0.7°C (Figure 3a).

Mean length of krill in catches was 47.7 mm and the sex-ratio of males and females was 0.99. There was a continued increase in the proportion of mature males as well as females with an enlarged thorax (Figures 3b and 3c). Mature females were not encountered. Towards the end of the period, feeding intensity decreased notably judging by the drop in the proportion of specimens with dark and dark green livers. About 100% of females had spermatophores.

(Period IV) 8 to 28 January 1990

The fishing ground shifted somewhat to the south-east (Figure 5). Targetted krill swarms were recorded as "tracks" with clearly defined daily vertical migration. At night-time (from 0 to 2:30) krill formed a sub-surface, scattered layer. The formation of "tracks", which during daylight hours adhered to the 50 to 110 mm layer (Figure 6a), began as dawn approached.

Krill density was low with the average being $p_v = 2.21$ g/m³. However, due to the increase in trawling duration ($\bar{\mathbf{m}}_t = 4$ hrs) and the relatively high catchability of the trawl ($\mathbf{P} = 0.1252$), commercial catches were taken ($\bar{\mathbf{m}}(\mathbf{Q}) = 15.9$ tonnes $\sigma_Q = 5.5$ tonnes). Moreover, catch per hour of trawling was the same as before, being on average 3.98 tonnes (Tables 2 and 3).

Wind force for the period increased from 2 to 4 on the Richter scale and temperature rose from 0.7° to 1.2°C (Figure 3a).

Mean krill length increased to 49 mm and the sex ratio was 2.05.

Male sexual maturity was virtually the same (Figure 3b), although females underwent some significant physical changes (Figures 3b and 3g). Female gonads fully matured and spawning was able to take place. Feeding intensity reached its maximum level in this period (Figure 3e) and catches per hour trawling increased (Figure 3a).

(Period V) 29 January to 18 February 1990

Fishing grounds were the same as for the previous period (Figure 5).

Targetted aggregations were formed from large swarms (Table 2). In the daylight hours swarms turned into large irregularly shaped patches or dense, extended layers. At night-time, concentrations remained at depths of less than 40 m where krill formed a sub-surface, dense layer from smaller swarms or sparse patches. Daily vertical migration was clearly defined (Figure 6b).

Catch per hour of trawling was $\bar{m}(Q/hr)$ = 6.2 tonnes, while catch per haul was $\bar{m}(Q)$ = 19.6 tonnes.

Mean krill length increased to 50 mm and the sex ratio of males and females was 1.08.

Wind force reached 3 on the Richter scale and water temperature dropped to 0.7°C (Figure 3a). The proportion of post-spawning males decreased due to their entering the "rest" stage (Stage II). The number of females with hypertrophied thoraxes as well as those bearing eggs decreased notably (Figures 3c and 3d) while feeding intensity increased slightly. Catches per hour trawling on average increased (Figure 3a).

(Period VI) 19 to 27 February 1990

The fishing ground was the same as previously (Figure 5). During the day, swarms with varying density field λ_σ formed aggregations. It was observed that adjacent swarms formed concentrations. At night-time, the distributional pattern of krill was practically unchanged in comparison with the previous Period V.

High density (p_v = 12.2 g/m^3) and a high trawl catchability rate (**P** = 0.101) enabled large catches ($\bar{m}(Q)$ = 18.1 tonnes) to be taken when trawling duration was relatively short. Catches per hour trawling were $\bar{m}(Q/hr)$ = 12.2 tonnes.

Daily vertical migration of krill was down when compared with the previous period (Figure 7). Wind force increased to 3.5 and the temperature rose to 1.5°C. Catches per hour trawling reached their maximum levels (Figure 3a). The proportion of males entering the "rest" reproductive period also increased (Figure 3b). Almost all females spawned. Sex ratio was 1.08. Mean krill length was 49.8 mm.

4. DISCUSSION

Over the observation period from November 1989 to February 1990, all types of krill aggregations were recorded at the fishing grounds around Coronation Island in accordance with an established classification system (Kalinowski and Witek, 1985):

- scattered forms (Period I);
- swarms and irregular forms in daylight hours and scattered forms at night-time (Periods II and III);
- layers in daylight hours and scattered forms at night-time (Period IV);
- irregular forms in daylight hours and scattered forms at night-time (Period V); and
- fields of swarms in the daytime and scattered irregular forms at night-time (Period VI).

The tendency of krill aggregations to change from scattered krill to swarm field was established on the basis of data from hydroacoustic surveys conducted in the South Orkney area in the period from November 1989 to February 1990 and also from other years, e.g. November 1984 to February 1985 (Kasatkina, 1987). Table 4 shows how the mean daily krill catch over various periods varied from 35 to 46 tonnes.

With the variation in distribution of targetted krill aggregations there also occurred significant changes in catch-per-unit-effort and the catchability rate (Tables 2 and 3). For example, the spatial redistribution of krill from scattered aggregations (Period I) to dense fields of swarms (Period VI) together with increased biomass density (concentrations) and trawl catchability made it possible to obtain practically an identical mean daily catch even though almost five times less fishing effort was expended.

The results of our studies agree well with data from earlier hydroacoustic assessments of fishing gear catchability in relation to krill (Kadilnikov *et al.*, 1989). The latest assessments demonstrated that the midwater trawl catchability coefficient is a random value and is the function of behavioural and distributional characteristics of the target species and the specifications and structural elements of the trawl. Catch-per-unit-effort depends on the aggregation density of the target species and the catchability of the trawl.

A comparative analyses of the dynamics of change in distributional characteristics of krill aggregations with environmental conditions and krill's biological condition allows us to draw the following preliminary conclusion.

Wind force appeared to be normal (2 to 4) and apparently had neither direct nor indirect effect on the type of aggregations formed and their density.

Water temperature had no direct impact on krill distribution, although increased temperature towards the end of the observation period raised the temperature gradient of the thermocline which improves conditions for phytoplankton (Latogursky *et al.*, 1972). This in turn leads to an increase in swarm density.

Low catches and scatterred swarms in Period I were paralleled by the greatest number of mating males, the least number of mature females and the lowest levels of feeding intensity. It should therefore be supposed that intense mating behaviour and low levels of feeding activity compelled krill to become more mobile, thus determining aggregation type and density. As a consequence the fishery was quite successful.

The change in swarm type and the increase in catches in Period II was linked to a decrease in krill mobility which was determined by a sharp drop in reproductive activity and improved feeding conditions.

The formation of the above type of aggregations and the decrease in swarm density in Period III may be primarily the result of a temporary worsening of feeding conditions and the sharp reduction in the number of females with an enlarged thorax due to egg maturation. It is known that a deterioration of feeding conditions leads to krill being scattered (Latogursky, 1972). Moreover, sexual maturation of females at different times means that they will descend to deeper waters to spawn at different times. This leads to an increase in the vertical extent of swarms, i.e., a decrease in density.

The fourth observation period witnessed an acute rise in surface water temperature, a much larger proportion of spawning females, a predominance of males over females by two to one and also the beginning of spawning. The increase in krill mean length to 49 mm and the increase in the number of spawning females should have significantly increased krill biomass on the fishing ground. Despite some negative factors, such as the increase in the number of males in catches (they are more mobile than females), the overall result was nevertheless positive and catches started to increase towards the end of this period.

In Period V the proportion of post-spawning males and females grew against a background of continued increased feeding activity and larger krill size. This facilitated the increase in aggregation density, krill biomass and, consequently, catch-per-unit-effort.

The type of aggregations observed in Period VI may be linked to the continued increase in the proportion of males and females feeding intensely who went into the "rest" reproductive stage (Stage II in males, non-enlarged thorax in females). This evidently enabled males and females of the same size groups to form separate swarms.

5. CONCLUSIONS

It may be concluded that in general a relationship exists between types of aggregations and the biological condition of krill within those aggregations. However, the results obtained should be regarded as preliminary since only data from one season have been examined.

Distributional characteristics of krill swarms change markedly over time in the fishing ground. This factor varies the catchability of the midwater trawl and affects the size of the catch-per-unit-effort. Therefore, when estimating CPUE using modelling it is essential, in our opinion, to examine the real distributional characteristics of krill in targetted aggregations and the catchability coefficients of the midwater trawls used during various periods of the fishery.

REFERENCES

Иванова, И.Ф. Оценка сравнительной эффективности работы двух тралов по результатам их промыслового использования. Доступность морских промысловых объектов для орудий лова и технических средств наблюдений. //Тр. АтлантНИРО, Калининград, АтлантНИРО, 1988: 23-30.

Касаткина, С.М. Результаты гидроакустической оценки характеристик распределения скоплений эвфаузиид в западно-атлантическом секторе Южного океана. //Тез. доклада II Всесоюзного совещания сыревые ресурсы Южного океана и проблемы их рационального использования. Керчь, 1987: 87-88.

Касаткина, С.М., Мысков А.С. Некоторые данные о скорости движения эвфаузиид. //Тез. докладов II Всесоюзного совещания сыревые ресурсы Южного океана и проблемы их рационального использования. Керчь, 1987: 89-90.

Латогурский, В.И., Баринов А.А., Первушин А.С. Вертикальное распределение *Euphausia superba* Dana и термоклин. Поведение водных беспозвоночных. //Материалы Первого Всесоюзного симпозиума. Борок, 1972: 72-79.

Латогурский, В.И. Об образовании поверхностных скоплений *Euphausia superba* Dana //Труды АтлантНИРО. Т. 42. Калининград, 1972: 126-132.

Оценка характеристик распределения промысловых объектов. //Методические указания. Калининград, АтлантНИРО, НПО Промрыболовство, 1985: 71.

ANON. 1984. Post-FIBEX Acoustic Workshop. Frankfurt, Federal Republic of Germany, September, *BIOMASS Rept. Ser. No. 40*: 106.

MILLER, D.G.M. and I. HAMPTON. 1989. Krill aggregation characteristic: spatial distribution patterns from hydroacoustic observations. *Polar Biology, 10* (2).

ENDO, Y. and T. ICHII. 1989. *CPUEs, Body Length and Growth of Antarctic Krill During 1987/88 Season on the Fishing Ground North of Livingston Island.* WS-KCPUE-89/8. Hobart, Australia: CCAMLR.

GODLEWSKA, M. and Z. KLUZEK.1988. The Density structure of krill aggregations and their diurnal and seasonal changes (BIOMASS III, October-November 1986 and January 1987). *Polish Polar Research*: 357-366.

KADILNIKOV, YU.V., S.M. KASATKINA., V.F. IVANOVA and A.S. MYSKOV. 1989 *Assessment of Krill Biomass in Fishing Grounds Using the Data on Fishing Intensity and Hydroacoustic Method.* SC-CAMLR-VIII/BG/10. Hobart, Australia: CCAMLR.

KALINOWSKI, J.M. and Z. WITEK. 1985. Scheme for classifying aggregation of Antarctic krill. *BIOMASS Handbook, 27*: 9.

KALINOWSKI, J.M.and Z. WITEK. 1982. Forms of Antarctic krill aggregations. *ICES Biol. Oceanogr. Comm. Memo C. M. 1982/L:60*: 8.

KASATKINA, S.M. 1989. Acoustic studies of catchability by midwater trawl of slow and fast moving commercial species. *Proceedings of the Institute of Acoustics, 11*, Part 3. ISBN Number 0946731 83.

SMITH, S.J. 1980. Comparison of two methods of estimating the variance of the estimate of catch-per-unit-effort. *Can. J. of Fish. Ag. Sci., 37* (12): 2346-2351.

WILLIAM, M. and J. HAMNER. 1984 Aspects of schooling in *Euphausia superba*. *Journal of Crustacean Biology, 4*, Sp. Number 1: 25-42.

Table 1: Specifications for trawl type 74/416.

Element	Value
Vertical opening in the trawl bag	42 m
Vertical opening of fine-meshed insertion	9.5 m
Horizontal opening of fine-meshed insertion	9.5 m
Horizontal opening between doors	56 m
Horizontal opening between trawl wings	33 m
Trawl length along shift from wing tips to fine-meshed insertion	141 m
Length of cable with tow legs	100 m
Trawling speed	3.0 to 3.3 knots
Length of trawl board	4 m
Mesh bar of bag netting	12 mm

Table 2: Mean values of krill distribution parameters and catchability of the 74/416 trawl in the fishing grounds off Coronation Island.

Parameter	Periods					
	18 November to 3 December 1989	4 December to 18 December 1989	19 December 1989 to 7 January 1990	8 January to 28 January 1990	29 January to 18 February 1990	19 February to 27 February 1990
Swarm distribution - mean layer depth (m)		100	95	100	77	70
Mean vertical extent of swarms (m)		15	18	5	17	19
Standard deviation of vertical extent of swarms (m)		4	7	2	6	8
Mean horizontal length of swarms (m)		72	89	28	89	75
Standard deviation of horizontal extent of swarms (m)		21	25	12	23	18
Mean swarm diameter (m) [it is assumed that swarms are of a cyclindrical shape]		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
Relative density of swarms in 3-dimensional space, β		0.0298	0.0982	0.2796	0.188	0.168
Density of a field of swarms in 2-dimensional space λ_s		2.98×10^{-5}	4.78×10^{-5}	5.4×10^{-3}	7.52×10^{-5}	1.11×10^{-5}
Mean krill density p_V, g/m^3 (calculated estimate)		4.49	4.07	2.20	5.88	9.46
Calculated estimate of total catchability of a 74/416 trawl		0.0605	0.068	0.1253	0.0807	1.101

Table 3: Results of targetting krill aggregations off Coronation Island.

Parameter	Periods					
	18 November to 3 December 1989	4 December to 18 December 1989	19 December 1989 to 7 January 1990	8 January to 28 January 1990	29 January to 18 February 1990	19 February to 27 February 1990
Mean catch per haul (tonnes)	13.4	15.1	13.3	15.9	19.6	18.1
Standard deviation of catch per haul (tonnes)	6.6	5.8	5.3	6.5	5.4	5.7
Mean trawling duration (hrs)	5.8	3.8	3.3	4.0	3.2	1.4
Standard deviation of hauling duration (hrs)	2.5	1.5	1.3	2.5	1.0	0.6
Mean catch per hour trawling (tonnes)	2.15	3.93	3.99	3.98	6.22	12.2
Relative error of mean catch per hour of trawling	0.21	0.209	0.195	0.157	0.138	0.277

Table 4: Daily krill catch and expended fishing effort.

Parameter	Periods					
	18 November to 3 December 1989	4 December to 18 December 1989	19 December 1989 to 7 January 1990	8 January to 28 January 1990	29 January to 18 February 1990	19 February to 27 February 1990
Mean daily catch (tonnes)	34.8	35	35	44.0	46.1	37.8
Standard deviation of daily catch	19.1	13.2	13.2	18.1	12.7	11.9
Mean fishing effort expended over 24 hours (hrs)	15.6	10.7	8.8	11.2	7.4	3.1
Standard deviation of mean fishing ffort expended over 24 hours (hrs)	6.5	4.1	3.4	3.5	2.9	1.4

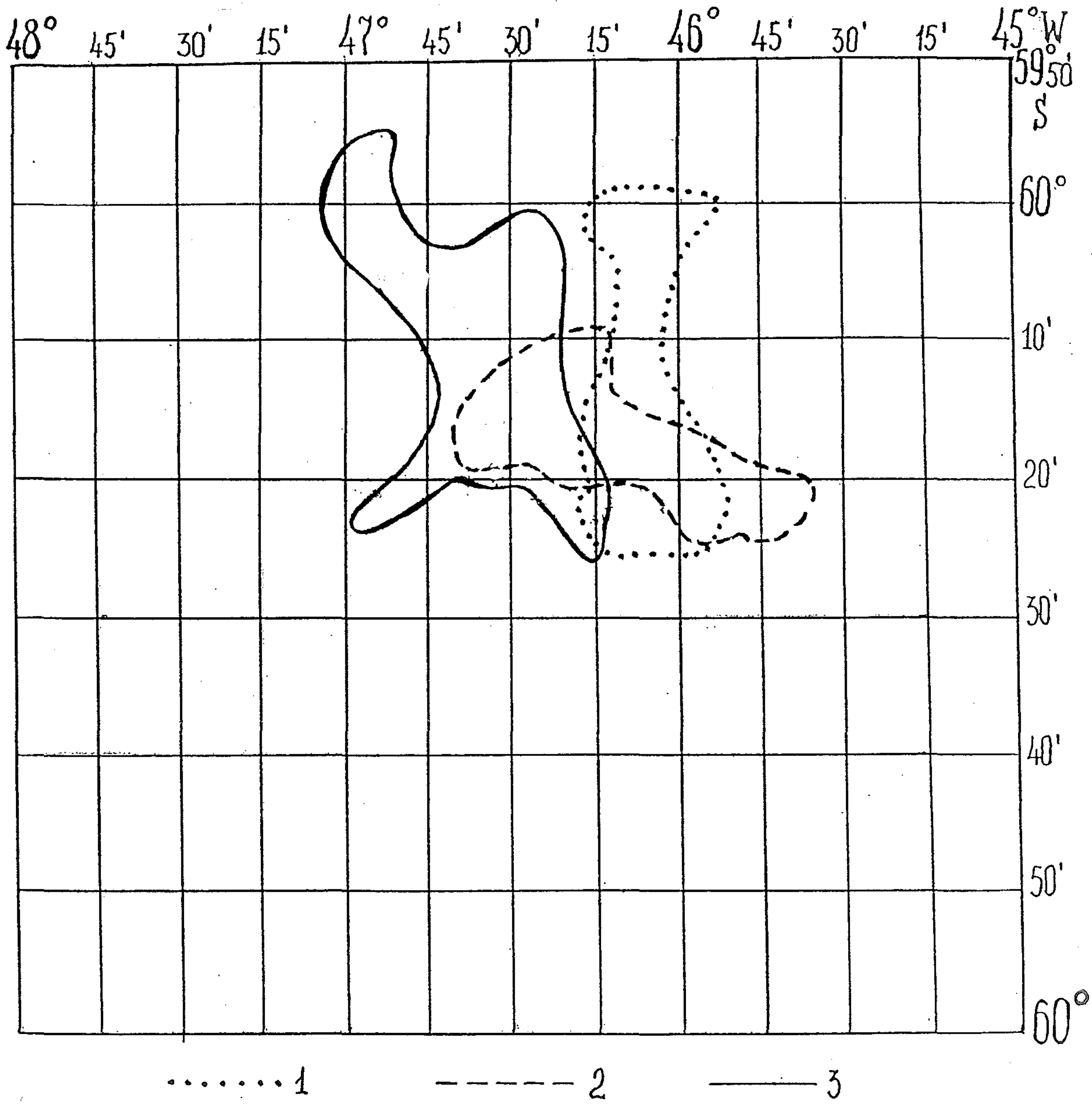


Figure 1: Fishing grounds in the Coronation Island area from 18 November 1989 to 7 January 1990.
Period I: 18 November to 3 December
Period II: 4 to 18 December
Period III: 19 December to 7 January.

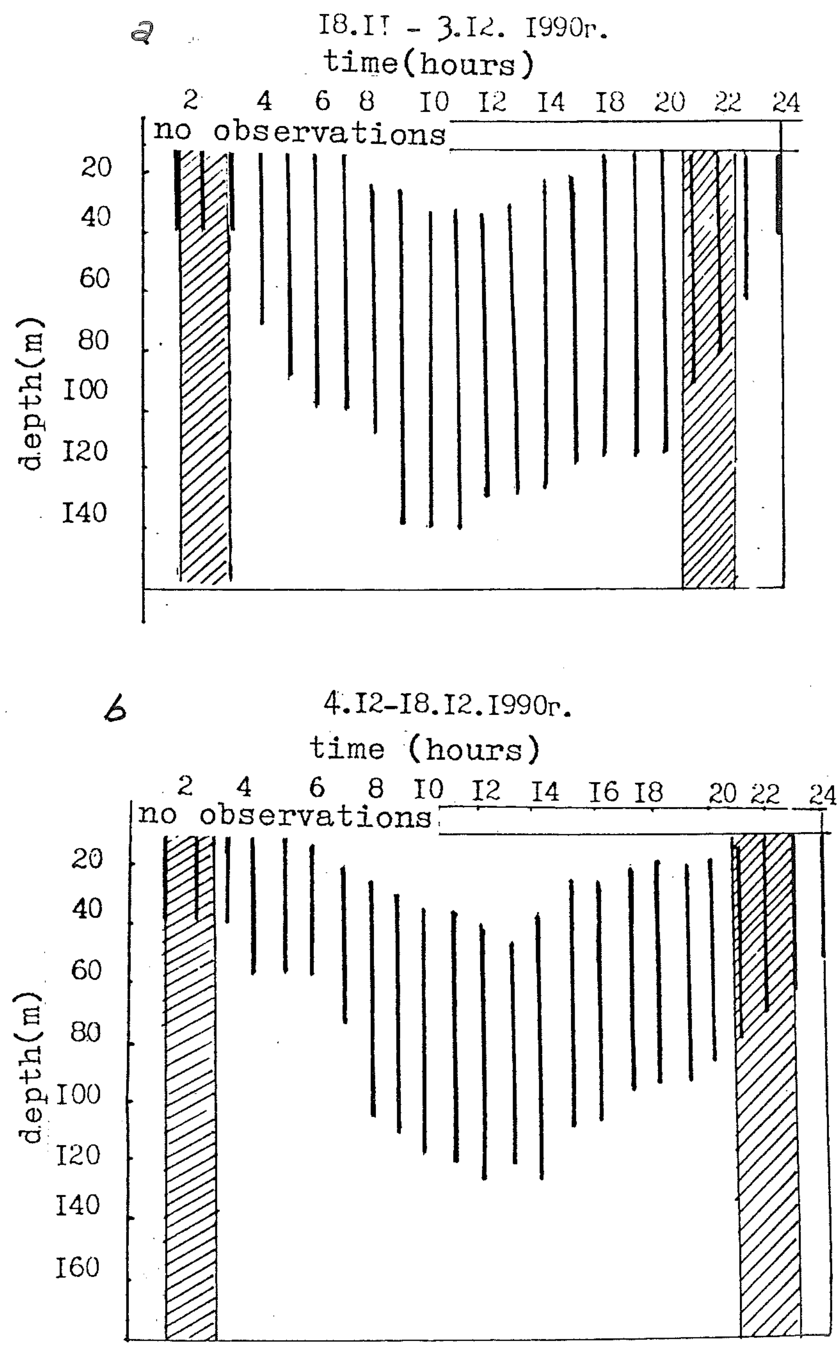


Figure 2: Daily vertical distribution of krill.
(a) from 18 November to 3 December 1989
(b) 4 to 18 December 1989
Shaded area represents dawn and dusk

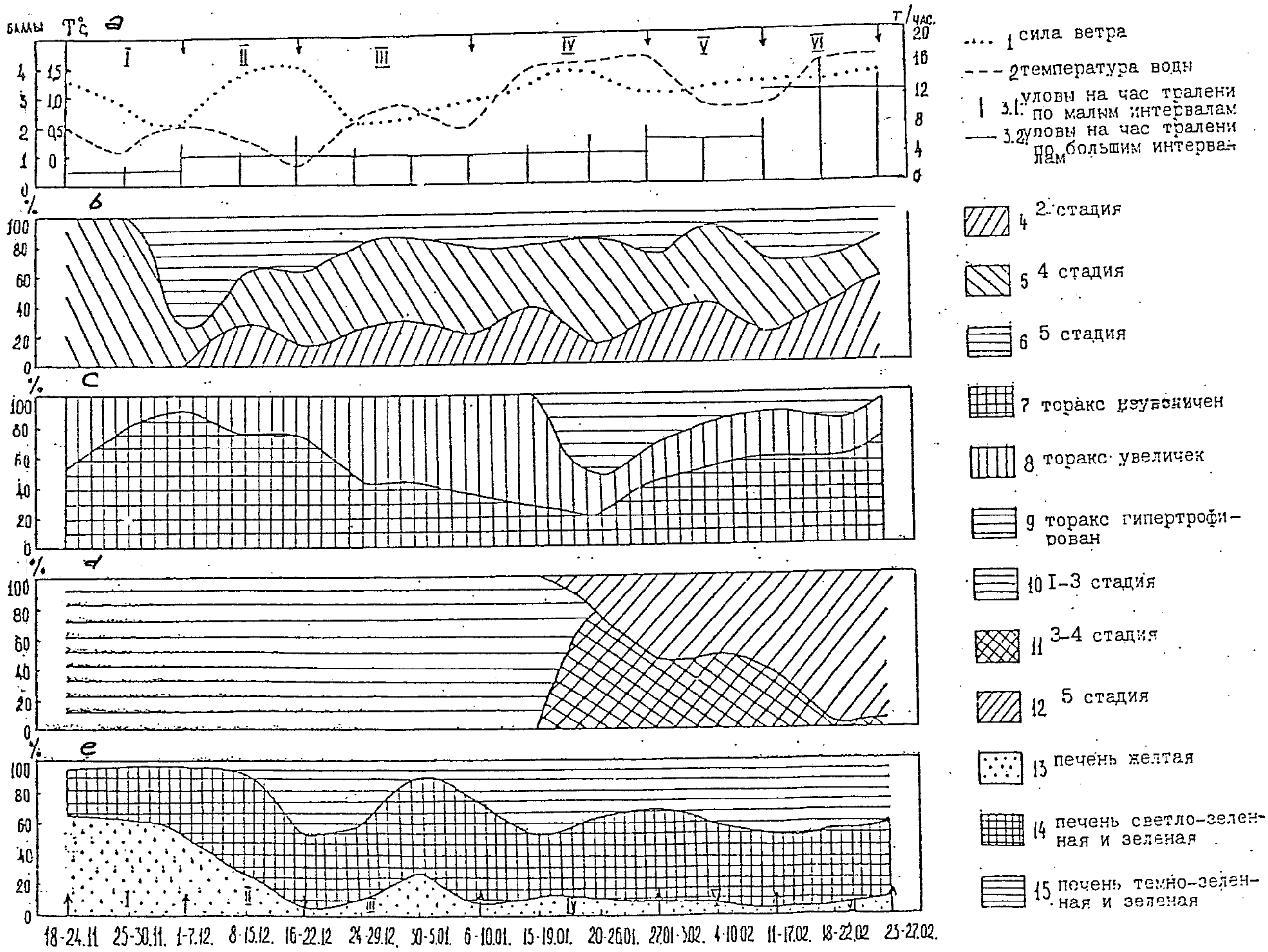


Figure 3: Wind force, water temperature in the 5 to 6 m layer.
(a) catches per hour of trawling; (b) male maturity stages; (c) female thorax condition; (d) female maturity stages; (e) krill feeding intensity.

1 - wind force
2 - water temperature
3.1 - catches per hour of trawling over short intervals
3.2 - catches per hour of trawling over long intervals
4 - Stage II
5 - Stage IV
6 - Stage V
7 - thorax not enlarged
8 - thorax enlarged
9 - hypertrophied thorax
10 - Stages I-III
11 - Stages III-IV
12 - Stage V
13 - liver yellow
14 - light-green/green liver
15 - dark-green/green liver

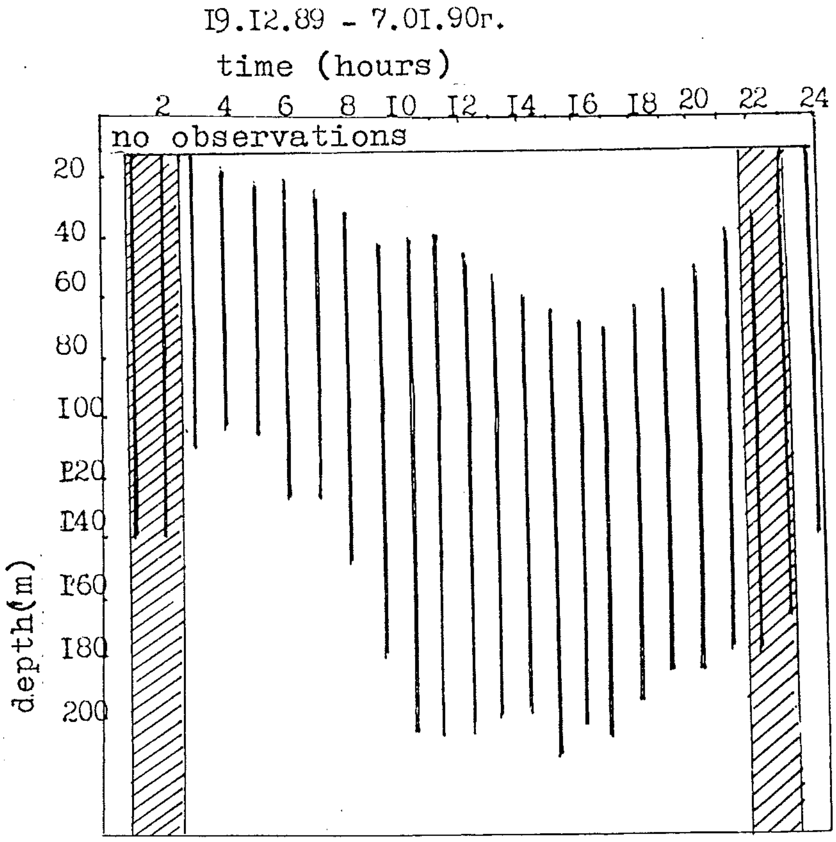


Figure 4: Daily vertical distribution in the fishing ground off Coronation Island, 19 December 1989 to 7 January 1990.

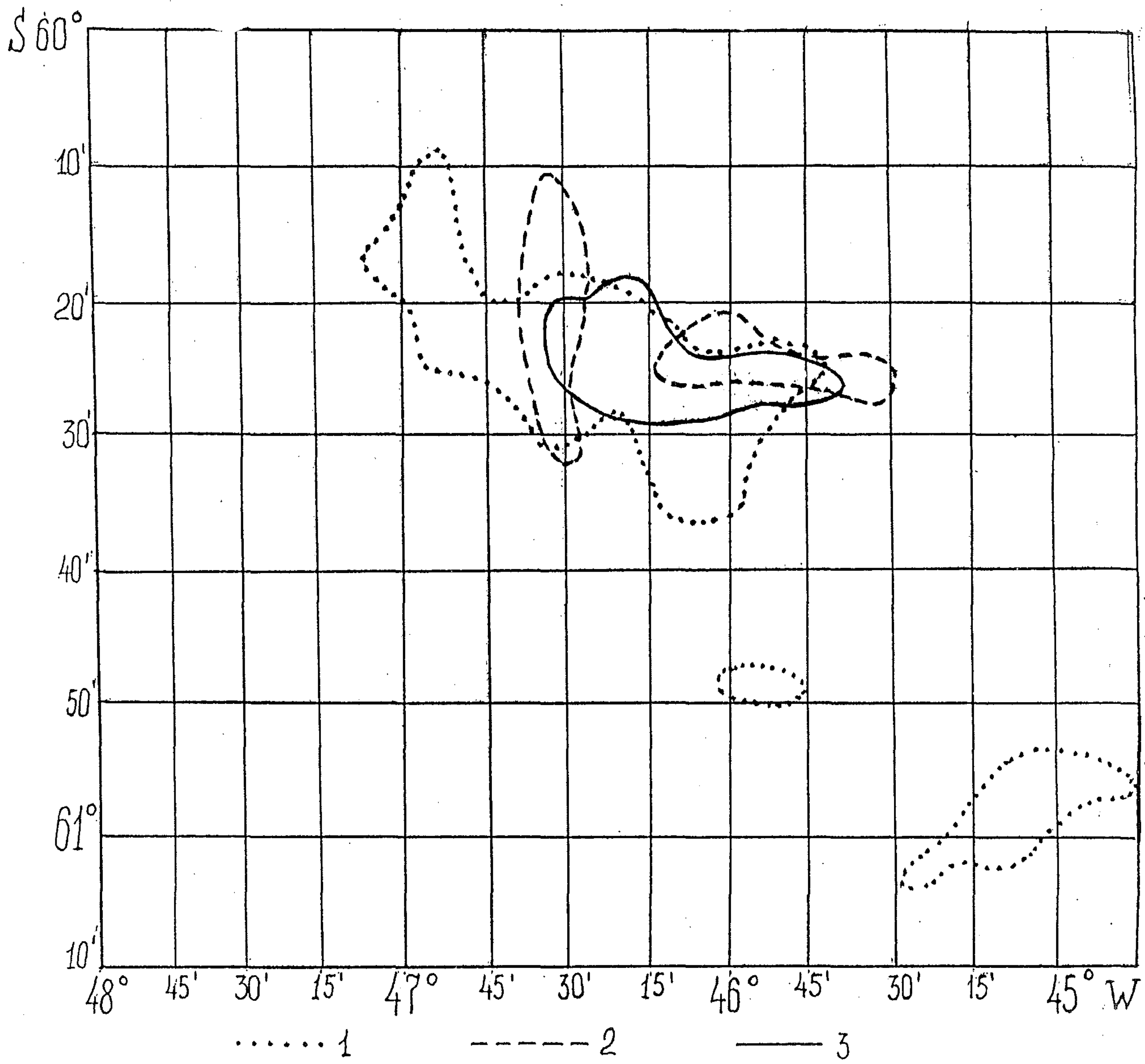
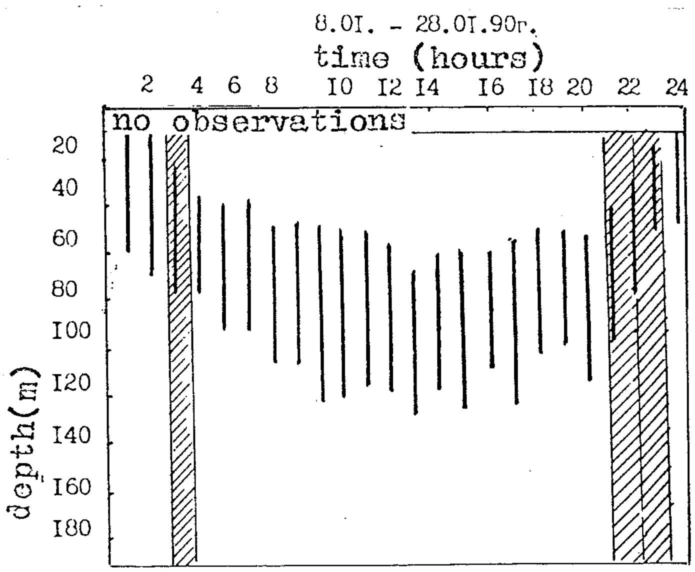


Figure 5: Fishing grounds off Coronation Island, 8 January to 27 February 1990.
Period I: 8 to 28 January
Period II: 29 January to 18 February
Period III: 19 to 27 February



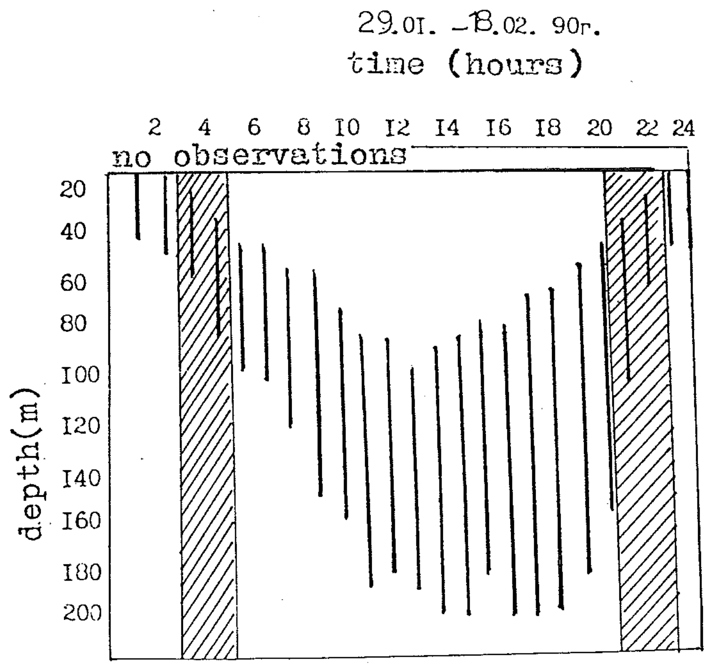


Figure 6: Daily vertical distribution of krill.
(a) 8 to 28 January 1990
(b) 29 January to 18 February 1990
Shaded area represents dawn and dusk

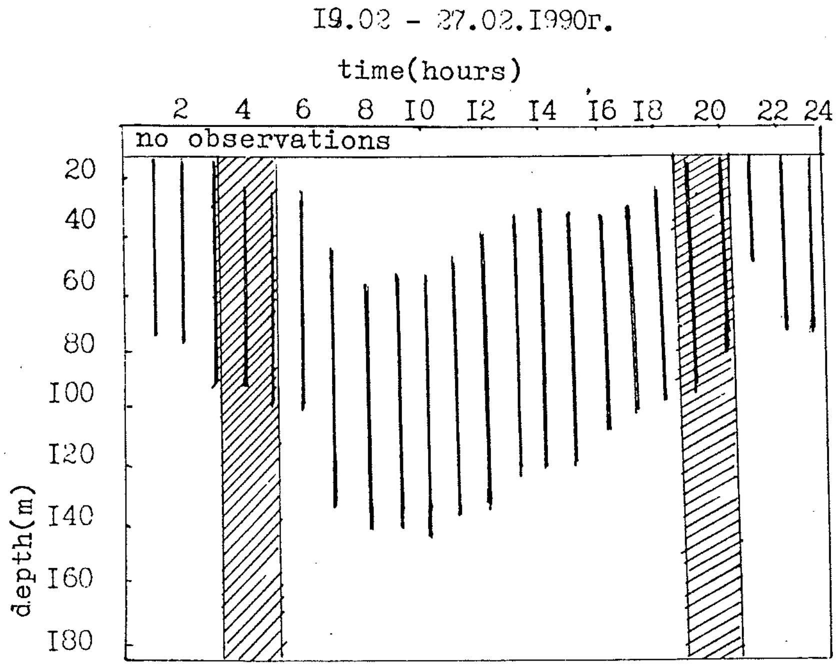


Figure 7: Daily vertical krill distribution in the fishing ground off Coronation Island, 19 to 27 February 1990.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

8 - tórax aumentado.
9 - tórax hiperatrofiado.
10 - fase I - III.
11 - fase III - IV.
12 - fase V.
13 - hígado amarillo.
14 - hígado verde y verde claro.
15 - hígado verde y verde oscuro.

Figura 4: Distribución vertical diaria del krill en el caladero de pesca de la isla Coronación, del 19 de diciembre 1989 al 7 de enero 1990.

Figura 5: Caladeros de pesca de la isla Coronación, del 8 de enero al 27 de febrero 1990.
Período I: 8 al 28 de enero.
Período II: 29 de enero al 18 de febrero.
Período III: 19 al 27 de febrero.

Figura 6: Distribución vertical diaria del krill.
(a) 8 al 28 de enero 1990
(b) 29 de enero al 18 de febrero 1990
Las zonas oscuras corresponden a las horas del crepúsculo.

Figura 7: Distribución vertical diaria del krill. Caladeros de pesca de la isla Coronación, del 19 al 27 de febrero de 1990.

MEASUREMENTS OF DIFFERENCES IN THE TARGET STRENGTH OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA*) SWARMS AT 38 KHZ AND 120 KHZ

I. Hampton*

Abstract

Differences in the target strength of adult (36 to 60 mm) Antarctic krill (*Euphausia superba*) at 38 and 120 kHz have been inferred from differences in the mean back-scattering strength of swarms simultaneously insonified at these two frequencies in studies off the South Orkneys and Elephant Island in March 1990. Back-scattering strengths at 120 kHz ran consistently about 7 dB higher than at 38 kHz, a difference which was regarded as too large to be explained by possible experimental error, and which was therefore attributed to real differences in average target strength at these two frequencies. The results are in good agreement with recent experimental work on the target strength of encaged *E. superba* at 38 and 120 kHz but are in major conflict with the 120 kHz - to - 50 kHz target strength conversion factor used at the Post-FIBEX Acoustic Workshop in 1984.

Résumé

Les différences d'intensité de réponse acoustique du krill antarctique (*Euphausia superba*) adulte (36 à 60 mm) à 38 et 120 kHz ont été inférées à partir des différences d'intensité moyenne de rétrodiffusion d'essaims insonifiés simultanément à ces deux fréquences dans des études au large des Orcades du Sud et de l'île Eléphant en mars 1990. A 120 kHz, les intensités de rétrodiffusion étaient constamment de 7 dB plus élevées qu'à 38 kHz; cette différence, considérée comme étant trop importante pour pouvoir s'expliquer par une erreur possible d'expérimentation, doit donc être attribuée à des différences réelles dans la réponse acoustique moyenne à ces deux fréquences. Les résultats concordent bien avec de récents travaux expérimentaux sur la réponse acoustique d'*E. superba* en enceinte à 38 et 120 kHz, mais sont en contradiction totale avec le facteur de conversion de la réponse acoustique de 120 kHz-à-50kHz utilisé à l'Atelier acoustique Post-FIBEX de 1984.

Резюме

Различия в силе акустической цели взрослого (30-60 мм) антарктического криля (*Euphausia superba*) при частоте в 38 и 120 кГц были определены по различиям в средней силе обратного акустического рассеяния скоплений, одновременно исследуемых эхолотом, работающим на данных частотах, в ходе исследований криля в районе Южных Оркнейских островов и острова Элефант в марте 1990 г. Величины силы обратного акустического рассеяния при

* Sea Fisheries Research Institute, Private Bag X2, Roggebaai, 8012, South Africa

частоте в 120кГц постоянно превышали величины, полученные при частоте в 38 кГц, приблизительно на 7 дБ. Эта разница была признана слишком значительной для того, чтобы отнести ее на счет возможных погрешностей в эксперименте, поэтому она была признана следствием реальных различий в средней силе акустической цели при этих двух частотах. Результаты хорошо согласуются с теми, которые были получены недавно в ходе экспериментальных работ по определению силы акустической цели помещенного в садок криля *E. superba* при частотах в 38 и 120 кГц, но в значительной мере противоречат коэффициенту пересчета силы акустической цели 120-50 кГц, использованному на Рабочем семинаре по акустике, проведенном в 1984 г. по завершении программы FIBEX.

Resumen

De los estudios realizados cerca de las islas Elefante y Orcadas del Sur durante marzo de 1990, se dedujeron las diferencias que ocurren en la potencia del blanco del krill antártico adulto (36-60 mm) (*Euphausia superba*), al emplear frecuencias de 38 y 120 kHz y considerando las diferencias en la potencia media de retrodispersión obtenida de los cardúmenes sondeados simultáneamente en ambas. Las potencias de retrodispersión a 120 kHz permanecieron constantes alrededor de 7 dB más altos que las obtenidas a 38 kHz, diferencia que se consideró demasiado grande para poder interpretarla como un error experimental, y por lo tanto se atribuyó a diferencias reales en la potencia promedio del blanco que ocurren en estas frecuencias. Los resultados concuerdan con un trabajo experimental reciente sobre la potencia del blanco de *E. superba* en captividad, donde se emplearon frecuencias de 38 y 120 kHz pero existe una gran disparidad con el factor de conversión de la potencia del blanco de 120 kHz a 50 kHz utilizado en el taller acústico realizado con posterioridad a FIBEX en 1984.

---

1. INTRODUCTION

Acoustic surveys of krill (*Euphausia superba*) abundance have commonly been conducted at echosounder frequencies of between 50 and 200 kHz, with 120 kHz being probably the most common frequency (Miller and Hampton, 1989). Knowledge of the frequency-dependence of krill target strength, and in particular, of the relation between target strength at 120 kHz and that at other commonly used frequencies, is therefore necessary for comparing and combining abundance estimates made at different frequencies.

To date the most controlled comparison of the frequency-dependence of *E. superba* target strength is one made by Foote *et al.* (1990) on live animals at South Georgia. Target strengths at 38 and 120 kHz were estimated by measuring the strength of the back-scatter from aggregations of encaged animals which varied in mean length from 30 to 39 mm. Calculated target strengths at 120 kHz were some dB higher than at 38 kHz, in general agreement with predictions from a fluid sphere theoretical model of Greenlaw (1979).

The present study was carried out on wild *E. superba* aggregations encountered off Coronation Island, South Orkneys and Elephant Island, South Shetlands, in March 1990 from

RS *Africana*, a 78-m research stern-trawler of the Sea Fisheries Research Institute, Cape Town, South Africa. The study was part of a broader investigation into krill aggregating and distribution patterns in these two regions.

Data were collected between 7 and 10 March from the edge of the shelf to the north-west of Coronation Island, and on 16 March from the north-western shelf edge of Elephant Island. Aggregations were simultaneously insonified at 38 and 120 kHz. Differences in average target strength at these two frequencies were computed from differences in the average strength of the back-scatter between the same vertical and horizontal limits.

2. MATERIALS AND METHODS

Simrad EKS-38 and EKS-120 echosounders were used. The transducers were hull-mounted 6 m below the surface, some 40 cm apart on the same stabilized platform. The combined Source Level and Voltage Receiving Sensitivity (SL + VRS) for both sounders was measured to within an estimated ± 0.5 dB by calibration with a standard copper sphere (Foote, 1983) immediately prior to the cruise. These values and other relevant calibration data for each sounder are shown in Table 1. The SL + VRS value for each sounder agreed to better than 1 dB with figures obtained by similar calibrations of these two sounders over the past three years. Spot checks on SL and VRS made before, during and after the cruise with a built-in hydrophone monitor indicated that the sounders were each probably stable to within 1 dB during the cruise.

The sounders were synchronized with each other and the echo signals fed into a dual-input, custom-built digital integrator and storage system where multi-channel echo-integration could be performed (Anon., 1986). In one system (System A), signals exceeding a pre-set threshold were integrated in real time in 5-m channels while in the other (System B) the entire echo-envelope, if exceeding the same threshold, was stored and subsequently integrated off-line. Integrations were restricted to the upper 100 m, the maximum range of the EKS-120 internal TVG (Time-Varied-Gain).

Corrections for TVG imperfections were applied at both frequencies, using measurements of receiver gain corresponding to 5-m depth channels between 5 and 100 m. For each integration interval the correction was taken as that applicable to the 5-m channel in which the acoustic back-scatter during the interval was strongest. The corrections were generally of the order of ± 1 dB, ranging from -1.40 dB at 35 m for the EKS-38 to +1.38 dB at 35 m for the EKS-120. The residual TVG-related error in back-scattering strength after correction was considered to be less than ± 0.5 dB at both frequencies.

Back-scatter comparisons, measured in terms of the Mean Surface Back-Scattering Strength (MSBS) were restricted to integration intervals where substantial and unmistakeable krill targets were detected. Initially the 38 kHz signal was integrated through System A and the 120 kHz signal through System B. Later, the inputs were interchanged to balance out the effect of possible differences in the two integrator systems. One integration was done between 5 and 100 m over an interval in which no krill were evident on either sounder in the upper 100 m, to check the level and frequency-dependence of the noise background.

Three aimed trawls were made with a commercial midwater trawl in the general area of the Coronation Island study, to identify targets and collect length distribution information. Two such trawls were also made in the Elephant Island study region.

3. RESULTS

Krill in both areas were generally found in discrete swarms which were clearly recorded to at least 200 m on both sounders (e.g., Figures 1 and 2). Fifteen comparable integration intervals were selected from the Coronation Island area and five from the Elephant Island region. The intervals varied in duration but were typically about 15 minutes long. Most intervals contained between 1 000 and 1 500 pings. In all, about 200 discrete swarms were recognizable in the former data set and about 50 in the latter.

The TVG-corrected MSBS values at 38 and 120 kHz and the differences between them (Δ MSBS) are shown for both sets of intervals in Table 2, and are plotted in Figure 3. The frequency change-over point is shown in both. Table 2 also shows the noise background at both frequencies (Interval 470).

It can be seen from Figure 3 that the MSBS values at the two frequencies track each other extremely well, with the 120 kHz values running some 7 dB higher throughout. The mean difference in MSBS (Δ MSBS), computed by averaging the anti-logs of the Δ MSBS values, was 7.1 dB off Coronation Island and 6.9 dB off Elephant Island. The noise background was some 8 dB below the lowest MSBS value, and furthermore did not exhibit the same frequency-dependence as the data from the krill, so it can be discounted as a source of error. Similarly, there was no noticeable difference in Δ MSBS when the frequencies were interchanged, removing any fear that the differences were an artefact of differences in the two integration systems.

Length frequencies for the three samples taken off Coronation Island are shown in Figure 4, and for the two Elephant Island samples in Figure 5. Mean lengths in the two area were 48.75 and 45.98 mm respectively.

4. DISCUSSION

The prime concern is whether the differences in back-scattering strength at the two frequencies are due to a real difference in average target strength at these frequencies, or to some experimental artefact. Because of the closeness of the transducers, essentially the same targets would have been insonified at both frequencies (ignoring random differences caused by any small time delay between firing of the two transmitters), so differences from this sources, which would in any event have been random, can be discounted. The only other artefact could have come from a gross error in the calibration of one or both of the sounders. However, in view of the accuracy achievable in sphere calibration of the SL + VRS parameter (conservatively ± 0.5 dB), the consistency of the hydrophone spot checks, and the agreement with previous sphere calibrations of the sounders (see Methods section), a corss-calibration error as large as 7 dB is considered to be highly unlikely. Even allowing for an error of 0.5 dB in the estimation of SL + VRS, and for the same error in the equivalent beam factor and in the TVG correction, gives an upper limit of only 1.5 dB for error in each system and a maximum calibration error of 3.0 dB in any comparison between them. The MSBS differences obtained can therefore be regarded as significant, indicative of a real target strength difference at the two frequencies.

The MSBS differences are in the same sense of the same order as those obtained by Mathisen and Macaulay (1983) in their investigations on the back-scattering from swarms of *E. superba* at 50 and 120 kHz, which suggests a target strength some 3 dB higher at 120 kHz than at 50 kHz. Furthermore, the differences are in good agreement with Foote *et al.*'s (1990) recent results from their cage experiments on *E. superba* target strength at 38 and 120 kHz. For their largest animals (mean length 39.4 mm), which were the closest in size to those in the present study, they obtained a mean target strength 8.2 dB higher at 120 kHz than at 38 kHz (Event 17, their Table I). Their computed theoretical difference for animals of this size, which they obtained by substituting their own sound-speed and density-contrast measurements into Greenlaw's (1979) fluid sphere scattering cross-section model, was 4.2 dB (Event 17, their Table III).

The increase in target strength with frequency is however in major disagreement with Kristensen's (1983) target strength spectrum for 40 mm tethered euphausiids in dorsal aspect, which shows a decrease in target strength of some 5 to 6 dB as frequency increases from 38 to 120 kHz (see Miller and Hampton, 1989, Figure 16). Kristensen's spectrum was used at the Post-FIBEX (First International Biomass Experiment) Acoustic Workshop in 1984 (BIOMASS, 1986) to develop a target strength/length relationship at 50 kHz from the one used for 120 kHz data. The result was to raise target strengths at 50 kHz by 5.5 dB compared to those at 120 kHz. Use of the present data, assuming that target strength differences between 38 and 50 kHz are small, would have resulted in all FIBEX density estimates made at 50 kHz being raised by 12.5 dB, an increase of 17.7 fold, amply demonstrating the importance of obtaining reliable *in situ* information on krill target strength spectra.

ACKNOWLEDGEMENTS

I gratefully acknowledge the input of Denzil Miller, Chief Scientist on *Africana*, into this study, and that of Johann Augustyn, Roger Hewitt, Mark Prowse and Rob Leslie in collecting the data.

REFERENCES

ANON. 1986. Research ship *Africana. Spec. Rep. Sea Fish. Res. Inst. S, Afr. 3*: 80.

BIOMASS. 1986. *BIOMASS Report 40.* Post-FIBEX Acoustic Workshop, Frankfurt, Federal Republic of Germany, September 1984. pp. 106.

FOOTE, K.G. 1983. Use of elastic spheres as calibration targets. In: NAKKE, O. and S.C. VENEMA (Eds). *Symposium on Fisheries Acoustics. FAO Fish. Rept. 300*: 52-58.

FOOTE, K.G., I. EVERSON, J.L. WATKINS and D.G. BONE. 1990. Target strength of Antarctic krill (*Euphausia superba*) at 38 and 120 kHz. *J. Acoust. Soc. Am. 87*: 16-24.

GREENLAW, C.F. 1979. Acoustic estimation of zooplankton populations. *Limnol. Oceanogr. 24*: 226-242.

KRISTENSEN, A. 1983. Acoustic classification of zooplankton. PhD Thesis: University of Trondheim, pp. 212. (Published as Report STF 44 A83187 of the Electronic Research Laboratory, Department of Electrical Engineering, University of Trondheim.)

MATHISEN, O.A. and M.C. MACAULAY. 1983. The morphological features of a super-swarm of krill, *Euphausia superba. Mem. Natl. Inst. Polar Res. Spec. Issue 27*: 153-164.

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill (*Euphausia superba* Dana). A review. *BIOMASS Sci. Ser. 9*: 166.

Table 1: Calibration data for EKS-38 and EKS-120 echosounders.

	38 kHz	120 kHz
SL + VRS (dB)	128.3	115.8
Pulse duration (ms)	0.90	1.00
Equivalent ideal beam factor (dB)	-19.6*	-18.0*
Absorption coefficient (dB/km)	10.5	40.0

* From manufacturer's specifications

Table 2: Mean surface back-scattering strength at 38 kHz (MSBS-38) and 120 kHz (MSBS-120), and the difference between them (MSBS) for all intervals.

Interval Number	MSBS-38 (dB)	MSBS-120 (dB)	MSBS (dB)
Coronation Island			
269	-46.1	-40.7	5.4
271	-55.3	-48.4	6.9
272	-55.1	-47.9	7.2
273	-47.7	40.7	7.0
274	-47.2	-40.9	6.3
275	-44.1	-37.5	6.6
276	-54.7	-48.1	6.6
277	-56.0	-47.4	8.6
279	-52.7	-45.0	7.7
280	-44.8	-37.7	7.1
281	-46.8	-40.0	6.8
282	-50.4	-43.7	6.7
Inputs Interchanged			
283	-50.5	-42.6	7.9
290	-46.4	-37.7	8.7
291	-46.8	-39.4	7.4
Mean			7.1
Elephant Island			
442	-44.7	-37.3	7.4
443	-54.9	-49.1	5.8
447	-51.5	-45.8	5.7
448	-53.4	-45.7	7.7
466	-55.8	-47.4	8.4
Mean			6.9
470 (Noise)	-63.2	-64.8	-1.6

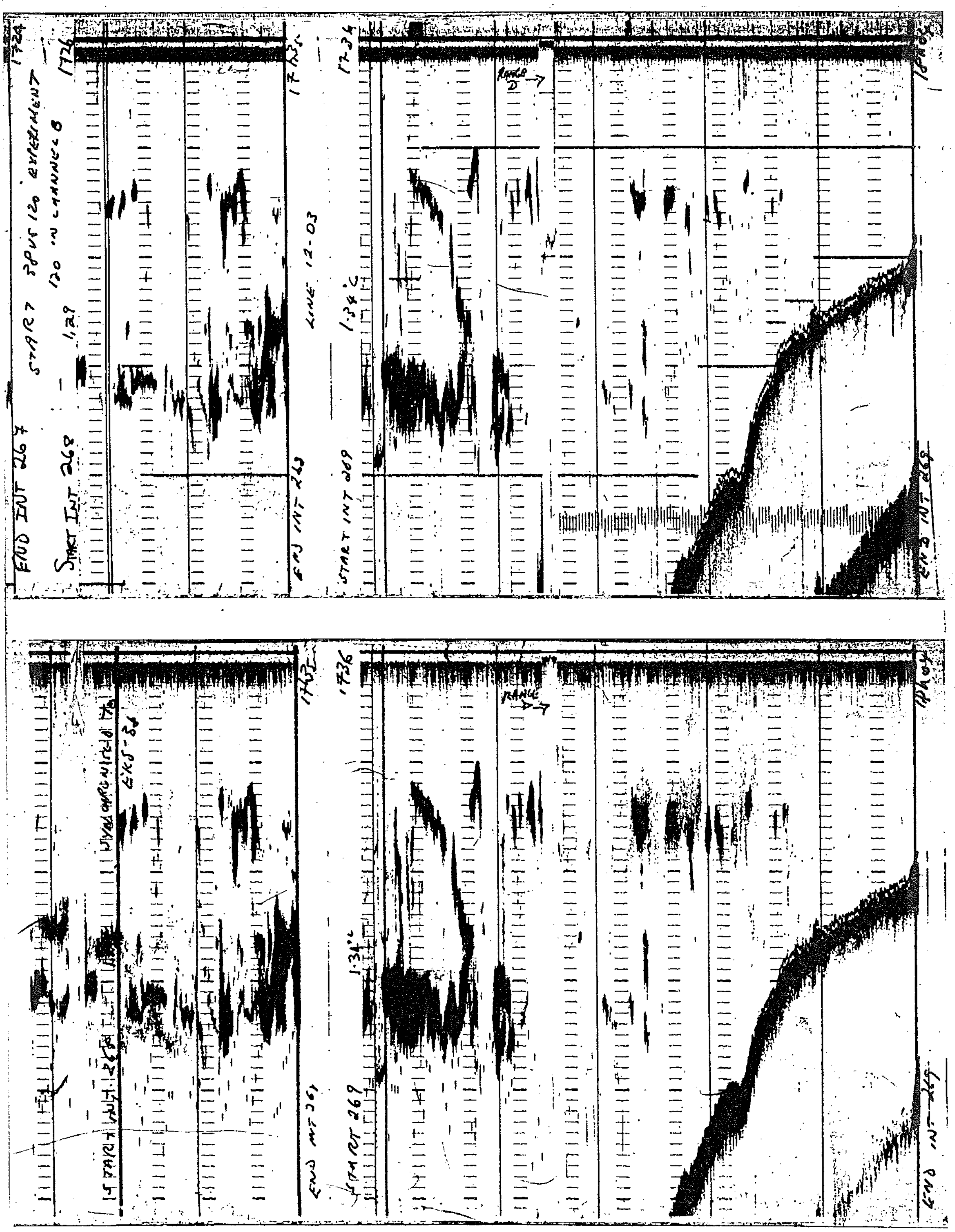


Figure 1: Echosounder recordings of krill swarms off Coronation Island made at 38 kHz (top) and 120 kHz (bottom). The distance between vertical lines is 1 n. mile.

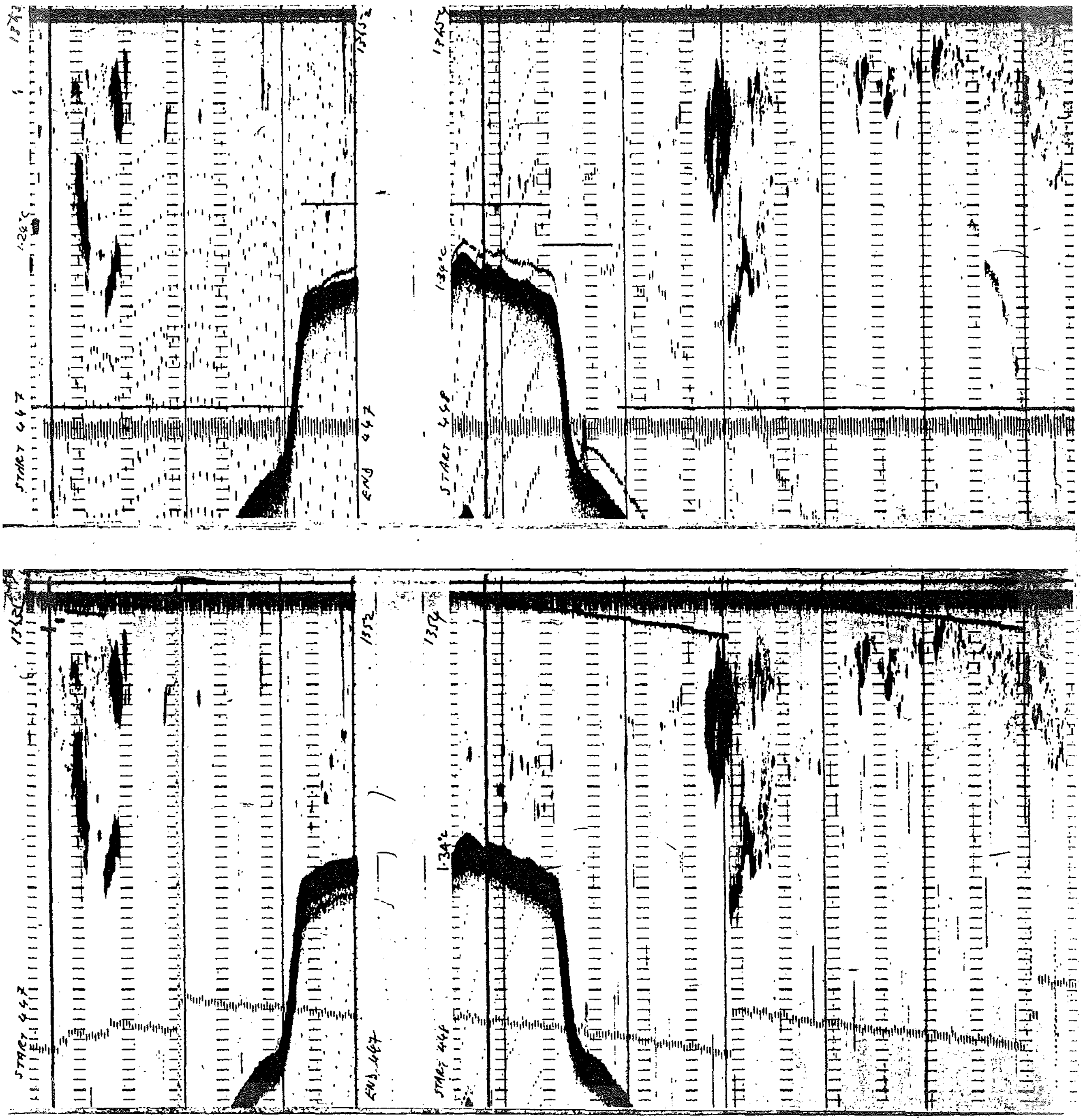


Figure 2: Echosounder recording of krill swarms off Elephant Island made at 38 kHz (top) and 120 kHz (bottom). The distance between vertical lines is 1 n. mile.

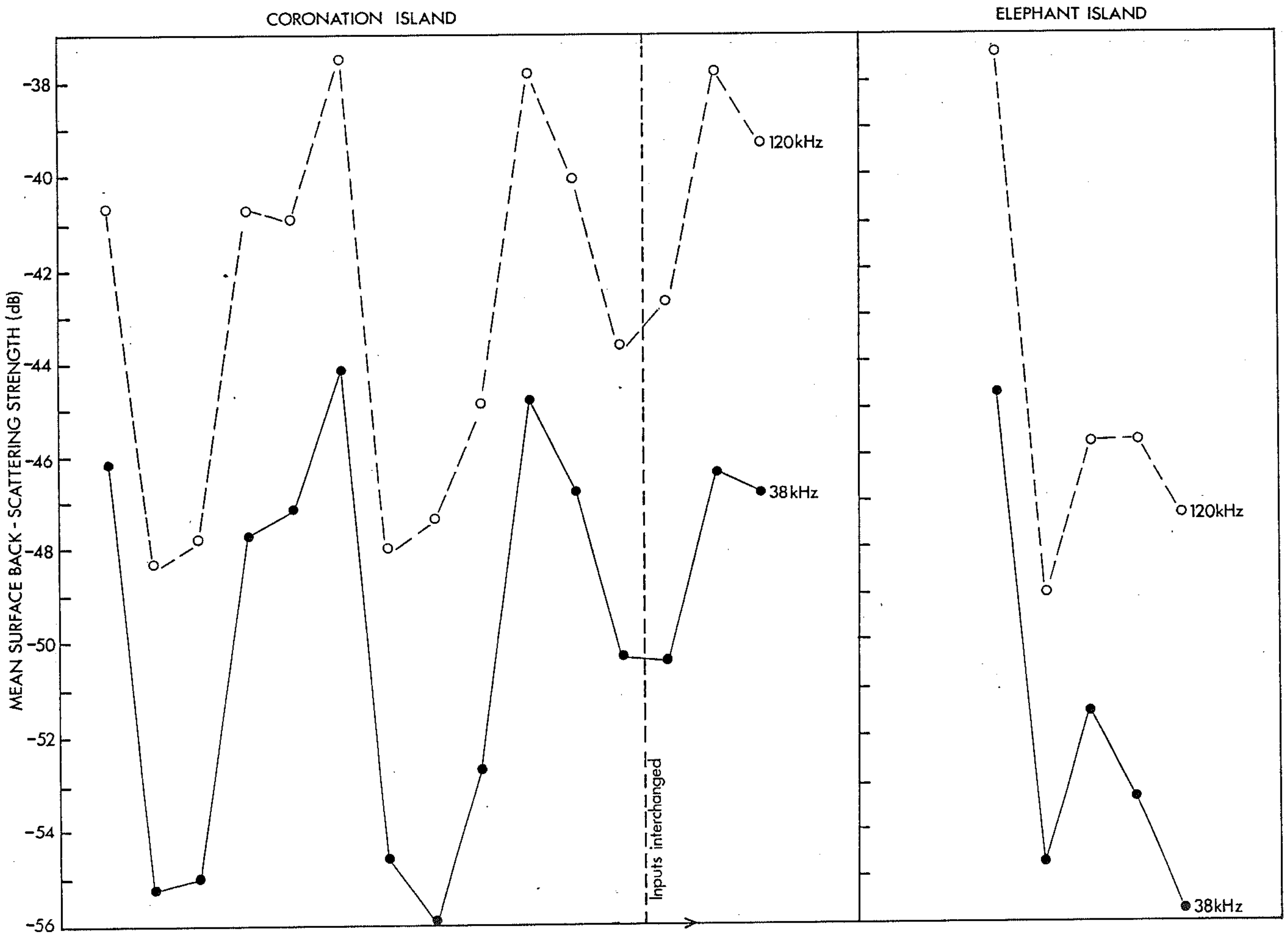


Figure 3: MSBS values at 38 and 120 kHz for all intervals. The dashed vertical line indicates the point at which the frequencies were interchanged between the two integration systems.

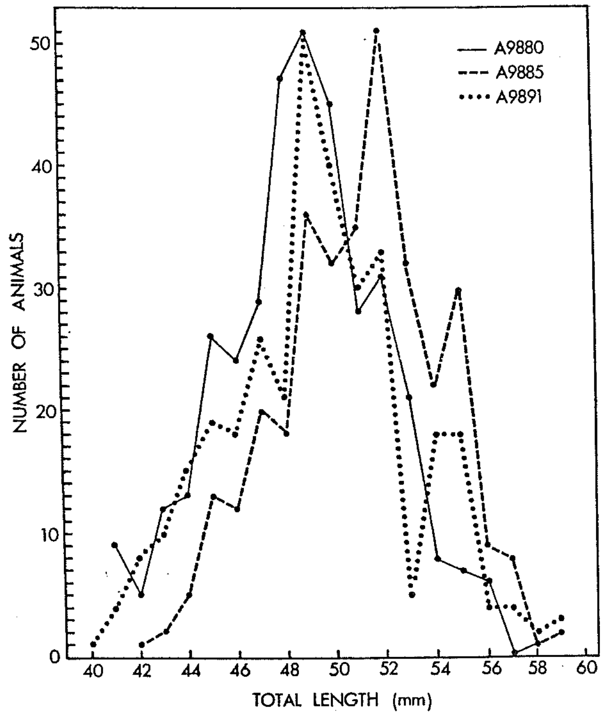


Figure 4: Length distributions of krill taken in Coronation Island trawls.

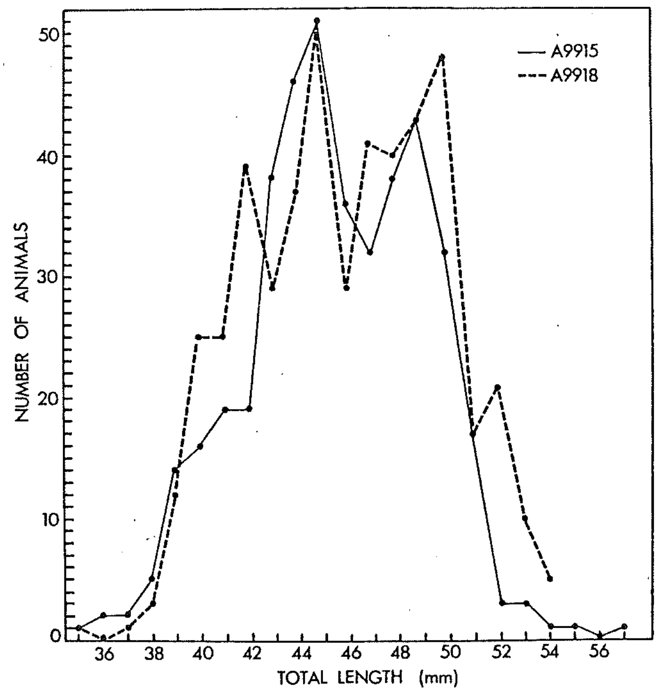


Figure 5: Length distributions of krill taken in Elephant Island trawls.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

MIDWATER TRAWL CATCHABILITY IN RELATION TO KRILL AND POSSIBLE WAYS OF ASSESSING GROSS CATCH

Yu.V. Zimarev*, S.M. Kasatkina* and Yu.P. Frolov**

Abstract

Research into midwater trawl catchability rates was carried out on the basis of data obtained from AtlantNIRO expeditions from 1983 to 1990 in the Scotia Sea. A methodology was developed for and applied to determining the rate of krill filtration through the trawl rope and netting and also the probability that krill will come into contact with various parts of the net as it passes through the trawl sides. Studies were based on the results of 250 hauls made with a 72/308 trawl. Catchability was worked out with the aid of fine-meshed chafers, hydroacoustic methods and theoretical calculations. A comparison of the experimental hydroacoustic assessment with the calculated one demonstrated that the theoretical model agreed well with the real situation. Analysis of the efficiency of midwater trawls in the krill fishery indicates that the potential exists for this efficiency to be increased.

Résumé

Une recherche sur les taux de capturabilité des chaluts pélagiques a été effectuée à partir de données provenant de campagnes AtlantNIRO de 1983 à 1990 dans la mer du Scotia. Une méthodologie a été développée puis utilisée pour déterminer le taux de filtration du krill au travers du maillage et la nappe du chalut, ainsi que la probabilité qu'a le krill d'entrer en contact avec les diverses parties du filet lorsqu'il traverse les parties latérales du chalut. Les études reposent sur les résultats de 250 traits effectués par un chalut de type 72/308. La capturabilité a été calculée à l'aide de tabliers de protection à maillage fin, par méthodes hydro-acoustiques et calculs théoriques. Une comparaison de l'évaluation hydro-acoustique expérimentale avec celle provenant de calculs a démontré que le modèle théorique correspond bien à la situation réelle. Une analyse prouve que l'efficacité des chaluts pélagiques dans la pêcherie de krill pourrait être accrue.

Резюме

Исследования уловистости разноглубинных тралов были выполнены по данным экспедиций АтлантНИРО за период 1983-1990 гг. в море Скотия. Была разработана и применена специальная методика определения интенсивности прохождения криля сквозь канатное и сетное полотно, а также вероятность соприкосновения криля с частями сетей при просеивании сквозь стенки трала. В основу работы положены результаты 250 тралений разноглубинным тралом 72/308. Оценка уловистости

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR

** NPO Promrybolovstva, 7 Donskoy Street, Kaliningrad 236000, USSR

производилась методом мелкоячейных покрытий, гидроакустическим методом и с помощью теоретических расчетов. Сравнение экспериментальной, гидроакустической и расчетной оценок показало хорошее совпадение теоретической модели с практикой. Анализ эффективности разноглубинного трала при облове криля позволяет сделать вывод о том, что имеются значительные резервы для увеличения его уловистости.

Resumen

Se llevaron a cabo investigaciones sobre el coeficiente de capturabilidad de los arrastres pelágicos a partir de los datos de las expediciones de AtlanNIRO realizadas desde 1983 a 1990, en el mar de Scotia. Se desarrolló una metodología para determinar el índice de filtración del krill a través de los cabos y paño de la red, así como la probabilidad de que éste entre en contacto con otras partes de la red cuando entra por los lados de la misma. Los estudios se basaron en los resultados de 250 lances en los que se utilizó un arrastre 72/308. Se pudo calcular la capturabilidad mediante parpallas o protectores de copo de malla fina, métodos hidroacústicos y cálculos teóricos. Al comparar los resultados de la evaluación hidroacústica y de la teórica se vio que el modelo teórico coincidía con la situación real. El análisis sobre la eficacia del arrastre pelágico en la pesca del krill indica que todavía es posible aumentarla.

---

1. INTRODUCTION

Krill is an important element in the Antarctic ecosystem. The rational development of the krill fishery hinges on the conservation of the Antarctic marine ecosystem and presupposes extensive scientific research into the habitat area of this crustacean. An integral part of this research includes studying the harmful effects inflicted on the krill habitat area by the fishery and the fishing gear used. Assessing fishing gear catchability rates and gross catch capability are essential components in solving many problems associated with the krill fishery.

The term "gross catch" means the number of individuals of a target species which make up the landed catch as well as those specimens perishing as a result of the impact of fishing gear.

Midwater trawl catchability rates are today being assessed using methods such as fine-meshed chafers (Karpenko, 1983), underwater observation (Zaferman and Serebrov, 1985), hydroacoustics (Berdichevsky, 1985; Kasatkina, 1989) and theoretical model methods (Kadilnikov, 1985). Each of these methods has proven to be inadequate when it comes to solving the task in hand.

The authors of this work have attempted to examine the process of krill fishing and the way the catch is formed in the trawl and also to devise approaches to assessing gross catch by integrating the methods mentioned above.

Yu.V. Zimarev was responsible for developing the methodology and running the calculations to determine the rate at which krill escapes through the trawl ropes and mesh. He also calculated the probability of krill coming into contact with parts of the net as it passed through. Krill distributional characteristics, trawl catchability rates and the methodology for determining the retaining qualities of the trawl were handled by S.M. Kasatkina. Finally, Yu.P. Frolov carried out underwater observations and the assessment on the rate at which krill passed through the trawl mesh using fine-meshed chafers.

2. MATERIALS AND METHODS

2.1 Experimental Hydroacoustic and Theoretical Model Assessments of Trawl Catchability

Data from AtlantNIRO surveys (1983 to 1990) in the Scotia Sea were used in the research on midwater trawl catchability in relation to krill.

It is a well known fact that scientific literature has seen various interpretations of the main parameters in fisheries science. This necessitates that we define the values and terms which will be used throughout this work.

Catchability (P) is the probability of taking a catch greater than zero (Kadilnikov, 1985).

The effective fishing area of the trawl over trawling time is that portion of physical space in which there is a likelihood greater than zero that the target species will be caught during the time spent trawling:

$$B = l_r \cdot h_1 \cdot V_t \tau_t, \qquad (1)$$

where B - effective fishing area, m^3
l_r - horizontal trawl opening, opening between trawl-boards, metres
V_t - trawling speed, m/s
τ_t - trawling time, seconds
h_1 - vertical effective fishing area of trawl with the condition that
h_1 - h_t when $h_1 < H$
h_1 - H when $h_1 > H$
where h_t - vertical trawl opening, metres
H - depth of water layer where target species is located, metres.

Total catchability (P) is the probability that a complex sequence of events will take place. It is expressed as a multiplicative equation in the form of a function of different catchability rates which facilitate the catch process:

$$P = P_r P_{k\text{-}c} \qquad (2)$$

where P_r - catchability of the front trawl rigging, i.e., the probability of the target species being caught in the trawl mouth from within the trawl's effective fishing area
$P_{k\text{-}c}$ - catchability of the trawl rope rigging and netting.

Hydroacoustic assessments of a trawl's retaining qualities are based on a comparison of the catch with krill biomass estimates. The latter are obtained from an echo-integrating apparatus in the trawl's effective fishing area and other compartments.

With regard to the second algorithm, the two echo-integrating systems on the vessel made it possible to assess biomass in the trawl's effective fishing area and in the trawl mouth (Kasatkina, 1988). Integration in the mouth of the trawl allows one to assess not only catchability rates, $P = P_r P_{k\text{-}c}$, but also the amount of krill being filtered through the trawl rope rigging and netting.

$$K_B = \frac{G}{Q+G} = 1 - \frac{Q}{W_y} \tag{3}$$

where $\mathbf{K_B}$ - the rate of krill passing through the trawl rope rigging and netting
Q - catch weight in kilograms
G - biomass of krill passing through the trawl rope rigging and netting (kg)
$\mathbf{W_y}$ - krill biomass in the trawl mouth (kg).

By using different numbers of depressor weights on one wing, it was possible to change the vertical opening of the trawl and thereby alter the angle of attack of a section of trawl netting under observation while studying the effects of the trawl's working parameters on the catchability coefficient.

Trawling speed was from 2.5 to 4.5 knots.

The level of escapement through the trawl rope rigging and netting with fine-meshed chafers in place was examined simultaneously with a hydroacoustic assessment of the coefficient $\mathbf{K_B}$.

Experimental assessments of catchability were compared with calculated ones using statistical probability models usually applied to fishing trawls (Methodical Instructions...1985). According to this theory, total trawl catchability and the component parts of this catchability are functions of behavioural and distributional characteristics of the target species and the structural specifications of the trawl itself. Maximum krill speed was taken to be **V** = 0.23 m/s (Kasatkina and Myskov, 1986; Hamner, 1984).

The following parameters describe the behavioural and distributional characteristics of targetted krill aggregations (Kadilnikov *et al.*, 1989):

- distribution of swarm depths;
- linear extent of swarms;
- biometric indicators;
- reaction speed of krill to the moving elements of the trawl;
- density of swarm fields λ_s (number of swarms per unit of water mass area);
- three-dimensional swarm density - β (ratio of swarm volume to habitat area);
- swarm biomass density;
- depth of swarm distribution.

2.2 Modeling the Process of Krill Fishing

In order to determine the rate at which krill pass through the trawl rope and netting, we applied a method used in calculating the distribution of the target species within the trawl during the trawling process (Zimarev, 1985 and 1988). Using a one-dimensional approximation, the following is a system of equations which describes the dynamics of krill numbers per unit volume:

$$\begin{cases} \frac{\sigma p}{\sigma t} + \frac{\sigma y}{\sigma x} = F \\ y = p_s \cdot v_s + p_d v_d \\ p = p_s + p_d \\ p_d v_d = -D \cdot \frac{\sigma p_d}{\sigma x} \\ p_s = p_s \end{cases} \tag{4}$$

where p - concentration of krill per unit volume (1/m³)
t - time (seconds)
x - spatial coordinate
y - flow of krill per unit volume (1/m²s)
F - function of krill inflow and outflow
p_s - the number of krill per unit volume which is affected by reotactic ambient factors (1/m³)
v_s - speed of transport of krill which is affected by rreotactic ambient factors (m/s)
p_d - the number of krill per unit volume which is in a state of agitation (1/m³)
v_d - speed of incidental runs (m/s)
D - coefficient of krill mobility (m²/s)
p_s - the probability that krill will respond to reotactic ambient factors.

The function of the inflow and outflow of krill (F) is the sum of two expressions; the first reflecting the amount of krill which passes through the rope sections and trawl netting and the second the herding effect of the trawl.

In order to obtain the single correct solution from the system of equations (4) it is necessary to establish the marginal and initial conditions for p. These conditions are obvious and do not require further explanation. The flow of krill through the front rigging of the trawl is the natural condition for the left edge of the particular area with x = 0. For example,

$$y_{x=0} = p v_t \tag{5}$$

On the right edge, i.e. in the cod line section , with x = L

$$y_{x=L} = 0 \tag{6}$$

where L = trawl length from the zero section to the cod line section under working conditions (metres).

Initial conditions for P are:

$$p_{t=0} = 0 \tag{7}$$

By solving the system of equations (4) numerically using the conditions specified (5 to 7), we find krill distributed along the longitudinal axis of the trawl, P. The integral mass of krill in this particular section of the trawl with the coordinate x and $N_E = [\vec{y}, \vec{s}]\, t$ is the amount of krill which has passed through area (s) of the trawl cover over time (t).

We will assume that krill is not injured each and every time it comes into contact with the net. We are concerned purely with the frequency of krill coming touching the net as it passes through. When assessing the likelihood of krill contacting the net we are invariably confronted by Buffon's "needle" problem. This problem, which has been reduced to two systems of parallel lines, has produced the following expression for determining the probability that krill will come into contact with the net:

$$P_c = \begin{cases} 1 & \\ \dfrac{2l}{\Pi a u_1 u_2} \left(\lambda - \dfrac{e}{2\Pi a u_1 u_2} \right) & l_\xi > 2au_1u_2 \\ & l_\xi < 2au_1u_2 \end{cases} \tag{8}$$

where P_c - the probability that krill will come into contact with the net
l_ξ - krill length (metres)
$u_1 u_2$ - net mounting coefficients
l - circumference of krill body (metres)
a - mesh bar

then the number of krill coming into contact with the net is expressed by the equation

$$N_m = P_c N_e \tag{9}$$

where N_m - the number of krill touching the net
N_e - the number of krill passing through the net.

It should be noted that injuries sustained by krill will not exceed the frequency with which they come into contact with the trawl net.

2.3 Analysis of the Level of Krill Escapement Using Net Chafers; Underwater Observations

Treshchev's methodology (Methodical Instructions...1983) was employed for the collection of data on krill escapement through the trawl. Beginning at the trawl bag and ending at the rope section, fine-meshed chafers were placed on parts of the trawl netting having different sized mesh bars. Visual observations of krill escapement and behaviour in various parts of the trawl were made using a towed underwater device; the Thetis. The fishing process was simultaneously filmed by a videocamera.

3. RESULTS

3.1 Hydroacoustic and Calculated Estimate of Catchability Rate

Research into the catchability of midwater trawls was carried out in the fishing grounds of the Scotia Sea (Sandwich, South Orkney, South Shetland and South Georgia Island areas). The dependency of the trawl's catchability on its working specifications and the distribution of targetted krill concentrations were examined. Krill was taken by several different types of trawl.

Research results are based on the trawl 72/308 whose specifications are listed in Table 2. In the course of the 250 hauls carried out by this trawl, catchability was assessed using hydroacoustic methods.

An assessment of the trawl's catchability in relation to several of its working specifications was made while fishing a concentration having rather homogeneous distributional characteristics. Such a concentration was chosen in order to negate the impact of these characteristics on the assessment.

Results of these assessments, where commercial concentrations are comprised of track-shaped small swarms, are presented below (Kasatkina, 1989). Mean characteristics of krill distribution based on 80 hauls in the Elephant Island area (January, 1985) were as follows:

- mean depth of swarm distribution, **H** (metres) 39
- mean depth of the upper edge of the swarm, $\mathbf{m}_h$ (metres) 21
- mean standard deviation of the depth of the upper edge of the swarm, σ_h (metres) 8
- mean swarm depth, **m (2c)** (metres) 3
- mean standard deviation of swarm depth, σ_{2c} (metres) 1
- mean horizontal extent of swarms, **m** (*l*) (metres) 14

- mean standard deviation of horizontal extent of swarms, σ_l,(metres) 4
- mean swarm diameter (assuming that the swarm is of a cylindrical shape) (metres) 18
- relative three-dimensional swarm density β 0.1211
- three-dimensional density of the swarm field, λ (metres^{-3}) 1.58.15^{-4}
- two-dimensional density of the swarm field, λ_s (metres^{-2}) 6.19.10^{-3}

Trawling speed ranged from 2.5 to 4.5 knots; netting angle of attack was between 5° and 9°.

Figure 1 gives the distribution of the catch size per hour trawling while Figure 2 shows the dependency of total catchability (**P**) and the escapement coefficient (**K_B**) of the target species upon the angle of attack (α) and trawling speed (**V_t**). It is clear from Figure 2 that as trawling speed and the angle of attack increase, so does krill escapement. Consequently, total catchability decreases.

At the same time an assessment of krill escapement through the trawl netting was carried out using fine-meshed chafers.The observed dependence of krill escape time on the angle of attack (α) and trawling speed (**V_t**) was in general maintained. It should be noted that in this case the relative escapement coefficient was assessed since the catchability of the chafers themselves is unknown and is taken conditionally to be equal to 1.

Table 2 presents the numerical characteristics of empirical distribution in relation to total catchability (**P**) and its component elements (**P_r, $P_{k\text{-}c}$, K_B**). Hydroacoustic assessment data came from a sample of 80 hauls. The empirical distributions themselves are given in Figure 3.

The biomass density distributions of targetted krill concentrations, which were measured in the trawl's effective fishing area (under the vessel) and in its mouth, are presented in Figure 1 and Table 3. From these illustrations it is clear that concentration density has also been practically unchanged.

An assessment of krill swarm parameters in various regions of the Scotia Sea demonstrated that these swarms evince little response to the vessel and trawl as they pass over them. The distribution patterns of swarm layers and their vertical extent within the trawl's effective fishing area were practically unchanged compared to the same parameters in the trawl mouth.

A hydroacoustic assessment of the 72/308 trawl catchability coefficient, carried out for a wide range of distributional characteristics of targetted krill concentrations and based on data from 250 hauls in various regions of the Scotia Sea, produced the following results. Trawl catchability (**P**) is dependent upon the spatial distribution of krill swarms relative to the effective fishing area of the trawl and, most importantly, on such distributional characteristics as λ_s and β. Catch per hour trawling depends largely on swarm density and to a lesser degree on distributional characteristics (Table 4).

A calculated assessment using models of statistical probability on the theory of fishing trawls was comparatively analysed against a hydroacoustic assessment. Table 5 demonstrates that although the mean values of both empirical and theoretical distributions of catchability coefficients differ, they are reasonably close (Kasatkina, 1988).

Table 6 contains data on the catchability rates of trawls of different design (72/308, 74/416, 76/400) and whose specifications are given in Table 1. Catchability assessment was performed using the calculated method. Keeping in mind the dependency of trawl catchability upon distributional characteristics, the latter were assumed to be the same for each trawl. Parameters of swarm fields in the South Orkney Islands fishing ground in February 1990 were selected as distributional characteristics (Table 7, Figures 4 to 6).

3.2 Analysis of a Process of Krill Passing Through the Trawl Netting

Trawl specifications upon which calculations were based are given in Table 8. A krill swarm with an even spatial distribution, a horizontal extent of 20 000 m, a vertical extent of 200 m and a concentration of 23.25 $1/m^3$, was chosen for the analysis. The mean length of specimens was taken to be 0.043 m and the mass, 0.0044 kg. It was assumed that the maximum body height was 0.018 m and the width, 0.007 m.

Calculations were performed using the theory of differential calculus. An integral interpolation method was used when approximating a differential equation model. The solution to the system of algebraic equations, constructed on the basis of a differential approximation, was achieved using the "run" method.

Implementation of this method meant that at any given moment it was possible to take a large volume of krill in individual sections of netting while allowing krill to pass through these sections and to determine the proportion of krill touching the net.

Table 9 illustrates the filtering capabilities of the netting sections of the three trawls being examined as well as the level of traumatism undergone by krill as they pass through the trawls.

Mean weighted estimates in relation to the 76/400 trawl put the frequency of krill contact with the net at between 26 and 29%. Trawl 74/416 achieved a rate of 9.2 to 13.3% and the 72/308 trawl rated between 20.1 and 27.7%.

The levels of krill escapement determined according to the model in equation (4) were consistent with the results of hydroacoustic assessments and methods using net chafers.

At the same time it should be noted that escapement levels through the rope and broad-meshed sections of the trawl in experimental surveys largely depend upon spatial swarm distribution. Moreover, theoretical calculations do not consider the swarming effect whereby krill enter the trawl as a continuous stream. Therefore the value of absolute escapement in the rope and broad-meshed sections obtained in this manner always exceeds observed levels. In both cases the herding effect of the trawl appears to be absent. It would therefore seem appropriate to use theoretical calculations in accordance with the proposed methodology to solve actual problems.

A more detailed analysis identified areas in the trawl where the greatest instances of contact with the net are likely to occur. Net zone 6 of the 76/400 trawl (see Table 8) which has a mesh bar of 0.04 m and a mounting coefficient of 0.28, is one of these areas. In regard to trawl 74/416, net zones 7 and 8 (mesh bars 1.2 and 0.8 m respectively, mounting - 0.2) are where krill/net contact is the highest. Finally, in trawl 72/308, the relevant net zones are 3, 4 and 5 (mesh bars 1.2, 0.8 and 0.4 m and mounting coefficients of 0.1, 0.147 and 0.159 respectively).

In general, theoretical calculations and actual experiments demonstrate a direct relationship between levels of krill escapement and mesh size, angle of attack and mounting coefficient of the net.

3.3 Underwater Observations, Evaluation of Krill Escapement Using Fine-Meshed Chafers

Visual observations revealed that separate krill swarms have different density. Most swarms consist of small, individual and localised patches with a greater concentration of biomass; the space between these patches is filled by relatively scattered krill.

Observation of krill swarm behaviour indicated the lack of a clearly defined defensive response of krill against the vessel and trawl passing overhead. As the vessel sailed above, the krill swarms remained practically at the same depth and density.

A comparison of the vertical extent of krill swarms in front of the trawl and in its mouth showed that it was virtually unchanged.

Underwater observations of the krill fishing process revealed that krill freely passes through the mesh of the trawl rope section when contact is made. The trawl ropes do not herd krill, i.e. krill escapement reaction is not observed.

A slight concentration of krill occurs when krill is on the outer side of the trawl rope section where small whirlpools are formed by the rope elements.

A quantitative assessment of krill escapement through the trawl rope section showed that the level of this phenomenon depends on the precision with which the mouth section is guided at krill swarms. If the swarm was positioned towards the centre of the trawl mouth, krill did not come into contact with the rope and broad-meshed sections of the trawl and passed into the fine-meshed section. If the trawl is not set accurately, a large part and perhaps even the entire swarm can pass through the rope and broad-mesh sections.

Data on krill retention by fine-meshed chafers indicated that about 15% of swarms trapped in the trawl mouth were in fact passing through the rope section and eventually escaped altogether. The amount of krill which escapes through the last row of rope meshes of the upper panel alone is approximately 1.5 tonnes per haul.

Krill filters just as freely through broad-meshed netting (mesh bar 1 200 to 400 mm) as it does through the trawl rope section.

As the mesh bar decreases towards the codend (i.e., the mesh becomes more compact), a relatively fine, though discernible, layer of water with increased pressure is formed near the trawl netting. This layer of water facilitates the removal of krill and other smaller organisms from the netting. The removal of krill to a certain degree decreases the level of escapement through the mesh. If, however, krill swarm density is high and swarm dimensions exceed the diameter of a particular conical cross-section of the trawl netting, krill are unavoidably squeezed through the mesh.

If we take an example where the targetted krill swarm has a vertical extent of 5 to 8 m and the belly section of the trawl has a cross-section diameter of 5 to 6 m and a mesh bar of 30 mm, then 0.33 kg of krill will escape through one square metre of netting. The amount of krill passing through increases to 1.14 kg when the cross-section diameter is 4 to 5 m and the mesh bar is 20 mm. Finally, when the cross-section diameter decreases to 3 to 4 m and the mesh bar to 18 mm approximately 4 kg of krill, in this case primarily smaller specimens, escapes.

These data indicate that krill filtration in the belly of the trawl is an unavoidable consequence of pressure being applied to smaller specimens.

It is also evident that krill will pass more freely into the trawl bag and the level of escapement will be lower when the angle of the netting into the trawl bag is designed to be less acute.

The efficiency of krill retention in the trawl depends upon the mesh shape used for fine-meshed inserts. A test of trawl bags using fine-meshed inserts, for example, showed that rhomboid-shaped mesh has better retaining qualities than hexagonal. Data on krill filtration through trawl bags having different shaped mesh inserts are presented in Table 10.

4. DISCUSSION

Hydroacoustic investigations demonstrated that total catchability is a random value due to the uniqueness of each haul: the trawling process is different each time as are the behaviour and distribution of the target species. Moreover, catchability $\mathbf{P}_r$ (the probability that the target species will pass from the effective fishing area of the trawl into the trawl mouth) largely depends upon the distributional characteristics of the targetted swarm. The most important of these characteristics are β, λ_s, and the mean standard deviation of the upper edge of the krill swarm (Tables 4, 6, 7, Figures 4 and 5). Trawling speed and the trawl's angle of attack (i.e., the relationship between the trawl mouth parameters and the fine-meshed insert) have a significant influence on the escapement coefficient $\mathbf{K}_B$.

As trawling speed and angle of attack increase, total catchability (**P**) and the catchability of the rope and net sections ($\mathbf{P}_{k-c}$) falls, although the amount of krill filtering through increases considerably (Figure 2, Table 6).

Assessment of targetted swarm parameters in the effective fishing area (in front of the trawl, beneath the vessel) and in the trawl mouth produced the following results:

(a) feable reaction of krill to the vessel and trawl as they passed (depth distribution and vertical extent of krill swarm in the effective fishing area were virtually unchanged compared with the same parameters in the trawl mouth);

(b) limited influence of trawl components such as boards and cables on krill swarms (biomass density in the effective fishing area and in the trawl mouth were practically unchanged) (Table 3); and

(c) underwater observations support the notion that krill have weak defense reactions in relation to abovementioned (b) structural elements of the trawl.

The level of krill damage is also dependent upon these parameters. Nevertheless, further theoretical studies are needed in the area of krill filtration through the trawl mesh. These studies must answer the questions of the relationship between krill damage and the geometrical parameters of the net as well as the biological and mechanical characteristics of the krill body itself, water current speeds and the extent to which the fullness of the trawl bag affects the rate of krill being squeezed through the net.

5. CONCLUSION

After examination of experimental and calculated data, it is possible to make the following conclusions.

Comparison of experimental hydroacoustic and calculated catchability assessments indicates that the theoretical model agrees well with the real situation. Analysis of the efficiency of midwater trawls in relation to the krill fishery demonstrates that there is a good chance that this efficiency can be increased.

Theoretical calculations of the extent of krill filtration through trawl netting and the frequency of contact with the net do not contradict our ideas about the trawling process. In any case, the may serve as a qualitative assessment of the impact of fishing with certain kinds of fishing gear on the gross catch of krill.

REFERENCES

Бердичевский, З.М. и др. 1984. Акустическая оценка уловистости трала. Рыбное хозяйство, №8: 60-63.

Заферман, М.Л., Серебров Л.И. 1985. Методы и результаты изучения коэффициентов уловистости тралов. Исследования по оптимизации рыболовства и совершенствования орудий лова. Сб. научн. трудов ВНИРО, М.: 84-94.

Зимарев, Ю.В. 1985. Влияние степени заполнения трала на его уловистость. Калининградский технич. ин-т рыб. пром-ти и хозя-ва. Калининград (Деп. в ЦНИИТЭИРХ, №673, РХ-Д85): 7с.

Зимарев, Ю.В. 1988. Скорость диффузионных потоков рыб. В кн. Промышленное рыболовство, Сб. трудов, Калининград: 104-107.

Кадильников, Ю.В. 1985. Основные положения и результаты статистической теории рыболовных тралов. Сб. теория промышленного рыболовства - М:ВНИРО,М. ВНИРО: 37-53.

Карпенко, Э.А. 1983. Исследование дифференциальной уловистости тралов. Сборник научных трудов ВНИРО, М. ВНИРО: 16-22.

Касаткина, С.М., Мысков А.С. 1987. Некоторые данные о скорости движения эвфаузиид. Тезисы докладов II Всесоюзного совещания сыревые ресурсы Южного Океана и проблемы их рационального использования. Керчь: 89-90.

Трещьев, А.И. 1983. Методические указания по сбору данных по селективности трала и травматической гибели рыб, прошедших сквозь ячею трала. М. ВНИРО: 21.

Расчетная оценка улавливающих качеств тралов. 1985. Методические указания. Калининград, НПО Промрыболовство, Калининград: 203.

KADILNIKOV, YU.V. *et al.* 1989. *Assessment of Krill Biomass in Fishing Grounds Using the Data on Fishing Intensity and Hydroacoustic Method.* SC-CAMLR-VIII/BG/10. Hobart, Australia: CCAMLR.

KASATKINA, S.M. 1989. Acoustic studies of catchability by midwater trawls of fast and slow moving species. *Proceedings of the Institute of Acoustics, 11*, Part 3. ISBN Number 0946731 83.

HAMNER, W.M. 1984. Aspects of schooling in *Euphausia superba. Journal of Crustacean Biology, 4,* Sp. Number 1: 25-42.

Table 1: Main specifications of midwater krill trawls.

Specifications	Trawl Type		
	72/308 m	74/416 m	76/400 m
Vertical trawl opening at the headline and foot-rope section (metres)	35	40	43
Horizontal and vertical openings of the mouth at the fine-meshed section (metres)	9.8	11.0	17
Horizontal opening between trawl boards (metres)	100	60	70
Horizontal opening between wings (metres)	40	35	37
Trawl length along the belly rope line from the end of the wings to the end of the fine-meshed section (metres)	115	141	138
Length of cable line with tow legs (metres)	150	100	100
Cables - angle of attack (degrees)	11.5	7.2	9.5
Netting in the horizontal plane - angle of attack (degrees)	7.5	4.9	4.2
Netting in the vertical plane - angle of attack (degrees)	6.3	5.9	5.4
Trawling speed (knots)	3.5	3.5	3.5
Length of trawl board rib (metres)	4	4	4
Mesh size (stretched) in trawl bag	6.5	10	12

Table 2: Catchability of the 72/308 trawl in relation to krill - results of a hydroacoustic survey.

Catchability Characteristics	Estimate of Mathematical Expectation	Non-Adjusted Mean Standard Deviation
$\mathbf{P}$	0.0582	0.0231
$\mathbf{P_r}$	0.3052	0.0831
$\mathbf{P_{k\text{-}c}}$	0.1907	0.0519
$\mathbf{K_B}$	0.8093	0.2

Table 3: Parameters of density distribution of targetted krill concentrations in the Elephant Island area, January 1985.

Parameter	Density in Effective Fishing Area of the Trawl (p_g, g/m³)	Density in Trawl Mouth (p_y, g/m³)	Catch Per Hour of Trawling (**Q/hr**, tonnes)
Estimate of mathematical expectation	7.0	6.6	8.3
Non-adjusted mean standard deviation	9.4	8.5	9.2

Table 4: Correlation of midwater trawl catchability with swarm distribution characteristics.

Swarm Characteristics	Total Catchability	Catch Per Hour of Trawling **Q/hr**
β	0.55	0.54
λ_g	0.65	
p_g	0.05	0.89

Table 5: Experimental and calculated assessments of the catchability coefficient of the 72/308 trawl in relation to krill in commercial fishing grounds.

Catchability	Experimental Assessment		Calculated Assessment		Comment
	Estimate of Mathematical Expectation	Non-Adjusted Mean Standard Variance	Estimate of Mathematical Expectation	Non-Adjusted Mean Standard Variance	
Total catchability (P)	0.0582	0.2231	0.0541	0.0167	Elephant Island January 1985
Total catchability (P)	0.0453	0.0274	0.0567	0.0167	South Orkney Islands December 1984
Total catchability (P)	0.0439	0.0304	0.0489	0.0153	South Orkney Islands January 1985
Total catchability (P)	0.0305	0.0197	0.0389	0.0107	Elephant Island November 1984

Table 6: Catchability coefficient calculated for several types of midwater trawl in relation to krill.

Krill Distributional Characteristics (Table 7)	Trawl Type						Note
	72/308		74/416		76/400		
	P	**K_B**	**P**	**K_B**	**P**	**K_B**	
I	0.0101	0.83	0.0145	0.73	0.0255	0.58	Figure 4
II	0.0181	0.83	0.0424	0.73	0.069	0.58	Figure 5
III	0.0292	0.83	0.0676	0.73	0.1096	0.58	Figure 6

Table 7: Distributional characteristics of krill aggregations in the fishing ground off South Georgia, February 1990.

Numerical Characteristics	Unit of Measurement	Swarm Field I	Swarm Field II	Swarm Field III
Mean depth of swarm distribution, **H**	m	150	200	50
Mean depth of the upper edge of the swarm, $\mathbf{m_h}$	m	109	88	26
Mean standard deviation of the depth of the upper edge of the swarm, σ_h	m	46	30	9
Mean swarm depth, **m** (2c)	m	18	19	18
Mean standard deviation of swarm depth, σ (2c)	m	9	8	3
Mean horizontal extent of swarms, **m** (*l*)	m	88	61	72
Mean standard deviation of horizontal extent of swarms, σ(*l*)	m	18	15	16
Mean swarm diameter **m** (2d)	m	102	78	92
Relative three-dimensional swarm density, β	-	0.022	0.116	0.294
Three-dimensional density of the swarm field, λ	m^{-3}	1.81×10^{-7}	9.18×10^{-7}	2.47×10^{-6}
Two-dimensional density of the swarm field, λ_s	m^{-2}	2.95×10^{-5}	1.83×10^{-4}	1.23×10^{-4}

Table 8: Trawl specifications.

Trawl (m)	Netting Zone Number	Mounting Coefficient	Radius of Trawl Mouth (m)	Fibre Diameter (m)	Mesh Bar (m)	Height of Netting Zone (m)
76/400	1	0.1500	18.80	0.0130	20.000	19.80
	2	0.1500	14.40	0.0130	15.000	14.85
	3	0.1500	11.20	0.0130	6.000	5.91
	4	0.1500	9.80	0.0100	6.000	5.94
	5	0.1500	8.40	0.0100	4.000	3.96
	6	0.2800	7.60	0.0012	0.040	9.60
	7	0.2000	4.75	0.0012	0.030	11.28
	8	0.2600	4.40	0.0012	0.020	13.52
	9	0.2800	3.00	0.0012	0.018	10.5
	10	0.4500	2.50	0.0012	0.012	14.29
	11	0.3000	1.25	0.0011	0.011	23.85
74/416	1	0.1700	19.00	0.0100	8.000	7.88
	2	0.1700	16.00	0.0100	8.000	7.88
	3	0.1700	15.00	0.0100	6.000	5.91
	4	0.1700	14.00	0.0100	6.000	5.91
	5	0.1700	12.00	0.0100	6.000	5.91
	6	0.1700	11.00	0.0100	4.000	3.94
	7	0.2000	10.00	0.0060	1.200	16.50
	8	0.2000	6.00	0.0050	0.800	16.50
	9	0.2500	4.25	0.0012	0.030	10.84
	10	0.2200	3.50	0.0012	0.020	10.40
	11	0.3000	2.75	0.0012	0.018	15.07
	12	0.4500	1.50	0.0012	0.012	15.18
	13	0.3000	1.00	0.0011	0.011	23.85
72/308	1	0.0899	10.78	0.0096	7.000	41.92
	2	0.0631	6.84	0.0096	7.000	6.99
	3	0.1004	6.18	0.0050	1.200	17.91
	4	0.1471	4.56	0.0040	0.800	8.70
	5	0.1594	3.84	0.0610	0.400	8.69
	6	0.1664	3.23	0.0031	0.200	6.11
	7	0.1624	2.88	0.0025	0.020	12.06
	8	0.1830	2.14	0.0022	0.016	29.03
	9	0.2300	0.78	0.0020	0.020	10.58
	10	0.2300	0.49	0.0020	0.012	30.78

Table 9: Krill escapement through and the amount of krill coming into contact with the trawl netting.

Netting Zone	76/400 m			74/416 m			72/308 m		
	Krill Filtered %	Contacted Max %	Contacted Min %	Krill Filtered %	Contacted Max %	Contacted Min %	Krill Filtered %	Contacted Max %	Contacted Min %
1	27.0	1.1	0.4	18.4	2.4	1.0	37	5.1	2.1
2	19.0	1.4	0.6	5.8	2.4	1.0	5.4	7.2	3.0
3	7.8	3.6	1.5	6.1	3.2	1.3	13.6	25.1	10.8
4	7.8	3.6	1.5	11.6	3.2	1.3	5.3	25.8	11.1
5	4.5	5.4	2.2	5.9	3.2	1.3	4.8	44.7	20.1
6	14.0	100	85.6	5.7	4.8	2.0	2.3	74.2	36.6
7	1.4	100	100	23.9	13.3	5.6	2.6	100	100
8	5.7	100	100	9.5	19.6	8.3	5.3	100	100
9	1.7	100	100	2.9	100	100	0.8	100	100
10	1.2	100	100	0.7	100	100	2.4	100	100
11	0.7	100	100	1.2	100	100			
12				0.5	100	100			
13				0.4	100	100			

Note: The level of krill escapement is determined in relation to the amount of krill caught while the number coming into contact with the net is determined in relation to the amount of krill filtered through the net panel.

Table 10: Specific krill escapement.

Shape of mesh inserts	Average value of krill escapement through the trawl bag, kg/m²		
Rhomboid	a=100 (30) mm 0.2	a=80 (20) mm 0.2	a=60 (18) mm 0.2
Hexagonal	a=100 (20) mm 0.2	a=80 (14) mm 0.3	a=60 (11) mm 0.8

Note: Mesh bar of fine-meshed inserts is given in brackets; "a" is the mesh bar of the trawl.

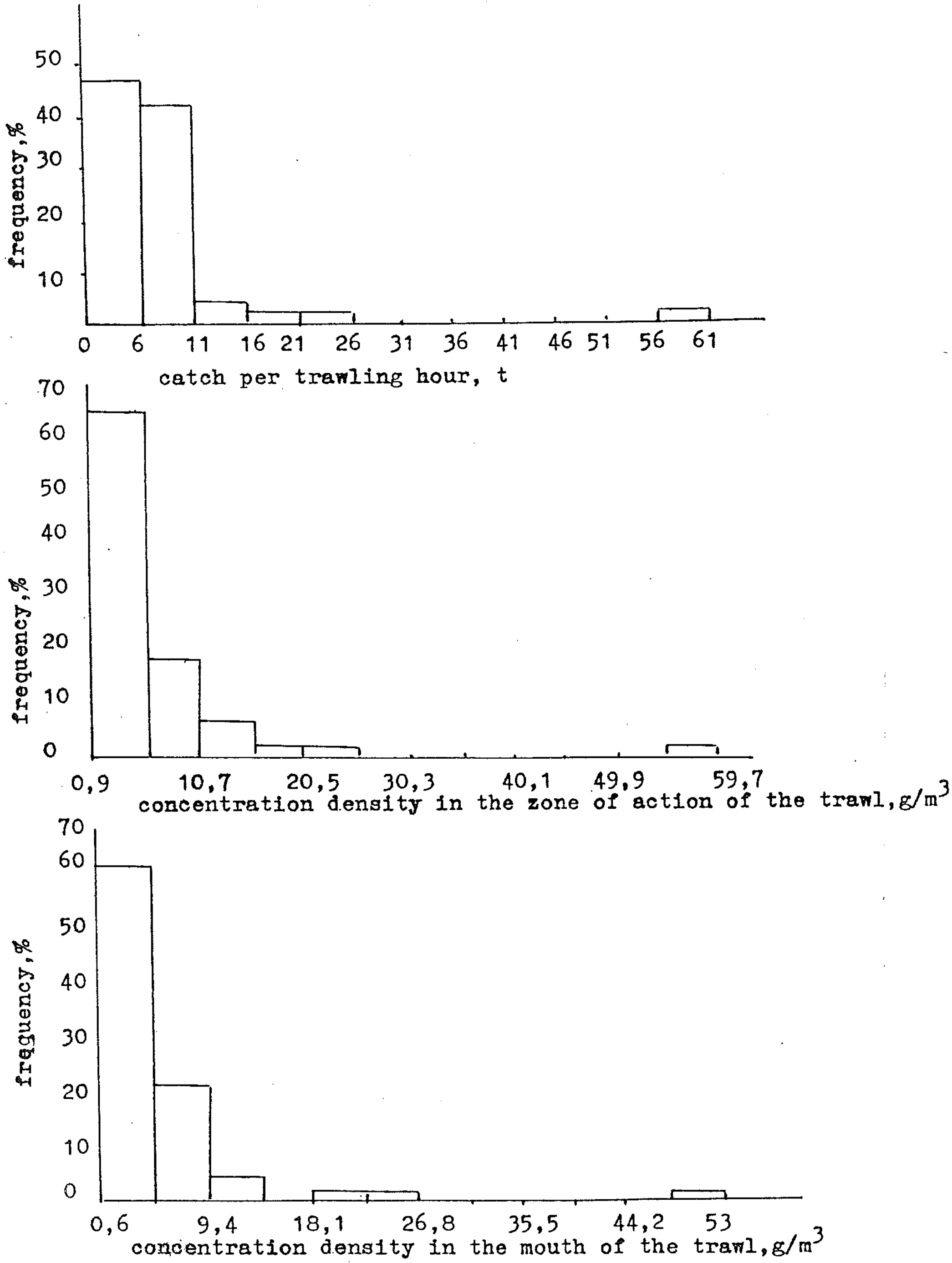


Figure 1: Density distribution of targetted krill aggregations and catch per hour of trawling during the hydroacoustic assessment of the catchability rate of the 72/308 trawl.

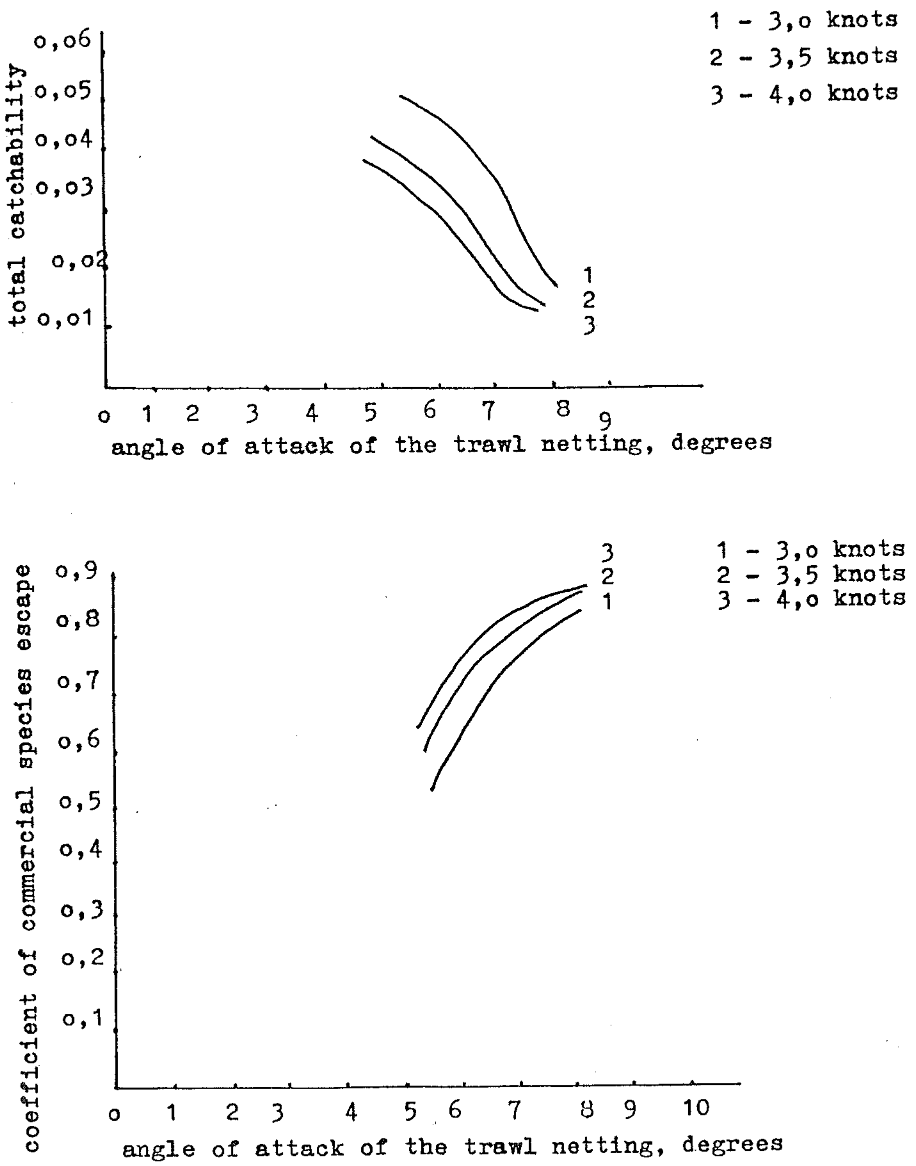


Figure 2: Relationship between total catchability of the 72/308 trawl, trawling speed and netting angle of attack according to hydroacoustic data.

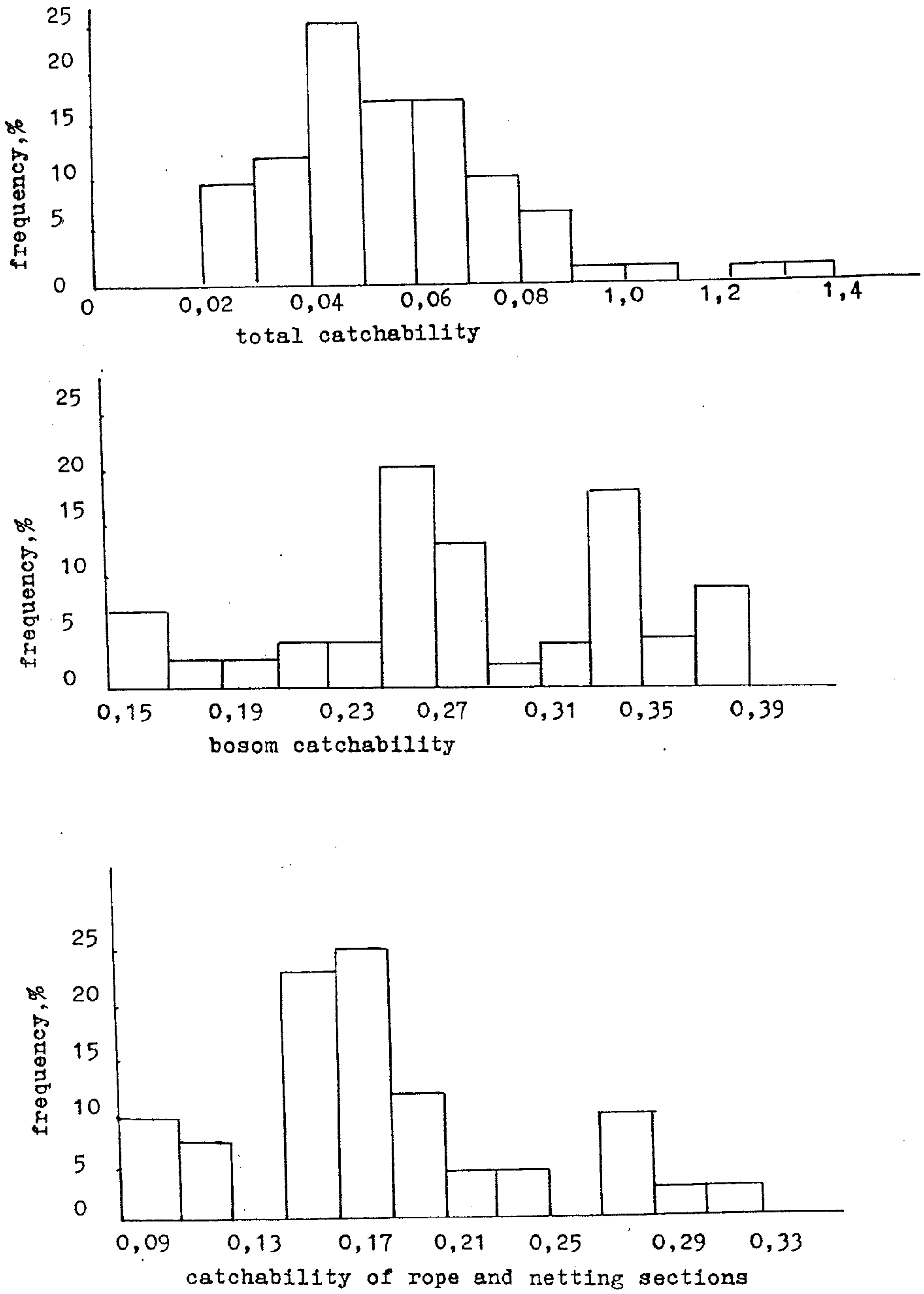


Figure 3: Histograms of distribution in relation to the catchability rate of the 72/308 trawl from targetted krill concentrations in the Elephant Island area in January 1985. (Hydroacoustic data).

Figure 4: Echogram of krill swarms in the Coronation Island fishing ground, February 1990.

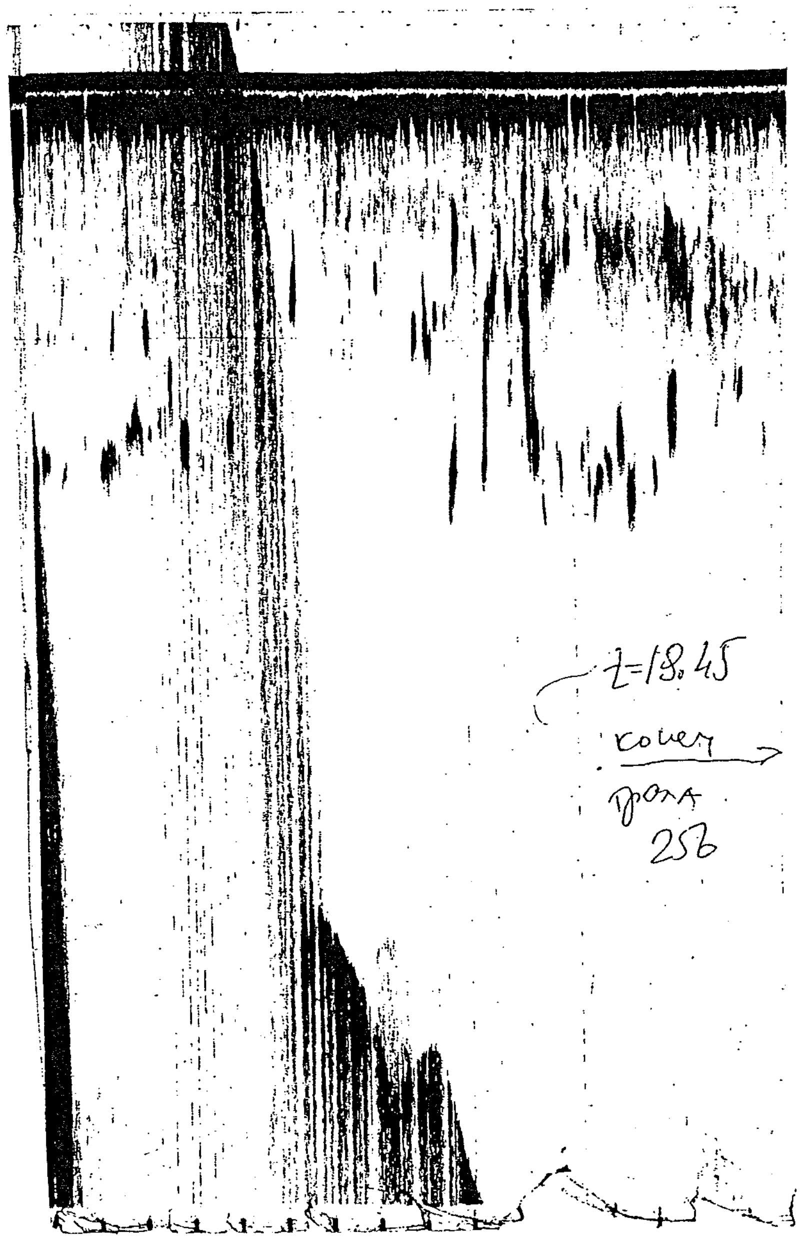


Figure 5: Echogram of krill swarms in the Coronation Island fishing ground, February 1990.

Figure 6: Echogram of krill swarms in the Coronation Island fishing ground, February 1990.

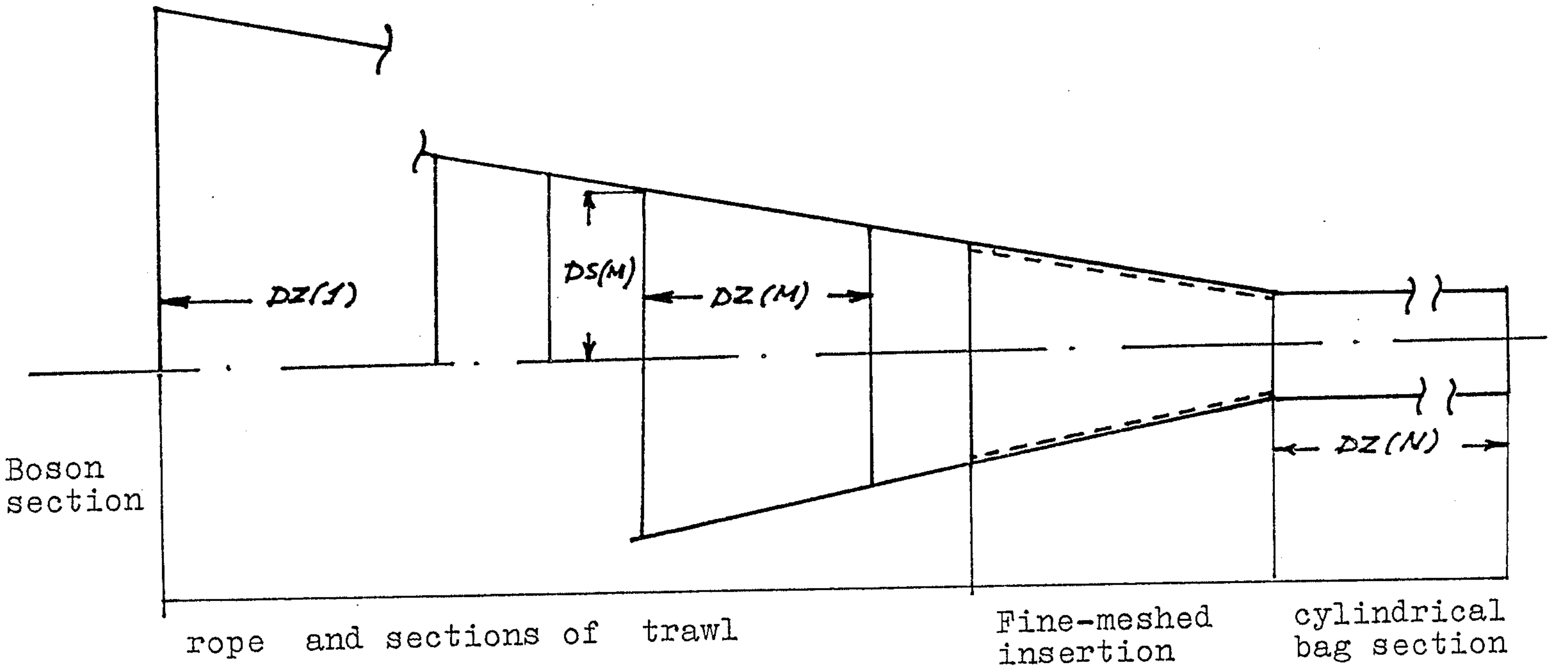


Figure 7: Design of trawl sections.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

KRILL BIOMASS ASSESSMENT IN STATISTICAL AREA 48 FROM THE RV *ATLANTNIRO* DATA - AUTUMN 1989/90

A.C. Fedotov*

Abstract

A krill biomass census survey was carried out at two fishing grounds in the South Sandwich and South Orkney Islands areas during a cruise by RV *AtlantNIRO* in March/April 1990. The survey was conducted in the upper 100 m layer using a modified Isaacs-Kidd trawl. Trawling speed was 3.2 to 3.6 knots. The total krill stock on the poorly studied site off the South Sandwich Islands was assessed at 3.8 million tonnes, most of which was concentrated in the waters of the Weddell Sea. In contrast to this site, the one off the South Orkney Islands is well-established in terms of both research and commercial harvesting. The overall krill stock here was estimated to be 1.1 million tonnes. Most of this stock was concentrated in the south-western part of the Coronation Island shelf.

Résumé

En mars/avril 1990, une campagne d'évaluation de la biomasse du krill s'est déroulée, à bord du navire de recherche *AtlantNIRO*, sur deux lieux de pêche des régions des îles Sandwich du Sud et des Orcades du Sud . La campagne a été menée dans la couche des 100 m supérieurs à l'aide d'un chalut Isaacs-Kidd modifié. La vitesse de chalutage était de 3,2 à 3,6 nœuds. Le stock total de krill du site - d'ailleurs insuffisamment étudié - au large des îles Sandwich du Sud a été estimé à 3,8 millions de tonnes, la plupart étant concentrée dans les eaux de la mer de Weddell. Par contre, le site au large des îles Orcades du Sud est bien établi, tant en matière de recherche que d'exploitation commerciale. Là, le stock global est estimé à 1,1 million de tonnes. Ce stock était en grande partie concentré dans la section sud-ouest du plateau de l'île du Couronnement.

Резюме

Учетная съемка биомассы криля была произведена на двух участках в районе Южных Сандвичевых и Южных Оркнейских островов во время рейса НИС *АтлантНИРО* в марте-апреле 1990 г. Учет криля проводился модифицированным тралом Айзекса-Кидда в верхнем 100-метровом слое. Скорость траления составила 3,2-3,6 узлов. Общий запас криля на малоизученном участке Южных Сандвичевых островов составил 3,8 млн.тонн. Основная доля этого запаса была сосредоточена в водах моря Уэделла. В отличие от первого участка, участок у Южных Оркнейских островов является традиционным как в плане научных исследований, так и промысла криля. Общий запас криля на этом участке был оценен в 1,1 млн. тонн. Основная часть этого запаса была сосредоточена в юго-западной части шельфа о. Коронейшн.

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR

Resumen

En un crucero a bordo del BI *AtlantNIRO* se llevó a cabo una prospección de censo en dos caladeros de pesca de las islas Sandwich y Orcadas del Sur durante los meses de marzo y abril de 1990. Esta se realizó en la capa superior de los 100 m y se hizo con un arrastre Isaacs-Kidd modificado. La velocidad del arrastre era de 3.2 a 3.6 nudos. La población total de krill en esta zona relativamente poco estudiada de las islas Sandwich del Sur, se calculó en unas 3.8 millones de toneladas, estando la mayoría concentrada en las aguas del mar de Weddell. En cambio, en la zona de las Orcadas del Sur, tanto la investigación como la pesca comercial hace tiempo que están bien establecidas. Allí, la población total se estimó en 1.1 millones de toneladas. La mayoría de la población se concentró en la zona sudoeste de la plataforma de la isla Coronación.

In the interests of rational use of Antarctic krill (*Euphasia superba* Dana) it is essential to carry out constant monitoring of the state of its stock both in traditional fishing grounds and in the other inadequately studied areas of its distribution. In this connection, an attempt was made to estimate krill biomass as part of the sixth cruise of RV *AtlantNIRO* to the Atlantic sector of the Southern Ocean.

The biomass assessment was carried out in the central (inadequately studied) and western (traditional fishing ground) area of the Antarctic in autumn 1990 (from 13 March to 8 April in the South Sandwich Islands study area and from 12 to 10 April in the South Orkney study area). The first study area, a vast expanse surrounding the South Sandwich Islands consisting of two parts; the northern (55° to 60°S; 32° to 18°W) and southern (60° to 67°S; 20° to 18°W), was affected by different types of Antarctic waters during the observation period, i.e. the Antarctic Circumpolar Current (ACC) and the Weddell Sea waters. The second study area was only subject to the influence of the waters of the northern periphery of the Weddell Sea eddy (Fedulov *et al.*, in press).

Krill was taken with an Isaacs-Kidd net, modified by Aseev-Samyshev (6 m^2; 6 mm mesh), in the upper 100 m layer using the double oblique hauling method (0-100-0 m) at a towing speed of 3.2 to 3.6 knots. Trawling depth was controlled by a trawl probe "Igla" attached to the top beam of the metal trawl rigging. The volume of filtered water was controlled by the flowmeter "General Oceanics" (model 2030). Distance between hauls during the first survey was 60 miles by latitude and longitude and during the second survey it was 30 miles by latitude and 40 miles by longitude. Krill density (specific biomass) was calculated using the formula:

$$K = \frac{m}{w}$$

where **k** = density, mg/m^3
m = catch, mg
w = swept water volume, m^3 (according to flowmeter readings);

Values of krill density obtained from various stations were interpolated to draw density isolines along selected intervals (Figures 1 and 2) and the area of layers having equal density was determined. Biomass in the 0 to 100 m layer was calculated in respect of each swarm. Overall biomass was determined as the sum of biomass by layer. Table 1 gives mean weighted (mg/m^3) and absolute (thousands of tonnes) biomass.

The extent to which krill avoid fishing gear during investigations was not considered since currently there is no methodology for working out this phenomenon.

Extensive areas of low specific biomass were typical of krill distribution both in the South Sandwich (Figure 1) and South Orkney (Figure 2) Island areas. Minimum values for mean weighted biomass (not including areas of high biomass density) did not exceed 30 mg/m^3 in the ACC and Weddell Sea waters of the South Sandwich Island study area and 50 mg/m^3 in the South Orkneys study area. The areas of high biomass density in the above waters coincided with dynamic elements such as meanders, mesoscale circulations and parts of the Frontal Zone between the waters of the ACC and the Weddell Sea. Maximum values for specific biomass (up to 2 443 mg/m^3) were recorded in the frontal zone area in the anticyclonic meander to the west of the South Sandwich Islands. Mean value of weighted biomass in the South Sandwich Islands study area was 145.9 mg/m^3 in the Weddell Sea waters and 24.9 mg/m^3 in the ACC and 202.7 mg/m^3 in the South Orkney Islands study area (Table 1).

The figure of 3.8 million tonnes for the total krill stock in the South Sandwich Islands study area, with the bulk of the stock concentrated in the Weddell Sea waters, suggests that the Weddell Sea waters are more abundant in krill than the ACC. Unfortunately, it is impossible to be more accurate in estimating krill biomass in the South Sandwich Islands area since no similar studies have been carried out there before. The only available data are from Japanese investigations conducted in January 1984-85 as part of the SIBEX II Program (Endo *et al.*, 1986). The Japanese estimates of specific biomass (mean value 193 mg/m^3, maximum value 1 233 mg/m^3; sampling gear is KYMT trawl of 9 m^2 with mesh size 3.4 mm) are close to ours. Bearing this in mind, as well as the paucity of data and the limitations involved in such a comparison, a relative similarity may point to an agreement between the krill stock size estimated in autumn 1990 in the South Sandwich Islands area and the long-term value.

In the South Orkney Islands area, where research and commercial exploitation of krill resources have been long established, the total stock was 1.1 million tonnes. Most of the stock was concentrated in the south-west part of the Coronation Island shelf, an area to which krill had been transported and then accumulated due to favourable circulation conditions, and where the commercial fishing fleet had been operating over an area of about 600 km^2. The specific biomass reached its greatest level here (on average up to 6 000 mg/m^3). It is worth noting that the similarity of krill biomass assessments over the years, despite intensive commercial exploitation, may indicate a continued relative stability of the krill stock in the area.

REFERENCES

ENDO, Y., T. IMASEKI and Y. KOMAKI. 1986. Biomass and population structure of Antarctic krill (*Euphausia superba* Dana) collected during SIBEX II Cruise of RV *Kaiyo Maru*. *Mem. National Institute of Polar Research*, Special Issue 44: 107-117.

FEDULOV, P.P., V.N. SHNAR, A.C. FEDOTOV and I.V. KRASOVSKY. 1990. *Preliminary Results of Research Cruise of RV AtlantNIRO to the West of the Atlantic Ocean Sector of the Antarctic in March-April 1990*. WG-Krill-90/24. Hobart, Australia: CCAMLR. (In Russian).

SUSHIN, V.A., L.G. MAKLYGIN and S.M. KASATKINA. 1990. *Summary Results of Krill Integrated Studies in Statistical Area 48 Carried Out in Research Cruises of RV Argus and RV Evrika in 1984-1988*. WG-Krill-90/23. Hobart, Australia: CCAMLR. (In Russian).

Table 1: Krill biomass in the 0 to 100 m layer in various areas of the Atlantic sector of the Southern Ocean, autumn 1990.

Study Area	Water Masses	Area (km^2)	Mean Weighted Biomass mg/m^3	Total Biomass (000 tonnes)
	Weddell Sea			
South Sandwich Islands	Northern Area	221 048.3	145.9 1 254.5* 22.7**	3 226.6
	Southern Area	69 343.4	22.9	159.1
	Antarctic Circumpolar Current			
		169 717.9	24.9	423.8
	Total:	460 109.6		3 809.5
South Orkney Islands	Weddell Sea	54 926.2	202.7 3 296.7* 43.7**	1 113.4

* Area of high biomass density (0.5 mg/m^3)
** Total area but excluding areas of high biomass density

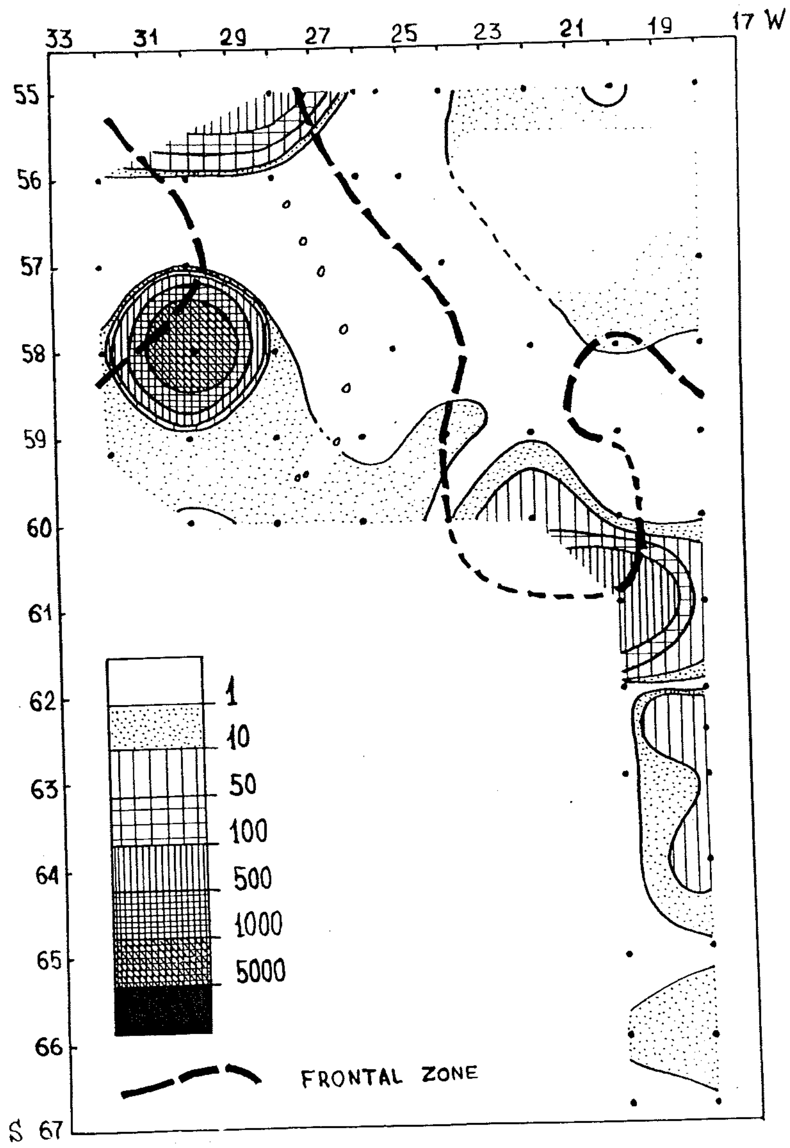


Figure 1: Distribution of *E. superba* (mg/m³) in the 0 to 100 m layer based on trawl data from the South Sandwich Island study area in March/April 1990.

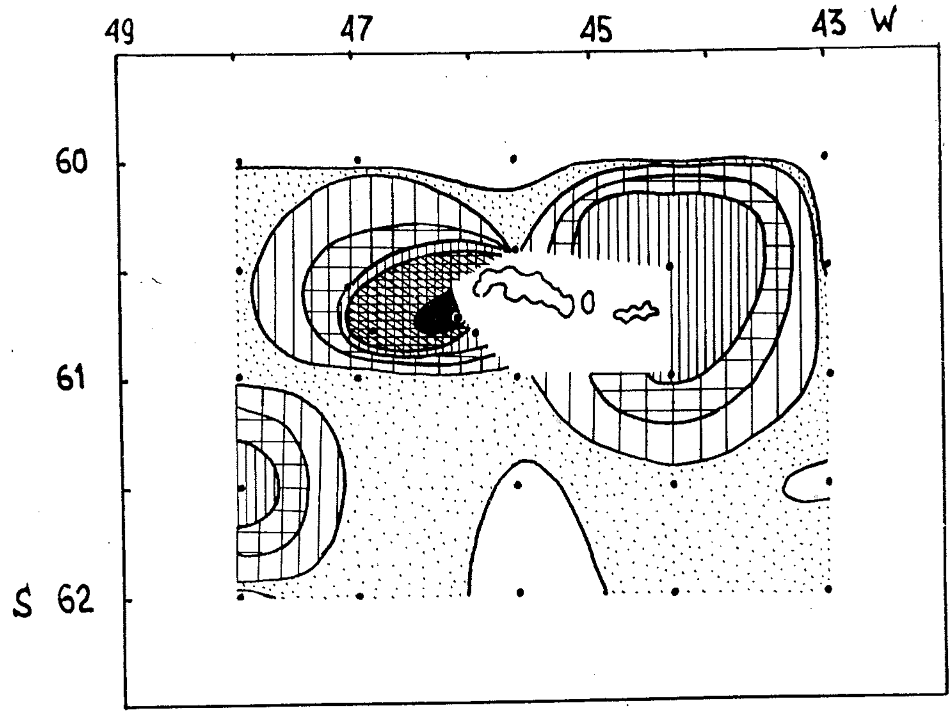


Figure 2: Distribution of *E. superba* (mg/m³) in the 0 to 100 m layer based on trawl data from the South Orkney Island study area in April 1990. (See Figure 1 for key).

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

WG-KRILL-90/19

DISTRIBUTION, BIOMASS AND CHARACTERISTICS OF THE *EUPHAUSIA SUPERBA* FISHERY AROUND SOUTH GEORGIA (SUBAREA 48.3)

V.I. Latogursky*, R.R. Makarov**, L.G. Maklygin**

Abstract

Krill distribution in the South Georgia area and many aspects of its variability have been extensively described in scientific literature. A summary of recent findings is discussed in this paper. There has been less focus on data concerning krill biomass assessments. The existing uncertainty in krill biomass assessment can be largely attributed to high variability and the wide range of biomass values obtained which in turn leads to uncertainty in interpreting krill biomass for the area. It was therefore only possible to begin to explain the reasons for the variability in the scale of krill swarms and to attempt to determine more reliable values of its biomass after a number of census surveys had been conducted. Results of the nine most representative surveys conducted by Soviet scientists in the area from 1974 to 1988 are summarized in this paper. The most important survey data and biomass assessments have been tabulated and illustrated by various survey maps. It was found that the distribution of krill swarms corresponds largely with areas where currents turn into eddies. Among these areas, aggregations of krill were observed most often to the east of the island and around 37°W. When the water circulation system is unfavourable, which means the absence of eddy formations, krill do not usually form aggregations and its density is low. When water dynamics are favourable for krill aggregations its biomass around South Georgia is approximately 400-800 thousand tonnes. Unfavourable conditions correspond to a biomass of an order of magnitude less. Short-term fluctuations of krill biomass in the South Georgia area are extremely significant. Biomass may differ by as much as eight times in a month. It also usually decreases in spring, regardless of the type of water circulation. Annual differences in krill biomass are undoubtedly associated with the volume of krill brought here by waters of the Scotia Sea Secondary Front. More extensive studies incorporating trawl and acoustic surveys of different temporal and spatial scales are recommended in order to make reliable assessments of krill biomass.

Résumé

La littérature scientifique a largement traité de la répartition du krill dans la région de la Géorgie du Sud et de nombreux aspects de sa variabilité. Un résumé de découvertes récentes est examiné dans ce document. Moins d'importance a été accordée aux données sur les évaluations de la biomasse du krill. L'incertitude actuelle touchant l'évaluation de la biomasse du krill est, dans une large mesure, imputable à la grande variabilité et à l'intervalle important des valeurs de biomasse obtenues. Ainsi, ce n'est qu'après quelques campagnes d'évaluation qu'il a été possible de commencer à expliquer les causes de la variabilité dans la

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR
** VNIRO, 17a Verkhnaya Krasnoselskaya Street, Moscow, USSR 107140

taille des essaims de krill et de tenter de déterminer des valeurs plus fiables de sa biomasse. Cette communication résume les résultats des neuf campagnes les plus représentatives menées par des scientifiques soviétiques dans cette zone de 1974 à 1988. Les données de campagnes et les évaluations de biomasse les plus importantes sont présentées sous forme de tableau et illustrées par plusieurs cartes des campagnes d'évaluation. Il ressort que la répartition des essaims de krill correspond en grande partie aux régions où les courants créent des tourbillons. Parmi ces zones, les concentrations de krill ont, le plus souvent, été observées à l'est de l'île et autour de 37°W. Lorsque le régime de circulation des eaux est défavorable, à savoir en l'absence de formations de tourbillons, le krill ne forme pratiquement pas de concentrations et sa densité est faible. Quand la dynamique de l'eau est favorable aux concentrations de krill, sa biomasse autour de la Géorgie du Sud est d'environ 400-800 milliers de tonnes. Les conditions défavorables correspondent à une biomasse d'un ordre de grandeur moins élevé. Les fluctuations à court terme de la biomasse du krill dans la zone de la Géorgie du Sud sont extrêmement significatives. La biomasse peut varier jusqu'à huit fois en un mois. De plus, elle décroît généralement au printemps, quel que soit le type de circulation des eaux. Les variations annuelles de la biomasse de krill sont sans aucun doute liées au volume de krill amené ici par les eaux du Front secondaire de la mer de Scotia. Il est recommandé d'effectuer des études plus approfondies, comportant des campagnes d'évaluation, tant par chalutage qu'acoustiques, des diverses échelles spatio-temporelles afin d'obtenir des évaluations fiables de la biomasse du krill.

Резюме

В научной литературе широко освещались как распределение криля в районе Южной Георгии, так и ряд аспектов его изменчивости. В данном труде рассматривается сводка последних выводов. Меньшее внимание было уделено данным, имеющим отношение к оценке биомассы криля. Существующая неопределенность в оценках биомассы криля может быть в основном отнесена на счет значительной изменчивости и широкого диапазона полученных значений биомассы, что в свою очередь приводит к неопределенности в оценке биомассы криля в этом районе. Таким образом, можно было сделать только исходные попытки объяснить причины изменчивости размера скоплений криля и, по проведении ряда учетных съемок, идентифицировать наиболее достоверные значения биомассы криля. В настоящей работе приводится сводка результатов девяти наиболее представительных съемок, выполненных в этом районе советскими учеными за период с 1974 по 1988 гг. Наиболее важные данные съемок и оценки биомассы были сведены в таблицы и проиллюстрированы различными картами, отображающими районы съемок. Было установлено, что распределение скоплений криля в значительной мере совпадает с местоположением районов, в пределах которых течения образуют круговороты. Среди этих районов особо богаты скоплениями криля были те, которые располагаются к востоку от острова и приблизительно на 37° з.д. В отсутствие благоприятных условий, т.е. формирования

круговоротов, криль обычно не собирается в агрегации и характеризуется низкой плотностью. При наличии динамики вод, благоприятной для формирования агрегаций криля, его биомасса в районе Южной Георгии составляет 400-800 тысяч тонн. Неблагоприятные гидродинамические условия соответствуют биомассе на порядок ниже. Краткосрочные колебания биомассы криля в районе Южной Георгии имеют чрезвычайно большое значение. В течение месяца биомасса может измениться в восемь раз. Также, биомасса обычно понижается в течение весеннего периода независимо от типа циркуляции вод. Ежегодные изменения биомассы криля без сомнения связаны с количеством криля, приносимого в данный район водами вторичного фронта моря Скотия. Для получения достоверных оценок биомассы криля рекомендуется провести более широкие исследования, включающие выполнение траловых и акустических съемок в разных временных и пространственных масштабах.

Resumen

Son numerosos los estudios científicos que tratan con amplitud sobre la distribución del krill y otros aspectos relacionados con su variabilidad en la zona de Georgia del Sur. En este trabajo se exponen los resultados más recientes pero no se ha centrado únicamente en los datos de las evaluaciones de biomasa. La actual incertidumbre a la hora de evaluar la biomasa de krill puede atribuirse básicamente a su gran variabilidad, y los distintos valores de biomasa obtenidos crea incertidumbre cuando se intenta calcular la biomasa de krill para dicha zona. Sólo después de realizar varias prospecciones de censo, sería posible explicar las razones que causan la variabilidad en la magnitud de los cardúmenes de krill e intentar un cálculo más fiable de la biomasa. En este trabajo se presentan los resultados de las nueve prospecciones más importantes realizadas entre 1974 y 1988. Los distintos mapas y tablas presentan los datos más importantes de las prospecciones y de las evaluaciones de biomasa. Se ha visto que la distribución de los cardúmenes de krill se corresponde con las zonas en las que las corrientes forman torbellinos; en estas zonas se constata que las concentraciones se forman en gran parte al este de la isla, próximo a los 37° W. Cuando el sistema de circulación del agua es desfavorable, lo que quiere decir que no se forman torbellinos, el krill no suele agruparse y su densidad es baja. En cambio, cuando la dinámica es favorable a la formación de concentraciones, la biomasa en las aguas de Georgia del Sur oscila entre las 400-800 mil toneladas. Las condiciones desfavorables corresponden a una biomasa de menor magnitud. Las fluctuaciones a corto plazo en la zona son muy significativas. La biomasa puede variar hasta ocho veces en un mes. También suele disminuir en primavera, sea cual sea la circulación del agua. Las diferencias anuales de la biomasa están sin duda relacionadas con el volumen de krill que fluye con las aguas del Frente secundario del mar de Scotia. Se recomienda que se hagan más estudios con prospecciones de arrastre y acústicas en diferentes escalas temporales y espaciales, para poder disponer de evaluaciones de biomasa más fiables.

1. INTRODUCTION

The South Georgia area holds a special place among those areas of the Southern Ocean where *Euphausia superba* forms aggregations. Soviet research vessels have been studying this area since 1965 although it was not until 1972 that commercial fishing began.

So far research has been of an integrated nature and has examined questions not only of euphausiid biology and its population resources but also matters concerning the physical environment and its biotic components, primarily plankton. This integrated approach has led to an increase in knowledge about various aspects of *E. superba* biology, especially krill distribution in relation to environmental conditions. Together with biomass assessments this has paved the way for the development of a rationally managed krill fishery in this area. Waters from the Weddell Sea transport krill to the South Georgia area which is located at the northern edge of its habitat (Marr, 1962; MacIntosh, 1973; Maslennikov and Solyankin 1980; Fedulov *et al.*, 1984). Investigations into size composition relative to water structure showed that krill may also be brought here by the waters of the southern periphery of the Antarctic Circumpolar Current (ACC) (Makarov *et al.*, 1980; Maslennikov *et al.*, 1983). This is supported by the fact that the same types of water correspond to the species composition of phytoplankton (Makarov *et al.*, 1984) and size composition of copepods (Vladimirskaya, 1978; Makarov *et al.*, 1986). Strictly speaking, krill aggregations which form off the island are augmented by the Secondary Frontal Zone of the Scotia Sea which is characterized by a constantly high density of *E. superba* (Maslennikov, 1978; Makarov *et al.*, 1980; Fedulov *et al.*, 1984).

After being carried along by the drift into the island's waters krill is retained here for a time (the "shade effect"; Shevtsov and Makarov, 1969) before continuing to flow with the currents in an easterly direction (Everson, 1976; Maslennikov and Solyankin, 1980). This retention of krill off the island will result in the formation of concentrations only when eddies and meanders develop around the island shelf and slope. Moreover, aggregations may be quite large in off-shore island waters (Maslennikov, 1979; Makarov *et al.*, 1980). When straight currents are prevailing krill is dispersed, abundance is low and aggregations in general are not formed. These types of conditions were observed in 1969 (Makarov *et al.*; 1980) and 1987. The nature of dynamic forces which facilitate the formation of krill concentrations is one of the most important factors determining the level of euphausiid abundance in the South Georgia area.

Experiments carried out in the South Georgia area showed that the largest aggregations of *E. superba* are formed around the northern edge of the island and it was here that later studies were conducted, a fundamental part of which included census surveys.

Although *E. superba* aggregations were encountered over the whole area, in certain areas they tended to form more regularly (Makarov *et al*, 1980; Sysoeva, Shevtsov, 1980). The type of bottom relief determines this regularity because this is where eddies and whirlpools are most often formed as a result of the interaction of the bottom relief with currents travelling by the island (Maslennikov, 1979).

Therefore the formation of *E. superba* aggregations depends primarily upon the direction of transportation by currents and factors influencing its retention in the shelf and slope waters of the island (Marr, 1962; MacIntosh, 1972; Makarov *et al.*, 1980). As opposed to aggregations in the southern part of the Scotia Sea, aggregations here, for example, are non-spawning (Makarov, 1978 and 1980). Processes occurring in this area, especially in relation to krill distribution and swarming, are entirely dependent upon physical environmental factors. The low status of the area in the functional structure of the *E. superba* habitat, especially in relation to its reproduction in the Atlantic sector, is a result of South Georgia being located at the edge of the habitat area in unusually low latitudes for this species and the dependence of the formation of krill aggregations upon drift transport both on the macro and meso-scales. The appearance of *E. superba* larvae in plankton is synchronous (by dates and size composition) with reproduction of the species in the southern part of the Scotia Sea (with allowance for drift periods), but not with the reproduction of krill near the island (Menshenina, 1988). Larvae and adult specimens are brought to the area by currents from the south or south-east. Larvae spawned in the island waters are eventually carried away from the region as indeed are adults.

Drift transportation of krill in the area and factors influencing swarming around the island are characterized by a high level of variability.

The most noticeable type of variability is seasonal. Aggregations occur here in almost all months of the year although spring research did not uncover any particularly large abundance. At this time the very profuse spring blooming takes place which, by analogy with spring in the Scotia Sea (see Makarov *et al.*, 1980), causes aggregations to break up. It is probable that as a result of dispersion krill is carried beyond the island waters. In other words *E. superba* abundance around South Georgia always drops with the onset of spring. This assertion is backed up by data from the fishery which always ceases operations in spring (Table 1).

Aggregations build up again with the onset of summer and are maintained until winter, i.e. the probability of encountering *E. superba* aggregations in the island waters increases during the other seasons although they may also be absent in winter (Latogursky, 1975; Heywood *et al.*, 1985). It is typical that if during summer *E. superba* aggregations occur most often toward the east of the region then in autumn and especially winter they are more prolific in the west (Latogursky, 1973).

Therefore the notable fluctuations in krill numbers over the whole year depend upon the variability of water dynamics in the mesoscale. Variability associated with the effects of meteorological conditions is especially short-lived. As cyclones pass, krill disperse and sink to deeper layers. After a time, however, the situation returns to its initial condition.

Interannual changes in krill distribution and particularly abundance are also possible. Apart from the situation in 1969 and 1978 as described earlier, a low level of abundance prevailed in the seasons 1982/83 and 1983/84. It should be noted that it has always been very difficult to identify and separate seasonal and interannual fluctuations in this area. Even surveys carried out more than once a year do not create a foundation for identifying the type of change taking place. During the above years the low abundance of *E. superba* can be attributed to the effects of the fishery. Interannual variations are caused by water advection from the Scotia Sea secondary front into the island area. This advection depends on the interaction of the large circulation systems of the Atlantic sector, i.e. the ACC and the Weddell Circulation (Maslennikov and Solyankin, 1979). It is difficult to evaluate these interactions using survey data from South Georgia alone. Nevertheless some indirect assessments have been made (Bogdanov, Solyankin, 1970), in particular in terms of analysing the variability of the latitudinal gradient of atmospheric pressure (Fedulov *et al.*, 1984). The data obtained correlate well with krill swarm density off the island.

Distribution trends and many aspects of its variability have been extensively described in scientific literature (see Lubimova *et al.*, 1980) (SC-CAMLR-I/BG/1). There has been less focus on data concerning specific biomass assessments of krill. In the work of Lubimova and Shevtsov (1980) the range of variability for krill biomass is given for the initial study period in the area (1965 to 1976) with values from 0.9 to 3.6 million tonnes. The uncertainty in krill biomass assessment can be largely attributed to high variability and the wide range of biomass values obtained which in turn leads to uncertainty in interpreting krill biomass for the area. It was therefore only possible to begin to explain the reasons for the variability in the scale of *E. superba* swarms and to attempt to determine the more reliable values of its biomass after a large number of census surveys had been conducted. Results of these studies are summarized in this paper.

2. SURVEY RESULTS

It is not possible to examine here all surveys conducted off the island, especially since some of them covered only limited area and were not representative. Therefore we have chosen only those surveys which are comparable according to area covered, fishing gear used, the number of stations made and availability of necessary background data and which were carried out using accepted methods (data from earlier studies were used only as a guide).

The study of *E. superba* distribution, swarm density and biomass assessment were carried out using standard methods (as in other areas of the Southern Ocean) based on census trawl surveys regularly conducted in the South Georgia area.

The general approach to conducting biomass assessments of krill in the area under investigation can be described by taking one of the most detailed surveys, which was made from 4 to 13 February 1975, as an example (see below - Survey 2).

The survey was conducted towards the north of the island between 34° and 41°W. Thirty-two hauls (generally lasting half an hour each) were carried out over this area of 54 450 square miles. Stations were made along five lines radiating out from the island with six to seven stations along each line.

A midwater trawl was employed at each station. The cross-section of the trawl opening at the level where fine mesh (10 to 14 mm) begins was 140 square metres and was taken as the working area of the trawl opening. Since the catchability coefficient was difficult to calculate it was taken to be equal to 1.

The density of *E. superba* in fished swarms (g/m^3) was worked out according to the size of the catch taken at each point of the survey and the amount of filtered water (this was calculated based on vessel speed (usually 2.8 knots), trawl opening and duration of haul).

At the same time the layer of water where krill swarms were distributed was recorded using hydroacoustic equipment. Values obtained for density were taken to be typical for the whole layer. Over the period of the survey in question, *E. superba* swarms were distributed in the upper 50 m layer in particular. More calculations were made to determine krill biomass bearing in mind the vertical distribution characteristic of euphausiids. Mean biomass was also estimated per square kilometre and square mile.

The density values obtained at each station were interpolated, biomass was calculated by strata (areas between adjacent isolines) and the results were summarized for the entire area of the survey.

This paper presents the results of seven surveys carried out using a commercial midwater trawl during various seasons from 1974 to 1988. Naturally the areas covered by the surveys and the number of hauls made were not identical. Most of the surveys were carried out in areas to the east, north and west of the island (between 40° and 34 °W and from 54°S to the shore (the boundary of territorial waters). The southern part of the island's waters was studied less frequently. Therefore the biomass values contained refer mainly to the north-west, north and north-eastern inshore waters of South Georgia.

Table 2 contains important details of the surveys and data obtained from observations on the quantitative parameters of *E. superba* concentrations. Each survey has a map (Figures 1 to 7) showing where it took place and areas where abundance of krill was found to be greatest.

It should also be noted that although trawls of identical area were not always used, their design and main parameters were similar (for details of each survey see below). As with the above example, the size of the trawl opening was calculated according to where the fine mesh section of the trawl began (data on trawl openings are shown in Table 2).

Each survey conducted with echosounders recorded vertical distribution and, consequently, biomass estimates were made based on the length of the layer where krill were distributed.

Therefore in calculating *E. superba* biomass for each survey all natural variables and parameters were taken into consideration which necessitated the introduction of changes into the above procedure of estimation.

In recent years the Isaacs-Kidd trawl has been used in a number of census surveys to make oblique hauls in the 0 to 100 m layer. Preliminary data indicate that this trawl has a catchability rate inferior to commercial trawls. Therefore it appears that *E. superba* biomass assessments made using the Isaacs-Kidd trawl are underestimates. In view of this, biomass assessments from Surveys 8 and 9 can only be used for rough comparison with assessments obtained from commercial trawl data.

We shall briefly examine the results of each survey individually. For ease of comparison each surveys has an identifying number.

The most important survey data and assessments of quantitative indices for the *E. superba* population are given in Table 1. Figures 1 to 4 show survey areas and also where large concentrations of krill were detected. Figures 5 to 7 give data on the system of surface currents for most of the surveys (a reading of 1 000 dB relative to the conditional surface).

Survey 1 (9 to 23 March 1974, *RV Salekhard*; Figure 1A)

Fifty-nine trawls were carried out to the north and east of the island. The survey itself together with additional searching operations made it possible to characterize in detail the distribution of *E. superba* in the area. The largest concentrations were discovered over the island slope (29 g/m^3) and at an oceanic depth (3.5 g/m^3) to the north-east of the island. Apart from these two areas in Figure 1A, the area to the far south-east should also be noted. Over the remainder of the survey area there were either very few euphausiids or none at all (especially in the western part of the region). Most often krill was distributed in the 0 to 100 m layer and deeper (up to 200 m). However in the area of massive swarming near the island, krill swarms were distributed in the upper layer from 12 to 35 m. These differences were taken into consideration when calculating biomass. The high values for density gave a high biomass assessment which was over 560 000 tonnes for the study area over the period of the survey (Table 2).

Comparison of *E. superba* distribution (Figure 1A) and water dynamics in the area (Figure 5A) showed that the largest concentrations of krill were encountered either in areas of strong eddies in the system of currents or on the edge of streams flowing together from opposite directions.

Survey 2 (4 to 13 February 1975, *RV Akademik Knipovich*; Figure 1B)

One of the most extensive by area, this survey covered 54 450 square miles and was carried out to the west, north and east of the island and consisted of 41 hauls. The average density of krill was 1.4 g/m^3. The largest concentrations were encountered to the east of the island. The survey was begun after two micro-surveys. The first was from 28 January to 3 February and consisted of 40 hauls and the second took place from 25 to 27 March and consisted of 23 hauls. Mean density in the micro-survey areas was 2.4 and 5.3 g/m³ respectively. *E. superba* biomass in aggregations in the east (see Table 2) made up more than half of the total biomass in the eastern part of the survey (511 000 tonnes). Overall biomass in the western and central parts of the survey was less (395 000 tonnes) than for aggregations in the west in March alone.

The nature of water dynamics is fully consistent with the location of sites with high abundance of krill (Figure 5B).

Survey 3 (12 to 18 June 1981, *RV Argus*, Figure 2A)

This survey was relatively small in area (18 hauls) and was carried out to the north-east of the island. Aggregations were encountered over all island slopes where krill density was almost 6 g/m³. With the exception of a handful of specimens, it is interesting that *E. superba* was practically absent in the open part of the area. It is typical that in such a situation localized swarming will only occur in waters near the shallows. Krill density in the area 37° and 38°W reached maximum levels - 5.64 and 5.15 g/m³ respectively. These values for krill swarm density and those approaching them were responsible for a fairly high total biomass for the survey period (476 000 tonnes, see Table 2).

Survey 4 (18 to 29 June 1981, *RV Argus*, Figure 2B)

Despite the increase in the size of the study area, this survey (23 hauls), which was carried out almost one month after Survey 3, showed a sharp drop in *E. superba* abundance. Areas of increased density were now towards the west. One of the areas (maximum density - 0.88 g/m³) was located at 37°W while the other was near the western extremity of the island (0.75 g/m³). Calculations showed that by comparison with June of the same year biomass decreased by six times (79 000 tonnes, see Table 2).

Survey 5 (1 to 4 June 1983, *RV Argus*, Figure 2C)

A census on krill abundance was carried out in the beginning of winter 1983 (17 hauls) in approximately the same location as Survey 4. The overall location of areas with increased abundance were also similar. Extremely localized and small aggregations of *E. superba* were noted in the area 36 °W (maximum density 5.6 g/m³) and to the west of the island (4.6 g/m³). This accounted for only 3% of the survey area. Over the rest of the territory no large swarms of euphausiids were encountered and many hauls were unsuccessful. On the whole this was responsible for the extremely low overall biomass assessment (54 000 tonnes, see Table 2).

The dynamic relief on the surface was homogeneous and lacked any clearly discernible eddies in the current field (Figure 6A). The lack of eddies which usually facilitate the formation of aggregations undoubtedly played a role in the low level of krill density and biomass. It was only in the very western part where the current began to flow south that somewhat larger levels of abundance were noted.

Survey 6 (22 November to 9 December 1986, *RV Gizhiga*, Figure 3A)

Although this was a fairly extensive survey (41 hauls), it did not cover territory further south than 54°S. It was carried out in the very beginning of the summer season and showed areas of high density in the western part of the region. Krill were dispersed over the remainder of the study area. As opposed to a number of other surveys (1, 3 and 5), aggregations of krill were also discovered a long way out to sea (maximum density here was 1.2 g/m^3.) although at the same time they were encountered in larger numbers in the area of the island shelf (maximum density 2.5 g/m^3). In the north-east part of the area there were practically no krill at all. They began to appear in small numbers only as the survey neared 54 °S. On the whole, areas of high krill abundance were characterized by their large size which was reflected by the values of the biomass assessments made over the survey area (607 000 tonnes, see Table 2).

Mesoscale eddies were noted in a number of areas which quite clearly coincided with areas of high krill abundance. As usual they appear to be the reason for the concentration of krill both around the continental shelf and further away from shore towards the oceanic zone. Although the survey did not cover the area east of the island, judging by the water dynamics it may be assumed that *E. superba* aggregations were present there.

Survey 7 (2 May to 5 June 1988, *Gr. Kovtun*, Figure 3B)

This survey was for the most part conducted in May. In fact it was a series of micro-surveys made in the north-east and northern sectors of the area of the shelf and the island slope. Observations were made from a fishing vessel which carried out several dozens of hauls in each area which in turn ensured a detailed assessment of *E. superba* aggregations in the area. The vessel's regime also included elements of a search close to where the fishing fleet operates. The data obtained can therefore be examined in conjunction with the results of other surveys.

Krill was encountered in the 0 to 50 (70) m layer and calculations of density and biomass were made in relation to that layer. The density of aggregations from the south-east to the north-west of the areas under investigation was 12.5 g/m^3, 14.1 g/m^3 and 8.6 g/m^3. Total biomass was estimated to be 1 402 000 tonnes (see Table 2).

Survey 8 (11 to 23 October 1984, *RV Evrika*, Figure 4A)

This was the first time that a survey was conducted around the whole island. An Isaacs-Kidd trawl was employed to make 66 hauls. On the whole the distribution tendencies of *E. superba* turned out to be the same as were previously observed. The main areas of high krill concentration were towards the east, north (this is usually rare) and western sectors of the study area. The largest concentrations were encountered in the north (in the area 37°W, maximum density 2.5 g/m^3), but in general, lower values prevailed. In essence it was only in those places marked on the map that krill density was high while in other areas covered by this extensive and detailed survey they were absent altogether. Despite the extent of the survey (its area was four-times that of Surveys 3, 4, 5 and 6) a low biomass figure was obtained over the period of investigations (3 800 tonnes, see Table 2).

It is very interesting to note that the water dynamics on the surface were conducive to the formation of krill aggregations (Figure 7A). Small local increases in density in each instance (place) coincided with more complex forms of dynamic relief. However, in keeping with the general seasonal variability of *E. superba* abundance in the region, there were very few observations in the area over the survey period.

It should be pointed out that repeated observations made here over the brief period 15 to 18 January 1985 in the south-east of the island showed dense swarms (density up to 5.9 g/m^3).

Survey 9 (20 January to 9 February 1988, *RV Evrika*, Figure 4B)

As in October 1984, this survey covered the area around South Georgia where 65 hauls were made with the Isaacs-Kidd trawl. The general distribution patterns were somewhat similar to those from Survey 8, although dense aggregations were encountered in the area around 37°W. An extensive area stretching from the south-east to the edge of the survey's range was noteworthy for its high abundance of krill. Two areas, located on the shelf and the outer part of the island slope to the east of the island and around 37°W, stood out due to their density which exceeded 10 g/m^3. Aggregations were extremely long, leading to a biomass estimate of 868 000 tonnes (see Table 2). It is worth repeating that census surveys made with the Isaacs-Kidd trawl give underestimates in regard to density and biomass of *E. superba*. It is therefore not impossible that over the period of the survey krill biomass could actually have been much greater.

3. DISCUSSION

Comparison of data on *E. superba* distribution with the pattern of currents (Figure 7B) showed generally favourable and regular conditions for swarming.

This brief description demonstrates that most surveys in the South Georgia area adequately covered those areas where krill forms concentrations. Despite slight differences in the number of hauls, the data obtained from each survey are entirely comparable.

A comparison of maps depicting the location of areas with high density of *E. superba* and patterns of water circulation around South Georgia during each survey shows an overlap of swarming areas and areas where currents turn into eddies. Even in those instances where biomass was quite low (e.g., Survey 8), abundance increased in places where dynamic activity was greater (cf. Figures 4B and 7A). Among these places, aggregations of *E. superba* were encountered most often in waters to the east of the island and around 37°W.

When the circulation system presents unfavourable conditions (such as the straight currents off the northern shore of the island, which means the absence of eddy formations leading to euphausiid concentration) aggregations do not form at the usual time and density is insignificant. This was the case for Survey 5 (cf. Figures 2A and 6A). This in turn was reflected by the biomass assessment for *E. superba.*

Territory was covered fairly evenly during the surveys and vessels did not specifically remain in areas of aggregations. Especially high values for density obtained after fishing a particular aggregation did not significantly effect the biomass estimate for any of the surveys. Therefore biomass estimates from each of the surveys only indicate the general picture of *E. superba* abundance for the relevant periods.

From the above we can see that krill swarming also occurs in other coastal areas of South Georgia. Although swarming in these areas occurs less regularly and on a smaller scale their very existence is invariably associated with irregular currents. Eddies around the island contribute to a general increase in krill abundance over the whole area and determine levels of density which vary from one survey to another. The biomass estimate for euphausiids changed in accordance with values for density in the study area. By comparing the estimates in Table 2 it is clear that they correspond to two levels of values which differ by an order of magnitude (tens of thousand and hundreds of thousands of tonnes). It is obvious that such large differences depend upon swarming conditions.

When conditions for water dynamics are favourable *E. superba* biomass is around 400-800 thousand tonnes. It is precisely when these kinds of conditions prevail and krill biomass reaches several hundred thousand tonnes that the fishing fleet is able to operate. The values of overall density estimated during the relevant survey are accepted as correct for the operation of fishing vessels. Summary data from early research in the area (1972 to 1981) shows that fishing was only conducted when density was 6 to 12 g/m³ (Fedulov *et al.*, 1984). In certain months there was a marked decrease in density and fishing did not take place (Fedulov *et al.*, 1984). During the periods when those surveys being reviewed in this paper (1 to 3, 6, 7 and 9) were carried out, commercial vessels did operate when density and biomass were high.

Thus the circumstances prevailing at the time of Surveys 1 to 3, 6, 7 and 9 are entirely usual for the area when there are favourable hydrological conditions. The values for biomass obtained from these surveys correspond to the normal level of accumulation of *E. superba* in the waters off South Georgia.

It will be recalled, however, that we are examining overall krill density in the survey area. As we have seen with individual cases, the extent to which *E. superba* forms aggregations in certain areas affects specific biomass values. In this regard it is extremely important to assess the extent of swarm formation within the confines of areas of aggregation.

There was no specific focus on areas where krill form aggregations proper during most of the surveys which were aimed at making integrated studies of off-shore waters. This would have made the research more expensive and time consuming and reduced the value of any results obtained. Surveys were carried out over brief periods, usually one or two weeks. The design used for Survey 2 (a survey plus and separate research into aggregations) was to some extent a compromise. Only rarely can such a survey design be used by research vessels which usually work to tight and varied schedules. However, this survey design turned out to be the most acceptable for expressing quantitative values graphically.

In order to characterize areas where krill aggregations are distributed, micro-surveys are needed to contour these areas and to carry out within their boundaries a series of hauls aimed at determining krill biomass. This was done in two instances only (Surveys 2 and 7). Calculations made using these data showed that more than half the total biomass may be in these aggregations and sometimes this value even approaches the total biomass (see data from Survey 2). Data from Survey 7 are indicative here and point to an especially high biomass of krill accumulated around the island in summer 1988. Considering the above, biomass could have reached 1.5 million tonnes. Therefore it may be assumed that *E. superba* summary biomass (i.e., total biomass and biomass concentrated in aggregations) regularly reaches a figure in the order of one million tonnes (Surveys 2 and 9) and sometimes greater (7). It should be recalled that a catchability coefficient of 1 was used when in reality it should have been lower.

Therefore standard surveys which do not focus on aggregations underestimate the value of *E. superba* biomass in the South Georgia area. It is also clear that in certain areas the high total biomass indicates the presence of fairly large aggregations of krill. Although the above only deals with variability in relation to total density it may nevertheless be assumed that the higher total density, the more likely the increase in the number and scale of aggregations.

As we have already emphasized, the fluctuations in *E. superba* biomass in the South Georgia waters are extremely significant. Moreover, the situation here is subject to rapid change. For example, the biomass figure may vary by as much as eight times in a month (cf. Surveys 3 and 4). During the 1982/83 and 1983/84 seasons unfavourable conditions predominated for an extended period (Survey 5) and due to low biomass and small catches the fishing fleet found it impossible to operate in the area (see catch statistics in Subarea 48.3, CCAMLR).

Annual differences (long-term trends) in *E. superba* biomass in the South Georgia area are undoubtedly associated with the volume of krill brought here by waters of the Scotia Sea Secondary Front. Short-term fluctuations in biomass may occur when there is an abrupt, although impermanent, change in the system of currents off the island. It should be recalled once again that the more regular changes in krill abundance in the area are of a seasonal nature. Krill biomass usually decreases in spring regardless of the type of circulation determining water dynamics. Although the type of circulation may be extremely favourable aggregations do not form and density is very low (see, e.g. data from Survey 8).

Variability of krill abundance is quite significant in the other seasons even when swarming conditions are favourable. Nevertheless the biomass figures for Surveys 1 to 3, 6, 7 and 9 are on the whole consistently high and it is only when this level of krill swarming has been reached that fishing operations can take place.

4. CONCLUSION

Individual observations made during the surveys indicate wide differences in *E. superba* biomass in the South Georgia area. This complicates research and leads to uncertainty in relation to many questions associated with assessing krill abundance. For the present we are restricted to speaking alternately about favourable and non-favourable conditions for swarming in the study area. These types of conditions also govern the regime of the fishing fleet. The above two biomass estimates which vary by an order of magnitude reflect the true differences in the notion of favourable and unfavourable conditions.

In reality the situation is more complex since transitions between the two levels of biomass are possible and it is as yet unclear how long these transitions take. In one example the transition interval was less than one month (cf. Surveys 3 and 4) but there are obviously other possibilities. This question should actually include an assessment of the combination of interannual and short-term variability. Interannual variability is associated with changes in the scale of krill transport towards the island whereas short-term variability is related to the conditions for the formation of aggregations in the area. The subsequent drift of krill beyond the island should also be borne in mind, although this question is especially complex and has so far been poorly studied. Indeed, with the breaking up of aggregations associated with changes in water circulation krill may remain in the island area in a dispersed form. As eddies build up again swarms reappear, however, due to the extended nature of this change, they may be carried away from the island. In other words, this transport is a constant phenomenon but its magnitude is the decisive factor.

Carrying out surveys in the island area alone is insufficient to research properly interannual variability. In order to assess the interaction of the ACC and the Weddell Circulation investigations should be made into the system of large-scale circulation. Together with large-scale surveys, it would appear worthwhile to continue the analysis of trends on the basis of indirect indices (Bogdanov and Solyankin, 1980; Fedulov *et al.*, 1984; Yakovlev and Altman, 198).

These factors should also reflect krill swarming conditions in waters adjacent to South Georgia. It is clear from the preceding discussion that more frequent and detailed surveys, including micro-surveys on aggregations, are necessary for further investigations into the variability of krill biomass in the area. International cooperation under the auspices of CCAMLR would be one way of addressing these tasks by way of a program of successive surveys conducted by various vessels over the period of a year. It should be noted that the discovery of the most common places of krill swarming in the eastern waters off the island and around 37°W is particularly important for conducting census surveys in relation to the CEMP monitoring program, for example.

The above is based on data from trawl catches. The use of hydroacoustic equipment in combination with controlled hauls undoubtedly ensures the speeding up of investigations and gives a more detailed impression of *E. superba* distribution and biomass. An assessment of the biotic background as well as biological characteristics of krill is also very important. These factors, which are not discussed in this paper, unquestionably influence swarming dynamics of *E. superba* in the area under investigation.

It should be stressed once more that data obtained from any survey correspond to single observations. This holds true for *E. superba* biomass assessments based on materials from each survey. It is important to have a realistic notion of an integral value for biomass which might be obtained as a result of further systematic research.

REFERENCES

BOGDANOV, M.A. and E.V. SOLYANKIN. 1970. Varying quantities of *Euphausia superba* Dana in the vicinity of South Georgia Island as related to hydrological regime. *Oceanology, 10* (4): 695-701. (In Russian).

EVERSON, I. 1976. Antarctic krill: a reappraisal of its distribution. *Polar Rec., 18* (112): 15-23.

FEDULOV, P.P., L.G. MAKLYGIN and A.V. REMESLO. 1984. Changeability of krill's concentration off South Georgia Island. *Rybnoe Khoziaistvo, 9*: 20-21. (In Russian).

HEYWOOD, R.B., I. EVERSON and J. PRIDDLE. 1985. The absence of krill from South Georgia, winter 1983. *Deep-Sea Res., 32* (2): 369-378.

LATOGURSKY, V.I. 1973. Biological peculiarities of Antarctic krill *Euphausia superba* Dana off South Georgia Island during winter seasons of 1969-1979 years. *Proc. AtlantNIRO, 53*: 135-150. (In Russian)

LUBIMOVA, T.G. and V.V. SHEVTSOV. 1980. Some data on Antarctic krill quantity in separate regions of the Southern Ocean. *Rybone Khoziaistvo, 11*: 21-25. (In Russian).

MAKAROV, R.R. On the biology of reproduction of *Euphausia superba* Dana. *Proc. VNIRO, 110*: 85-88. (In Russian).

MAKAROV, R.R. 1980. The study of the composition of the population of *Euphausia superba* Dana 1852 (Crustacea, Eucarida, Euphausiacea). In: *Biological Resources of the Antarctic Krill.* Moscow: VNIRO. pp. 89-113. (In Russian).

MAKAROV, R.R., V.V. MASLENNIKOV, E.V. SOLYANKIN and V.V. SHEVTSOV. 1980. Quantitative distribution and conditions for formation of swarms of *Euphausia superba* Dana with reference to some areas in the Atlantic and Pacific Ocean. In: *Biological Resources of the Antarctic Krill.* Moscow: VNIRO. pp. 114-145. (In Russian).

MAKAROV, R.R., M.V. SEREBRIAKOVA and E.V. SOLYANKIN. 1984. Phytoplankton drift transport and distribution in the vicinity of South Georgia Island. *Oceanology, 24*: 143-149. (In Russian).

MAKAROV, R.R. L.L. MENSHENINA and V.A. SPIRIDONOV. 1986. Investigation of zooplankton communities off South Georgia. *Antarctica, 25*: 186-201. (In Russian).

MACKINTOSH, N.A. 1972. Distribution of post-larval krill in the Antarctic. *Discovery Rep., 36*: 95-156.

MESLENNIKOV, V.V. 1972. On the effect of water dynamics on the distribution of *Euphausia superba* Dana in the area of South Georgia. *Proc. VNIRO, 75*: 107-117. (In Russian).

MESLENNIKOV, V.V. 1979. Peculiarities of horizontal circulation in the area of South Georgia. *Antarctica, 18*: 140-143. (In Russian).

MESLENNIKOV, V.V. and E.V. SOLYANKIN. 1979. On annual shift of the water interaction zone in the Weddell Sea and the Antarctic circumpolar current. *Antarctica, 18*: 118-122. (In Russian).

MESLENNIKOV, V.V. and E.V. SOLYANKIV. 1980. The role of water dynamics in the maintenance of *Euphausia superba* Dana population in the Weddell Sea. *Oceanology, 20*: 295-300. (In Russian).

MESLENNIKOV, V.V., E.V. SOLYANKIN, V.A. SPIRIDONOV and M.V. SYSOEVA. 1983. To the investigation of the origin of specimens of *Euphausia superba* Dana occurred off South Georgia. In: *Antarctic krill. The Distribution Pattern and Environment.* Moscow: Lyogkaya i pishchevaya promyslennost: 74-85. (In Russian).

MARR, J.W.S. 1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). *Discovery Rep., 22*: 33-464.

MENSHENINA, L.L. Seasonal variability of the distribution of *Euphausia superba* larvae off South Georgia. In: *Fisheries Research: Contemporary Problems.* Collected papers. Moscow: VNIRO. pp. 40-58. (In Russian).

SHEVTSOV, V.V. and R.R. MAKAROV. 1969. On the biology of krill. *Proc. VNIRO, 66*: 177-206. (In Russian).

SYSOEVA, M.V. and V.V. SHEVTSOV. 1980. The size composition, biological state and distribution of *Euphausia superba* Dana off South Georgia. In: *Biological Resources of the Antarctic Krill.* Moscow: VNIRO. pp. 146-167. (In Russian).

VLADIMIRSKAYA, E.V. 1975. Zooplankton distribution in the Scotia Sea in autumn and winter. *Oceanology, 15*: 520-525. (In Russian).

VLADIMIRSKAYA, E.V. 1978. Zooplankton distribution in the vicinity of South Georgia Island in summer 1975. *Oceanology, 18*: 519-523. (In Russian).

Table 1: Seasonal fluctuations in krill abundance around South Georgia with the onset of spring (based on fishing catch statistics, 000' tonnes).

Year	July	August	September	October	November
1985	36.3	14.4	0.5	4.9	4.4
1986	16.5	4.5	6.4	1.7	0.03
1987	37.7	25.1	16.9	4.5	-
1988	62.4	34.7	5.8	-	-

Table 2: Main results of surveys in the South Georgia area (1974 to 1988).

Survey Number	Dates	Vessel	Gear	Trawl Opening (sq. m)	Survey Area (sq. m)	Biomass	
						Total (000' tonnes)	Per sq. km (tonnes)
1	9-23 Mar 1974	*Salekhard*	CT	135	51690	560	108.4
2	4-13 Mar 1975	*Akademik Knipovich*	CT	80	33370	906	28.6
					E (2100)	(220)	(104.8)
					W (2800)	(450)	(160.7)
3	Jun 1981	*Argus*	CT	190	12700	476	37.9
4	Jul 1981	*Argus*	CT	190	14700	79	5.4
5	1-4 Jun 1983	*Argus*	CT	190	11700	54	4.6
6	22 Nov-9 Dec 1986	*Gizhiga*	CT	190	12600	607	48.2
7	2 May to 5 Jun 1988	*Kovtun*	CT	200	(2820)	(1402)	(310)
8	11-23 Oct 1984	*Evrica*	IK	8	48113	3.8	0.1
9	20 Jan-9 Feb 1988	*Evrica*	IK	8	79120	868	10.9

CT - commercial trawl, IK - Issacs-Kidd trawl
Data from micro-scale surveys are in brackets

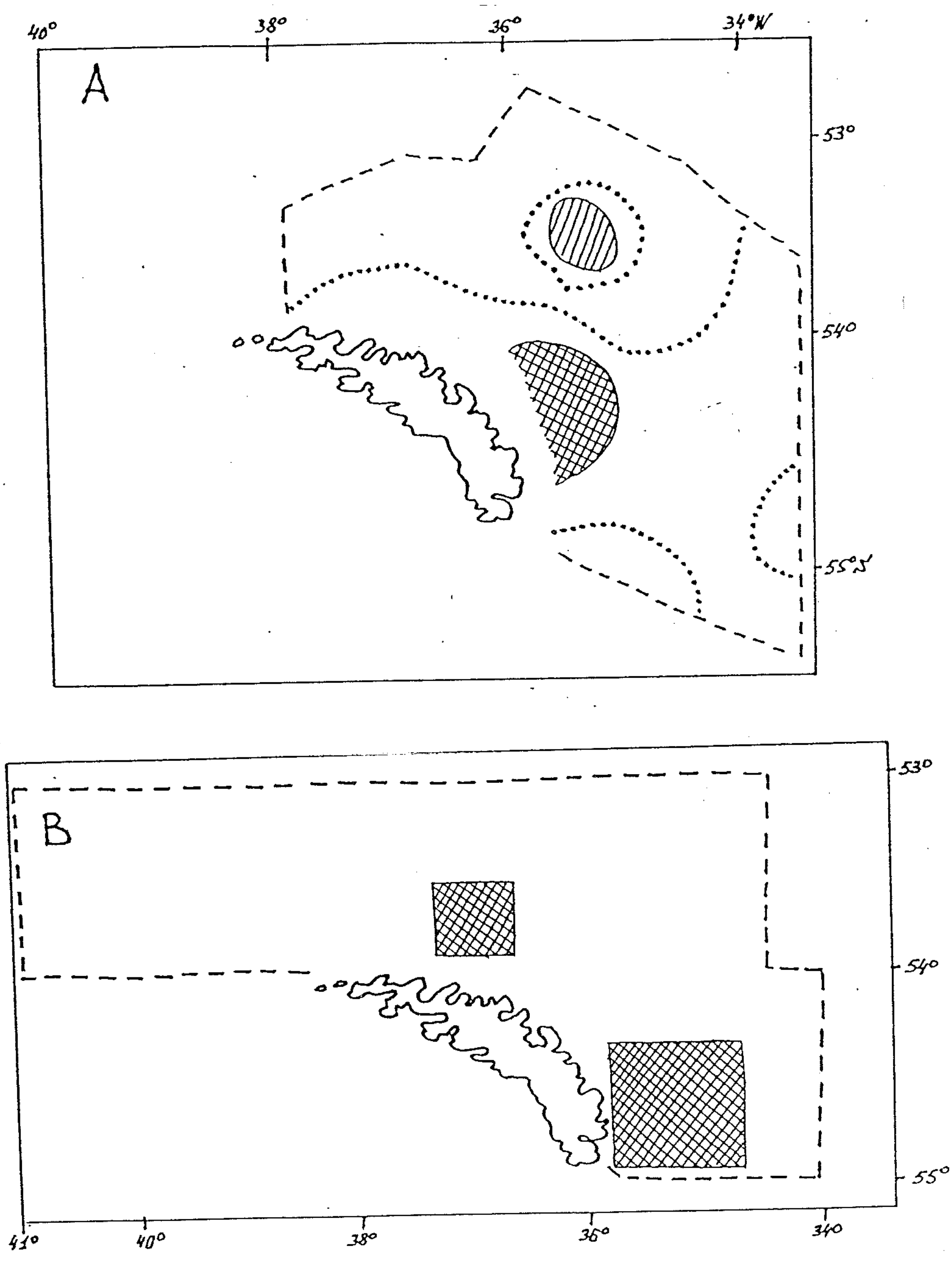


Figure 1: Krill distribution and areas of high krill abundance. A - Survey 1, 9 to 23 March 1974; B - Survey 2, 4 to 13 February 1975.

—— areas of high krill abundance, krill density, where indicated, is in g/m^3;
- - - survey boundaries;
..... boundary of areas where hauls yielded no catches.

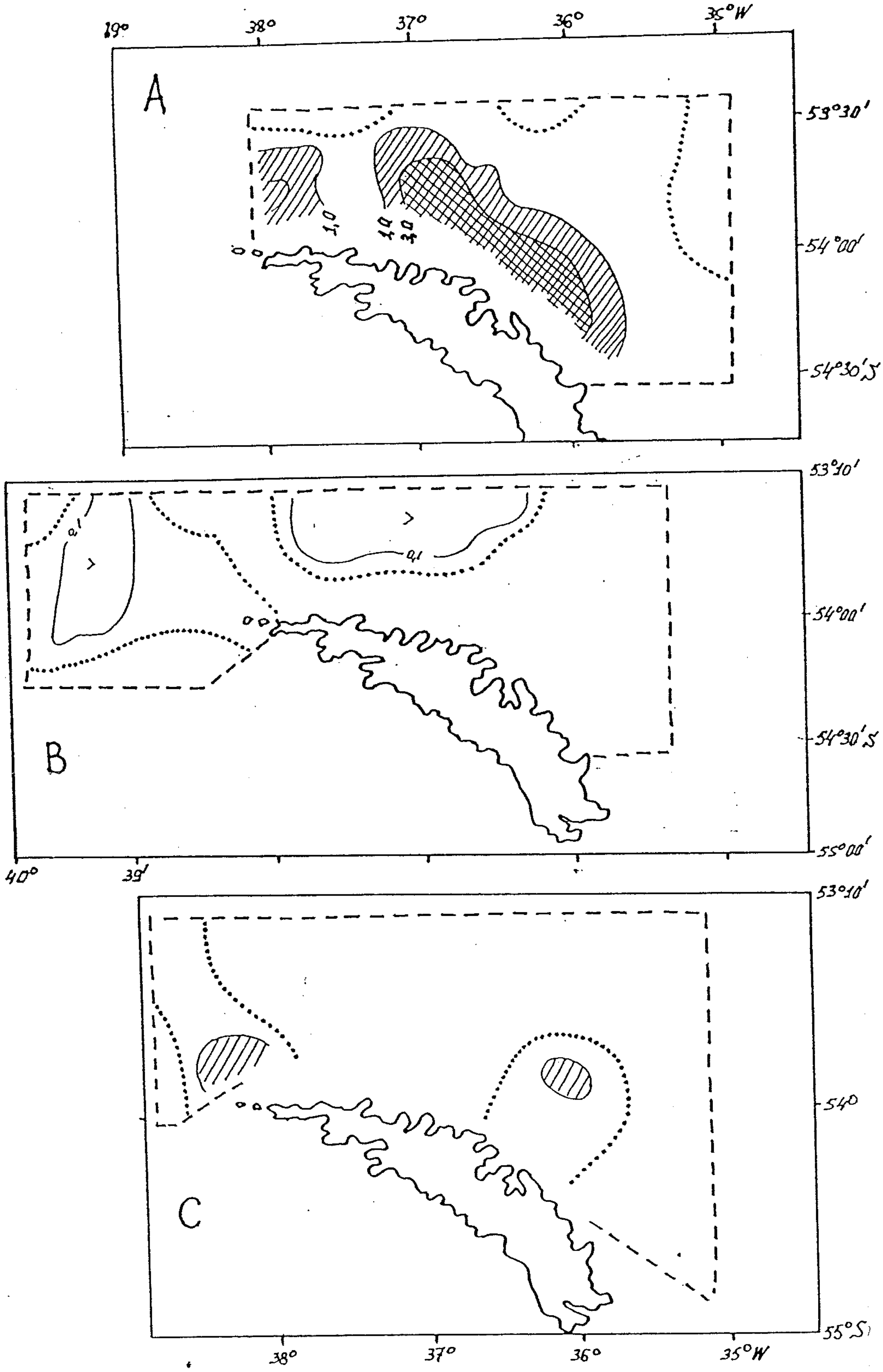


Figure 2: Krill distribution and areas of high krill abundance. A - Survey 3, 12 to 18 June 1981; B - Survey 4, 18 to 29 June 1981; C - Survey 5, 1 to 4 June 1983. (See Figure 1 for explanation of keys).

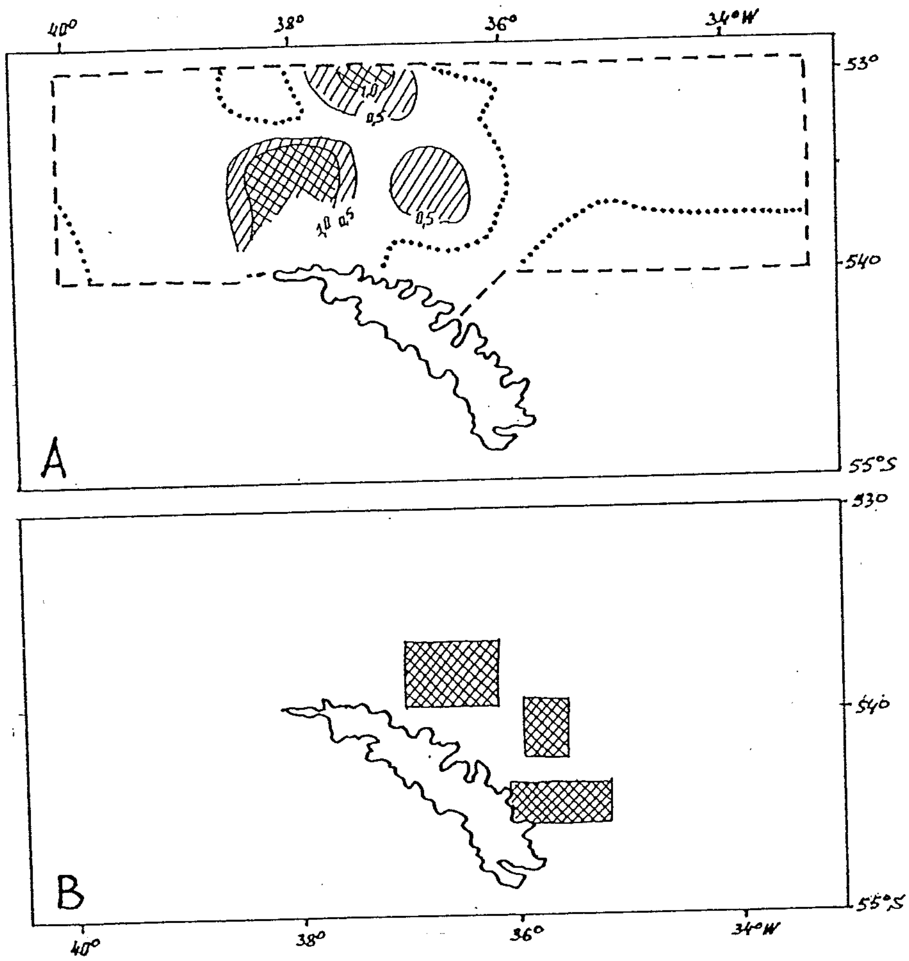


Figure 3: Krill distribution and areas of high krill abundance. A - Survey 6, 22 November to 9 December 1986; B - Survey 7, 2 May to 5 June 1988. (See Figure 1 for explanation of keys).

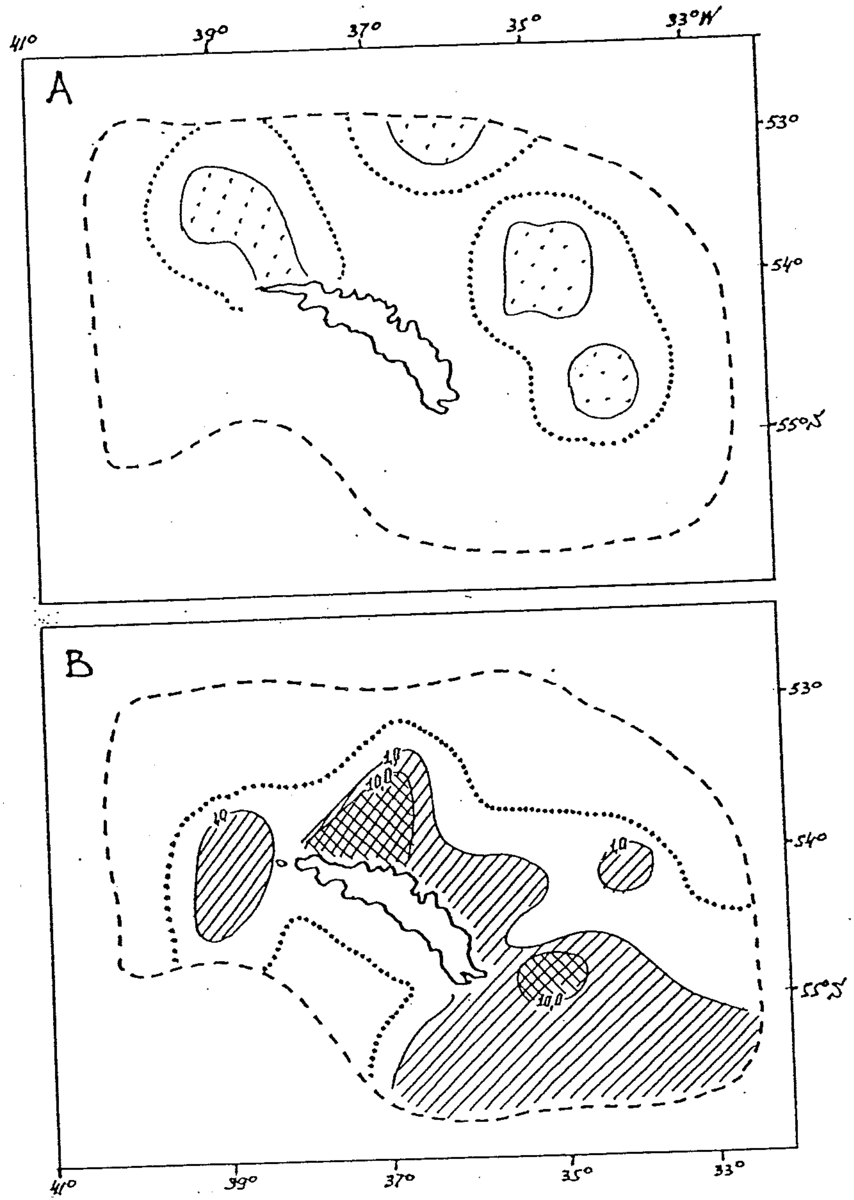


Figure 4: Krill distribution and areas of high krill abundance. A - Survey 8, 11 October to 23 October 1984; B - Survey 9, 2 January to 9 February 1988. (See Figure 1 for explanation of keys).

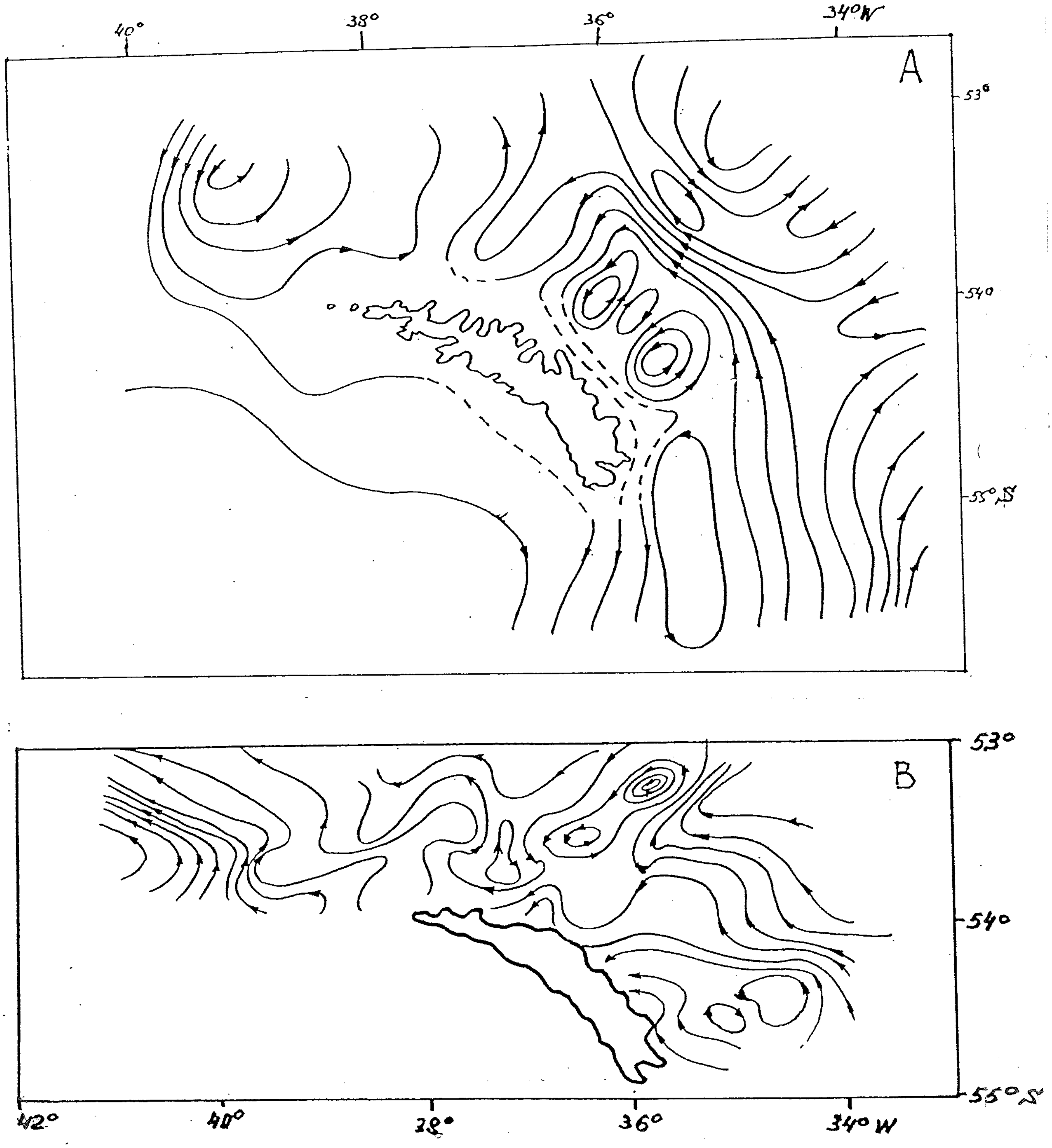


Figure 5: System of currents on the surface. A - Survey 1, 9 to 23 March 1974; B - Survey 2, 4 to 13 February 1975.

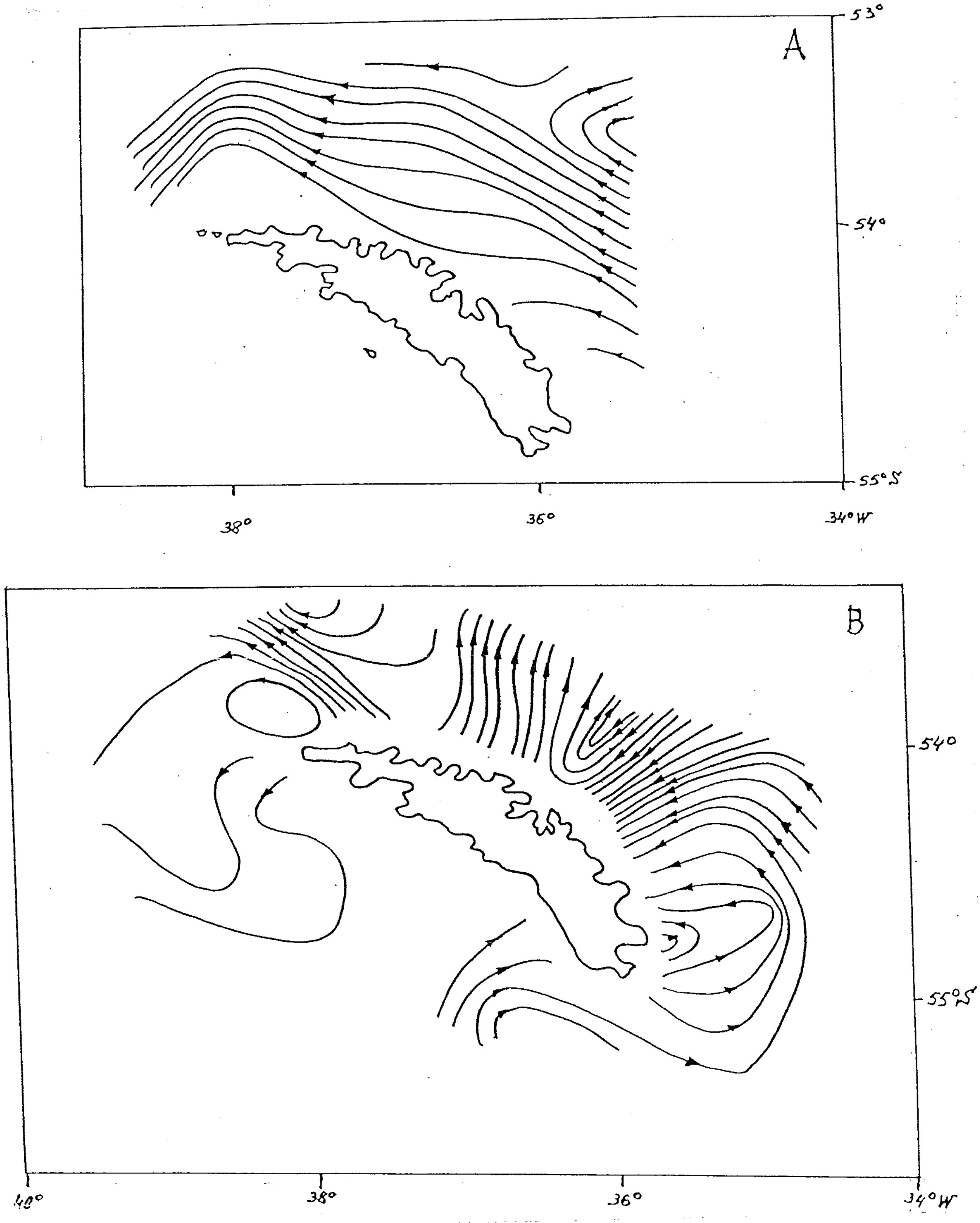


Figure 6: System of currents on the surface. A - Survey 5, 1 to 4 June 1983; B - Survey 6, 22 November to 9 December 1986.

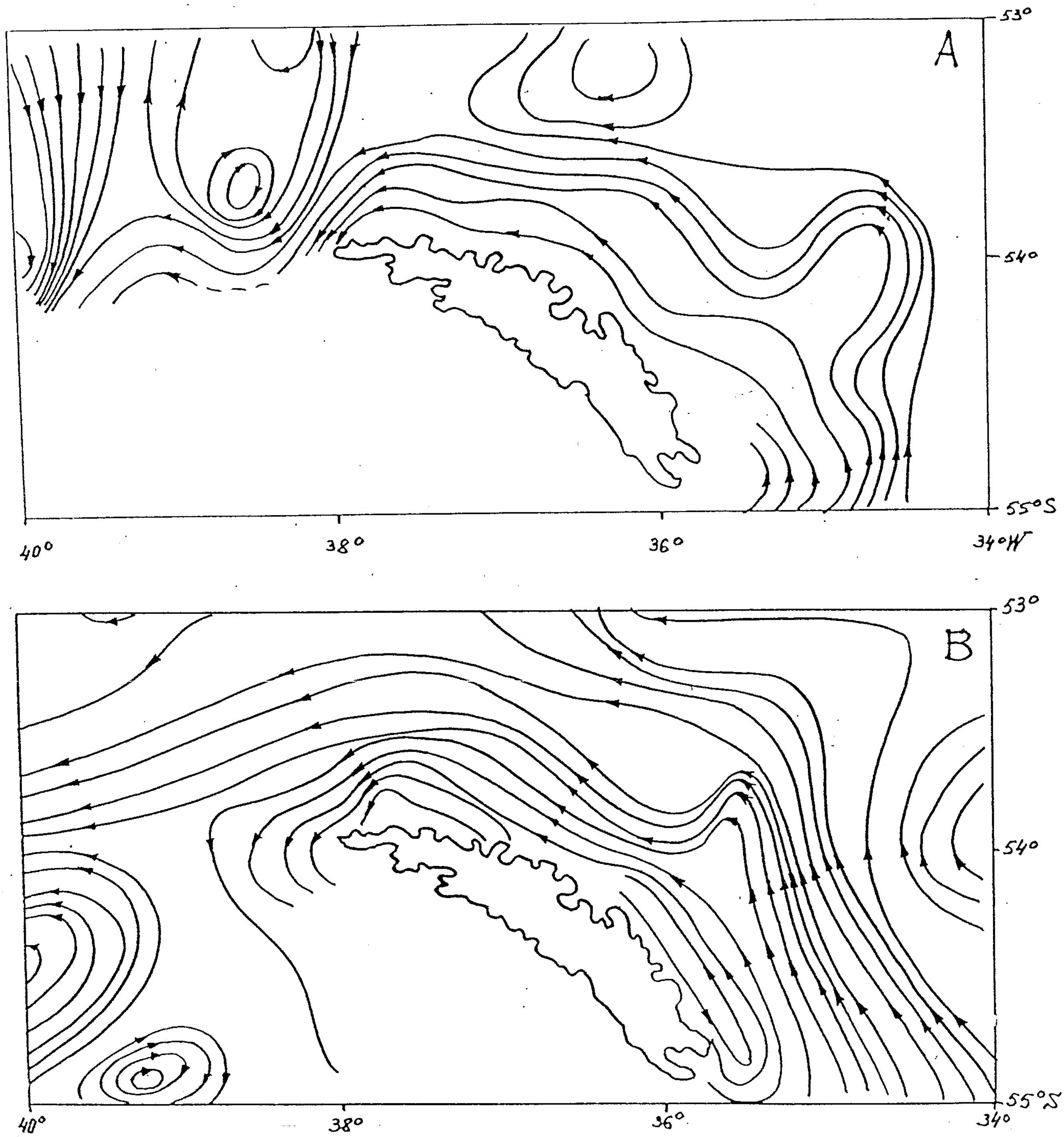


Figure 7: System of currents on the surface. A - Survey 8, 11 to 23 October 1984; B - Survey 9, 10 January to 9 February 1988.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

Figura 4: Distribución y localidades conocidas por su abundancia de krill. A - prospección 8, 11 al 23 de octubre 1984; B - prospección 9, 2 de enero al 9 de febrero 1988. (véase Fig. 1 para explicación de las claves).

Figura 5: Sistema de corrientes en la superficie. A - prospección 1, 9-23 marzo 1974; B - prospección 2, 4-13 febrero 1975.

Figura 6: Sistema de corrientes en la superficie. A - prospección 5, 1-4 junio 1983; B - prospección 6, 22 noviembre-9 diciembre 1986.

Figura 7: Sistema de corrientes en la superficie. A - prospección 8, 11-23 octubre 1984; B - prospección 9, 10 de enero - 9 de febrero 1988.

KRILL (*EUPHAUSIA SUPERBA* DANA) RESOURCES AND DISTRIBUTION IN THE WILKES LAND AREA IN THE SEASONS 1986 TO 1989

V.N. Dolzhenkov and V.P.Timonin*

Abstract

Results of krill (*Euphausia superba* Dana) resource surveys carried out along the Wilkes Land coast from 1986 to 1989 are presented in the paper. The surveys mainly focused on the search for exploitable krill aggregations. Two research vessels were simultaneously involved in the survey with one vessel conducting commercial krill fishing. The whole survey area from the coast to approximately 64°S between 130° and 150°E was subdivided into three subareas taking into account an area to the north of the edge of the continental slope. Each subarea was described in terms of the number of krill aggregations, regularity of their observations, krill density and total krill biomass. It was found that the above parameters are closely related to variability in oceanographic conditions and extent of the ice cover. If ice conditions are favourable, the subarea between 143° and 150°E was considered as the most valuable for the krill fishery. Krill aggregations were most frequently and regularly observed in the subarea. The mean annual density of krill in the subarea was 1 475 tonnes per square mile. The total biomass of krill in the Wilkes Land area was assessed as being about 1×10^6 tonnes.

Résumé

Les résultats des campagnes d'évaluation de la biomasse de krill (*Euphausia superba* Dana) effectuées le long de la côte de la Terre de Wilkes de 1986 à 1989 sont présentés dans ce document. Les campagnes ont tout particulièrement porté sur la recherche de concentrations exploitables de krill. Deux navires de recherche y ont pris part simultanément, l'un d'eux menant des activités de pêche commerciale de krill. La totalité de l'aire couverte par la campagne, de la côte à environ 64°S, entre 130 et 150°E, a été divisée en trois sous-zones, y compris une région située au nord du bord de la pente continentale. Chaque sous-zone a été décrite en termes de nombre de concentrations de krill, de fréquence de leurs observations, de densité du krill et de biomasse totale du krill. Il ressort que les paramètres ci-dessus sont étroitement liés à la variabilité des conditions océanographiques et à l'étendue de la couverture de glace. Dans des conditions glaciaires favorables, la sous-zone s'étendant entre 143 et 150°E, est considérée comme étant la plus profitable pour la pêche au krill. Le plus souvent, les concentrations de krill ont été rencontrées dans cette sous-zone dont la densité annuelle moyenne de krill est de 1 475 tonnes par mille carré. Dans la zone de la Terre de Wilkes, la biomasse totale du krill est estimée être d'environ 1×10^6 tonnes.

* TINRO, Vladivostock, USSR

Резюме

В настоящем труде представлены результаты съемок ресурсов криля (*Euphausia superba* Dana) в водах вдоль Земли Уилкса, выполненных в 1986-1989 гг. При съемках основное внимание было сосредоточено на поисках пригодных для промысла агрегаций криля. В съемке одновременно участвовали два судна, при этом одно из них вело промысел криля в коммерческом режиме. Район съемки (от побережья приблизительно до 64° ю.ш. между 130 и 150° в.д.) был подразделен на три подрайона с учетом пространства к северу от кромки континентального склона. При описании каждого подрайона было указано количество находящихся в нем агрегаций криля, регулярность их обнаружения, плотность криля и общая биомасса криля. Было установлено, что вышеприведенные параметры тесно связаны с изменчивостью океанографических условий и протяженностью ледового покрова. При наличии благоприятных ледовых условий подрайон между 143 и 150° в.д. был признан наиболее перспективным для промысла криля. В этом подрайоне агрегации криля наблюдались наиболее часто и регулярно. Средняя годовая плотность криля в данном подрайоне составляла 1475 тонн на квадратную милю. По оценкам, общая биомасса криля в районе Земли Уилкса составляет $1x10^6$ тонн.

Resumen

Este trabajo presenta los resultados de las prospecciones dedicadas al recurso krill (*Euphausia superba* Dana) en la costa del Territorio de Wilkes, entre 1986 y 1989. Las prospecciones se centraron principalmente en la búsqueda de concentraciones de interés comercial. Participaron en ellas dos buques de investigación, uno de los cuales realizó pesca de tipo comercial. Se dividió al área estudiada en tres subáreas, desde la costa hasta los 64°S aproximadamente, entre 130° y 150°E, y se tuvo en cuenta la zona norte limítrofe con el talud continental. De cada una de estas subáreas, se describen el número de concentraciones, la regularidad de las observaciones, la densidad y por último la biomasa total de krill. Se ha encontrado que los parámetros anteriores están íntimamente relacionados con la variabilidad de las condiciones oceanográficas y la extensión de la capa de hielo. Se considera que, cuando las condiciones del hielo son propicias, la subárea situada entre los 143° y los 150°E, es la más valiosa para la pesca, ya que en ella se observan con cierta frecuencia y regularidad concentraciones de krill. La densidad media anual de krill en dicha subárea es de 1 475 toneladas por milla cuadrada, y se ha calculado que la biomasa total de krill en el Territorio de Wilkes es de $1x10^6$ toneladas.

1. INTRODUCTION

Expeditions carrying out studies of krill distribution and spatial and temporal variability of krill concentrations in the Pacific Ocean and in the East Indian Ocean sectors of Antarctic waters have been undertaken by TINRO[1] and TURNIF[2] (Vladivostok, USSR) since 1966. A large area of the Antarctic was surveyed, covering waters to the north of the ice edge. Estimates of krill biomass were obtained on the basis of integrated surveys (including trawl sampling) and surveys of krill "patch" concentrations (fished regularly during surveys). The total krill biomass during the years of observation was from 1.4 to 2.3×10^6 tonnes to the east of the Balleny Is (to 60°W) and from 1.4 to 2.3×10^6 tonnes to the west of the Balleny Is (to 60°E). The biomass of krill both in aggregations (dense exploitable concentrations) and in dispersed, amply spaced concentrations, was taken into account. Dispersed concentrations of krill were most frequently and widely observed in the south of the surveyed area but aggregations of krill were observed less frequently.

Studies of aggregations were of direct commercial importance and attracted most of the research effort. For this reason, the size of the survey area was eventually reduced slightly. As it turned out, during each year of observation aggregations of krill were observed most regularly along the continental slope in the coastal waters of Wilkes Land and further to the west to 110°-120°E, in the Balleny Is area and further to the east along the ice edge right up to the Bellingshausen Sea.

The most intensive and systematic surveys were conducted in the area adjacent to Wilkes Land. The surveys became more regular and standardized after the 1986 season. Two vessels were annually deployed in the area between 130° and 150°E; one vessel was in charge of research and the other was mainly engaged in fishing. However, some fishing was, also conducted by the research vessel in order to enable the commercial importance of krill aggregations located by the vessel to be evaluated.

2. MATERIALS AND METHODS

The material obtained over the last four seasons (1986 to 1989[3]) is examined in this paper in terms of distribution and total biomass of *Euphausia superba.*

Fishing for krill was done by a commercial-sized trawl with a vertical opening of 42 to 44 m. Mesh size in the codend was 10 mm. A trawl catchability coefficient of 0.3 was applied in the calculations.

The following formula was used for calculation of the total krill biomass:

$$P = \frac{pSH}{shK}$$

where **P** = total biomass (tonnes),
p = average catch per hour of trawling (tonnes),
S = total area surveyed (square miles),
s = area fished per hour of trawling (square miles),
H = average height of the concentration (m)
h = vertical opening of the trawl (m),
K = catchability coefficient of the trawl.

---

1 Pacific Ocean Research Institute for Fisheries and Oceanography
2 Pacific Ocean Administration for Fisheries and Research Fleet, USSR Ministry for Fisheries
3 The annual period used is the split-year 1 July to 30 June. Split-year is denoted by the calendar year in which the split-year ends, i.e., 1989 indicates the split-year 1988/89).

The area surveyed was arbitrarily subdivided into three subareas (Figure 1). The first subarea includes the northernmost extremity of the continental slope (500 to 2 000 m depth) from 64°40' to 64°10'S, the third includes the southernmost extremity of the continental slope from 64°10' to 65°00'S and the second located between the first and third subareas, including the continental slope between 64°30' and 65°30'S.

The location of areas where krill aggregations were observed is shown in Figures 2 to 4 by month and by year. As can be seen, almost all of the aggregations observed were encountered near the outside boundary of the continental shelf and over the upper part of the continental slope. This is exactly the position of the frontal zone between the waters of the west-bound Antarctic Coastal Current and southern boundary waters of the east-bound Antarctic Circumpolar Current. Taking into account dynamics of water masses, it appears that krill aggregations are found mostly within the field of influence of meso-scale eddies and meanders in this frontal zone. Available information on water circulation is also incorporated in Figures 2 to 4. Unfortunately, hydrological data were not available for all periods of observation and, in some cases, they were incomplete. Such data were not available for the waters south of the area in which krill aggregations were located. These waters were always found covered by ice with krill concentrations observed in immediate proximity to the ice edge. When positions and sizes of areas in which krill were located are considered in relation to the existing system of currents in the surveyed area, it becomes obvious that krill distribution is closely correlated with gyres. This is particularly obvious from the data for subarea I in 1988 and for subarea II in 1989. In cases when meso-scale gyres were not observed, the number and size of krill aggregations were remarkably reduced.

The condition of the ice in the subareas surveyed was quite different. The most favourable ice conditions were observed in subarea I where the water was free from ice until mid to late April. The ice conditions were more severe in subarea II, which was covered by ice from late March to mid-April. Subarea III was the most unfavourable in this respect. As a rule, work in this subarea became impossible from mid- to late March. Due to heavy ice conditions resulting from the influence of the nearby Balleny Ice Massif. Sometimes, even in the summer, more than half of the subarea (1989) or the whole subarea (1988) was covered with heavy ice.

Varying numbers of aggregations of krill were observed annually in all subareas. The entire area over the continental slope, where krill aggregations are encountered, should be regarded as an area of high krill abundance. Of course, krill aggregations did not always occur in the same locations. Periods of their formation also varied. Therefore, the influence of a certain spatial and temporal variability in water dynamics on a meso- and micro-scale is obvious. In particular, this variability is greater in the frontal zone. In other cases, particularly in subarea III where the ice conditions are most severe, some sectors are inaccessible for observations. Moreover, during daily surveys, the probability of observing krill aggregations during the night diminishes.

3. DISCUSSION

Krill aggregations which were observed in each of the subareas during the austral spring-summer seasons of 1986 to 1989 are discussed and described below. In Figures 2 to 4 distribution of observed krill aggregations is depicted by month. Localities of krill aggregations are sequentially numbered in order to allow cross referencing with the tables. A detailed description of each subarea surveyed (area surveyed, krill density and total biomass) is given in Tables 1 to 3.

In 1986, 1987 and 1989, the most dense krill concentrations (500 to 1 000 tonnes per square mile) in subarea I were usually observed in central and western parts (Table 1 and Figure 2). In 1988 krill concentrations occurring in both central and eastern parts of the subarea were not so dense (136 to 327 tonnes per square mile); nevertheless krill was found over the whole of the subarea and was more abundant than in other years. However, the density of krill in these aggregations was low. In comparison with the other three years, the total biomass of krill in the subarea in 1988 was smaller by a factor of 2. Krill aggregations were most regularly observed between 64°30'-65°33'S, and 131°30'-133°00'E.

The most dense aggregations of krill (1 130 to 1 430 tonnes per square mile) in subarea II were found in the western and central parts of the subarea (Figure 3, Table 2). Less dense aggregations (113 to 410 tonnes per square mile) were also observed here. In 1989, krill aggregations were located in the central and eastern parts of the subarea. Their density was relatively low (51 to 360 tonnes per square mile). As in subarea I, large numbers of aggregations in subarea II were associated with a total low density of krill. Aggregations were found more regularly between 65°00'-66°10'S, and 137°-140°E. One of the interesting findings is a sector of subarea II where density of aggregations and total biomass of krill were consistently at their highest during the years of observation (except 1986). The sector comprises aggregation numbers 4, 7, 15 and 16 (see Figure 3, Table 2).

In 1986, the most dense aggregations (2 405 tonnes per square mile) in subarea III were found in the centre of this subarea. In 1986, aggregations were also observed in this part of the subarea as well as in the eastern part. Their density was lower by a factor of 4 (574 to 615 tonnes per square mile). Dispersed concentrations of krill were observed in 1989 only in the western part of the subarea (up to 70 tonnes per square mile). The rest of the continental slope area in this subarea was covered with ice. During the 1988 season the entire subarea was inaccessible for the same reason. The most stable aggregations appeared to be in a sector between 65°50'-66°10'S, and 145°-147°E.

As can be seen, whilst the location of krill aggregations is variable it is possible to denote subareas where aggregations are located most regularly every year. Subarea III is characterized by the highest total biomass of krill. Krill resources in subarea I appear to be the smallest notwithstanding the most favourable ice conditions for krill surveys.

Averaged over four years, the biomass of krill in aggregations in subarea I (303 square miles) was 114 000 tonnes, 263 000 tonnes in subarea II (561 square miles), and 556 000 tonnes in subarea III (576 square miles). As can be seen, the biomass of krill in subareas II and III differs although the areas of both subareas covered with aggregations are almost the same. Krill biomass in subarea III is twice as great as it is in subarea II. Data for many years show that optimum conditions for the formation of krill aggregations do not appear simultaneously in each of the subareas surveyed. Whereas in 1986 aggregations were quite localized in all subareas, during the 1987 season abundant aggregations were observed only in subarea III. In the remaining subareas they were strongly localized only in certain small sectors. The 1988 season was characterized by a large number of aggregations in all subareas (subarea III was inaccessible for observations). In 1989 aggregations were widely observed only in subarea II.

4. CONCLUSION

Therefore, when ice conditions are favourable, subarea III can be regarded as the most important for krill fishing. The average annual density of krill aggregations in the subarea was 1 475 tonnes per square mile. Average annual resources and density of krill were considerably less in subareas I and II, however, these subareas were also of significant commercial value because krill aggregations are maintained longer. The total average annual biomass of krill in the entire area of the Wilkes Land coast between 130° and 150°E are almost 1×10^6 tonnes, and the average density of aggregations is 660 tonnes per square mile. These estimates should evidently be regarded as minimum estimates because considerably higher values may be obtained from a more detailed survey.

Table 1: Assessments of krill resources for subarea I (64° to 66°S, 130° to 136°E).

Sequential Number of Localities with Krill Aggregations	Period of Observation	Area of Localities with Krill Aggregations	Mean Catch Per Hour (tonnes)	Mean Density tonnes/square mile	Total Biomass (tonnes x 10^3)
1	1986 12 to 16 February	58	7.6	698	40.5
2	1986 20 to 21 April	50	12.2	1 000	50.0
3	1986 24 to 30 April	300	3.5	158	47.5
4	1987 12 to 15 April	127	14.0	1 510	191.5
5	1988 9 to 11 February	39	6.2	225	8.8
6	1988 11 to 13 February	25	3.6	136	3.4
7	1988 13 to 16 February	55	5.1	138	7.6
8	1988 16 to 20 February	77	7.4	327	25.2
9	1988 2 to 4 April	41	9.4	283	11.6
10	1988 7 to 10 April	73	5.2	195	14.2
11	1989 25 March to 6 April	367	16.4	504	185.2

Table 2: Assessments of krill resources for subarea II (64° to 66°S, 136° to 143°E).

Sequential Number of Localities with Krill Aggregations	Period of Observation	Area of Localities with Krill Aggregations	Mean Catch Per Hour (tonnes)	Mean Density tonnes/square mile	Total Biomass (tonnes x 10^3)
1	1986 5 to 7 February	42	4.9	443	18.6
2	1986 19 to 20 February	41	10.3	1 178	48.3
3	1986 11 to 15 April	76	13.2	1 130	85.8
4	1987 31 March to 15 April	111	20.8	1 854	205.8
5	1988 5 February	12	2.8	113	1.4
6	1988 6 to 7 February	10	5.0	410	4.1
7	1988 20 Feb to 15 March	274	40.0	1 430	392.5
8	1988 26 to 29 March	88	13.0	296	27.2
9	1988 21 to 22 March	21	16.2	220	4.6
10	1988 11 to 16 April	93	13.3	116	10.3
11	1989 27 Jan to 1 Feb	201	3.4	68	13.7
12	1989 27 to 28 February	189	2.3	51	9.5
13	1989 3 to 4 March	155	4.4	116	18.0
14	1989 28 Feb to 1 March	103	3.1	76	8.0
15	1989 3 to 13 March	468	6.4	173	81.1
16	1989 13 to 19 March	223	8.6	283	64.1
17	1989 16 to 18 March	25	10.4	360	8.9
18	1989 17 to 21 March	114	11.6	99	11.3

Table 3: Assessments of krill resources for subarea III (64°40' to 66°20'S, 143° to 150°E).

Sequential Number of Localities with Krill Aggregations	Period of Observation	Area of Localities with Krill Aggregations	Mean Catch Per Hour (tonnes)	Mean Density tonnes/square mile	Total Biomass (tonnes x 10^3)
1	1986 22 Feb to 19 March	260	26.0	2 405	625.5
2	1987 30 Jan to 8 Feb	107	3.7	177	19.0
3	1987 5-28 Feb to 18 Mar	430	10.3	615	264.4
4	1987 12 to 27 March	356	14.0	574	204.4
	1988*				
	1989**				
5	1989 2 to 7 February 25 to 27 February	599	3.3	70	42.7

* The entire area was covered with ice
** Part of the area east of 145°20'E was covered with ice

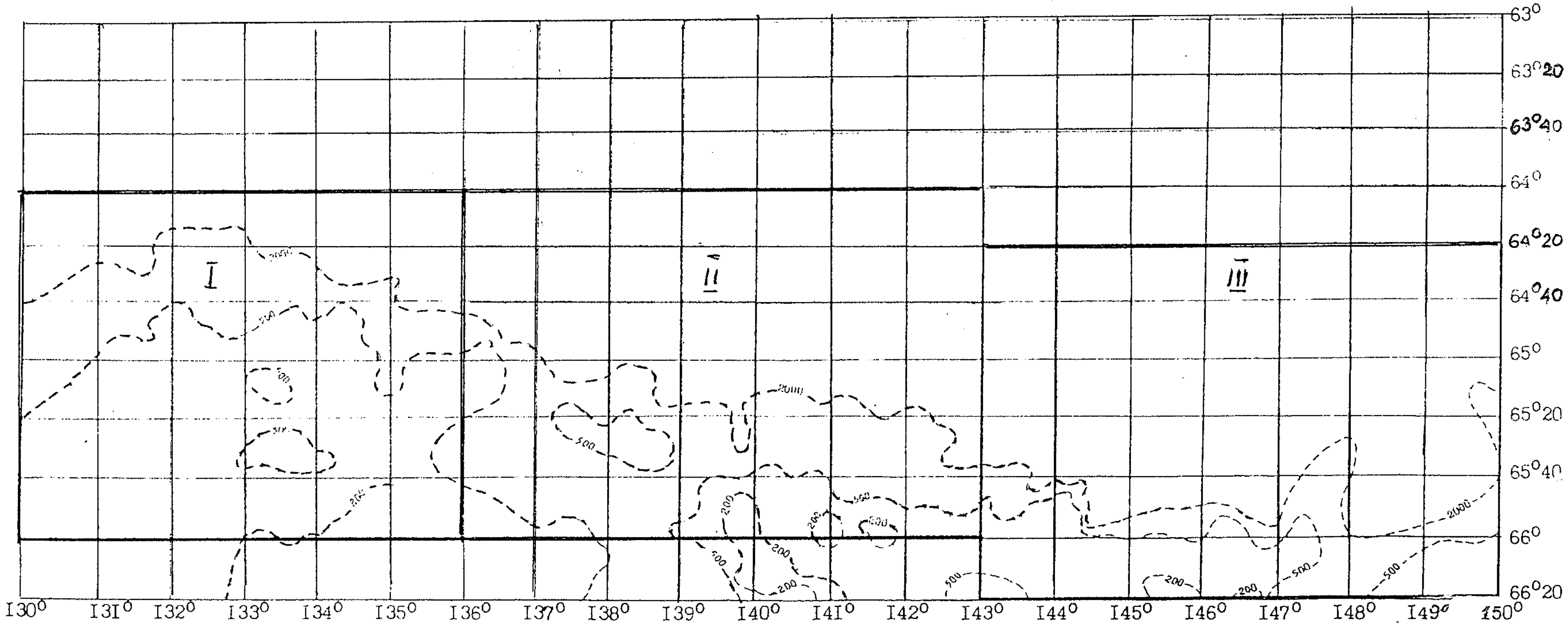


Figure 1: Area of survey of krill resources (subareas I to III) from 1986 to 1989.

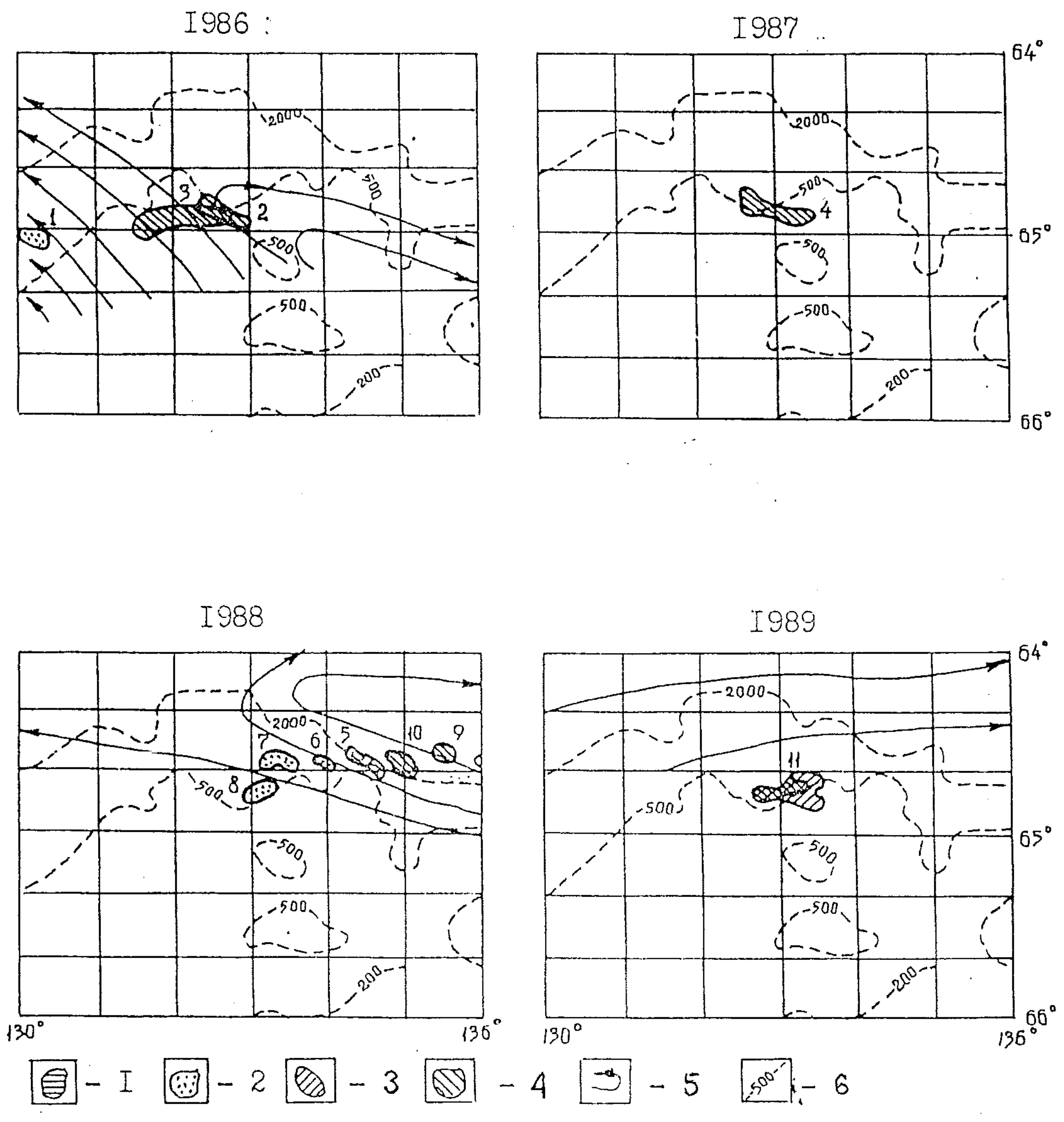


Figure 2: Distribution of exploitable krill aggregations in subarea I (1986 to 1989).
1 - January, 2-February, 3-March, 4-April, 5-direction of current, 6-isobaths (m).

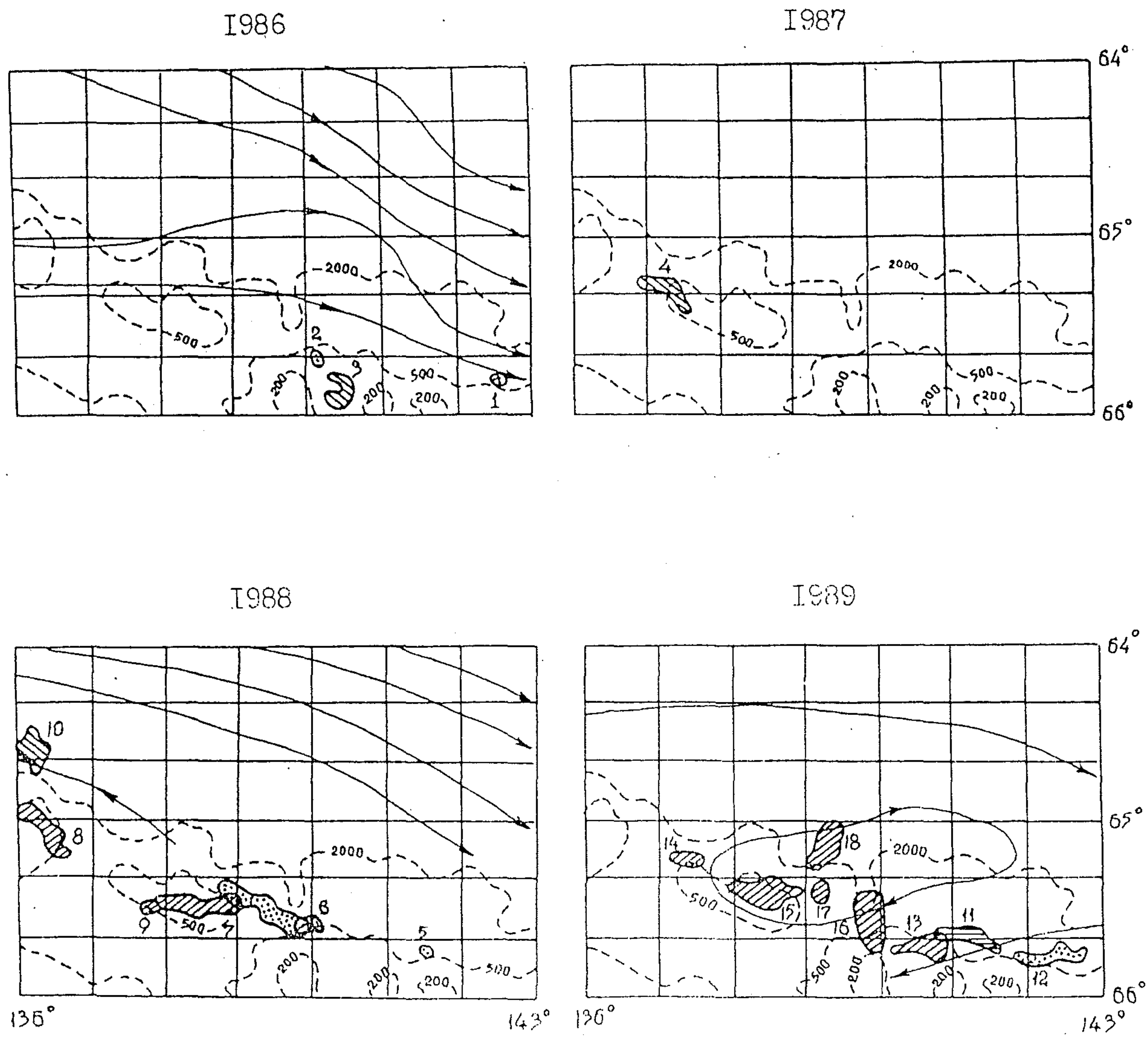


Figure 3: Distribution of exploitable krill aggregations in subarea II (1986 to 1989). (See Figure 2 for key)

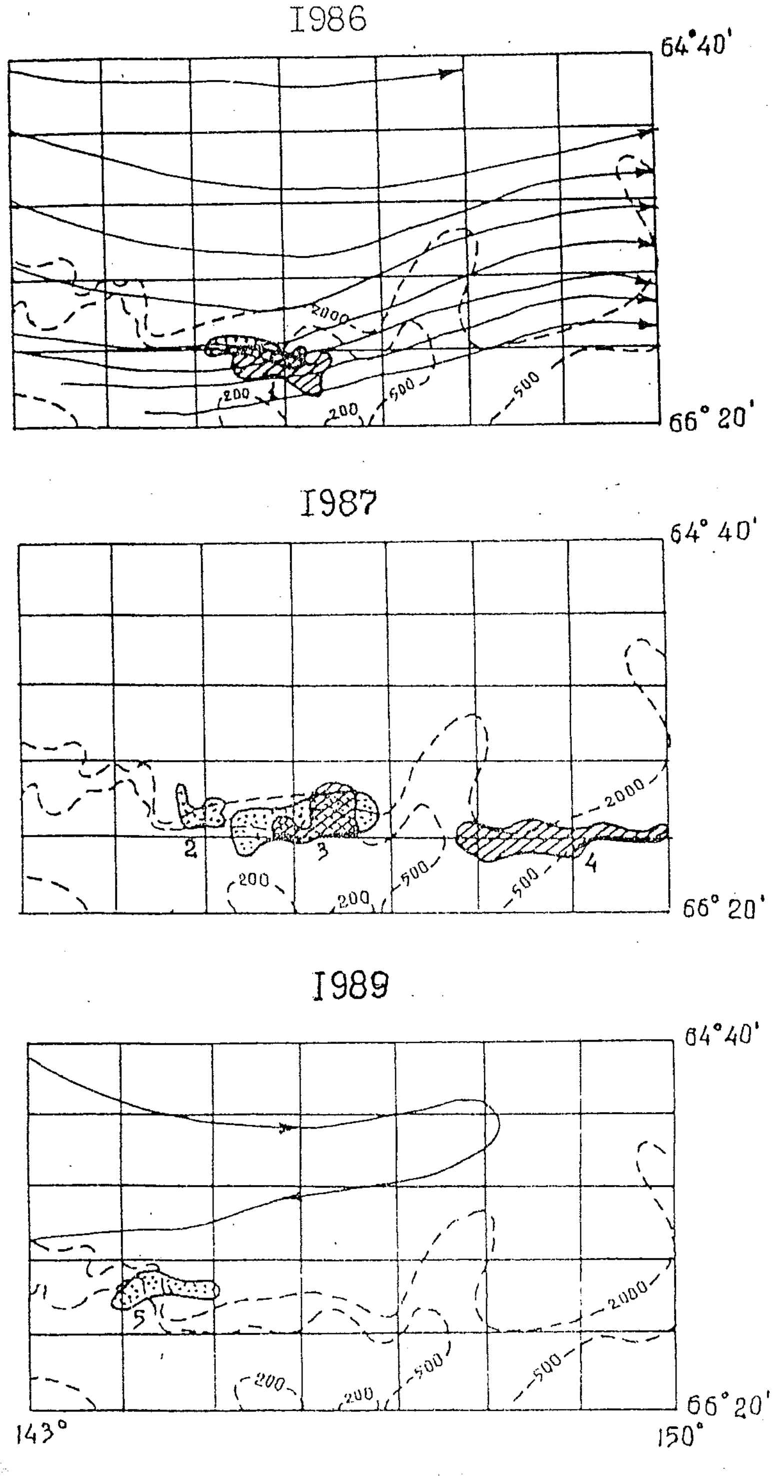


Figure 4: Distribution of exploitable krill aggregations in subarea III (1986, 1987 and 1989). (See Figure 2 for key)

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

WG-KRILL-90/17

THE STATUS OF KRILL (*EUPHAUSIA SUPERBA* DANA) RESOURCES IN CCAMLR STATISTICAL DIVISIONS 58.4.2 AND 58.4.3 FROM 1988 TO 1990. RESULTS OF ACOUSTIC SURVEYS

V.A. Bibik and V.N.Yakovlev*

Abstract

Since 1977 the YugNIRO Research Institute (Kerch, USSR) has carried out biological and ecological monitoring of krill resources in the central part of the Indian Ocean sector of the Antarctic (CCAMLR Statistical Divisions 58.4.2 and 58.4.3). Results of surveys conducted from 1988 to 1990 are discussed in the paper. It was found that the increase in krill biomass observed in the area in 1990 is linked with the abundant 1986 and 1987 year-classes and with a diminished rate of emigration of krill of these year-classes from the area in 1989/1990.

Résumé

Depuis 1977, l'Institut de recherche YugNIRO (Kerch, URSS) a effectué le contrôle biologique et écologique des ressources de krill dans la partie centrale du secteur de l'océan Indien de l'Antarctique (divisions statistiques 58.4.2 et 58.4.3 de la CCAMLR). Les résultats des campagnes d'évaluation menées de 1988 à 1990 sont discutés dans ce document. Ils révèlent que l'augmentation de la biomasse du krill observée dans cette zone en 1990 est liée à l'abondance des classes d'âge de 1986 et 1987 et de la diminution du taux d'émigration du krill de ces classes dans cette zone en 1989/1990.

Резюме

Начиная с 1977 г. ЮгНИРО (Керчь, СССР) выполняет мониторинг биологических и экологических параметров ресурсов криля в центральной части индоокеанского сектора Антарктики (Статистические участки АНТКОМа 58.4.2 и 58.4.3). В настоящем документе рассматриваются результаты съемок, выполненных в 1988-1990 гг. Было установлено, что отмеченное повышение биомассы криля в этом районе в 1990 г. связано с вступлением в запас мощных годовых классов 1986 и 1987 гг., а также с пониженными темпами миграции криля этих годовых классов из данного района в 1989/1990 г.

Resumen

Desde 1977 el instituto de investigación YugNIRO ha realizado estudios ecológicos y biológicos de seguimiento del krill en la parte central del océano Indico Antártico (Divisiones Estadísticas 58.4.2 y 58.4.3 de la CCRVMA). Este trabajo presenta los resultados de las prospecciones realizadas entre 1988 y 1990. Se ha visto que el aumento de la biomasa del krill en la zona durante 1990 está relacionada con la abundancia de las clases anuales de 1986 y 1987 y con un índice de emigración de krill menor de estas clases en la zona durante 1989/90.

---

* YugNIRO, Sverdlov str., 2, Kerch, USSR

1. INTRODUCTION

Since 1977 the YugNIRO Research Institute (Kerch, USSR) has carried out biological and ecological monitoring of krill resources in the central part of the Indian Ocean sector of the Antarctic (CCAMLR Statistical Divisions 58.4.2 and 58.4.3). Integrated trawl/acoustic krill census surveys have been carried out over the whole area (south of 60°S between 60 and 80° E) and, in particular, in the southern coastal waters of the area (south of 65°30'S). Until 1988 krill biomass was determined by a technique based on the processing of echosounder records and trawl catch data, but after this, only acoustic survey techniques were used. Results of acoustic surveys conducted from 1988 to 1990 are presented in the paper.

2. MATERIALS AND METHODS

Data on survey areas, spacing of survey tacks and integrated intervals are given in Table 1. The boundaries of survey areas were not fixed from year to year. Therefore, data in Table 1 covers only areas where the same level of detail and accuracy in biomass assessment was obtained during the period under consideration. In the open ocean this area falls between 60° and 75°E; near the coast - between 60° and 69°E.

The following set of hydroacoustic equipment was used: a "Sargan" sonar, a "SIORS" echo-integrator and a "USOD" sonar-integrator bridge device with a working frequency of 136 kHz. A copper ball, 26 mm in diameter, was used to determine the acoustic constant. Krill target strength was calculated using the formula:

$$TS = -97.2+20.01 \text{ LogL}$$

Two types of trawls were used for krill sampling: an Isaacs-Kidd midwater trawl with a 6.0 sq. m opening and a Samyshev-Yevdokomov scientific trawl with a 30 sq. m opening. Trawling speed was 2.5 to 3.0 knots. During the night when krill migrates to the surface, the surface layer was regularly sampled in order to validate results of the hydroacoustic survey. The results obtained were used to map krill density distribution.

3. DISCUSSION OF THE RESULTS

In 1988 no macro-scale survey was conducted in the Sodruzhestva Sea, although a survey of its southern part (to the south of 65°50'S between 59° and 80°E) was made. The total biomass of krill in the surface layer of the area was $3.5 \pm 0.6 \times 10^3$ tonnes, and mean density was 41 g/m^2. In the eastern part of the area, krill was found in loose aggregations with a mean density of 34 g/m^2. Dispersed aggregations and separate shoals of krill were most frequently observed on echo-records. The higher krill density was observed in the western part between 60° and 69°E, which was designated the standard survey area (Figure 1). Mean density in the area was 48 g/m^2 (Table 1). Dense but unstable concentrations of krill in the form of shoals and aggregations of about 0.5 miles in length were observed over the continental slope between 61° and 62°30'E. Daily catches by scientific survey vessels varied within a range of 10 to 35 tonnes. The biomass of exploitable krill concentrations (high density concentrations) was $0.3 \pm 0.05 \times 10^3$ tonnes.

In 1989 the macro-scale survey was carried out in February and the meso-scale survey was carried out during the first ten days of March (Figure 2). Krill biomass over the whole of the survey area (540×10^3 square miles) was 12.0 ± 4.0. In the coastal waters of the area (53×10^3 square miles) it was $4.0 \pm 0.7 \times 10^3$ tonnes. In the waters between 60° and 69°E of the survey area total krill biomass was $3.5 \pm 0.6 \times 10^3$ tonnes, and the biomass of the exploitable krill concentrations was $0.5 \pm 0.09 \times 10^3$ tonnes. Krill density in the surface layer was 92 g/m^2

(Table 1). In contrast to 1988, dense krill concentrations were observed not only over the continental slope, but also in the waters between 68° and 69°E, which is an area where krill concentrations in the Sodruzhestva Sea are most frequently observed .

In 1990 the macro-scale survey indicated an increase in the observed frequency of dense krill concentrations, mainly in the western part of the area between 60° and 75°E (Figure 3). Echo-records of a group of shoals (5 to 6 shoals per mile) of up to 200 m in length and 15 m deep were most frequent. Dispersed concentrations up to 20 miles in length were also observed. Mean density was 47 g/m^2 (Table 1). Echo-records of krill to the east of 75°E were not frequent; shoals were usually 5 to 7 m deep, spaced wide apart. Mean density was 12 g/m^2. Mean density for the whole of the area surveyed (60° to 80°E, $760x10^3$ square miles) was 39 g/m^2.

A considerable spatial variation in krill density was also a characteristic feature of coastal waters (Figure 4). In the east of the area, krill density was about 32 g/m^2, whereas in the west it was 167 g/m^2. Krill biomass in concentrations having a density of 850 g/m^2 and more, was estimated to be 0.8±0.15 g/m^2. The most stable concentrations of krill (5 500 g/m^2 maximum) were observed over the continental slope between 65° and 66°E. These concentrations were repeatedly recorded on a micro-scale during the summer.

The abovementioned data on krill biomass and density demonstrated that in 1990 there was a considerable increase in both parameters as compared with 1988 and 1989, mainly in the west of the area surveyed (60° to 70°E). Krill density in the surface layer of the "standard" survey area (south of 60°S between 60° and 75°E) in 1990 was close to its average value for the period from 1977 to 1987, considerably less (1.5 to 2.0 times) than in 1977 to 1979, but considerably higher (3 to 4 times) than in 1986/1987.

On the basis of many years of observations, it is considered that variations in krill biomass in the area are mainly dependent on annual variations in circulations of the atmosphere and the hydrosphere. These environmental parameters determine conditions for reproduction and the replenishment of the "local" krill population. Since 1988, a remarkable growth in atmospheric circulation activity has been observed over the area surveyed, leading to an increase in meandering of current fields to the south of the Antarctic Divergence. Such conditions were responsible for a reduction in the emigration rate of krill from the Sodruzhestva Sea in comparison with the previous period (1986 to 1988) and for an increase in krill biomass in the area.

The data in Table 2 show that an increase in biomass is mainly observed in length groups 38.1 to 45.0 and 45.1 to 52.0 mm (identified as 1987 and 1988 year-classes), i.e. the size groups mostly retained in the area in 1989/1990.

4. CONCLUSION

Results of the integrated census surveys of krill from 1988 to 1990 confirmed earlier findings of the YugNIRO Research Institute that a high natural variability of krill biomass is observed in the Sodruzhestva Sea.

In our opinion, the primary cause for the krill biomass variability is inter-annual variability in atmospheric circulation which determines the level of isolation of the area from adjacent waters. If this level increases, the biomass of krill grows only gradually, because of the inertia of biological processes. If the level of isolation decreases and immigration of krill from adjacent areas is limited, a reduction of krill biomass occurs. It is this tendency which has apparently been observed during recent years.

Table 1: Results of acoustic census surveys in the Sodruzhestva Sea in 1988 to 1990.

Survey Number	Survey Period	Scale	Survey Area Boundaries	Survey Area (square km)	Tack Spacing (miles)	Integrated Distance (miles)	Mean Surface Krill Density (g/m²)	Biomass x 10^6 tonnes	
								Total	Exploitable Concentrations
1	1988 (February to early March)	Meso	66° to 67°S 60° to 69°E	42 000	25	4	48	2.0±0.3	0.3±0.05
2	1989 (February)	Macro	60° to 60°40S 60° to 75°E	540 000	125	30	22	12±4	-
3	1989 (1 to 10 March)	Meso	65°50' to 60°55'S 60° to 69°E	37 800	28	4	92	3.5±0.6	0.5±0.09
4	1990 (January)	Macro	60°67°S 60° to 75°E	590 000	125	30	47	28±9	-
5	1990 (February to early March)	Meso	65°30' to 67°08'S 60° to 69°E	53 800	25	4	167	9.0±1.5	0.8±0.15

Table 2: Length composition of krill (%) in the Sodruzhestva Sea (65°30' to 68°00'S, 60° to 80°E) from 1988 to 1990. (Sampling by Isaacs-Kidd trawl).

Year	Length Class (mm)				
	≤30.0	30.1 to 38. 0	38.1 to 46.0	46.1 to 54.0	>54.0
1988	18.9	24.2	37.3	18.8	0.8
1989	8.0	27.9	46.0	17.5	0.6
1990	3.0	9.4	50.1	35.0	2.5

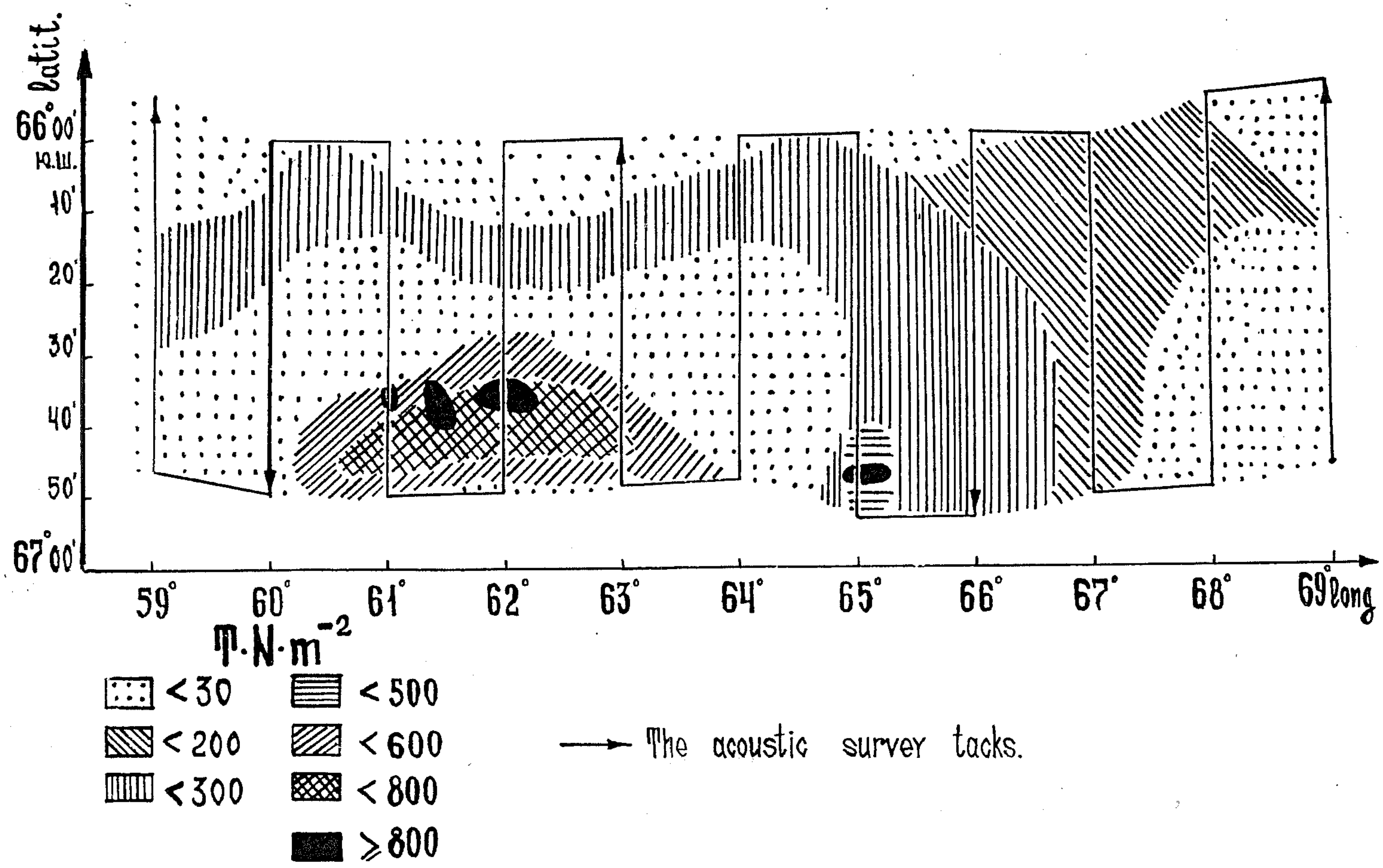


Figure 1: Density of krill in the surface layer (tonnes per square mile) in late February/early March 1988 (meso-scale survey).

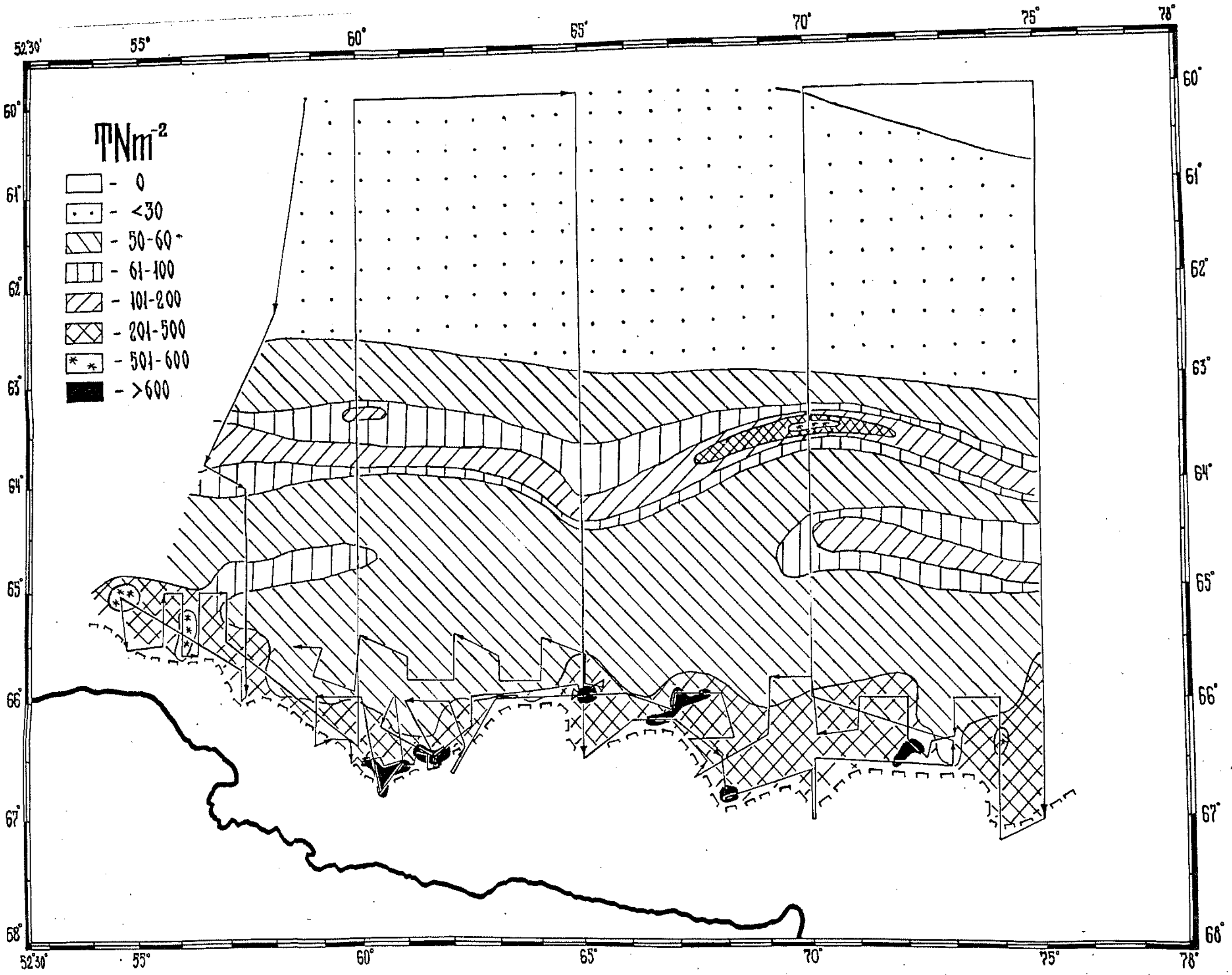


Figure 2: Density of krill in February/early March 1989 (macro- and meso-scale surveys).

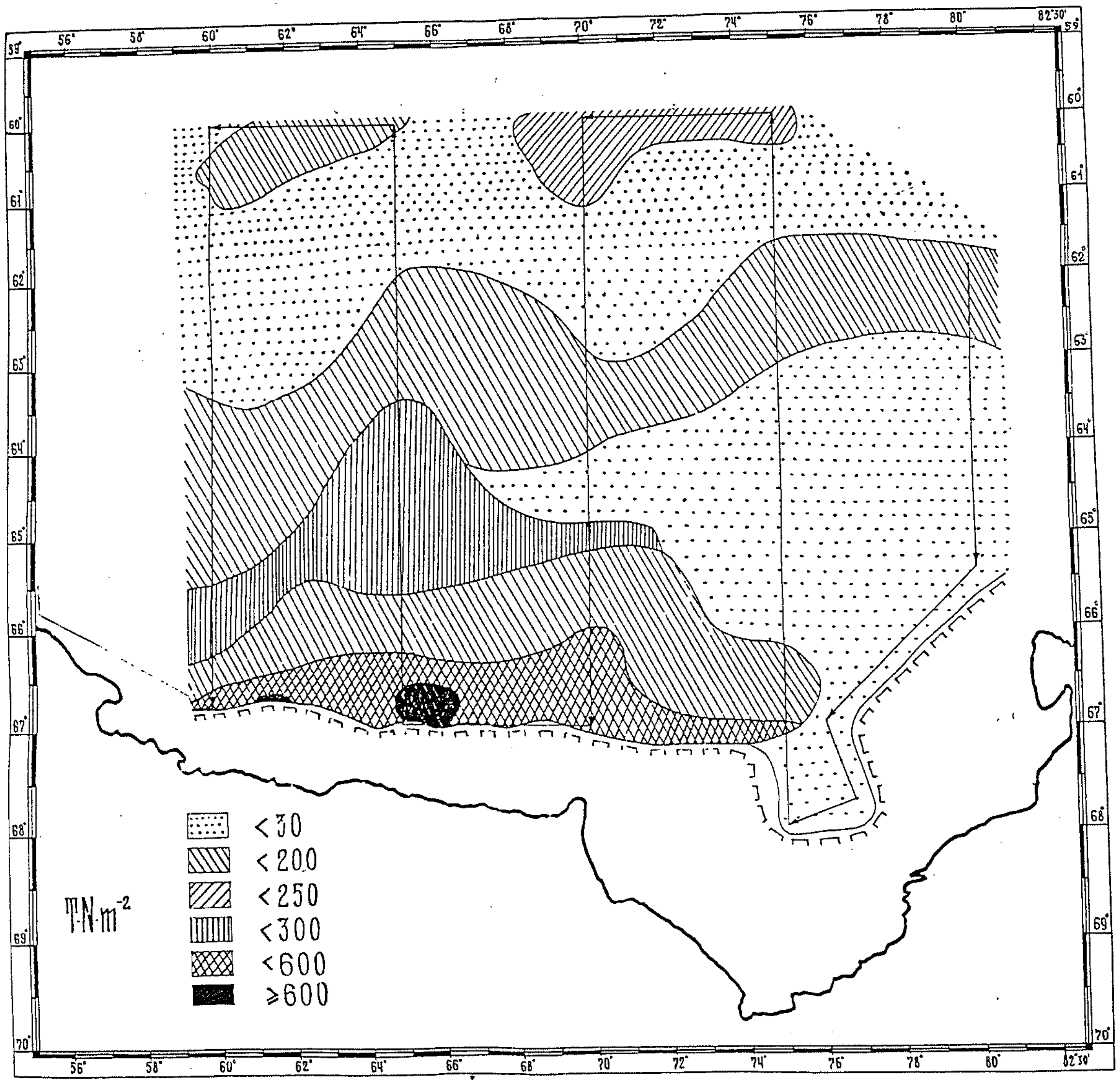


Figure 3: Density of krill in January 1990 (macro-scale survey).

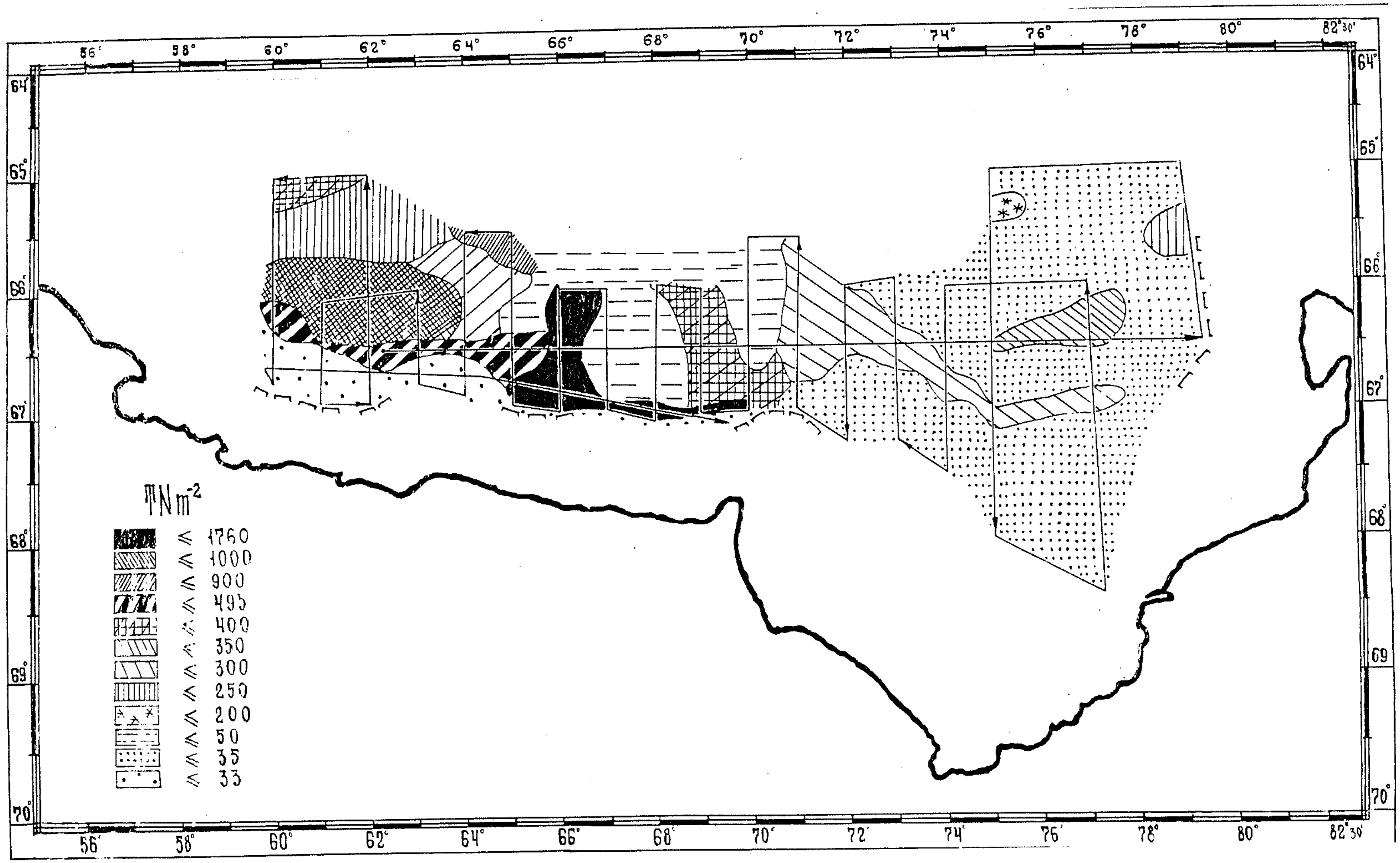


Figure 4: Density of krill in February/early March 1990 (meso-scale survey).

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

FACTORS TO CONSIDER IN DEVELOPING MANAGEMENT MEASURES FOR KRILL

W.K. de la Mare*

Abstract

A brief review of the objectives of the Convention for the Conservation of Antarctic Marine Living Resources is given along with an outline of steps for the evolution of management procedures for krill fisheries. Various possible elements of procedures such as reactive, predictive, and feedback management, modelling, indicator species, pulse fishing, and the use of open and closed areas and seasons are outlined. Some interim management measures are suggested which could be implemented while a more generally applicable management is being developed.

Résumé

Une brève vue d'ensemble des objectifs de la Convention sur la conservation de la faune et la flore marines de l'Antarctique est présentée ici, avec un aperçu des stades d'évolution des procédures de gestion des pêcheries de krill. Les grandes lignes des éléments possibles des procédures telles que la gestion réactive, prédictive et en retour, la modélisation, les espèces indicatrices, la pêche par à-coups et l'utilisation de l'ouverture et de la fermeture de zones et de périodes sont tracées. Plusieurs mesures de gestion intérimaires, pouvant être mises à exécution en attendant le développement d'une politique de gestion applicable de façon plus générale sont proposées.

Резюме

Делается краткий обзор целей Конвенции по сохранению морских живых ресурсов Антарктики, а также в общих чертах описываются меры по усовершенствованию процедур управления промыслом криля. Дается описание всевозможных элементов этих процедур, таких как реагирующее, прогнозирующее управление, управление с обратной связью, а также моделирование, виды-индикаторы, пульсирующий промысел и применение режима открытых-закрытых районов и сезонов. Предлагаются некоторые меры по управлению, которые могли бы быть введены на время, пока более универсальная система управления находится на стадии разработки.

Resumen

Se presenta una reseña de los objetivos de la Convención para la Conservación de los Recursos Vivos Marinos Antárticos además de las directrices para el desarrollo de las medidas de administración para las

* Centre for Marine and Ecological Research, Soerlaan 33, 1186 JG Amstelveen, Netherlands

pesquerías de krill. Se detallan varios posibles tipos de procedimiento tales como administración suplementaria, reactiva y pronóstica, modelado, especies indicadoras, pesca por pulso y el empleo de áreas y temporadas abiertas y de cierre. Se sugieren algunas medidas de administración interinas que podrían ponerse en práctica mientras se elabora un sistema de administración más general.

---

1. INTRODUCTION

If krill (*Euphausia superba*, Dana) were considered in isolation it is reasonably certain that the potential annual harvest is large; of the order of perhaps tens of millions of tonnes over Antarctic waters as a whole. This potential has been crudely guaged by considering the food consumption of baleen whales in the Antarctic (Laws, 1977). The baleen whales were the object of major fisheries, with some species being depleted to only a small fraction of their pristine abundance (IWC, 1990). This dependence of endangered and depleted whale stocks on the stocks of krill, adds the dimension of establishing the yield of krill than can be taken while ensuring that depleted resources are able to recover to at least a healthy proportion of their original abundance.

The conservation of species which are dependent on krill forms an integral part of objectives of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). This is in contrast to the situation under which most other fisheries have been managed in the past, and this raises the need for new approaches to fishery conservation. In any case, the problems that have been encountered in conserving fish stocks elsewhere point to the desirability of considering fresh approaches to fishery management in the Antarctic.

Fishery management is defined as the process whereby conservation measures are set in place to ensure that the objectives of conservation (including rational use) of fishery resources are achieved. Conservation also involves ensuring that species that are not exploited will be maintained at levels of abundance, such that their replacement rate is not seriously diminished. Rational use is defined to be the sustainable utilization of a resource in perpetuity. A rational fishery should be efficient, both in terms of the cost and investment in fishing, and the cost and investment required to ensure that the conservation objectives of the Convention are being met.

2. OBJECTIVES OF CCAMLR

The general objectives of CCAMLR are given in Article II of the Convention as follows:

"1. The objective of this Convention is the conservation of Antarctic marine living resources.

2. For the purposes of this Convention, the term 'conservation' includes rational use.

3. Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:

   (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;

(b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and

(c) prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes with the aim of making possible the sustained conservation of Antarctic marine living resources."

A number of authors have discussed the objectives of CCAMLR, particularly how they require interpretation to render their meaning more precise (for example, Edwards and Heap, 1981; Beddington and de la Mare, 1984). De la Mare (1986a), suggests that an approach which can overcome the problem of having objectives which are in themselves too general is to develop subsidiary objectives which are designed to have a precise interpretation. An important property required for subsidiary objectives is that they are framed in terms of quantities which can be estimated robustly, thus allowing the degree to which objectives are met to be assessed. When subsidiary objectives are achieved it is assumed that the overall, general objectives of the Convention will also be achieved.

A given approach to management may lead to specific subsidiary objectives, and these may differ in detail from subsidiary objectives specified for a different management approach. Moreover, other subsidiary objectives may arise from considerations of the nature of fisheries, for example, a steady yield might be given a higher priority than maximizing catches. Thus, the formulation of subsidiary objectives is a subject which will need to be considered in the light of specific approaches to fishery management.

3. OTHER ASPECTS OF THE CONTEXT IN WHICH CONSERVATION STRATEGIES WILL BE FORMULATED

A fishery for krill around the Antarctic has been developing slowly for more than a decade, with a recent period in which the fishery contracted while various technical problems in handling the catch were investigated. These problems now appear to be largely overcome, and the krill fishery is once again expanding. It has been found in other fisheries (for example, the Peruvian anchovy fishery) that the overall size of a fishery can increase dramatically over a relatively short time. Fishery operations tend to concentrate on known fishing grounds; there is no reason for fishing fleets to search for, or to travel to new fishing grounds so long as the existing grounds remain productive.

Krill is regarded as a key species in waters around Antarctica; it forms a major part of the diet of many species, the conservation of which is included within the objectives of the Convention. However, available information about the ecology of the Antarctic marine ecosystem, the distribution and abundance of krill, along with incomplete knowledge about basic krill demography, such as mortality and longevity, mean that it is not possible to predict what level of krill harvest will be within the overall objectives of the Convention. In addition, the abundance and distribution of krill is likely to fluctuate from year to year. The various techniques used to estimate the abundance of animal populations also give results which are uncertain. Thus, management procedures have to cope with uncertainty arising from both ecological and sampling variability.

Variability is not the only consideration arising from incomplete knowledge; for various reasons, errors will be made in applying conservation measures. Two types of errors are possible: (1) applying measures such that opportunities for larger harvests are missed; and, (2) measures are not sufficient to prevent over-harvesting. An important property of a rational management procedure is that it should detect and correct both types of error. In evaluating possible management procedures, particular consideration should be given to their properties in either correcting errors, or insensitivity to the effects ot error.

3.1 Designation of Management Areas

It is widely regarded that the appropriate entity to manage in fisheries is a unit (or biological) stock. A unit stock is defined as a group of individuals of the same species whose gains by immigration and losses by emigration are negligible in relation to the rates of growth and mortality (Holden and Raitt, 1974). In general, a stock may be defined as an exploitable group of animals, of which there may be more than one per species, existing in a common spatial arrangement, but with limited genetic exchange between adjacent populations of the same species, usually designated on a geographical basis. A stock may or may not coincide with a unit stock; the lack of coincidence would not usually be intentional, but rather the product of incomplete knowledge of ecological processes.

The important point is that the designation of stocks for management is an integral part of the formulation of management procedures. It should be borne in mind whether a given procedure is intended to manage unit stocks or otherwise. Where a unit stock is assumed, it is important to examine the potential effect on achieving conservation objectives arising from failure to identify the unit stock correctly. Conversely, if stocks are arbitrary units, the properties of the conservation strategy for conserving unit stocks should be evaluated.

3.2 Decision Rules

Decision rules are a fundamental part of a rational management procedure. A decision rule designates what action, in terms of applying or varying conservation measures, is to be taken for any given assessment of the state of the stocks within a management unit or area. Assessment can be defined as the evaluation of the state of stocks within a management unit in the light of management objectives. However, the state of the stocks must be measured on some objective basis, and hence subsidiary objectives must be defined in relation to the available objective measures of stock status.

Clear-cut decision rules are important as a component for the evaluation of management procedures. It is difficult to predict the properties of a management procedure if its implementation would not be based on well specified decision rules. Moreover, well specified decision rules have a role in facilitating consensus decision-making.

3.3 Harvesting Objectives

It is not sufficient to consider only the ecological aspects of management, although the production from the Antarctic marine ecosystem is an ecological constraint which is ultimately limiting. Within the ecological constraints there is scope for adjusting management procedures so that they have differing properties, advantages and disadvantages, for the fishing industries and CCAMLR. For example, the industry may prefer catches that are relatively constant from year to year. Yet either strategy has to achieve the same conservation objectives. In general, objectives such as ensuring conservation, attaining the highest possible yield, and minimizing fluctuations in catch from year to year cannot all be fully achieved simultaneously. For example, steady catches are attained by accepting a lower average yield.

3.4 Data and Assessment Methods

Assessment of the status of stocks is usually dependent on statistical procedures for estimating the parameters which constitute the input to management procedures. Inevitably the parameter estimates will be uncertain due to both sampling variability and the possible failures of assumptions underlying the statistical methods. The desirable property of assessment methods and the management procedure is robustness, which can be defined in terms of making correct decisions even though underlying assumptions have not been satisfied.

It is important that the properties of assessment methods be examined as nearly as possible in the circumstances in which they would be used; that is, within the framework and decision rules of a given management procedure. For example, a method of assessment may be imprecise, and hence any single estimate would lead to a low probability of making a correct management decision. However, if the method were to lead to correct decisions on average, then a procedure which always took the action implied by the method would achieve the overall objectives. Conversely, using a procedure which took the imprecision into account, by reducing catches in proportion to the uncertainty, could also achieve the objectives.

Each of these procedures would have different properties, particularly in the short-term. The first procedure could be designed to maximize the average yield, but it would initially lead to erratic application of conservation measures, until sufficient data accumulated to stabilize the estimates of the decision parameters. The second procedure would tend to lead to the conservative application of measures until sufficient data accumulated to estimate the level of harvest within the overall objectives, but with the advantage of a lower degree of fluctuation in the harvest from year to year.

3.5 Time Frame for Implementation

A further element to consider in developing management procedures is the length of time required for full implementation. Different possible procedures may take different lengths of time before it becomes clear what the long-term general level of fishing might be, or until sufficient data accumulate to apply them confidently. Possible procedures should be evaluated to attempt to indicate the time scale involved in any such initial phase, and as a corollary, what steps, if any, are necessary to ensure that the objectives of the Convention are being met in any interim period before the strategy becomes fully effective. Where the information base is not yet adequate, a staged implementation may be necessary. This may involve the application of some conservation measures so as to guarantee the achievement the Convention's conservation objectives, but in a way which would allow a safe level of harvest while the data necessary for the ultimate implementation of a full management procedure are gathered.

4. SOME EXAMPLES OF POSSIBLE ELEMENTS OF MANAGEMENT PROCEDURES

In order to give more substance to the general discussion above, a few elementary management options will be examined in the context of their likely power to meet the objectives of the Convention, along with their implications for the Commission and the fishing industry.

Six examples will be examined.

(1) Reactive management.
(2) Predictive management (modelling).
(3) Open and closed areas.
(4) Indicator species.
(5) Pulse fishing.
(6) Feedback management.

The selection of these six options does not imply that the list is exhaustive, or that combinations of some of them may not also be useful approaches to explore. The intent of the discussion here is to examine some potential procedures from two points of view: (1) to discuss some initial consideration arising from concrete examples; and, (2) to use these examples to consider how to evaluate possible management procedures.

In general, it is not necessary to examine every aspect of the performance of any given procedure. The process of evaluation is in some senses also a process of elimination. The first step is to examine whether a procedure can work in ideal circumstances, using, for example, analytical mathematical methods or computer simulation studies. The evaluation of a given procedure need only proceed to the point where it becomes clear that it can fail to meet the objectives of the Convention. At this point, it has to be modified or discarded.

Candidates which survive such testing then need to be examined under more realistic circumstances, with the cycle of modification or rejection continuing until there are a few which appear to have the capacity to meet the objectives of the Convention. These final candidates then need to be analyzed in the greatest detail to determine their properties of robustness in terms of working under feasible worst-case conditions. Weight needs to be given to the economic aspects of the performance of the surviving candidates as a factor in making final choices.

4.1 Reactive Management

Reactive management is the practice of implementing conservation measures only after the need for them is apparent. In the context of CCAMLR, this would mean that catches would be unregulated until such time as stocks of either target or dependent species declined to levels below that ensuring their stable recruitment, or to below the level of maximum net annual increment, or changes occurred which were not potentially reversible over two or three decades.

In terms of formulating decision rules, it would be necessary to determine where such levels are, or what kind of changes would not be reversible over two to three decades. An approach with these general objectives has the difficulty that the criteria which would indicate whether the objectives are being met cannot be defined in measurable terms in advance.

For example, recruitment can only be shown to have become unstable (i.e., declined) well after the fact. In most fish stocks, recruitment is highly variable from year to year, and so it will take a number of years of data to determine whether there has been a true decline in recruitment rather than chance fluctuations showing a number of years of poor recruitment. The essential problem is to detect the 'signal' about recruitment from 'noisy' data. The first part of such a problem is to decide at which point that a fishery-induced decline in recruitment is more likely than the effects of chance. In essence, this question is equivalent to, what is the probability that there will be a failure to implement conservation measures when they are in fact required? The corollary is, what is the probability that conservation measures would be put in place when in fact they were not necessary?

Even when the technical difficulties in estimating recruitment are ignored, there is a high probability of failing to introduce conservation measures in a timely fashion, with the possibility that stocks may be seriously depleted. A likely consequence will be that fisheries will be unstable, going through cycles of boom and bust (for some examples see Allen and McGlade, 1986), with potentially irreversible impacts on the ecosystem as a whole.

The problems are multiplied when it is the recruitment of a dependent (consumer) species that is to be maintained. For example, for whales, it is very difficult to estimate recruitment (de la Mare, 1987 and 1989). In addition, any trend in the recruitment of consumer or prey species might be interpreted as being related to some other environmental trend rather than to the effects of harvesting. Thus, the causes of changes in an ecosystem may not be unambiguously identifiable after the event. This may lead to a delay, or even a failure, in reaching consensus that management measures are needed, and this could result in harvesting leading to an irreversible impact upon the ecosystem.

Hence, a procedure relying upon a purely reactive approach seems unsuitable for meeting the recruitment objective unless both recruitment and the estimates of it are both not subject to high levels of random variability.

4.2 Predictive Management (Modelling)

Predictive management involves predicting the levels of catch which can be taken by considering information already known about the system, or that can be determined by further studies carried out before harvesting has changed the system in such a way that there is a failure to meet the Convention's objectives. It is an approach largely based on having some form of model about the system. The model may even be so crude as to not even be identified as a model in the usual sense, for example, the idea of predicting a level of krill harvest on the basis of what was once eaten by large whales is such a crude model. However, much more sophisticated models can be built considering multiple species and energy flows and the like.

The application of multi-species models for the management of the Antarctic marine ecosystem has been discussed by Butterworth (1984), Beddington and de la Mare (1984), de la Mare (1986a) and Miller (1986). Modelling needs to be built on the more arbitrary approaches outlined above. Butterworth (1984) suggests that there should first be interim measures to delimit management areas, agree on target levels for stock size and to monitor stocks, accompanied by empirical (i.e., production) modelling rather than an analytical approach which attempts to incorporate parameters for which density-dependent changes have been measured.

Beddington and de la Mare (1984) and de la Mare (1986a) emphasize that simulation modelling can be a valuable tool in evaluating strategies for the acquisition of information about a system, in designing a regulatory framework from an ecosystem perspective, enabling potential management procedures to be tested and refined by applying them to a whole range of artificial exploited systems of increasing complexity. This approach can reduce the high overhead costs of feedback methods requiring a great deal of data, resource surveys, stock assessments, etc. As summarized by Beddington and de la Mare (1984), "modelling cannot substitute for experimentally rigorous observation. Conversely, unguided observation provides only data not insight."

While modelling has a valuable role in the development of long-term strategies for the conservation of Antarctic marine ecosystems, a well balanced strategy should begin with simple, pragmatic interim safeguards (and model-tested) empirical approach.

4.3 Open and Closed Areas and Seasons

This is defined as the declaration of a series of open and closed areas, perhaps combined with open and closed seasons, selected with the objective of ensuring sufficient protection of target species within closed areas to maintain ecosystems there, while also ensuring sufficient recruitment from both closed and open areas to maintain fishing. In theory, such an approach would require little or no regulation of fishing operations in the open areas, provided that there were limited effects on stocks in the closed areas. The critical step is the selection of boundaries between open and closed areas in a manner which ensures ecological as well as economic viability of this management regime.

One implication of this approach is that in open areas, heavy fishing upon krill might cause localized effects on some consumer species, but some small-scale regional disruption could be acceptable over the Convention Area as a whole.

In managing a single species resource, krill appear to be well suited to such an approach, having semi-discrete concentrations related to quasi-stationary cyclonic gyres, but with considerable exchange between each. However, the distribution of consumer species may not be determined solely by the concentration of krill, but may also be influenced greatly by other factors such as the distribution and condition of sea ice, or the location of suitable breeding sites. This may lead to complications in choosing the sizes and locations of open and closed areas.

Nevertheless, even arbitrarily selected open and closed areas may have practical value as an interim approach, being simple, inexpensive and not demanding very detailed prior knowledge of the components of the system (de la Mare, 1986a).

4.4 Indicator Species

One possibility for detecting deleterious effects of krill fishing on the suite of krill predators is to monitor condition factors of a small range of predators (Green-Hammond *et al*, 1983). These were termed indicator species, with the implication that changes in condition, such as body fat, or fecundity, would predict that the changes in population status of krill predators would follow. This concept has, at least in part, underlain the general approach adopted by the CCAMLR Ecosystem Monitoring Program (CEMP). There are three general problems to be addressed in applying the indicator species concept which can be summed up as coverage, calibration and extrapolation.

The existing CEMP program is concentrated on a small number of areas selected because of logistical constraints, and continuing research programs which had already acquired data. Thus, at this stage, the CEMP program has limited coverage, and so can only detect the effects of krill fishing within the foraging range of the selected predators. If the krill fishery operates substantially outside this range, the program will have little power to detect the effects of krill-fishing on krill predators. The obvious solution is to concentrate the existing fishing activity into one of the CEMP monitoring regions, and to exclude the fishery from a similar site as a kind of experimental 'control'. If none of the existing sites form a suitable replicate, then the CEMP program may have to consider augmenting the set of sites. The question of mounting what amounts to an 'experiment' along these lines warrants further serious consideration.

Calibration means identifying the relationship between krill abundance and the selected predator condition factor. In general, it would be expected that there will be a non-linear relationship between krill abundance and predator condition factors. At high levels of krill abundance, the predator condition will be saturated, that is further increases in krill will produce negligible further increase in predator condition. At lower levels of krill abundance, predator condition would still be expected do decline more slowly than krill abundance if, as is likely, predators are able to home in on krill concentrations. It may transpire that the predator condition factors will not give sufficient early warning to prevent the fishery from over-exploiting the krill stocks in terms of their optimal single-species management.

Assuming that a suitable condition factor could be identified and calibrated, it would be an article of faith that the use of the condition factor as a decision parameter in a management procedure would result in conservation of other krill-dependent predators. However, as Beddington and de la Mare (1985) point out, extrapolation to wide-ranging predators would probably be conservative where fishing is limited to the foraging range of selected shore-based predator populations.

4.5 Pulse Fishing

Pulse fishing entails harvesting intensely within a given area until the stock is reduced to a certain point, and then moving to other areas until the stock recovers in the first area. The point where fishing ceases in a given area is usually determined on economic rather than ecological grounds, but decision rules could in theory be formulated to comply with the objectives of the Convention. This would require initial surveys to estimate the size of the pulse which can be applied. A discount should be made to allow for uncertainty in this estimate. The criteria for deciding when to cease fishing should be pre-determined. Part of the costs of this approach should include surveys during the non-fishing period to monitor recovery towards a pre-determined point at which fishing is to be resumed.

In practice, pulse fishing has been applied with questionable effectiveness to the management of single or multi-species fisheries. Its application to the management of ecosystems is far more doubtful, even when the system is pristine. Intensive fishing reducing a key species to a very low level might favour certain of the consumer species more than others. For example, if the prey species has a habit of swarming, those predators feeding on swarms will be disadvantaged far more by intensive fishing than predators consuming prey individually. Hence, pulse fishing applied intensively might alter the community structure of an ecosystem very significantly.

In the case of Antarctic marine ecosystems the situation is more difficult in that the larger baleen whales are so depleted that recovery within the stipulated twenty or thirty years is uncertain. Thus, there is a danger that pulse fishing upon krill swarms may apply pressures beyond the principles specified in Article II of the Convention.

4.6 Feedback Management

The importance of basing fisheries management on feedback principles is now also being recognized (Tanaka, 1984; de la Mare, 1986a). The discussion on feedback given here is based on that of de la Mare (1986a). Properly designed feedback systems have a number of important advantages over non-feedback systems. These include improved accuracy and stability in attaining objectives and reduced sensitivity to error in the model assumed to apply to the controlled system.

The implication of applying control systems theory and feedback to living resource conservation is that it directs attention to the examination of system input and output. For a convention such as CCAMLR, the total system under discussion is the ecosystem in a given region, combined with a conservation strategy. Thus, the part of system to be controlled (at least along some partial dimension) is the ecosystem, and the management procedure forms a control system. The system input is formed from the objectives of the Convention, and hence, the system output is some set of observed attributes of the ecosystem. In control systems theory terms, the catches are not necessarily considered as part of the output of the system, but they are the principle control action which can be applied to drive the ecosystem towards a specified set of objectives.

Suppose that it was decided that the abundance of an exploited fish stock should not fall to below say $\mathbf{X}_{min}$ (to ensure stable recruitment) and that the optimal level of the stock was somewhat higher at $\mathbf{X}_{opt}$. Similarly, suppose that some predator is to be maintained at a level above $\mathbf{Y}_{min}$ and to have a desirable level of $\mathbf{Y}_{opt}$. Thus the input to the system is $\mathbf{X}_{opt}$ and $\mathbf{Y}_{opt}$ and its output is the observed values of **X** and **Y**. Feedback control would lead to catches being increased, if the observed values of **X** and **Y** were above their target levels, but some reduction in catches would be required if either **X** or **Y** were below target. The changes in catches would be governed by some form of decision rule, which could be rather complex, but which would include some element of proportionality in that small differences between the observed and target values for **X** and **Y** lead to smaller adjustments in catches than do large discrepancies between the observed values and their targets. If the observed values of **X** or **Y** were to be found below the minimum levels then catching would cease until the stocks had recovered towards the target level.

Simulation studies of such a regulatory system, in a single species context, have shown that the probabilities of erroneously curtailing exploitation on a stock or inadvertently reducing it to below the minimum level can both be controlled (de la Mare, 1986b and 1989). However, it has also been shown that the time to detect and correct errors can be relatively long because of the effects of variability in estimates of absolute or relative abundance (de la Mare, 1984 and 1986a).

The example outlined above is not intended to be definitive, but to illustrate how feedback regulation might work, and in particular to highlight three important principles. The first principle is that the initial rate of exploitation should be basically feasible in terms of a likely level of sustainable yield. This requires that an estimate of abundance is available for each exploited stock in advance of the substantial development of its fishery, or that other basic safeguards are put in place such as closed areas and seasons as suggested earlier. This is important for two reasons: (1) that it helps to avoid over-capacity in the fishery; and (2) it helps to ensure that the reduction in the biomass of the stock occurs over a sufficiently long time span to allow sufficient data to accumulate so that errors in the predicted yield can be identified and corrected, before the consequences become serious for the fishery. The second principle requires that the objectives for the regulatory system should be framed in terms of aspects of the status of the controlled system which can be estimated robustly. The third principle is that the regulatory framework specifies what actions are required given the observed values of status of the controlled system. These principles are also an important factor in creating an environment in which scientific consensus is more readily obtained.

5. TOWARDS AN OVERALL STRATEGY

A management procedure for krill should favour steady fisheries which are ecologically sustainable as well as economically efficient. It is essential that the management procedure should limit the risk of accidental failure to achieve the objectives of the Convention. Moreover, the costs of management should be commensurate with the value of the fisheries. Within these general constraints, management is ultimately an empirical process, and to determine the highest levels of harvest of krill which will be compatible with the objectives of CCAMLR requires monitoring of the effects of fishing. However, in the short to medium term, approaches should be sought which will ensure that the objectives of the Convention are met without requiring commitments to research and monitoring activities which are excessive in comparison with the importance of the fisheries.

The strategy approaches outlined in this document all have various advantages and disadvantages. Choosing suitable long-term strategies may be a process which will require a number of years for evaluation and implementation. Thus, there is a need for interim procedures to ensure that the development of fisheries does not outstrip the basis on which they can be managed. Therefore, it might be useful to consider a procedure which can be implemented in stages, which may include elements drawn from (a) Open and Closed Areas and Seasons; (b) Feedback Management; and, (c) Predictive Management. The emphasis on particular elements will depend on the subsidiary objectives for harvesting, as well as a weighing of the costs incurred to collect the data and undertake other associated activities of particular management strategies. It is premature to indicate the detailed form that a long-term strategy for krill conservation might take. However, it is possible to indicate a basic structure, with emphasis on the elements which are appropriate to implement in the interim as part of the first stages of setting up an overall management procedure. The framework might then contain the following elements:

(i) Selection and designation of open and closed sectors for krill harvesting. In the present state of knowledge of the dynamics of the Antarctic marine ecosystem, it would be prudent to designate several (say six) sectors, and open some of these (say three) to krill fishing.

(ii) In each of the sectors open to the fishery, a number of subareas are designated which are open for fishing, the remaining subareas to remain closed as an interim measure to ensure sufficient stock escapes the fishery each year to maintain recruitment and essential ecological processes. Alternatively, separate interim catch limits be set at modest levels for each sector open for fishing. Some or all of the subareas may be involved in the CEMP program.

(iii) Interim measures for krill fishing should apply until replaced by improved management procedures as they develop. The time frame envisaged for the interim measures would be that required to evaluate and choose the next stage of the overall strategy. This time scale could be of the order of five years or more.

(iv) During the interim period, as full a data collection as possible should be made on fishing operations, target and selected consumer species, and on the physical environment. Only those data necessary for the implementation of agreed management procedures would ultimately be required to be submitted to CCAMLR. However, since it is not possible to specify the ultimate data requirements in advance, extensive data of all types should be collected and archived by Members.

(v) CCAMLR should facilitate cooperation in the collection and analysis of these data.

(vi) Eventual phasing-in of feedback management if and when increases in yields are sought, or if data collected in the course of monitoring indicated that recruitment was failing in exploited or dependent species.

6. OUTLINE OF A WORKPLAN FOR DEVELOPING A MANAGEMENT PROCEDURE

Developing a management procedure will be a complex task which involves the selection of criteria to examine the potential performance of procedures to provide the ultimate basis for making choices. The aim is not to develop the best possible management procedure to last for all time, but to approach the problem pragmatically to ensure that the Commission at any stage has a management procedure sufficient for its current needs, but that it is also anticipating what kind of procedure will be needed in the short to medium term. Failure to plan actively ahead may well leave the Commission reacting to unnecessary surprises which could have been avoided with the application of some forethought. An outline of the steps involved in the initial phases of such a tentative workplan is as follows:

1. Refine the objectives of conservation and formulate any subsidiary objectives.

2. Choose initial candidate strategies.

3. Identify and initiate interim conservation measures to ensure objectives are met while longer-term procedures are under development.

4. Undertake the first round of examination of candidate procedures, and any refinements or additions necessary to objectives.

5. Conduct a major review of progress. Select candidate procedures for intensive analysis. Refine objectives and procedures if necessary.

6. Undertake intensive analysis of final candidates, similar to step (4), but with additional particular attention costs and benefits to fisheries and the Commission.

7. Conduct the next major review of progress. If suitable procedures have been identified then proceed to formal adoption of the decision rules and conservation measures by the Commission. Otherwise, refine objectives and procedures; repeat steps (6) and (7).

The time scale involved overall depends partly on the priority and resources assigned to the process by the Commission and its Members. However, assuming basic progress is tied to the annual meeting of the Commission, the time scale could be five to six years. That does not mean that the procedure existing after that time would be perfect, but that it would be adequate for meeting the basic objectives. A cycle of improving the procedures would continue in the face of new developments in the fisheries and to take into account improvements in assessment methodology.

REFERENCES

ACMRR. 1980. Report of the Advisory Committee on Marine Resources Research Working Group on the Scientific Basis of Determining Management Measures. Hong Kong. 10 to 15 December, 1979. *FAO Fish. Rep.* (236): 149.

ALLEN, P.M. and J.M. MCGLADE. 1986. Dynamics of discovery and exploitation: The case of Scotian Shelf groundfish fisheries. *Can. J. Fish. Aquat. Sci. 43*: 1187-1200.

BEDDINGTON, J.R. and W.K. DE LA MARE. 1984. Marine mammal fishery interactions: Modelling and the Southern Ocean. In: *Selected Scientific Papers, 1982-1984, Part II.* Hobart, Australia: CCAMLR. pp. 155-178.

BUTTERWORTH, D.S. 1984. Antarctic ecosystem management. In: *Selected Scientific Papers, 1982-1984, Part II.* Hobart, Australia: CCAMLR. pp. 15-41.

DAWSON, L. 1980. Glossary of terms and concepts used in fishery management. Report of the Advisory Committee on Marine Resources Research Working Group on the Scientific Basis of Determining Management Measures. Hong Kong, 10-15 December, 1979. *FAO* Fish. Rep. (236): 115-130.

DE LA MARE, W.K. 1984. On the power of catch-per-unit-effort series to detect declines in whale stocks. *Rep. Int. Whal. Commn 34*: 655-664.

DE LA MARE, W.K. 1986a. *Some Principles for Fisheries Regulation from an Ecosystem Perspective.* SC-CAMLR-V/BG/13. Hobart, Australia: CCAMLR. p. 12, mimeo.

DE LA MARE, W.K. 1986b. Simulation studies on management procedures. *Rep. Int. Whal. Commn 36*: 429-450.

DE LA MARE, W.K. 1987. An overview of recent work on the management of exploited whale populations. Paper SC/M87/R presented to the Management Workshop of the Scientific Committee of the International Whaling Commission, Reykjavik, March 1987. p. 12, mimeo.

DE LA MARE, W.K. 1989. Further simulation studies on management procedures. *Rep. Int. Whal. Commn*, Special Issue 11: 157-169.

EDWARDS, D.M. and J.A. HEAP. 1981. Convention on the Conservation of Antarctic Marine Living Resources: A commentary. *Polar Record 20*: 353-362.

GREEN-HAMMOND, K.A., D.G. AINLEY, D.B. SINIFF and N.S. URQUHART. 1983. Selection criteria and monitoring requirements for indirect indicators of changes in availability of Antarctic krill applied to some pinniped and seabird information. Report to the US Marine Mammal Commission, Contract No. MM2324753-6.

HOLDEN, M.J. and D.F.S. RAITT. 1974. Manual of fisheries science. Part 2. Methods of resource investigation and their application. *FAO Fish. Tech. Pap.* 115. p. 214.

LAWS, R.M. 1977. The significance of vertebrates in the Antarctic marine ecosystem. In: LLANO, G.A. (Ed.). *Adaptations Within Antarctic Ecosystems.* Washington: Smithsonian.

MILLER, D.G.M. 1986. *Modelling and Decision Making as Part of the CCAMLR Management Regime.* SC-CAMLR-V/BG/17. Hobart, Australia: CCAMLR. p. 13, mimeo.

TANAKA, S. 1984. On the method for calculating catch quotas. *Bull. Int. North Pacific. Fish. Commn 42*: 98-103.

TOWARDS AN INITIAL OPERATIONAL MANAGEMENT PROCEDURE FOR THE KRILL FISHERY IN SUBAREAS 48.1, 48.2 AND 48.3

D.S. Butterworth*

Abstract

An operational management procedure for krill (*Euphausia superba*) in Subareas 48.1, 48.2 and 48.3 requires a basis for the assessment of resource status, and an algorithm for specifying the levels of regulatory mechanisms (e.g., a catch control law) that depends on the results of the assessment. The development and selection of a procedure requires a basis for the simulation testing of procedures, and an operational definition of CCAMLR Article II to provide criteria against which to assess procedure performance. Suggestions are made under each of these headings. Assessment of resource status is provided by the CPUE "Composite Index" proposed by the Workshop on the Krill CPUE Simulation Study. Annual TACs are restricted to an initial ceiling (C_c) for a five year period, with a reference CPUE level ($CPUE_{ref}$) calculated as the average CPUE over that time. Thereafter TACs may increase by c_r% per annum. However, this increase may be suspended or reversed in any year, depending on how many of the previous three years' CPUE values fall below a target level of 0.75 $CPUE_{ref}$. An operating model of krill dynamics in the region is developed for simulation testing purposes. A provisional operational interpretation of Article II is proposed: the primary objective is to prevent the expected lowest biomass of krill over a 20-year harvesting period from falling below 60% of its average unexploited level; subject to this constraint, accumulated catches should be as large as possible without substantial associated probability that TAC reductions may prove necessary during the 20-year period considered. Simulation tests, including one particular test of robustness to the assumptions of the operating model, are carried out to **illustrate** the overall process proposed; for this **illustrative** exercise, the choice of catch control law parameters would probably lie between (C_c=1 million tonnes; c_r=15%) and (C_c=2 million tonnes; c_r=10%). Suggestions for proceeding with further investigations of possible operational management procedures are made. It is proposed that possible alternative suggestions for such procedures should be made in a similar fashion to that set out in the paper. Suggestions by others for alternative forms and parameter values (or their probable ranges) for the krill dynamics operating model used for testing procedures are encouraged.

Résumé

Une procédure de gestion opérationnelle du krill (*Euphausia superba*), dans les sous-zones 48.1, 48.2 et 48.3, nécessite une base pour l'évaluation de l'état des ressources et un algorithme pour préciser les niveaux des mécanismes régulateurs (par ex.: une loi de contrôle de capture) qui dépende des résultats de l'évaluation. La sélection et l'élaboration d'une procédure nécessitent une base pour les tests par simulation des procédures, et une définition opérationnelle de l'Article

* Department of Applied Mathematics, University of Cape Town, Rondebosch 7700, South Africa

II de la CCAMLR pour fournir des critères selon lesquels évaluer la performance de la procédure. Des suggestions sont faites sous chacun de ces titres. Une évaluation de l'état des ressources est fournie par "l'Indice composite" de la CPUE, proposée par l'Atelier sur l'Etude par simulation de la CPUE du krill. Les TAC annuels sont limités à un plafond initial (C_c) pour une période de 5 ans, avec un niveau de référence CPUE ($CPUE_{ref}$), calculé comme la CPUE moyenne pour cette période. Par la suite, les TAC peuvent augmenter de c_r% par année. Toutefois, cette augmentation peut être suspendue ou inversée n'importe quelle année, selon le nombre de valeurs CPUE des trois années précédentes qui tombe au dessous du niveau fixé de 0.75 $CPUE_{ref}$. Un modèle opérationnel de la dynamique du krill dans la région est développé pour des raisons de tests par simulation. Une interprétation provisoire et opérationnelle de l'Article II est proposée: l'objectif premier est d'empêcher la biomasse de krill prévue comme étant la plus faible, pour une période d'exploitation de 20 ans, de tomber au dessous de 60% de son niveau moyen non exploité; sujettes à cette restriction, les captures cumulées devraient être aussi importantes que possible, sans la probabilité substantielle associée que les réductions du TAC peuvent prouver nécessaires pendant la période des 20 années considérées. Des tests de simulation, comprenant un test particulier de robustesse envers les suppositions du modèle opérationnel, sont effectués pour **illustrer** le procédé d'ensemble proposé; pour cet exercice **explicatif**, le choix des paramètres de loi de contrôle des captures se situerait probablement entre (C_c=1 million de tonnes; c_r=15%) et (C_c=2 millions de tonnes; c_r=10%). Des suggestions sont faites pour la poursuite d'autres études sur des procédures possibles de gestion opérationnelle. Il est proposé de suggérer, d'une manière similaire à celle décrite dans ce document, des alternatives possibles pour de telles procédures. Des suggestions d'une autre provenance pour d'autres formes et valeurs des paramètres (ou leurs variations probables) pour le modèle opérationnel de la dynamique du krill, utilisé pour les procédures de tests, sont encouragées.

Резюме

Для разработки оперативной процедуры управления промыслом криля (*Euphausia superba*) в Подрайонах 48.1, 48.2 и 48.3 необходимо определить основу для оценки состояния этого запаса и зависящий от результатов этой оценки алгоритм, согласно которому устанавливается уровень регулирования (напр. - органичение вылова). Для разработки и отбора процедуры необходимо определить основу экспериментальной проверки эффективности процедур посредством моделирования. Также необходимо иметь рабочую интерпретацию Статьи II Конвенции АНТКОМ, предоставляющую критерии оценки эффективности процедур. По каждому из этих вопросов вносятся предложения. Оценка состояния запаса может быть выполнена посредством вычисления комплексного индекса CPUE, который был предложен Рабочим семинаром по исследованию CPUE криля методом математического моделирования. На протяжении первых пяти лет устанавливается порог ежегодных уровней TAC (C_c), при этом контрольный уровень CPUE ($CPUE_{ref}$) вычисляется как

средняя величина CPUE за этот период. После этого величины TAC могут увеличиваться на c_r% в год. Тем не менее, в зависимости от того, уровень скольких показателей CPUE за предыдущие три года ниже целевого уровня, равного 0,75 $CPUE_{ref}$, в течение любого года введение этого увеличения может быть временно отложено или уровень TAC может быть снижен. Рабочая модель динамики криля в этом районе была разработана в целях экспериментальной проверки посредством математи-ческого моделирования. Предлагается предварительная рабочая интерпретация Статьи II: основной задачей является предотвращение снижения предполагаемой минимальной биомассы криля на протяжении 20 лет промысла до уровня, ниже 60% ее средней величины в доэксплуатационный период. С учетом этого ограничения, аккумулированный вылов следует поддерживать на максимально возможном уровне, при котором не предполагается возникновение необходимости снижения уровня TAC на протяжении рассматриваемого 20-летнего периода. Экспериментальная проверка посредством математического моделирования, включая один конкретный тест на устойчивость по отношению к допущениям, сделанным в рабочей модели, была выполнена для того, чтобы **продемонстрировать** весь предлагаемый процесс; в рамках этого **наглядного примера** параметры ограничения вылова, вероятно, находятся в диапазоне (C_c=1 миллион тонн; c_r=15%) и (C_c=2 миллиона тонн; c_r=10%). Вносятся предложения по дальнейшему исследованию возможных вариантов оперативных процедур управления. Предлагается выдвигать возможные альтернативные процедуры, следуя приведенному в настоящей работе методу. Прочим исследователям, занимающимся этими вопросами, предлагается внести предложения по возможным альтернативным формам и параметрам (или их возможным диапазонам) рабочей модели динамики криля, служащей для экспериментальной проверки эффективности процедур управления.

Resumen

El desarrollo de un procedimiento operativo de administración para el krill (*Euphausia superba*) en las Subáreas 48.1, 48.2 y 48.3 necesita una base para la evaluación de la condición de los recursos y de un algoritmo para determinar el alcance de los instrumentos regulatorios (por ej. una legislación pesquera), que depende de los resultados de la evaluación. El desarrollo y selección de un procedimiento necesita una base sobre la cual se pueda estudiar la factibilidad de los procedimientos y una definición operacional del artículo II de la CCRVMA, para lograr obtener un criterio que permitirá analizar el resultado de este procedimiento. Se hacen sugerencias bajo estos apartados. La evaluación de la condición del recurso se obtiene utilizando el "índice compuesto", propuesto por el Taller de Estudios de Simulación de la CPUE del Krill. Las capturas anuales totales permitidas (TAC) están restringidas a un nivel inicial (C_c) por un período de cinco años,

con un nivel de referencia de CPUE ($CPUE_{ref}$) calculado como el CPUE medio referido a ese tiempo. Las capturas totales permisibles pueden ser aumentadas luego en un C_r% por año. Sin embargo, dependiendo de cuántos valores de CPUE de los tres años previos hayan sido inferiores al objetivo de 0.75 $CPUE_{ref}$, este aumento puede ser suspendido o revocado en cualquier año. Se ha desarrollado un modelo operativo de la dinámica del krill en la región con el fin de realizar estudios de simulación. Se propone una interpretación operativa provisoria del artículo II: el objetivo primario es impedir que la biomasa de krill disminuya en un período actividades pesqueras de 20 años, a menos del 60% de su nivel promedio sin explotar; sujeto a esta restricción, las pescas acumuladas deberán ser lo más voluminosas posible, sin que exista una gran probabilidad de que se necesite reducir los TAC durante el período de 20 años que se está considerando. Los estudios de simulación, incluida una prueba especial para sustentar las suposiciones del modelo operacional, se llevan a cabo para **ilustrar** el proceso general propuesto; para los fines de este ejercicio **ilustrativo**, la selección de parámetros de la ley de control de pesca oscilaría posiblemente entre (C_c=1 millón de toneladas; c_r=15%) y (C_c=2 millones de toneladas; c_r=10%). Se han hecho recomendaciones para continuar con los estudios de eventuales procedimientos operacionales de administración. Se propone que se formulen otras sugerencias en relación a formas alternativas de estudio de un modo similar a las que se exponen en el presente trabajo. Se anima que se hagan otras propuestas sobre modos y valores de parámetros alternativos (o sus rangos probables) para el modelo operativo de la dinámica del krill que es utilizado en el estudio de factibilidad de los procedimientos.

---

1. INTRODUCTION

The annual circumpolar Antarctic krill catch over recent seasons has been approaching 0.5 million tonnes. The first meeting of the CCAMLR Working Group on Krill held earlier this year agreed that this level of catch was unlikely to be having much impact on the circumpolar krill population (CCAMLR, 1989a). However, it also noted that about 90% of this catch has been taken from particular locations in Statistical Area 48, and was unable to say whether or not the catch was having an adverse effect on local predators. In conclusion, the Working Group recommended that the fishery should not greatly exceed the current level of catch until assessment methods are developed further and until more is known about predator requirements and local krill availability.

These deliberations of the Working Group serve to emphasise that the krill fishery has now reached a level (in Statistical Area 48, and specifically Subareas 48.1, 48.2 and 48.3) where controls may be necessary. Therefore CCAMLR needs to give urgent attention to the development of an initial operational management procedure for krill in this region. This contribution is intended as an aid and a spur to such development.

An operational management procedure for krill in this region (Subareas 48.1, 48.2 and 48.3) and its development involve four components:

(i) a basis for assessing the status of the krill resource in the region;

(ii) an algorithm for specifying appropriate levels of regulatory mechanisms (e.g., a catch control law) as a function of the results of such assessment;

(iii) a basis for simulation testing of the performance of the management procedure (i.e., components (i) and (ii) above); and

(iv) an operational definition of CCAMLR Article II to provide criteria against which performance can be assessed.

Each of these components is discussed in turn below. This discussion is in the context of a developing fishery - hence the reference to an "initial" procedure. The regulatory mechanism suggested is a TAC (Total Allowable Catch), whose size is determined by an assessment ("estimator") of the relative size of the krill resource at the time. The management procedure suggested thus consists of this combination of a control law and an estimator.

Simulation testing of the procedure requires the specification of an underlying model of the dynamics of the krill resource, which is referred to as the "operating model" (terminology suggested by Linhart and Zucchini, 1986). This model is used to generate data typical of those which would be used in practice to assess the state of the krill resource. Application of the estimator to these data provides an estimate of the relative size of the resource, and substituting this into the catch control law provides the TAC. This TAC is then fed back into the operating model, so that it affects the "actual" size of the resource and thus has an impact on the assessment data generated by the model for the next year of the simulation. In this way, the likely effect on the resource of the application of a management procedure over a certain number of years can be assessed.

The testing does not involve the use of a single operating model only. There is insufficient information available to specify an operating model of the dynamics of krill in Subareas 48.1, 48.2 and 48.3 with particular certainty at this time. Therefore it is also important to test how robust (i.e., insensitive) the performance of a management procedure is to biologically plausible variations of the structure and choices for the parameter values of the operating model.

A particular example of this process is reported in this paper, together with numerical results for the performance of a number of variants of the catch control law suggested. It is important that the context in which these results are presented is clearly understood, so this context has been set out below.

(i) The numerical results have been given as an aid in the **illustration** of the process suggested. While they are, of course, intended to bear **some** relation to the actual situation in Subareas 48.1, 48.2 and 48.3, they are **NOT** put forward at this stage as a specific basis for the choice between different management options.

(ii) The form of the management procedure, the basis for testing it, and the specification of performance objectives that are set out below, are not the only approaches possible. The important point, however, is that all have been set out in **operational** terms. If alternatives are to be suggested (as indeed it is a purpose of this paper to encourage), it is **ESSENTIAL** that they too be set out in operational terms, so that an objective process for assessment of performance remains viable.

(iii) Even if the particular approach suggested here should be preferred, it will become clear later in the paper that numerous far-reaching assumptions, for which relatively little justification can be offered at present, have had to be made in setting up the operating model used for testing the management procedure suggested. It would be surprising if other scientists with expertise concerning this resource did not consider at least some of these assumptions to be inadequate, inappropriate or incorrect. Again, it is a purpose of this paper to encourage others to voice just such reservations. But it is inadequate to offer the reservations alone. What must be provided AS WELL is alternative (and presumably better) assumptions, or indications of the quantitative extents to which it is considered that the original assumptions may be in error. It is precisely such information which is relevant to testing any management procedure that may be suggested - not only the one set out below.

The process which is being suggested is one which is already being used by other International Fishery Organisations. The Scientific Committee of the International Whaling Commission (IWC) is occupied with a very similar exercise as a primary component of the Comprehensive Assessment of Whale Stocks (IWC, 1988, 1989a and 1989b). The International Commission for the South East Atlantic Fisheries (ICSEAF) has recently designed a series of simulation tests for management procedures under its consideration (ICSEAF, 1989). The ICES Working Group on Methods of Fish Stock Assessment (ICES, 1988) has also stressed that assessment methods should be subjected to simulation tests of this type. It therefore seems appropriate for CCAMLR to give consideration to similar simulation studies in the context of the management of the krill fishery.

2. RESOURCE STATUS ASSESSMENT

Hydroacoustic surveys by research vessels operating independently of the fishery to assess the status of the krill resource in Subareas 48.1, 48.2 and 48.3 do not appear to be a likely immediate candidate for the routine provision of regular stock-size estimates (Miller and Hampton, 1989). As far as absolute estimates are concerned, the matter of the appropriate specification of krill target strength has yet to be settled satisfactorily. Annual surveys to provide a sufficiently precise relative biomass index seem unlikely to be viable because of their high costs and the small number of suitable vessels available world-wide.

The potential of CPUE as an index of krill abundance has been under investigation by CCAMLR, and a "Composite Index" has been suggested (CCAMLR, 1989b). Such a composite index is assumed in this analysis to provide the basis for the assessment of the status of the krill resource in Subareas 48.1, 48.2 and 48.3, and is referred to as "CPUE" hereafter. The relative size of the resource at a particular time is inferred from the ratio of CPUE at that time to a reference level. Since no historic CPUE data (in respect of the Composite Index) are available, this reference level is provided by the average value of the CPUE over the first five years of the operation of the management procedure, and will be termed $CPUE_{ref}$.

CCAMLR (1989b) drew attention to the likely non-linearity in the relationship between krill biomass and CPUE (i.e., that a drop in CPUE) would imply (on average) a greater proportional fall in krill biomass. This factor has been taken into account in the operating model which generates CPUE data as a function of the size of the krill biomass, as detailed in Appendix I* .

More sophisticated assessment methods could also be considered, for example those using catch-at-length (or, if possible, catch-at-age) data, though these would still also require data input of some index of relative abundance such as CPUE. The overall process whereby the incorporation of these methods into a management procedure should be investigated, would remain the same.

---

* Details of the program are available on request to the author

3. THE REGULATORY MECHANISM ALGORITHM

The regulatory mechanism proposed is catch limitation (i.e., TAC). Why not effort limitation? - a mechanism which would "automatically" decrease the amount taken if the resource size falls has many attractions. The problems with effort limitation appear to be two-fold. First, the non-linearity in the CPUE-biomass relationship means that catches would be reduced by a smaller proportion than the decrease in size of the resource, and this reduction might not be adequate to prevent over-exploitation. More importantly, however, the "effort" of the composite CPUE index proposed (CCAMLR, 1989b) is a complex derived measure, and not something that could form the basis of a practical management regulation. The types of effort measure which could be used in such regulations (e.g., vessel-days) are unlikely to fulfil the needs required because of severe non-linearity effects. This is because processing time requirements are often the limiting factor in the quantity of krill that is caught (Butterworth, 1988); thus the index of catch-per-vessel day may remain almost unchanged despite a substantial drop in resource abundance.

The krill fishery is a developing fishery. During such a phase of the fishery, three considerations would seem to be appropriate.

(i) Until catches reach a certain level (C_c), there is no need to impose restrictions.

(ii) Once that level (C_c) has been reached, the rate (c_r) at which the fishery expands further should be limited.

(iii) The determinant of the rate of expansion permitted should be that the accumulation of data for assessment purposes during that expansion phase is adequate to allow for timeous detection of and reaction to the possibility that exploitation drives the resource below a level considered satisfactory.

In the analysis presented in this paper, management (and the availability of CPUE data) is assumed to commence after 10 years of annual catches of 0.4 million tonnes, a scenario which corresponds roughly to the present situation in Subareas 48.1, 48.2 and 48.3. Catches are assumed to increase immediately to the initial ceiling (C_c), where they are maintained for five years to obtain $CPUE_{ref}$. In reality, catches would not necessarily reach C_c so rapidly. The consequences of this would be that the results of this analysis reflect a greater degree of resource depletion than would occur in practice under the procedure described here.

After this initial five year period, catches increase by a certain percentage (c_r) each year over the balance of the 20-year period that is considered. However, provision is necessary to suspend or even reverse this increase if assessment indicates that the size of the resource has fallen too low. To this end a target CPUE level ($CPUE_{tar}$) is chosen; because of the non-linearity of the CPUE-biomass relationship, this target level is set quite high relative to the reference level:

$$CPUE_{tar} = 0.75\ CPUE_{ref} \qquad (1)$$

The simplest catch control algorithm might be one that requires catch reductions immediately CPUE drops below $CPUE_{tar}$. However, this could lead to unnecessarily and undesirably large inter-annual TAC fluctuations due to the fact that CPUE itself would be expected to fluctuate considerably from year to year. This is because natural fluctuations in recruitment produce fluctuations in krill biomass which are likely to be quite substantial even in the absence of exploitation (see Figure 1). Further, the CPUE-biomass relationship will have a stochastic component. To offset these problems, the catch control law for the TAC in year y is based on the CPUE values for the previous three years (y-1, y-2 and y-3):

$$C(y) = \begin{cases} C(y-1)[1-2c_r/100] & \text{if all of CPUE(y-1), CPUE(y-2), CPUE(y-3)} < CPUE_{tar} \\ C(y-1) & \text{if any two of CPUE(y-1), CPUE(y-2), CPUE(y-3)} < CPUE_{tar} \\ C(y-1)[1+c_r/100] & \text{otherwise} \end{cases} \quad (2)$$

(i.e., if two of the last three CPUE values are less than the target level, the catch increment is suspended; and if all three are less, the TAC is reduced by twice the increment percentage).

This paper intends no implication that the control law of equation (2) is the best possible. Clearly other laws could be conceived, and almost certainly some of these will lead to better performance by the associated management procedure - further investigations along these lines should be carried out in due course. Equation (2) has been used here because it is simple to comprehend, simple to implement in the simulation analyses, and happens to perform adequately for the illustrative purposes for which it has been introduced.

4. THE BASIS FOR TESTING THE PROCEDURE'S PERFORMANCE

The operating model of the dynamics of the krill resource in Subareas 48.1, 48.2 and 48.3 which is used to generate CPUE data for the simulation testing of the management procedure described above, is detailed in the Appendix. This Appendix also provides information on the assumptions made, and the basis for choosing particular values for the various model parameters.

Only one test of robustness is carried out in this paper. This test is designed to ascertain to what extent the performance of the procedure deteriorates if the size (and consequently the productivity) of the krill resource is only half that assumed in the operating model.

In a full analysis, many other tests of the robustness of the management procedure to biologically plausible variations of the operating model structure and parameter values should also be carried out. This paper does not, of course, pretend to offer such a complete analysis. The single test has been included to serve as an illustration of the sort of analysis which is required.

5. ARTICLE II: OPERATIONAL DEFINITIONS OF PERFORMANCE CRITERIA

The operating model suggested in the Appendix is unashamedly a simple single-species model. How can this be reconciled with CCAMLR's Article II, which specifically requires that considerations wider than those of single-species harvesting be taken into account in management? In particular, the Article states that the indirect effect of harvesting must be considered, and it is precisely this concern that is evident in the extract of the Report of the Working Group on Krill (CCAMLR, 1989a) which was referenced earlier ("whether or not the catch was having an adverse effect on local predators").

Taking such indirect effects into account explicitly requires a credible multi-species model of the dynamics of krill and krill predators in the region under consideration, where the parameters of this model can be estimated with reasonable precision from pertinent data. Those data requirements include long time series of abundance estimates of the populations in question; such requirements cannot be met now, nor in the short or medium term in the future.

Since an explicit approach thus seems impossible, the only alternative would appear to be one which attempts to take account of the requirements of Article II in an implicit manner. The interpretation suggested here (for the interim, not all time) is thus:

(i) aim to keep the krill biomass at a level higher than would be the case if only single-species harvesting considerations were of concern; and

(ii) focus on the lowest biomass that occurs over the projection period considered, rather than the average biomass at the end of the period as might be the case in a single-species context.

The underlying intent of Article II in the context of krill harvesting is surely that such exploitation should not unduly affect the predators which depend on krill for their food. The interpretation above seeks to achieve this by ensuring that krill biomass is maintained at a reasonably high level, and so remains an adequate food source for predators.

The interpretation suggested still requires translation into operational terms. In a single-species context, an objective might typically be to maintain the resource biomass (on average) at 50% of its average unexploited level, corresponding to a size assumed to provide MSY (maximum sustainable yield). Bearing in mind the interpretation of Article II suggested above, this transforms, for the purpose of the illustrative exercise of this paper, to the following.

I. Attempt to prevent the expected lowest biomass of krill over a 20-year harvesting period from falling below 60% of its average unexploited level.

The 60% figure given may be criticised as being somewhat arbitrary. But this "arbitrariness" needs to be viewed in the context of the equally near-arbitrary level of some of the targets conventionally adopted for fisheries management elsewhere in the world. For example, data are seldom adequate to allow estimation of the fraction of the mean unexploited biomass level at which MSY (in an average sense) is achieved; use of the 50% figure that corresponds to the Schaefer model is little more than a convenient and conventional assumption in most situations. The important point to note about the 60% figure put forward is that it is LARGER than the MSY level usually assumed for assessments of relatively short-lived prey species.

This objective is naturally not the only one appropriate for a developing krill fishery. Two other considerations that should sensibly also be addressed (within the constraint of I. above) are as follows.

II. Aim to obtain as large a total catch as possible over a 20-year harvesting period.

III. Minimise the chance that a TAC reduction becomes necessary during a 20-year harvesting period.

Naturally objectives II. and III. cannot be satisfied simultaneously, and the choice of an appropriate trade-off between them by the management authority would be necessary.

In order to assess the performance of the management procedure in terms of objectives I. to III., quantitative measures need to be specified. The simulation analysis has been used to calculate five statistics which relate to these objectives. Since the analysis is stochastic, the statistics change from one 20-year simulation to the next, so that both the mean and the standard deviation are given for each distribution that has been obtained from the results of a large number of simulations. The five statistics are listed below.

(i) Average annual catch over 20 years: C_{av} (objective II.).

(ii) Catch in twentieth year: C_{20}.

(iii) Biomass after 20 years relative to average unexploited biomass: B_{21}/K.

(iv) Lowest biomass during 20 years, relative to average unexploited biomass: $(B/K)_{min}$ (objective I.).

(v) Average annual probability that a TAC reduction will be made between projection year 6 and year 20 (i.e., number of reductions over this period divided by 15): P_{redn} (objective III.).

(Statistics (ii) and (iii) are not directly relevant to the objectives suggested, but are helpful in interpreting the other results).

6. RESULTS AND DISCUSSION

Calculations were carried out for a variety of combinations of the catch control law parameters C_c (initial ceiling) and c_r (subsequent increase rate). In each case, 1 000 simulations of the 20-year projection period under management were computed, and the means and standard deviations of the resultant distributions were calculated.

Figure 1 shows the distributions of B_{21}/K and $(B/K)_{min}$ for the case of no exploitation at all after the commencement of management (C_c=c_r=0). Note that even in the absence of exploitation, biomass values substantially below the average unexploited level K can occur because recruitment fluctuates from year to year.

Table 1 lists the means and standard deviations of the distributions of the five statistics of interest, for various C_c and c_r values. Certain trends that would be expected are evident in the Table: as either C_c or c_r is increased, C_{av} and C_{20} become larger, P_{redn} increases, but B_{21}/K and $(B/K)_{min}$ decrease. The increase in P_{redn} values is only marked for the largest catch increase rate (c_r) options listed; this in turn leads to corresponding substantial increases in the standard deviations of C_{av} and C_{20} for the largest c_r values. Increases in the standard deviations of B_{21}/K and $(B/K)_{min}$ are scarcely evident as the extent of exploitation is increased, with changes apparent only for the largest c_r values listed.

Figures 2a and 2b compare the distributions of B_{21}/K and $(B/K)_{min}$ in the absence of further exploitation (C_c=c_r= 0) with those for the control law option C_c=2 million tonnes and c_r=15% per annum. Note that the latter option corresponds to objective I) in that the expected $(B/K)_{min}$ value is 60%.

The robustness test of a 50% reduction in the size of the krill resource assumed in the operating model has been carried out for a few of the control law parameter combinations of Table 1 which yielded an expected $(B/K)_{min}$ value close to 60%. The results are shown in Table 2. Where results for two different c_r values are given for a particular C_c value, it is evident that $(B/K)_{min}$ shows greater sensitivity when the larger of the two c_r values is used.

If the choice of a specific management procedure were to be made on the basis of the results in Table 2 (in reality, of course, a considerable number of robustness tests would need to be carried out), such a choice would probably lie between the two control law options (C_c=1 million tonnes; c_r=15%) and (C_c=2 million tonnes; c_r=10%). The latter provides a larger total catch over the period considered, but at the expense of a greater likelihood that the TAC will fail to show steady growth, as a result of TAC decreases being implemented in some years.

7. CONCLUDING REMARKS

Obviously there is scope for further analyses along the lines illustrated above, if the approach suggested is considered to have potential in respect of the development of an operational management procedure for krill in Subareas 48.1, 48.2 and 48.3. It is, however, important to consider the relative priority for attention to be given to each of the four components of the process:

(i) the assessment method (the "estimator");

(ii) the catch control law;

(ii) the operating model and robustness tests for performance evaluation; and

(iv) the interpretation of Article II to provide operational definitions of management objectives.

Further developments with respect to (i) and (ii) might be carried out most effectively by individual researchers, for reporting at future CCAMLR meetings. However, if their efforts are to be focussed effectively, progress first needs to be made on components (iii) and (iv). Component (iv) falls within the purview of CCAMLR's Working Group for the Development of Approaches to Conservation of Antarctic Marine Living Resources, and the pertinent sections of this paper are offered as a contribution to their further deliberations. Component (iii) would seem to be most appropriately addressed by the Working Group on krill. It is most desirable that there should be some general agreement on the operating model and robustness tests to be used to evaluate the performance of candidate operational management procedures **BEFORE** further attempts are made to develop and investigate such procedures.

The management procedure discussed in this paper is very simple and uses a minimum of data (only CPUE). Does this mean that other information ("ancillary data") regarding krill and its predators in the region concerned is of no consequence in the formulation of management decisions, and that these decisions would become effectively automated? Exactly the same question has arisen in the IWC's Scientific Committee in the context of its investigation of alternative management procedures. The remarks of that Committee's Sub-Committee on Management Procedures (IWC, 1989b) seem (in a broad sense) to be equally appropriate to krill as to whale management:

> "In terms of the development of alternative management procedures, the Sub-Committee recognised that it is possible in principle to augment a management procedure to allow for the planned collection and analysis of at least some types of ancillary data. However, it strongly believed that it would never be possible to develop a grand all-encompassing procedure that could handle internally all relevant possible types of ancillary data. Indeed, it rejected the concept of a management procedure that accepted data in one end and produced a single unassailable and unalterable assessment out the other end (42?).
>
> Rather, the Sub-Committee believed that it would always be necessary for the Scientific Committee to exercise its scientific judgement in providing stock assessment advice to the Commission. Even after a management procedure has been adopted by the Commission as a result of this current development process, the Scientific Committee and the Commission should weigh the import of other data available for a stock, which have not been used explicitly in the management procedure, against the assessment generated by that procedure. However, that being said, the Sub-Committee emphasised that the primary purpose of developing an alternative management procedure

that was as robust as possible to uncertainties in data and violations in assumptions, was to minimise the chances of it producing inappropriate assessment advice. The Sub-Committee believed that in the normal course of events, the catch limit produced by the management procedure should be accepted unchanged by the Committee, and that the catch limit should only be varied in the face of very strong contrary evidence from ancillary data."

ACKNOWLEDGEMENTS

Helpful discussions with Denzil Miller (Sea Fisheries Research Institute, South Africa), and particularly his suggestions on sources for estimates of various parameters used in the operating model, are gratefully acknowledged. Jane De Decker (University of Cape Town) kindly prepared the Figures.

GLOSSARY

This glossary provides a list of the symbols used in the main text of the paper, together with their definitions, for the convenience of readers. It does not include symbols which occur in the Appendix only; the definitions of such symbols may be found in the Appendix itself.

y	"Year" (i.e., fishing season index).
CPUE	"Composite Index" of krill abundance suggested by CCAMLR (1989b).
CPUE(y)	CPUE in year y.
$CPUE_{ref}$	Average value of CPUE over the first five years of operation of the management procedure.
$CPUE_{tar}$	Target CPUE which is set as a fraction (0.75) of $CPUE_{ref}$; the decision to increase, maintain or decrease the TAC depends on how many of the CPUE values for the previous three years fell below $CPUE_{tar}$ (see equation (2)).
C_c	Initial TAC ceiling imposed during the first five years of operation of the management procedure.
c_r	Annual percentage increase of the TAC which may be permitted after the first five years of operation of the management procedure.
C_y [or C(y)]	TAC in year y.
C_{av}	Average annual catch over the first 20 years of operation of the management procedure $$\left(\sum_{y=1}^{20} C_y/20 \right)$$
C_{20}	TAC in twentieth year of operation of the management procedure.
B	Exploitable krill biomass at the start of year y (subsequently termed "biomass").

K | Average biomass in the absence of any harvesting.

B_{21}/K | Biomass after 20 years of operation of the management procedure, as a proportion of K.

$(B/K)_{min}$ | Minimum biomass during 20 years of operation of the management procedure (i.e., $\min(B_1, B_2, \ldots, B_{20})$), as a proportion of K.

P_{redn} | Number of occasions between years y=6 and y=20 that the TAC is reduced, divided by 15.

REFERENCES

ANON. 1986. Post-FIBEX Acoustic Workshop. *BIOMASS Report Series No. 40*: 106.

BEDDINGTON, J.R. and J.G. COOKE. 1983. The potential yield of fish stocks. *FAO Fish. Biol. Tech. Pap. 242*: 47.

BERGH, M.O. and D.S. BUTTERWORTH. 1987. Towards rational harvesting of the South African anchovy considering survey imprecision and recruitment variability. *S. Afr. J. mar. Sci. 5*: 937-951.

BRINTON, E. and A.W. TOWNSEND. 1984. Regional relationships between development and growth in larvae of Antarctic krill, *Euphausia superba*, from field samples. *J. Crust. Biol. 4* (1): 224-246.

BUTTERWORTH, D.S. 1988. A simulation study of krill fishing by an individual Japanese trawler. In: *Selected Scientific Papers, 1988 (SC-CAMLR-SSP/5)*. Hobart, Australia: CCAMLR. pp. 1-108.

CCAMLR. 1989a. Report of the First Meeting of the Working Group on Krill (Southwest Fisheries Centre, La Jolla, California, USA, 14-20 June 1989). SC-CAMLR-VIII/4. pp. 41.

CCAMLR. 1989b. Report of the Workshop on the Krill CPUE Simulation Study (Southwest Fisheries Centre, La Jolla, USA, 7-13 June 1989). *SC-CAMLR-VIII/3*. pp. 57.

CLARK, C.W., A.T. CHARLES, J.R. BEDDINGTON and M. MANGEL. 1985. Optimal capacity decisions in a developing fishery. *Mar. Resource Econ. 2*(1): 25-53.

DE LA MARE, W.M. 1984. On the power of catch-per-unit-effort series to detect declines in whale stocks. *Rep. int. Whal. Commn* 34: 655-661.

EVERSON, I. 1984. Areas of seabed within selected depth ranges in the south-west Atlantic and Antarctic Peninsula regions of the Southern Ocean. Cambridge: British Antarctic Survey. pp. 20.

ICES. 1988 Report of the Workshop on Methods of Fish Stock Assessment (Reykjavik, Iceland, 6-12 July 1988). *ICES Document C.M. 1988/Assess: 26*. pp. 117.

ICSEAF. 1989. Report of the *ad hoc* Working Group on Stock Assessment Methodology (METH) (Madrid, Spain, 23-28 June 1989). *Document ICSEAF/89/METH/11*. pp. 51.

IWC. 1988. Comprehensive Assessment Workshop on Management (Reykjavik, Iceland, 23-25 March 1987). *Rep. int. Whal. Commn 38*: 163-70.

IWC. 1989a. Comprehensive Assessment Workshop on Management Procedures (Lowestoft, UK, 6-10 February 1989). *Rep. int. Whal. Commn. 41* (special issue 11): 29-44.

IWC. 1989b. Report of the Sub-Committee on Management Procedures (Annex E of the Report of the Scientific Committee, San Diego, May 1989). *Rep. int. Whal. Commn.* 41. (In press.)

LAWS, R.M. 1977. Seals and whales of the Southern Ocean. *Phil. Trans. Roy. Soc. London Ser. B 279*: 81-96.

LUBIMOVA, T.G., R.R. MAKAROV, V.V MASLENNIKOV, V.V. SHEVTSOV and K.V. SHUST. 1982. The ecological peculiarities, stocks and rôle of *E. superba* in the trophic structure of the Antarctic ecosystem. In: *Selected Papers Presented to the Scientific Committee of CCAMLR, 1982-1984, Part II.* Hobart, Australia: CCAMLR. p. 391-505.

LINHART, H. and W. ZUCCHINI. 1986. *Model Selection.* New York: John Wiley & Sons. pp. 301.

MILLER, D.G.M. 1989a. The relationship between krill (*Euphausia superba*) fishing areas in the west Atlantic and the species' circumpolar distribution. SC-CAMLR-VIII/Background paper. pp. 6.

MILLER, D.G.M. 1989b. Commercial krill fisheries in the Antarctic. In: *Selected Papers Presented to the Scientific Committee of CCAMLR, 1989.* Hobart, Australia: CCAMLR. p. 229-281.

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill (*Euphausia superba Dana*): a review. *BIOMASS Sci. Ser. No. 9*: 166.

MORRIS, D.J., J.L. WATKINS, C. RICKETTS, F. BUCHHOLTZ and J. PRIDDLE. 1988. An assessment of the merits of length and weight measurements of Antarctic krill *Euphausia superba. Br. Antarct. Surv. Bull. 79*: 27-50.

NAGANOBU, M. 1986. A proposal for stock biomass estimate of *Euphausia superba* Dana by the environmental index Q_{200} in comparison with Hampton's method. *Memoirs of National Institute of Polar Research Special Issue 40*: 194-196. (Extended abstract).

NAGANOBU, M. and T. HIRANO. 1982. Geographical distribution of the Antarctic krill, *Euphausia superba*, and its environmental structure. *Memoirs of National Institute of Polar Research Special Issue 23*: 1-4. (Extended abstract).

ROSENBERG, A.A., J.R. BEDDINGTON and M. BASSON. 1986. Growth and longevity of krill during the first decade of pelagic whaling. *Nature* 324 (6093): 152-154.

SIEGEL, V. 1987. Age and growth of Antarctic Euphausiacea (Crustacea) under natural conditions. *Mar. Biol. 96*: 483-495.

Table 1: Results from a 20-year projection of the krill operating model. The means and standard deviations (in parenthesis) over 1 000 stochastic simulations are given for a variety of catch control law parameter values. All biomass units are million tonnes.

Ceiling on catch for first five years	Subsequent annual catch increase	Average annual catch over 20 years		Catch in 20th year		Final/Average unexploited biomass		Lowest/Average unexploited biomass		Average annual prob. quota reduction made	
C_c	$C_r(\%)$	C_{av}		C_{20}		B_{21}/K		$(B/K)_{min}$		P_{redn}	
0	0	Unexploited				0.99	(0.21)	0.70	(0.09)	[0.015	(0.052)]
0.5	5	0.67	(0.04)	0.96	(0.14)	0.98	(0.21)	0.69	(0.09)	0.016	(0.053)
	10	0.94	(0.11)	1.86	(0.39)	0.97	(0.23)	0.69	(0.09)	0.012	(0.047)
	15	1.37	(0.23)	3.49	(0.96)	0.94	(0.21)	0.68	(0.09)	0.013	(0.048)
	20	1.97	(0.48)	6.14	(2.21)	0.89	(0.21)	0.67	(0.09)	0.016	(0.048)
	25	2.92	(0.88)	10.46	(4.62)	0.80	(0.21)	0.65	(0.09)	0.019	(0.053)
	30	4.31	(1.53)	16.84	(8.93)	0.68	(0.26)	0.59	(0.12)	0.024	(0.056)
1.0	5	1.34	(0.09)	1.93	(0.26)	0.96	(0.22)	0.69	(0.09)	0.015	(0.048)
	10	1.86	(0.24)	3.62	(0.87)	0.93	(0.21)	0.68	(0.09)	0.017	(0.055)
	15	2.66	(0.50)	6.59	(2.11)	0.89	(0.23)	0.66	(0.09)	0.017	(0.055)
	20	3.88	(0.97)	11.62	(4.62)	0.79	(0.23)	0.62	(0.10)	0.021	(0.059)
	25	5.44	(1.80)	17.32	(9.41)	0.67	(0.28)	0.56	(0.12)	0.031	(0.065)
2.0	5	2.67	(0.17)	3.84	(0.54)	0.92	(0.20)	0.66	(0.09)	0.016	(0.052)
	10	3.69	(0.49)	7.11	(1.78)	0.86	(0.21)	0.64	(0.09)	0.019	(0.053)
	15	5.15	(1.06)	12.24	(4.49)	0.76	(0.22)	0.60	(0.10)	0.024	(0.057)
	20	7.05	(1.92)	16.93	(8.99)	0.64	(0.26)	0.50	(0.13)	0.041	(0.072)
4.0	5	5.31	(0.38)	7.54	(1.19)	0.86	(0.20)	0.61	(0.09)	0.021	(0.064)
	10	7.16	(1.10)	13.03	(4.14)	0.74	(0.22)	0.56	(0.10)	0.033	(0.070)
	15	9.25	(2.08)	16.42	(8.16)	0.62	(0.26)	0.46	(0.13)	0.057	(0.080)

Table 2: Sensitivity of the results of 20-year projections of the krill operating model to the size assumed for the krill resource. A duplicate set of results is shown for each choice of catch control law parameter values: the first is for the original model as reported in Table 1; the second corresponds to halving the assumed average unexploited biomass (and hence productivity) of the krill resource.

Ceiling on catch for first five years C_c	Subsequent annual catch increase $C_r(\%)$	Average annual catch over 20 years C_{av}		Catch in 20th year C_{20}		Final/Average unexploited biomass B_{21}/K		Lowest/Average unexploited biomass $(B/K)_{min}$		Average annual prob. quota reduction made P_{redn}	
0.5	20	1.97	(0.48)	6.14	(2.21)	0.89	(0.21)	0.67	(0.09)	0.016	(0.048)
		1.92	(0.50)	5.71	(2.37)	0.79	(0.22)	0.62	(0.10)	0.021	(0.059)
	25	2.92	(0.88)	10.46	(4.62)	0.80	(0.21)	0.65	(0.09)	0.019	(0.053)
		2.78	(0.86)	9.05	(4.61)	0.65	(0.27)	0.56	(0.12)	(0.025	(0.042)
1.0	15	2.66	(0.50)	6.59	(2.11)	0.89	(0.23)	0.66	(0.09)	0.017	(0.055)
		2.61	(0.52)	6.22	(2.26)	0.76	(0.23)	0.60	(0.10)	0.025	(0.060)
	20	3.88	(0.97)	11.62	(4.62)	0.79	(0.23)	0.62	(0.10)	0.021	(0.059)
		3.54	(1.00)	8.74	(4.68)	0.63	(0.25)	0.51	(0.13)	0.039	(0.068)
2.0	10	3.69	(0.49)	7.11	(1.78)	0.86	(0.21)	0.64	(0.09)	0.019	(0.053)
		3.57	(0.53)	6.43	(2.05)	0.73	(0.21)	0.56	(0.10)	0.035	(0.071)
	15	5.15	(1.06)	12.24	(4.49)	0.76	(0.22)	0.60	(0.10)	0.024	(0.057)
		4.60	(1.08)	8.09	(4.09)	0.62	(0.26)	0.46	(0.13)	0.060	(0.080)
4.0	5	5.31	(0.38)	7.54	(1.19)	0.86	(0.20)	0.61	(0.09)	0.021	(0.064)
		5.16	(0.46)	6.91	(1.46)	0.70	(0.21)	0.50	(0.09)	0.047	(0.087)

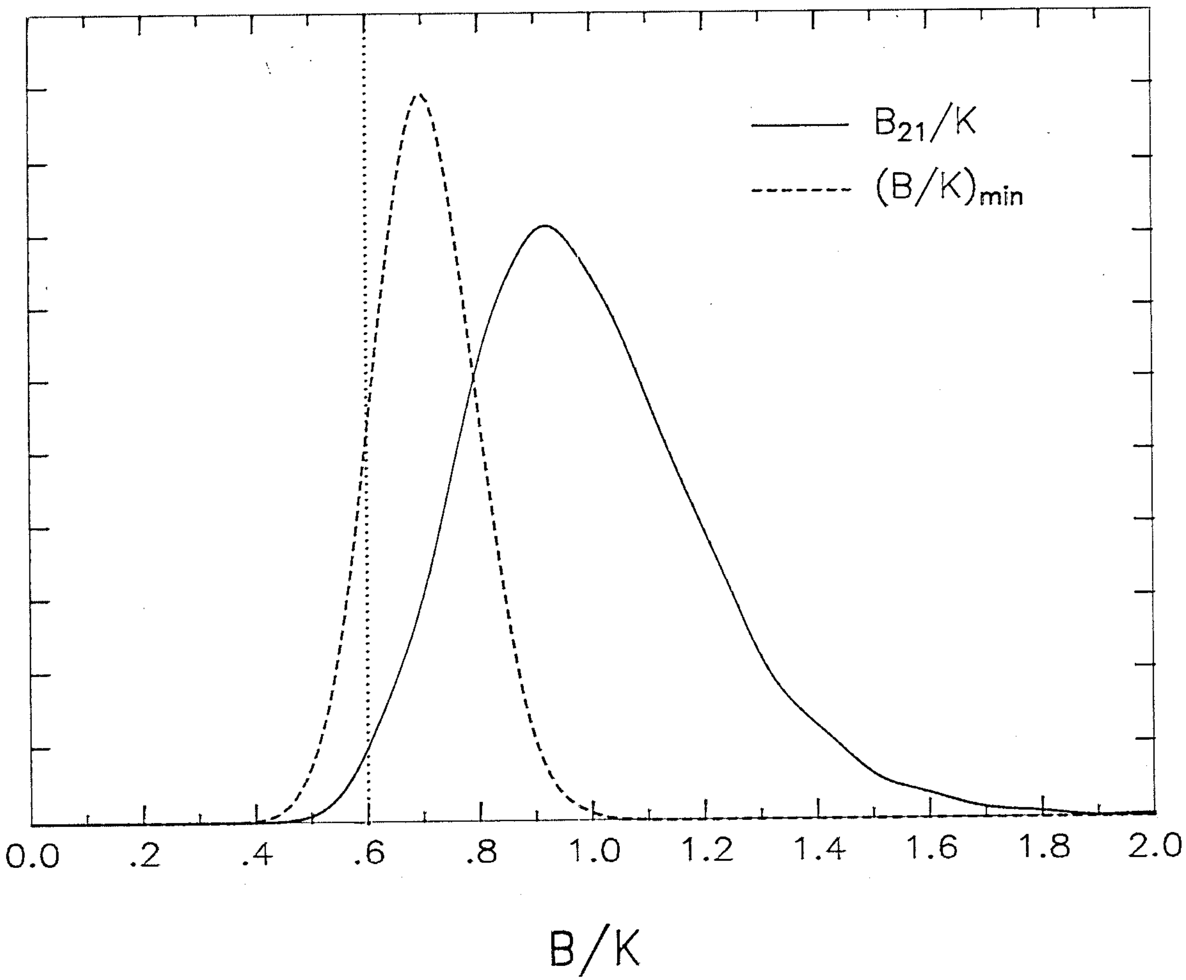


Figure 1: Biomass distributions relative to the average unexploited population size (K) are shown for the case of no exploitation after the management procedure comes into operation (C_c=c_r=0). The solid curve shows the distribution of the biomass after the 20 year period considered: B_{21}/K. The dashed curve shows the distribution of the lowest biomass over this period: $(B/K)_{min}$.

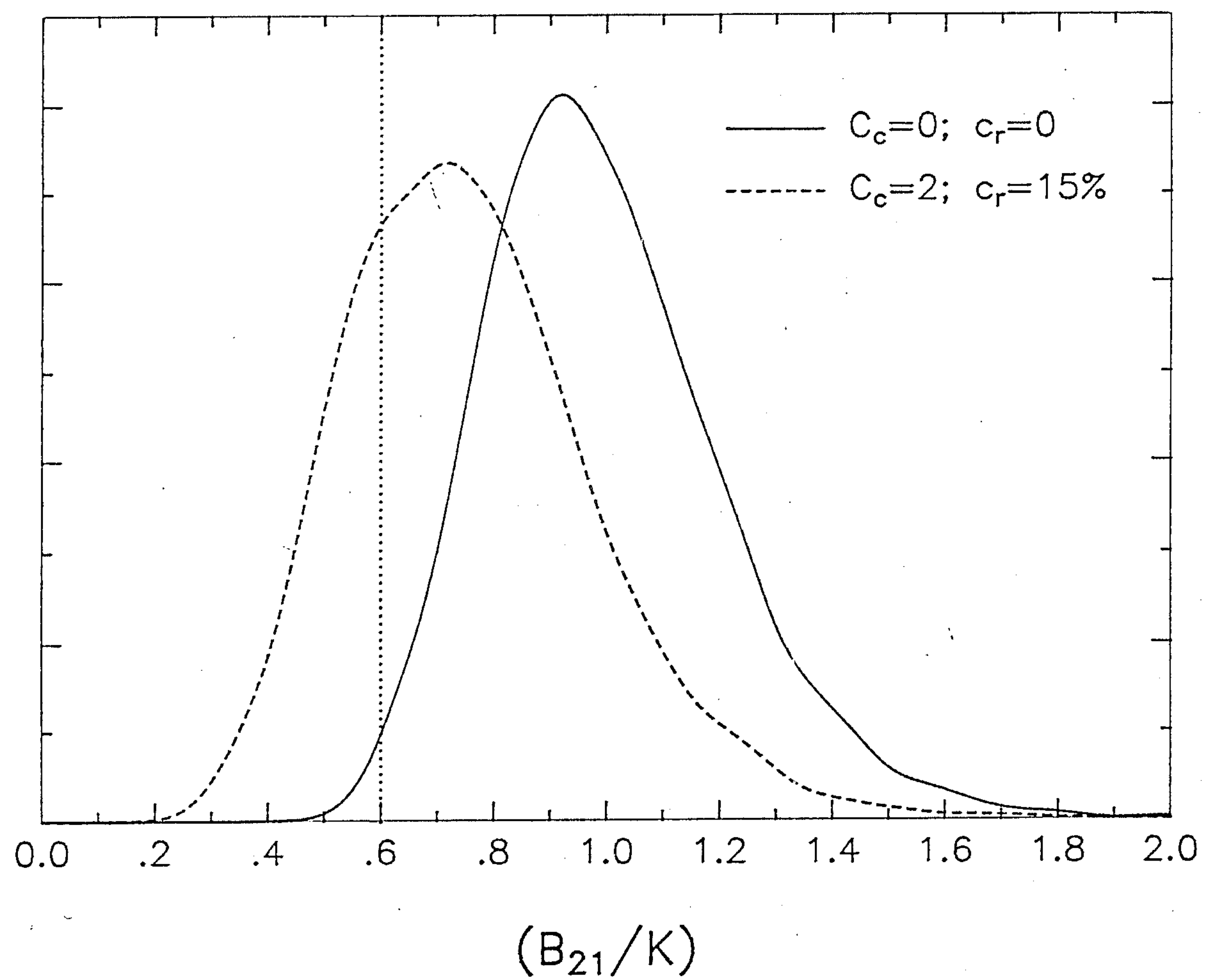


Figure 2a: The distribution of B_{21}/K for the case of no exploitation after the management procedure comes into operation (C_c=c_r=0) (solid curve) is compared with that for the catch control law with C_c=2 million tonnes and c_r=15% per annum (dashed curve).

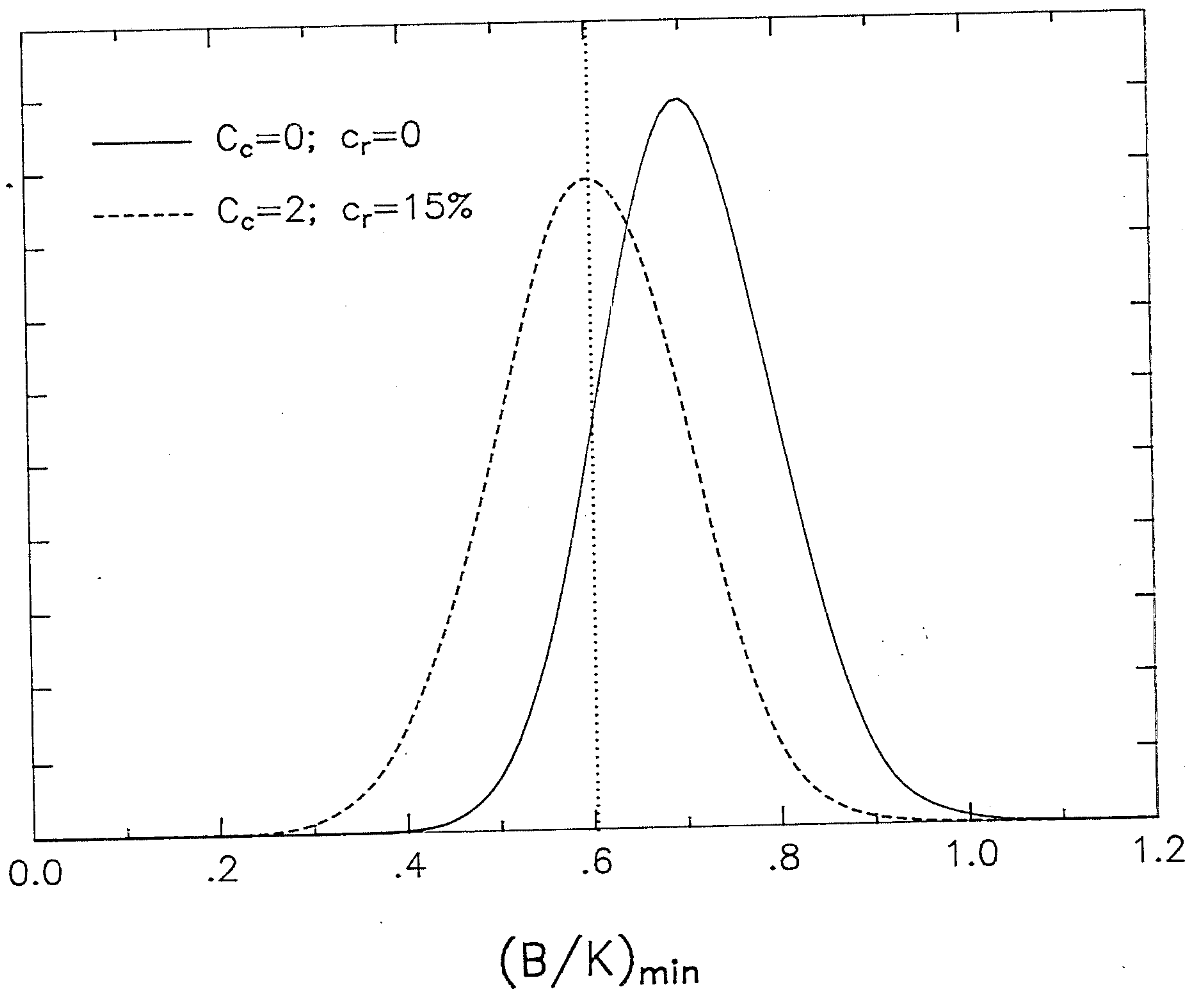


Figure 2b: As for Figure 2a, except that distributions of $(B/K)_{min}$ are shown for the two sets of catch control law parameter values in question.

[Note: The distribution curves were produced by smearing the results of 8 000 simulation runs using a normal kernel. The standard deviation of the kernel was set at 0.04 throughout, which was found necessary to produce reasonably smooth results for the B_{21}/K distribution. This choice means that the standard deviations of the $(B/K)_{min}$ distributions are inflated by about 10% in the Figures; the corresponding inflation of the B_{21}/K distributions is negligible.]

Liste des tableaux

Tableau 1: Résultats du modèle opérationnel du krill sur une projection de 20 ans. Les moyennes et les écarts-types (entre parenthèses) sur 1 000 simulations stochastiques sont donnés pour diverses valeurs des paramètres de la loi de contrôle des captures. Toutes les unités de biomasse sont en millions de tonnes.

Tableau 2: Sensibilité des résultats du modèle opérationnel du krill à la taille présumée pour les ressources de krill, sur une projection de 20 ans. Deux séries de résultats sont données pour chaque choix de valeurs des paramètres de la loi de contrôle des captures : la première correspond au modèle original ainsi qu'il était rapporté dans le tableau 1; la deuxième correspond au partage en deux de la moyenne supposée de la biomasse non-exploitée des ressources de krill.

Liste des figures

Figure 1: Les distributions de la biomasse, relatives à la taille moyenne de la population non-exploitée (K), sont montrées pour le cas où il n'y aurait pas d'exploitation après la mise en place de la procédure de gestion (C_c=c_r=0). La courbe en trait plein montre la distribution de la biomasse après la période de 20 ans considérée: B_{21}/K. La courbe en tirets montre la répartition de la biomasse la plus basse pour cette période : $(B/K)_{min}$.

Figure 2a: La distribution de B_{21}/K, pour le cas où il n'y a pas d'exploitation après la mise en place de la procédure d'administration (C_c=cr=0) (courbe en trait plein), est comparée avec celle de la loi de contrôle des captures, avec C_c=2 millions de tonnes et c_r=15% par année (courbe en tirets).

Figure 2b: Identique à la Figure 2a, à l'exception des distributions de $(B/K)_{min}$ qui sont données pour les deux séries de valeurs des paramètres de la loi de contrôle des captures en question.

[Nota. - Les courbes de distribution ont été produites en lissant les résultats de 8000 cas de simulation, en utilisant un noyau normal. L'écart-type du noyau a été fixé à 0.04 tout au long de la procédure, ce qui a été prouvé nécessaire pour produire des résultats raisonnablement lisses pour la distribution B_{21}/K. Ce choix signifie que les écarts-types des répartitions $(B/K)_{min}$ sont réhaussés d'environ 10% dans les figures; la hausse correspondante des distributions de B_{21}/K est négligeable.]

Список таблиц

Таблица 1: Результаты 20-летнего прогнозирования, полученные посредством прогона рабочей модели динамики криля. Средние значения и величины стандартного отклонения (в скобках) за 1000 стохастических прогонов приводятся для ряда параметров ограничения вылова. Биомасса в миллионах тонн.

Таблица 2: Чувствительность результатов 20-летнего прогнозирования посредством прогона рабочей модели динамики криля к принятой величине запаса криля. Для каждого выбранного параметра ограничения вылова приводятся два результата:

первая величина была получена при прогоне исходной модели, описанной в Таблице 1; вторая величина соответствует половинному значению предполагаемой доэксплуатационной биомассы (и следовательно продуктивности).

Список рисунков

[Примечание: Кривые распределения были вычислены с помощью распределения результатов 8 000 прогонов модели при нормальном ядре. Стандартное отклонение ядра при всех прогонах было установлено на уровне 0,04, что было необходимо для получения достаточно однородных результатов вычислений распределения B_{21}/K. Данный выбор означает, что величины стандартного отклонения распределения $(B/K)_{min}$ на рисунках увеличены приблизительно на 10%; соответствующим увеличением распределения B_{21}/K можно пренебречь.]

Lista de las tablas

Lista de las figuras

Figura 1: Se muestran las distribuciones de la biomasa en relación al tamaño medio de la población sin explotar (K), cuando no hay explotación, una vez que el procedimiento de administración ha entrado en efecto ($C_c = c_r = 0$). La curva continua muestra la distribución de la biomasa después del período de 20 años considerado: B_{21}/K. La curva quebrada muestra la distribución de la biomasa de menor tamaño durante este período: $(B/K)_{min}$.

Figura 2a: La distribución de B_{21}/K cuando no hay explotación, una vez que el procedimiento de administración ha entrado en efecto ($C_c = c_r = 0$) (curva continua) se compara con aquella para la ley de control de pesca con C_c=2 millones de toneladas y c_r=15% por año (curva quebrada).

Figura 2b: Igual que Fig. 2a, con la excepción de que se muestran las distribuciones de $(B/K)_{min}$ para los dos conjuntos de valores de parámetros de ley de control de pesca.

[Nota: Las curvas de distribución se obtuvieron uniformando los resultados de 8 000 simulaciones usando una distribución normal. La desviación estándar de la distribución normal se fijó en 0.04 para toda la operación, la cual se encontró necesaria para producir resultados más o menos uniformes para la distribución B_{21}/K. Esto significa que en las figuras, las desviaciones estándar de las distribuciones $(B/K)_{min}$ están abultadas en un 10% aproximadamente; el abultamiento correspondiente a la distribución B_{21}/K es insignificante.]

AN OPERATING MODEL FOR KRILL DYNAMICS IN SUBAREAS 48.1, 48.2 AND 48.3

1. FORMULATION

Basic Dynamics:

$$N_{y+1,a+1} = \begin{cases} N_{y,a}e^{-M} & 0 \le a < 3 \\ N_{y,a}(1-F_y)e^{-M} & 3 \le a \le 7 \end{cases} \quad \text{(A1)}$$

where $N_{y,a}$ is the number of krill of age a at the start of year (fishing season) y,
F_y is the fishing mortality in year y, and
M is the natural mortality.

Stock-Recruit Relationship:

$$N_{y,0} = \begin{cases} R\exp(\varepsilon_y) & B_y \ge 0.2K \\ (B_y/K)\,R\exp(\varepsilon_y) & B_y \le 0.2K \end{cases} \quad \text{(A2)}$$

where $B_y = \sum_{a=3}^{7} w\, N_{y,a}$ (A3)

$K = R\exp(\sigma_r^2/2) \sum_{a=3}^{7} w_a\, e^{-Ma}$ (A4)

ε_y from $N(0; \sigma_r^2)$

$N(0; \sigma^2)$ is a normal distribution of zero mean and variance σ^2, and

w_a is the mass of krill of age a,

(i.e., B is the spawning biomass, here taken to be the same as the exploitable biomass, and K is the average value of the spawning biomass in the absence of exploitation.)

Catch in Mass:

$$C_y = \sum_{a=3}^{7} w_a F_y N_{y,a}$$

$$= F_y B_y \quad \text{(A5)}$$

CPUE-Biomass Relationship:

$$\text{CPUE}(y) = q\sqrt{\tilde{B}_y}\,\exp(n_y) \qquad \text{(A6)}$$

where $$\tilde{B}_y = \sum_{a=3}^{7} w_a N_{y,a}(1-F_y/2) = (1 - F_y/2)\, B_y \qquad \text{(A7)}$$

q is the catchability coefficient, and

n_y from $N(O; \sigma_q^2)$.

2. PARAMETER VALUES AND ASSUMPTIONS

(1) Single Stock

It is assumed that the krill resource in sub-Areas 48.1 + 48.2 + 48.3 can be treated as a single stock for management purposes, and that there is no substantial immigration of krill to or emigration of krill from the region.

(2) Natural Mortality

It is assumed that the natural mortality rate M is independent of both year and age. (Actually, although equations A1 and A4 above make this assumption, the results would be unchanged if M were age-dependent for $a < 3$.)

A value of $M = 0.6\ yr^{-1}$ [calculated from data in Brinton and Townsend, 1984, on the survivorship of animals from age 2 (30 to 43 mm in length) to age 3 and 3+ (44 to 60 mm in length)] was used in the calculations. Appropriate values for M may depend on the particular growth equation used - see (9) below.

(3) Age at Maturity

Knife-edge maturity is assumed, with the age at maturity taken to be 3 years (Siegel, 1987). Equations A2 and A3 could be regarded as making an implicit assumption that the reproductive output of an individual mature krill is proportional to its mass.

(4) Nature of the Fishery

Equations A1 and A5 model the fishery as a pulse fishery at the beginning of the "year". This would seem defensible because krill fishing in Subareas 48.1, 48.2 and 48.3 takes place over a short period each year.

(5) Age-Specific Selectivity

Fishing selectivity is assumed to be knife-edged with a constant value from age 3 upwards. The choice of age 3, which is the same value as assumed for the age at maturity, is partly for calculational convenience. However, it does correspond to a krill length of 47 mm - see (9) below - which does not seem an unreasonable estimate for a "length-at-first-capture". Probably selectivity is not constant with age, but increases somewhat for the older (larger) krill which are preferred by the fishery for most of the krill products.

representation of the North Sea herring spawning biomass - recruitment data. This formulation is also used for management procedure investigations for the South African anchovy resource (e.g., Bergh and Butterworth, 1987).

(7) A Value for Median Recruitment R in Equation A2

The assumptions required here are certainly the most wide-ranging and tenuous of all those made, which is the particular reason why the robustness test carried out in the main text involved the value chosen for this parameter.

One starts with the estimate by Laws (1977) of an annual consumption of 147 million tonnes of krill in the Antarctic by baleen whales since removed, which (to be conservative) is scaled down to 100 million tonnes. Since Subareas 48.1, 48.2 and 48.3 comprise only a part of krill's circumpolar habitat, an appropriate fraction of this figure has to be taken as an estimate of the potential krill surplus production in this region. This fraction is assumed to be given by the ratio of the krill biomass in the region to the circumpolar biomass; Miller (see Appendix 2) gives four different estimates of this ratio, and his central figure of (about) 20% has been used.

Thus whales subsequently removed from the region are assumed to have consumed 20 million tonnes per annum in the past. It is further assumed that those whales "harvested" the krill at close to its MSY level, and this level is taken to be 50% of the average unexploited krill biomass (K). Finally, for computational convenience, it is assumed that the whales exhibited the same age-specific selectivity pattern when feeding on krill as has been assumed in (5) above for the fishery. (There is an apparent inconsistency here, in that the stock-recruitment relationship of equation A2 will result in an MSY level somewhat less than 0.5K. However, equation A2 may be considered to be an approximation to a more dome-shaped function, for which the MSY level is somewhat higher than would be deduced using equation A2.)

The parameter R is then obtained by solving the simultaneous equations:

$$\begin{cases} 0.5K = R\exp(\sigma_r^2/2) \sum_{a=3}^{7} w_a e^{-Ma} (1-F)^{a-3} \\ C = F\,(0.5K) \end{cases} \qquad \text{(A8)}$$

where C = 20 million tonnes. Given values for the other parameters as specified above and below, the results are:

$$\begin{cases} R\exp(\sigma_r^2)e^{-3M} = 2.7 \times 10^{12} \text{ recruits to the fishery} \\ C = 63 \text{ million tonnes} \end{cases} \qquad \text{(A9)}$$

(8) A Value for σ_R

Recruitment has been assumed to fluctuate log-normally about its median value from one year to the next. These deviations from the median are assumed to be independent (i.e.,auto-correlation is assumed to be zero). The extent of these fluctuations is given by the value of σ_R. The analysis has assumed $\sigma_R = 0.4$. This value is reasonably central over the wide range of values estimated for a large number of populations of marine species world-wide (Beddington and Cooke, 1983).

(i.e.,auto-correlation is assumed to be zero). The extent of these fluctuations is given by the value of σ_R. The analysis has assumed $\sigma_R = 0.4$. This value is reasonably central over the wide range of values estimated for a large number of populations of marine species world-wide (Beddington and Cooke, 1983).

(9) Values for Mass-at-Age w_a

The growth curve fitted by Rosenberg, Beddington and Basson (1986):

$$l_a = 60[(1 - \exp(-.45a)] \text{ mm} \qquad \text{(A10)}$$

was used to provide length-at-age values. Since this curve was fitted assuming that growth takes place over a short summer season only, the average length ($\bar{l}_a$) of krill of age a at the start of the season was taken to be:

$$\bar{l}_a = 0.5 \, (l_a + l_{a+1}) \qquad \text{(A11)}$$

It should be noted that use of different growth curves may imply different values for M, with faster growth corresponding to larger M - see 2) above.

These lengths were converted into masses by use of a relationship from Morris, Watkins, Ricketts, Buchholz and Priddle (1988):

$$w = 3.39 \times 10^{-6} \, l^{3.23} \quad \text{(w: gm; } l\text{: mm)} \qquad \text{(A12)}$$

The resultant masses-at-age (in gm) used were: $w_3 = 8.7$; $w_4 = 11.7$; $w_5 = 14.0$; $w_6 = 15.6$; $w_7 = 16.7$.

Contributions of krill of age 8 or more were ignored in the analysis.

(10) Catch Series

The time series of catches used is as follows:

(i) Years y = -9 to 0: Fixed historic catch: $C_y = 0.4$ million tonnes.
(ii) Years y = 1 to 5: Fixed catch at initial ceiling level: $C_y = C_c$.
(iii) Years y = 6 to 20: C_y given by control law of equation (2) in main text.

The simulations assume that the TAC set by the control law is always caught. Given the TAC and B_y, equation A5 can be used to calculate the fishing mortality F_y, and then equation A1 applied to provide the dynamic response of the resource. Care must be taken that $F_y < 1$ (i.e., that the TAC set is in fact available for capture); however, no instances of $F_y \geq 1$ occurred in the computations carried out for this paper.

(11) CPUE - Biomass Relationship

The definition of $\tilde{B}_y$ in equation A7 allows for the fact that the krill biomass will be reduced by the fishery during the course of the season, since CPUE would be related to some average level of the biomass over the season.

The exponent of $\tilde{B}_y$ in equation (A6) must be less than 1 if CPUE is to drop by proportionally less if biomass decreases. Little basis is available for the specific numerical choice of 0.5 (i.e., a square root relationship); an improved basis for the choice will require more data and research regarding the "Composite Index" (Anon,

(12) A Value for σ_q

The form of equation A6 implies that the variance about the CPUE-biomass relationship is dominated by catchability fluctuations. These are assumed to be independent from one year to the next, and log-normally distributed.

Simulation studies (e.g., Butterworth, 1988) have provided some indication of the size of the sampling variance contribution to equation A6, but such an analysis is not yet available for the "Composite Index" (Anon., 1989b). However, the size of the sampling variance will decrease as the catch taken grows, so that it seems likely that catchability fluctuations will be the dominant contributor to the overall variance.

The value of $\sigma_q = 0.2$ chosen is a "typical" figure. For example, de la Mare (1984) found that the coefficients of variation (approximately equal to σ_q) for 42 whale CPUE series were typically in the range 0.2 to 0.5. Fits of population models to CPUE data for four hake stocks off Southern Africa yield values of σ_q from 0.12 to 0.16 (A.E. Punt, pers. commn).

THE RELATIONSHIP BETWEEN KRILL (*EUPHAUSIA SUPERBA*) FISHING AREAS IN THE WEST ATLANTIC AND ITS CIRCUMPOLAR DISTRIBUTION

D.G.M. Miller*

1. INTRODUCTION

At its recent meeting in La Jolla, the CCAMLR Working Group on Krill recognized a number of difficulties inherent in the assessment of krill abundance and distribution throughout the Convention Area (SC-CAMLR-VIII/4). Historically, however, as more than 90% of the commercial krill catch has been taken from within Statistical Area 48, the Working Group agreed that the task of assessing krill distribution and abundance can be reduced to manageable proportions by initially focusing on the areas (particularly Subareas 48.1, 48.2 and 48.3) being fished.

Despite agreement that current catch levels are unlikely to be having much impact on the circumpolar krill population, the Working Group was unable to give any indication whether or not the present krill catch is having an adverse impact on local predators. For this reason, the Working Group recommended that krill catches should not greatly exceed current levels, at least until assessment methods are developed to provide reliable estimates and more is known about requirements of predators in relation to local krill availability. Consequently, the need to develop more suitable procedures for assessing krill distribution/abundance was recognized as important and was encouraged by the Working Group.

2. MATERIALS AND METHODS

The geographical extent of Subareas 48.1, 48.2 and 48.3 (from which more than 90% of historical krill catch has been taken (Miller, 1989b) was originally calculated by Everson (1984). In this study, the size of the following four regions was calculated (Figure 1):

(a) CCAMLR Convention Area;

(b) area south of 55°S;

(c) area containing krill concentrations (as defined by Lubimova *et al.*, 1982); and

(d) area south of the mean summer position of the 0°C isotherm (as defined by Naganobu and Hirano, 1982).

These regions were considered to represent four possible limits for the global distribution of krill (Naganobu, 1986; Miller and Hampton, 1989) and their size was calculated using a specially developed computer program based on a Lambert Geographical Projection.

The FIBEX (First International BIOMASS Experiment) mean krill density estimate for the west Atlantic sector of the Southern Ocean (Anon., 1986) was extrapolated to give a global biomass of krill within each of these four regions. Similarly, the FIBEX maximum krill density estimate for the West Atlantic was used to obtain an upper limit for the biomass of krill in the three subareas of Statistical Area 48.

* Sea Fisheries Research Institute, Private Bag X2, Roggebaai 8012, South Africa

3. RESULTS

The size of different subareas of Statistical Area 48 and corresponding estimates of krill biomass are given in Table 1. The rest of the table presents calculated areas and corresponding estimates of krill biomass in the regions of possible global limits of krill distribution described above.

By comparing krill biomass in different subareas of Statistical Area 48, where historically more than 90% of krill catches is taken, it has become evident that some evaluation of the impact of present catch levels on krill resources in these subareas is required.

A possible surplus of krill circumpolar productivity resulting from a reduction in stocks of large baleen whales, could be estimated conservatively at around 100 million tonnes (based on a figure of 147 million tonnes given by Laws, 1977). Since Subareas 48.1, 48.2 and 48.3 comprise only a part of the circumpolar krill resource, an appropriate fraction of this surplus productivity has to be taken into account in the calculation of the availablekrill biomass in Statistical Area 48. This fraction is given by the ratio of the krill biomass in Statistical Area 48 to the circumpolar biomass and was estimated at about 20% based on the figures presented in Table 1. The value 20% has been used in the Operational Model of Krill Dynamics in Subareas 48.1, 48.2 and 48.3 developed by Butterworth (see main paper).

It is clear that the implication of the range of evaluations presented in Table 1 merits further discussion, particularly within the type of analysis undertaken by Butterworth (this volume). At this stage we did not draw any other conclusions in order to avoid pre-empting such discussions.

Table 1: Size of various regions of the Southern Ocean and their estimated krill biomass.

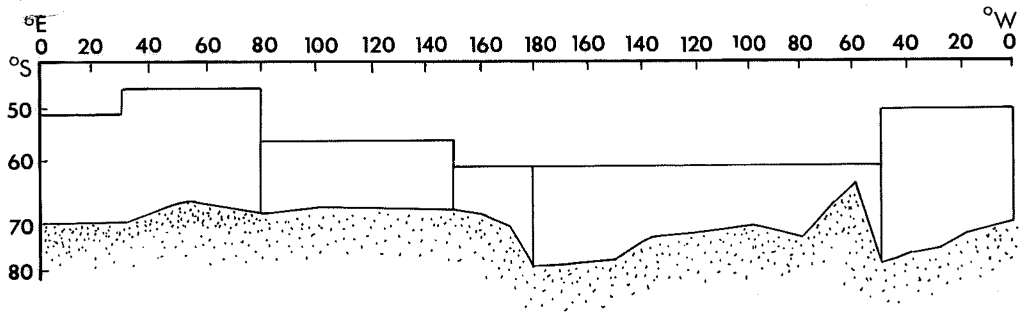
Region	Area km² x 10^3	Krill Density g/m²	Ratio Areas Fished to Circumpolar Range (%)	Krill Biomass tonnes x 10^6
Subareas fished				
48.1	922.987	*4.46	-	4.12
48.1 W	592.156	*4.46	-	2.64
48.1 E	330.831	*4.46	-	1.48
48.2	850.997	*4.46	-	3.79
48.3	1341.672	*4.46	-	5.98
Total size of areas fished				
	3115.656	*4.46	-	13.89
		**31.65	-	98.61
Circumpolar ranges of krill distribution				
CCAMLR Convention Area				
	33419.845	*4.46	9.32	149.05
Area south of 50°S				
	31697.702	*4.46	9.83	141.37
+Area of krill concentrations				
	4126.749	*4.46	75.50	18.40
+Area south of 0° C isotherm				
	16123.469	*4.46	19.32	71.91

* FIBEX mean density estimate (from Table X in Anon., 1986)

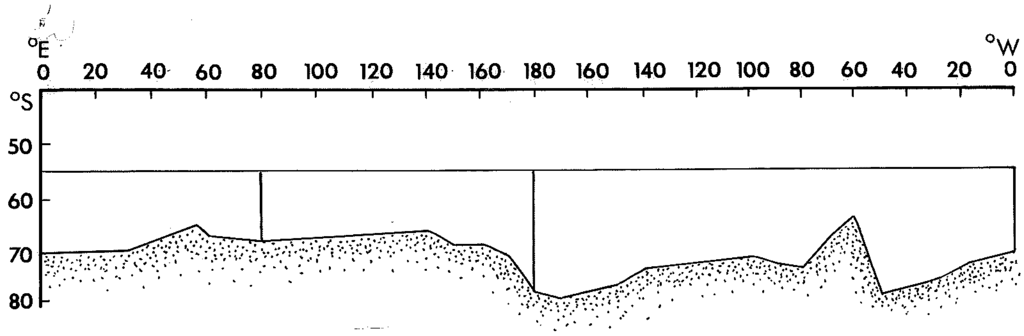
** FIBEX maximum density estimate (from Table VII in Anon., 1986)

\+ For practical purposes these areas can be considered to circumscribe Subareas 48.1, 48.2 and 48.3 completely.

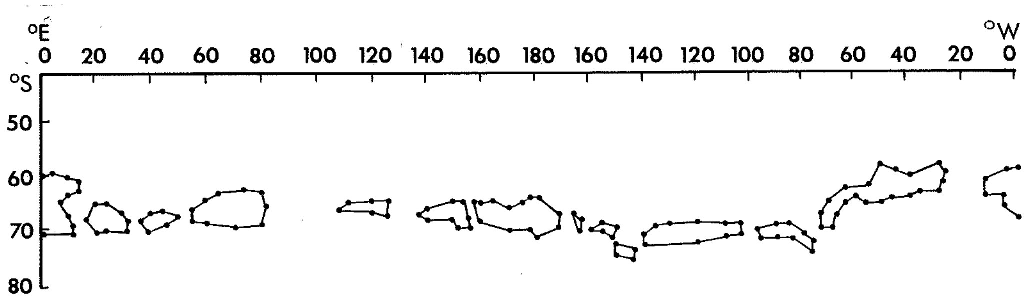
(a) CCAMLR Convention Area



(b) Area south of 55°S



(c) Area of krill concentration (after Lubimova *et al.*,1982)



(d) Area south of the 0°C isotherm (after Naganobu and Hirano, 1982)

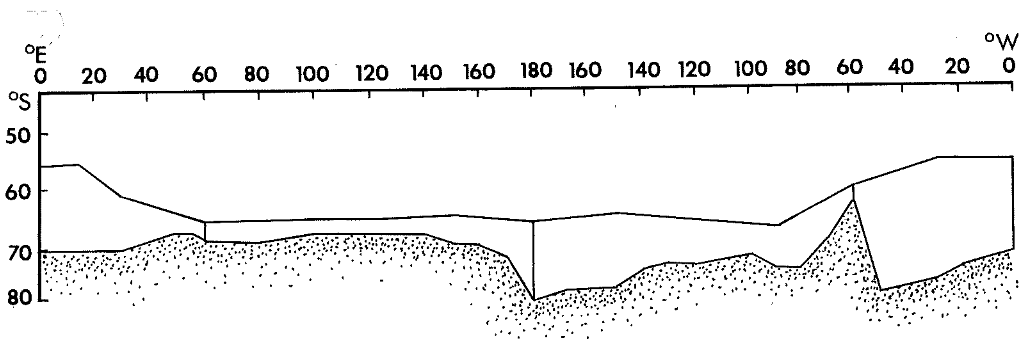


Figure 1: Various regions of ocean considered in the estimation of the global distributional range of krill.

II. ANTARCTIC FISH

WG-FSA-90/13

ANALYSIS OF RESULTS FROM DEMERSAL FISH SURVEYS AT SOUTH GEORGIA, UNDERTAKEN BY THE UNITED KINGDOM AND THE USSR, JANUARY AND FEBRUARY 1990

(Report of a Joint UK/USSR Workshop, 23 to 27 July 1990)

Abstract

The report describes discussions and analyses of the data from a survey from MV *Hill Cove* in January 1990 and RV *Akademik Knipovich* in February 1990 around South Georgia. Both surveys were characterized by large numbers of small hauls interspersed with a few large catches. The small number of large catches cause a disproportionate increase in the estimated standing stock of *Champsocephalus gunnari*. The paper describes the ways in which these large hauls were considered in the analysis. No ideal method was found for incorporating the large hauls into the analysis.

Résumé

Ce rapport décrit les discussions et les analyses des données provenant d'une campagne d'évaluation effectuée à bord du navire marchand *Hill Cove* en janvier 1990 et du navire de recherche *Akademik Knipovich* en février 1990 autour de la Géorgie du Sud. Les deux campagnes étaient caractérisées par de nombreux petits chalutages entrecoupés de quelques captures importantes. Le nombre restreint de captures importantes cause une augmentation disproportionnée de l'évaluation du stock existant de *Champsocephalus gunnari*. Ce document décrit les différentes manières selon lesquelles l'analyse traite ces chalutages importants. Aucune méthode idéale n'a été décelée pour incorporer ces grands traits dans l'analyse.

Резюме

Настоящий отчет описывает обсуждение и анализ данных, полученных судном *Hill Cove* в январе 1990 г. и НИС *Академик Книпович* в феврале 1990 г., в районе Южной Георгии. Для обеих съемкок было характерно получение множества небольших уловов и лишь нескольких крупных уловов. Небольшое количество крупных уловов вызвало непропорциональное завышение оценки биомассы *Champsocephalus gunnari*. В данном документе описывается, каким образом данные по крупным уловам учитывались при анализе. Идеального метода включения данных по крупным уловам в анализ найдено не было.

Resumen

Este informe trasunta los debates y análisis de la información obtenida de una prospección realizada alrededor de Georgia del Sur por el BI *Hill Cove* en enero de 1990 y por el BI *Akademik Knipovich* en febrero de 1990. Ambas prospecciones se caracterizaron por la vasta cantidad de lances pequeños mezclados con pocas capturas voluminosas. Estas últimas fueron la causa de un aumento desproporcionado en la estimación de la biomasa permanente de *Champsocephalus gunnari*. Este documento describe como se consideraron estos lances voluminosos en los análisis, pero no se logró encontrar un método ideal para incorporar estos lances en los análisis.

---

1. INTRODUCTION

The workshop was held at Renewable Resources Assessment Group, Imperial College, London from 23 to 27 July 1990.

The following participated in the workshop: I. Everson (Convener and Rapporteur), M. Basson, G. Parkes, M. Bravington (part of the time: C. Jones) from the UK and P. Gasiukov and K. Shust from the USSR. Interpretation was provided by Irina Kirillova and Alan Parfitt.

The Convener welcomed participants and outlined the general aims of the workshop which were to analyze the results from the UK survey using the trawler *Hill Cove* (January 1990) and the USSR research vessel *Akademik Knipovich* (February 1990) so as to provide biomass estimates for the major fish stocks at South Georgia.

Dr Shust reported that the *Akademik Knipovich* had only returned to Sevastopol at the end of May 1990 and this had left little time in which to prepare for this workshop. He and his colleagues in the USSR were very keen to see improved collaboration between the respective national groups and had worked very hard in preparation for the workshop. Data had been provided to the UK in the formats requested, in advance of the workshop, and a report describing the survey was tabled. Copies of survey logsheets were also available. The Convener, on behalf of the group, thanked Dr Shust and his colleagues for their efforts.

The data from the *Hill Cove* survey had been sent to USSR in advance of the workshop and a report, in preparation for the next CCAMLR Working Group on Fish Stock Assessment meeting, was abstracted to provide a description of the UK survey.

A draft agenda had been circulated in advance of the workshop and this was agreed with minor modifications. The agenda as adopted is given in Annex 1.

2. DATA

Data from both surveys were available for the workshop and were loaded onto computer. These data included station lists and positions, catch and sample data. No age data were available because samples had not been fully analyzed.

3. DESCRIPTION OF SURVEYS

Both surveys had been undertaken in accordance with the design submitted by Dr Everson in December to CCAMLR. The survey area was divided into 27 rectangles half a degree of latitude by one degree of longitude, as are the CCAMLR fine-scale reporting areas. The area was stratified into three depth strata: 50 to 150, 150 to 250, 250 to 500 metres. A description of the allocation of stations is given in Paper 2 and the planned survey design in Annex 2.

Even though nearly all the haul positions for this design were taken from previous surveys, it had been the experience of both ships that on arrival at these positions the ground was found to be unsuitable for trawling. Alternative locations within the same depth stratum were therefore fished. Both surveys had encountered a great deal of difficulty in the area to the southern part of the west shelf (squares 19 and 20).

The reports of the two surveys were discussed separately.

3.1 *Akademik Knipovich*

GRT	3 000 tonnes
Power	2 000 hp
LOA	89 m

Details of the trawl net used for the survey were not available at the workshop. These were to be forwarded to the Convener as soon as possible. The dimensions of the net had been measured during a previous cruise. These calibrations were used to estimate net dimensions during the survey. The width of the net was estimated to vary from 20 to 22 m and the headline height from 5 to 6.5 m.

All hauls were described as 'Control hauls'. These are not repeated hauls but normal hauls within the specified series.

All hauls were intended to last for 30 minutes at a speed of 3 to 3.5 knots. Hauls were frequently terminated early due to rough ground. Most hauls were made during daylight although, when time became short, some were made after dark.

Catches were sorted into species on board immediately following the haul. In the case of small catches, all the catch had been sorted. For large catches, greater than 2 tonnes, a sub-sample was taken for biological sampling while the remainder of the catch was processed in the factory. The total weight of each species was determined from the amount of frozen products produced in the factory.

Samples for length distribution and biological sampling were obtained from random sub-samples from the catch. Sex was not determined from fish used in the length frequency samples.

Three adjacent hauls in rectangles 17 and 12 were not part of the original design (Annex 2) and their purpose was questioned. Dr Shust suggested that the intended location may have been unsuitable and that one at least might be the only ground on which it was possible to trawl in the vicinity.

The large haul of 23 tonnes had been made on a known concentration, as implied in the text of Paper 1 and it was a random haul within the predetermined survey design.

Information was presented about the USSR research vessel *Anchar* which has conducted another bottom trawl survey. The survey design is based on different principles of stratification. Trawling was only undertaken during daylight. Detailed information will be presented at the 1991 meeting of the CCAMLR Working Group on Fish Stock Assessment.

3.2 *Hill Cove*

GRT	1 591 tonnes
Power	2 000 hp
LOA	60 m
Beam	13.1 m

The intended towing speed was 3 to 3.5 knots over the ground. This was not always possible due to wind and tidal effects. A few hauls were made at 4 or even 5 knots and it was questioned whether the net would have fished efficiently on the bottom at these speeds. It was confirmed that evidence from net damage and the seabed polishing the bobbins indicated that the net had fished efficiently.

Although most of the hauls were made during daylight a significant proportion were made after dark. It was suggested that this might have some effect on the catch rate as some species, particularly *Champsocephalus gunnari*, tend to migrate off the bottom at night.

The catch was sorted on the factory deck. Small catches, generally less than 2 tonnes, were sorted completely by species into baskets. All of these were analyzed unless there was a very large number of small fish of similar size in the catch in which case a minimum of 100 individuals was measured.

Sub-samples of several baskets were taken from large catches. These sub-samples were fully analyzed. The total catch was determined from the proportion of the fish in the sub-samples to the number of the baskets in the total catch.

It was agreed that the report of the *Hill Cove* survey to be tabled in 1991 at the meeting of the CCAMLR Working Group on Fish Stock Assessment, would include maps showing the species distribution over the surveyed area.

There was some discussion on Coefficients of Variation.

4. DISTRIBUTION OF MAJOR SPECIES

4.1 *Champsocephalus gunnari*

Summarizing results from the *Akademik Knipovich* survey Dr Shust reported that *C. gunnari* was widespread around South Georgia but was only present in dense concentrations at some locations. These areas of high concentration were on the northern side of the west end of the island, near the shelf break west-southwest of the Willis Islands and around Shag Rocks. Around South Georgia the largest catches tended to be in the 150 to 250 m depth stratum. Dr Shust felt that there was a tendency for smaller fish to be present in the shallower depth stratum (50 to 150 m).

Dr Shust mentioned the results from previous surveys and concluded that there had been some redistribution of major concentrations over the shelf during the past five years. He felt that there was some tendency for the fish to migrate within Subarea 48.3 with the larger fish moving over greater distances.

The results from the *Hill Cove* survey indicated a broadly similar pattern of distribution around the island.

Samples had been taken for electrophoretic analysis. Preliminary results indicated that there may be separate populations at Shag Rocks and also that there may be evidence of separate populations being present around South Georgia. This study, being undertaken by Dr G. Carvalho at Bangor University, is likely to be expanded next season.

Dr Shust drew the attention of the group to similar studies on krill undertaken by the USSR. Initial results had indicated the presence of several populations but subsequent research had shown this not to be the case.

The results from the *Hill Cove* and *Akademik Knipovich* surveys had shown an essentially similar pattern of spatial distribution with low concentrations being present over much of the shelf, but relatively few large concentrations. It was thought that the presence of concentrations at more or less the same location on the two surveys, one month apart, gave some support to the view that there may be more than one stable concentration present.

There was some discussion on the vertical migration patterns of *C. gunnari*.

Dr Gasiukov showed a series of echocharts, obtained by an AtlantNIRO ship on an earlier survey, that indicted that the fish were very close to the bottom during the day but tended to migrate clear of the seabed after dark. Mr Parkes and Dr Shust also reported seeing the same phenomenon on Furuno colour video displays. Dr Everson reported that he was hoping to quantify this effect during a future survey planned for January 1991.

It was agreed that survey results from Shag Rocks should be analyzed separately from those from the mainland of South Georgia. It was also agreed that time of day should be taken into account in analyzing the data.

4.2 *Dissostichus eleginoides*

Both surveys had indicated that this species is present around Shag Rocks. The *Hill Cove* survey had caught large numbers of small specimens and both vessels had caught larger specimens there. Isolated large individuals were found around South Georgia on the *Hill Cove* survey although *Akademik Knipovich* made a large catch in the vicinity of Clerke Rocks.

The main distribution of this species is known to extend down to at least 1 000 m and it is also known to be semi-pelagic, hence bottom trawl surveys are likely to grossly underestimate its biomass.

4.3 *Patagonotothen brevicauda guntheri*

This species was only caught at Shag Rocks. None have been reported from South Georgia on previous surveys and Dr Shust stated that commercial catches had only been made in the vicinity of Shag Rocks.

Dr Shust also noted that the largest concentrations were generally made earlier in the season in November to January.

4.4 Other Species

Notothenia gibberifrons, *Pseudochaenichthys georgianus* and *Chaenocephalus aceratus* were found to be widespread over the shelf on South Georgia. Few large catches were reported. *Hill Cove* caught 600 kg of *C. aceratus* to the south-west of South Georgia; these may have been feeding on the small *C. gunnari* present at the same location. *Akademik Knipovich* had only two hauls of this species greater than 100 kg.

5. ESTIMATION OF BIOMASS

All analyses were undertaken in parallel by USSR and UK scientists at the workshop and the results cross-checked to ensure consistency. Major discrepancies are recorded in the narrative of the report.

5.1 Swept Area Method

It was agreed that the standard swept area method described by Saville (1977) would be used for the first analyses.

5.2 Estimation of Biomass of *Champsocephalus gunnari*

There was some discussion on the way in which data should be grouped for the analyses. It was agreed that Shag Rocks data should be treated separately to those from the mainland of South Georgia. The following other models were agreed:

Determine biomass

Model 1 within fine-scale rectangles and by depth strata. The biomass would then be the sum of all rectangle and depth stratum values.

Model 2 within fine-scale rectangles irrespective of depth.

Model 3 within each depth stratum over the whole of the two areas (South Georgia and Shag Rocks).

Results from applying model 1 are given in Table 1 (*Hill Cove*) and Table 2 (*Akademik Knipovich*). These are summarized below:

Ship	Shag Rocks		South Georgia	
	Biomass	N	Biomass	N
Hill Cove	111 459	9	74 271	59
Akademik Knipovich	71 700	13	1 301 588	70

Reference to Table 1 indicates that 65% of the estimated biomass at Shag Rocks from the *Hill Cove* survey is present in the shallowest depth stratum of grid square 3. This was due to a single haul of 40 tonnes. Similarly in Table 2, 92% of the estimated biomass at South Georgia from the *Akademik Knipovich* survey is present in the 150 to 250 m depth stratum of grid square 8. This was due to one haul of 23 tonnes. It was felt that these large hauls were exerting an excessive influence on the biomass estimate and therefore warranted different analytical procedures. This is discussed further later.

The small number of hauls within each depth stratum and grid square, in many cases only one, meant that for many combinations of grid square and depth it was impossible to estimate variance for this model.

In view of these limitations to the analysis it was decided not to proceed further with this approach. The other two approaches provide for much larger sample sizes within each grouping and hence allow an estimation of variance to be made.

Applying model 2, analysis by grid square, gave the following summary results:

Analysis by Mr Parkes						
Ship	Shag Rocks			South Georgia		
	Biomass	N	CV (%)	Biomass	N	CV (%)
Hill Cove	278 431	8	83	75 576	59	79
Akademik Knipovich	121 680	13	34	597 424	70	79

Analysis by Dr Gasiukov						
Ship	Shag Rocks			South Georgia		
	Biomass	N	CV (%)	Biomass	N	CV (%)
Hill Cove	378 233	8	12	76 141	59	63
Akademik Knipovich	154 208	13	34	726 386	70	79

Discrepancies were noted between the results of the analyses performed by Mr Parkes and Dr Gasiukov using model 2. The source of this discrepancy was the result of differences in the interpretation of model 2. The equations that were used are given below:

Mr Parkes:

$$\hat{B} = \Sigma_s \hat{B}_s = \Sigma_s \left[\left[\sum_{i=1}^{n_s} C_i/A_i \right] A_s/n_s \right]$$

Dr Gasiukov:

$$\hat{B} = A\,\bar{x}_{st}$$

where $\bar{x}_{st} = \sum_{h=1}^{H} S_h\,\bar{x}_h / \sum_{h=1}^{H} S_h$

$$\bar{x}_h = 1/N_h \sum_{i=1}^{N_h} x_i^h / S_h i$$

The results after stratification into the three depth strata, model 3, are given in Table 3 and summarized below:

Ship	Shag Rocks			South Georgia		
	Biomass	N	CV (%)	Biomass	N	CV (%)
Hill Cove	278 937	9	83	95 405	59	63
Akademik Knipovich	108 652	13	31	877 817	70	69

Both model 2 and model 3 are strongly influenced by the large hauls mentioned above and it was concluded that they were responsible for the major difference between the biomass estimates from the two surveys. It was ageed that it would be desirable to develop alternative procedures for the analysis of these large hauls.

Table 3 indicates that biomass is strongly influenced by depth and it was agreed that, of the three models considered so far, model 3 provided the best estimator of biomass in the areas of moderate or low catch rates which predominated around the island.

At Shag Rocks there was a difference between the results from the two surveys, with the greatest biomass on the *Hill Cove* survey being present in the 50 to 150 m depth stratum whereas on the *Akademik Knipovich* survey the greatest biomass was in the 150 to 250 m stratum.

6. TREATMENT OF CLOSELY GROUPED HAULS

Concern was expressed that the three adjacent hauls in rectangles 17 and 12 as mentioned in section 3.1 may have been made on the same concentration of fish. If this were the case, it might mean that some form of replication had taken place. There were two schools of thought, one suggesting that the data from the three hauls should be summed and treated as being equivalent to a single long haul, the other that they should be treated as samples of equal status to all others in the survey.

In the absence of further information regarding these hauls it was decided to treat them as part of defined regions within the South Georgia area. This division was made in two ways, the first of which involved defining an area containing all hauls that appear to form a group. This was achieved by using data from four adjacent grid squares 12, 13, 17 and 18 within the 150 to 250 m depth stratum and analyzing these separately from the remainder of the South Georgia data. The second way was to divide the South Georgia area into two, a region of generally higher biomass west of 37° and a lower biomass region east of 37°.

The results from this comparison are set out below. The analyses were made using data from all hauls.

Akademik Knipovich survey, grouping data from grids 12, 13, 17 and 18 into one area and the rest of South Georgia into a second area; stratification by depth strata.		
Biomass of *Champsocephalus gunnari*		
	Grid 12....18	Remainder of South Georgia
150 to 250 m stratum	190 623 (N=12)	734 112 (N=21)
<u>Total biomass for South Georgia</u>		
50 to 150 m stratum		2 740
150 to 250	190 623 + 734 112	924 735
250 to 500		9 363
Total		936 838 N=70 CV=43%

Akademik Knipovich survey divided into east and west South Georgia regions		
East South Georgia		
50 to 150 m	2 030	N=8
150 to 250 m	12 103	N=17
250 to 500 m	4 818	N=12
Total	18 953	N=37 CV=38%
West South Georgia		
50 to 150 m	805	N=7
150 to 250 m	946 536	N=16
250 to 500 m	4 553	N=10
Total	951 895	N=33 CV=70%
South Georgia Total	970 848	N=70 CV=69%

The different systems of stratification do not change the results by more than 5 or 10%. These analyses include results from all hauls.

7. TREATMENT OF LARGE CATCHES

The very strong effect of the large hauls on the *Hill Cove* survey (40 tonnes at Shag Rocks) and *Akademik Knipovich* survey (23 tonnes at South Georgia) can be clearly seen from the results if they are excluded from the analysis. The following results duplicate those in section 6 with the exception that the large haul of 23 tonnes at station 16 has been excluded from the analysis, greatly reducing the estimated biomass.

Akademik Knipovich survey, grouping data from grids 12, 13 17 and 18		
Biomass of *Champsocephalus gunnari*		
	Grid 12....18	Remainder of South Georgia
150 to 250 m stratum	190 623 (N=12)	18 271 (N=20)
Total biomass for South Georgia		
50 to 150 m stratum		2 740
150 to 250 m	190 623 + 18 271	208 894
250 to 500 m		9 363
Total		220 997 N=69 CV=43%

Akademik Knipovich survey dividing survey into east and west South Georgia regions		
East South Georgia		
50 to 150 m	2 031	N=8
150 to 250 m	12 104	N=17
250 to 500 m	4 818	N=12
Total	18 953	N=37 CV=38%
West South Georgia		
50 to 150 m	805	N=7
150 to 250 m	296 861	N=15
250 to 500 m	4 554	N=10
Total	302 220	N=32 CV=49%
South Georgia Total	321 173	N=69 CV=46%

The above analyses exclude data from the large haul of 23 tonnes made at station 16.

A major difference in biomass estimates between the different methods of stratification was noted and it was agreed that this merited further attention.

One of the basic assumptions of the swept area method (SAM) is that the frequency distribution of catches is normal. Both surveys contained a large proportion of hauls where catches were less than 1 tonne and a much smaller number of larger catches with, in each case, one very large catch (Figure 1). It was agreed that for the small catches SAM was valid. It was not thought to be valid for the extremely large hauls. Its validity for the intermediate sized hauls, between about 1 and 10 tonnes, was also questioned.

There was much discussion on this subject and time prevented a full exploration of the possible analyses. However, it was accepted that all large hauls were valid and should be incorporated into the total biomass estimates. The following describes the general approaches that were discussed.

The simplest approach was to treat the highest values as freak occurrence which were not representative of the overall situation but rather represented a local very high biomass. To reduce the effect on the biomass estimate it was suggested that the value be reduced by an order of magnitude. However, it was thought that such an arbitrary reduction would be very unwise as it had no logical basis to support it and, furthermore, might be seen as questioning the techniques of those people engaged in data collection.

An alternative was to treat the extreme values as being unusual examples of hauls of moderate size. The extreme values were therefore replaced with the mean of all hauls greater than 1 tonne but excluding the largest value. The results from this approach are summarized below:

Akademik Knipovich Mean 'large haul' value = 6 393 kg over a towing distance of 1.75 nm		
South Georgia		
50 to 150 m	2 740	N=15
150 to 250 m	321 412	N=33
250 to 500 m	9 363	N=22
Total	333 515	N=70 CV=42%
Shag Rocks		
50 to 150 m	4 439	N=3
150 to 250 m	104 088	N=9
250 to 500 m	124	N=1
Total	108 653	N=13 CV=31%
Hill Cove Mean 'large haul' value = 4 029 kg over a towing distance of 2.0 nm		
South Georgia		
50 to 150 m	1 234	N=8
150 to 250 m	93 502	N=39
250 to 500 m	667	N=12
Total	95 405	N=59 CV=63%
Shag Rocks		
50 to 150 m	51 515	N=5
150 to 250 m	2 676	N=3
250 to 500 m	0	N=1
Total	54 193	N=9 CV=38%

The results, as expected, give a much reduced biomass estimate and also, since the largest values have been reduced, the coefficients of variation are also reduced. In the case of South Georgia this is from 60 to 42% and at Shag Rocks from 83 to 38%.

A second approach was to assume that the extreme hauls were unusual events, and to try to estimate how often such a concentration of fish might occur. Existing swept area methods were used to estimate biomass from all other stations, and then an adjustment was made by first finding the proportion of total swept area covered by the highest density in the middle stratum of western South Georgia, in which all the larger catches were made. This proportion was then multiplied by the density of the haul from station 16, and then by the total seabed area in the middle stratum of western South Georgia. A similar adjustment was made for the *Hill Cove* results at Shag Rocks, but using the whole of the shallowest stratum.

Results: South Georgia, *Akademik Knipovich* survey		
Adjustment for large haul		
Large haul adjustment (LHA): 216 264 = C * A * a16 / sum(a) (in tonnes)		
Catch rate in haul 16 (kg/sq. km)	1 036 036	= C
Seabed area, west South Georgia, 150 to 250 m	10 342.1	= A
Swept area, haul 16	0.0222	= a16
Total swept area, west South Georgia, 150 to 250 m	1.0999	= sum(a)

Akademik Knipovich
Grouping data from grids 12, 13, 17 and 18. Large haul analyzed separately.

Stratum	Grid 12....18	Remainder
150 to 250 m	190 623	18 271
	Total by Stratum	
50 to 150 m	2 740	
150 to 250 m	208 894	
250 to 500 m	9 363	
Total	220 997 (excluding large haul adjustment)	
LHA	216 264	
Total	437 261	

Akademik Knipovich
Survey divided into eastern and western South Georgia. Large haul analyzed separately.

Stratum	Eastern South Georgia
50 to 150 m	2 030
150 to 250 m	12 103
250 to 500 m	4 818
Total East South Georgia	18 951
Stratum	Western South Georgia
50 to 150 m	805
150 to 250 m	296 860
250 to 500 m	4 554
Total West South Georgia	302 220
Total	321 169 (excluding large haul adjustment)
LHA	216 264
Total	537 433

Results: Shag Rocks, *Hill Cove* Survey		
Adjustment for large haul (LHA):		
184 787 = (catch rate, haul 82)*(total seabed area in Shag Rocks, shallow stratum)*(swept area of haul 82)/(total swept area in Shag Rocks, shallow stratum)		
Hill Cove survey: Stratification by depth strata only, excluding haul 82		
Stratum	Shag Rocks, Total by Stratum	
50 to 150 m	44 825	
150 to 250 m	2 677	
250 to 500 m	0	
Total Shag Rocks	47 502	(excluding large haul adjustment)
LHA	184 787	
Total	232 289	

A third approach was to treat all samples as being part of a highly skewed distribution and apply a transformation to the catch rates in order to normalize the distribution. While having considerable merit as an approach, it was recognized some difficulty might be encountered in determining a suitable transformation to apply to the data.

8. DAY/NIGHT DIFFERENCES

It was accepted that the diurnal vertical migration pattern of *C. gunnari* was likely to influence the results from bottom trawl surveys, however time did not permit a thorough examination of the data to quantity the effect.

9. BIOMASS ESTIMATES FOR OTHER SPECIES

With the exception of *Dissostichus eleginoides* where one large haul was made during the *Akademik Knipovich* survey the distribution of catch rates for all other species did not vary widely. It was accepted that, in view of the high catches of *D. eleginoides*, the data from that species should be treated in the same way as those for *C. gunnari* described above. It was agreed that the standard swept area method should be appropriate for these analyses. The results from the two surveys are presented below.

Note: In each column the biomass is given with the percentage CV in brackets.

Species	South Georgia				Shag Rocks			
	Hill Cove		*Akademik Knipovich*		*Hill Cove*		*Akademik Knipovich*	
	Biomass	%CV	Biomass	%CV	Biomass	%CV	Biomass	%CV
C. aceratus	14 226	(37)	14 424	(26)	0		0	
P. georgianus	5 761	(28)	12 200	(28)	37	(73)	0	
N. gibberifrons	12 417	(28)	21 891	(23)	267	(39)	0	
N. rossii	1 481	(76)	3 915	(30)	0		0	
D. eleginoides	335	(39)	3 020*	(33)	9 631	(55)	1 693	(21)
P.b. guntheri	0		0		13 608	(90)	1 918	(45)
N. larseni	590	(23)	0		50	(85)	0	
N. nudifrons	129	(51)	0		46	(62)	0	
N. squamifrons	1 239	(59)	5 977	(98)	120	(44)	414	(55)
Other Species	2 877	(19)	606	(34)	338	(51)	67	(67)

* Excludes large catch from Clerke Rocks

The results, although in some cases showing quite large differences, do demonstrate a reasonable degree of concordance between the two surveys. The general trends in biomass indices between the surveys, with *Akademik Knipovich* providing generally higher values, is followed through the results. The presence of zero as a biomass value indicates that no catch was made of that species by the respective vessel for the area.

The results for *D. eleginoides* are strongly affected by the known distribution of the species as described in section 4.2. It was agreed that bottom trawl surveys should not be used in isolation to provide biomass estimates for this species.

10. CONCLUSIONS

The group concluded that due to the highly skewed nature of the catch distribution it was difficult to determine a suitable index of abundance. The small number of large hauls had caused many analytical problems and the best way of dealing with them had not been finally resolved. Several methods which attempt to deal with these problems were considered. When these methods were applied it was possible to reduce the CVs of estimates of biomass. It was felt that the swept area method, stratified by depth, but excluding the very largest hauls would provide a useful minimum index of biomass. It should be remembered that the relative catching power of each vessel is unknown and therefore both survey estimates are of equal validity.

Possible further spatial stratifications were discussed including a north-south division along latitude 54°.

The evidence for diurnal vertical migration of *Champsocephalus gunnari* indicated that in future, bottom trawl surveys should be conducted in daylight when the fish are closest to the seabed.

The distribution of biomass between depth strata in the South Georgia area follows that of previous surveys, the greatest proportion being present in the middle (150 to 250 m) depth stratum. It was suggested that a more appropriate depth division might be as follows:

50 to 100 m
100 to 200 m
200 to 300 m
300 to 500 m.

It was agreed that this should be investigated using the results from this and previous surveys.

It was agreed that the swept area method alone did not provide a good estimate of biomass for *D. eleginoides* and that for this species other methods need to be taken into consideration.

Lack of time had prevented the participants from investigating the relationship between coefficient of variation and sample size. It was agreed that such analyses should be undertaken so as to plan future surveys more efficiently. Further work was also required on sample sizes and the spatial distribution of sampling stations.

In spite of the short time between the completion of the surveys it was possible to undertake analyses of full datasets at the workshop. This was seen as a most welcome development. All the participants hoped that the cooperative analysis, established at this workshop, could be repeated in the future.

It was also agreed that there is a great deal of merit in collaborating on future surveys at all stages and it was felt that the two surveys this year leading up to this workshop demonstrated that such collaboration was useful not only for the two national groups present but also in the wider context of CCAMLR. The wish was further expressed that such collaboration might also include krill surveys.

11. RECOMMENDATIONS

The group recommended that the CCAMLR fine-scale grid squares should be used as a basis for designing surveys to ensure that the whole area of interest receives adequate coverage.

The group recommended that consideration should be given to designating grid squares within which surveys had suffered significant gear damage and to determining how necessary it was to obtain samples within them.

The swept area method is suitable for widely distributed species that are present in low density. Certain species, particularly *C. gunnari*, do occur in local dense concentrations and the group recommended that attention should be given to designing surveys and analyzing results to take account of this form of distribution.

The group recommended that analyses of survey data should be undertaken in the first instance by depth stratum and major area, such as Shag Rocks, South Georgia in total or in four quandrants.

The group recommended that particular attention should be given to methods of estimating biomass from surveys which contain a small number of unusually large hauls.

The group strongly recommended that collaborative links should be strengthened to allow joint work in the field and in analyzing results as this can only improve the quality of the results.

12. ADOPTION OF THE REPORT

The report of the workshop was adopted.

13. CLOSURE OF THE MEETING

The Convener thanked all participants for their cooperation and efforts and thanked Dr Beddington and the Renewable Resources Assessment Group (Imperial College, London) for hosting the workshop and providing secretarial assistance and computing facilities. He also thanked the interpreters and all colleagues of the UK and the USSR participants, who were involved in preparations for the workshop.

The Convener expressed the wish that similar workshops would be possible in the future and that the recommendations to cooperate and collaborate more fully in future would bear fruit.

Dr Shust extended his thanks, on behalf of the USSR participants, to all involved in the workshop and he supported the Convener's view that the workshop had been very successful.

The Convener closed the meeting.

PAPERS TABLED

1. KOZLOV, A.N. and K.V. SHUST. USSR Fish Stock Assessment Survey Made in Subarea 48.3 in February 1990.

2. PARKES, G. *Hill Cove* Survey Report. (Draft).

REFERENCES

SAVILLE, A. (Ed.). 1977. Survey methods of appraising fishery resources. *FAO Fish. Tech. Pap. 171*: 76.

Table 1: Results of the analysis by grid-square and depth strata (Model 1) of the *Hill Cove* survey.

	N	Biomass	%CV	Total
South Georgia	59	74 271	81	81
Shag Rocks	9	111 459	208	208
Total	68	185 730	208	208

	South Georgia *C. gunnari* Biomass	Shag Rocks *C. gunnari* Biomass
50-150 m		
3	0	72 520
5	0	36 803
8	0	0
9	0	0
14	349	0
15	4	0
21	465	0
25	43	0
25	13	0
150-250 m		
2	0	0
5	0	2 137
8	12 906	0
9	540	0
10	77	0
12	7 467	0
13	457	0
14	988	0
15	266	0
16	669	0
18	49 040	0
19	17	0
20	32	0
21	229	0
22	119	0
24	71	0
25	58	0
26	33	0

Table 1 (continued)

	South Georgia *C. gunnari* Biomass	Shag Rocks *C. gunnari* Biomass
250-500 m		
2	0	0
7	0	0
8	53	0
9	81	0
10	0	0
11	46	0
12	35	0
13	13	0
16	43	0
18	0	0
21	147	0
22	8	0
25	0	0
Total	74 271	111 450

Table 2: Results of the analysis by grid-square and depth strata (Model 1) of the *Akademik Knipovich* survey data.

	N	Biomass	%CV	Total
South Georgia	70	1 301 580	47	47
Shag Rocks	13	71 700	47	47
Total	83	1 373 287	47	47

		South Georgia *C. gunnari* Biomass	Shag Rocks *C. gunnari* Biomass
1.00			
	5.00	0	3 645
	8.00	77	0
	9.00	22	0
	13.00	44	0
	14.00	576	0
	21.00	489	0
	22.00	4	0
	25.00	169	0
	26.00	682	0
2.00			
	2.00	0	23 836
	4.00	0	10 007
	5.00	0	34 380
	8.00	1 199 312	0
	9.00	1 232	0
	10.00	808	0
	12.00	70 794	0
	13.00	2 057	0
	14.00	301	0
	15.00	156	0
	16.00	2 884	0
	17.00	2 352	0
	18.00	5 045	0
	21.00	7 940	0
	22.00	1 392	0
	24.00	81	0
	25.00	125	0

Table 2 (continued)

	South Georgia *C. gunnari* Biomass	Shag Rocks *C. gunnari* Biomass
3.00		
5.00	0	32
8.00	1 853	0
9.00	614	0
10.00	355	0
11.00	168	0
12.00	488	0
14.00	2	0
15.00	238	0
16.00	1 788	0
18.00	406	0
21.00	132	0
25.00	0	0
26.00	0	0
Total	1 301 580	71 700

Table 3: Results of the analysis by depth strata (Model 3) for the *Hill Cove* survey and for the *Akademik Knipovich* survey.

Hill Cove

		N	Biomass	
	South Georgia			
	50-150 m	8	1 234.78	
	150-250 m	39	93 502.84	
	250-500 m	12	667.02	
	Shag Rocks			
	50-150 m	4	276 260.19	
	150-250 m	3	2 676.81	
	250-500 m	1	0.00	
Totals				
		N	Biomass	%CV
South Georgia		59	95 405	63
Shag Rocks		9	278 937	83

Akademik Knipovich

		N	Biomass	
	South Georgia			
	50-150 m	15	2 740.18	
	150-200 m	33	865 712.99	
	250-500 m	22	9 363.36	
	Shag Rocks			
	50-150 m	3	4 439.46	
	150-200 m	9	104 088.00	
	250-500 m	1	124.06	
Totals				
		N	Biomass	%CV
South Georgia		70	877 817	69
Shag Rocks		13	108 652	31

Please Note: The column sums in several tables are not identical to the given totals, due to rounding.

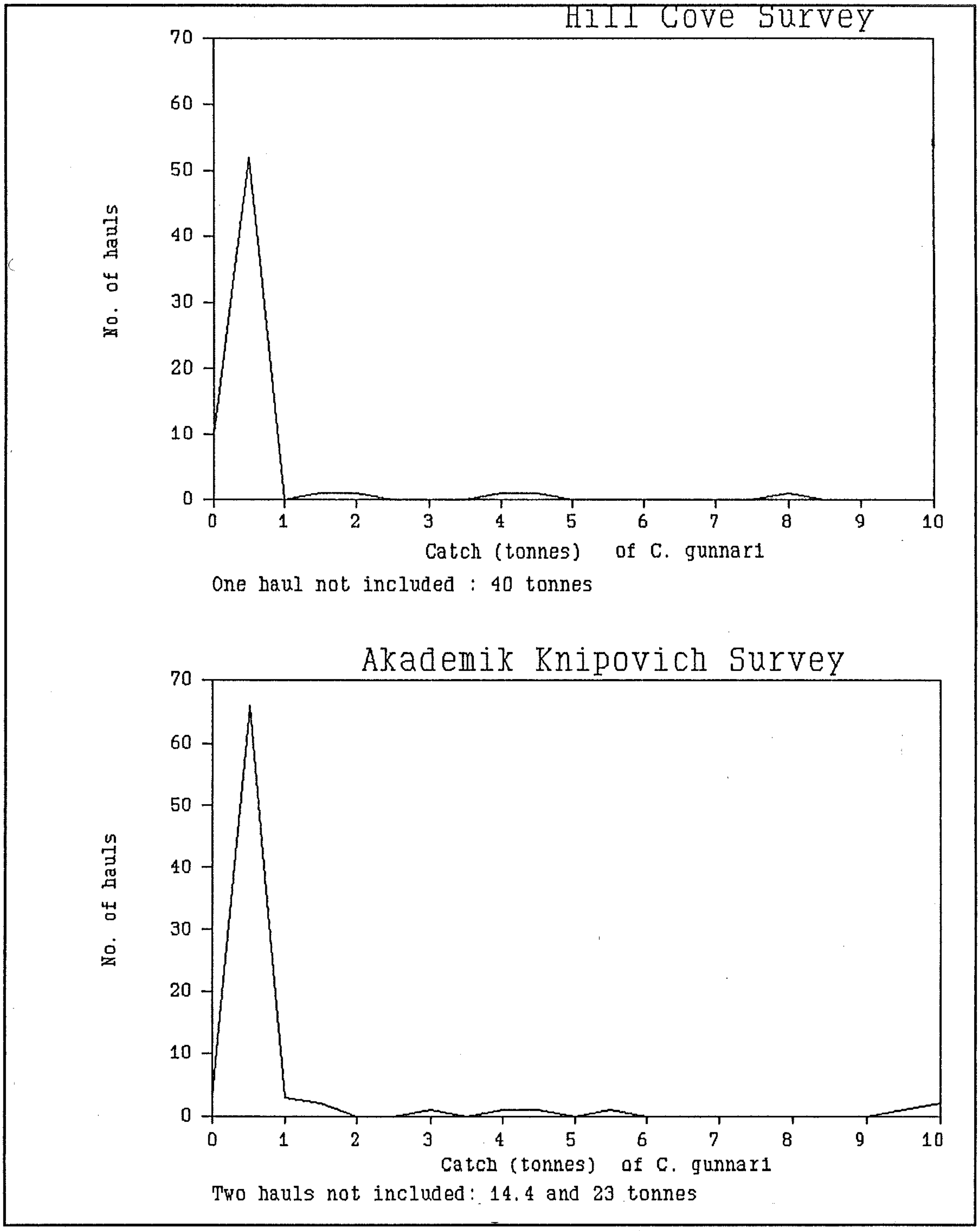


Figure 1: Frequencies (number of hauls) of catches by size (in tonnes) for the *Hill Cove* survey and the *Akademik Knipovich* survey. Note that, in both cases, the horizontal axis has been truncated for presentation; hauls not shown on the graphs are indicated below each figure.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

AGENDA FOR THE UK/USSR WORKSHOP
(23 to 27 July, 1990)

1. Appointment of rapporteur.
2. Check, load onto computer and validate data from both surveys against field data logbooks.
3. Provide a full description of both surveys.
4. Check cruise track data against UK and USSR hydrographic charts.
5. Determine biomass of major species within CCAMLR fine-scale reporting areas (half degree of latitude by one degree of longitude).
6. Determine population structure of the dominant species in the South Georgia area.
7. Assess the effectiveness of current survey techniques and recommend plans for future surveys.
8. Adoption of the report.

PROPOSED SURVEY DESIGN

(Submitted by United Kingdom)

1. Objectives

To estimate the standing stock of demersal fish in the vicinity of South Georgia.

2. Survey Design

The survey area has been divided into sampling rectangles according to the CCAMLR fine-scale data reporting format. These are half a degree of latitude by one degree of longitude and are specified by the coordinates of the rectangle nearest to the equator.

Previous surveys have stratified the sampling by depth within depth ranges 50-150, 150-250 and 250-500 m. The same approach has been adopted for this survey. The area of seabed within depth has been estimated and the values give in Table 1.

Sampling intensity has been determined based on the method of Francis (1984). The estimated values have been slightly adjusted to ensure adequate coverage of all rectangles with more than 200 sq. km of seabed within a depth range. The proposed sampling locations are shown in Table 2.

Depth strata where there is less than 200 sq. km of seabed within a rectangle will be assumed to have the same density as that within the most appropriate adjacent rectangle or rectangles. Decisions as to the most suitable adjacent rectangles to select have been based on the degree of continuity of the relevant depth contour into adjacent rectangles. The proposed system is outlined in Table 3.

3. Sampling Methods

Each sampling section will consist of one representative bottom trawl with the net fishing for 30 minutes on the bottom.

The net used will be essentially the same as that used on the previous surveys undertaken by Poland in conjunction with USA and UK. This is a standard commercial bottom trawl 32/36 with a codend mesh of 80 mm and fitted with a 40 mm liner.

Estimates of total catch, by weight and number, will be made and the catch sampled to provide the length, age, weight and maturity stage composition for each species.

References

FRANCIS, R.I.C.C. 1984. An Adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research, 18*: 59-71.

Table 1: Areas of seabed, South Georgia Subarea 48.3

The areas are presented as square kilometres and assume a total area within each rectangle of 3 548.2 km².

Coordinates of NE Corner		Areas of Seabed Within Depth Ranges (m)					
°S	°W	50-100	100-150	150-200	200-250	250-500	>500
53	43	0.0	0.0	0.0	0.0	12.4	3 536.1
53	42	0.0	0.0	217.8	264.2	507.8	2 558.8
53	41	0.0	26.7	129.2	36.5	52.2	3 303.9
53 30	42	0.0	153.9	215.8	114.7	221.0	2 841.1
53 30	41	0.0	1 049.1	586.4	483.2	310.2	1 118.3
53 30	40	0.0	6.5	59.4	71.1	401.8	3 009.7
53 30	39	0.0	0.0	0.0	170.5	710.1	2 667.9
53 30	38	334.4	340.3	430.8	574.4	420.3	1 448.4
53 30	37	133.4	527.3	781.9	307.7	1 085.0	713.2
53 30	36	0.0	0.0	134.4	1 402.5	885.8	1 125.8
53 30	35	0.0	0.0	0.0	59.7	320.6	3 168.2
54	39	0.0	0.0	114.1	940.3	579.4	1 914.6
54	38	124.9	171.3	1 332.4	1 103.2	797.2	0.0
54	37	181.6	121.9	12.2	11.0	0.0	0.0
54	37 so	250.5	270.6	660.7	485.2	214.5	0.0
54	36	329.2	270.8	391.2	481.9	191.7	0.0
54	36 so	88.2	48.7	29.2	11.0	0.0	0.0
54	35	17.8	83.6	138.1	1 782.5	388.3	1 138.2
54 30	39	0.0	0.0	0.0	245.8	124.1	3 178.6
54 30	38	0.0	0.0	663.0	866.4	418.5	1 600.6
54 30	37	107.9	362.9	732.3	755.0	1 102.4	481.2
54 30	36	355.9	181.1	201.8	1 049.0	362.8	0.0
54 30	35	500.7	527.6	397.4	788.6	1 065.8	95.1
54 30	34	0.0	100.1	259.7	100.1	430.6	2 657.9
55	37	0.0	0.0	10.4	26.0	56.0	3 456.2
55	36	0.0	79.6	171.9	458.7	167.3	2 670.9
55	35	0.0	1 234.8	548.1	960.7	770.3	34.6
55	34	0.0	484.1	183.9	140.6	240.7	2 495.5
55 30	35	0.0	0.0	0.0	0.0	137.8	3 410.7
TOTAL		2 424.5	6 040.76	8 402.15	13 690.5	11 974.6	48 625.4

Table 2: Proposed positions for sampling stations during South Georgia groundfish survey, January 1990.

2a - Sampling stations in vicinity of Shag Rocks

Fine-Scale Grid			Proposed Station Positions		
° Min	° Min				
South	West	Depth	Latitude	Longitude	
53 0	43 0	C	+++	+++	
53 0	42 0	B	53.38	42.30	*
		C	53.33	42.70	*
53 0	41 0	A	+++	+++	
		B	+++	+++	
		C	+++	+++	
53 30	42 0	A	+++	+++	
		B	53.52	42.40	*
		C	53.68	42.35	!
53 30	41 0	A	53.53	41.78	*
		A	53.72	41.57	*
		A	53.62	41.41	**
		B	53.80	41.68	*
		B	53.85	41.25	*
		B	53.77	41.33	**
		C	53.92	41.70	*
53 30	40 0	A	+++	+++	
		B	+++	+++	
		C	53.53	40.81	!

For explanation of symbols see notes following Table 2b.

Table 2 (continued)

2b - Sampling stations in vicinity of South Georgia

Fine-Scale Grid			Proposed Station Positions		
° Min	° Min				
South	West	Depth	Latitude	Longitude	
53 30	39 0	B	+++	+++	
		C	53.89	39.55	
53 30	38 0	A	53.91	38.47	
		B	53.72	38.03	
		B	53.75	38.36	
		B	53.77	38.61	
		C	53.72	38.45	*
53 30	37 0	A	53.80	37.17	
		B	53.68	37.58	
		B	53.70	37.08	*
		B	53.65	37.23	**
		C	53.89	37.27	
53 30	36 0	B	53.90	36.20	
		B	53.90	36.27	
		B	53.77	36.90	
		B	53.71	36.88	
		C	53.71	36.37	
53 30	35 0	B	+++	+++	
		C	53.93	35.83	
54 0	39 0	B	54.12	39.24	
		B	54.03	39.10	*
		B	54.30	39.23	!
		C	54.09	39.28	
54 0	38 0	A	54.11	38.04	**
		B	54.15	38.64	
		B	54.28	38.34	
		B	54.31	38.53	
		B	54.41	38.85	
		B	54.49	38.60	
		C	54.32	38.82	!
54 0	37 0	A	54.24	37.83	
		B	54.36	37.65	
		B	54.30	37.90	
54 0	36 0	A	54.18	36.32	
		B	54.04	36.37	
		B	54.22	36.43	*

Table 2b (continued)

Fine-Scale Grid			Proposed Station Positions		
° Min	° Min				
South	West	Depth	Latitude	Longitude	
54 0	35 0	A	54.99	35.44	
		B	54.10	35.68	
		B	54.15	35.77	
		B	54.30	35.85	
		B	54.47	35.65	*
		C	54.88	35.35	
54 30	39 0	B	54.58	39.17	!
		C	+++	+++	
54 30	38 0	B	54.73	38.57	
		B	54.67	38.35	
		B	54.61	38.07	
		C	54.84	38.33	
54 30	37 0	A	54.55	37.47	*
		B	54.77	37.25	*
		B	54.80	37.03	*
		B	54.85	37.18	**
		C	54.97	37.00	*
54 30	36 0	A	54.55	36.88	*
		B	54.94	36.21	**
		B	54.69	36.96	**
		C	54.97	36.10	!
54 30	35 0	A	54.89	35.69	
		A	54.72	35.54	
		B	54.62	35.21	
		B	54.51	35.83	
		B	54.68	35.31	**
		C	54.43	35.27	
54 30	34 0	A	+++	+++	
		B	54.90	34.98	
		C	54.82	34.90	
55 0	37 0	B	+++	+++	
		C	+++	+++	
55 0	36 0	A	+++	+++	
		B	55.17	36.22	*
		B	55.07	36.28	**
		C	+++	+++	

Table 2b (continued)

Fine-Scale Grid			Proposed Station Positions		
° Min	° Min				
South	West	Depth	Latitude	Longitude	
55 0	35 0	A	55.19	35.39	
		A	55.08	35.35	
		B	55.27	35.92	
		B	55.31	35.37	
		C	55.12	35.92	*
			55.46	35.26	
55 0	34 0	A	55.07	34.96	
		B	55.27	34.85	*
		C	+++	+++	
55 30	35 0	C	+++	+++	

Notes:

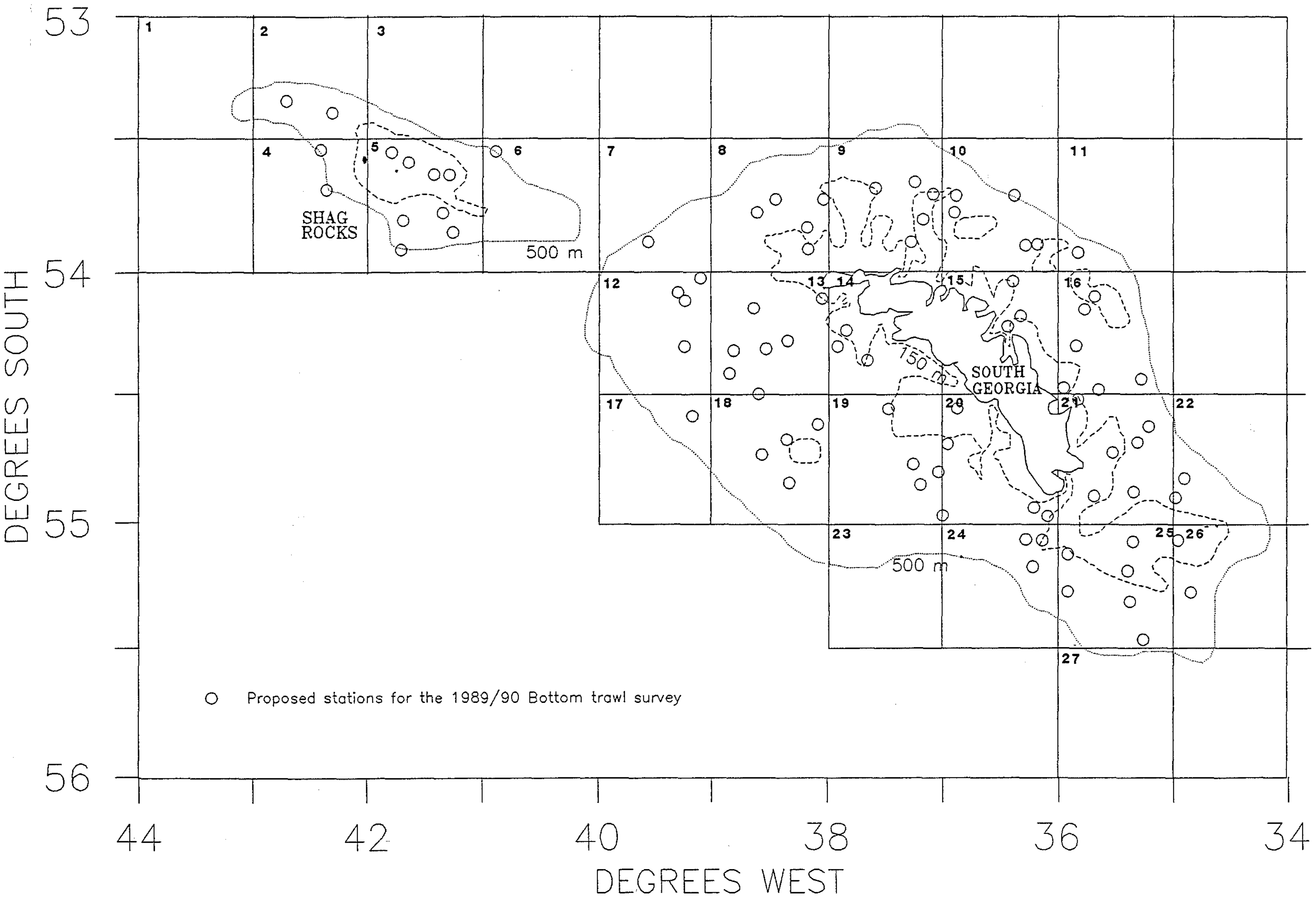
* signifies that a position has been taken from the 1986/87 USA/Polish survey.
** signifies that a position has been taken from the 1987/88 USA/Polish survey.
! signifies that this position has not been sampled before.
+++ +++ signifies that there is some seabed within the depth range but this is insufficient to warrant allocating a sampling station. See Table 3.
No indicator in the final column indicates that the station was sampled during the 1988/89 UK/Polish survey.

The depth ranges are:

A = 50-150 m
B = 151-250 m
C = 251-500 m

Table 3: Density estimates to be used in unsampled rectangles.

Unsampled Rectangle	Depth	Density Derived from:
53 00 43	C	Use value from 53°00'S, 43°W
53 00 41	A	Use mean value from 53°30'S, 41°W
	B	Use mean value from 53°30'S, 41°W
	C	Use value from 53°00'S, 43°W
53 30 42	A	Use mean value from 53°30'S, 41°W
53 30 40	A	Use mean value from 53°30'S, 41°W
	B	Use mean value from 53°30'S, 41°W
54 30 39	B	Use mean value from 53°30'S, 38°W
53 30 35	B	Use mean of all values in 53°30'S, 36°W and 54°00'S, 35°W
54 30 39	C	Use mean of all values in 53°00'S, 39°W and 54°30'S, 38°W
54 30 34	A	Use mean of all values in 55°00'S, 35°W and 55°00'S, 34°W
55 00 37	B	Use mean value from 54°30'S, 37°W
	C	Use mean value from 54°30'S, 37°W
55 00 36	A	Use mean value from 55°00'S, 35°W
	C	Use mean value from 55°00'S, 35°W
55 00 34	C	Use mean of all values in 53°30'S, 36°W and 54°00'S, 35°W
55 30 35	C	Use mean value from 55°00'S, 35°W



53
54
55
56
DEGREES SOUTH
44
42
40
38
36
34
DEGREES WEST
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
SHAG ROCKS
SOUTH GEORGIA
500 m
150 m
500 m
Proposed stations for the 1989/90 Bottom trawl survey

TOOTHFISH, *DISSOSTICHUS ELEGINOIDES*, AT SOUTH GEORGIA

I. Everson and S. Campbell*

Abstract

The *Dissostichus eleginoides* fishery at South Georgia has expanded greatly in recent years. It has been claimed that the exploited fish are senescent and not contributing to the breeding population (CCAMLR-VIII, paragraph 106). Histological examination of the gonads of a small sample of fish taken from a commercial longliner in January 1990 indicates that the fish are sexually mature and, at the time of sampling, are approaching spawning condition.

Résumé

La pêcherie de *Dissostichus eleginoides* en Géorgie du Sud s'est considérablement développée ces dernières années. Certains ont déclaré que les poissons exploités sont sénescents et ne contribuent pas à la population reproductrice (CCAMLR-VIII, paragraphe 106). Un examen histologique des gonades d'un échantillon modeste de poissons prélevé d'un palangrier commercial en janvier 1990 indique que les poissons ont atteint la maturité sexuelle et, qu'au moment de l'échantillonnage, ils approchent des conditions de reproduction.

Резюме

За последние годы промысел *Dissostichus eleginoides* в районе Южной Георгии существенно увеличился. Была высказана точка зрения о том, что при этом промысле вылавливается стареющая рыба, не входящая в состав размножающейся части популяции (CCAMLR-VIII, пункт 106). Гистологический анализ гонад на материале небольшой пробы рыбы, взятой из улова, полученного коммерческим судном в ходе ярусного промысла в январе 1990 г., показывает, что рыба, входящая в состав улова, была половозрелой и в момент взятия пробы находилась на стадии, близкой к нерестовой.

Resumen

La pesquería de *Dissostichus eleginoides* en Georgia del Sur ha aumentado considerablemente en los últimos años. Se ha sostenido que los peces capturados son senescentes, y por lo tanto no forman parte de la población reproductora (CCAMLR-VIII, párrafo 106); pero, al examinar histológicamente las gónadas de una pequeña muestra de peces capturados por un palangrero comercial, en enero de 1990, se pudo constatar que los peces estaban en estado de madurez sexual y próximos a desovar.

* National Environment Research Council, British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, United Kingdom

1. INTRODUCTION

During the Eighth Meeting of CCAMLR it was noted that the Scientific Committee had recommended that a TAC of 1 200 tonnes be set for *Dissostichus eleginoides* in Subarea 48.3. That estimate was based on very limited data, but since this represented the best scientific advice available, most Members were content to use it as the basis for setting a TAC. The USSR opposed this view and stated that the longline fishery takes senescent fish. Consequently they did not agree that setting any TAC for the longline fishery was justified (CCAMLR-VIII, paragraph 106).

We know of no fishery anywhere in the World which takes a significant proportion of the estimated production and which is removing senescent fish and have therefore sought to investigate this claim.

2. MATERIAL AND METHODS

A small sample of five fish was obtained from the USSR longlining vessel *Olyokminsk* when it visited the UK station at King Edward Point, South Georgia on 28 January 1990. The fish were fresh and had been caught recently in the vicinity of Shag Rocks. The fish were measured, weighed and sex and maturity stage determined according to the scale in SC-CAMLR-VIII, page 243. In order to unequivocally determine the maturity stage of gonads, samples were frozen for histological examination in the UK. Otoliths and scale samples were removed for age determination. Details of the fish are given in Table 1.

Gonad samples were thawed into formol saline and stained. Sections of gonads (3 microns) were prepared and examined under a microscope. Photomicrographs of the sections are shown in Figures 1 and 2.

3. DISCUSSION

All of the five fish in the sample were of a size similar to those that were caught in a bottom trawl survey earlier in the month (Parkes *et al.*, 1990).

Histological sections of the ovaries show ova approximately 2 mm in diameter. The ova are in the developing phase consistent with the subjective observation that they were at stage 2 when caught. Testes are clearly developing and consistent with the observation that they were at stage 2. The gonads from all fish in this sample are therefore consistent with the fish developing towards spawning. There is no evidence that they are senescent.

4. CONCLUSIONS

It is impossible to judge the maturity status of fish caught in the 1988/89 season from this sample; however, it is clear that this sample from the 1989/90 seasons is composed totally of fish developing towards spawning condition. We see no reason to believe that the situation was any different during the 1988/89 season.

We therefore suggest that the assertion that the fish were senescent is almost certainly in error and that, had the point been discussed during either the Working Group on Fish Stock Assessment or Scientific Committee meetings some clarification would have been provided.

REFERENCES

CCAMLR-VIII. 1989. *Report of the Eighth Meeting of the Commission (CCAMLR-VIII).* Hobart, Australia: CCAMLR. pp. 27-28.

PARKES, G.B., I. EVERSON, J. ANDERSON, Z. CIELNIASZEK, J. SZLAKOWSKI and R. TRACZYK. 1990. *Report of the UK/Polish Fish Stock Assessment Survey Around South Georgia and Shag Rocks in January 1990.* SC-CAMLR-IX, document WG-FSA-90/11.

SC-CAMLR. 1989. *Report of the Eighth Meeting of the Scientific Committee (SC-CAMLR-VIII).* Hobart, Australia: CCAMLR. pp. 243.

Table 1: *Dissostichus eleginoides* from South Georgia, 28 January 1990.

Specimen Reference	Length (cm)	Weight (g)	Sex	Maturity Stage	Gonad Photomicrograph
1	81	4690	F	2	Figure 1 top
2	78	4300	M	2	Figure 2 top
3	85	5850	F	2	Figure 1 centre
4	86	5830	M	2	Figure 2 lower
5	84	5340	F	2	Figure 1 lower

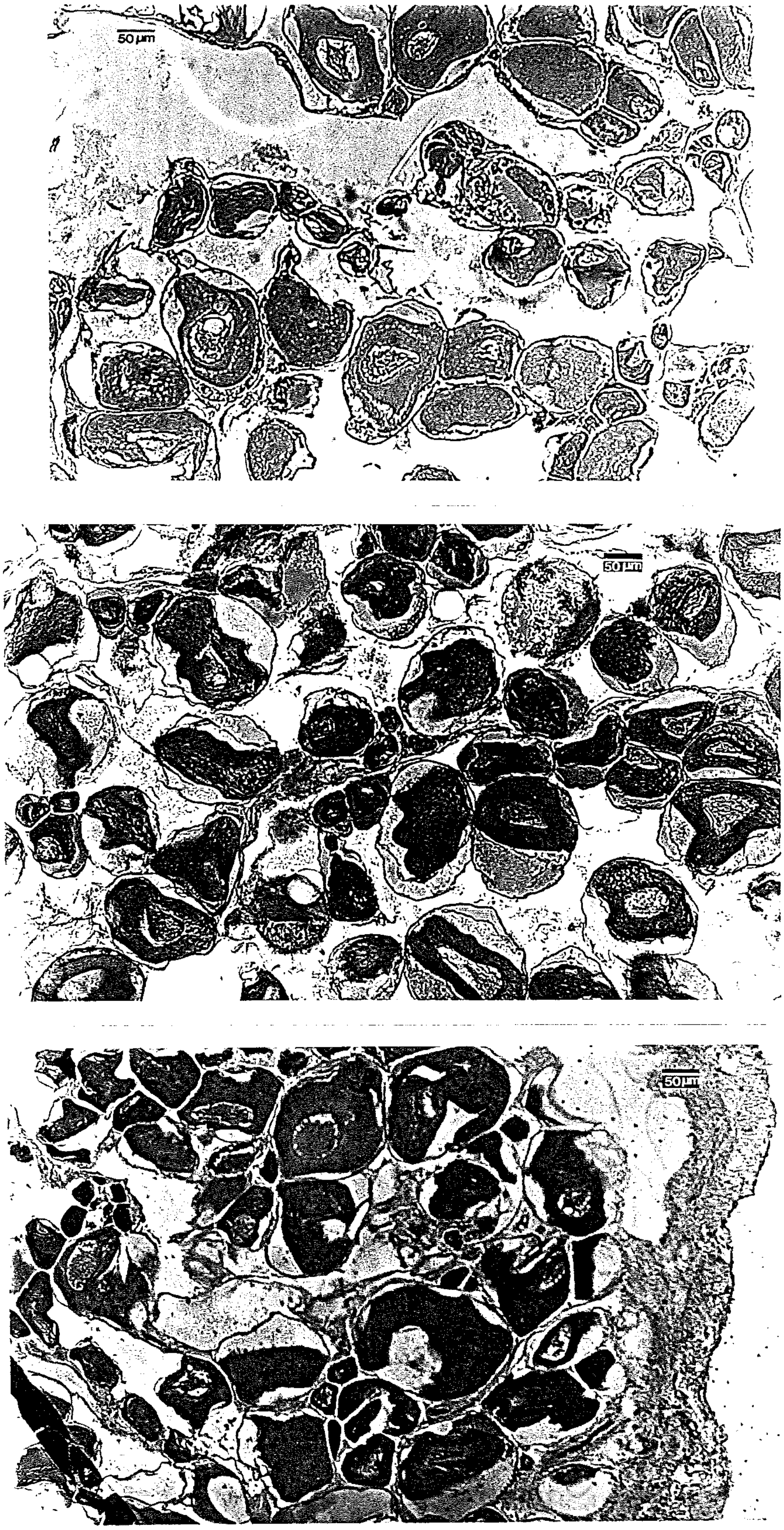


Figure 1: Histological sections of *Dissostichus eleginoides* ovaries. Top from specimen reference number 1, centre from specimen reference number 3 and lower from specimen reference number 5.

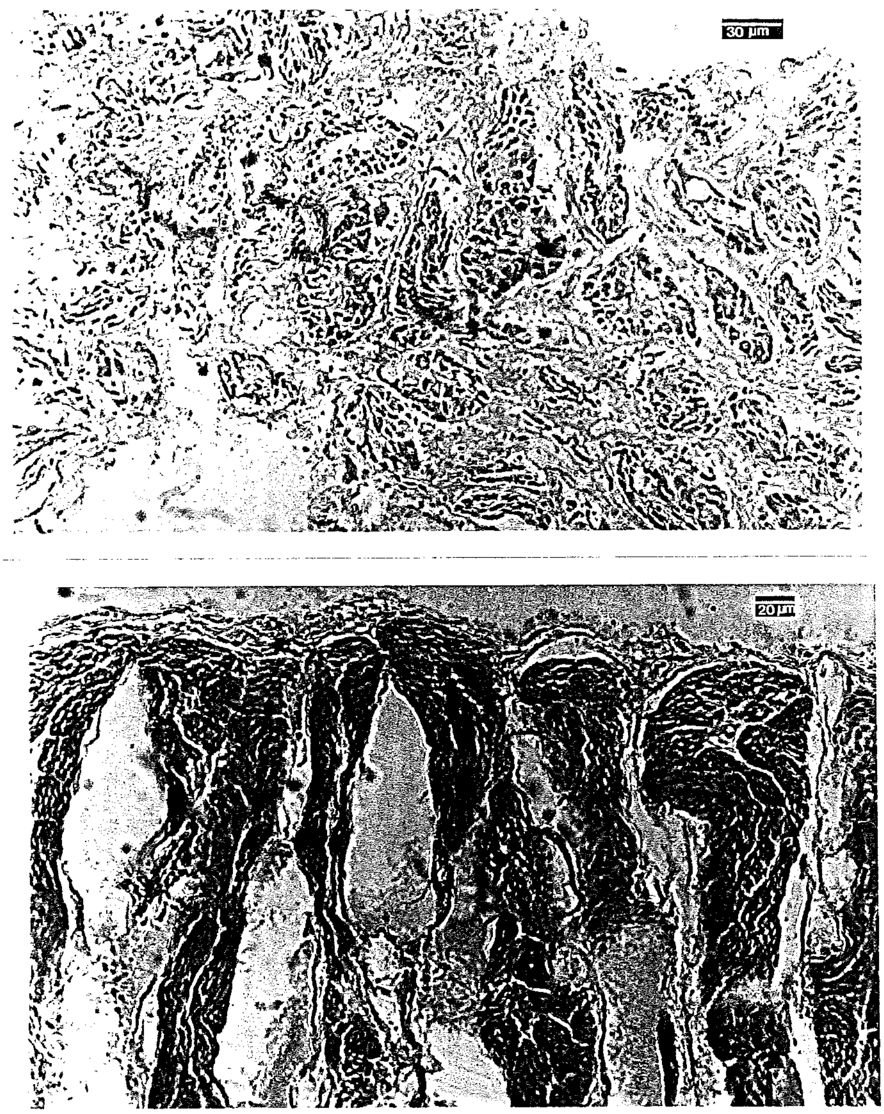


Figure 2: Histological sections of *Dissostichus eleginoides* testes. Top from specimen reference number 2, lower from specimen reference number 4.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

A DECLINING TREND IN THE ABUNDANCE OF *NOTOTHENIA ROSSII MARMORATA* AND *NOTOTHENIA GIBBERIFRONS* OBSERVED IN FJORDS IN TWO SITES IN THE SOUTH SHETLAND ISLANDS

E. Barrera-Oro and E. Marschoff*

Abstract

A declining trend observed in the abundance of *Notothenia rossii marmorata* and *Notothenia gibberifrons* in fjords in two sites in the South Shetland Islands (Subarea 48.1), is analyzed by a nested ANOVA and demonstrated as significant. The material for the current study was obtained with trammel nets at Potter Cove, King George/25 de Mayo I., over a period of eight years from 1983 to 1990 and in waters around Half-Moon I., Moon Bay, in 1989. The analysis was based on the proportion of catches of the abovementioned species in relation to *Notothenia neglecta*, a species with similar ecological habits in the fjords. Since sampling by this method did not utilize a consistent amount of effort between years, the analysis made use of standardized catch data by expressing the catches of *N. rossii* and *N. gibberifrons* in proportion to the catches of *N. neglecta*. A similar declining trend had been reported in the 1960s and 1970s for neighbouring sites in the South Shetland Islands. This phenomenon might be explained as a consequence of the depletion of the stocks due to commercial exploitation in the area in the early 1980s.

Résumé

La tendance au déclin observée dans l'abondance des espèces *Notothenia rossii marmorata* et *Notothenia gibberifrons* dans les fjords de deux sites des îles Shetland du Sud, fait l'objet d'une analyse par emboîtements ANOVA et se révèle significative. Le matériel étudié a été obtenu par filets trémails à Potter Cove, île du Roi George/25 de Mayo, sur une période de huit ans, entre 1983 et 1990 et dans les eaux entourant l'île Half-Moon, baie Moon, en 1989. L'analyse était basée sur la proportion de captures des espèces mentionnées par rapport à *Notothenia neglecta*, une espèce aux habitudes écologiques similaires dans les fjords. L'échantillonnage par cette méthode ne nécessitant pas une valeur constante d'effort entre années, l'analyse a utilisé des données de capture standardisées en exprimant les captures de *N. rossii* et de *N. gibberifrons* proportionnellement aux captures de *N. neglecta*. Une pareille tendance à la baisse a déjà été signalée dans les années 60 et 70, en des sites proches, dans les îles Shetland du Sud. Le présent phénomène peut être expliqué comme étant une conséquence du déclin des stocks dû à l'exploitation commerciale dans cette région depuis le début des années 80.

* Instituto Antártico Argentino, Dirección Nacional del Antártico, Cerrito 1248, 1010 Buenos Aires, Argentina

Резюме

Посредством гнездового анализа (ANOVA) была проанализирована и, в итоге, признана значительной тенденция к сокращению численности фиордовой рыбы видов *Notothenia rossii marmorata* и *Notothenia gibberifrons* на двух участках в районе Южных Шетландских островов (Подрайон 48.1). Использованные в настоящем исследовании данные были получены с помощью многостенных сетей в бухте Поттер-Коув острова Кинг-Джордж на протяжении восьми лет с 1983 по 1990 гг. и в водах вокруг острова Хаф-Мун в заливе Мун-Бей в 1989 г. Анализ был основан на процентном отношении уловов вышеупомянутых видов к уловам вида *Notothenia neglecta*, обладающего сходными экологическими характеристиками. Поскольку при таком сборе проб промысловое усилие изменяется из года в год, при анализе использовались стандартизированные данные по уловам, выраженные как процентное отношение уловов *N. rossii* и *N. gibberifrons* к уловам *N. neglecta*. В 1960-х и 1970-х годах были получены сведения о существовании подобных тенденций к сокращению запасов на близлежащих участках Южных Шетландских островов. Причиной данного явления в этом районе может быть истощение этих запасов в результате коммерческого промысла в начале 1980-х годов.

Resumen

Se ha utilizado el ANOVA anidado para analizar la disminución observada en la abundancia de *Notothenia rossii marmorata* y *Notothenia gibberifrons* en fiordos situados en dos zonas distintas de las islas Shetland del Sur (Subárea 48.1), concluyéndose que esta disminución es muy marcada. El material de estudio fue recogido mediante redes de trasmallo en Caleta Potter, isla Rey Jorge/25 de Mayo, durante un período de ocho años, de 1983 a 1990 y en las aguas que circundan la isla Media Luna, Bahía Luna, en 1989. El análisis consistió en una comparación de las capturas de las especies mencionadas anteriormente, y *Notothenia neglecta*, especie de hábitos ecológicos similares en los fiordos. Debido a la diferencia anual que existe en el esfuerzo pesquero empleado en la toma de muestras por este método, el análisis utilizó datos estándar de capturas y los expresó como proporción de capturas de *N. rossi* y *N. gibberifrons*, en relación a *N. neglecta*. Una disminución similar se observó en las décadas de los años 60 y 70, en localidades cercanas, en las islas Shetland del Sur. Este fenómeno puede ser interpretado como una consecuencia de la merma en las poblaciones debido a la explotación comercial en el área a principios de los años 80.

---

1. INTRODUCTION

At the Eighth Meeting of the Scientific Committee the Chilean Delegation reported a recent decline in the abundance of *Notothenia rossii marmorata* and *Notothenia gibberifrons* caught in fjords of South Bay, Doumer I., Palmer Archipelago. Since the implementation by the Instituto Antártico Argentino of routine sampling of fish a similar situation has been observed in neighbouring sites in the South Shetland Islands: Potter Cove (Jubany Station), King George/25 de Mayo I. and Moon Bay (Cámara Station), Livingston I.

This paper presents an analysis on the abundances of fjord *N. rossii marmorata* and *N. gibberifrons* in relation to the abundance of *Notothenia neglecta*, a species with similar ecological habits. Comparisons with earlier data taken from the literature, are also made.

2. METHODS

Samples were obtained using trammel nets (length 25, 35 and 50m; width 1.5m; mesh 2.5cm) at Potter Cove from 1983 to 1990 and in waters around Half Moon I. (Moon Bay, Livingston I.) in 1989 (Figure 1. A). At Potter Cove, the net was always located in the same site (Figure 1. B) at depths from 5 to 50m. The same procedure was followed at Moon Bay, covering a depth range from 5 to 35m.

Since sampling was not aimed at monitoring the abundance of fjord-fish, fishing effort was not controlled, with the result that various yields were obtained per haul (Figure 2). Potter Cove data from 1990 were obtained as part of an ecological study requiring continuous sampling with a limited fishing period for each net. All sampled fish were used for other studies (Barrera-Oro, 1989; Casaux *et al.*, 1990; Barrera-Oro and Casaux, 1990) where morphometric and meristic data, sex, maturity stages, ages and stomach contents were determined.

In order to have a measure of abundance of *N. rossii marmorata* and *N. gibberifrons* standardized for all samples, the proportion of these species in relation to *N. neglecta* was calculated as follows:

$$\text{Proportion(b)} = \frac{\text{Nb}}{\text{Nn} + \text{Nb}} \qquad (1)$$

where **Nb** is the number of specimens of the species considered (*N. rossii marmorata* or *N. gibberifrons*), and
Nn is the number of specimens of *N. neglecta.*

Differences between years have been tested with a nested ANOVA design (Table 1A) using the arcsin of the square root transformation, which is recommended for the analysis of proportions (Sokal and Rohlf, 1981). Data from Half Moon I. obtained in 1989 are presented in Table 1B.

As the trammel net is a passive sampling device, catches depend on fish activity. Our assumption is that changes in population sizes will be reflected in proportional changes in catches.

Trammel nets of different length and different sampling periods were used in the study. Nevertheless, as the location of nets was kept constant, the same fraction of the population was sampled over the years. The resultant increase in variance was dealt with by the nesting observations. It forms part of the error term. As variations between hauls are considered as replicates within months, the sum of squares due to the possible changes in fishing gears and sampling periods are used for the comparison of the higher levels. Thus, the effect will be a decrease in the power of the test.

3. RESULTS AND DISCUSSION

As expected, all *N. rossii marmorata* specimens collected were juvenile. *N. gibberifrons* individuals were mainly juvenile, with a limited number of adults. This catch composition, found at a water depth of 5 to 50 m, is in agreement with the known pattern of depth distribution of *N. gibberifrons*.

Figure 3 shows the yearly total catches of *N. rossii marmorata* and *N. gibberifrons* at Potter Cove, expressed as proportions (Equation 1). An overall declining trend is evident for both species, and its significance is demonstrated by the ANOVA results (Table 2).

Published information on fjord-fish taken at similar depths in sites close to Potter Cove and Moon Bay contain data on accumulated catches for non-comparable periods. To make these data comparable with ours, we calculated from them the proportion of catches of *N. rossii marmorata* and *N. gibberifrons* in relation to *N. neglecta*, with the following results: 0.12 *N. rossii marmorata* and 0.044 *N. gibberifrons* in summer 1965/66 at Moon Bay (Bellisio, 1967); 0.38 *N. rossii marmorata* in December 1969 at Fildes Bay, King George I. and 0.48 *N. rossii marmorata* in January 1971 at Discovery Bay, Greenwich I. (Moreno and Bahamonde, 1975); 0.43 *N. rossii marmorata* in summer 1979/80 at Admiralty Bay, King George I. (Linkovski *et al.*, 1983).

It should be noted that data from Fildes Bay and Discovery Bay were obtained by hook and line gears, while at Admiralty Bay gill nets were used. For Half Moon I., combined catches of hook and line gears and trammel nets were reported.

Although this information is not fully comparable in significance tests, it is clear that before 1980 the proportion of *N. rossii marmorata* was well above the starting point of our series at Potter Cove (1983). Around Half Moon I., the proportion of *N. rossii marmorata* obtained by Bellisio (1967) in 1965/66 is three times greater than in 1989 (0.038). In this year, there was not a single capture of *N. gibberifrons*, while a proportion of 0.044 was obtained for this species in 1965/66.

The data series obtained at Potter Cove seems to start after the onset of a declining trend (Figure 2). In this area the abundances of *N. rossii marmorata* and *N. gibberifrons* attained a minimum during 1985/86. The six to seven years preceding this were characterized by commercial catches in the Antarctic Peninsula, Subarea 48.1 (Kock, 1986; Nast *et.al.*, 1988; Tiedtke and Kock, 1989). This decline was demonstrated as highly significant ($P<0.001$). Considering that *N. neglecta* has been not commercially exploited it is reasonable to attribute the recent low abundances of juvenile *N. rossii marmorata* and *N. gibberifrons* to the depletion of the stocks in the area. If so, the phenomenon should affect a wide geographical region, a fact confirmed by the Chilean Delegation's comment on South Bay.

This decrease, implies that in future years recruitment to the commercial fisheries will be low, and recovery to levels close to maximum sustainable yield (MSY) might well take more than two or three decades.

REFERENCES

BARRERA-ORO, E.R. 1989. Age determination of *Notothenia gibberifrons* from the South Shetland Islands, Antarctic Peninsula Subarea (Subarea 48.1). In: *Selected Scientific Papers 1988, Part II (SC-CAMLR-SSP/5)*. Hobart, Australia: CCAMLR. pp. 143-160.

BARRERA-ORO, E.R. and CASAUX, R.J. 1990. Feeding selectivity in *Notothenia neglecta*, Nybelin, from Potter Cove, South Shetland Islands, Antarctica. *Antarctic Science* 2 (3): 207-213.

BELLISIO, N.R. 1967. Peces antárticos del sector argentino (Parte IV): *Parachaennichthys charcoti, P. georgianus* y *Harpagifer bispinnis antarcticus* de Bahía Luna. *Publ. Serv. Hidrogr. Nav.* 904: 1-57.

CASAUX, R.J., A.S. MAZZOTTA and E.R. BARRERA-ORO. 1990. Seasonal aspects of the biology and diet of nearshore nototheniid fish at Potter Cove, South Shetland Islands, Antarctica. *Polar Biol.* 11: 63-72.

KOCK, K.-H. 1986. The state of exploited Antarctic fish stocks in the Scotia arc region during SIBEX (1983-1985). *Arch. Fischwiss. 37* (Beih. 1): 129-186.

LINKOWSKI, T.B., P. PRESLER and C. ZUKOWSKI. 1983. Food habits of nototheniid fishes (Nototheniidae) in Admiralty Bay (King George Island, South Shetland Islands). *Polish Polar Research, 4* (1/4): 79-95.

MORENO, C.A. and N. BAHAMONDE. 1975. Nichos alimentarios y competencia por alimento entre *Notothenia coriiceps neglecta* Nybelin y *Notothenia rossii marmorata* Fischer en Shetland del Sur, Antártica. *Serie Científica del Instituto Antártico Chileno,* 25/26: 33-34.

NAST, F., K.-H. KOCK, D. SAHRHAGE, M. STEIN and J.E. TIEDTKE. 1988. Hydrography, krill and fish and their possible relationship around Elephant Island. In: SAHRHAGE, D., (Ed.). *Antarctic Ocean and Resources Variability.* Berlin, Heidelberg: Springer-Verlag. pp. 183-198.

TIEDTKE, J.E. and K.-H. KOCK. 1989. Structure and composition of the demersal fish fauna around Elephant Island. *Arch. Fischwiss.* 39: 143-169.

SOKAL, R. R. and J.F. ROHLF. 1981. *Biometry.* New York: W.H. Freeman and Company. p. 859.

Table 1: Summary of specimens of each species caught at A) Potter Cove and B) Moon Bay.

A)

Level 1 (years)	Level 2 (months)	Number of Replicates	Number of Specimens Caught in Each Replicate		
			N. neglecta	*N. rossii*	*N. gibberifrons*
1983	April	7	2,12,16,15 2,1,4	4,6,9,5,0 0,3	Not recorded
	May	9	6,5,11,3,6 6,5,2,8	7,3,2,8,0 0,3,2,6	
	June	3	13,17,32	4,2,2	
	October	1	39	2	
	November	3	26,2,0	1,16,2	
1984	January	5	35,11,18,15 13	16,4,4,5,5	
	February	2	3,12	1,2	
	March	2	26,31	13,15	
	April	6	10,36,5,24 5,19	2,5,2,5,2 1	
	October	2	21,20	11,10	
	November	2	10,25	1,3	
	December	3	28,16,25	11,4,6	
1985	April	5	5,11,8,14,24	0,1,3,7,3	1,8,16,1,3
	May	5	10,14,28,7 31	0,6,3,4,2	11,13,3,15 13
	August	3	56,8,25	4,0,1	2,14,0
	September	3	41,15,21	0,0,2	3,0,13
	October	1	9	0	1
1986	February	3	27,20,8	9,2,2	3,4,1
	March	4	16,40,34,27	0,0,3,2	1,14,1,2
	April	6	34,29,27,33 32,11	0,2,1,0,0,1	1,4,0,3,0,1
	May	2	28,25	4,0	2,0
	December	5	37,14,11,29 20	4,0,1,0,3	1,0,0,0,0

Table 1A) (continued)

Level 1 (years)	Level 2 (months)	Number of Replicates	Number of Specimens Caught in Each Replicate		
			N. neglecta	*N. rossii*	*N. gibberifrons*
1987	January	2	35,12	2,2	0,0
	February	3	6,17,22	1,1,0	0,0,0
	March	3	23,37,18	0,0,0	0,0,0
	April	4	27,33,48,31	0,0,2,0	1,0,1,1
	May	2	12,26	1,3	0,0
	November	1	70	6	0
	December	4	2,26,21,44	0,0,2,1	0,0,0,0
1988	January	3	18,51,13	1,1,0	0,0,0
	October	2	7,48	6,0	0,2
	November	2	21,9	4,0	0,0
	December	2	23,33	0,0	0,0
1990	January	10	26,5,25,16,7 9,2,7,21,5	0,0,1,0,0 0,0,1,1,0	0,0,1,0,0 0,0,0,2,0

B)

Year	Month	Number of Replicates	Number of Specimens Caught in Each Replicate		
			N. neglecta	*N. rossii*	*N. gibberifrons*
1989	January February	2 1	57,52 95	2,1 5	0,0 0

Table 2: ANOVA of proportions of *N. gibberifrons* and *N. rossii marmorata* using the arcsin of square root transformation.

a) *N. rossii marmorata*

Source (Level)	DF	Sum of Squares	Mean Square	F	Probability	Percentage of Variance
Years	6	11908.306	1984.718	8.7007	0.00003	34.4055
Months	27	6158.961	228.110	1.2654	0.20592	5.0655
(Error)	86	15503.397	180.272			60.5291

b) *N. gibberifrons*

Source (Level)	DF	Sum of Squares	Mean Square	F	Probability	Percentage of Variance
Years	4	8458.203	2114.551	15.3911	0.00002	54.0275
Months	17	2335.601	137.388	1.3514	0.19897	4.8200
(Error)	53	5388.212	101.664			41.1525

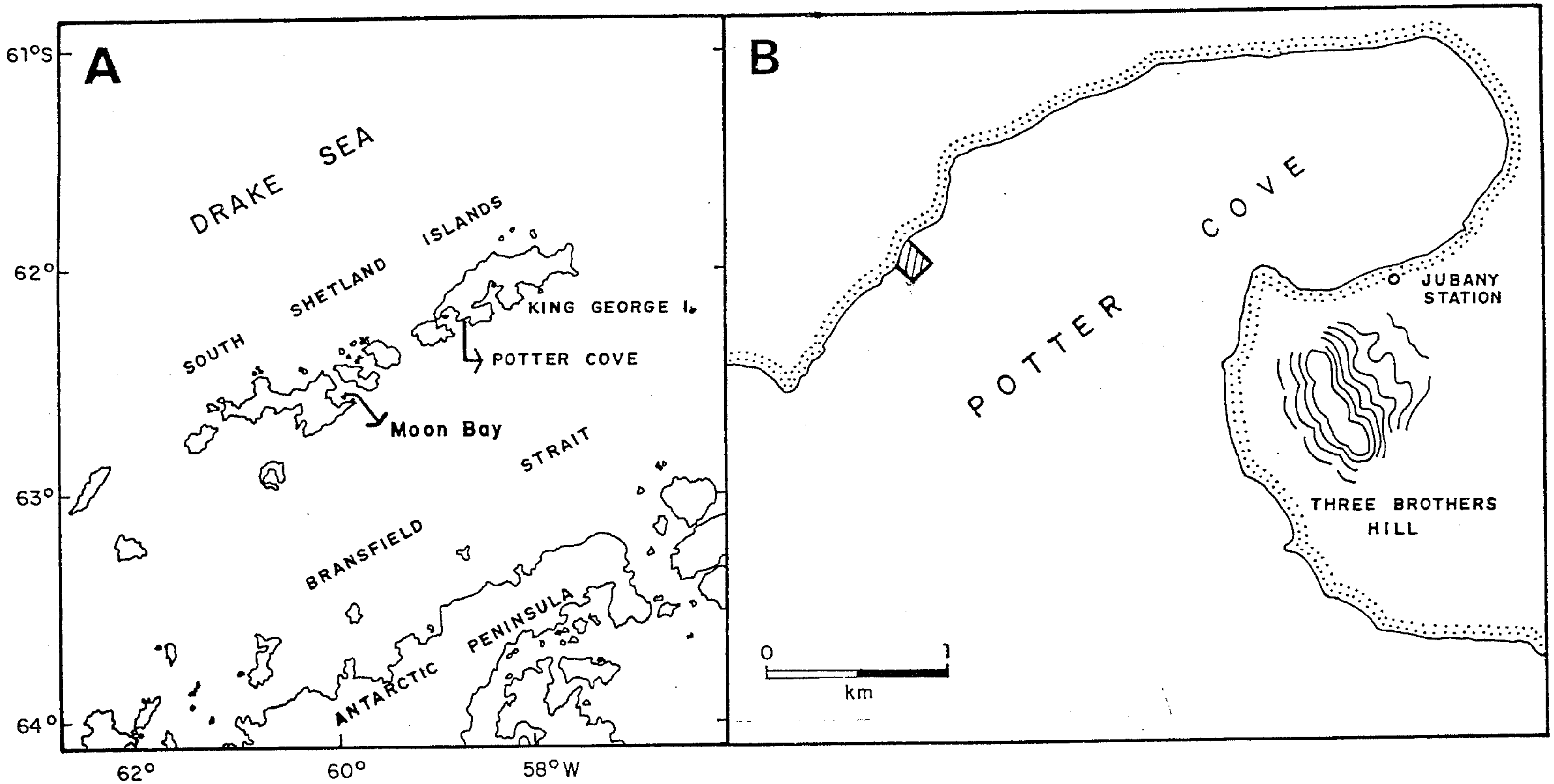


Figure 1: Location of sampling sites: (A) Moon Bay, (B) Potter Cove.

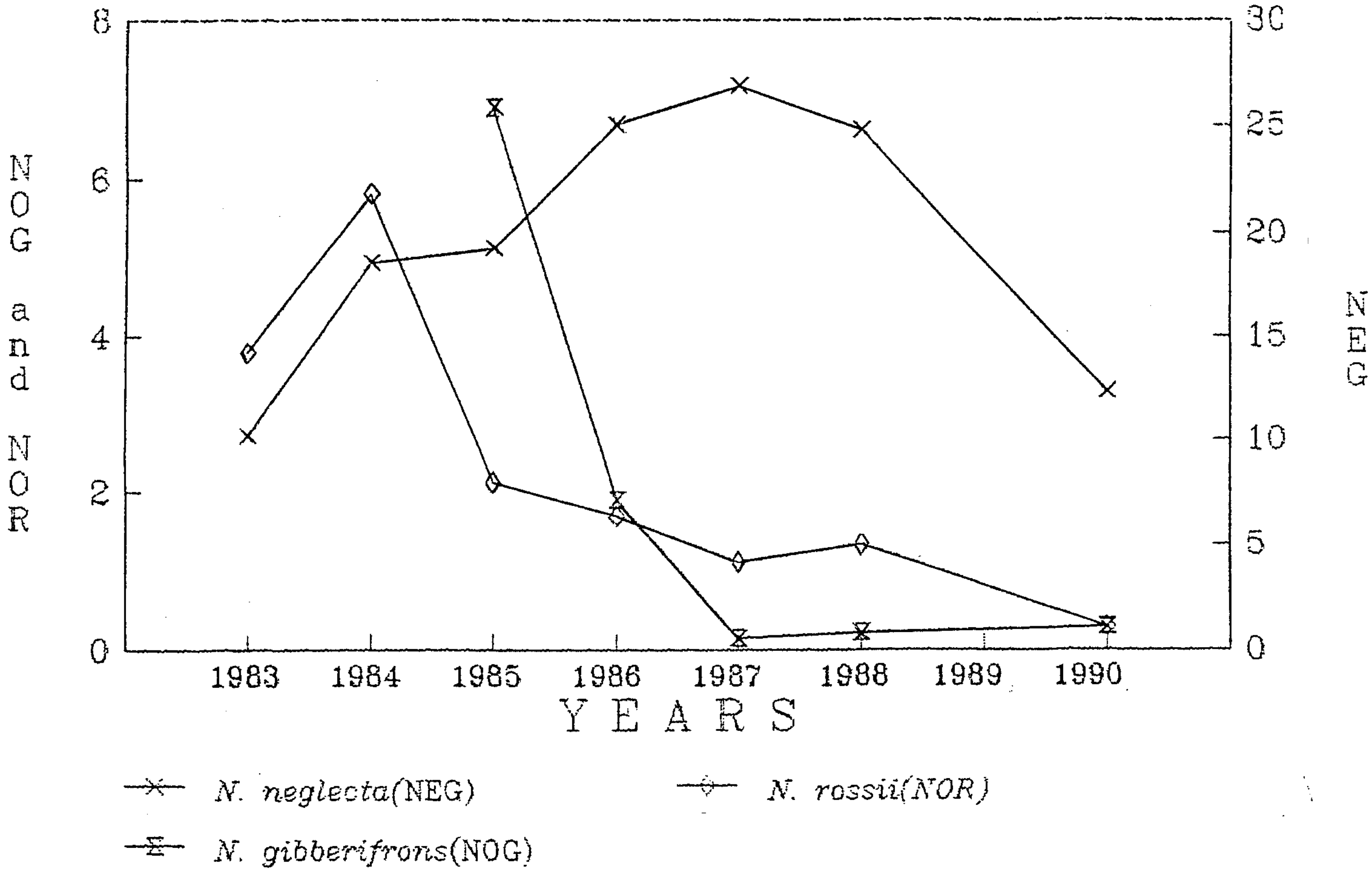


Figure 2: **Annual mean catches-per-haul (number of specimens).**

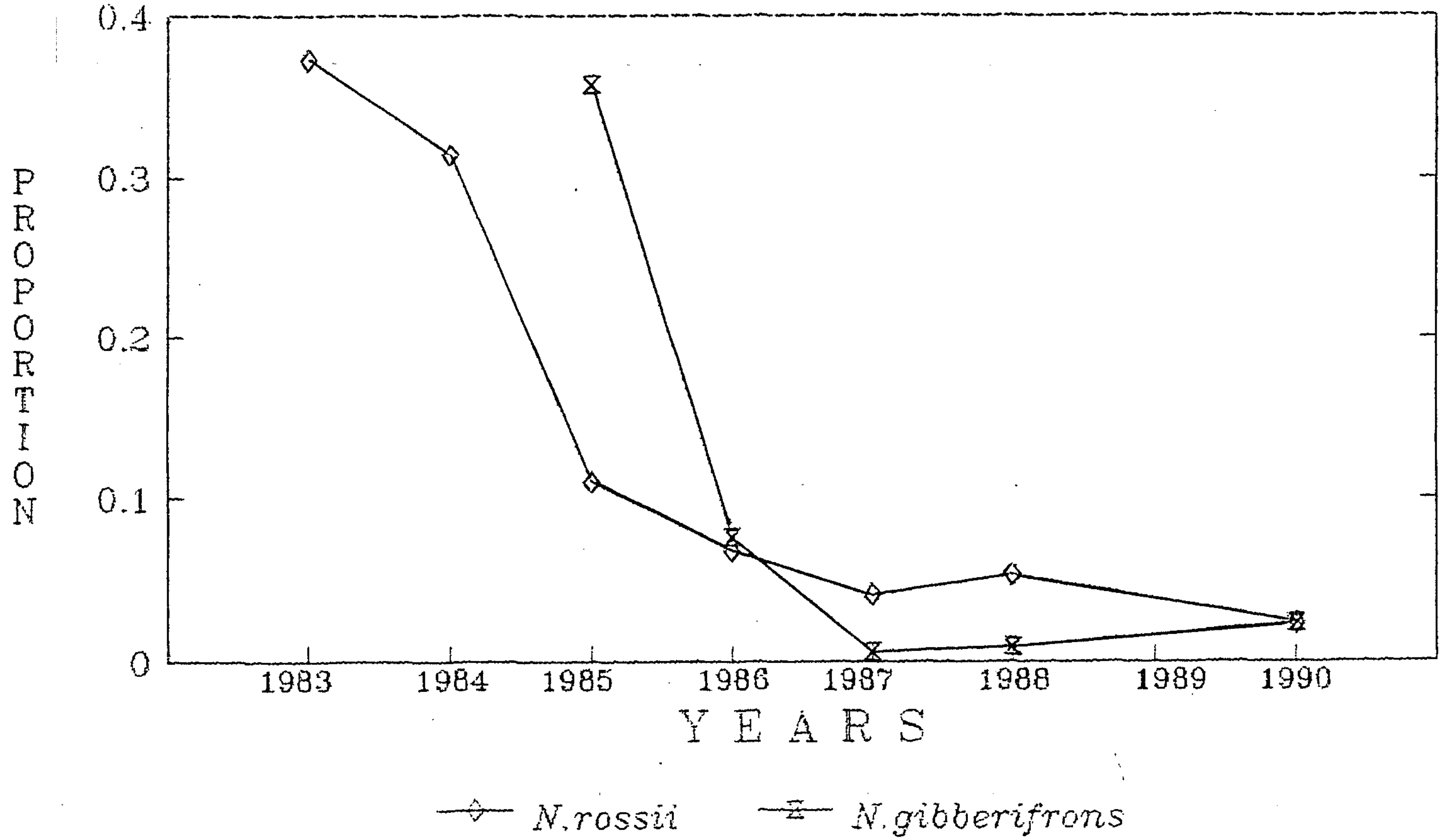


Figure 3: Annual catches of *N. rossii* and *N. gibberifrons* expressed as proportions of *N. neglecta* catches (see text, Equation 1).

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

THE FISHERY FOR *PATAGONOTOTHEN BREVICAUDA GUNTHERI* IN CCAMLR SUBAREA 48.3

I. Everson and C. Mitchell*

Abstract

Fine-scale data supplied to CCAMLR for 1987/88 showed that the catches of *Patagonotothen brevicauda guntheri* were five times greater in the South Georgia area than at Shag Rocks. Previous survey data and reports to the CCAMLR Working Group on Fish Stock Assessment indicated that this species was only ever caught at Shag Rocks. Therefore the South Georgia catches were almost certainly of another species. The small size of *P.b. guntheri* means that they can only be caught with net meshes so small that they would also catch undersized individuals of other, larger species. Survey results suggest that such fishing is likely to have a significant effect on other species. *P.b. guntheri* has been reported as a by-catch of other fisheries; this suggests that illegal nets were used.

Résumé

Les données à échelle précise fournies à la CCAMLR pour 1987/88 ont révélé que les captures de *Patagonotothen brevicauda guntheri* sont cinq fois plus importantes dans la zone de la Géorgie du Sud qu'aux îlots Shag. D'anciennes données de campagnes et des rapports fournis au Groupe de travail de la CCAMLR chargé de l'évaluation des stocks de poissons indiquent que cette espèce n'a jamais été capturée qu'aux îlots Shag. Il semble donc que les captures de Géorgie du Sud aient concerné une autre espèce. Vu sa taille modeste, *P.b. guntheri* ne peut être capturé qu'à l'aide de filets à très petites mailles, entraînant assurément la capture d'individus inférieurs à la taille légale, appartenant à d'autres espèces plus grandes. Les résultats des campagnes d'étude révèlent qu'une telle pêche risque d'affecter sensiblement d'autres espèces. La déclaration de *P.b. guntheri* en tant que capture accessoire d'autres pêcheries laisse présumer que des filets illégaux ont été utilisés.

Резюме

Представленные в АНТКОМ мелкомасштабные данные за 1987/88 гг. свидетельствуют о том, что общий вылов *Patagonotothen brevicauda guntheri* в районе Южной Георгии в пять раз превышал общий вылов этого вида в районе скал Шаг. По данным ранее проведенных съемок и сведениям, содержавшимся в отчетах, представленных Рабочей группе АНТКОМа по оценке рыбных запасов, этот вид вылавливался исключительно в районе скал Шаг. Следовательно, в районе Южной Георгии скорее всего были получены уловы

* National Environmental Research Council, British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, United Kingdom

другого вида. В связи с тем, что особи вида *P.b. guntheri* характеризуются небольшим размером, их промысел можно вести только сетями с такой мелкой ячеей, которая также удерживает молодь других, более крупных видов рыб. По результатам съемки можно предположить, что такой промысел, вероятно, будет оказывать значительное влияние на прочие виды. Поступали сведения о присутствии особей вида *P.b. guntheri* в приловах при промысле других видов рыб. В связи с этим можно предположить, что использовались запрещенные типы сетей.

Resumen

De la información a escala fina suministrada a la CCRVMA para el período 1987/88, se desprende que las capturas de *Patagonothen brevicauda guntheri* fueron cinco veces superiores en el área de Georgia del Sur que en las Rocas Cormorán. La información recogida por las prospecciones anteriores y la enviada al Grupo de Trabajo para la Evaluación de las Poblaciones de Peces de la CCRVMA, ha indicado que esta especie había sido capturada sólo en el área de las Rocas Cormorán. Por ende, las capturas en Georgia del Sur eran, seguramente, de otras especies. Debido al pequeño tamaño de *P.b. guntheri*, sólo se le puede capturar con redes de malla tan pequeñas que, irremediablemente, capturarán también ejemplares juveniles de otras especies de mayor tamaño. Los resultados de las prospecciones indican que una pesquería de este tipo tendría un gran impacto en otras especies. Se ha notificado la pesca de *P.b. guntheri* en las capturas secundarias de otras pesquerías, lo que insinúa que se utilizaron redes ilegales para tales efectos.

---

1. INTRODUCTION

During the past ten years there has been a fishery for *Patagonotothen brevicauda guntheri* in CCAMLR Subarea 48.3 (South Georgia) resulting in reported annual catches of between five and thirty-five thousand tonnes. The only biomass estimate available is from the Spanish trawl survey in 1986/87 (Balguerías, 1989). The reported catches are listed in Table 1.

In 1988 CCAMLR introduced Conservation Measure 12/VII which limited the total catch for the season to 13 000 tonnes. In the following year the total allowable catch (TAC) was set at 12 000 tonnes (Conservation Measure 16/VIII). At the end of the fishing season catch and effort data, which include location and amount of catches by fine-scale rectangle (half a degree of latitude by one degree of longitude) and ten-day period, are required to be sent to CCAMLR.

P.b. guntheri are small fish, rarely growing larger than 20 cm. They are not covered by any of the minimum mesh regulations included in Conservation Measure 2/III.

The only nation fishing for *P.b. guntheri* is the USSR and they have reported that directed fishing on this species is only undertaken in the Shag Rocks region of Subarea 48.3 (SC-CAMLR-VII, p. 165 and SC-CAMLR-VIII, p. 276).

We have analysed the fine-scale data that have been supplied to CCAMLR in order to provide further information on the fishery.

2. FINE-SCALE DATA ON THE *P.B. GUNTHERI* FISHERY

At the time of preparation of this report the only season for which fine-scale data were available was 1988. Records related to the *P.b. guntheri* fishery are summarised in Tables 2 to 4.

The Shag Rocks region of Subarea 48.3 may be conveniently described by a rectangle extending from latitude 53° to 54°S and longitude 40° to 44°W. There are no reports of *P.b. guntheri* being taken as by-catch in the krill fishery.

3. DISTRIBUTION OF CATCHES

The breakdown of catches within the two regions, Shag Rocks and South Georgia is given in Table 5.

These results indicate that approximately five times as much *P.b. guntheri* were caught around South Georgia as at Shag Rocks. This is at variance with information reported in the CCAMLR Working Group on Fish Stock Assessment Reports which states that the species is only taken at Shag Rocks (SC-CAMLR-VII, p. 165 and SC-CAMLR-VIII, p. 276).

Examination of survey data supports this information. Data from all trawl surveys in Subarea 48.3, whether using bottom or pelagic trawls, indicates that *P.b. guntheri* is only ever found around Shag Rocks (e.g., Balguerías, 1989; Parkes *et al.*, 1989 and 1990). The catches from South Georgia that are reported to be of *P.b. guntheri* are not of that species, and are, therefore, almost certainly of some other species.

4. BY-CATCHES IN THE *P.B. GUNTHERI* FISHERY

In the directed fishery for *P.b. guntheri* the proportion of the target species in the catches is high. However, there are some situations when large catches of other species have been reported. For example, catches from bottom trawls (Table 3) during February 1988 around South Georgia indicate that the icefish *Champsocephalus gunnari* made up one quarter of the catch. While it is understandable that by-catches will be made it must be remembered that they are being made using gear designed for the target species.

P.b. guntheri are small fish and rarely grow larger than 20 cm (Figure 1). In order to catch fish of this size it would be necessary to use a mesh considerable finer than that permitted under Conservation Measure 2/III for other species. A net operating with a mesh as fine as this is likely to catch large numbers of small fish of other species and hence the by-catch species are likely to be dominated by small individuals. Of particular concern is *Dissostichus eleginoides* at Shag Rocks. Results from a recent survey show that large numbers of small individuals of this species (Figure 2) are present in the area and hence a fishery directed at *P.b. guntheri* is likely to have a significant effect on them.

5. *P.B. GUNTHERI* AS A BY-CATCH SPECIES

Significant catches of *P.b. guntheri* have been reported from other directed fisheries. For example, in the directed fishery for *C. gunnari* the proportion of *P.b. guntheri* in the total reported for the two species includes an average of almost a quarter of *P.b. guntheri* as by-catch. This must be viewed with considerable concern because the minimum mesh size permitted for *C. gunnari* is 80 mm which, providing the provisions of Conservation Measure 2/III section 2 are complied with, would not retain even large *P.b. guntheri*. The only way in which such large by-catches could be made would be by the use of an illegal mesh or a device to obstruct or diminish the size of the meshes.

6. CONCLUSIONS

Our analyses based on the fine-scale data reported to CCAMLR lead us to the following conclusions.

(i) Since survey results indicated that *P.b. guntheri* are not found at South Georgia, reported catches of this species in South Georgia waters must be in error, due to either misidentification of species or to misreporting of the location of capture.

(ii) At Shag Rocks where *P.b. guntheri* are known to be present, the fishery is currently catching a significant proportion of small fish of other species.

(iii) Significant by-catches of *P.b. guntheri* in other target fisheries indicates that nets that contravene Conservation Measure 2/III are being used.

REFERENCES

BALGUERIAS, E. 1989. Informe de resultados 'Antártida 8611' biología pesquera. Resultados de L. Campaña 'Antártida 866'. *Publ. Espec. Inst. Oceanogr.*, 2: 267-483. Madrid.

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*. SC-CAMLR-VIII, document WG-FSA-89/6.

PARKES, G.B., I. EVERSON, J. ANDERSON, Z. CIELNIASZEK, J. SZLAKOWSKI and R. TRACZYK. 1990. *Report of the UK/Polish Survey Around South Georgia and Shag Rocks in January 1990*. SC-CAMLR-IX, document WG-FSA-90/11.

Table 1: Reported catches of *P.b. guntheri.*

Split-Year	Reported Landings (tonnes)	Biomass Estimate (tonnes)
1979	15 011	-
1980	7 381	-
1981	36 758	-
1982	31 351	-
1983	5 029	-
1984	10 586	-
1985	11 923	-
1986	16 002	-
1987	8 810	81 000
1988	13 424	-
1989	13 016	-

Table 2: CCAMLR fine-scale data relevant to *P.b. guntheri* from midwater trawls. (Coordinates of locations within the Shag Rocks area are underlined; ANI - *Champsocephalus gunnari*; NOG - *Notothenia gibberifrons*, NOT - *Patagonotothen brevicauda guntheri*, LXX - Myctophidae).

Date		Target Species	Lat. (°S)	Long. (°W)	ANI	NOG	NOT	LXX	Other
1987									
Aug	21-31	ANI	54	37	25	10	5		39
Dec	1-10	NOT	54	40	0	0	374	0	0
	11-20	LXX	54	41	0	0	0	210	0
	21-31	LXX	54	41	1808	182	313	2994	396
1988									
Jan	1-10	ANI	54	41	242	0	228	69	4
		NOT	54	38	20	0	795	0	0
	11-20	ANI	54	41	2408	21	357	130	88
	21-31	ANI	54	41	1929	0	407	0	103
Feb	1-10	ANI	54	38	1165	0	136	0	76
	11-20	ANI	54	38	1423	0	0	0	0
	21-28	ANI	54	38	2256	86	0	0	54
Mar	1-10	LXX	54	38	0	0	10	230	0

Table 3: CCAMLR fine-scale data relevant to *P.b. guntheri* from bottom trawls. (For species codes used see Table 2).

Date		Target Species	Lat. (°S)	Long. (°W)	ANI	NOG	NOT	LXX	Other
1987									
Aug	21-31	ANI	54	37	904	4	13		
Dec	1-10	NOT	54	40	0	0	60	0	0
	11-20	NOT	54	40	33	0	403	8	96
	21-31								
1988									
Jan	1-10	NOT	54	38	94	0	2266	0	2
		ANI	54	38	602	125	70	0	9
	11-20	NOT	54	38	0	182	716	0	6
	21-31	NOT	54	38	0	214	272	0	133
Feb	1-10	NOT	54	38	281	0	1000	0	0
		NOT	54	38	244	0	795	0	0
	11-20	NOT	54	38	0	0	1026	0	0
		NOT	54	38	0	0	1539	0	31
	21-28	NOT	54	38	202	0	818	0	0
Mar	1-10	NOT	54	38	409	0	1671	0	0

Table 4: CCAMLR fine-scale data relevant to *P.b. guntheri* where fishing gear is not specified. (For species codes used see Table 2).

Date		Target Species	Lat. (°S)	Long. (°W)	ANI	NOG	NOT	LXX	Other
1987									
Nov	1-10	ANI	54	38	38	0	14	0	0
	11-20	ANI	54	38	79	0	29	0	0
	21-30	ANI	54	38	15	0	7	0	0
Dec	11-20	ANI	54	41	6		4	0	2
	21-31	ANI	54	41	178	0	96	0	53

Table 5: Catches of major fish species at South Georgia and Shag Rocks. NB: These data apply only to data records which include *P.b. guntheri*. (For species codes used see Table 2).

Species:	ANI	NOG	NOT	LXX	Other
Shag Rocks	6604	203	2242	3411	745
South Georgia	7757	621	11182	230	350

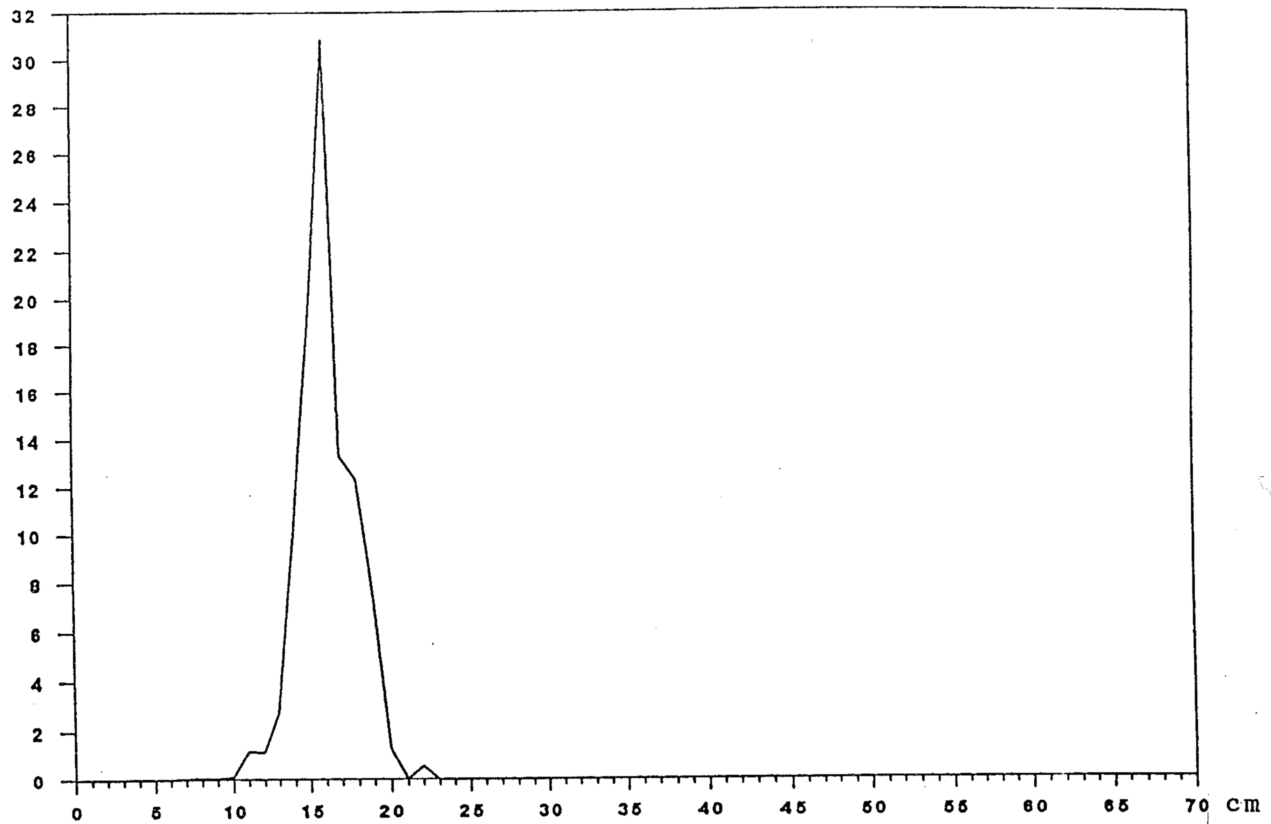


Figure 1: Size frequency distribution of *P.b. guntheri* at Shag Rocks from the UK survey in 1990 (Parkes *et al.*, 1990).

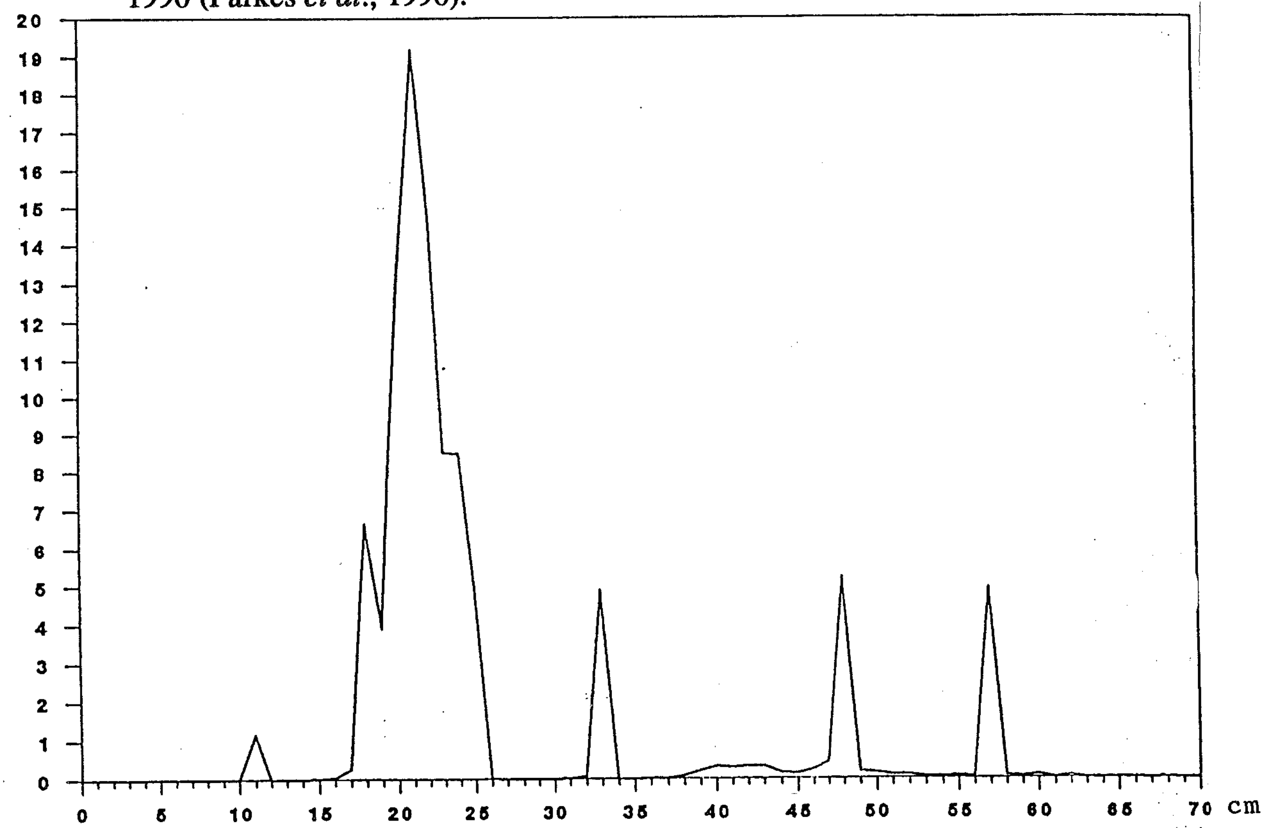


Figure 2: Size frequency distribution of *D. eleginoides* at Shag Rocks from the UK survey in 1990 (Parkes *et al.*, 1990).

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

AGE DETERMINATION OF *CHAMPSOCEPHALUS GUNNARI* LÖNNBERG, 1905 (CHANNICHTHYIDAE) TAKEN IN THE SOUTH GEORGIA AREA IN 1990

P.N. Kochkin*

Abstract

In January/February 1990 the UK and the USSR conducted two research cruises using the vessels RV *Hill Cove* and RV *Akademik Knipovich* to study the status of the *Champsocephalus gunnari* stock in the South Georgia area. In February 1990 the size composition of catches taken by *Akademik Knipovich* had three peaks corresponding to size groups of 16-18, 24-26 and 30-34 cm. Only vertebra samples (**n**=140) were used in age determination. Age groups from 1+ to 9+ were present in catches. Two peaks in size composition correspond with fish of the 1987 and 1985/86 year classes. The first small peak corresponds with the strong 1988 year class.

Résumé

En janvier/février 1990, la Grande-Bretagne et l'URSS ont mené deux campagnes de recherche sur les navires de recherche *Hill Cove* et *Akademik Knipovich* afin d'étudier l'état du stock de *Champsocephalus gunnari* en zone de Géorgie du Sud. En février 1990, la composition par tailles des captures effectuées par l'*Akademik Knipovich* a connu trois points culminants correspondant aux groupes de taille de 16 à 18, de 24 à 26 et de 30 à 34 cm. La détermination des âges n'a été effectuée qu'à partir d'échantillons de vertèbres (**n**=140). Les groupes d'âge de 1+ à 9+ étaient présents dans les captures. Deux des niveaux optimaux dans la composition par tailles correspondent aux poissons appartenant aux classes des années 1987 et 1985/86. Le premier point culminant faible, correspond à la classe forte de l'année 1988.

Резюме

С целью изучения состояния запаса *Champsocephalus gunnari* в районе Южной Георгии в январе-феврале 1990 г. Советским Союзом и Соединенным Королевством были выполнены два научно-исследовательских рейса на судах *Hill Cove* и *Академик Книпович*. В феврале 1990 г. по данным, получен-ным судном *Академик Книпович*, распределение размеров имело три пика, соответствующие размерным группам 16-18, 24-26 и 30-34 см. При определении возраста использовались только образцы позвонков (**n**=140). В уловах присутствовали особи, принадлежащие к размерным группам от 1I до 9I. Два пика в размерном составе соответствуют рыбе возрастных классов 1987 и 1985/86 гг. Первый небольшой пик соответствует мощному годовому классу 1988 г.

* VNIRO, 17a Verkhnaya Krasnoselskaya Street, Moscow, USSR 107140

Resumen

Durante enero/febrero de 1990, la URSS y el RU llevaron a cabo dos campañas de investigación empleando los buques RV*Hill Cove* y *Akademic Knipovich*, con el objeto de estudiar el estado de la población de *Champsocephalus gunnari* en el área de Georgia del Sur. En el mes de febrero de 1990, la composición por tallas de las capturas del *Akademic Knipovich* tuvo tres máximos correspondientes a los grupos de tallas de 16-18, 24-26 y 30-34 cm. Sólo se utilizaron muestras de vértebras (n=140) para la determinación de la edad y sólo se encontraron formando parte de la captura los grupos de edades de 1+ a 9+. Los dos máximos en la composición por tallas correspondieron a los peces de las clases anuales de 1987 y 1985/86. El primer máximo de menor intensidad corresponde a la recia clase anual de 1988.

1. INTRODUCTION

The accuracy of fish population structure assessments and, consequently, setting an optimum catch quota depends on the accuracy of age determination. Since *Champsocephalus gunnari* is one of the most abundant fish species exploited in the Antarctic, it is of primary importance that its age strcture be determined accurately. Assessing the age of this species is made more difficult because it lacks scales, has poorly calcified bones and small otoliths which are, without special treatment, almost opaque. Published data on *C. gunnari* age determination are therefore somewhat contradictory.

2. RESULTS

In January/February 1990 the UK and the USSR conducted two research cruises on the vessels RV *Hill Cove* and RV *Akademik Knipovich* to study the status of the *C. gunnari* stock in the South Georgia area. Investigations of the size composition of catches revealed three well-defined peaks. In January 1990 these peaks corresponded to size groups 14-16, 22-24, and 31-33 cm with the maximum being in the second size group (*Hill Cove*) while in February they were 16-18, 24-26 and 30-34 cm with the maximums being in the second and third size groups (*Akademik Knipovich*).

Two fish age-reading structures (otoliths and vertebrae), to be used in determining the age composition of *C. gunnari* stocks, were collected on board the *Akademik Knipovich.* Taking into consideration the similarity of age/length data obtained from a separate examination of otoliths and vertebrae (Kochkin, 1985) and the high labour intensity of treating otoliths having multiple growth lines we conducted age determinations in laboratory conditions using vertebrae only. The work was carried out according to a methodology described in an earlier work (Kochkin, 1980). Examination of age-reading preparations (n=140) showed up to six dark lines on vertebrae of fish 14 to 21 cm long (Figure 1). As in previous studies (Kochkin, 1985), each fourth line was taken to be an indicator of one year's growth. Yearly growth marks in vertebrae preparations for the age groups observed usually appear as two dark lines, or more rarely a single wide one (Figures 2 to 8). Our age/length data were on the whole close to analogous UK data from the *Hill Cove* cruise.

3. DISCUSSION

An analysis of age/length and length frequency distribution data, would seem to suggest that in January 1990, specimens born in 1987 were dominant in catches, whereas in February, specimens born in 1985/86 and 1987 were the most abundant. The first small peak in length composition of catches indicates the presence of a strong 1988 year class.

The latest publications on *C. gunnari* growth (Radtke, 1987, 1988 and 1990) indicate a significantly slower growth rate when compared with earlier data produced by most authors (see Table 1). It should be noted that the American scientist, R. Radtke, determined age by counting microincrements of otoliths using an electronic scanning microscope. Radtke's tabular and graphic data on daily growth rates of all age groups of *C. gunnari* (1987, 1988 and 1990) suggest that this species may hatch in all seasons. This conclusion contradicts previous data indicating simultaneous spawning and, consequently, a relatively short period of hatching. It should be noted that a great deal of caution is necessary when determining fish age by counting daily microincrements on otoliths since, according to G. Pannella's data, the inner structure of otoliths is wholly sequential only in the first three to four years of life (Pannella, 1971). It is recommended that these investigations be carried out on only young fish in non-exploited populations (Campana and Neilson, 1982).

It should also be kept in mind that our age/length assessments in 1990 gave results very similar to those obtained from 1981 to 1987 and is almost entirely accounted for by the variations in the size limits, worked out graphically (Kochkin, 1986; Kochkin, 1989), for fish of different ages. This is evidence of a relatively constant growth rate among contemporaneous *C. gunnari* of different generations and allows an approximate age/length structure of a population to be established in the absence of age determinations over a certain period of time.

REFERENCES

Кочкин, П.Н. 1980. Методика изготовления препаратов из позвонков рыб с целью определения их возраста. Вопр. ихтиологии, Т. 20, вып. 6 (125): 941-944.

Кочкин, П.Н. 1985. Анализ регистрирующих структур и линейный рост щуковидной белокровки *Champsocephalus gunnari Lönnberg* (*Channichthyidae*). Вопр. ихтиологии, Т. 25, вып 5: 834-843.

CAMPANA, S.E. and J.D. NEILSON. 1982. Daily growth increments in otoliths of Starry Flounder (*Platichthys stellatus)* and the influence of some environmental variables in their production. *Can. Joun. Fish. Aquat. Sci., 39* (7): 937-942.

GUBSCH, G. 1982. Zur Verbreitung und Biologie der Eisfiche (Chaenichthidae) im atlantischen Sector der Antarktis. *Fischereiforsch., 20* (2): 39-47.

KOCHKIN, P.N. 1986. A rapid method for estimating mean length of *Champsocephalus gunnari* from a range of age classes. CCAMLR/86/FA/12. Hobart, Australia. p. 12.

KOCK, K.-H. 1981. Fischereibiologische Untersuchungen an drei antarktischen Fischarten: *Champsecephalus gunnari* (Lönnberg, 1905), *Chaenocephalus aceratus* (Lönnberg, 1906) und *Pseudochaenichthys georgianus* (Norman, 1937) (Notothenioidei, Channichthyidae). *Mitt. Inst. Seefisch.,. 32*: 226. Hamburg.

OLSEN, S. 1955. A contribution to the systematics and biology of Chaenichthyids from South Georgia. *Nytt Magaz. Zool., 3*: 79-93. Oslo.

PANNELLA, G. 1971. Fish otoliths: daily growth layers and periodical patterns. *Sci., 173* (4002): 1124-1127.

RADTKE, R.L. 1987. Age determination of the Antarctic fishes *Champsocephalus gunnari* and *Notothenia rossii* from South Georgia. SC-CAMLR-VI/BG/43: 1-43. Hobart, Australia: CCAMLR.

RADTKE, R.L. and D.J. SHAFER. 1988. Age and growth estimates of the commercially important Antarctic fishes *Champsocephalus gunnari* and *Notothenia rossii* from South Georgia. *Antarct. J., 23* (5): 142-143.

RADTKE, R.L. 1990. Age determination of the Antarctic fishes *Champsocephalus gunnari* and *Notothenia rossii marmorata* from South Georgia. *Polar Biol., 10*: 321-327.

SOSINSKI, J. 1981. Biologia porownawcza Kergelen (*Champsocephalus gunnari* Lönnberg, 1905) z refonow Antarktyki. *Studia i materialy MIR, Ser. B, 48*: 91. Gydnia.

SOSINSKI, J. 1985. Some data on taxonomy and biology of the Antarctic icefish, *Champsocephalus gunnari* (Lönnberg, 1905). *Acta Ichthyol, et Piscat., 15*.

Table 1: *C. gunnari* growth according to various authors.

Age in years	Olsen 1955	Kock 1981	Sosinski 1981		Gubsch 1982	Kochkin 1985	Radtke 1990*
1	-	15.8	-	-	-	14.0	14.7
2	-	22.3	21.1	21.3	-	21.1	19.7
3	27.1	27.9	27.6	28.0	26.7	27.2	24.2
4	32.8	33.3	33.6	32.8	29.4	32.7	28.2
5	35.1	37.7	37.1	36.7	37.3	37.5	31.8
6	36.9	43.2	39.2	39.1	40.9	41.6	35.1
7	37.6	46.0	40.4	40.3	44.4	45.3	38.0
8	39.3	48.5	41.7	41.6	48.4	48.6	40.7
9	41.2	-	42.8		48.2	51.4	43.0
10	40.5	-	44.5		-	53.9	45.2
11	41.5	-	44.8		-	56.1	47.1
12	42.5	-	44.7		-	58.0	48.8
13	-	-	48.7		-	59.7	50.4
14	-	-	48.9		-	-	51.8
15	-	-	51.4		-	-	53.1

* Data were calculated according to the author's linear growth equation.

Table 2: Age/length data on *C. gunnari* in the South Georgia area, February 1990.

Age in Years	Variations in Overall Length (cm)	Number of Specimens
1+	14-21	24
2+	21-27	23
3+	27-33	28
4+	32-37	21
5+	35-41	16
6+	38-46	10
7+	47-52	15
8+	54	1
9+	55	2

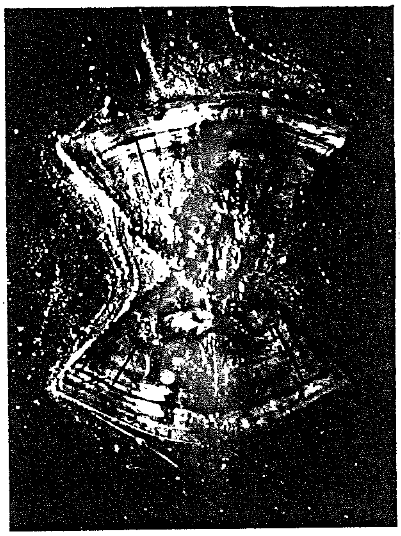


Figure 1: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Juvenile. TL=16.5 cm. Age 1⁺ years. 17 February 1990.

Figure 2: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Male (♂ III). TL=21 cm. W=60 g. Age 2⁺years. 17 February 1990.

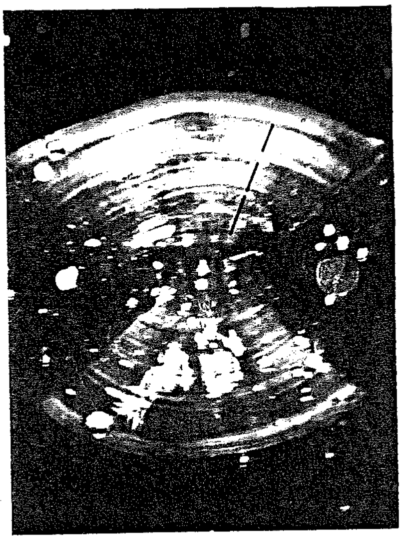


Figure 3: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Female (♀ II-III). TL=29 cm. W=130 g. Age 3⁺years. 22 February 1990.

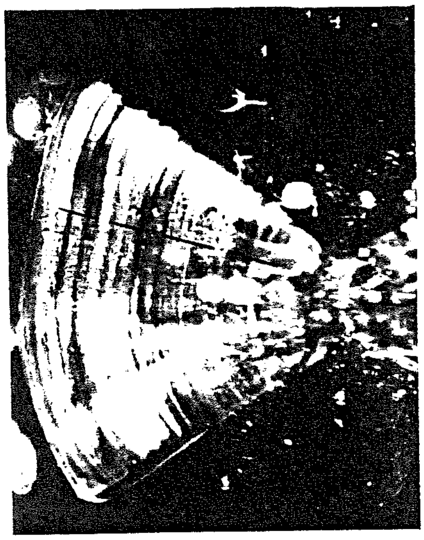


Figure 4: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Female (♀ III). TL=34 cm. W=250 g. Age 4⁺years. 17 February 1990.

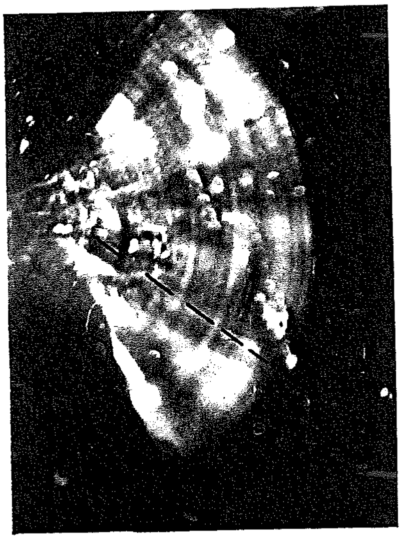


Figure 5: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Female (♀ III). TL=37 cm. W=350 g. Age 5+years. 22 February 1990.

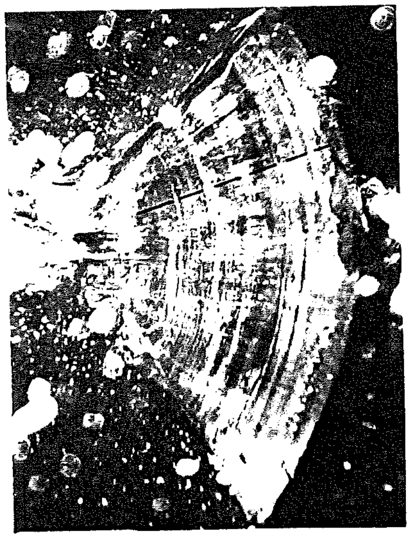


Figure 6: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Female (♀ III). TL=38 cm. W=400 g. Age 6+years. 26 February 1990.

Figure 7: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Male (♂ III). TL=43 cm. W=650 g. Age 6+years. 17 February 1990.

Figure 8: Vertebrae of *C. gunnari* taken by RV *Akademik Knipovich* in the South Georgia area in February 1990. Female (♀ III). TL=54.5 cm. W=1 400 g. Age 8+years. 17 February 1990.

Список рисунков

Lista de las tablas

Lista de las figuras

TRAWL BAG SELECTIVITY IN THE *CHAMPSOCEPHALUS GUNNARI* FISHERY

V.G. Bidenko* and I.G. Istomin**

Abstract

Experiments on trawl bag selectivity during fishing on pre-spawning concentrations of *Champsocephalus gunnari* were carried out in June 1990 in the South Georgia area concurrently with trawl surveys as part of the main biological and oceanic research program. The results presented here are based on 29 hauls and, due to the limited time available for experiments, should be considered as preliminary. $L_{50\%}$ was 24.8 cm and the selectivity factor was 3.10 for a mesh size of 80 mm. Comparison of these results with results from previous years demonstrates close similarity. A significant increase in modal length (up to 34-35 cm) as well as earlier sexual maturation of fish were noted. It was suggested that the use of Polish type chafers and a reinforced outer cover on trawl bags reduces the stress on the mesh threads and increases mesh openings therefore enhancing their selectivity properties. Further experiments are recommended in order to fully understand the mechanism involved.

Résumé

Des expériences sur la sélectivité des poches de chalut au cours de la pêche effectuée sur des concentrations de *Champsocephalus gunnari* en état de préponte furent tentées en juin 1990 dans la région de la Géorgie du Sud, ainsi que des campagnes d'évaluation par chalutage, dans le cadre du programme principal de recherche biologique et océanique. Les résultats présentés dans cette communication sont basés sur 29 traits et, étant donné le peu de temps disponible pour les expériences, devraient être considérés comme préliminaires. $L_{50\%}$ était de 24,8 cm et le facteur de sélectivité de 3,10 pour un maillage de 80 mm. La comparaison de ces résultats avec ceux des années précédentes révèle une étroite similarité. L'augmentation importante de la longueur modale (atteignant 34 - 35 cm) a été notée, de même que la maturation sexuelle plus précoce des poissons. Il a été avancé que l'utilisation de tabliers de type polonais et d'une couverture renforcée à l'extérieur des poches de chalut réduit la pression sur les fils du maillage et augmente l'ouverture de la maille, améliorant ainsi les propriétés de sélectivité. Des expériences complémentaires sont préconisées afin de mieux saisir le mécanisme en jeu.

Резюме

В июне 1990 г. одновременно с траловыми съемками, являющимися частью основной программы биологических и океанических исследований, были выполнены экспери-

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR
** VNIRO, 17a Verkhnaya Krasnoselskaya Street, Moscow, USSR 107140

менты по селективности мешков тралов при облове преднерестовых концентраций *Champsocephalus gunnari* в районе Южной Георгии. Представленные результаты были основаны на данных, полученных по 29 тралениям. В связи с тем, что время, предоставленное для проведения экспериментов, было ограничено, данные результаты следует рассматривать как предварительные. Для ячеи размером в 80 мм величина $L_{50\%}$ равнялась 24,8 см и фактор селективности - 3,10. Сравнение этих результатов с полученными за предыдущие годы указывает на их близкое сходство. Было отмечено значительное увеличение модальной длины (до 34-35 см), а также более раннее наступление половозрелости рыб. Высказывается предположение о том, что использование фартуков, применявшихся при промысле Польшей, и силовых внешних покрытий траловых мешков снижает нагрузку на волокна ячей и увеличивает их открытие, улучшая таким образом селективность трала. Для полного понимания данного механизма рекомендуется провести дополнительные эксперименты.

Resumen

Dentro del programa principal de investigación biológica y oceánica, se realizaron experimentos de selectividad con redes de saco, los cuales se compaginaron con prospecciones de arrastre. Estos estudios se llevaron a cabo en junio 1990, en la zona de Georgia del Sur y se centraron en las concentraciones de *Champsocephalus gunnari* durante la época previa al desove. Los resultados presentados en este trabajo se basan en 29 lances, pero debido a las limitaciones de tiempo dedicadas a los experimentos, deberán considerarse como preliminares. Para una luz de malla de 80 mm. se obtuvo un $L_{50\%}$ de 24.8 cm y un factor de selección de 3.10. Cuando se comparan dichos resultados con los de años anteriores, se ve que existen ciertas similitudes entre ellos. Se ha constatado un incremento importante de la talla modal (hasta 34 o 35 cm), así como una madurez sexual más temprana de los peces. Se indica que, el uso de protectores del copo polacos y de un forro reforzado en el exterior de la red de saco, disminuyen la tensión soportada por los hilos de la red y aumentan la abertura de las mallas, con lo que se obtiene una mejora de las propiedades de selección. Se recomienda la realización de nuevos experimentos con el fin de comprender mejor los mecanismos de este proceso.

---

1. INTRODUCTION

Results of experiments on trawl bag selectivity in the *Champsocephalus gunnari* fishery are presented in this work. Experiments were carried out on board BMRT *Anchar* in June 1990 in the South Georgia area concurrently with trawl surveys within the main biological and oceanic research. Due to the limited time that was available, the following material should be viewed as preliminary. Extensive theoretical and experimental research on trawl bag selectivity in the *C. gunnari* fishery should be conducted in the near future on the basis of this material. The paucity of data obtained from experimental work has made it necessary to include the results of previous studies.

Experiments were conducted on board the *Anchar* by Dr V.G. Bidenko (AtlantNIRO) and engineer I.G. Istomin (VNIRO) who were greatly assisted by the scientific team and the crew.

2. SCHEDULE AND AREA

Selectivity hauls were made from 17 to 20 June 1990 in an area having the mean coordinates of 54°25'S, 38°10'W at depths of 230 to 250 m. The four-mile-long fishing site extended in a north-south direction and had a sand-silt bottom.

Mean swell was approximately five on the Beaufort scale, atmospheric temperature from -1° to +2° and surface water temperature about 1.3°. No strong currents were registered.

Trawling was carried out 24 hours per day in both directions (wind permitting). The target species comprised from 80 to 100% of catches.

3. MATERIALS AND METHODS

BMRT *Anchar* is a stern freezer trawler with a displacement of 2 120 tonnes and a main engine of 2 000 hp.

Fishing gear was a standard soviet-made four-panel kapron[1] trawl "Khek-4M", used for fishing for bottom and off-bottom species (Figures 1 and 2). The triple-cable rigged (cable length - 100 m) trawl was equipped with a ground rope having 300 and 400 mm diameter bobbins and metal triple-slitted 5.5 m^2 trawl-boards with a dry weight of 1 780 kg (Figure 3).

Trawling speed during the study was from 3.0 to 3.4 knots. The trawl had a vertical opening of 7.5 m; the distance between the boards was 68 m when 550 m long wires were used.

A standard four-panel trawl bag type 7173 used in the *C. gunnari* fishery was used in the selectivity study. The double twine of the single-layer trawl bag was made of spun kapron fibres 3.1 mm in diameter. The nominal mesh size was 80 mm.

Investigations followed a methodology which incorporates the basic principles generally adopted for selectivity experiments (Treschev, 1974; VNIRO, 1983, AtlantNIRO, 1989 a, b) with a few modifications. These changes made it possible to consider more fully the nature of the fishery and the specific problems to be addressed.

The trawl bag was equipped with nine 5.8 m long bands of 35 mm kapron rope which were evenly spaced along the codend part of the trawl bag at 1.3 m intervals. The bag was then placed in a fine-meshed outer cover (fish retaining bag) larger than the bag itself and enveloping the entire trawl bag. To prevent damage caused by contact with the bottom and during hauling, it was also covered with 8.6 m long bands of rope. The rear 9 m of the outer cover was sheathed with heavy duty webbing. The lengthwise edges of the outer cover were reinforced by four kapron side ropes. The front part of the outer cover was attached to the front of the

1 a USSR-made polyamide-6 fibre

trawl bag along its external perimeter while the back part of the outer cover, which is 2 m longer than the trawl bag, was equipped with its own codend rope. The nominal mesh size of the outer cover was 35 mm, which ensured the retention of all fish passing through the trawl bag.

In order to prevent damage and undue wear and tear to the outer cover, trawling ceased when a catch of 5 to 6 tonnes had been taken.

The weight of fish retained in the trawl bag, as well as the weight of the fish passing into the outer cover, was determined by direct weighing using fish baskets of known volume, and by weight of frozen fish produce. Samples from the trawl bag and the outer cover were processed in the usual way for this type of experiment. After each haul, size composition and rate of escapement were determined and a full biological analysis of samples was conducted once daily to determine fish biometry.

The inner mesh size of the trawl bag was measured after every 10 hauls with the help of a wedge-shaped gauge used in ICNAF. Measurements were taken in three cross-sections, both along the trawl bag and around its perimeter. The mesh size of the trawl bag when filled with fish was measured on deck by means of dividers when catches exceeded three tonnes.

4. RESULTS

Data obtained from the 29 hauls made using the trawl bag described above are given in Table 1. Trawling duration was from 10 to 70 minutes with the average being 44 minutes. Mean catch-per-haul was approximately 1.5 tonnes (approximately 2.0 tonnes/hour). Data on fish length frequency distribution and biometric characteristics for the period being studied are given in Table 2. Details of the sex composition of the exploited population and maturity stages of individual fish are given in Table 3 (data from V.P. Shopova, AtlantNIRO).

Preliminary data on fish retention by the trawl bag aggregated over all hauls made during the experiment are presented in Table 4 on ICSEAF SELDAT Form 1.

A trawl-bag selectivity curve was constructed from these data (Figure 4). The method of sliding means (Treschev, 1974) was used to calculate experimental values.

In this instance, the length of fish retained in the trawl bag at 50% equals:

$$l_{50} = 24.8 \text{ cm}$$

and the selectivity factor equals:

$$K_s = \frac{l_{50}}{B} = \frac{24.8}{8.01} = 3.10$$

where $\mathbf{K_s}$ = selectivity factor;
$\mathbf{l_{50}}$ = overall length of fish retained at a 50% retention rate;
B = mesh size.

5. ANALYSIS OF RESULTS

Analysis of the results obtained reveals the unusual composition of this particular *C. gunnari* stock:

- dominance of females (80% of all specimens recorded);
- high modal length (34 to 35 cm);
- the insignificant amount of smaller (less than 25 cm) size groups accounting for less than one percent of the population; and
- absence of immature fish.

Extensive data from previous years give a modal length of 24 to 26 cm (AtlantNIRO, 1986). Moreover, Polish and Spanish scientists have reported a mean length of 23.4 cm at 50% maturity. However, we have observed a distinctly earlier maturation and larger fish size in the population (see Table 2.). The observed pre-spawning condition of the population is enough to suggest that under any other conditions fish would be more able to pass through the mesh and the selective properties of the mesh would be greater. Therefore it would appear to be illogical to consider any increase in mesh size.

A more promising solution to the problem of increasing the selective properties of trawl bags is the introduction of of a design aimed at easing the tension in the mesh threads. AtlantNIRO scientists (Ivanova *et al.*, 1989) noted that in a number of cases Polish-type chafers led to some reduction of net selectivity properties but not by any means, did they worsen them to any considerable degree.

In the above-mentioned study where South-West Atlantic hake was being taken by trawls, the inner-mesh size was 114 to 115 mm. At a 50% retention rate and without the reinforced outer cover, the modal length was 38.5 cm, whereas a modal length of 40.93 cm was achieved when using the reinforced Polish-type chafer. This demonstrates the improved selectivity of trawl bags when using a reinforced outer cover. This is caused by the decreased tension on the main part of the net webbing occasioned by the reinforced outer cover which, apparently takes most of the strain during trawling. In any case, it is attached for this reason. A more open mesh is less tense and allows fish to pass through more freely. The angle of the corner of the top mesh in the trawl bag was 44.2° when equipped with a reinforced outer cover and 36.6° without it.

This clearly confirms the results of a modelling experiment in a flume tank conducted in AtlantNIRO by engineer E.L. Baev and scientist N.M. Ivanova. Figure 5 shows the elongation of the mesh threads of a trawl bag without the Polish-type chafer. Figure 6 clearly shows that using a reinforced outer cover decreases the tension on the threads of the main net webbing and significantly widens mesh openings (in both cases, a fine-meshed bag filled with plastic balls was placed inside the trawl to simulate a catch).

Simulated trawling at a speed of 3 to 3.5 knots with a catch of 50 tonnes showed the mean values of the angle of the corner of the top mesh in the trawl bag (based on measurements of all meshes along its length) to be:

- for models with reinforced outer cover - 34.3°; and
- for models without reinforced outer covers - 26.1°.

Of course, there are other ways to decrease the tension of the mesh threads (by placing net webbing over riblines, belly lines, etc.); however, special research and *in situ* experiments are needed in relation to the *C. gunnari* fishery.

6. CONCLUSION

Experiments on trawl bag selectivity on pre-spawning concentrations of *C. gunnari* demonstrated that $l_{50\%}$ was 24.8 cm and the selectivity factor was 3.10 for a mesh size of

80 cm. Comparison of these results with those from previous years shows close similarity. A significant increase in the modal length (up to 34-35 cm) as well as earlier sexual maturation of fish were noted.

It is suggested that the use of Polish-type chafers and a reinforced outer cover on trawl bags decreases the stress on the mesh threads and increases mesh openings and therefore selective properties of the mesh. Further experiments are required to fully understand the mechanism involved.

REFERENCES

АтлантНИРО. 1986. Оценка параметров селективности промысловых тралов относительно рыб районов АЧА и ЮЗА по результатам исследований в 1981-1985 гг. Калининград, издательство АтлантНИРО.

АтлантНИРО. 1989. Методические указания по сбору данных по биометрии рыб при производстве траловых съемок. Калининград, издательство АтлантНИРО.

АтлантНИРО. 1989. Указания по регистрации параметров орудия лова, режимах его эксплуатации при проведении траловых съемок. Калининград, издательство НПО промрыболовства.

Трещев А.И. 1974. Научные основы селективного рыболовства. Москва, Пищевая промышленность.

ВНИРО. 1983. Методические указания по сбору данных по селективности тралов и травматической гибели рыб, прошедших сквозь ячею кутка. Москва, издательство ВНИРО.

IVANOVA, N.M. *et al.* 1989. Study of the influence of the Polish-type enforcement topside chafer on trawl codend selectivity in the Cape hake fishery (AtlantNIRO, Kaliningrad, USSR): document 890577 SAC/89/S.P./6 rev., Madrid.

Table 1: Results of trawl selectivity experiments.

Number	Trawl Number	Date	Start Time	Trawl Duration (mins)	Weight (kg)	
					Catch	Escapement
1	2	3	4	5	6	7
1	312	17.06	12.05	11	3000	25
2	313	"	13.55	10	2000	10
3	314	"	15.37	20	4500	51
4	315	"	19.03	17	2000	32
5	316	"	20.41	23	1000	48
6	317	"	22.26	52	1500	30
7	319	18.06	06.35	40	000	32
8	320	"	08.25	52	1900	96
9	321	"	10.35	37	2200	63
10	322	"	12.42	38	900	46
11	323	"	15.00	50	1700	60
12	324	"	17.35	50	1300	50
13	325	"	20.10	40	1100	35
14	326	"	22.25	50	900	70
15	327	19.06	00.45	40	740	35
16	328	"	02.35	45	600	32
17	329	"	04.50	46	500	67
18	330	"	07.32	61	1300	140
19	331	"	09.55	53	1000	55
20	332	"	12.25	55	2100	106
21	333	"	14.55	50	2300	60
22	334	"	17.00	55	950	97
23	335	"	19.25	36	750	40
24	336	"	21.43	54	800	70
25	337	20.06	00.37	51	800	66
26	338	"	03.20	55	530	50
27	339	"	06.00	60	1500	62
28	340	"	09.00	60	900	75
29	341	"	11.30	58	1300	77
Total: 29				1269	41070	1 680

Table 2: Biometry of *C. gunnari* around South Georgia.

Length (cm)	Number of specimens	Girth (mm), ϕ		Height (mm), H		Breadth (mm), B		Eccentricity of Fish Body	Weight (g), G	
		ϕ	σ_ϕ	H	σ_H	B	σ_B	$E=\frac{H^2 - B^2}{H^2}$	G	σ_G
1	2	3	4	5	6	7	8	9	10	11
19	1	68.0	-	21.0	-	18	-	0.515	20	-
20	-	-	-	-	-	-	-	-	-	-
21	1	75.0	-	23.0	-	18	-	0.623	20	-
22	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-
24	2	101.5	2.1	35.0	0.0	29.0	1.4	0.560	75.0	7.1
25	9	101.1	6.2	35.4	4.0	28.9	3.6	0.578	87.6	22.9
26	44	107.8	6.4	37.8	3.7	30.4	3.1	0.594	104.3	24.3
27	74	113.4	5.7	40.4	4.0	31.5	3.3	0.626	107.7	24.6
28	74	116.9	7.5	41.2	4.2	32.9	4.0	0.602	121.9	30.8
29	81	120.9	6.9	43.3	4.1	34.7	3.7	0.598	143.0	27.6
30	63	128.4	8.5	45.5	4.2	37.0	3.9	0.582	174.1	25.4
31	53	133.5	9.7	47.9	4.7	38.4	4.7	0.598	187.1	37.4
32	89	141.3	7.4	50.5	3.7	40.8	4.4	0.589	212.9	35.5
33	125	145.5	7.1	51.7	3.7	41.4	3.9	0.599	233.3	29.8
34	137	151.4	8.1	54.3	4.5	42.9	4.2	0.613	262.1	35.4
35	127	155.8	9.1	54.9	5.4	45.2	4.7	0.568	282.5	36.0
36	77	163.1	9.6	58.2	4.4	46.2	4.2	0.608	318.1	46.8
37	62	168.6	8.8	58.8	5.2	47.5	4.3	0.589	347.1	40.6
38	40	172.3	9.3	61.0	5.6	49.2	4.6	0.591	372.0	41.1
39	14	181.2	14.2	63.5	7.3	50.9	6.5	0.598	406.1	46.0
40	14	184.6	10.4	65.0	5.3	52.7	5.0	0.585	458.2	31.9
41	10	187.7	5.0	64.8	4.8	54.2	5.4	0.548	480.0	50.0
42	1	180.0	-	61.0	-	55.0	-	0.432	475.0	-
43	2	184.0	12.7	67.5	10.6	54.5	0.7	0.590	567.5	10.6

Table 3: Stages of maturity of *C. gunnari*.

Length class (cm)	Males				Females				Total
	Quantity	II	III	IV	Quantity	II	III	IV	
19	1			-	-	-	-	-	1
21	1	-	1	-	-	-	-	-	1
24	-	-	-	-	2	-	-	2	2
25	2	-	2	-	7	1	1	5	9
26	12	1	10	1	32	6	1	25	44
27	14	3	6	5	60	2	1	57	74
28	18	3	11	4	56	3	1	52	74
29	18	2	9	7	63	3	-	60	81
30	16	2	6	8	47	-	-	47	63
31	10	-	5	5	43	1	-	42	53
32	8	-	3	5	81	-	-	81	89
33	13	-	6	7	112	-	1	111	125
34	17	-	3	14	120	-	-	120	137
35	24	-	6	18	103	-	-	103	127
36	13	-	4	9	64	-	-	64	77
37	17	-	8	9	45	-	-	45	62
38	17	-	3	14	23	-	-	23	40
39	6	-	-	6	8	-	-	8	14
40	8	-	2	6	6	-	-	6	14
41	5	-	2	3	5	-	-	5	10
42	1	-	-	1	-	-	-	-	1
43	1	-	-	1	1	-	-	1	2
Total:	222	11	87	123	878	16	5	857	1100

Table 4: Mesh selectivity data for *C. gunnari*: Covered codend experiments (ICSEAF SELDAT , Form 1).

Length of Fish	Number of Fish Caught			Percentage of Fish Retained
	In Codend	In Cover	Total	
A	B	C	D	E
17	-	1	1	0
18	-	7	7	0
19	-	16	16	0
20	30	38	68	44.1
21	-	20	20	0
22	-	20	20	0
23	-	24	24	0
24	38	64	102	37.3
25	534	373	907	58.9
26	1436	866	2302	62.4
27	2984	1430	4414	67.6
28	5927	1619	7546	78.5
29	5071	1071	6142	82.6
30	5756	821	6577	87.5
31	8207	646	8853	92.7
32	14287	833	15120	94.5
33	19382	654	20036	96.7
34	21138	578	21716	97.3
35	23114	350	23464	98.5
36	13204	144	13348	98.9
37	10511	53	10564	99.5
38	6963	23	6986	99.7
39	4763	2	4765	100.0
40	2603	0	2603	100.0
41	1387	0	1387	100.0
42	344	0	344	100.0
43	237	0	237	100.0
44	59	0	59	100.0
45	-	-	-	-
46	28	0	28	100.0
Total no. of fish	148003	9653	157656	
Total weight (tonnes)	41.07	1.68	42.75	

Country: USSR, Date: 17 to 28 June 1990
Codend made of Kapron (type of fibre)
Mesh size in codend (mm) - 80.1. Mesh size in cover (mm) - 35.2
Duration of haul (min) - 1 269. Name of vessel - *Anchar* (AtlantNIRO)
Tonnage (GRT) - 2 120. Engine power (HP) - 2 000
Type of trawler - stern trawler

Remarks: Trawl codend with 44 mm mesh bar, without Polish-type chafer. 29 hauls, total hauling duration - 1269. Catches-per-haul from 0.5 to 4.5 tonnes.

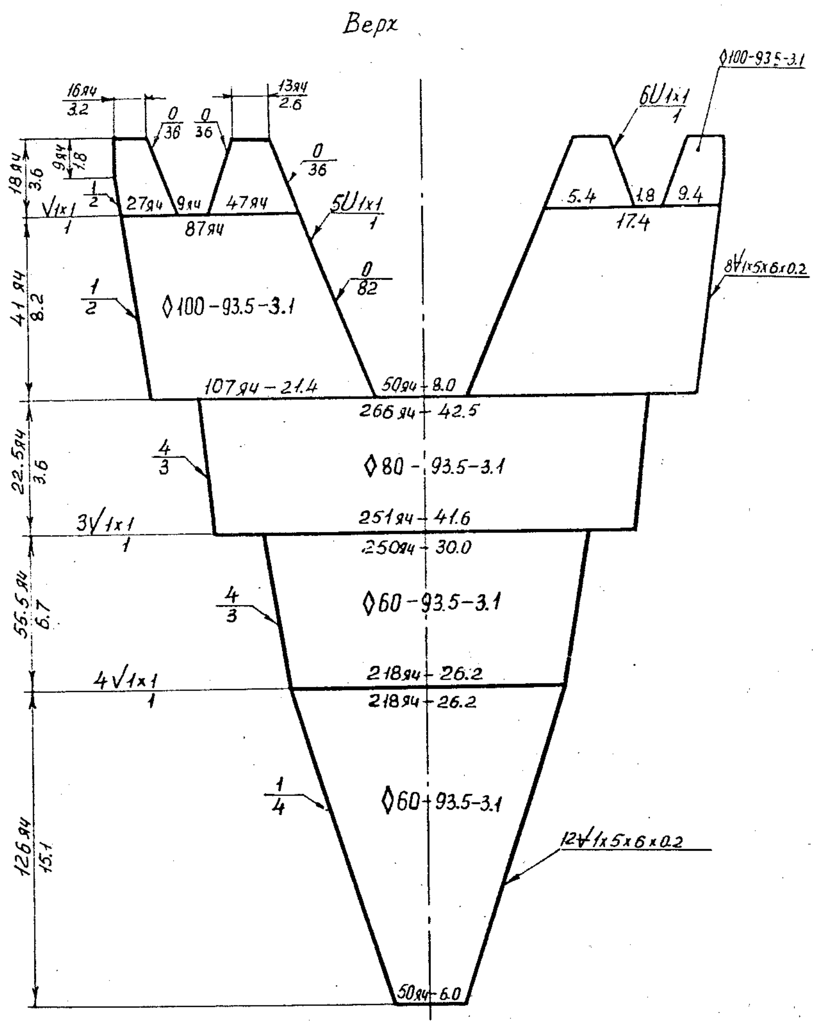


Figure 1: Top panel of trawl “Khek-4M”.

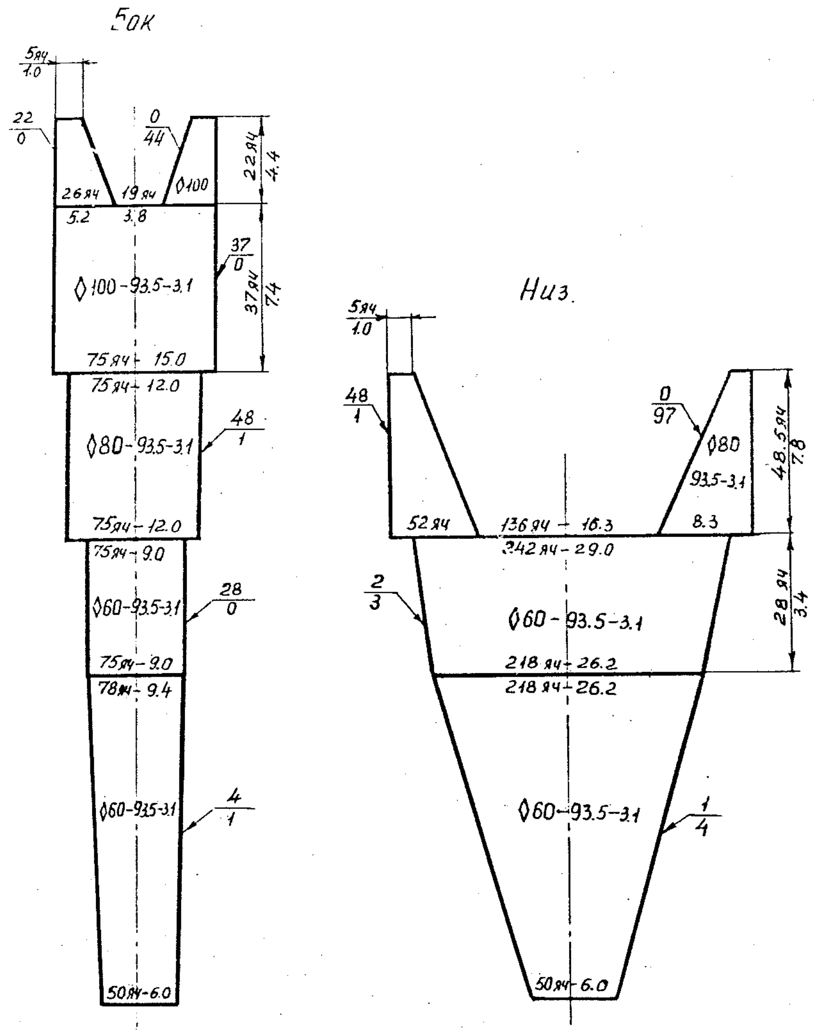


Figure 2: Side and bottom panels of trawl "Khek-4M".

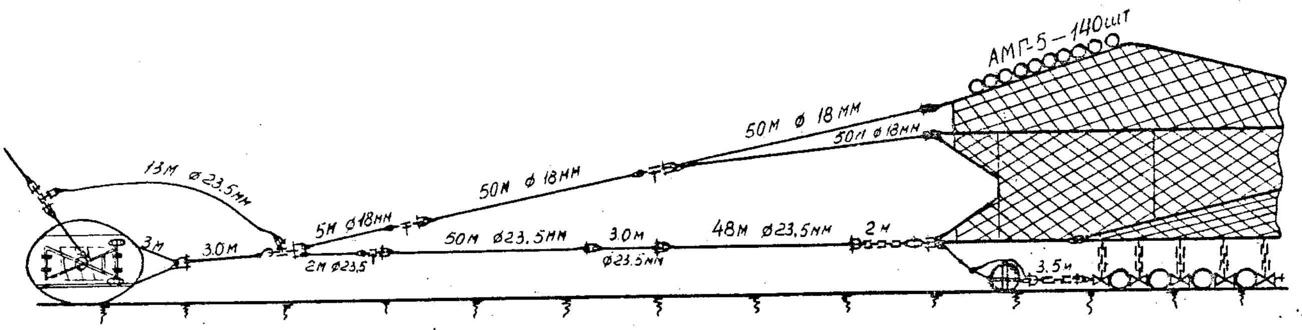


Figure 3: Rigging of trawl “Khek-4M”.

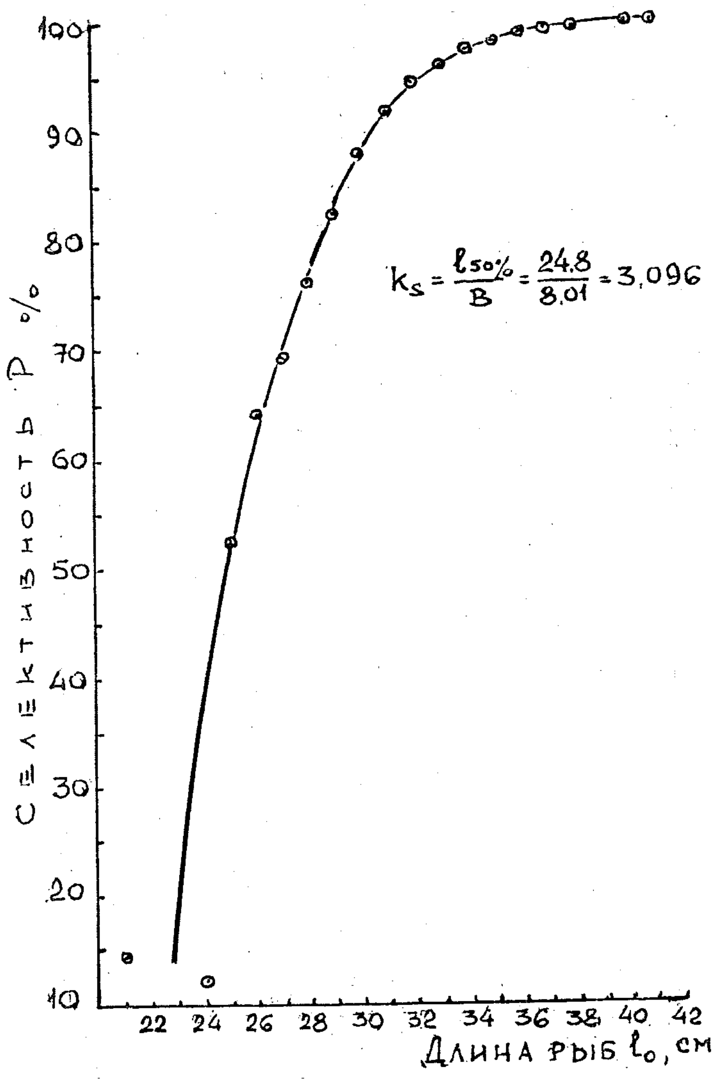


Figure 4: Selectivity curve for trawl bag with mesh size B=80.1 mm in respect of *C. gunnari* on the South Georgia Shelf (BMRT *Anchar*, June 1990. Number of hauls N=29. Calculations made using the method of sliding mean).

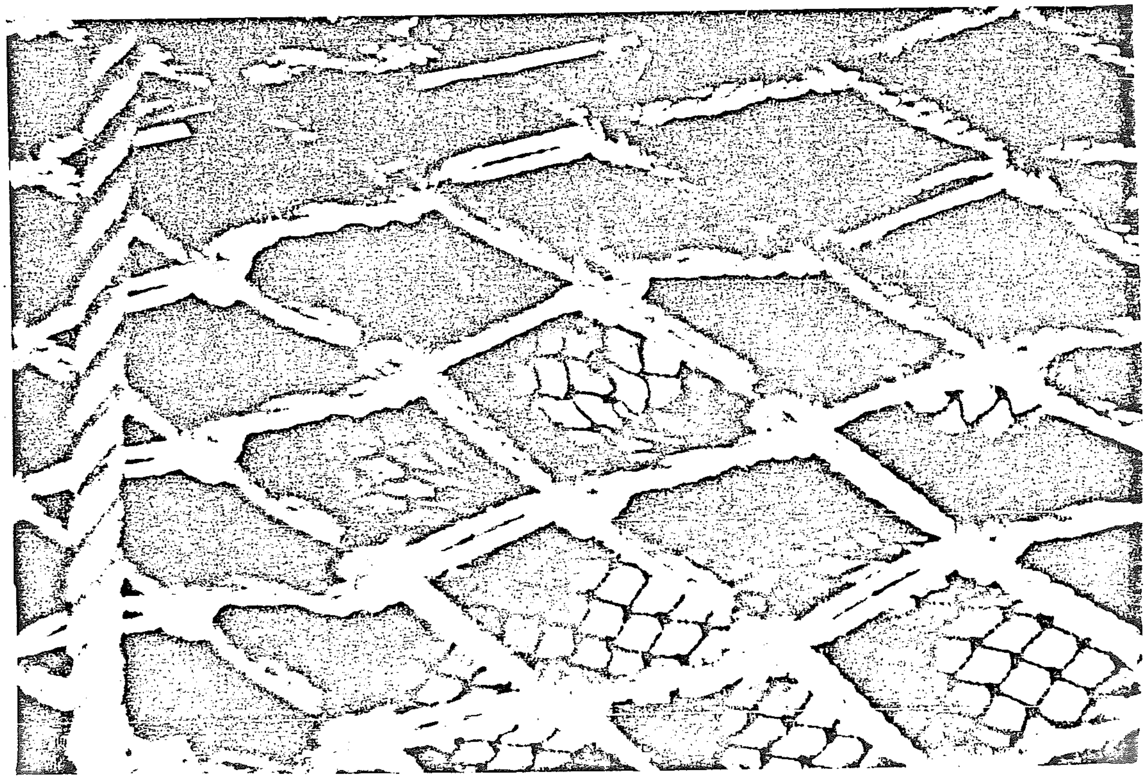


Figure 5: Mesh of trawl bag with simulated catch minus reinforced outer cover.

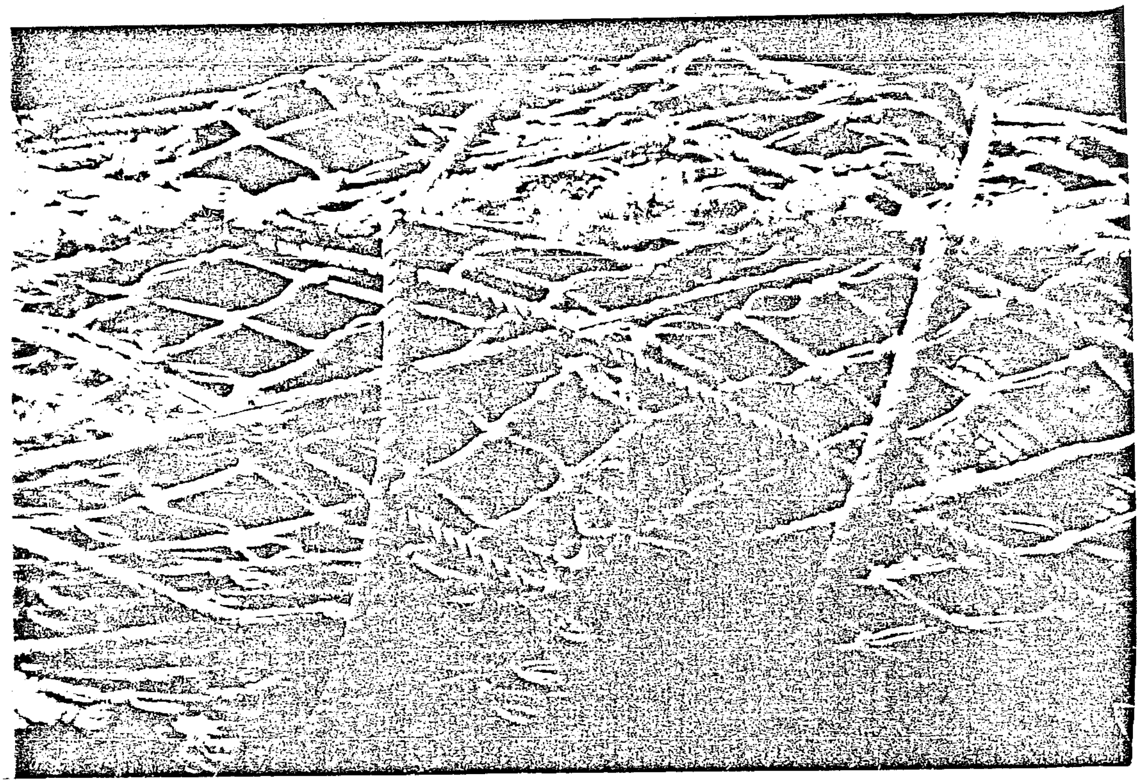


Figure 6: Mesh of trawl bag with simulated catch with reinforced outer cover.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

ON THE INSTANTANEOUS NATURAL MORTALITY RATE OF *CHAMPSOCEPHALUS GUNNARI*, SOUTH GEORGIA (SUBAREA 48.3)

G.A. Frolkina and R.S. Dorovskikh*

Abstract

The instantaneous rate of natural mortality (M) of *Champsocephalus gunnari* in the South Georgia area was assessed using six different methods. Data on size composition of catches from 1964/65 to 1968/69 and the age/length key for the first half of 1972 were used in the calculations. The results provided a wide range of estimates for M. The discussion of the results suggested that M=0.56 should be used in stock assessment for *C. gunnari* in Subarea 48.3.

Résumé

Le taux instantané de mortalité naturelle (M) de *Champsocephalus gunnari* dans la zone de la Géorgie du Sud a été estimé selon six méthodes distinctes. Pour les calculs, on s'est servi des données sur la composition en tailles des captures de 1964/65 à 1968/69 et de la clé âges/longueurs pour la première moitié de 1972. Les résultats ont offert une gamme étendue d'estimations de M. L'examen des résultats semble montrer que M=0,56 devrait être utilisé lors de l'évaluation des stocks de *C. gunnari* dans la sous-zone 48.3.

Резюме

Коэффициент мгновенной естественной смертности (M) вида *Champsocephalus gunnari* в районе Южной Георгии был оценен шестью имеющимися методами. В расчетах были использованы данные по размерному составу за 1964/65 - 1968/69 гг. и размерно-возрастные ключи за первую половину 1972 г. В результате был получен широкий диапазон оценочных значений коэффициента M. Анализ результатов указывает на то, что при оценке запаса *C. gunnari* в Подрайоне 48.3 следует использовать M=0,56.

Resumen

Se evalúa el coeficiente de mortalidad natural instantánea (M) de *Champsocephalus gunnari* en la zona de Georgia del Sur, mediante seis métodos distintos. Para los cálculos se han empleado datos de composición por tallas de las capturas correspondientes a las temporadas 1964/65 a 1968/69, además de datos de la clave edad/talla del primer semestre de 1972. Se han obtenido una amplia gama de resultados de M, que una vez examinados y debatidos, demuestran que el valor adecuado de M para la evaluación de la población de *C. gunnari* en la Subárea 48.3 es de M=0.56 .

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR

1. INTRODUCTION

K.-H. Kock (1981) was the first to determine the instantaneous rate of natural mortality using the methods of Pauly (M=0.61) and Richter-Efanov (M=0.22). The author himself admitted that the results varied to such a degree that interpreting them was very difficult indeed. Realising that the results were contradictory and using for the most part, earlier assessments of *Notothenia rossii*, Kock made the preliminary assumption that **M** was between 0.22 and 0.38. The CCAMLR Working Group on Fish Stock Assessment later adopted 0.35 as the value of this coefficient.

Recent research, however, has determined a value of 0.45 (Sparre, 1989) and 0.55 (Frolkina and Dorovskikh, 1989) for **M.** This research was carried out using age/length composition data from catches of the "pristine" *C. gunnari* population according to the methods of Baranov, Beverton and Holt and several other methods. Therefore in 1989 the CCAMLR Working Group on Fish Stock Assessment used **M**=0.50 in its calculations as well as the previously accepted estimate of 0.35.

Since Sparre (1989) singled out the Heinke method (M=0.56) from all those used, the Working Group decided that this value could be used in the future on an equal footing with M=0.35 (CCAMLR-VIII, paragraph 49). The Working Group recognised the importance of accurately determining a value for **M** and decided to address the question once again in 1990 at the Ninth Meeting of CCAMLR. Taking the above factors into consideration, the authors decided to tackle once more the problem of obtaining a more precise value for **M.** In contrast to a previous study (Frolkina and Dorovskikh, 1989), the number of methods used was increased and included the Heinke, Robson-Chapman methods as well as an approach outlined in a paper by Gasiukov and Dorovskikh (1990).

2. MATERIALS AND METHODS

Data on size composition from catches taken from the seasons 1964/65 to 1968/69 were used (Table 1) as was the age/length key for the first half of 1972 (Table 2). Unlike the authors' study in 1989, growth parameter calculations and estimates of **M** were carried out using data for each individual season and for the entire period. Age composition over all seasons was determined using two procedures. The basic algorithms are described below.

(i) The Baranov Method (1914):

When fishing is either not taking place or is insignificant it is assumed that the instantaneous rate of mortality **Z=M** and

$$M = ln\left(\frac{N_{a+1}}{E_{a+1}} / \frac{N_a}{E_a}\right)$$

where N_a = catch of age group a which is fully represented in the catch; and
E_a = fishing effort.

It is assumed that fishing effort for groups a and $a+1$ is the same, i.e. $E_a = E_{a+1}$, and, consequently,

$$M = ln\,(N_{a+1}/N_a)$$

(ii) The Heinke Method (1913):

$$M = ln \frac{N_a + N_{a+1} + N_{a+2} + \dots}{N_{a+1} + N_{a+2} + \dots}$$

N_a is the same here as it is for the Baranov method.

(iii) The Beverton-Holt Method (1956):

$$M = \frac{1}{\bar{t} - t'}$$

where $\bar{t}$ = mean age in the catch;
t' = first age group, fully represented in the catch,

$$\bar{t} = \frac{\sum_{a=t'}^{t_k} (a+0.5) \cdot N_a}{\sum_{a=t'}^{t_k} N_a}$$

t_k = oldest age group in the catch.

(iv) The Robson-Chapman Method (1961):

$$M = ln \left(1 + \frac{1}{\bar{t} - t'} \right)$$

where $\bar{t}$ and t' are the same as for the Beverton-Holt method.

(v) The Alverson-Carney Method (1975):

$$M = \frac{3 \cdot K}{e^{T \cdot K} - 1}$$

where **K** = Bertalanffy growth equation parameter; and
T = age at which population biomass is at its maximum.

(vi) The approach suggested by Gasiukov and Dorovskikh (1990):

This approach is based on the construction of a regression curve between the rate of annual fishing mortality and fishing effort. Particular attention is paid to the value of the parameter a in this equation:

$$F_y = a + b \cdot E_y$$

where a, b = parameters of the equation;
E_y = fishing effort in year y; and
F_y = rate of fishing mortality in year y.

VPA is tuned to various values for the rate of natural mortality when calculating fishing mortality coefficients. From the suite of values **M** is taken to be the one at which the estimate of the independent parameter ***a*** is close to zero.

The following two procedures were used to calculate the age structure of the catches. The first assumes that the following data are known:

- size composition of catches; and
- age/length key.

Size composition data is used in estimating components of size classes in the catch:

$$p_a = \frac{n_l}{\sum_{l_n}^{l_k} n_l}$$

where n_l = number of fish of length l in the catch;
l_n = minimum length in the catch; and
l_k = maximum length in the catch.

The age/length key is used in determining the component of age class ***a*** which belongs to size class ***l***:

$$p_a^l = \frac{n_a^l}{\sum_{a=a_1}^{a_2} n_a^l}$$

where n_a^l = number of fish aged a of length l in the key;
a_1 = minimum age of fish of length l;
a_2 = maximum age of fish of length l;

The component of age group ***a*** in the catch is determined by the formula:

$$p_a = \sum_{l=l}^{l_2} p_l \cdot p_a^l$$

where l_1 = minimum length which may correspond to class a; and
l_2 = maximum length which may correspond to class a.

Kimura's algorithm is the basis of the second procedure for determining age composition (Kimura, 1987). This algorithm presupposes the same initial data as does the first procedure, however the age/length key may refer to a period independent of time at which data on size composition was collected.

Size composition components are estimated in the same way as in the first procedure although components of the age/length key are worked out using the following formula:

$$p_a^l = \frac{n_a^l}{\sum_{l=l_1}^{l_2} n_a^l}$$

The algorithm functions in the following iterational way:

Step 1. Starting values are determined for components of age composition in a catch:

$$p_a = \frac{1}{a_k},\ a=1,2,\ldots,a_k$$

where a_k = the number of age groups in the key.

Step 2. Estimates of these components are made for all size classes using data on the age/length key:

$$p_l' = \sum_{a=1}^{a_k} p_a \cdot p_a^l$$

Step 3. New estimates of the components of age composition are calculated according to the formula:

$$p_a' = p_a \cdot \sum_{l=l_n}^{l_k} \frac{p_l \cdot p_a^l}{\sum_{j=a_1}^{a_2} p_j \cdot p_j^l}$$

Step 4. The premise $\left| p_a - p_a' \right| < 8$ is validated. If it is accurate then:

- the new estimates of $\mathbf{p}_a'$ become current, i.e. $P_a = p_a'$, $a = 1,2,\ldots a_k$; and
- calculations given in Step 2 are continued.

3. RESULTS OF CALCULATIONS AND DISCUSSION

Age composition of catches from 1964/65 to 1968/69 and for the period as a whole is shown in Table 3. Mean length by age group for each season was calculated as the mean weighted value of length for each age group (Table 4).

The data presented served as a starting point for determination of parameters of Bertalanffy's growth curve (Table 5). Values for mean length determined using less than three elements in the sample were eliminated during calculations. Thus, the background data obtained (Tables 3 to 5) were used in calculating values of **M** for each season individually and for the entire period using all of the methods shown (Table 6). It should be noted that the small sample size in seasons 1964/65 and 1967/68 brings into question the reliability of estimates for parameters $\mathbf{L_\infty}$ and **K** since the length recorded for *C. gunnari* significantly excedes the asymptotic length and **K** is much greater than the values obtained when larger samples were taken. Therefore the Alverson-Carney method was not employed to estimate **M** for those seasons.

The results provided a wide range of estimates for **M** (from 0.16 to 1.13). It is interesting to observe that in two of the methods (Beverton-Holt and Robson-Chapman) mean age varies considerably from season to season:

Season	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
$\bar{t}$	5.8	4.9	4.3	4.1	4.6	4.6

Therefore, when in season 1964/65 mean age is the greatest, **M** is accordingly the lowest (Beverton-Holt, Robson Chapman methods) and in 1968/69, when mean age is the lowest then **M** (derived using the above two methods) is the greatest in comparison with the estimates of other methods.

The bottom two rows of Table 6 present the mean estimates of **M** for each season and for the whole period. The first gives values obtained using all methods while the second disregarded maximum and minimum values. In practically every case the estimate of the mean value of **M** was either equal to or greater than 0.50. Therefore any future use of **M**=0.35 will be incorrect. This view is supported by the method suggested by Gasiukov and Dorovskikh (1990).

Table 7 gives the mean weighted values of fishing mortality for the main age groups (3 to 5) calculated by VPA using the Laurec-Shepard tuning method. This was done at various levels of natural mortality which were used to construct the following regression equation:

$$F_y = a + b \cdot E_y$$

Table 8 shows **a** and **b** from the regression equation as well as the correlation coefficient which demonstrates the close link between the two. Analysis of these data indicates that the highest point of intersection (**a**=0.183) occurs at M=0.35. The smallest positive value (**a**=0.045) occurs at M=0.56. Moreover, when there is a transition of **M** from 0.56 to 0.70, the intercept sign changes from positive to negative (Table 9, Figure 1).

It may therefore be assumed that the rate of natural mortality for *C. gunnari* is not less than 0.56.

4. CONCLUSION

The authors consider that their results show the instantaneous rate of natural mortality for *C. gunnari* in Subarea 48.3 (South Georgia) to be 0.56.

REFERENCES

BABAYAN, V.K., T.I. BULGAKOVA, P.G. BORODIN and YU.N. EFIMOV. 1984. Методические рекомендации. Применение математических методов и моделей для оценки запасов рыб. Москва. ОНТИ, ВНИРО: 4-42.

KOCK, K.-H. 1981. Fischereibiologische Untersuchungen an drei antarktischen Fischarten: *Champsocepohalus gunnari* (Lönnberg, 1905), *Chaenocephalus aceratus* (Lönnberg, 1906) und *Pseudochaenichthys georgianus* Norman, 1937 (Nototheniodei, Channichthyidae). In: *Mitteilungen aus dem Institut für Seefischerei der Bundesforschungsanstalt für Fischerei.* Hamburg, N 32: 228.

FROLKINA, ZH.A. and R.S. DOROVSKIKH. 1989. On the assessment of Bertalanffy growth equation parameters and the instantaneous natural mortality rate of South Georgia mackerel icefish. In: *Selected Scientific Papers, 1989 (SC-CAMLR-SSP/6).* Hobart, Australia: CCAMLR. pp. 29-36.

SPARRE, P. 1989. Some comments on the estimation of natural mortality for *C. gunnari*, *N. squamifrons* and *P.b. guntheri*, based on Soviet data. In: *Report of the Eighth Meeting of the Scientific Committee (SC-CAMLR-VIII).* Hobart, Australia: CCAMLR. Annex 6: 294-300.

KIMURA, D. 1987. Mixtures of empirical distributions: An iterative application of the age/length key. *Biometrics* 43: 23-35.

GASIUKOV, P.S. and R.S. DOROVSKIKH. 1990. *State of the Stock and TAC Assessment of the Patagonotothen guntheri for the 1990/91 Season in the South Georgia Area (Subarea 48.3).* WG-FSA-90/28. Hobart, Australia: CCAMLR. pp. 22.

Table 1: Age composition of the "pristine" *C. gunnari* population by season.

Length (cm)	1964/65	1966/67	1967/68	1968/69	1964-69
16-17	0	3	0	0	3
18-19	0	18	0	0	18
20-21	0	9	2	14	25
22-23	0	2	8	77	87
24-25	0	23	53	138	214
26-27	4	53	111	123	291
28-29	4	91	55	41	191
30-31	4	79	19	23	125
32-33	1	50	28	39	118
34-35	4	67	38	26	135
36-37	6	72	55	17	150
38-39	14	63	46	7	130
40-41	8	78	10	0	96
42-43	13	27	0	2	42
44-45	14	13	0	0	27
46-47	2	8	0	1	11
48-49	2	6	0	3	11
50-51	0	8	0	2	10
52-53	0	6	0	3	9
54-55	0	5	0	3	8
56-57	0	0	0	0	0
58-59	0	0	0	1	1
Total	76	681	425	520	1701

Table 2: Age/length key for the first half of 1972.

Length (cm)	Age group									
	1	2	3	4	5	6	7	8	9	10
16-17	15	0	0	0	0	0	0	0	0	0
18-19	25	2	0	0	0	0	0	0	0	0
20-21	1	41	0	0	0	0	0	0	0	0
22-23	0	43	8	0	0	0	0	0	0	0
24-25	0	83	9	0	0	0	0	0	0	0
26-27	0	29	69	0	0	0	0	0	0	0
28-29	0	0	100	0	0	0	0	0	0	0
30-31	0	0	88	8	0	0	0	0	0	0
32-33	0	0	48	50	2	0	0	0	0	0
34-35	0	0	0	83	9	0	0	0	0	0
36-37	0	0	0	42	46	2	0	0	0	0
38-39	0	0	0	13	61	13	0	0	0	0
40-41	0	0	0	0	13	36	1	0	0	0
42-43	0	0	0	0	11	11	6	0	0	0
44-45	0	0	0	0	0	4	11	0	0	0
46-47	0	0	0	0	0	3	7	1	0	0
48-49	0	0	0	0	0	0	7	3	1	0
50-51	0	0	0	0	0	0	4	4	2	0
52-53	0	0	0	0	0	0	1	5	3	0
54-55	0	0	0	0	0	0	0	2	4	2

Table 3: Age composition of the "pristine" *C. gunnari* population determined using two procedures for calculations.

Age	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
1	0	20	0	0	20	16
2	1	129	103	355	588	384
3	11	228	169	183	591	616
4	9	132	81	53	275	246
5	20	121	68	18	227	238
6	17	83	16	3	119	131
7	16	29	0	4	49	45
8	1	10	0	4	15	12
9	0	7	0	3	10	10
10	0	1	0	2	3	2

Table 4: Mean length in the "pristine" *C. gunnari* population by age group.

Age	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
1	-	17.7	-	-	17.7	17.3
2	26.0	21.3	23.5	22.2	22.3	23.0
3	28.3	28.7	27.5	27.3	27.9	28.4
4	35.2	34.2	34.5	33.5	34.2	34.0
5	38.8	37.8	37.0	36.4	37.6	37.5
6	41.3	40.2	38.7	39.7	40.2	40.3
7	44.1	45.2	-	47.8	45.1	45.6
8	47.5	50.5	-	51.0	50.5	50.5
9	-	51.9	-	52.3	52.5	52.0
10	-	54.0	-	56.3	54.0	54.0

Table 5: Estimate of Bertalanffy growth curve parameters for each season and for the whole period determined by using two procedures for calculating age composition.

Parameter	Seasons					
	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
L_∞(cm)	47.5	86.7	45.6	77.4	80.9	82.0
t_0	0.83	-1.45	-0.34	-0.66	-1.34	-1.35
k	0.414	0.088	0.304	0.119	0.099	0.098
Sample size	5	9	5	8	10	9
Youngest group	3	1	2	2	1	1
Oldest group	7	9	6	9	10	9

Table 6: Estimates of natural mortality rate by season using various methods.

Method	Seasons					
	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
Baranov	0.80	0.77	0.78	0.96	0.75	0.82
Beverton-Holt	0.36	0.53	0.77	0.90	0.62	0.63
Heinke	0.16*	0.47	0.70	1.13**	0.61	0.64
Robson-Chapman	0.31	0.43	0.57	0.64	0.48	0.49
Carney	-	0.38	-	0.34	0.37	0.37
Estimate of mean **M** (Option 1)	0.475	0.516	0.705	0.794	0.566	0.590
(Option 2)	0.490	0.516	0.705	0.710	0.566	0.590

* minimum value of **M**
** maximum value of **M**

Table 7: Standardized fishing effort and mean weighted fishing mortality for the main age groups (3 to 5) at different levels of natural mortality.

Season	Effort	F (mean weighted)			
		M=0.35	M=0.50	M=0.56	M=0.70
1982/83	20 420	1.521	1.396	1.343	1.210
1983/84	15 798	2.274	2.005	1.884	1.564
1984/85	2 984	0.854	0.589	0.492	0.296
1985/86	4 483	0.259	0.186	0.159	0.104
1986/87	20 035	1.131	0.905	0.811	0.589
1987/88	15 941	0.913	0.691	0.604	0.414
1988/89	7 972	0.345	0.248	0.213	0.141
1989/90	1 497	0.113	0.089	0.079	0.057

Table 8: Parameters of a regression correlation between the rate of fishing mortality and fishing effort at different levels of natural mortality.

Natural Mortality Rate	Parameters		Correlation Coefficient **R**
	a	**b**	
0.35	0.183	0.0000667	0.718
0.50	0.081	0.0000613	0.722
0.56	0.045	0.0000586	0.721
0.70	0.022	0.0000510	0.715

Table 9: Preliminary estimates of fishing mortality obtained from the regression equation in Table 8.

	F (Preliminary)			
	M=0.35	**M=0.50**	**M=0.56**	**M=0.70**
20 420	1.545	1.333	1.242	1.019
15 798	1.237	1.049	0.971	0.784
2 984	0.382	0.264	0.220	0.130
4 483	0.482	0.356	0.308	0.207
20 035	1.519	1.309	1.219	1.000
15 941	1.246	1.058	0.979	0.791
7 972	0.715	0.570	0.512	0.384
1 497	0.283	0.173	0.133	0.054
0	0.183	0.081	0.045	-0.022

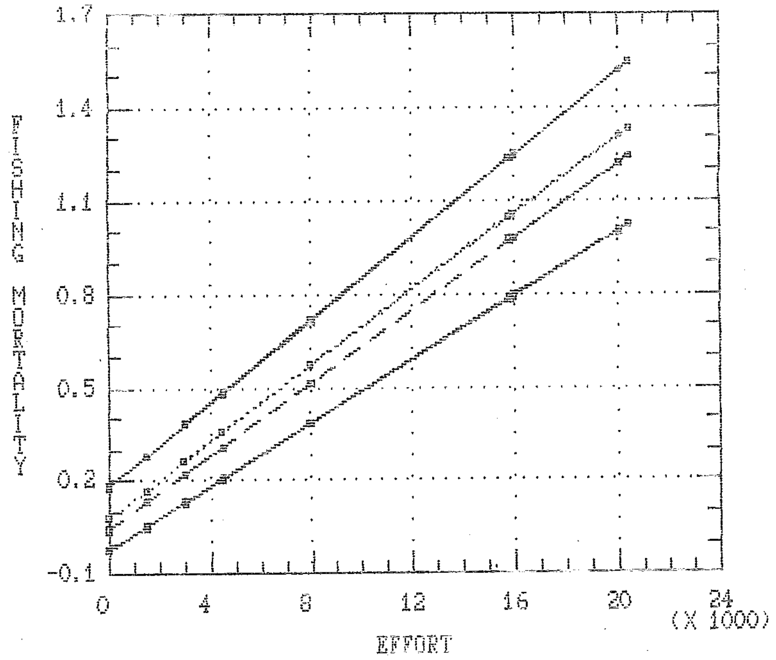


Figure 1: Functions of fishing mortality coefficients and fishing effort for different values of natural mortality.
1 - **M**=0.35 3 - **M**=0.56
2 - **M**=0.50 4 - **M**=0.70

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

STANDARDIZATION OF FISHING EFFORT FOR *CHAMPSOCEPHALUS GUNNARI* IN THE SOUTH GEORGIA AREA (SUBAREA 48.3)

P.S. Gasiukov*

Abstract

Traditional calculation of catch-per-unit-effort series is inflexible in its use of data types and has no estimate of accuracy. A standardized CPUE index for *Champsocephalus gunnari* fishing in Subarea 48.3 is derived using a multiplicative model and data from many different classes (countries, types of vessel, fishing gear, months and years). Multiple regression is used to solve the model and the resultant yearly standardized CPUE shows the same trends independent of the values selected to standardize the model. The mean coefficient of variation for the CPUE values was 0.399.

Résumé

Le calcul traditionnel des séries de capture par unité d'effort est rigide dans son utilisation des types de données et sa précision n'a pas été estimée. Un indice de CPUE standardisé pour la pêche de *Champsocephalus gunnari* dans la sous-zone 48.3 est dérivé au moyen d'un modèle multiplicatif et de données de nombreuses classes distinctes (pays, types de navires, engins de pêche, mois et années). La régression multiple est utilisée pour résoudre le modèle et la CPUE résultante annuelle standardisée révèle les mêmes tendances indépendantes des valeurs sélectionnées pour standardiser le modèle. Le coefficient moyen de variation pour les valeurs de CPUE était de 0,399.

Резюме

При традиционных вычислениях набора величин вылова на единицу промыслового усилия неизменно используются одни и те же типы данных, а также при таких вычислениях не выводится показатель степени точности. Стандартизированный показатель СЗГУ для промысла *Champsocephalus gunnari* в Подрайоне 48.3 был получен путем использования мультипликативной модели и данных широкого ряда классов (страны, типы судов, орудия лова, месяцы и годы). При выполнении расчетов по этой модели используется многократная регрессия, при этом полученные стандартизированные годовые показатели CPUE проявляют одни и те же тенденции, независимо от величин, использованных в стандартизации модели. Средний коэффициент изменчивости показателей СЗГУ равняется 0,399.

---

* AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, USSR

Resumen

El método de cálculo empleado comúnmente para estimar las series de captura por unidad de esfuerzo es bastante limitado en los tipos de datos utilizados y no da lugar a la estimación de la precisión. Mediante el uso de un modelo multiplicativo y datos de muchos tipos (países, tipos de embarcación, aparejos de pesca, meses y años), se logra inferir un índice de CPUE normalizado para la pesca de *Champsocephalus gunnari* en la Subárea 48.3. Se usa la regresión múltiple para resolver el modelo, y la CPUE anual normalizada resultante muestra las mismas tendencias, independiente de los valores que fueron seleccionados para normalizar el modelo. El coeficiente de variación promedio para los valores de CPUE fue de 0.399.

1. INTRODUCTION

The principal method for determining the stock of *Champsocephalus gunnari* from the South Georgia area (Subarea 48.3) is virtual population analysis (VPA) (Borodin and Kochkin, 1988; Basson *et al*., 1989; Frolkina and Gasiukov, 1989). It is known that in order to use the method correctly it is necessary to substantiate the selection of terminal coefficients of fishing mortality. For this purpose values of fishing effort for a number of years of fishing are used as additional information (Pope and Shepherd, 1985).

An attempt to use fishing effort to tune the VPA when studying *C. gunnari* stocks was made in the paper by Frolkina and Gasiukov (1989).

This task is complicated by the fact that fishing for *C. gunnari* is characterized by a considerable intra-annual irregularity and marked dynamics. Whereas fishing was at first carried out by means of bottom trawls, in recent years midwater trawls have been used. This impedes the formation of a sequence of monotypical (standardized) values of fishing effort. In the abovementioned paper fishing effort was standardized in the following way. A certain type of vessel was selected as standard and, on the basis of information recorded in the STATLANT B form, a sequence of catch-per-unit-effort values was developed by years of fishing. Standardized values of fishing effort were then calculated by dividing summary catch by respective values of catch-per-unit-effort.

This method is simple, but possesses a number of disadvantages. It does not use information on fisheries of other countries and other types of vessels, and does not take into account the intra-annual heterogeneity of the fishery. When this method is in practical use, an index of accuracy is not defined. The situation becomes particularly complex if the commercial significance of the vessel selected as a standard changes with the passage of time.

The method of standardizing fishing effort based on a multiplicative model (Robson, 1966; Gavaris, 1980) is free of the disadvantages mentioned above and is considered to have potential for use in this fishery.

2. MULTIPLICATIVE MODEL OF STANDARDIZING FISHING EFFORT

The multiplicative model described in the paper by Gavaris (1980) is summarized here. The basic model involves representing a standardized value of catch-per-effort by means of the following formulae:

$$U = U_R \cdot P_{1J_1}^{X_{1J_1}} \cdot P_{2J_2}^{X_{2J_2}} \cdot P_{TJ_T}^{X_{TJ_T}} \qquad (1)$$

where U is the standard value of catch-per-unit-effort,
U_R is the value of catch-per-effort for a certain combination of categories selected as references,
P_{ij_i} is the relative power of the J_i^{th} category in the i^{th} category type,
X_{ij} is 1, if u is pertinent to j categories, and is 0 in other cases,
T_k is a number of different category types.

It is suggested that each element ***u*** may be classified as belonging to a definite category ***j*** in category type ***i***. For example, type of vessel, fishing division, month within year and finally fishing year may be considered to be category types.

The value U_R is a number which is characteristic for a given combination of categories. A given combination (i.e., reference categories) is determined beforehand from each type of category. Their characteristic feature is the equality to 1 of a respective coefficient of relative power.

The concept of a 'standard' is a set of categories which corresponds to a certain value of catch-per-effort; all other values of catch-per-effort are given in relation to the latter. For example, a standard may be catch-per-effort for a certain type of vessel using a certain gear in a certain month of a certain year.

A standardized value for catch-per-effort for a given type of category is calculated by formula (1), if the respective indices are substituted. Having selected 'year of fishing' as a type of category, one may calculate standardized values of catch-per-effort for a sequence of fishing years and consider them to be an abundance index. At the same time, total value of fishing effort is obtained by dividing total catch by a standardized value of catch-per-effort.

Parameters of the multiplicative model are calculated with multiple linear regression after logarithmic transformation (1):

$$ln\ U_\iota = ln\ U_R + \sum_{i=1}^{T} ln\ P_{ij_i} \cdot X_{ij_i} \qquad (2)$$

where $ln\ u_\iota$ is a dependent variable,
ι is the number of the set, ι=1,...,M,
X_{ij} is an independent variable.

At the same time, model parameters satisfy the following limitations:

$$\sum_{i=1}^{K_i} ln\ P_{ij_i} = 0\ ,\ i=1,2,...,T \qquad (3)$$

where K_i is the number of categories in i category types.

The sequence of calculations when defining model parameters is made in accordance with the algorithm of multiple regression (Draper and Smith, 1966). Goodness of fit test is characterized by the multiple coefficient of correlation. Estimates of the values of standard errors and confidence intervals possess some peculiarities. These are described in detail by Gavaris (1980).

The practical application of the multiplicative model for standardizing fishing effort may entail some complications which are caused by a possible lack of correlation of the system matrix (2). Corresponding modifications of the algorithm for the standardization of model parameters are described in the paper by Gasiukov (1990).

3. DATA USED

Standardizing fishing effort for *C. gunnari* in the South Georgia area (Subarea 48.3) is made with the aid of statistical data which are stored in the CCAMLR data base. A study of available information showed that in order to solve a problem the data since 1981/82 could be used. However, it should be noted that for the first two years of this period, data on fishing effort were scanty.

The whole of the commercial statistics allows for classification into the following categories:

- country;
- type of vessel;
- fishing gear;
- month within year; and
- year of fishing.

The total number of all the types is 31, the volume of the set being 103 elements.

4. RESULTS OF CALCULATIONS AND DISCUSSION

Results of standardizing fishing effort for the *C. gunnari* fishery for the period from 1981/82 to 1989/90 are represented in Tables 1 to 3. Since the selection of reference categories does not effect algorithm activity, they are not referred to in this paper, but such information is contained in Table 2. It is adopted as a standard value (tonnage class 10) in October which used bottom-fishing gear.

The multiple coefficient of correlation is 0.801, i.e., goodness of fit is high enough. Figure 1 shows a plot of the temporal trend of standardized values of catch-per-fishing-effort with 95% confidence intervals. A considerable vagueness in the estimates for the first two fishing seasons used for calculations is especially noticeable on the graph. This is obviously due to the small volume of the sample for these seasons. In the 1981/82 season the data on fishing effort were available for only 5% of the total catch for the season. Therefore, it is not recommended to use these estimates for the subsequent calculations, taking into account their high degree of uncertainty.

A calculation was also made in which the data for the 1980/81 and 1981/82 seasons were excluded. These results are not given as they are practically identical to those given in Table 3.

Use of the multiplicative model showed that the temporal trend of values of catch-per-unit-effort obtained was independent of the values selected as a standard, although absolute values differed. The values obtained may be used as an index of abundance when assessing the stocks.

ACKNOWLEDGEMENT

The author acknowledges Dr D. Agnew, CCAMLR Data Manager, for his prompt provision of the information required for calculations.

REFERENCES

BASSON, M, J.R. BEDDINGTON and W. SLOSARCZYK. 1989. *The Status of the Champsocephalus gunnari Stock in the South Georgia Area.* WG-FSA-89/8 Rev. 1. Hobart Australia: CCAMLR. p. 34.

BORODIN, R. and P.N. KOCHKIN. 1988. *Champsocephalus gunnari Stock Status in the South Georgia Area.* WG-FSA-88/32. Hobart Australia: CCAMLR. p. 14.

DRAPER, N.R. and H. SMITH. 1966. *Applied Regression Analysis.* New York: J. Wiley and Sons, Inc. p. 392.

FROLKINA, J. and P. GASIUKOV. 1989. *1989/90 Stock Status and TAC Assessment for Champsocephalus gunnari in the South Georgia Area (Subarea 48.3).* WG-FSA-89/22 Rev. 1. Hobart, Australia: CCAMLR. p. 14.

GASIUKOV, P.S. 1990. Application of the multiplicative model for fishing effort standardization in a special case. NAFO SCR Doc. 90/50. p. 14.

GAVARIS, S. 1980. Use of the multiplicative model to estimate catch rate and effort from commercial data. *Can. J. Fish. Aquat. Sci. 37*: 2272-2275.

POPE, J.G. and J.G. SHEPHERD. 1985. A comparison of the performance of various methods for tuning VPAs using effort data. *J. Cons. Int. Explor. Mer. 40*: 176-184.

ROBSON, W.E. 1966. Estimation of the relative fishing power of individual ships. *ICNAF Res. Bull. 3*: 5-14.

Table 1: Statistical characteristics of standardizing fishing effort for the *C. gunnari* fishery in the South Georgia area (Subarea 48.3).

Analysis of Variance

Source of Variation	DF	Sums of Squares	Mean Squares	F-Value
Intercept	1	6.110E0001	6.110E0001	
Regression	27	3.717E0001	1.377E0000	4.982
Type 1	2	5.981E0000	2.990E0000	10.820
Type 2	3	2.229E0000	7.431E-001	2.689
Type 3	2	5.650E-001	2.825E-001	1.022
Type 4	11	3.644E0000	3.312E-001	1.199
Type 5	9	8.724E0000	9.693E-001	3.508
Residuals	75	2.073E0001	2.764E-001	
Total	103	1.190E0002		

Coefficient of multiple correlation R=0.801
Coefficient of multiple correlation R squared = 0.682

Table 2: Coefficients of the multiplicative model.

Category	Code	Variable	Coefficient	Standard Error	Number of Observations
1	3	Intercept	1.751	0.233	103
2	2				
3	10				
4	10				
5	1983				
1	1	1	-3.332	0.720	3
	2	2	-2.051	0.583	20
2	1	3	1.560	0.640	19
	3	4	-0.133	0.134	38
	4	5	1.360	0.737	2
3	9	6	0.176	0.653	1
	11	7	0.230	0.164	19
4	1	8	-0.099	0.252	12
	2	9	0.029	0.284	7
	3	10	-0.056	0.268	7
	4	11	-0.180	0.284	7
	5	12	-0.393	0.297	5
	6	13	-0.630	0.280	6
	7	14	-0.298	0.260	9
	8	15	-0.593	0.276	7
	9	16	-0.079	0.302	5
	11	17	-0.306	0.240	12
	12	18	-0.450	0.257	13
5	1981	19	-1.084	0.368	4
	1982	20	0.346	0.808	1
	1984	21	-0.235	0.216	14
	1985	22	-0.250	0.381	3
	1986	23	-0.921	0.279	6
	1987	24	-0.592	0.196	28
	1988	25	-1.007	0.209	21
	1989	26	-0.830	0.324	5
	1990	27	-0.247	0.304	5

Table 3: Standardized values of catch-per-unit-effort for *C. gunnari*.

Predicted Catch Rate

Standards Used Variable Numbers: 3 2 10 10

Year	Total Catch	Catch Rate			
		Prop.	Mean	SE	Effort
1981	29 464	0.249	2.083	0.765	14 142
1982	47 454	0.057	6.607	4.680	7 182
1983	131 576	0.961	6.443	1.492	20 420
1984	80 664	0.807	5.106	1.131	15 798
1985	14 293	0.640	4.789	1.777	2 984
1986	11 368	0.893	2.536	0.699	4 483
1987	71 853	0.897	3.586	0.732	20 035
1988	37 736	0.748	2.367	0.488	15 941
1989	22 213	0.935	2.786	0.734	7 972
1990	7 268	1.000	4.856	1.676	1 497

Average CV for the mean: 0.319

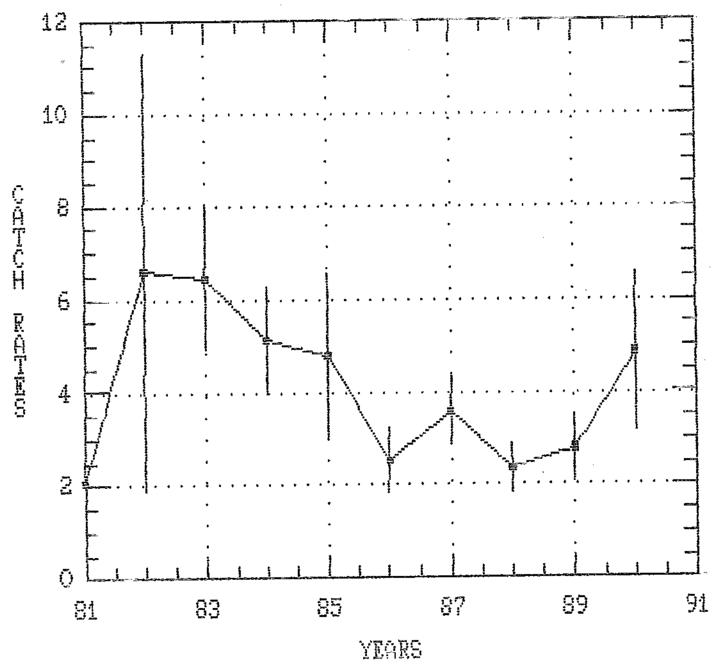


Figure 1: Standardized values of catch-per-unit-effort for *C. gunnari* from 1981/82 to 1989/90.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

WG-FSA-90/35

SEASONAL AND INTER-ANNUAL VARIABILITY IN THE DISTRIBUTION OF *ELECTRONA CARLSBERGI* IN THE SOUTHERN POLAR FRONT AREA (THE AREA TO THE NORTH OF SOUTH GEORGIA IS USED AS AN EXAMPLE)

A.N. Kozlov, K.V. Shust and A.V. Zemsky*

Abstract

From 1987 to 1989 VNIRO (USSR) conducted six trawl and acoustic surveys in the area to the north of South Georgia Is between 49° to 54°S and 25° to 40°W. The area is within the Polar Frontal Zone where mesopelagic fish from the family Myctophidae are found most frequently and regularly. Seasonal and interannual variability in distribution, density and biomass of the most abundant species of myctophids, *Electrona carlsbergi*, are analyzed and summarized in this paper. The species is also known to form large concentrations throughout the year. Results of surveys showed that the distribution and behaviour of *E. carlsbergi* are strongly related to environmental conditions in the area as well as to the availability and distribution of zooplankton. *E. carlsbergi* was found over the entire study area. The largest concentrations of the species, however, were found mainly along edges of the frontal zone where such fundamental environmental characteristics of water masses as currency dynamics, temperature and density, attain the highest level of variation. The most large-scale and dense concentrations of *E. carlsbergi* were observed in summer (December to February) when fish were distributed in the upper 50-100 m layer. The smallest and less dense concentrations were observed in the winter (June) at 200 m and deeper. The spring and autumn months were noted as transitional for parameters of vertical distribution and density of fish concentrations. Calculations of biomass of *E. carlsbergi* in the area indicated that its variability during the year is related to parameters of spatial and vertical distribution of fish. Interannual variability of *E. carlsbergi* biomass in the area was also observed.

Résumé

De 1987 à 1989, VNIRO (URSS) a mené six chalutages et campagnes acoustiques dans la région au nord de l'île de la Géorgie du Sud, entre 49 et 54°S et 25 et 40°W. Cette région est située à l'intérieur de la zone frontale polaire dans laquelle les poissons mésopélagiques de la famille des Myctophidae se rencontrent le plus fréquemment et le plus régulièrement. Cette communication présente une analyse et une récapitulation de la variabilité saisonnière et interannuelle dans la répartition, la densité et la biomasse d'*Electrona carlsbergi*, l'espèce la plus abondante des Myctophidae. Cette espèce est également connue pour former de grande concentrations tout au long de l'année. Les résultats des campagnes ont montré que la distribution et le comportement d'*E. carlsbergi* sont étroitement liés aux conditions de l'environnement de la région ainsi qu'à la disponibilité et répartition du zooplancton. *E. carlsbergi* a été trouvé dans la totalité de la zone

* VNIRO, 17a Verkhnaya Krasnoselskaya Street, Moscow, USSR 107140

étudiée. Toutefois, ses plus grandes concentrations ont été principalement rencontrées le long des bords de la zone frontale, là où les caractéristiques fondamentales d'environnement des masses d'eau, telles que la dynamique, température et densité des courants, atteignent les niveaux de variation les plus élevés. L'extension et la densité les plus élevées des concentrations d'*E. carlsbergi* ont été observées en été (décembre à février), lorsque les poissons sont répartis dans la couche supérieure de 50 à 100 m. Les plus faibles ont été observées en hiver (juin) à 200 m ou plus. Il a été constaté que les mois de printemps et d'automne étaient transitoires pour les paramètres de distribution verticale et de densité des concentrations de poissons. Les calculs de biomasse d'*E. carlsbergi* dans cette zone indiquent que sa variabilité au cours de l'année est fonction des paramètres de distribution spatiale et verticale des poissons. La variabilité de la biomasse d'*E. carlsbergi* dans cette zone a également été étudiée.

Резюме

За период с 1987 по 1989 гг. ВНИРО (СССР) было выполнено шесть траловых и акустических съемок в районе к северу от Южной Георгии между 49-54° ю.ш. и 25-40° з.д. Этот участок находится в пределах полярной фронтальной зоны, где наиболее часто и регулярно встречаются мезопелагические виды рыб семейства Myctophidae. В настоящем документе суммируются и анализируются данные по сезонной и межгодовой изменчивости распределения, плотности и биомассы наиболее многочисленного вида семейства миктофид - *Electrona carlsbergi*. Также известно, что на протяжении года этот вид образует крупные скопления. Результаты съемок показывают, что распределение и поведение *E. carlsbergi* в значительной мере связаны с состоянием окружающей среды района, а также с доступностью и распределением зоопланктона. *E. carlsbergi*, была обнаружена на акватории всего изучаемого района. Тем не менее, наиболее крупные скопления были обнаружены у кромки фронтальной зоны, где такие основные характеристики водных масс, как динамика, температура и плотность характеризуются наиболее высокой степенью изменчивости. Наиболее значительные по величине и плотности скопления *E. carlsbergi* наблюдались в течение лета (декабрь - февраль), когда рыба находилась в верхнем слое воды (50-100 м). Самые мелкие скопления, характеризующиеся низкой плотностью, наблюдались зимой (июнь) на глубинах в 200 м и более. Параметры вертикального распределения и плотности скоплений рыбы находились на переходной стадии в течение весенних и осенних месяцев. Вычисления биомассы запаса *E. carlsbergi* в данном районе показали, что ее внутригодовая изменчивость связана с параметрами пространственного и вертикального распределения. Также наблюдалась межгодовая изменчивость биомассы *E. carlsbergi* в данном районе.

Resumen

Entre 1987 y 1989, VNIRO (URSS) realizó seis prospecciones de arrastre y acústicas en el área al norte de las islas de Georgia del Sur, entre los 49° y 54°S y los 25° y 40°W. El área está situada dentro de la Zona del Frente Polar, que es donde se encuentran más frecuentemente los peces mesopelágicos de la familia Mictophidae. En este documento se analiza y resume la variabilidad estacional e interanual de la distribución, densidad y biomasa de la especie más abundante de mictófidos, *Electrona carlsbergi*, la cual tiende a formar grandes concentraciones durante el año. De acuerdo a los resultados de las prospecciones, la distribución y el comportamiento de *E. carlsbergi* están íntimamente relacionados con las condiciones ambientales y con la disponibilidad y distribución del zooplancton en el área. *E. carlsbergi* se encontró en toda el área de estudio, empero, las mayores concentraciones se encontraron principalmente a lo largo de los límites de la Zona del Frente Polar, en donde aquellas características ambientales fundamentales de las masas de agua tales como la dinámica de corrientes, temperatura y densidad, alcanzan las máximas variaciones. El mayor volumen y densidad de las concentraciones de *E. carlsbergi* se observaron en verano (diciembre a febrero), cuando los peces se distribuyen en el estrato superior, entre los 50 a 100 m. Los volúmenes y densidades más bajos fueron observados en invierno (junio) a partir de los 200 m de profundidad. Los meses de primavera y otoño fueron considerados de transición para los parámetros de distribución batimétrica y densidad de las concentraciones de peces. Los cálculos de biomasa de *E. carlsbergi* en el área indican que la variabilidad de esta especie durante el año es una función de la distribución batimétrica y espacial de los peces. Se estudió también la variación interanual de la biomasa de *E. carlsbergi* en el área.

1. INTRODUCTION

Lantern fish, or myctophids (Myctophidae), are widely distributed throughout the Southern Ocean. Due to the number of different species, wide distribution and the high abundance of some species, they represent the bulk of ichthyofauna in the mesopelagic zones of the high seas. About 14 or 15 myctophid species are the most frequently encountered in the Southern Ocean, the majority of which are characterised by circumpolar distribution. The most abundant myctophid species are found in the area of the Southern Polar Front or the Polar Frontal Zone (PFZ) which surrounds the entire Antarctic region from 50° to 60°S and encroaches further to the north or south in some areas. Very few species, however, form large and dense concentrations and their distribution tends to be localised and subject to high levels of variability.

2. RESULTS AND DISCUSSION

Electrona carlsbergi is the most studied of the more abundant myctophids which have high biomass and form regular concentrations. Over many years, the basic biological features, distribution patterns, areas, timing and conditions for the formation of concentrations have been studied in various parts of the Southern Ocean. The largest and most dense aggregations of *E. carlsbergi* occur in the PFZ to the north of South Georgia between 49° and 54°S and 40° and 25°W. *E. carlsbergi* forms regular concentrations in virtually all seasons over this extensive area of more than 160 thousand square miles. However fish concentrations in this area are extremely unevenly distributed and there are significant fluctuations in the timing of formation and dissipation of concentrations, and in their size, depth of distribution and density. This area proved useful for incidental and directed research into spatial and temporal changes in the environment and *E. carlsbergi* distribution. Soviet scientists conducted a series of studies in this area on board RV *Vozrozhdenie*. They worked for almost two years from October 1987 to June 1989, over which time six detailed oceanographic and acoustic-trawl surveys were carried out. Results of these integrated surveys demonstrated that different environmental conditions in different areas of the PFZ at various times of the year (rate of warming of the surface layer, rate of stratification of water layers, aspects of water dynamics and zooplankton distribution) determine the spatial heterogeneity of *E. carlsbergi* distribution. *E. carlsbergi* was found over the entire study area in the PFZ, although this myctophid species formed concentrations on the edges of the frontal zone in areas where fundamental dynamic and physical phenomena (currents, temperature, density) attain the highest levels of variation. These high-variability areas where the frontal waters converge with Antarctic water masses have the most potential in terms of concentration formation for this species.

It was also discovered that these concentrations adhere very closely to areas of quasi-stationary meandering currents, in other words, the periphery of gyre formations at the junctions of various water masses. It appears that these high-variability areas of the frontal zone play a significant role in the build-up of plankton, duration of fish feeding periods and, consequently, their stable and long-lasting concentrations.

Along the southern border of the PFZ between 40° and 36°W, 30° and 25°W and 49° and 53°S (Figures 1 to 5) *E. carlsbergi* formed fairly regular and large-scale concentrations. At the same time, the location of *E. carlsbergi* schools over the study area of the PFZ varies from season to season and from year to year. During the uncharacteristically cold spring/summer season of 1987 (October-December), *E. carlsbergi* schools were distributed mainly to the north of 50°S, while in the autumn/winter season (April to December, 1987) they occurred to the south of 50°S (Figures 1 to 4). In summer 1988 (December) the areas of large concentrations were to the south of 50°S (Figure 5). The nature of diffusion and interaction of warm and cold waters generally determined, the geographical position of *E. carlsbergi* concentrations which followed the line of the southern edge of the front. This pattern is broken at 40°W where the concentrations extend to 49°S, and at 26° to 23°W where they extend to the south of 53° to 54°S.

Seasonal patterns of vertical distribution and behaviour variations of *E. carlsbergi* were identified. During the spring season (September/October), low-density concentrations were not long, stretching from 0.5 to 10 miles. These concentrations were distributed mainly at depths between 150 and 350 m and had a considerable vertical extent of 50 to 300 m. As the surface temperature rose from 1.5° to 4.9°C, echo recordings showed an increase in the density and length of concentrations near the thermal front. At this time, *E. carlsbergi* concentrations were most frequently recorded in the eastern sector of the area (30° to 25°W) where sub-Antarctic waters merge with the cold Antarctic waters. Analysis of the vertical extent of *E. carlsbergi* at different times of the day demonstrated that in spring concentrations are found at similar depths (100 to 450 m) both during the day and at night. It should be noted that during the night fish were more scattered; the vertical extent of concentrations registered on echo recordings was up to 200-300 m. The shape of the echo recordings indicated the presence of separate shoals or groups of shoals with a smaller vertical extent of between 20 and 200 m. Daily vertical migration at this time was weak, which on the whole led to a decrease in vertical distribution during the formation of shoals. Typical echo-charts of *E. carlsbergi* concentrations in spring are given in Figures 6 to 8.

Compared with the spring season, summer (December to January) witnessed considerable changes in *E. carlsbergi* distribution and behaviour. During this period, fish were located closer to the surface (from 10 to 100 m) at night, while during the day concentrations descended to depths of 160 to 200 m. The length of concentrations increased dramatically and varied from five to 30 miles and longer. In summer, concentrations were ribbon-shaped and very dense, with a vertical extent from 10-50 to 100-120 m. The majority of *E. carlsbergi* concentrations adhered to the peripheries of meandering currents where the temperature varied from 1.9° to 5.0°C. Typical echocharts of *E. carlsbergi* concentrations in summer are shown in Figures 9 to 12.

Changes in the vertical distribution of *E. carlsbergi* are probably due to the redistribution of zooplankton which occurred in summer. After winter, plankton rises towards the surface and new generations begin to develop, most of the plankton is found in the upper 50 to 100 m layer. Fish feeding occurred on the edge of this layer. Results of research carried out at daily stations revealed that if there is a good food supply, *E. carlsbergi* concentrations are able to keep to the same depths in the course of 24 hours without having to migrate vertically each day.

In autumn (March to April), *E. carlsbergi* concentrations begin to move to deeper waters, are almost constantly spread over depths between 200 and 400 m (more often 220 to 350 m) and do not rise to the upper 100 m layer. In the course of a day, the depth of *E. carlsbergi* distribution does not alter significantly, regardless of the extent or density of concentrations. Moreover, in the morning *E. carlsbergi* forms shoals and later in the day develops more dense concentrations with a considerable vertical extent (up to 200 m). Typical echocharts of *E. carlsbergi* concentrations in autumn are given in Figures 13 to 15.

Compared with autumn, depth of *E. carlsbergi* distribution in winter (June) was practically unchanged. Scattered low-density concentrations were spread over depths of 200 to 400 m and had a vertical distribution of up to 200 m. Daily migrations were not extensive. Density increased during the day and decreased at night. Echocharts of typical *E. carlsbergi* concentrations in winter are given in Figures 16 to 18.

It is apparent that vertical distribution of *E. carlsbergi* concentrations and its behaviour are subject to seasonal variations which are, to a large extent, linked to the seasonal distribution of its primary food, zooplankton. In autumn, it has been noted that these fish tend to migrate to and remain at depths of 200 to 300 m for a long period before the beginning of summer. This is due to the fact that winter plankton also drops to these levels. The overall pattern of *E. carlsbergi* vertical distribution generally remains the same each season and each year.

Data from trawl-acoustic surveys, carried out in different seasons and years, showed that at any given moment from 0.5 to 2.9 million tonnes of *E. carlsbergi* are present in the studied area of the PFZ. Biomass and density calculations made from echo surveys are given in Table 1.

Investigations showed considerable seasonal and interannual fluctuations in the quantitative distribution of *E. carlsbergi* which may lead to significant changes in the instantaneous biomass. The largest and most dense concentrations of *E. carlsbergi* in this area form in summer when the biomass is capable of reaching 3 million tonnes. *E. carlsbergi* biomass can also be substantial in the other seasons (500 to 1 100 x 10^3 tonnes).

Acoustic assessments of *E. carlsbergi* density and biomass were carried out in different seasons not only for the entire study area, but also over smaller individual sites of temporary concentrations having an area of 500 to 700 miles^2 (Table 2).

3. CONCLUSIONS

Following the investigations, fairly distinct patterns emerged in respect of the distribution and behaviour of the most abundant myctophid species, *E. carlsbergi*, in the PFZ to the north of South Georgia. These patterns suggest that the situations outlined above are typical for a particular period, taking into account seasonal and interannual variability of environmental factors. Moreover, when assessing a given situation it is essential to take into consideration both the general patterns of distribution (adherence of the greater part of *E. carlsbergi* concentrations to higher latitudes in areas of pronounced meandering currents and on the edge of gyre formations) and the characteristics of distribution and behaviour (vertical migration, accumulation, feeding characteristics) for a particular season.

In regard to layers where feeding takes place, *E. carlsbergi* tends to be concentrated in the epipelagic zone in summer and the mesopelagic zone in spring and autumn. Furthermore, it is most likely that feeding conditions during the foraging period determine the pattern of vertical migration: *E. carlsbergi* displays a distinctive daily rhythm in its distribution and behaviour. Depending on the time of the day, concentration density also changes. Aspects of this rhythm depend on the season, time of the day, area and zooplankton concentration.

Table 1: Biomass and density calculations made from echo surveys.

Month and Year	Area of Concentration Distribution (x10^3 square mile)	Biomass (x10^3 tonnes)	Concentration Density (x10^3 tonnes per square mile)
October to November, 1987	54.1	743	4 - 145* 13.8**
December, 1987	73.1	2 944	6 - 284 40.2
March to April, 1988	85.7	911	4 - 87 10.6
June, 1988	95.1	526	4 - 19 5.5
October to November, 1988	95.6	810	3 - 61 8.5
April to May, 1989	29.6	1 107	6 - 257 37.4

* density range
** mean value

Table 2: *E. carlsbergi* biomass and concentration density over localised sites of the PFZ in December 1988.

Month and Year	Area of Concentration Distribution (x10^3 square mile)	Biomass (x10^3 tonnes)	Concentration Density (x10^3 tonnes per square mile)
2 to 5 December, 1988	532	13 811	6 - 77* 26.0**
9 to 12 December, 1988	687	17 885	7 - 102 26.0
18 to 20 December, 1988	676	11 278	9 - 80 16.7

* density range
** mean value

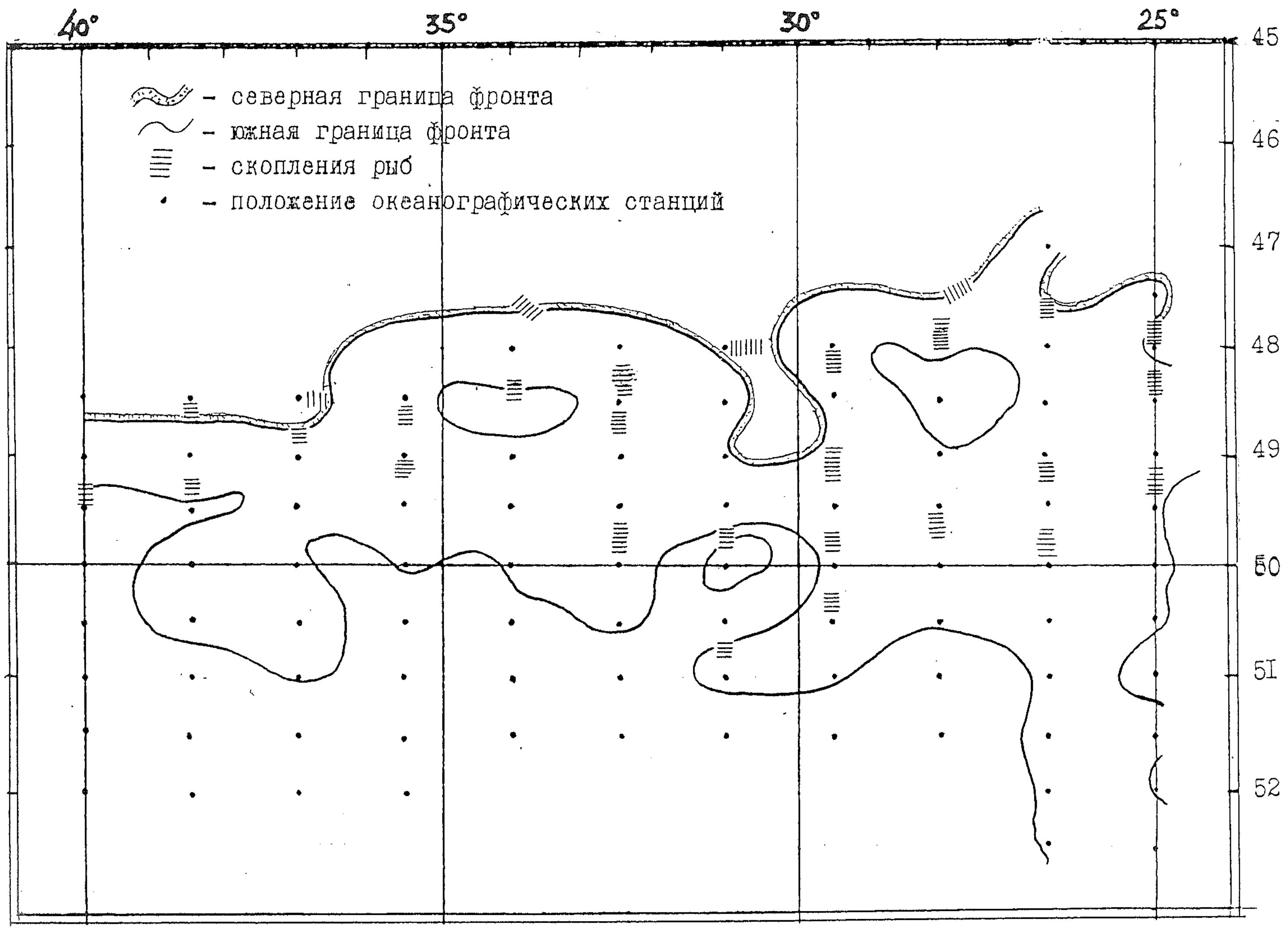


Figure 1: Distribution of large concentrations of *E. carlsbergi* over the Polar Frontal Zone to the north of South Georgia (October to November 1987).

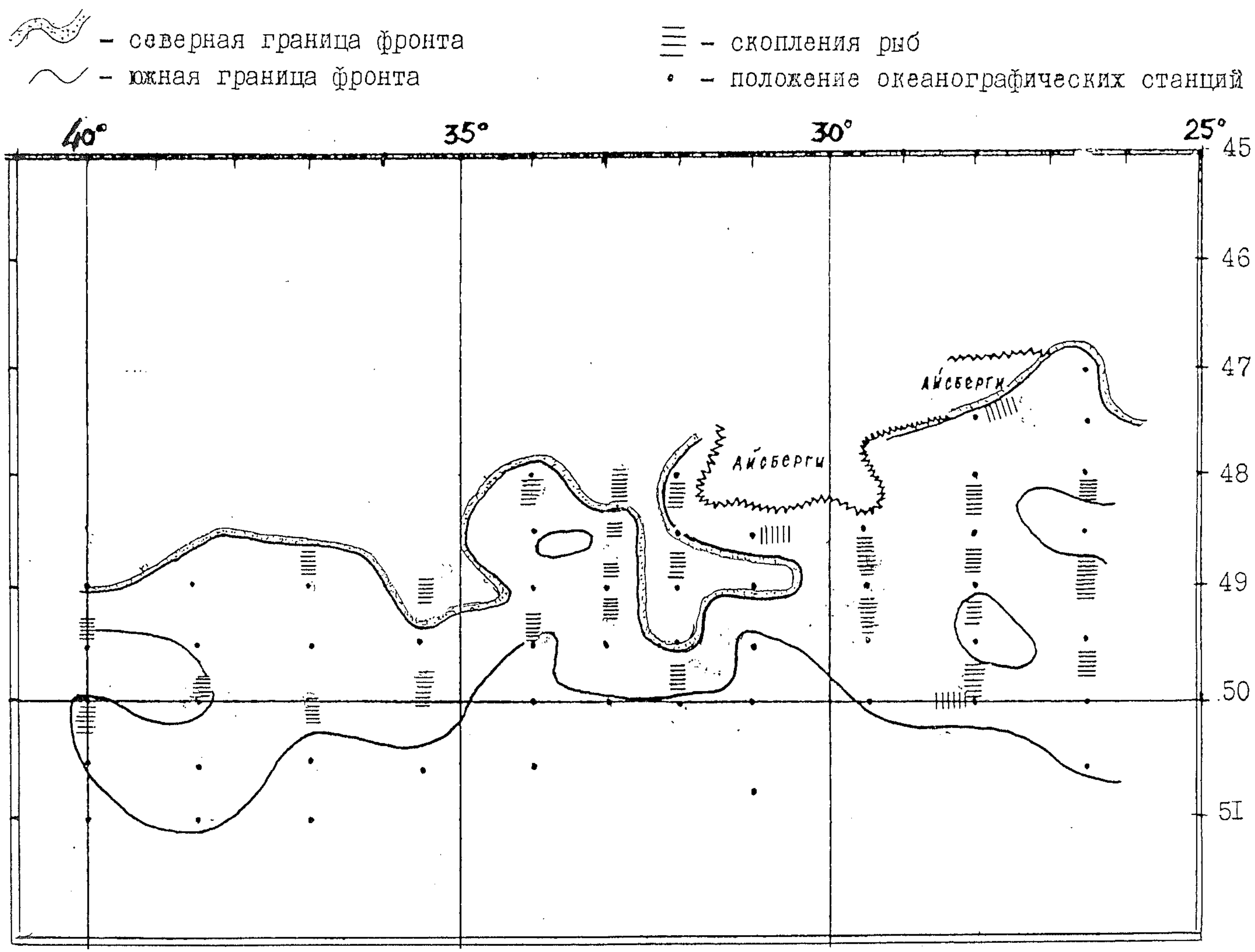


Figure 2: Distribution of large concentrations of *E. carlsbergi* over the Polar Frontal Zone to the north of South Georgia (December to January 1987/88).

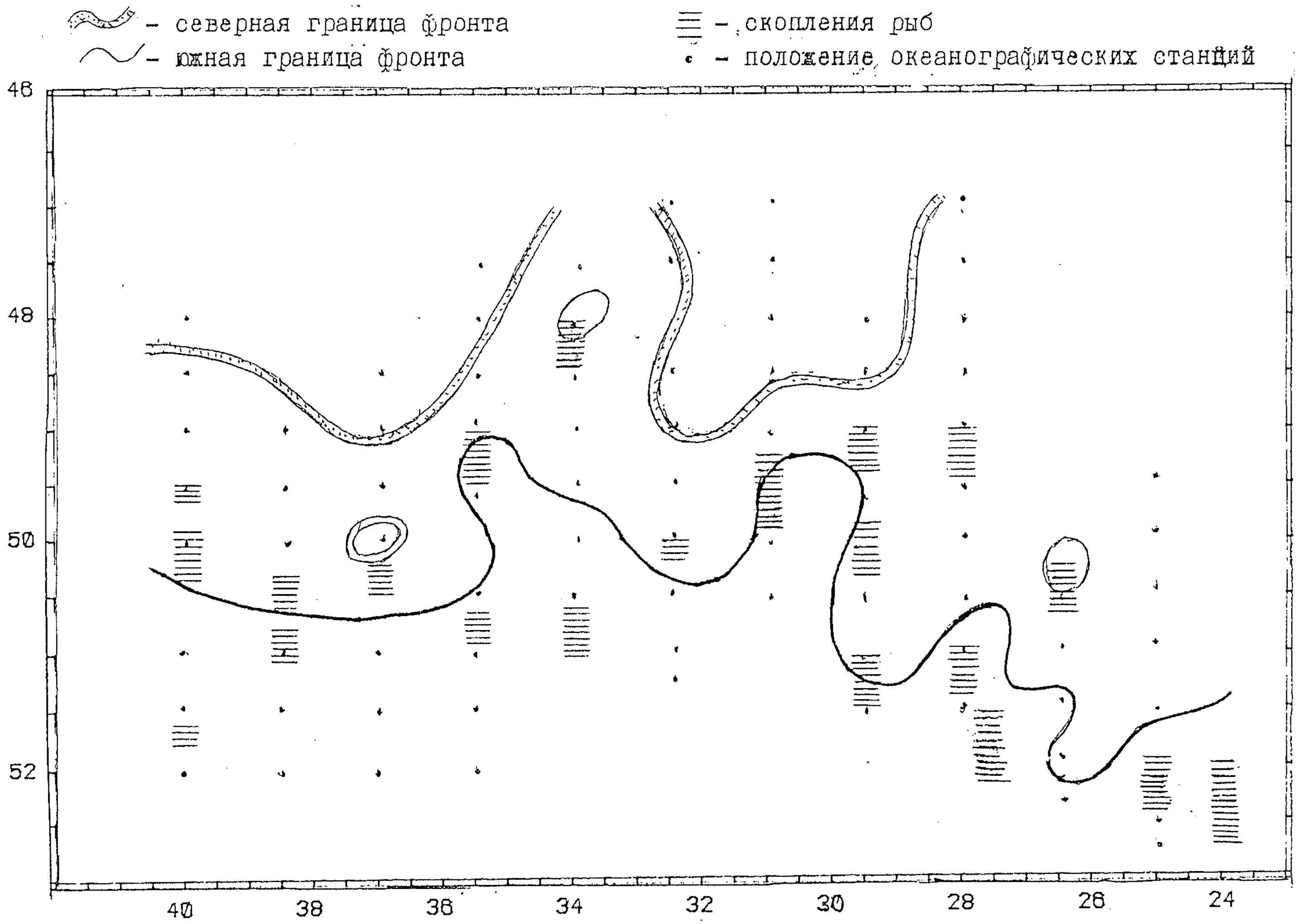


Figure 3: Distribution of large concentrations of *E. carlsbergi* over the Polar Frontal Zone to the north of South Georgia (March to April 1988).

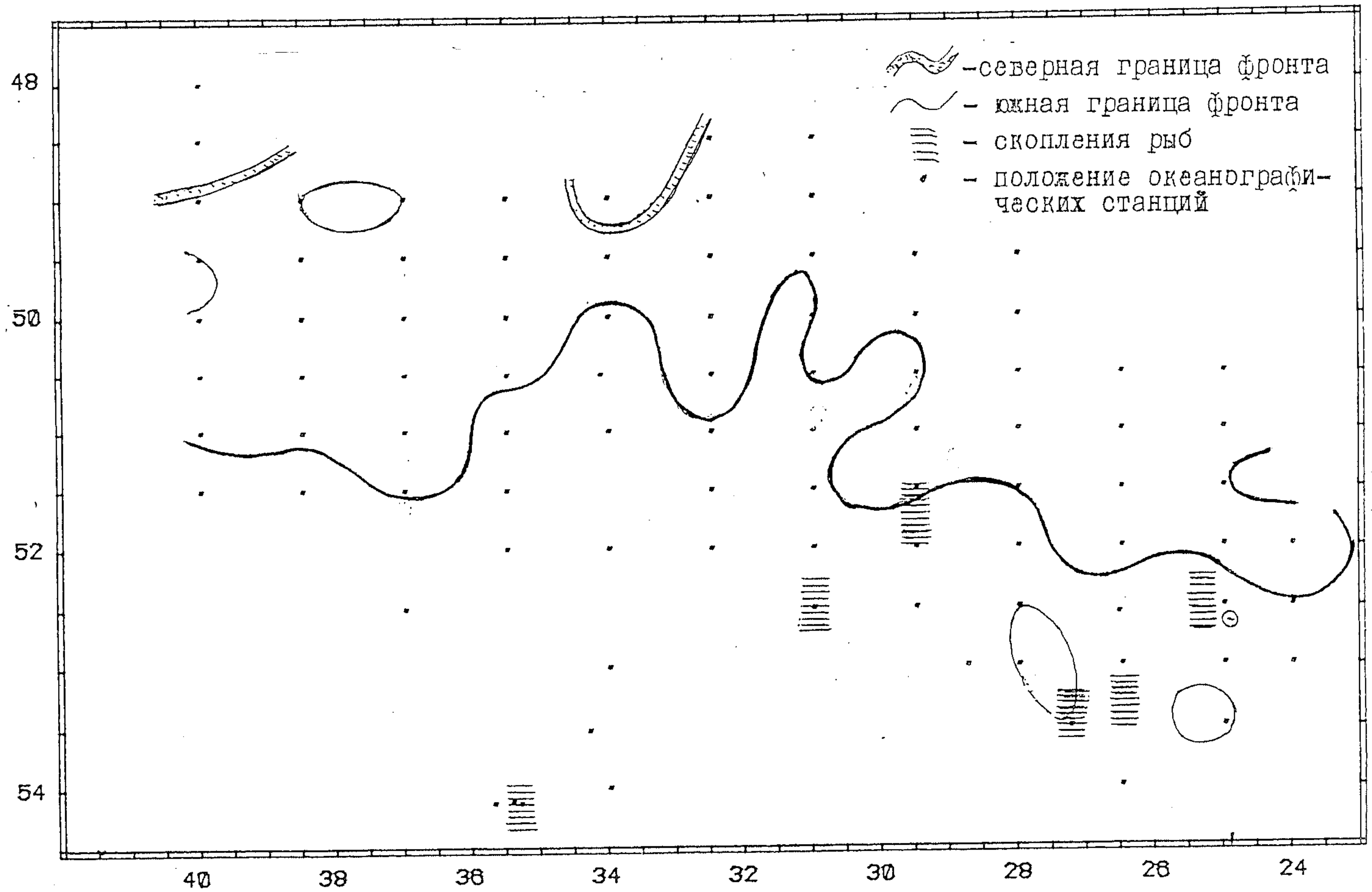


Figure 4: Distribution of large concentrations of *E. carlsbergi* over the Polar Frontal Zone to the north of South Georgia (June 1988).

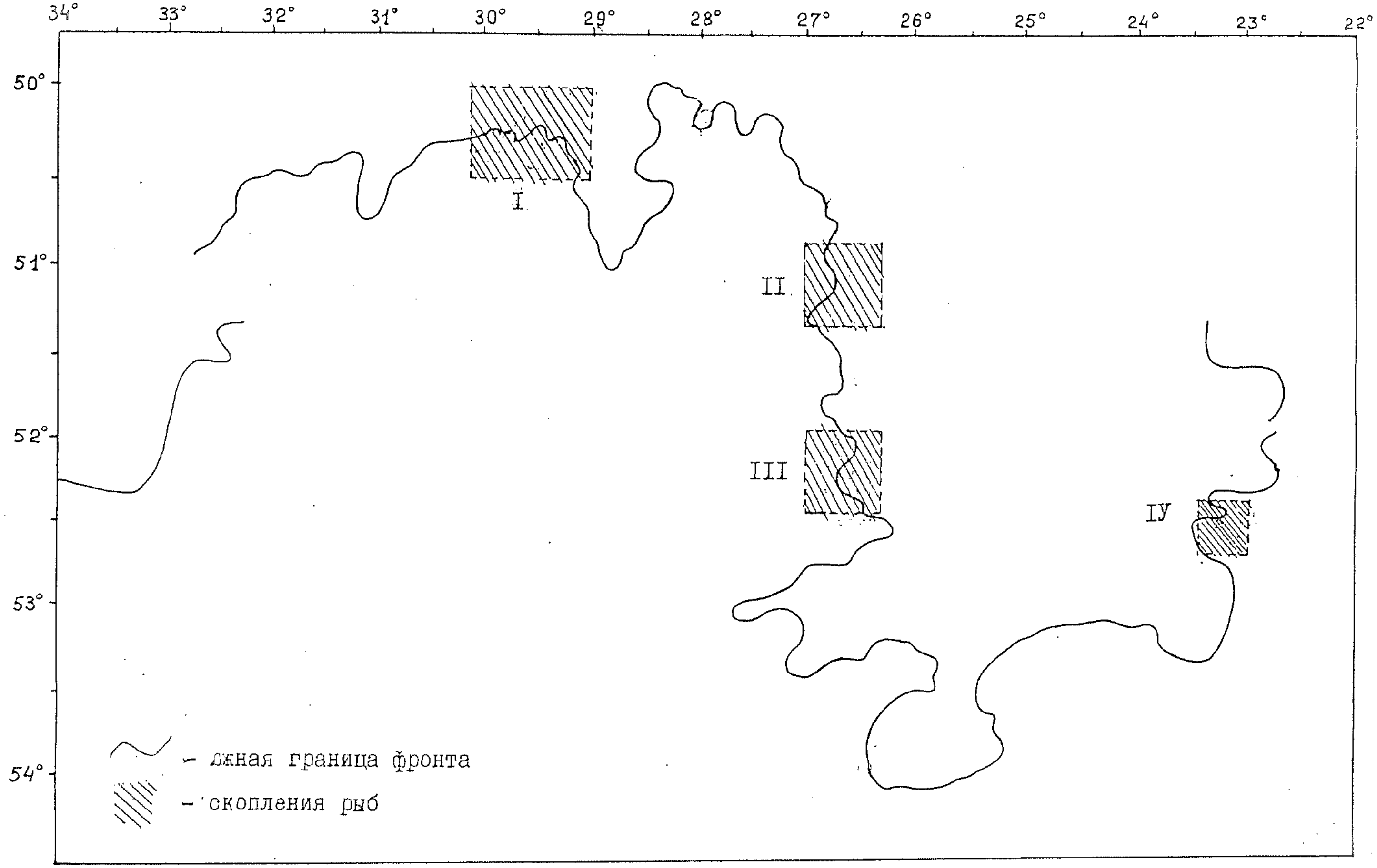


Figure 5: Distribution of large concentrations of *E. carlsbergi* over separate areas of the Polar Frontal Zone to the north of South Georgia (December 1988).

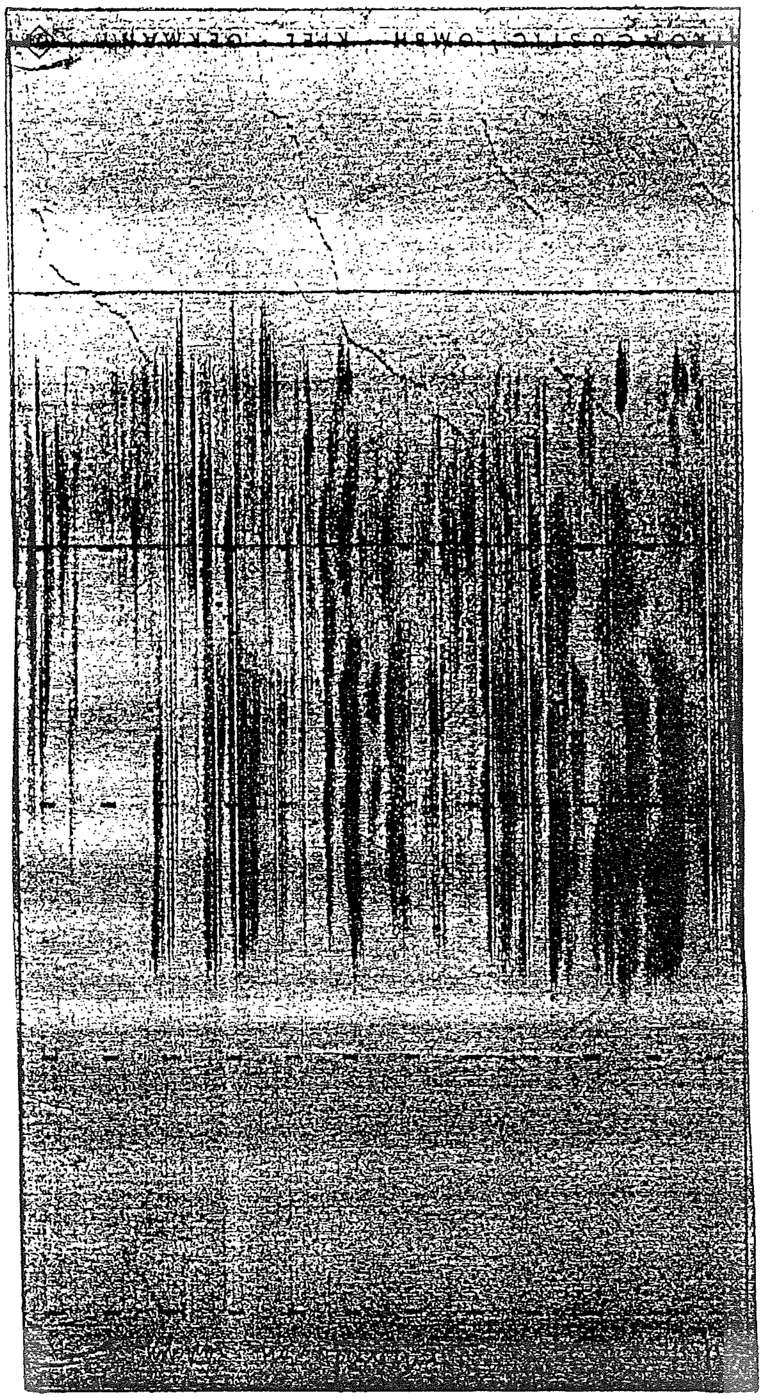


Figure 6: Echocharts of *E. carlsbergi* concentrations in the evening (21:00 to 22:00) at depths of 100 to 380 m in the Polar Frontal Zone (September 1988).

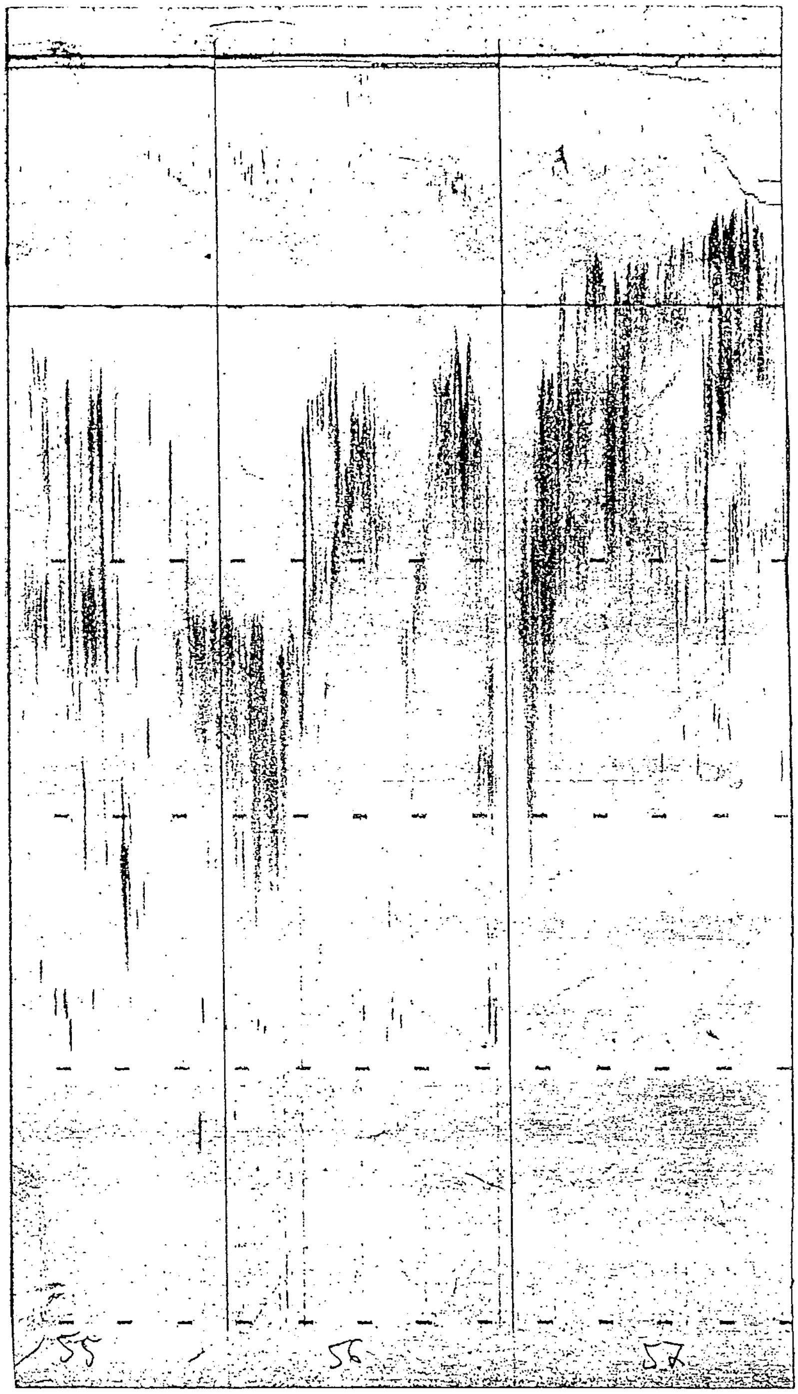


Figure 7: Echocharts of *E. carlsbergi* concentrations in the morning (6:00 to 7:00) at depths of 70 to 350 m in the Polar Frontal Zone (September 1988).

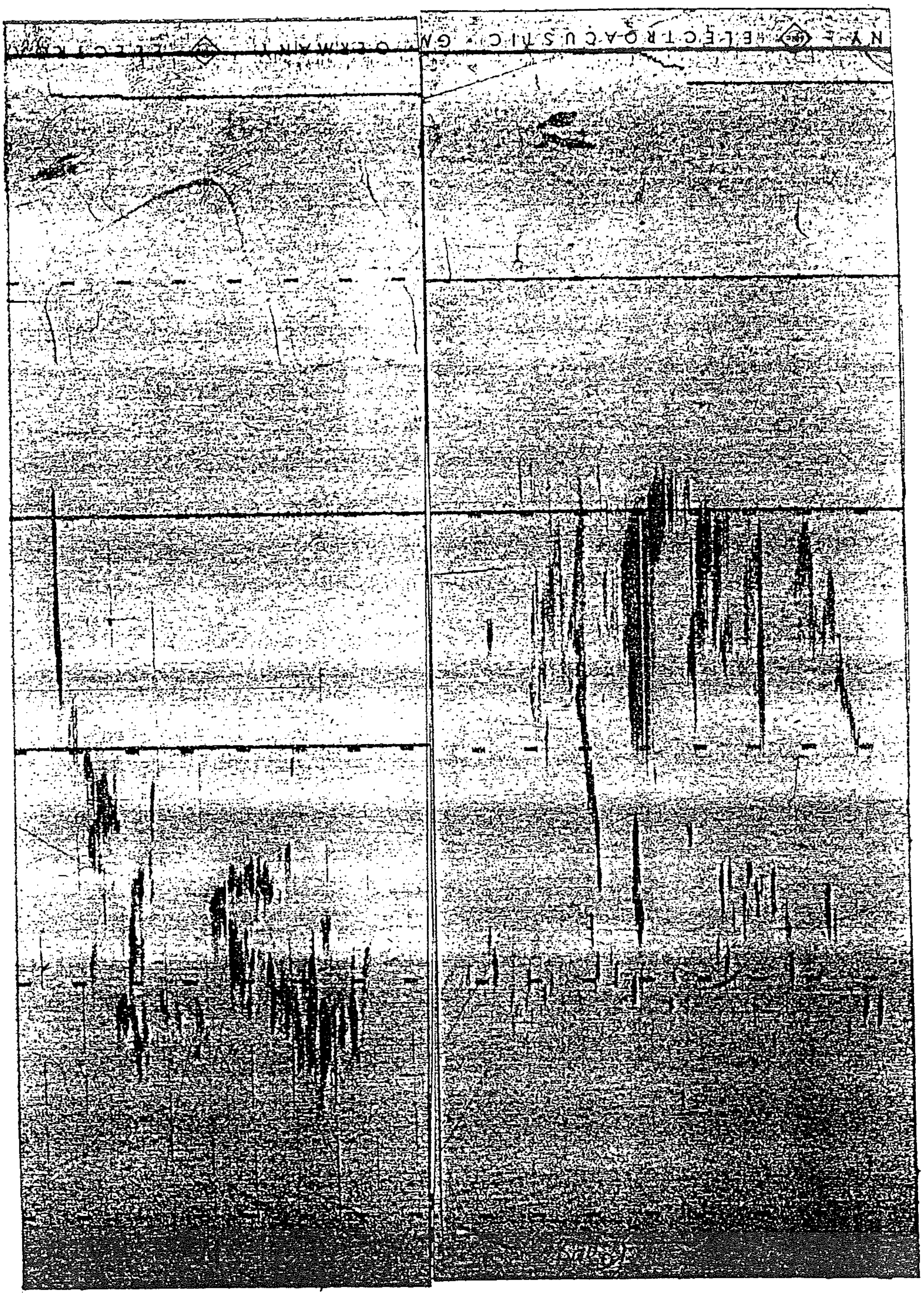


Figure 8: Echocharts of *E. carlsbergi* concentrations during the day (12:00 to 14:00) at depths of 190 to 450 m in the Polar Frontal Zone (September to October 1988).

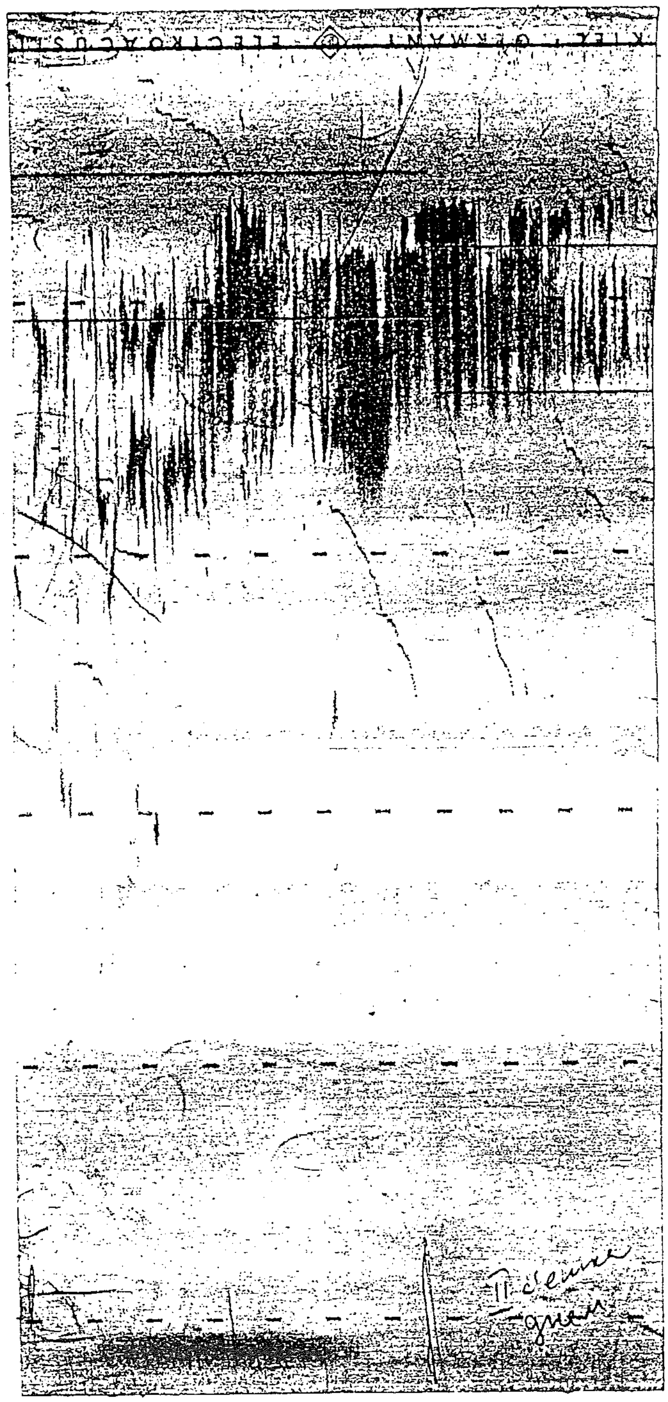


Figure 9: Echocharts of *E. carlsbergi* concentrations during the day (14:00 to 15:00) at depths of 60 to 200 m in the second fine-scale survey area (December 1988).

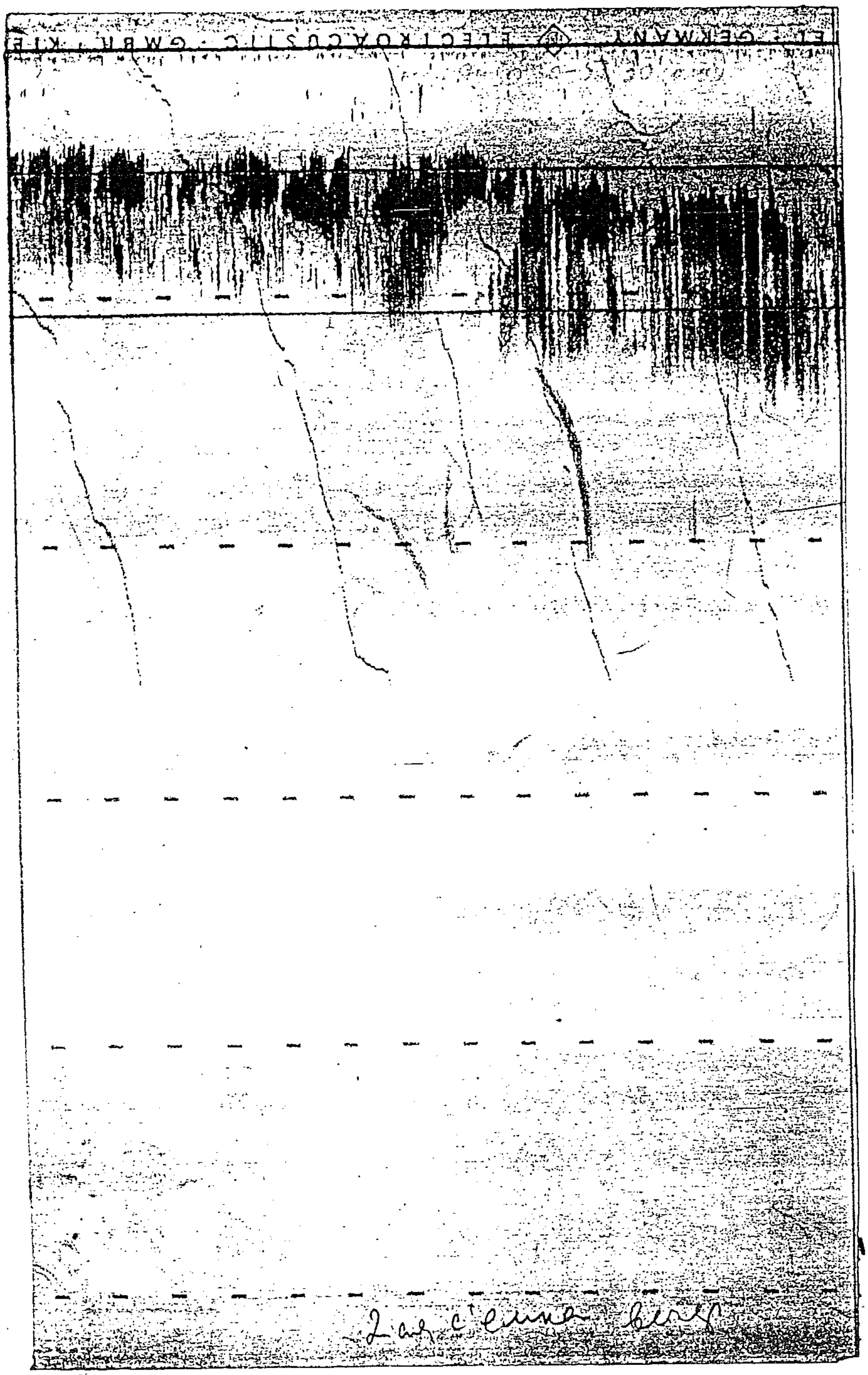


Figure 10: Echocharts of *E. carlsbergi* concentrations in the evening (19:00 to 20:00) at depths of 40 to 130 m in the second fine-scale survey area (December 1988).

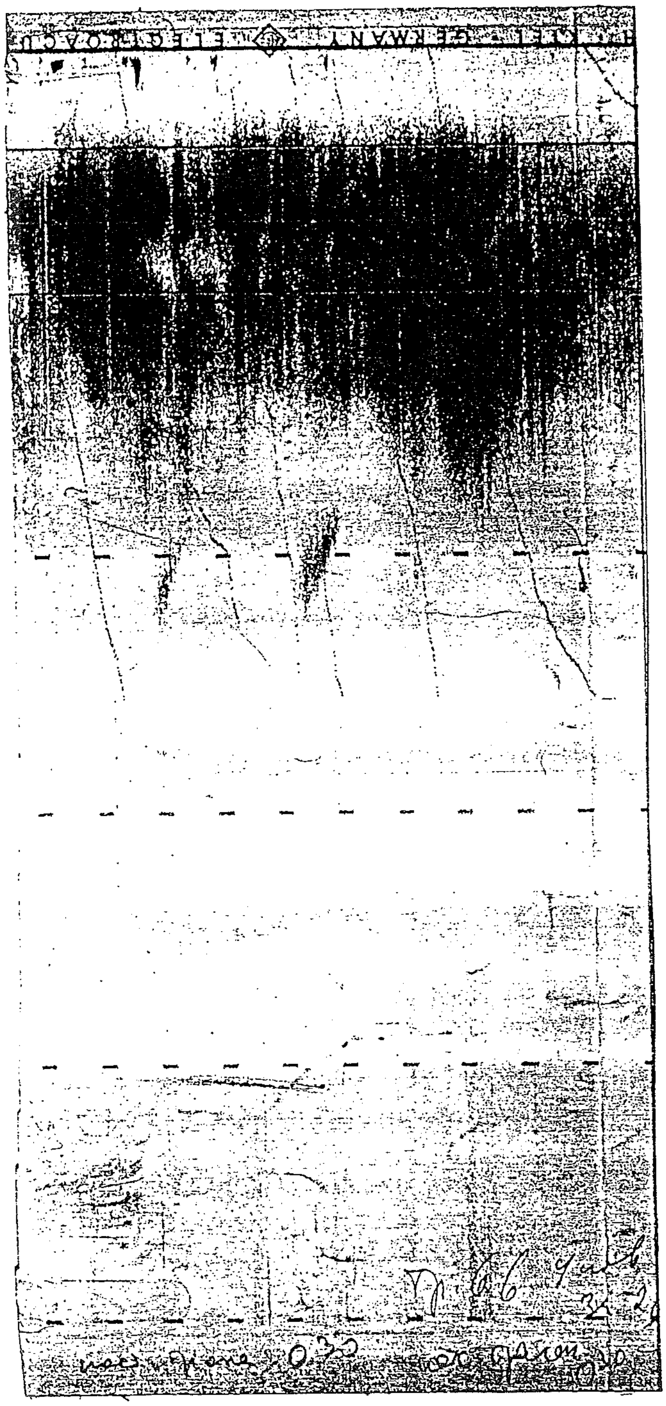


Figure 11: Echocharts of *E. carlsbergi* concentrations at night (00:30 to 01:30) at depths of 40 to 180 m in the third fine-scale survey area (December 1988).

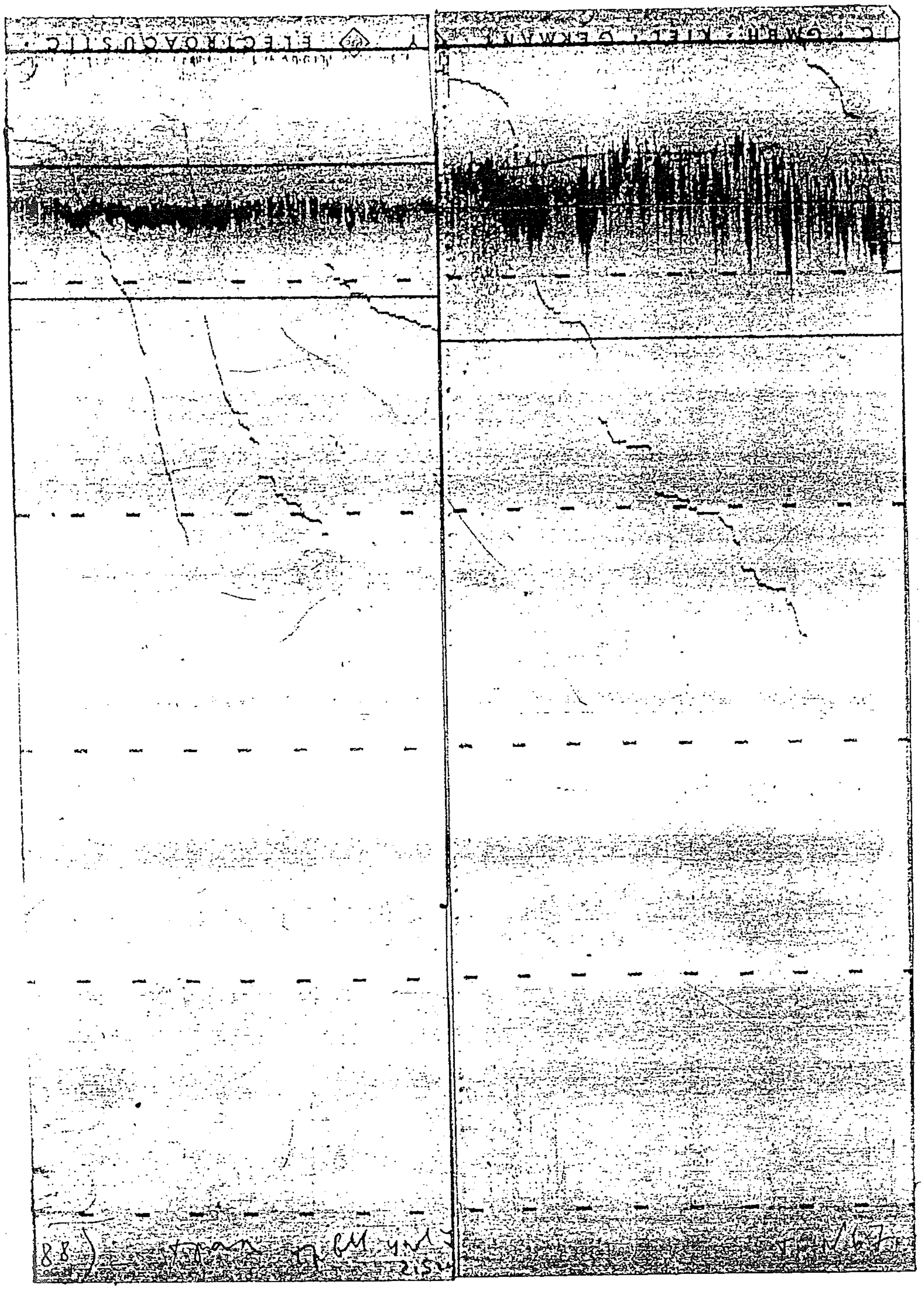


Figure 12: Echocharts of *E. carlsbergi* concentrations during the day [17:00 to 18:00 (a)] at depths of 70 to 80 m in the area of the third fine-scale survey and in the morning [05:00 to 06:00 (b)] at depths of 50 to 100 m.

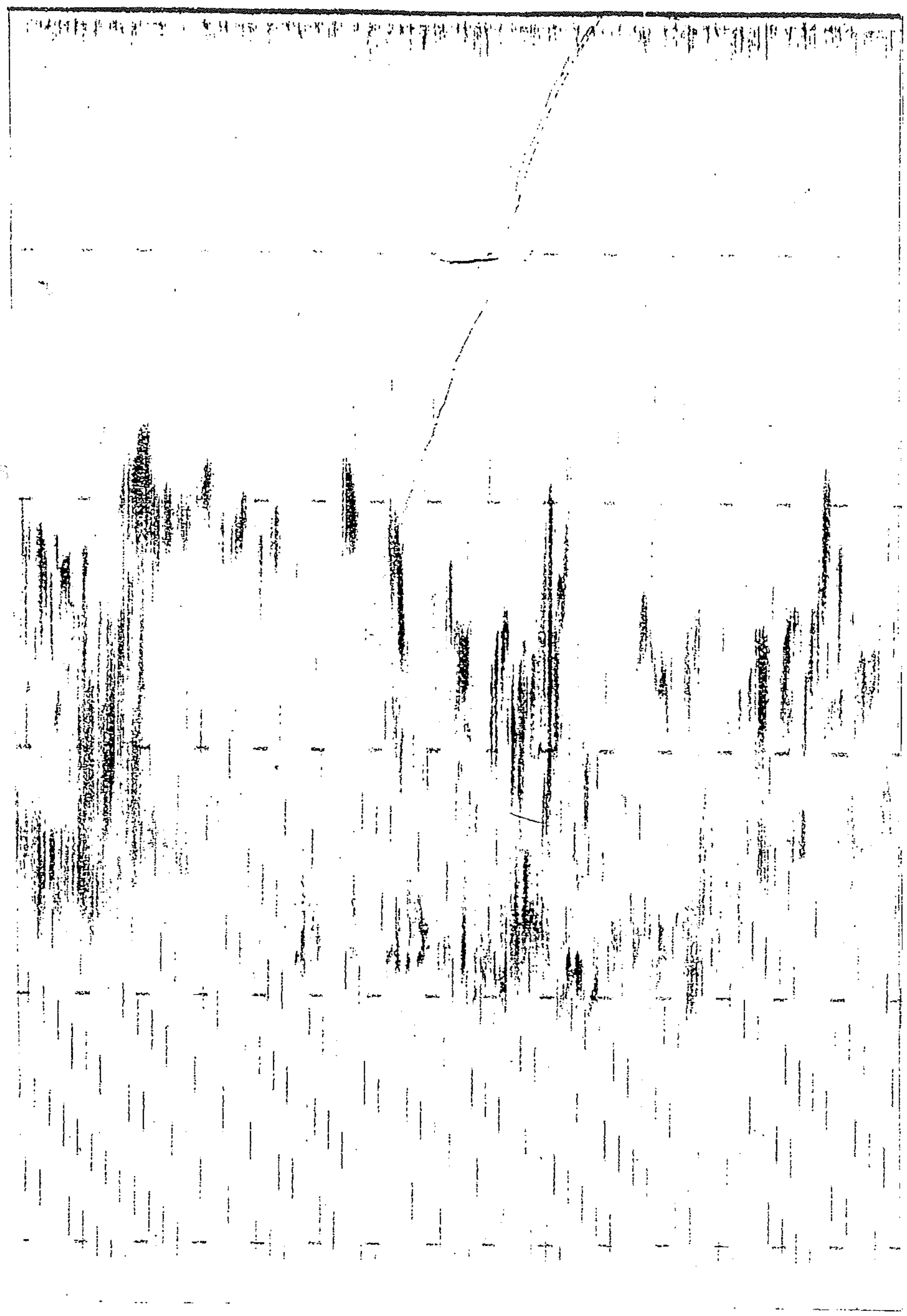


Figure 13: Echochart of haul No. 58.

Mean surface density $\bar{P}_s$ =51.9 t/mile^2

Mean density by volume $\bar{P}_v$ =0.04 specimens/m^3 or 0.32 g/m^3

Change in density by volume:
at 17:00 - P_v=0.03 specimens/m^3 or 0.16 g/m^3.

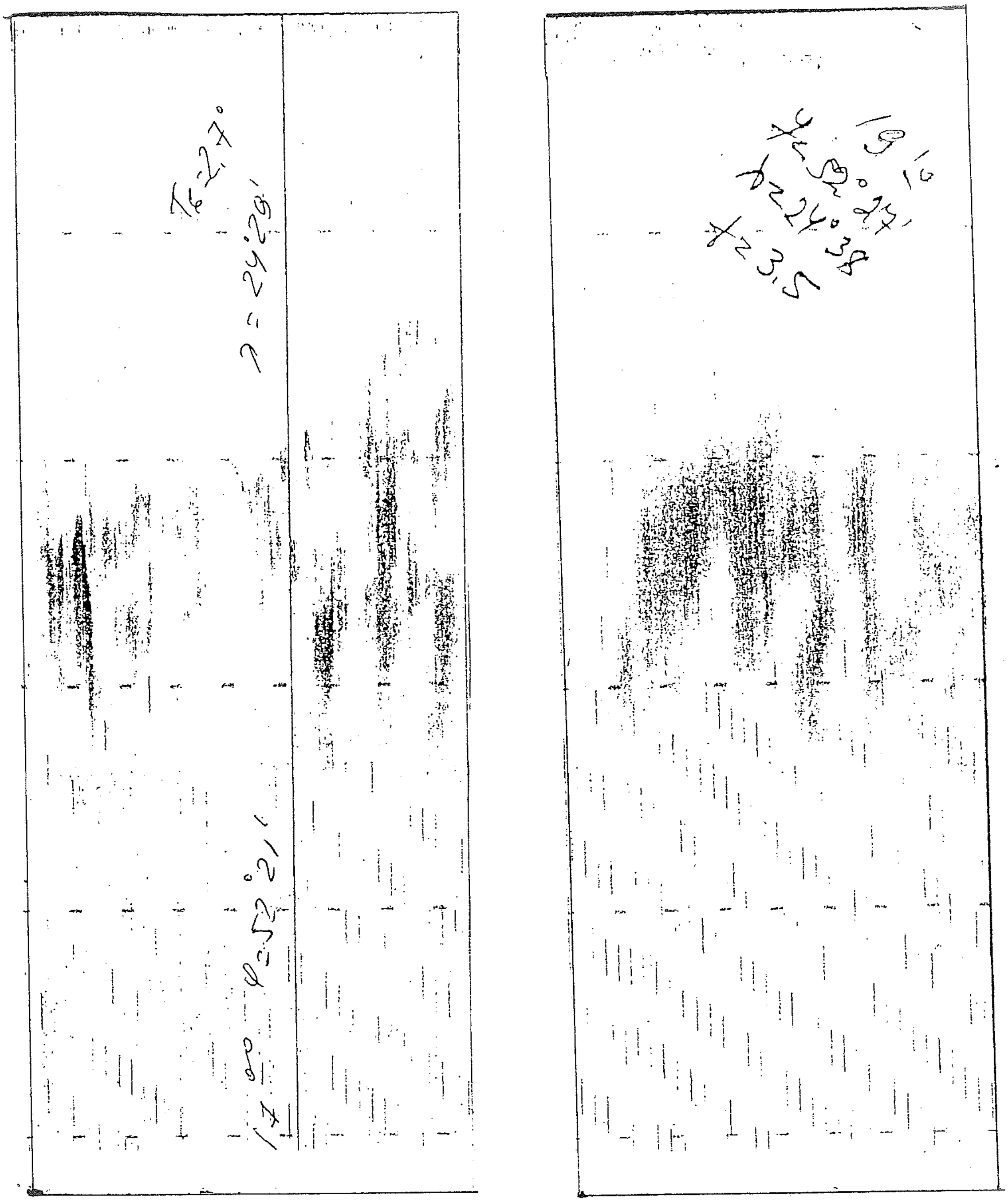


Figure 14: Typical echochart of *E. carlsbergi* concentrations in the second half of the day and during the evening.
Change in surface density:
at 17:00 - P_s=25.8 tonne/$mile^2$; at 19:00 - P_s=24.4 tonne/$mile^2$.

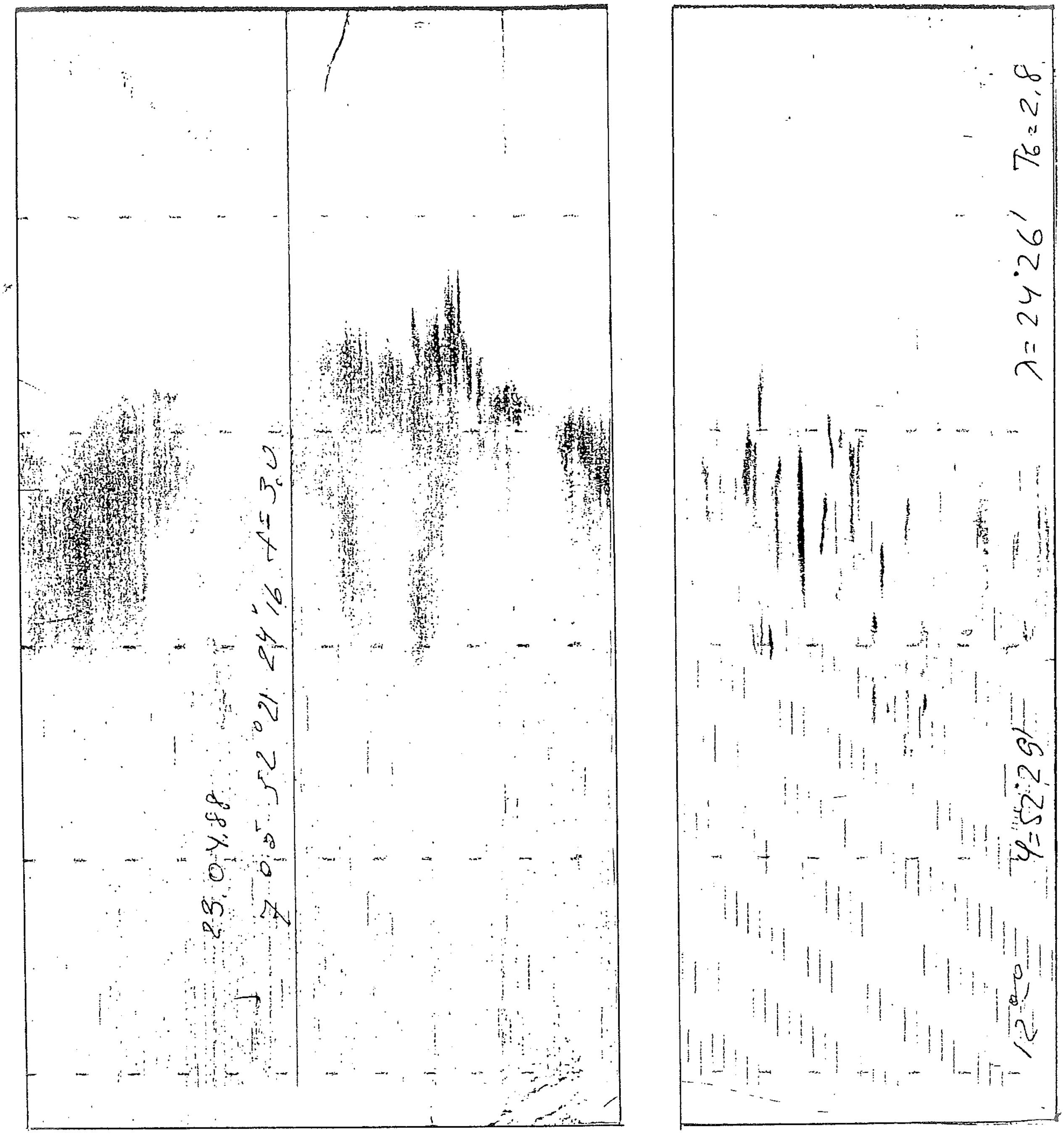


Figure 15: Typical echochart of *E. carlsbergi* concentrations in the morning and daylight hours.
Change in surface density:
at 7:00 - P_s=26.1 tonne/mile²; at 12:00 - P_s =24.8 tonne/mile².
Change in density by volume:
at 7:00 - P_v=0.01 specimens/m³; at 12:00 - P_v =0.02 specimens/m³ or 0.16 g/m³.

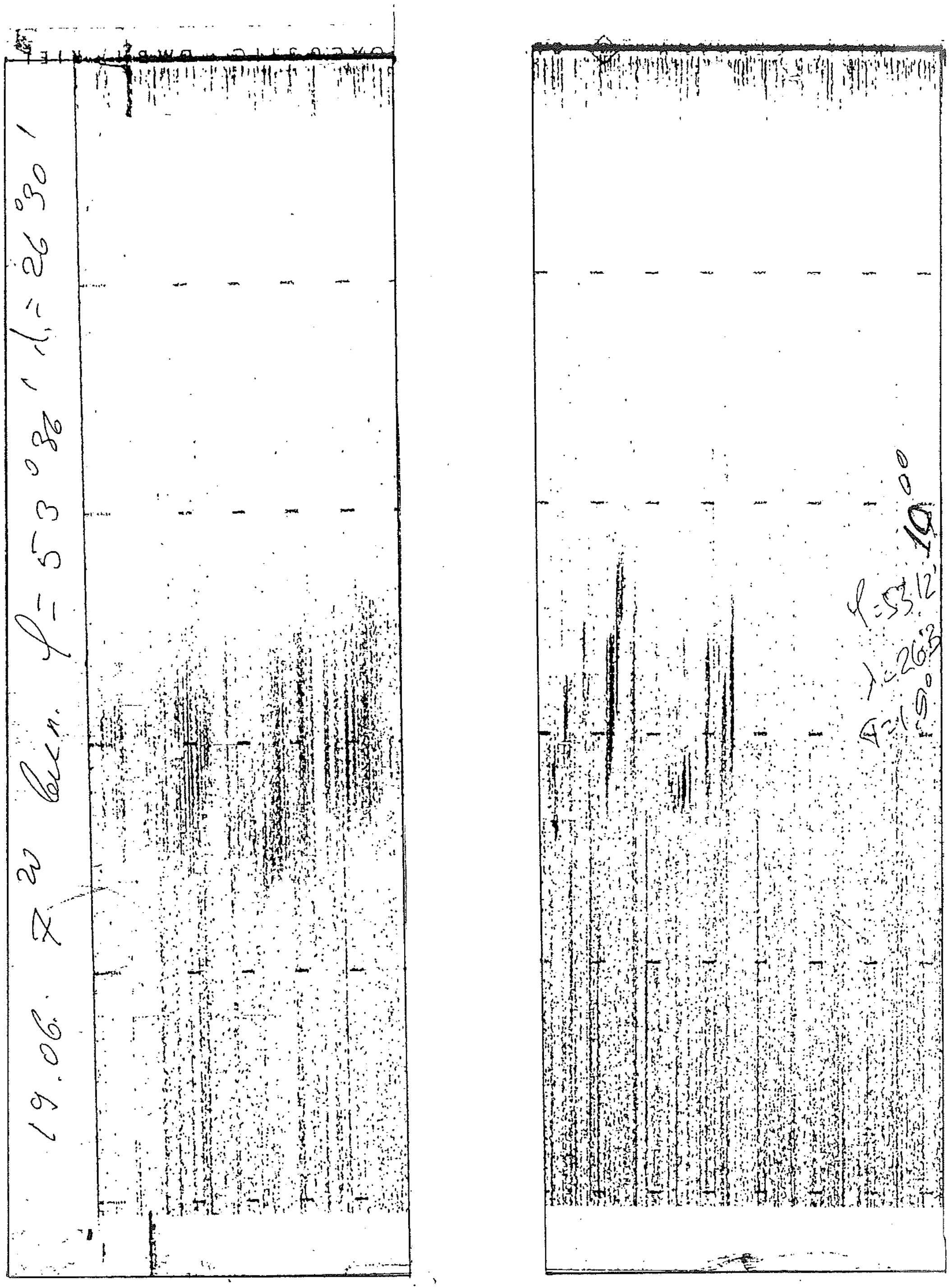


Figure 16: Echochart of *E. carlsbergi* concentrations in the morning and daylight hours.

At 8:00	surface density	$\bar{P}_s$ =17.7 tonne/mile^2
	density by volume	$\bar{P}_v$ =0.007 specimens/m^3 or 0.056 g/m^3.
At 10:00	surface density	$\bar{P}_s$ =18.0 tonne/mile^2
	density by volume	$\bar{P}_v$ =0.01 specimens/m^3 or 0.08 g/m^3.

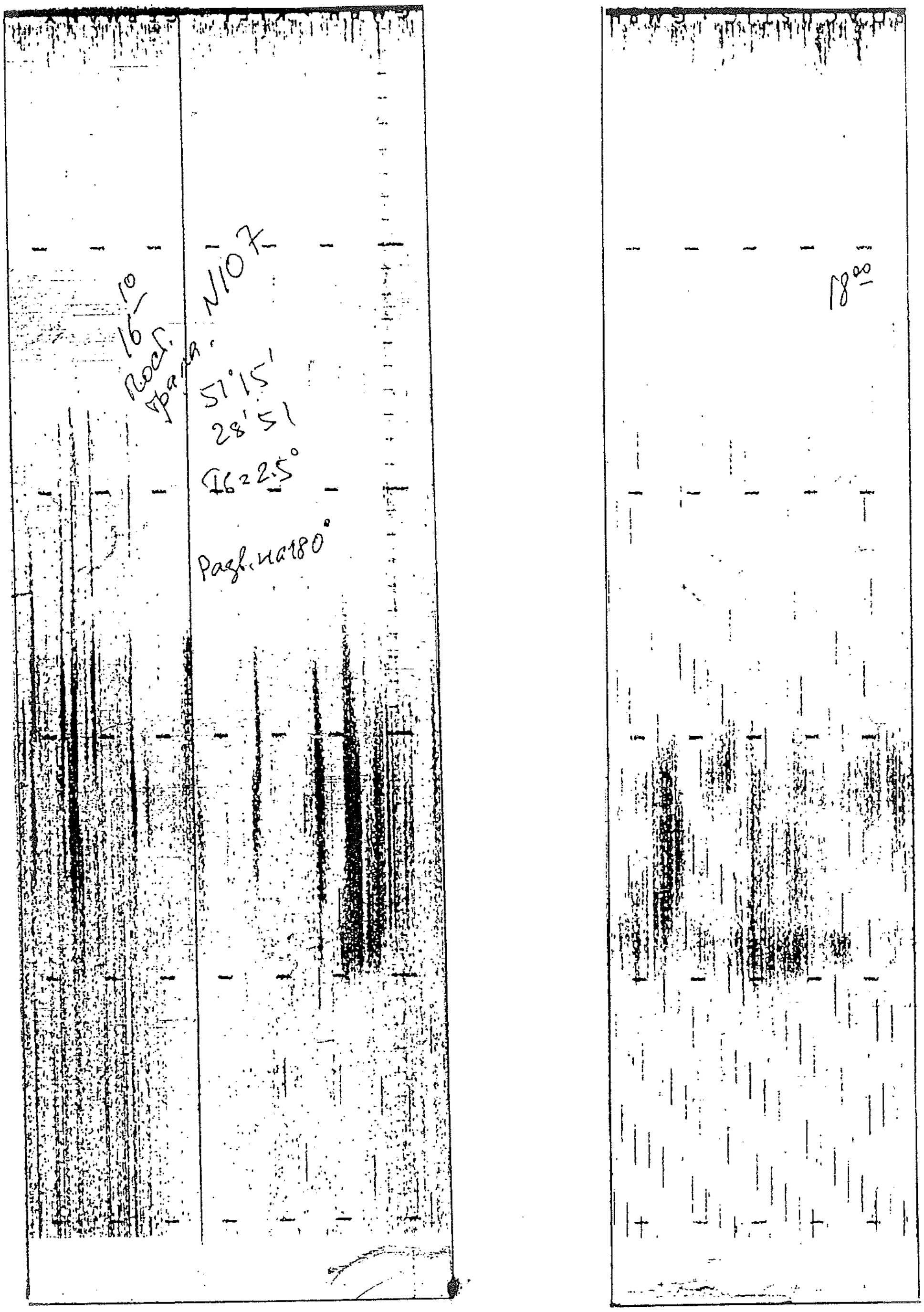


Figure 17: Echochart of haul No. 107.

At 16:10	surface density	$\bar{P}_s$=36.2 tonne/mile^2
	density by volume	$\bar{P}_v$ =0.01 specimens/m^3 or 0.08 g/m^3.
At 18:00	surface density	$\bar{P}_s$ =30.3 t/mile^2
	density by volume	$\bar{P}_v$ =0.007 specimens/m^3 or 0.056 g/m^3.

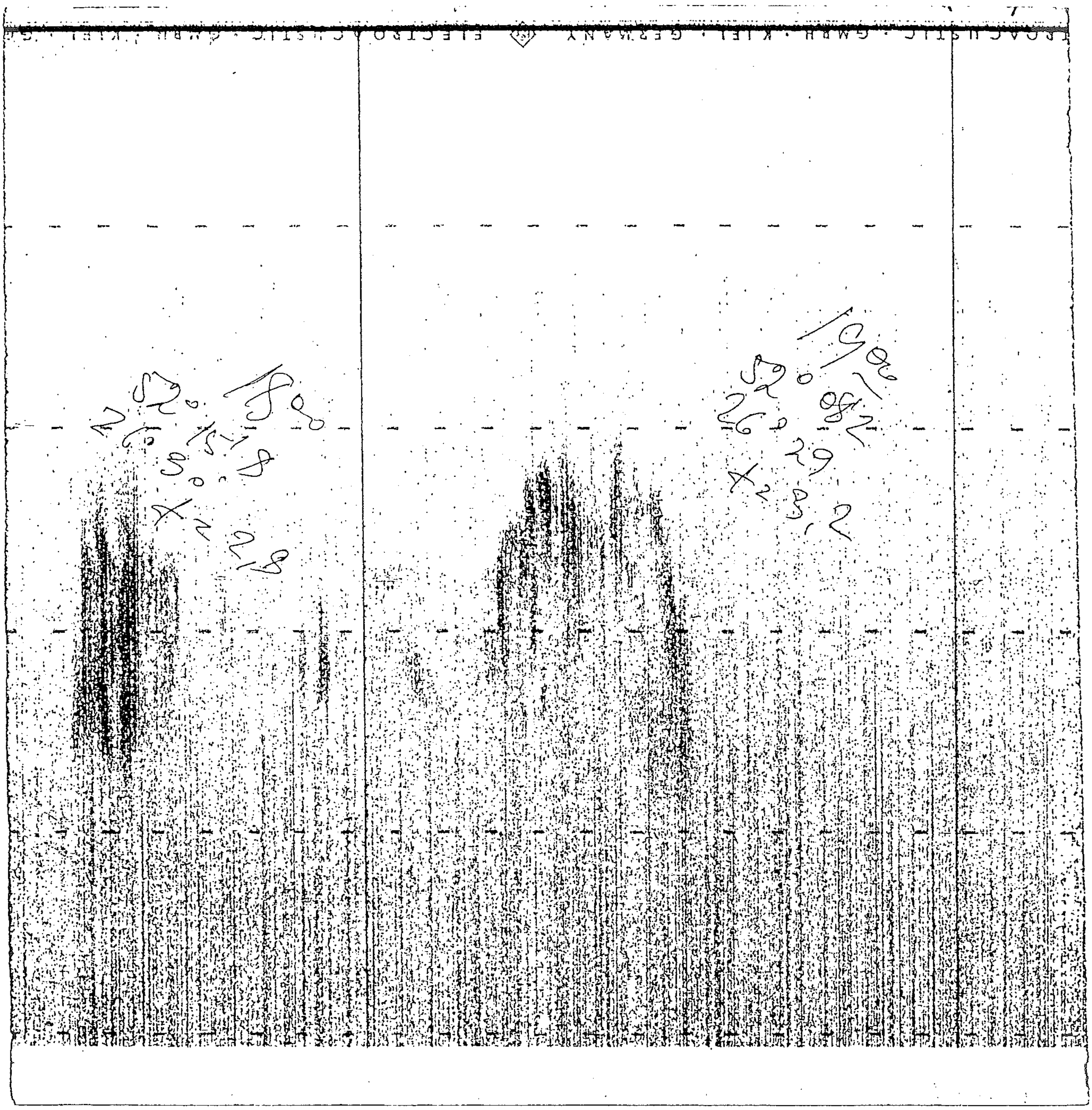


Figure 18: Typical night-time echochart of *E. carlsbergi*. Neither density assessment nor trawling were carried out in this case.

Liste des tableaux

Liste des figures

Figure 13: Enregistrement acoustique du trait № 58.

Densité moyenne en surface $\bar{P}_s$=51.9 t/mille^2

Densité moyenne par volume $\bar{P}_v$=0.04 spécimens/m^3 ou 0.32 g/m^3

Figure 14: Enregistrement acoustique typique des concentrations d'*E. carlsbergi* pendant l'après-midi et la soirée.
Changement de densité de surface:
à 17h00 - P_S = 25.8 tonnes/mille^2; à 19h00 - P_S=24.4 tonnes/mille^2.
Changement de densité par volume:
à 17h00 - P_V=0.03 spécimens/m^3 ou 0.16 g/m^3.

Figure 15: Enregistrement acoustique typique des concentrations d'*E. carlsbergi* pendant la matinée et de jour.
Changement de densité de surface:
à 7h00 - P_S =26.1 tonnes/mille^2; à 12h00 - P_S=24.8 tonnes/mille^2.
Changement de densité par volume:
à 7h00 - P_V=0.01 spécimens/m^3 ou à 12h00 - P_V= 0.02 spécimens/m^3 ou 0.16 g/m^3.

Figure 16: Enregistrement acoustique typique des concentrations d'*E. carlsbergi* pendant la matinée et de jour.

A 8h00 densité de surface $\bar{P}_S$ =17.7 tonnes/mille^2;
densité par volume $\bar{P}_V$=00007 spécimen/m^3 ou 0.056 g/m^3.
A 18h00 densité de surface $\bar{P}_S$ =18.0 tonnes/mille^2
densité par volume $\bar{P}_V$=0.01 spécimen/m^3 ou 0.08 g/m^3.

Figure 17: Enregistrement acoustique du trait № 107.

A 16h10 densité de surface $\bar{P}_S$ =36.2 tonnes/mille^2;
densité par volume $\bar{P}_V$=0.01 spécimen/m^3 ou 0.08 g/m^3.
A 10h00 densité de surface $\bar{P}_S$ =30.3 tonnes/mille^2
densité par volume $\bar{P}_V$=0.007 spécimen/m^3 ou 0.056 g/m^3.

Figure 18: Enregistrement acoustique nocturne typique d'*E. carlsbergi*. Aucune évaluation de densité ni aucun chalutage n'a été effectué dans ce cas.

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

Figura 7: Ecogramas de concentraciones de *E. carlsbergi* en las mañanas (6:00 a 7:00 hrs) en un rango de profundidad de 70 a 350 m en la Zona del Frente Polar (septiembre 1988).

Figura 8: Ecogramas de concentraciones de *E. carlsbergi* durante el día (12:00 a 14:00 hrs) en un rango de profundidad de 190 a 450 m en la Zona del Frente Polar (septiembre a octubre de 1988).

Figura 9: Ecogramas de concentraciones de *E. carlsbergi* durante el día (14:00 a 15:00 hrs) en un rango de profundidad de 60 a 200 m en el área de la segunda prospección a escala fina (diciembre de 1988).

Figura 10: Ecogramas de concentraciones de *E. carlsbergi* en las tardes (19:00 a 20:00 hrs) en un rango de profundidad de 40 a 130 m en el área de la segunda prospección a escala fina (diciembre de 1988).

Figura 11: Ecogramas de concentraciones de *E. carlsbergi* en las noches (00:30 a 1:30 hrs) en un rango de profundidad de 40 a 180 m en el área de la tercera prospección a escala fina (diciembre de 1988).

Figura 12: Ecogramas de concentraciones de *E. carlsbergi* durante la tarde [17:00 a 18:00 hrs (a)] a profundidades de 70 a 80 m en el área de la tercera prospección a escala fina y en la mañana [05:00 a 06:00 hrs (b)] a profundidades de 50 a 100 m.

Figura 13: Ecograma del lance No. 58

Densidad media de la superficie $\bar{P}_S$ =51.9 t/milla^2

Densidad media por volumen $\bar{P}_V$ =0.04 especímenes/m^3 ó 0.32 g/m^3

Figura 14: Ecograma típico de las concentraciones de *E. carlsbergi* durante la tarde y noche.
Cambio en la densidad superficial:
a las 17:00 hrs - P_S=25.8 t/milla^2; a las 19:00 hrs - P_S =24.4 t/milla^2.
Cambio de la densidad por volumen:
a las 17:00 hrs - P_V =0.03 especímenes/m^3 ó 0.16 g/m^3.

Figura 15: Ecograma característico de concentraciones de *E. carlsbergi* en las mañanas y en horas de luz.

Figura 16: Ecogramas de concentraciones de *E. carlsbergi* en las mañana y en horas de luz.
A las 8:00 hrs:

densidad superficial $\bar{P}_S$ =17.7 t/milla^2

densidad por volumen $\bar{P}_V$ =0.007 especímenes/m^3 ó 0.056 g/m^3.

A las 10:00 hrs:

densidad superficial $\bar{P}_S$ =18.0 t/milla^2

densidad por volumen $\bar{P}_V$ =0.01 especímenes/m^3 ó 0.08 g/m^3.

Figura 17: Ecograma del lance No. 107.
A las 16:10 hrs:

densidad superficial $\bar{P}_S$ =36.2 t/milla^2

densidad por volumen $\bar{P}_V$ =0.01 especímenes/m^3 ó 0.08 g/m^3.

A las 18:00:

densidad superficial $\bar{P}_S$ =30.3 t/milla^2

densidad por volumen $\bar{P}_V$ =0.007 especímenes/m^3 ó 0.056 g/m^3.

Figura 18: Ecograma nocturno característico de *E. carlsbergi.* En este caso no se efectuó arrastre ni se calculó la densidad.

WG-FSA-90/36

A FUNCTIONAL DIVISION OF *ELECTRONA CARLSBERGI* (TÅNING, 1932) AREA OF HABITAT IN RELATION TO THE LATITUDINAL ZONATION OF THE SOUTHERN OCEAN

A.V. Zemsky and S.A. Zozulya*

Abstract

During the cruise of the RV *Vozrozhdenie* (VNIRO, USSR) in March/April 1990 an integrated study survey was conducted in the Southern Atlantic along two meridional transects at 17° and 20°W in the latitudes from 37°30' to 55°30'S. The survey was mainly focussed on studies of distribution of adult and pre-spawning *Electrona carlsbergi* and also on searching for possible spawning areas of the species. During the survey the following zones within the study area were identified as having different vertical structures of water masses: Subtropical Zone, Subtropical Frontal Zone, Sub-Antarctic Zone, Polar Frontal Zone and Antarctic Zone. Samples of *E. carlsbergi* were analysed by length composition, sex ratio and maturity stages in relation to the location where samples had been taken. The following division of the *E. carlsbergi* area of habitat was suggested after the analysis: feeding area - Polar Frontal Zone; reproduction area - Sub-Antarctic Zone and Subtropical Frontal Zone. The centre of the species' area of habitat is in the Sub-Antarctic Zone because the greatest range of fish length and stages of gonad maturity has been observed in this zone.

Résumé

Au cours de la campagne du navire de recherche *Vozrozhdenie* (VNIRO, URSS) en mars/avril 1990, une campagne d'étude intégrée fut effectuée dans l'Atlantique sud, le long de deux transects méridiens à 17° et 20°W, entre les latitudes de 37°30' et 55°30'S. La campagne d'étude était principalement axée sur un examen de la répartition d'*Electrona carlsbergi* adulte et en état de préponte ainsi que sur la recherche des frayères potentielles de l'espèce. Durant la campagne d'étude, les zones suivantes, possédant chacune une différente structure verticale des masses d'eau, ont été identifiées dans l'aire étudiée: la zone subtropicale, la zone frontale subtropicale, la zone subantarctique, la zone frontale polaire et la zone antarctique. Des échantillons d'*E. carlsbergi* ont été analysés en matière de composition en longueurs, sex ratio et stade de maturité, relativement à la position de leur prélèvement. Après analyse, la division suivante de l'habitat d'*E. carlsbergi* a été proposée: aire d'alimentation - zone frontale polaire; aire de reproduction - zone subantarctique et zone frontale subtropicale. Le centre de l'aire d'habitation de l'espèce est présumé être dans la zone subantarctique, le plus grand éventail de longueurs et de stades de maturité des gonades ayant été observé dans cette zone.

* VNIRO , 17a Verhnaya Krasnoselskaya Street, Moscow, USSR

Резюме

В ходе рейса НИС *Возрождение* (ВНИРО, СССР) в марте - апреле 1990 г. в южном секторе Атлантики была выполнена комплексная съемка вдоль двух меридиональных разрезов между 17° и 20°з.д. и 37°30'-55°30'ю.ш. Основной целью съемки было изучение распределения взрослых и преднерестовых особей вида *Electrona carlsbergi*, а также поиск возможных нерестовых участков этого вида. В ходе съемки в изучаемом районе были выделены следующие зоны, характеризующиеся различной вертикальной структурой водных масс: субтропическая зона, субтропическая фронтальная зона, субантарктическая зона, полярная фронтальная зона и антарктическая зона. Был выполнен анализ размерного и полового состава и стадий половозрелости особей *E. carlsbergi* в зависимости от места сбора проб. В результате анализа было предложено следующее деление ареала распространения вида *E. carlsbergi*: район кормления - полярная фронтальная зона, район воспроизводства - субантарктическая зона и субтропическая фронтальная зона. Центральной частью ареала распространения этого вида является субантарктическая зона. В этой зоне наблюдался наиболее широкий диапазон размеров и стадий половозрелости.

Resumen

Durante el crucero del BI *Vozrozhdenie* (VNIRO, URSS) en marzo/abril de 1990, se efectuó una prospección de estudio integrado en el Atlántico austral, a lo largo de dos transectos en los meridianos 17° y 20°W y entre las latitudes 37°30' y 55°30'S. La prospección estuvo enfocada en el estudio de la distribución de *Electrona carlsbergi* en los estados adulto y previo al desove, y en la determinación de las posibles zonas de freza de la especie. Durante este estudio se establecieron zonas con distintos perfiles de masas de agua, dividiéndose éstas en: Subtropical, Frente Subtropical, Subantártica, Frente Polar y Antártica. Se analizó la composición por tallas, la proporción de sexos y estados de madurez de *E. carlsbergi* en función del lugar de recolección de las muestras. Posteriormente, una vez analizados los datos, se propuso la siguiente división del área en donde predomina la especie: área de alimentación - Zona del Frente Polar; área de reproducción - Zonas Subantártica y Subtropical. Se cree que el área de mayor concentración de la especie es la zona subantártica, ya que fue en esa área en donde se observó la mayor gama de tallas de peces así como individuos en distintas fases de maduración gonadal.

1. AIMS AND TASKS

The search for new fishing grounds and target species in recent years has opened up great opportunities for exploiting mesopelagic fish of the Southern Ocean (Lubimova *et al.*, 1983 a, b). One of the most promising of these is *Electrona carlsbergi* (Myctophidae). In the southern summer this species forms dense and fairly stable feeding concentrations near the southern boundary of the Polar Frontal Zone (PFZ). To date the basic distribution patterns, behaviour, timing and size of concentrations have been determined for this species in the PFZ waters in relation to environmental conditions (Maslennikov *et al.*, 1990). However, the question of the functional division of *E. carlsbergi*'s habitat is as yet unresolved. This is because only juvenile specimens typically inhabit the PFZ area where integrated studies of this species have been concentrated over a number of years (Kozlov and Zemsky, 1988). During the fifteenth cruise of RV *Vozrozhdenie* in 1989, the VNIRO conducted integrated studies in the central part of the Atlantic sector of the Southern Ocean on distribution of adult and pre-spawning fish and possible spawning areas.

2. MATERIALS AND METHODS

From 20 March to 10 April 1989, two longitudinal transects were made along 17° and 20°W in the latitudinal band between 37°30' and 55°30'S. The choice of these two meridians was dictated by the theory that the reproductive part of the *E. carlsbergi* distribution area coincides with the thalassic bathyal, in particular central oceanic ridges. It is assumed that dynamic conditions favourable for spawning occur in ridge areas, due to powerful meandering currents and an increased level of gyre activity. Therefore we attempted as far as possible to approximate the transects, for the most part in their northern sections, to the crest of the South Atlantic Ridge (Figure 1). A small-scale survey of the area bounded by 40°00' to 42°30'S and 16°00' to 17°00'W was also carried out. The distance between stations on the transects was 30 miles (each 30' of latitude and longitude in the small-scale survey area). Echosounding was used in the upper 1 000 m layer using the Neil Brown Mark IIIB system. Methodologies contained in the following works were used to define the boundaries of the frontal zones: Antipov *et al.*, 1987; Belkin *et al.*, 1988; Deacon, 1982.

Over the period of research 26 hauls were performed using a midwater cable trawl with a mouth opening of 3 600 m^2. Trawling speed was usually 3 to 3.5 knots; with a trawling duration of 1 hour.

Because of the known relationship between the distribution of *E. carlsbergi* and the Intermediate Antarctic Water Mass (Krefft, 1974) and also of the sub-Antarctic nature of the species, trawling depth to the north of the PFZ gradually increased from 140 to 600 m, which corresponds to the depth of the nucleus of this water mass in its northern sector. The depth of this nucleus (interim minimum salinity) was determined using data obtained from hydrological stations. Trawling stations were as far as possible spread evenly over the transects, depending on changes in vertical water structure (Figure 2). As a result, trawling was carried out whether readings from hydrological gear were available or not.

3. DISCUSSION OF RESULTS

3.1. Latitudinal Zonation Along Transects 17° and 20°W

Along the transects (Figures 3 and 4) we identified the following latitudinal zones from north to south (Figure 5): Subtropical Zone (STZ), Subtropical Frontal Zone (STFZ), Sub-Antarctic Zone (SAZ), Polar Frontal Zone (PFZ) and Antarctic Zone (AZ). The discovery in the central part of the South Atlantic, of a fairly broad STFZ bounded by two temperature/salinity fronts, together with analogous results obtained in the southern part of the Pacific Ocean (Belkin *et al.*, 1988; Kryukov and Sapozhnikov, 1987) off the southern coast of

Africa (Lutjeharms and Valentine, 1984; Lutjeharms, 1985; Lutjeharms and Foldvik, 1986) points at circumpolar distribution of STFZ (with the natural exception of Drake Passage). By comparison with current knowledge of this little-explored region (Clifford, 1983; Deacon, 1982; Gordon and Molinelli, 1982; Valentine and Lutjeharms, 1983), on our transects the Subtropical Front (STF, or the northern boundary of the STFZ) is located slightly further to the north, while the PFZ is much further to the south.

The northern boundary of the STFZ passed between 38° and 39°S and the southern boundary between 41°30' and 42°S at 20°W and between 42°30' and 43°S at 17°W. Moreover, an anticyclonic meandering current on the southern boundary of the STFZ (or a gyre formed in this frontal area) has been identified along the transect of 20°W at 44° to 45°S.

The northern boundary of the PFZ (Sub-Antarctic Front) at 20°W was located between 48° and 48°30'S. At 17°W this boundary was crossed three times (at 46°30' to 47°, 47°30' to 48° and 48°30' to 49°S) due to the meandering of the current.

The relatively extended nature of the meandering boundary of the PFZ (Polar Front) along the transect of 20°W (beginning from 54°S) was detected only at 52° to 53°S. At 17°W the southern boundary of the PFZ passed between 54°30' and 55°S. However, water structure typical for this front was noted over a series of stations made right up to 50°30'S. Therefore, considerable disruptions were detected along the longitudinal transects. This is connected with the strong meandering streams of the Antarctic Circumpolar Current (ACC) interacting with the South Atlantic Ridge.

3.2 Functional Division of the Area of Habitat of *E. carlsbergi*

More than 28 fish species of the Myctophidae family were taken in the course of trawling. *E. carlsbergi* was the most common species, being encountered in 20 of the 26 hauls. It was found in the catches of two hauls in the Antarctic Zone, four hauls in the PFZ, seven hauls in the SAZ, and seven hauls in the STFZ. The species was not encountered in the Subtropical Zone. Catch locations for *E. carlsbergi* are shown in Figure 6. Analysis of *E. carlsbergi* size composition and biological condition was performed with the boundaries of identified latitudinal zones kept in mind.

<u>Size characteristics of *E. carlsbergi*</u>. More than 2 000 specimens were measured along the transects. Data on changes in *E. carlsbergi* size (length) in relation to latitudinal zonation gives the following picture:

in the AZ - from 7.5 to 9.0 cm., M=8.06 cm, N=206;
in the PFZ - from 7.0 to 9.5 cm., M=8.20 cm, N=613;
in the SAZ - from 7.0 to 10.5 cm., M=8.6 cm, N=828;
in the STFZ - from 7.5 to 10.5 cm., M=8.73 cm, N=425.

The greatest length range was in the SAZ, while the highest modal length was in the STFZ. Minimal changes in length were noted in the PFZ and AZ, while the smallest modal lengths were also typical for these zones. In other words, an increase in the modal length occurs from south to north with the maximum variation in length being in the SAZ and the maximum length of adult specimens in the STFZ.

<u>Maturation of *E. carlsbergi*</u>. When examining the biological characteristics of the species, it should be noted that during our survey the change in maturation of male and female gonads was found to be related to the latitude of a place where the specimens were caught. This is the first time such information has been obtained and it deserves more detailed examination than other biological parameters.

During studies along the transects more than 800 specimens of *E. carlsbergi* underwent biological analysis. Figure 7 shows that fish with gonads only at the second stage of development are usually present in the AZ and PFZ. Specimens with both second stage and more mature gonads (up to fifth stage) are found in the SAZ. Moreover, within this zone the proportion of gonads at later stages of maturity increases from south to north. Only second and third stage gonads, almost in equal numbers, occur in the southern part of the SAZ (haul No. 58). Females with fourth and fifth stage gonads appear in the central part of the SAZ, while the number of fish with second stage gonads gradually decreases. Thus, the central part of the SAZ may be considered the main distribution area of maturing fish with gonads at the third stage of maturity. To the north of 45°S (possibly due to the influence of meandering currents/gyres in the STFZ), only individual specimens having second stage gonads are encountered, while adult fish with fourth and fifth stage gonads are the most common. The northern part of the SAZ is chiefly an area of pre-spawning specimens. The STFZ is dominated by fish of fifth stage gonad maturity and, as such, may be seen as a zone of distribution of adults capable of spawning. Maturing specimens with gonads still far from the spawning stage are encountered individually in this zone (e.g., one specimen with third stage gonads was found in haul No. 50).

In addition to the analysis of *E. carlsbergi* maturity in relation to the boundaries of latitudinal zones, we have taken another approach to presenting the data being analysed (see Figure 8). Representative hauls are represented on the horizontal axis, however only the absolute shift of trawling position from south to north, not the sequence of hauls, was taken into consideration. The number of fish at one or another stage of maturity (as a percentage of the total number), used as the basis for bioanalysis of each catch, is presented on the vertical axis. This method made it possible to identify three areas (zones) along the horizontal axis; a zone where only females at the second stage of maturity are present; a zone containing fish at various stages of maturity (from second to fifth) and a zone where fish at the fifth stage of maturity predominate. If one takes into account the zones in which the trawling was carried out it becomes clear that the first zone corresponds to the PFZ, the second to the SAZ, and the third to the STFZ.

Figure 9 shows the percentages of males and females of *E. carlsbergi* at different stages of maturity by latitudinal zones. All males and females analysed in the AZ and PFZ turned out to be at Stage II of maturity. The following percentages were obtained for the SAZ: females found at various stages of maturity, from Stages II to V, with the latter dominating significantly (Stage II - 7%, Stage III - 18%, Stage IV - 8%, Stage V - 67%); males were mainly Stage II, males at Stage V were absent (Stage II - 53%, Stage III - 33%, Stage IV - 14%). The situation is considerably different in the STFZ (males: Stage III - 1%, Stage IV - 1%, Stage V - 99%; females: Stage III - 36%, Stage IV - 62%, Stage V - 3%). In this zone both males and females at Stage II of maturity were present; the overwhelming majority of females had gonads at Stage V of maturity as did some males. Furthermore, there was only a small number of females at the Stage III of maturity. It must also be noted that, unlike females, males in the STFZ appear at the Stages III and IV as well as Stage V. Moreover, these types of specimens are extremely abundant.

In our opinion, all the above data on the different maturity stages of *E. carlsbergi* gonads for males and females prove that the STFZ is the part of the distribution area of habitat of this species in which reproduction takes place.

Having analysed the combined percentages of males and females at different stages of maturity by latitudinal zones, we will now examine the change in the ratio of gonad maturity in relation to change in male and female size.

Only females at Stage II (7.5 to 9.0 cm length) are encountered in the AZ (Figure 10). Although the condition of female gonads was similar in the PFZ, there was a notably wider range of length - from 7.0 to 9.5 cm. The largest range of size for females is in the SAZ (from 7.0 to 11.0 cm), where fish of all maturity stages are encountered. The greatest variety of maturity stages was among specimens from 7.5 to 9.0 cm. Stage V of maturity begins to be identifiable in females from 8.0 cm long. For females 8.5 cm long, Stage V was found in 55% of specimens, and for females 10.0 cm and longer, in 100%. Large females from 8.5 to 10.5 cm are common in the STFZ where a distinct predominance of Stage V was noted for females of all sizes.

On the whole a similar picture emerges in respect of the change in percentages of male *E. carlsbergi* at different stages of maturity by latitudinal zones in relation to length (Figure 11). Males from 7.5 to 8.5 cm at Stage II are typical of the AZ. Only males at Stage II were found in the PFZ, however their size range was larger from 7.0 to 9.0 cm. The widest size range occurs in the SAZ (6.5 to 10.5 cm). All maturity stages except for the fifth are common in this zone, with males from 8.0 to 9.5 cm long commanding the greatest diversity of maturity stages. Males reach fullest maturity (Stage IV accounts for 22%) at 8.5 cm, while the gonads of 9.5 cm and longer specimens are exclusively at the Stage IV. Males at Stage II were not detected in the STFZ where the range of change in size, only 1.5 cm, is generally smaller (from 8.0 to 9.5), however, most specimens tend towards the upper end of the range. Stage IV of maturity begins when males attain 8.0 cm and is dominant from 8.5 cm (58%, 65% and 84% for fish of 8.5, 9.0 and 9.5 cm length respectively). Stage V of maturity was noted for males 9.0 cm in length. The largest percentage of Stage V of maturity (6%) among examined fish was observed at 9.5 cm, which is the maximum length in this zone.

It should be noted that only juvenile specimens of *E. carlsbergi* appeared in catches in the two southern zones (AZ and PFZ). Figure 12 shows the dynamics of change in sexual maturity of *E. carlsbergi* females at different lengths. Both juvenile and adult females are present in the SAZ. Adult specimens were noted at over 7.0 cm in length (15%), and from 7.5 to 11.0 cm practically all females had mature gonads. Only juvenile females from 8.0 to 10.5 cm were typical of the STFZ.

<u>E. carlsbergi sex ratios</u> in different latitudinal zones were the following:

AZ	-	males - 54%	females - 46%
PFZ	-	males - 49%	females - 51%
SAZ	-	males - 46%	females - 54%
STFZ	-	males - 51%	females - 49%

Figure 13 shows *E. carlsbergi* sex ratios by zones in relation to fish length. In the AZ males are predominant from 7.0 to 8.0 cm (7.5 cm - 67%, 8.0 cm - 62%). For specimens over 8.0 cm the sex ratio is almost equivalent with females being slightly dominant (53%) and for fish over 8.5 cm females account for 100%. In the PFZ a predominance of males was observed in specimens from 7.0 to 8.0 cm (67, 63, 67%); from 8.5 to 9.0 cm females begin to dominate and account for 100% at 9.0 cm and longer. The SAZ has a more complex sex ratio, where males of 7.0 to 8.0 cm in length are dominant, accounting for 93% of specimens at 8.0 cm. At 8.5 cm the situation is more even (48% males, 52% females) although the proportion of females thereafter increases, reaching 100% at 10.5 cm and longer. It must be noted that large males are typical of this area, accounting for 25% at 10.0 cm. For specimens from 7.5 to 9.0 cm in the STFZ a gradually decreasing predominance of males was observed (100, 88, 66%). At lengths over 9.0 cm females become predominant, overwhelmingly so at lengths over 10.5 cm.

<u>E. carlsbergi weight, feeding and fat reserves</u>. Weight of the species under investigation also changes by latitudinal zones. To the north, a trend was observed towards an increase in weight from 7.3 g in the PFZ to 11.2 g in the STFZ. Mean weight in the SAZ was 9.1 g. This tendency held true for weight analysis of males and females made separately. Males weighed 7.4 g in the PFZ, 8.5 g in the SAZ and 9.9 g in the STFZ. Correspondingly, females weighed 8.4, 10.2 and 10.7 g.

Feeding intensity also changes between the southern and northern areas. A decrease in feeding activity was observed between the PFZ and the STFZ, i.e. away from the main feeding area. The mean index of stomach fullness in the PFZ was 1.18, 1.01 in the SAZ and 0.96 in the STFZ.

Visually determined fat content was also subject to change depending on the latitude of the area where the fish was taken. It was 1.47 in the PFZ, 1.16 in the SAZ and 0.82 in the STFZ.

4. CONCLUSION

(i) After research carried out from March to April 1989 in the central part of the Atlantic sector of the Southern Ocean the following zones with different water structures were identified (from north to south): Subtropical Zone, Subtropic Frontal Zone, Sub-Antarctic Zone, Polar Frontal Zone and the Antarctic Zone.

(ii) On longitudinal transects along 17° and 20°W significant disruptions to latitudinal zonation due to strong meandering of the ACC and its interaction with the South Atlantic Ridge were identified. Thus, our data do not support the generally-held view that the ridge does not affect the dynamics of the ACC.

(iii) *E. carlsbergi* is closely linked with the Antarctic Intermediate Water Mass. This is supported by the increase in depth from south to north of water layers where the samples are taken. *E. carlsbergi* is a typical representative of mesopelagic ichthyofauna in the PFZ, SAZ and STFZ. The northern boundary of the STFZ limits the penetration of *E. carlsbergi* into the north. The species is not found in the Subtropical zone.

(iv) Analysis of *E. carlsbergi* length in relation to the latitude of catch location provided a picture contrary to the generally accepted biological law that the length and mass of living organisms increases from north to south. We have established that smaller fish inhabit the PFZ, the maximum range of body length is typical for the Sub-Antarctic and the largest body lengths are found in the STFZ. The above law obviously only applies when there is an even distribution of all species functional activities throughout the entire area in which the species exists, i.e. feeding and reproduction have to take place in all latitudinal zones. Considering the increase in body length from south to north (from the PFZ to the STFZ) our investigations show an exception to this biological law in connexion with the species' feeding activities on the southern periphery of its habitat and spawning in the northern part.

(v) Analysis of *E. carlsbergi* distribution at various stages of maturity shows that (a) only fish at Stage III of maturity occur in the PFZ; (b) SAZ is a zone of distribution mainly for fish at the Stages III and IV-V (southern and northern parts of the zone respectively); and (c) STFZ is primarily a zone of distribution for spawning fish.

(vi) The onset of sexual maturity of *E. carlsbergi* in the SAZ is observed at a length of over 7.0 cm, and at length over 7.5 cm all fish are mature. Adult females in the STFZ are noted at a length of over 8.0 cm.

(vii) Stage V of maturity is observed in the SAZ among *E. carlsbergi* females 8.0 cm and longer, reaching 100% at 10.0 cm. Stage V of maturity is observed among females of all sizes in the STFZ (8.5 to 10.5 cm).

(viii) *E. carlsbergi* feeding intensity decreases between the PFZ in the south and the STFZ in the north, i.e. between feeding and spawning areas.

(ix) Analysis of our data makes it possible to propose the following functional division of the *E. carlsbergi* area of habitat: PFZ - feeding area, SAZ and STFZ - reproduction area. Moreover, the SAZ is the centre of the species' habitat because it is precisely in this zone that the greatest range of lengths among specimens and females at all stages of maturity are observed.

REFERENCES

Антипов, Н.Н., И.И. Масленников, С.М. Прямиков. 1987 Положение и структура Полярной фронтальной зоны в западной части тихоокеанского сектора Антарктики. В сб.: "Биолого-океанографические исследования тихоокеанского сектора Антарктики", М., ВНИРО: 19-32.

Белкин, И.М., А.М. Гриценко, И.И. Крючков. 1988. Термохалинная структура и гидрологические фронты. - В кн.: "Экосистемы субантарктической зоны Тихого океана", под ред. М.Е. Виноградова и М.В. Флинта, М., Наука: 28-36.

Крючков, В.В., В.В. Сапожников. 1987. Океанологические особенности вод субантарктической области Тихого океана. - Рыбное хозяйство, Т. 6: 33-37.

Любимова, Т.Г., К.В. Шуст, Л.А. Лисовенко, В.А. Земский, И.С. Студенецкая. 1983a. Биологические ресурсы Южного океана. - Обзор. информ. ЦНИИТЭИРХ, вып. 2: 52 с.

Любимова, Т.Г., К.И. Шуст, Ф.М. Трояновский, А.Б. Семенов. 1983b. К экологии массовых видов миктофид атлантического сектора Антарктики. - Антарктика, М., Наука, вып. 22: 99-106.

Масленников, В.В., С.А. Зозуля, В.Е. Полонский. 1990. Рекомендации по поиску скоплений электроны Карлсберга в пределах Южной полярной фронтальной зоны (океанологическое обоснование). М., изд. ВНИРО: 31 с.

Федоров, К.Н. 1983. Физическая природа и структура океанических фронтов. - Л., Гидрометеоиздат: 296 с.

CLIFFORD, M. A. 1983. A descriptive study of the zonation of the Antarctic Circumpolar Current and its relation to wind stress and ice cover. M.S. thesis, Nex. A & M Univ., College Station. 93 pp.

DEACON, G.E.R. 1982. Physical and biological zonation in the Southern Ocean. *Deep - Sea Res.,. 29*: 1-15.

GORDON, A.L. and E. MOLEINELLI. 1982. *Southern Ocean Atlas*. Pt. 1. Thermohaline and chemical distribution and the atlas data set. N.Y.: Columbia Univ. Press. p. 1-111.

KOZLOV, A.N., A.V. ZEMSKY. 1988. Propiedades de la distribucion y caracteristica biologica de las especias masivas de Myctophidae en el area abierta del Atlantico sudoccidental. - "Resumenes de trabajos de investigacion correspondientes al Quinto simposio cientifico". Comision Tecnica Mixta del Frente Maitimo,. 28-30 noviembre, 1988, Mar del Plata, Argentina. p. 24-25.

KREFFT, G. 1974. Investigation of midwater fish in the Atlantic Ocean. *Ber. Dt. wiss. kommn. Meerforsch, 23*(3): 226-245.

LUTJEHARMS, J.R.E. and H.R. VALENTINE 1984. Southern Ocean thermal fronts south of Africa. *Deep - Sea Res., 31*: 1461-1476.

LUTJEHARMS, J.R.E. and A. FOLDVIK A. 1986. The thermal structure of the upper ocean layers between Africa and Antarctica during the period December 1978 to March 1979. *S. Afr. J. Antarct. Res, 16*: 13-20.

VALENTINE, H.R. and J.R.E. LUTJEHARMS. 1983. Oceanic thermal fronts in the Southern Ocean. Council for Scientific and Industrial Research. *CSIR Research Report 558*: 53.

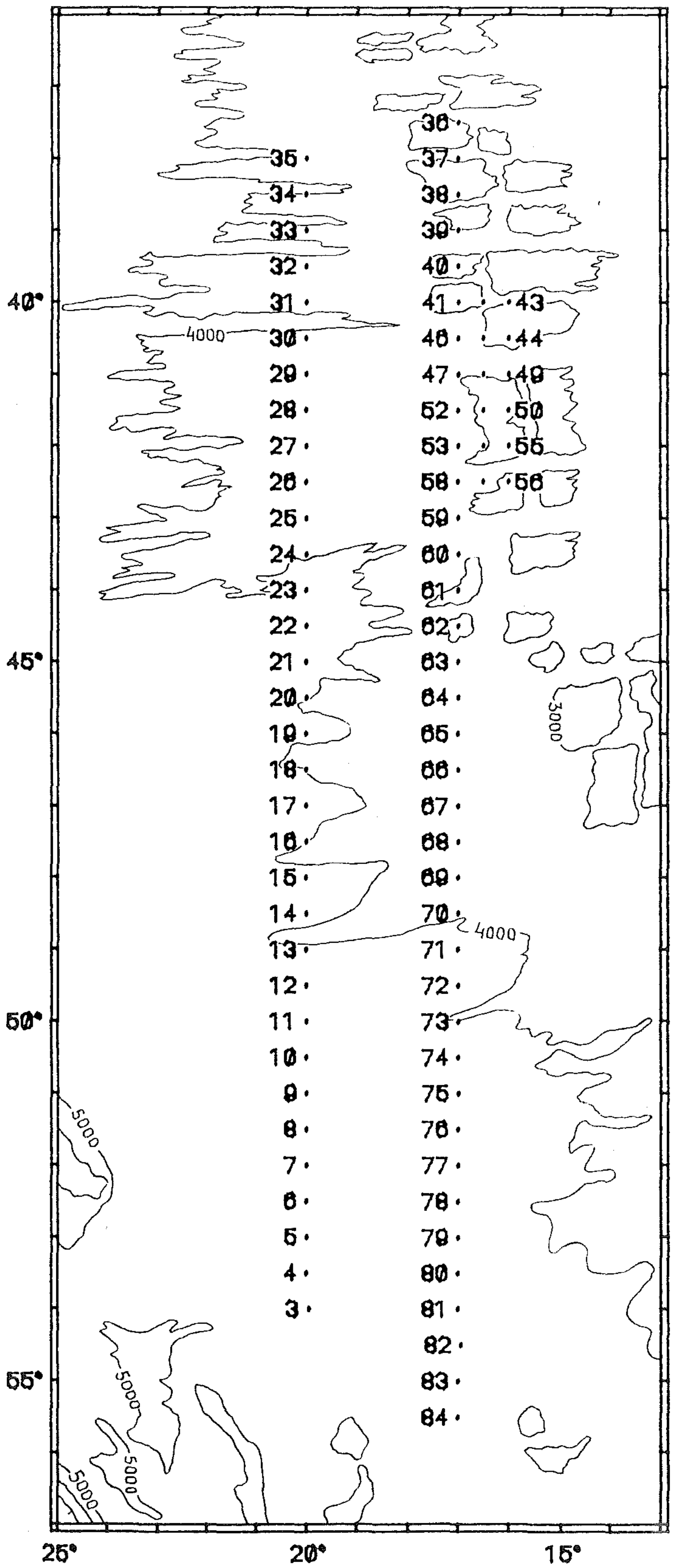


Figure 1: Locations of hydrological stations and bottom topography (GEBCO, 1984).

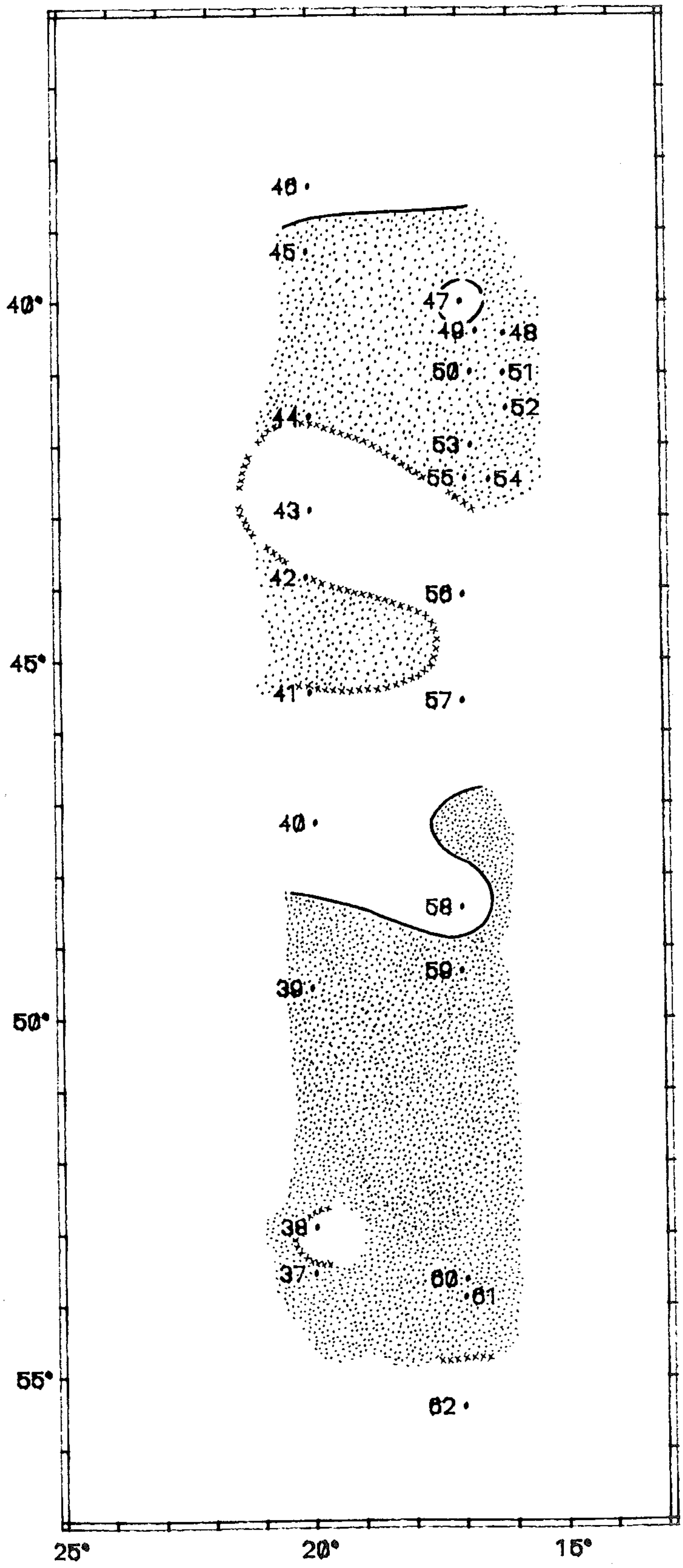


Figure 2: Locations of trawl stations.

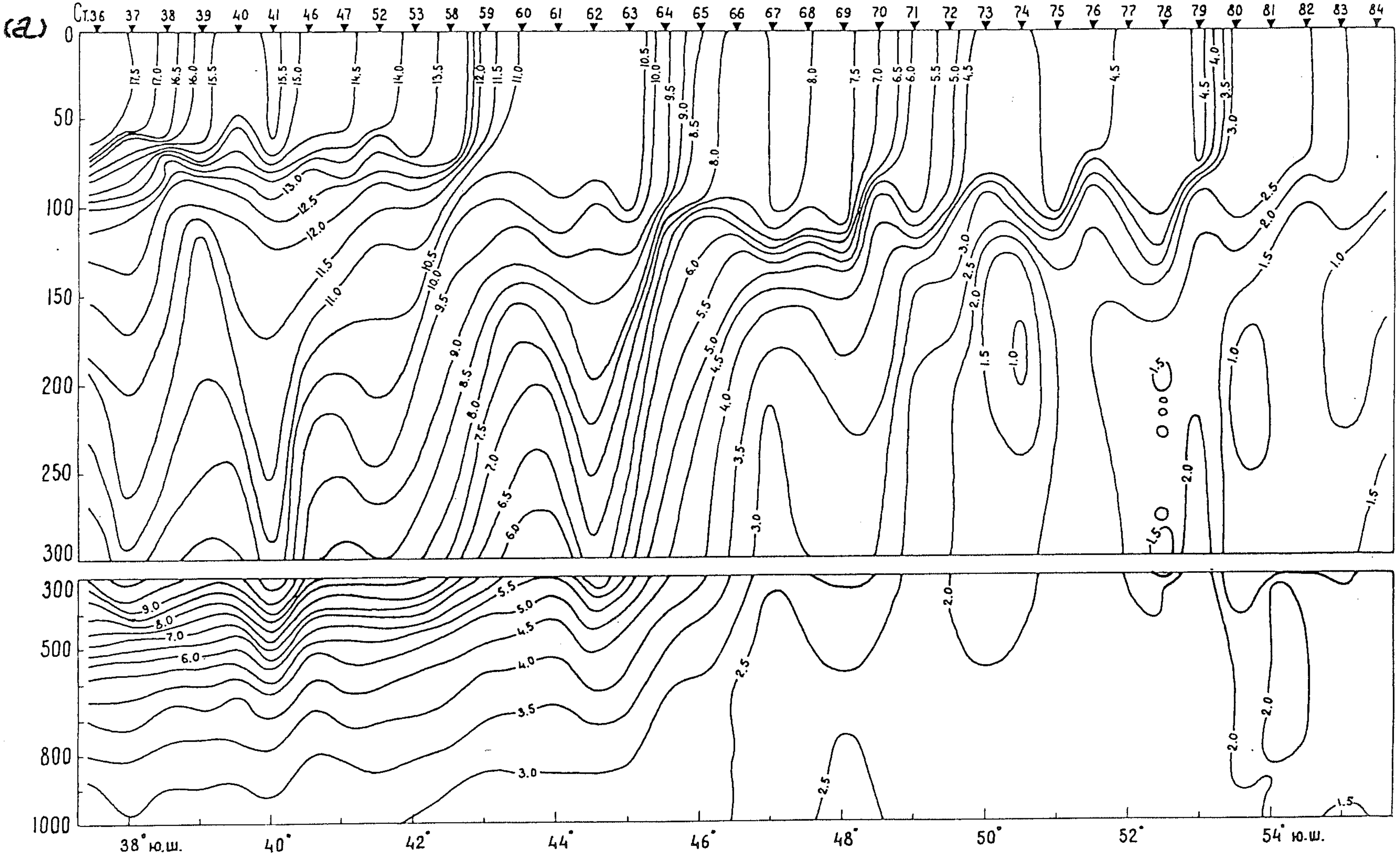
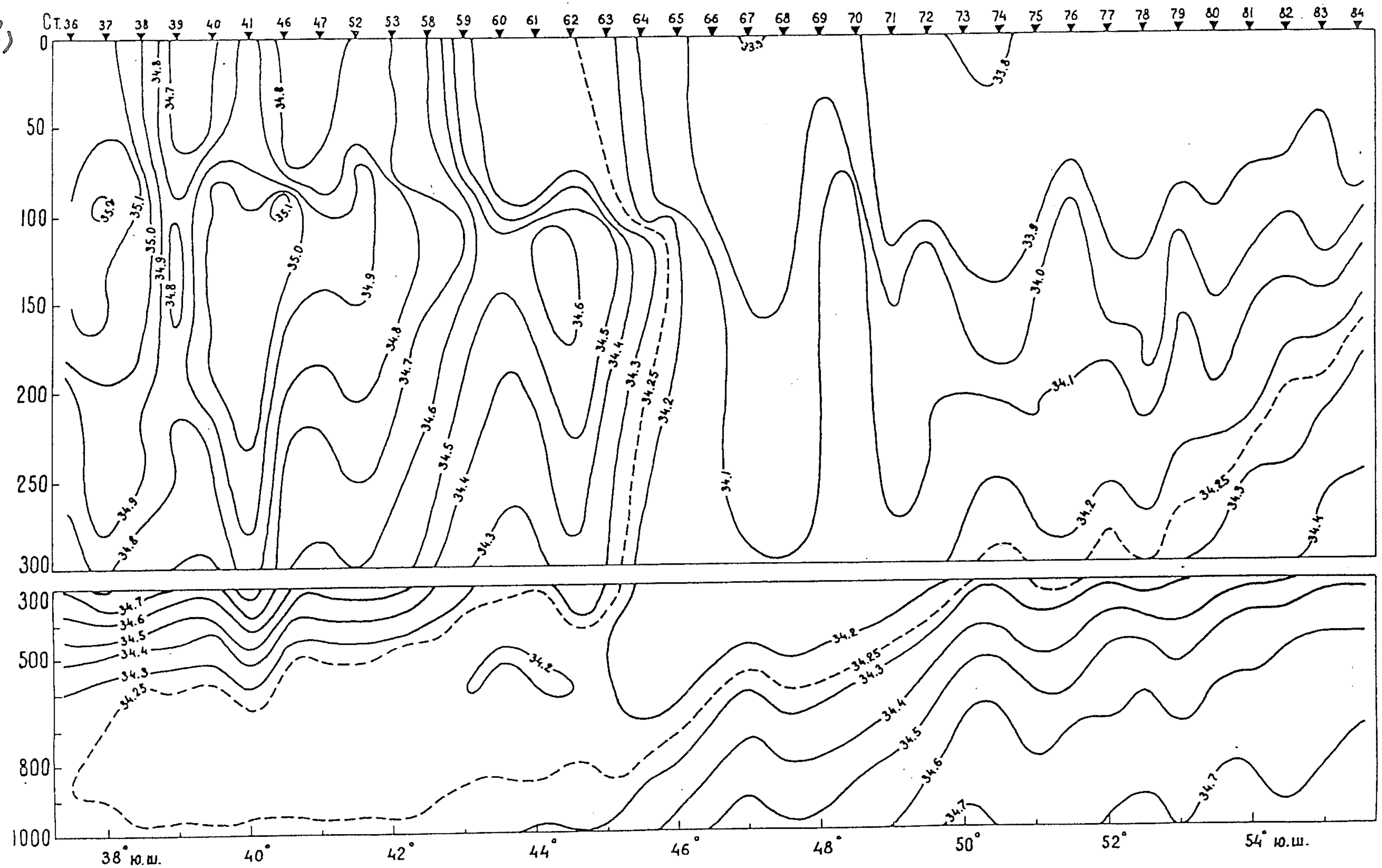


Figure 3: Temperature (a) and salinity (b) along the 17°W transect.

(в)



Ст. 36
37
38
39
40
41
46
47
52
53
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
0
50
100
150
200
250
300
300
500
800
1000
38° ю.ш.
40°
42°
44°
46°
48°
50°
52°
54° ю.ш.
35.2
35.1
35.0
34.9
34.8
34.7
34.6
34.5
34.4
34.3
34.25
34.2
34.1
34.0
33.9
33.8

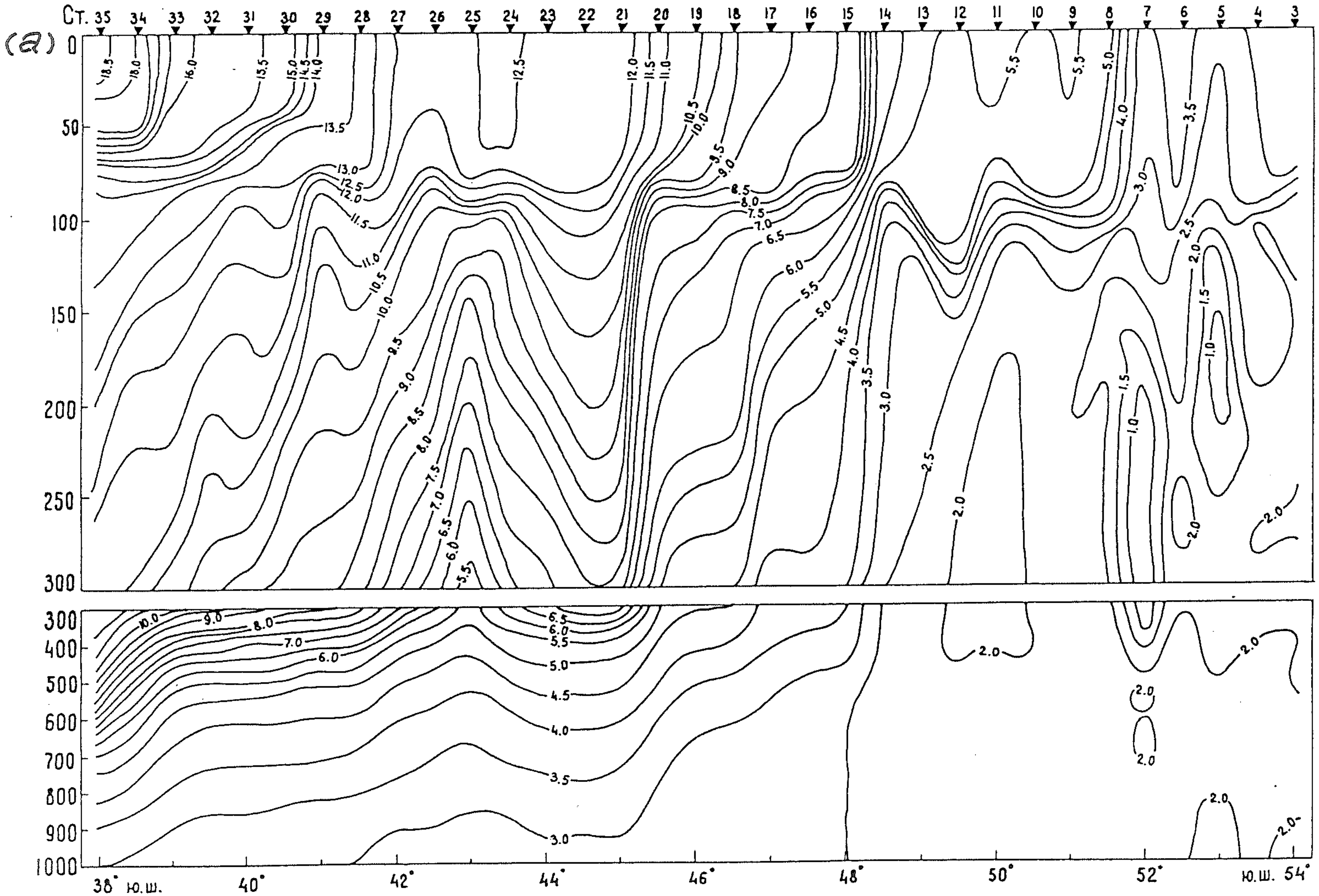
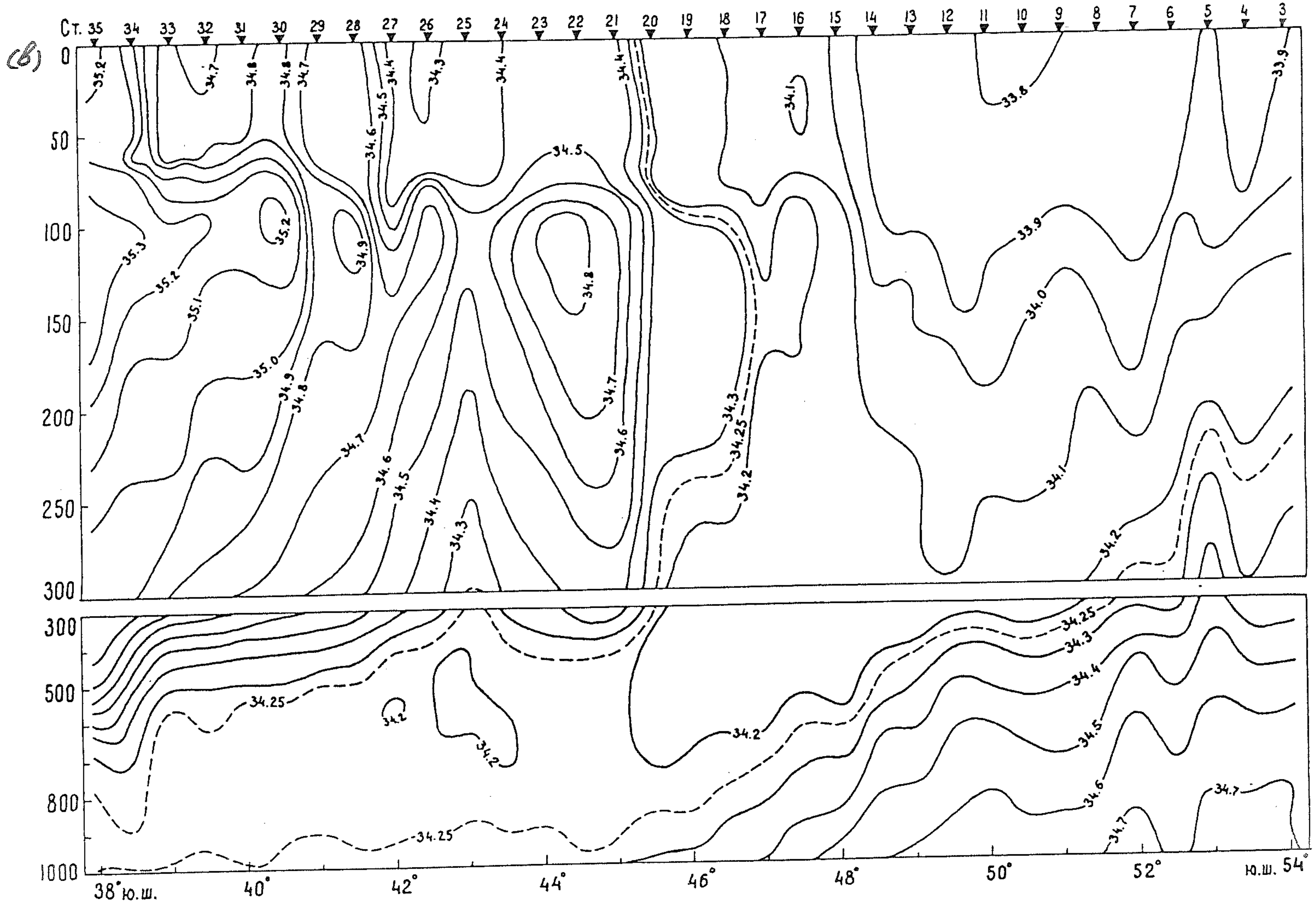


Figure 4: Temperature (a) and salinity (b) along the 20°W transect.


(в)
Ст. 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3
0
50
100
150
200
250
300
300
500
800
1000
35.2
35.3
35.2
35.1
35.0
34.9
34.8
34.7
34.6
34.5
34.4
34.3
34.25
34.2
34.1
34.0
33.9
33.8
38° ю.ш.
40°
42°
44°
46°
48°
50°
52°
ю.ш. 54°

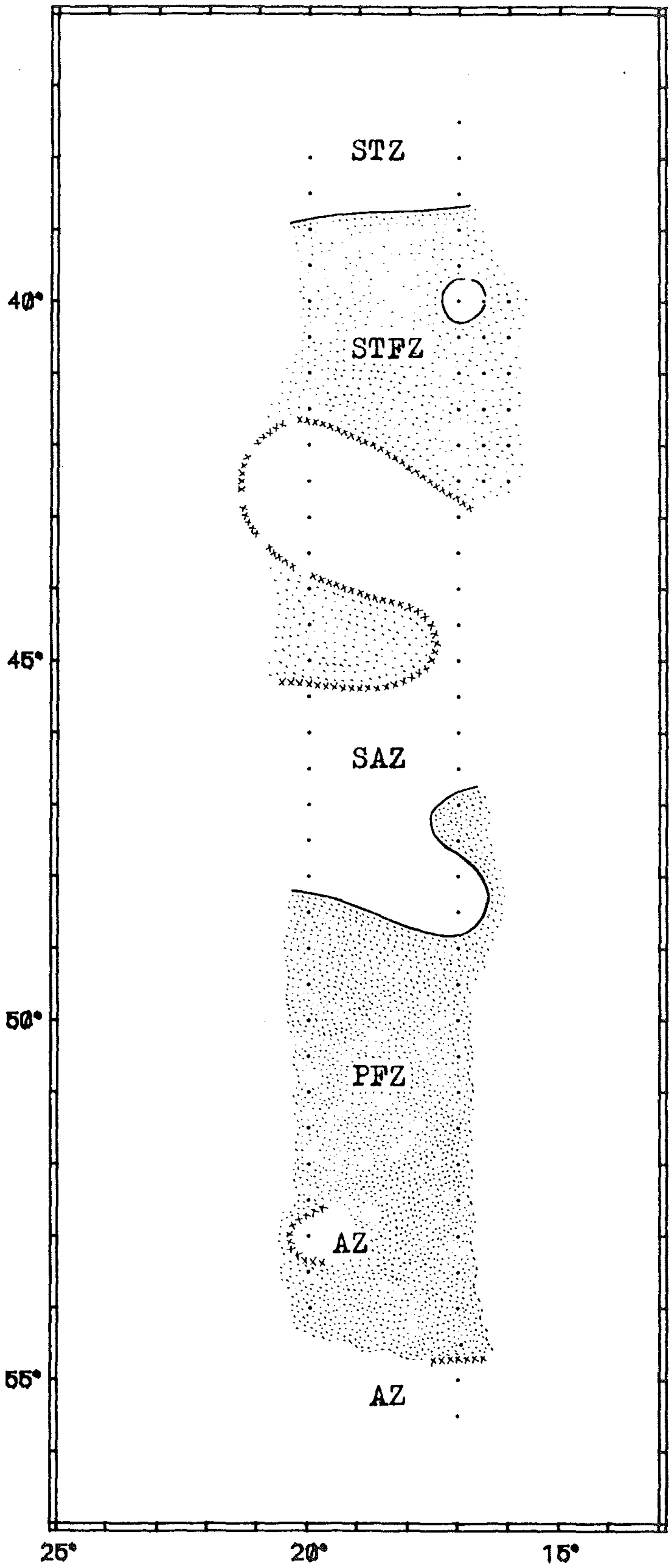


Figure 5: Boundaries of latitudinal zones: STZ - Subtropical zone; STZF - Subtropical Frontal zone; SAZ - Sub-Antarctic zone; PFZ - Polar Frontal zone; AZ - Antarctic zone.

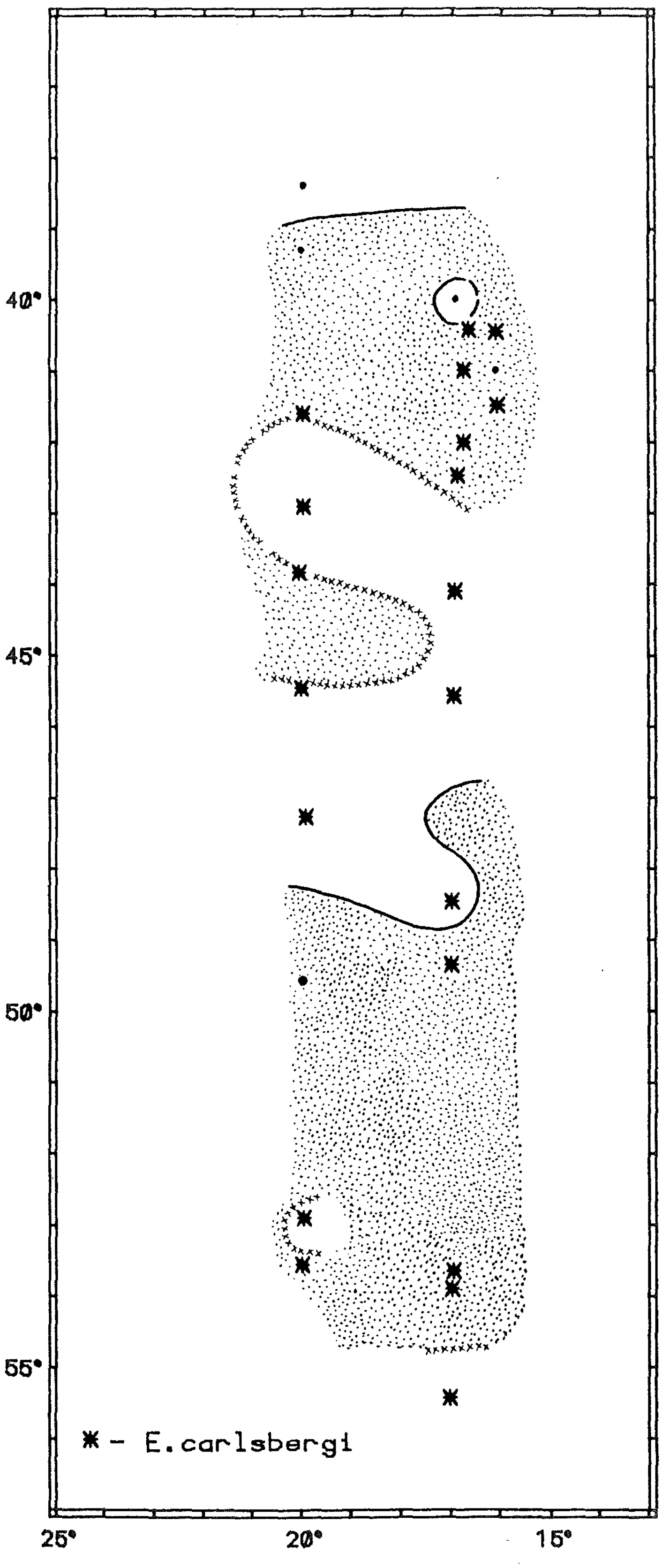


Figure 6: Distribution of *E. carlsbergi* catches along longitudinal transects.

- • non-representative hauls,
- * catches containing *E. carlsbergi*.

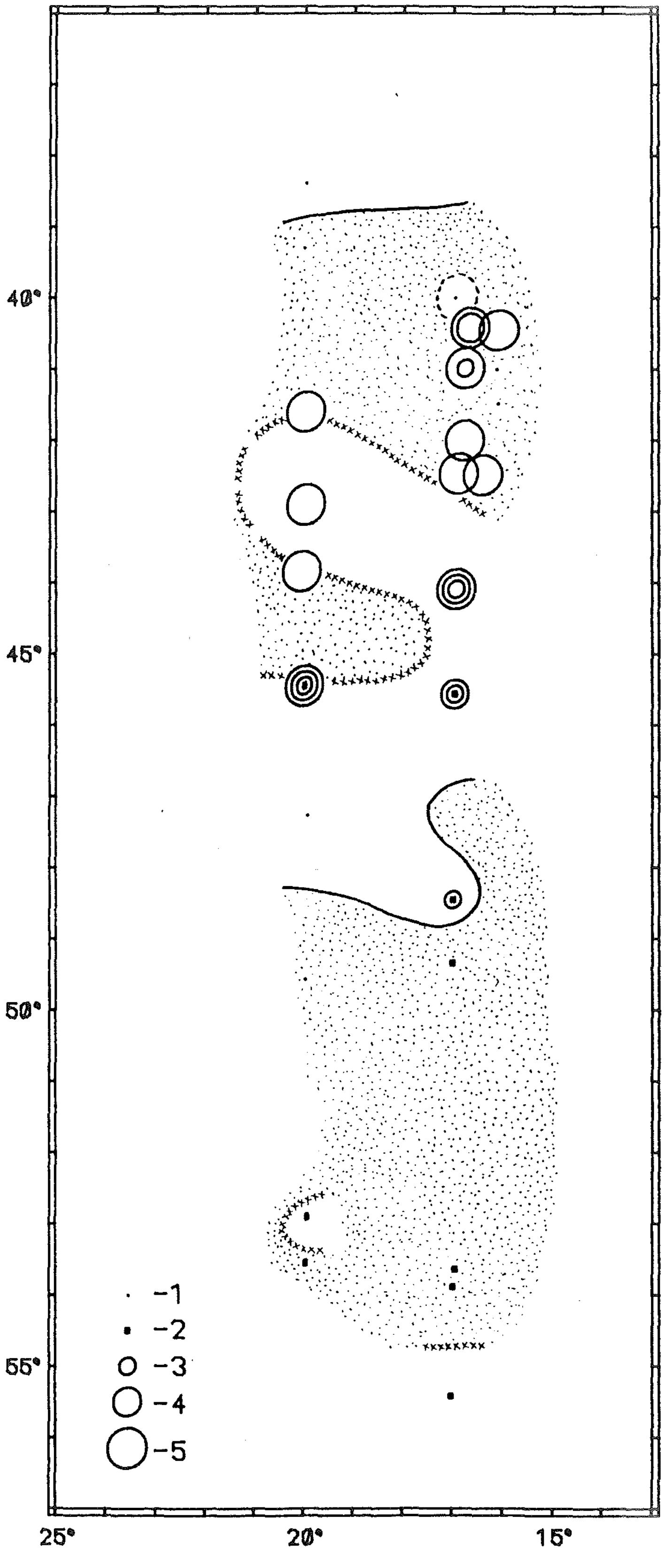


Figure 7: Distribution of female *E. carlsbergi* at various stages of maturity. 1 - non-representative hauls; 2, 3, 4, 5 - females at maturity Stages II, III, IV, V respectively.

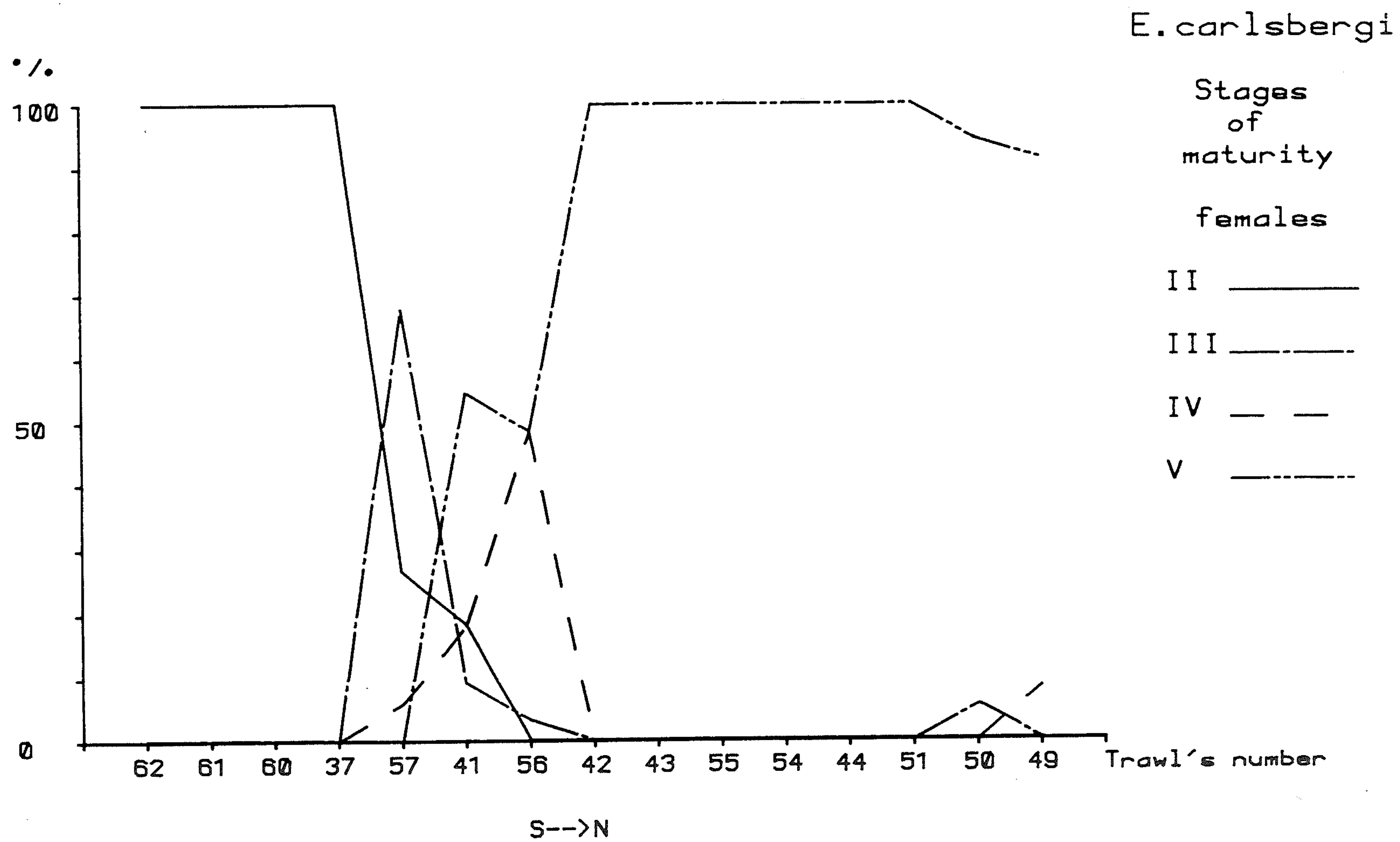


Figure 8: Percentages of males and females of *E. carlsbergi* in trawl catches at different maturity stages.

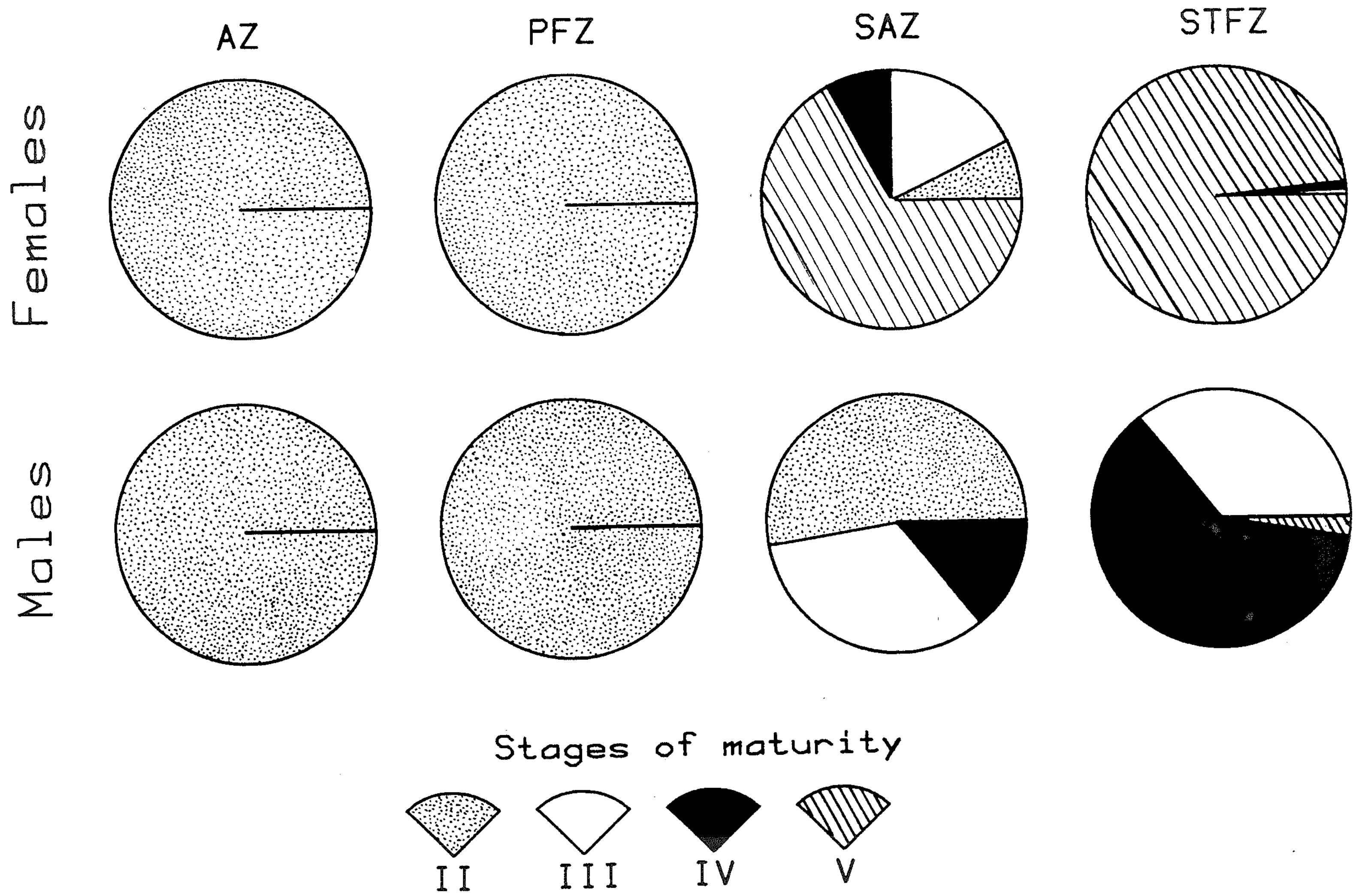


Figure 9: Percentages of males and females of *E. carlsbergi* at different maturity stages by latitudinal zones.

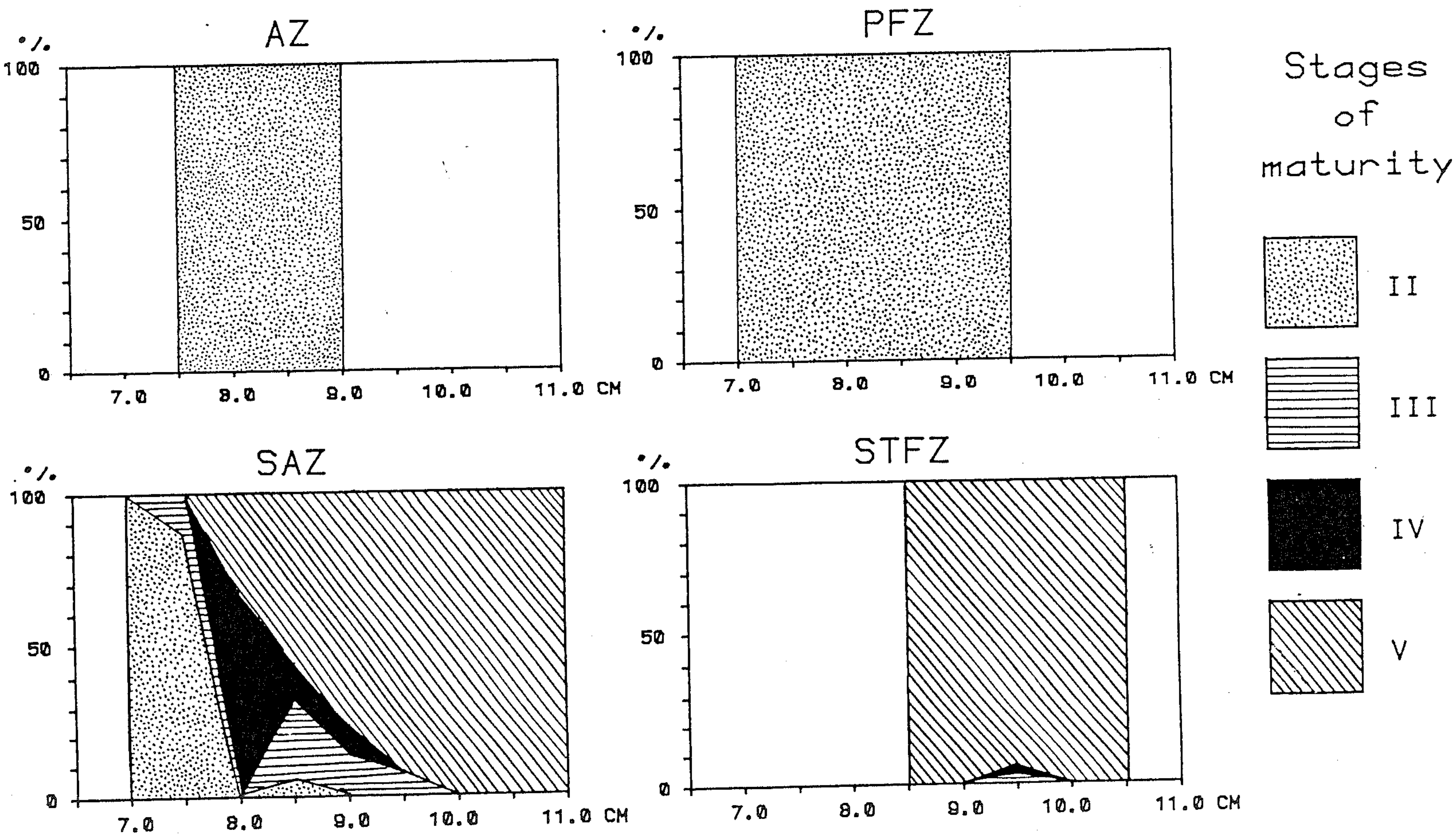


Figure 10: Percentages of females of *E. carlsbergi* at different maturity stages by latitudinal zones and fish lengths.

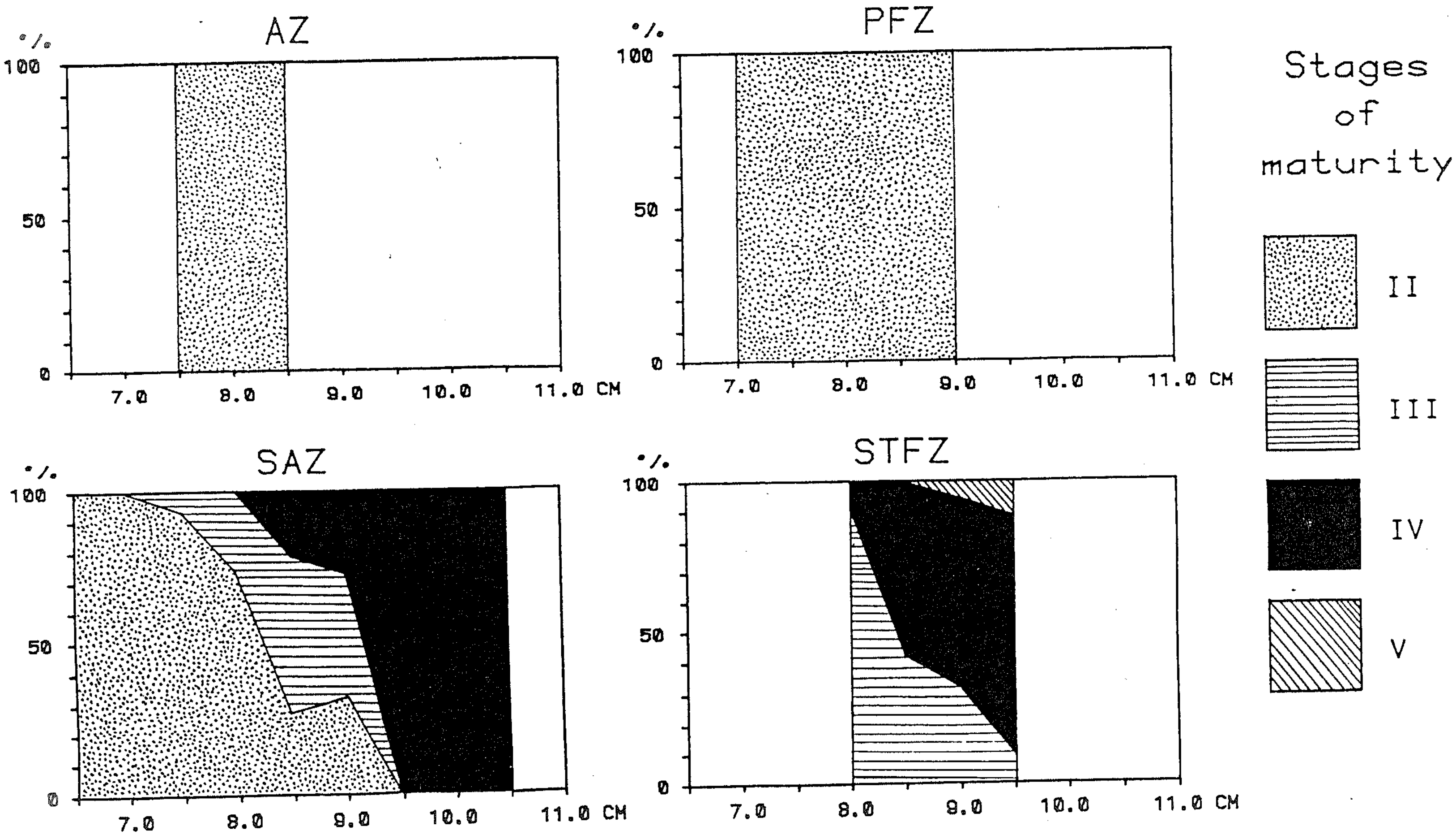


Figure 11: Percentage of males of *E. carlsbergi* at different maturity stages by latitudinal zones and fish lengths.

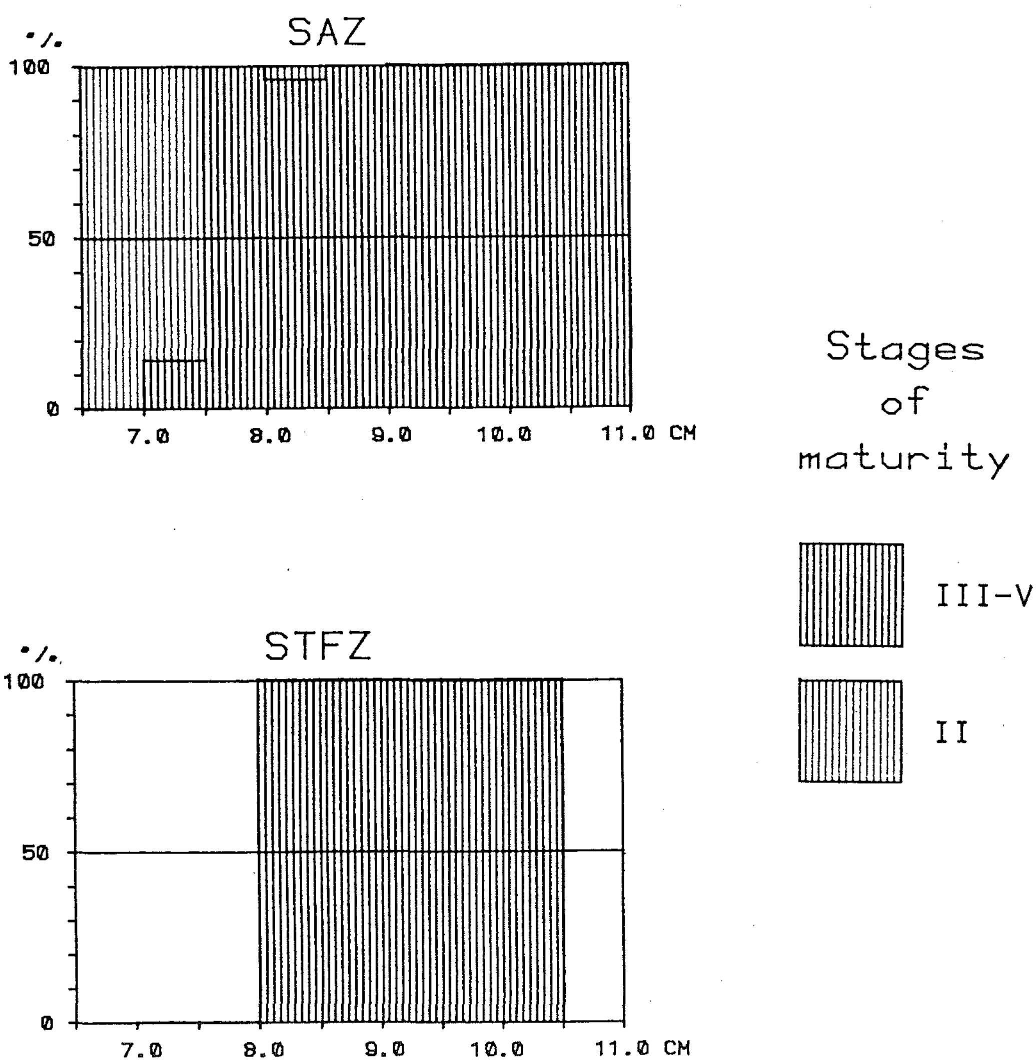


Figure 12: Onset of sexual maturity in *E. carlsbergi* females at different lengths.

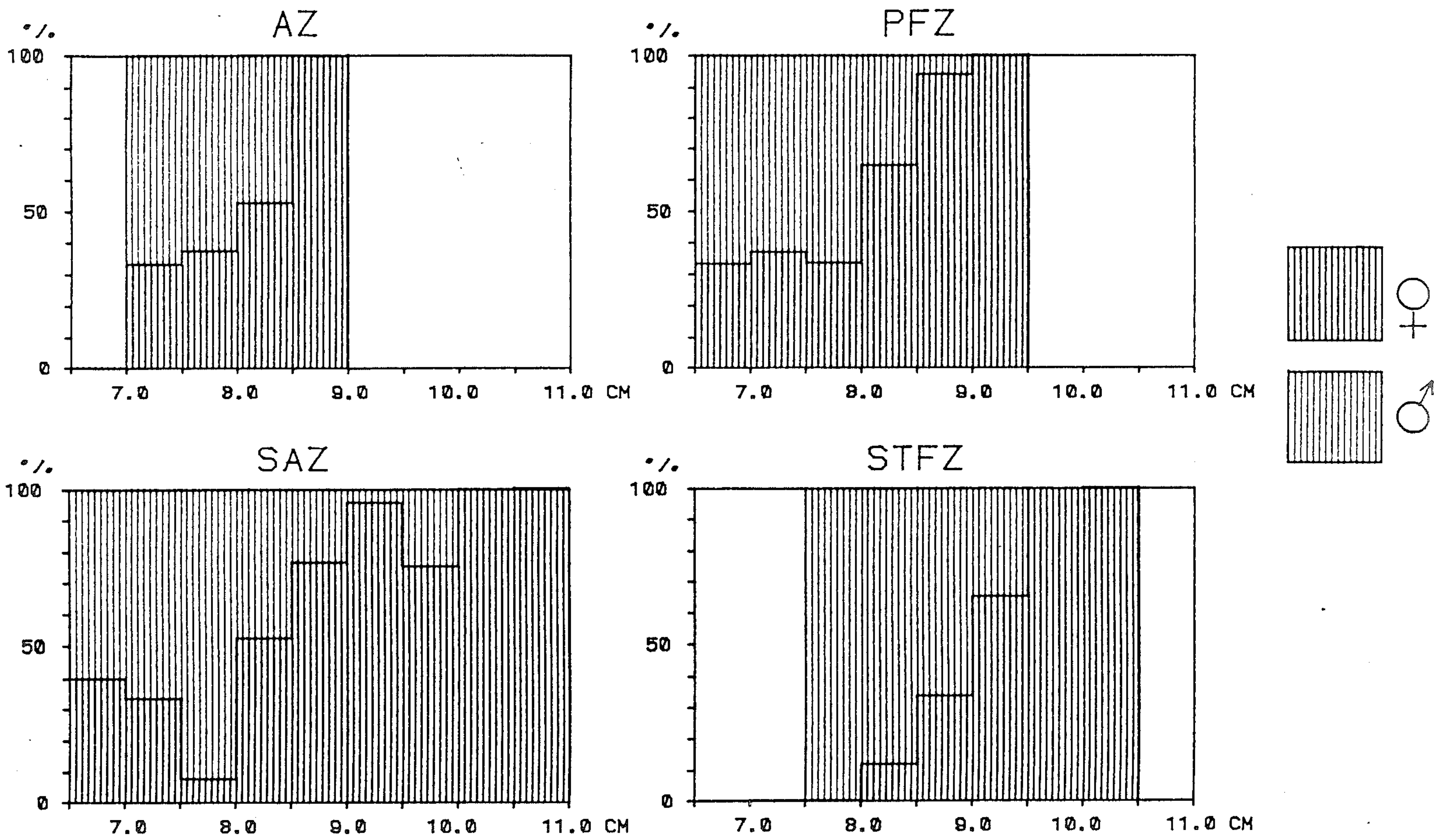


Figure 13: Sex ratio of *E. carlsbergi* at different lengths.

Liste des figures

Список рисунков

Lista de las figuras

WG-FSA-90/20

ON REPRODUCTION OF *ELECTRONA CARLSBERGI* (TÅNING)

G.P. Mazhirina*

Abstract

This paper presents results from histological examinations of gonads of *Electrona carlsbergi* from the Atlantic sector of the Southern Ocean. From materials available it has been ascertained that *E. carlsbergi* spawns in the notal waters. Maturation of females begins when body length reaches 76 to 78 mm. Vitellogenesis is asynchronous. Vitelline eggs have a diameter from 150 to 650 µm; in hydrated oocytes it is up to 900 µm. Maturation of ovaries is continuous, and spawning is serial. The spawning season is long and coincides with summer/autumn in the Southern Hemisphere.

Résumé

Ce document présente les résultats de l'examen histologique des gonades d'*Electrona carlsbergi* du secteur Atlantique de l'océan Austral. A partir du matériel disponible, il a été confirmé qu'*E. carlsbergi* se reproduit dans les eaux subantarctiques. La maturité des femelles commence lorsque la longueur du corps atteint 76 à 78 mm. La vitellogénèse est asynchrone. Les œufs vitellins ont un diamètre de 150 à 650 µm atteignant parfois 900 µm dans les ovocytes hydratés. La maturation des ovaires est continue et la ponte périodique. La saison de ponte est étendue et correspond à la période été-automne de l'hémisphère sud.

Резюме

В настоящем труде представлены результаты гистологического исследования гонад *Electrona carlsbergi* из атлантического сектора Южного океана. По имеющимся материалам было установлено, что нерест *E. carlsbergi* происходит в субантарктических водах. Созревание самок начинается при достижениии ими длины в 76-78 мм. Вителлогенез асинхронный. Диаметр яиц с вителлиновой оболочкой равняется 150-650 микромиллиметрам, он достигает 900 микромиллиметров на стадии гидратированного ооцита. Созревание яичников непрерывное, нерест периодический. Нерестовый сезон продолжительный и совпадает с летне-осенним периодом в южном полушарии.

* Polar Research Institute of Marine Fisheries and Oceanography (PINRO), 6 Knipovich Street, Murmansk, 183763, USSR

Resumen

En este documento se exponen los resultados de los exámenes histológicos de las gónadas de *Electrona carlsbergi* del sector atlántico del océano Austral. De la información disponible, se ha descubierto que *E. carlsbergi* se reproduce en la zona subantártica. La maduración de las hembras se inicia cuando la longitud total es de 76-78 m. y la vitelogénesis es asincrónica. Los huevos vitelinos tienen un diámetro de entre 150 a 650 µm y pueden alcanzar los 900 µm en los oocitos hidratados. La maduración de los ovarios es continua mientras que el desove es seriado. La época de freza es prolongada y coincide con el período verano/otoño del hemisferio sur.

1. INTRODUCTION

Electrona carlsbergi (Tåning, 1932) is a notal-Antarctic species and its distribution is circumpolar. The species inhabits waters of the Antarctic Convergence, wherein it forms concentrations during the major part of the year (Hulley, 1981; Naumov *et al.*, 1981; Bekker, 1983; Kornilova, 1987; Zaselsky, 1988 and others). According to Hully (1981) *E. carlsbergi* spawns beyond the Antarctic region. From the occurrence of larvae it has been inferred by V.N. Efremenko (Lisovenko and Efremenko, 1983) that the reproductive area of the species coincides with the notal zone.

A study of gonads in female *E. carlsbergi* from the Antarctic Convergence and the Argentine Basin areas has been undertaken with the aim of determining where and when this species spawns, specifying the type of area in which it reproduces and delineating zones of its expatriation. Results of the study are presented in this paper.

2. MATERIALS AND METHODS

Observations were carried out and materials collected during surveys by the RV *Artemida* in December-February 1987-1988 and January-April 1989. Samples were collected over the area from 40° to 54°S and between 8° and 59°W. Samples were collected from trawl catches taken within the 50 to 1 500 m depth range. Length of fish (SL) was measured to the nearest 1 mm from the tip of the snout to the base of median rays of the caudal fin.

A total of 4 380 females were examined. 160 fish were preserved in Bouin's fluid for further analysis.

Preparation and histological treatment was conducted in accordance with standard methods: treatment with alcohol, gradually increasing its concentration, followed by treatment with xylene and embedding in paraffin. Sections of samples (5-6 µm thick) were stained with haemozyline according to Heidengain's method (Roskin and Levinson, 1957).

The growth of egg cells was described using terminology suggested by V.A. Meien (1927).

The number of eggs in a batch was determined by counting ripe and vitelline eggs by size. The number of batches of ripening eggs was estimated from weights of hydrated oocytes.

The physiological condition of ovaries was evaluated by a 6-point scale (Sakun and Butskaya, 1963).

3. RESULTS

3.1 Development of Egg Cells

The process of egg development may be divided into three periods: nuclear transformations, protoplasmatic and trophoplasmatic growth.

By the beginning of protoplasmatic growth nuclear transformations have been completed and a thin layer of cytoplasm develops in oocytes. Later, the growth of oocytes occurs at the expense of an increase in the cytoplasm volume. We distinguish two phases in the period of trophoplasmatic growth: young oocytes and monolayer follicle.

At the beginning of slow growth oocytes are usually of regular shape and have a diameter from 10 to 30 µm. The membrane has no structure. The cytoplasm is heterogeneous; the intensity of colour in its different parts varies.

At the end of the protoplasmatic growth period, the diameter of the oocyte reaches 90 to 120 µm, and that of the nucleus reaches 56 to 69 µm. The membrane consists of two layers: an internal one - a membrane in itself - and an external one, formed by follicular epithelium cells. The cytoplasm is pale and uniform in colour.

The further development of oocytes and the beginning of trophoplasmatic growth are associated with the ripening of fish gonads. This period may be divided into the following phases: 1 - vacuolization and accumulation of fat, 2 - initial accumulation of yolk, 3 - intensive trophoplasmatic growth, 4 - yolk-filled oocyte, 5 - mature oocyte.

Vacuolization of the cytoplasm occurs before the yolk accumulation phase.

In oocytes of 100 to 500 µm in diameter small vacuoles appear in a peripheral zone and later form a cortex. Thereafter, vacuoles develop in an area near the nucleus. The contents of vacuoles is lipoid which is washed away during treatment of preparations. The external surface of the oocytes is made up of membranes of follicular and connective tissue.

In the phase of initial yolk accumulation, tiny insertions of yolk are observed to appear in oocytes of 180 to 2 020 µm in diameter. Granules of yolk gradually fill the cytoplasm and fat vacuoles are pushed towards the nucleus.

In oocytes undergoing intensive trophoplasmatic growth, the amount of trophic substance increases at the expense of accumulation of yolk granules of increased size. The number of fat balls reduces as they coalesce. The diameter of the oocytes reaches 500 µm.

In the vitelline oocyte phase the diameter of the cells is up to 500-650 µm. The only fat ball of 180-200 µm in diameter is found in the centre of the egg cell. The nucleus is displaced towards the animal pole of the egg.

The phase of maturation is associated with yolk hydration and homogenization. The oocyte grows to 850-900 µm in diameter. The follicular membrane is thin and is loosely attached to the oocyte membrane proper. During this phase, egg cells are released from follicles and are ready for spawning.

3.2 Maturity Stages

Developmental stages are defined by gonad functional status, which is characterized by the presence of a specific set of egg cells in one the of the phases described above.

The following maturity stages were distinguished by observation of the fine structure and variations in weight of the gonads (Table 1).

Field observations and cytological examination provided materials for comparative analysis of reproductive system condition in female *E. carlsbergi* from two zoogeographical zones: notal and Antarctic.

To the south of the Antarctic Convergence (Antarctic zone) catches were made up of specimens of 65 to 96 mm in length. In the Argentine Basin (notal zone) fish were from 70 to 103 mm in length. Males were smaller than females: they did not exceed 95 mm in length, whereas females were up to 103 mm long. In the Antarctic zone the male/female ratio was close to 1:1.1; in the notal zone males prevailed, the sex ratio being 1:0.9. In the notal zone the maturity coefficient for females of less than 78 mm length was low - from 0.5 to 1.0%. The diameter of more fully developed oocytes did not exceed 100 μm. A histological analysis showed that the more fully developed generation of egg cells were in the monolayer follicle phase. Females with such oocytes were regarded as immature (maturity stage II). Females larger than 78 mm were considered as mature because the diameter of egg cells and weight of their ovaries were still increasing.

In January the maturity coefficient for mature females varied from 1.1 to 2.7%. More fully developed egg cells were found to be in the initial yolk accumulation phase (maturity stage III).

By mid-February the vitellogenesis was almost complete in the majority of fish and empty follicular membranes - an indication of partial spawning - were found in some of them. The maturity coefficient increased to 11.4% (maturity stages IV, IV-V, see Figure 1).

In April all females larger than 78 mm had yolk-filled eggs, many contained traces of partial spawning. The maturity coefficient varied from 4.8 to 14.7%. Ovaries were in maturity stages IV-V and VI-VIII (Figure 2).

In prespawning fish the diameter of yolk-filled eggs varied from 150 to 650 μm, the diameter of hydrated oocytes - from 700 to 800 μm. There are several successive peaks (waves) on the plot of oocyte size frequency distribution (Figure 3). Each is likely to correspond with a group of cells of synchronous development. The number of oocytes gradually decreased as their size increased. Oocytes of 100 to 150 μm diameter (beginning of trophoplasmatic growth) comprised more than 50% of the total number of eggs measured. According to the classification suggested by Lisovenko (1985), oogenesis of this type is very similar to a serial fluctuated type. A serial oogenesis implies that there is a possibility of replenishment of spawned eggs by reserve oocytes which may be developed into successive batches of eggs for later spawning.

According to Oven (1976), a serial spawning is typical for the majority of species with continuous oogenesis. Unfortunately it was not possible in experimental conditions to count for *E. carlsbergi* the number of eggs in one batch. An attempt was therefore made to estimate the possible number of egg batches from the weight of hydrated oocytes (Table 2).

Our data suggest that the number of batches of ripening egg cells calculated as a ratio of the theoretical maturity coefficient to observed maturity coefficient, is not less than 7.

The maturity coefficient of female *E. carlsbergi* from the Antarctic zone did not exceed 1.4%. In most fish, more fully developed egg cells were found to be in the monolayer follicle phase (Figure 4). In some fish, egg cells commencing trophoplasmatic growth were found. These eggs developed faster than the majority of cells and were usually being reabsorbed (Figure 5). This phenomenon may be interpreted in two ways: (1) resorption of "excessive" oocytes during early stages of ontogenesis (Persov, 1963), and (2) resorption of older oocytes due to unfavourable ambient conditions for reproduction.

In our opinion, low water temperature is one of the most important factors. During our observations water temperature in the Antarctic zone in the 50 to 360 m depth layer varied from 0.8° to 2.5°C. In the notal zone at depths of 380 to 460 m where spawning females were found, water temperature was from 3.8° to 10.3°C. In view of this variation in water temperature it may be hypothesized that the fish cannot spawn in the Antarctic zone at all or that no spawning might have occurred in the period in which the observations were made.

Failure to spawn and the dependence of spawning on ecological factors have been noted for myctophids many times in the past. Expatriation of subtropical species *Lobianchia dofleini* and *Lobianchia gemellarii* into colder waters of the Continental Shelf of North America results in inhibition of growth and resorption of sex cells (O'Day and Nafpaktitis, 1967). The Norwegian researcher, I. Gjøsaeter (1981) came to the conclusion that *Notoscopelus kroeyerii*, a boreal species in the North Atlantic, is capable of forming aggregations of non-breeding fish in Norwegian waters.

4. CONCLUSIONS

Results obtained show that *E. carlsbergi* breeds in the notal zone. The spawning season of this species is extended and covers summer and autumn. Ripening of ovaries is continuous and this species is a serial spawner. Expatriation of *E. carlsbergi* into colder waters of the Antarctic zone south of the Antarctic Convergence results in inhibition of growth and resorption of egg cells. It is unlikely that individuals at this stage of gonad development will spawn.

REFERENCES

HEKKER, V.E. 1983. *Myctophidae of the World Ocean*. Moscow: Nauka Press. pp. 109-114. (In Russian).

GJØSAETER, I. 1981. The history and ecology of the myctophid fish *Notoscopelus elongatus kroeyerii* from the northeast Atlantic. *Fish. Dir. Skr. HavUnders, 17* (3): 133-152.

HULLEY, R.A. 1981. Results of the research cruises of FRV *Walter Herwig* to South America. Family Myctophidae (Osteichthyes, Myctophiformes). *Arch. Fisch. Wiss., 31* (1): 40-42.

KORNILOVA, G.N. 1987. Environmental conditions for the formation of concentrations of *Electrona* species. Abstract. In: *Resources of the Southern Ocean and Problems of their Rational Exploitation. Second All-Union Conference 22-24 September 1987. USSR Ministry of Fisheries*. Kerch. pp. 118-120. (In Russian).

LISOVENKO, L.A. and V.N. EFREMENKO. 1983. Characteristic features of reproduction of abundant mesopelagic fish of the west Antarctic. *VNIRO Research Report*. Moscow. p. 18-29. (In Russian).

LISOVENKO, L.A. 1985. On oogenesis of egg-laying marine fishes and approaches to evaluation of their fecundity. In: *On Reproductive Cycles in Fish from Waters at Different Latitudes*. Moscow: Nauka Press. pp. 55-64. (In Russian).

MEYEN, V.A. 1927. Observations over yearly variations in redfish ovaries (*Perca fluviatilis*). *Rus. Zool. Zhurnal.*, *7* (4): 75-113. (In Russian).

NAUMOV, A.G., M.F. SVETLOV, A.N. KOZLOV and I.A. PINSKAYA. 1981. Some features of distribution and feeding of *E. carlsbergi* (Myctophidae) in the Scotia Sea. *Voprosy ikhtiologii, 21* (3): 467-472. (In Russian).

O'DAY, W.T. and B.G. NAFPAKTITIS. 1967. A study of the effects of expatriation on the gonads of two myctophid fishes in the North Atlantic Ocean. *Bull. Mus. Camp. Zool.*

OVEN, A.S. 1976. *Distinctive Features of Oogenesis and Spawning Pattern in Marine Fishes.* Kiev: Naukova dumka. p. 131. (In Russian).

PERSOV, G.M. 1963. "Population" and "final" fecundity of fish as exemplified by humpback introduced to the White and Barents Seas. *Voprosy ikhtiologii, 3* (3): 490-496. (In Russian).

ROSKIN, G.I. and L.B. LEVINSON. 1957. *Microscopic Techniques.* Moscow: Sovetskaja Nauka Press. p. 467. (In Russian).

SAKUN, O.F. and I.A. BUTSKAJA. 1963. *Identification of Maturity Stages and Study of Sexual Cycles in Fish.* Moscow: Rybnoe khozjaistvo. p. 36. (In Russian).

ZASELSKY, V.S. 1988. Ecological and biological features of the distribution of *E. carlsbergi* near Shag Rocks and Black Rocks in the winter season. Abstracts of Reports at the All-Union Conference. *Biological Resources of the Thalassobathyal Zone of the World Ocean.* Moscow. pp. 24-26. (In Russian).

Table 1: Maturity stages of ovaries.

Maturity Stage	Weight (mg)	Maturity Coefficient (%)	Composition of Sex Cells	Functional Condition
I	12-30	0.1-0.2	Oogonia	Juvenile
II	40-90	0.5-1.1	Oogonia, oocytes in protoplasmatic growth	Not ripe
III	108-550	1.1-7.8	Oogonia, oocytes in protoplasmatic and trophoplasmatic growth (phase of vacuolization, initial vitellogenesis, intensive trophoplasmatic growth)	Ripening Intensive accumulation of yolk and fat in ovaries
IV	660-1 000	7.3-10.8	Oogonia, oocytes in protoplasmatic and trophoplasmatic growth (phase of vacuolization, intensive trophoplasmatic growth, vitelline oocytes)	Prespawning condition Vitellogenesis close to completion
IV-V	1 010-2 050	11.5-14.7	Oogonia, oocytes in protoplasmatic and trophoplasmatic growth (phase of vacuolization, intensive trophoplasmatic growth, ripening)	Functionally mature Hydrated eggs rest freely in ovaries
VI-VIII	400-1 000	2.5-9.5	Oogonia, oocytes in protoplasmatic and trophoplasmatic growth (phase of vacuolization, initial vitellogenesis, intensive trophoplasmatic growth). Empty follicular membranes.	Ripening of the next back of eggs after extrusion of previous batch
VI	No data available			Extrusion Ovaries after extrusion of last batch of ovulated eggs

Table 2: Number of batches of ripening egg cells for *E. carlsbergi* at maturity stage IV-V.

Body Weight (mg)	Ovaries (mg)	Total Number of Oocytes Over 100 µm in Diameter ($x10^3$)	Weight of 50 Hydrated Oocytes (mg)	Weight of Ovaries Filled with Hydrated Oocytes (mg)	Maturity Coefficient (C_1) (%)	Theoretical Maturity Coefficient* (C_2) (%)	Naumber of Batches (C_2/C_1)
8 100	1 191	44.2	10.8	9 550	14.7	118.0	8.0
16 150	2 050	40.3	17.5	14 100	12.7	87.3	6.9
9 350	994	23.7	14.2	6 730	10.6	72.0	6.8

* Theoretical maturity coefficient is calculated from weight of ovaries filled with transparent eggs.

Figure 1: *E. carlsbergi* ovary at maturity stage IV-V. A hydrated oocyte in the centre. Magnification - 20 x 10.

Figure 2: *E. carlsbergi* ovary at maturity stage VI-VIII. Residual follicle in the centre. Older oocytes in phase of intensive trophoplasmatic growth. Magnification - 20 x 10.

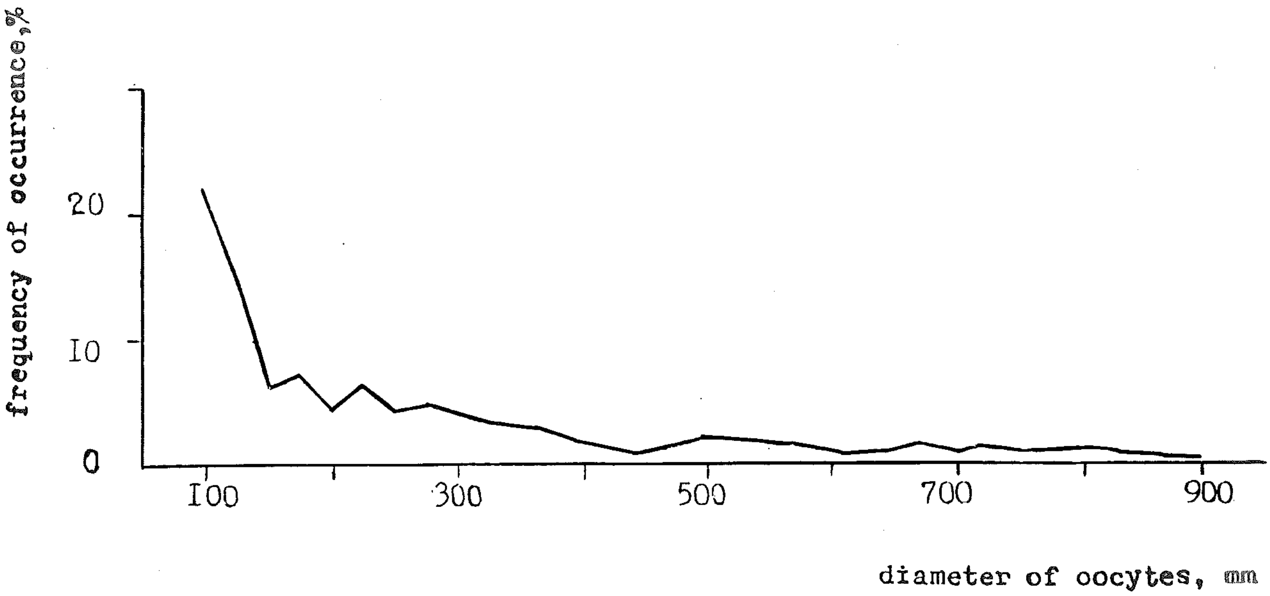


Figure 3: Size distribution of vitelline eggs in *E. carlsbergi* at maturity stage IV-V.

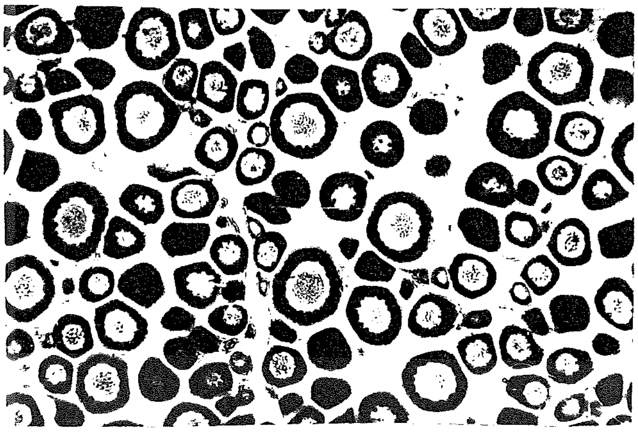


Figure 4: *E. carlsbergi* ovary at maturity stage II. Older oocytes in monolayer follicle phase. Magnification - 20 x 10.

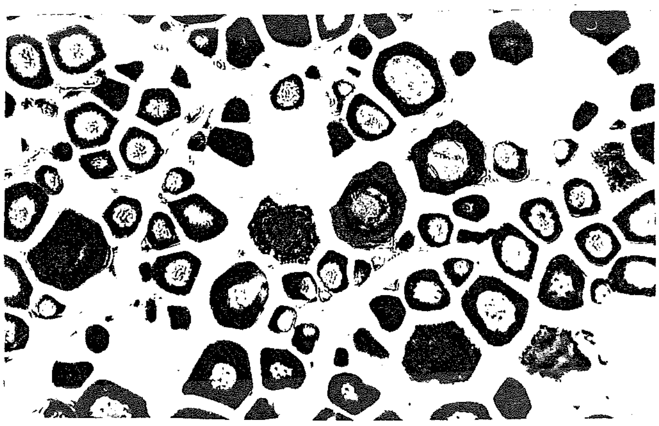


Figure 5: *E. carlsbergi* ovary at maturity stage II. Resorption of fast-growing oocytes. Magnification - 20 x 10.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

WG-FSA-90/18

FEEDING AND FOOD INTAKE OF *ELECTRONA CARLSBERGI* (TÅNING, 1932) MYCTOPHIDAE

O.V. Gerasimova*

Abstract

In summer and autumn *Electrona carlsbergi* feeds mainly on copepods. Daily food intake estimated by various methods was from 3.7 to 5.6% of fish body weight. The amount of food consumed by *E. carlsbergi* during the year in the waters to the south of the Antarctic Convergence is about 15 times fish body weight.

Résumé

En été et automne, *Electrona carlsbergi* se nourrit principalement de copépodes. La consommation journalière de nourriture est estimée par diverses méthodes varier entre 3,7 et 5,6% du poids du corps du poisson. La quantité de nourriture consommée par *E. carlsbergi* en une année dans les eaux au sud de la Convergence antarctique est égale à environ 15 fois le poids du corps du poisson.

Резюме

В летне-осенний сезон вид *Electrona carlsbergi* в основном кормится веслоногими. Оценки объема потребляемой ежедневно пищи, полученные различными методами, колеблются в пределах 3,7-5,6% веса тела. Годовой объем пищи, потребляемой видом *E. carlsbergi* в водах к югу от антарктической конвергенции, превышает вес тела особей этого вида приблизительно в 15 раз.

Resumen

Entre verano y otoño, *Electrona carlsbergi* se alimenta principalmente de copépodos. El consumo de alimento diario, estimado por diversos métodos, osciló entre un 3.7% y un 5.6% del peso del pez. La cantidad de alimento consumido por *E. carlsbergi* durante el año en las aguas meridionales de la Convergencia Antártica es, aproximadamente, 15 veces el peso del pez.

* Polar Research Institute of Marine Fisheries and Oceanography (PNIRO), 6 Knipovich Street, Murmansk, 183763, USSR

1. INTRODUCTION

Electrona carlsbergi (Tåning) is one of the most abundant species of the Myctophidae family living in the Southern Ocean. It is a typical plankton eater feeding predominantly on phytophagous copepods. *Electrona carlsbergi* itself is a food of squid and some species of fish and birds (Zaselsky *et al.*, 1985).

Published data give a fairly complete picture of species composition of food consumed by *E. carlsbergi*, frequency of occurrence and size of individual prey species (Naumov *et al.*, 1981; Rembiczewski *et al.*, 1978; Zaselsky *et al.*, 1985). A number of papers provide a comparative analysis of *E. carlsbergi* feeding spectra in different parts of the Southern Ocean. (Kozlov, Tarverdieva, 1989; Oven *et al.*, 1990; Tarverdieva, 1986).

For an understanding of the role of *E. carlsbergi* in the ecosystems of the Southern Ocean, quantitative data on its food intake is most important. So far little is known about this matter. In particular, Naumov *et al.* (1981) assumed that in summer the daily food intake of *E. carlsbergi* in the Scotia Sea is close to the total index of consumption which is 3.37% of fish body weight.

The basic objective of the present paper is to estimate the daily and annual food intake of *E. carlsbergi* using various methods.

2. MATERIALS AND METHODS

Materials for studying feeding of *E. carlsbergi* were collected in February-March 1989 in the area to the south of the Antarctic Convergence between 1° and 38° W during the cruise of RV *Artemida.*

A sample of at least 25 fish were taken from every catch for analysis. Fish length was measured to the nearest 1 mm, and the weights to the nearest 10 mg. Sex and maturity stage were identified visually. Stomach contents were examined under a binocular microscope, food items were counted and identified as accurately as possible. Large intact crustaceans (euphausiids, hyperiids) were measured. Since the food bolus of one fish was normally very small, from 15 to 25 samples from the same catch were combined for weighing. For calculation of the mean total index of stomach fullness the derived value was divided by the sum of weights of the examined fish. Altogether 914 fish from 21 hauls were examined.

3. RESULTS AND DISCUSSION

In summer copepods were the major prey items in the diet of *E. carlsbergi* in the Antarctic Convergence area. Frequency of occurrence of prey items slightly differed depending on fish length: copepods from the genus Calanus (*C. simillimus*, *C. tonsus*) prevailed in the diet of fish below 70 mm, *Rhincalanus gigas* were consistently predominant in larger fish. On the whole, the frequency of copepod and *R. gigas* occurrence was up to about 50% and 28% respectively of the total number of food items.

In addition to copepods, *Parathemisto gaudichaudi* (normally less than 6 mm in length), *Thysamoessa macrura, Limacina helicina var. australis*, and chaetognaths occurred in the diet of *E. carlsbergi*. Hyperiids were predominantly preyed on by individuals below 70 mm in length. The frequency of occurrence of euphausiids, chaetognaths and pteropods in fish of all size groups was practically constant.

The daily feeding rhythm of *E. carlsbergi* was determined using the averaged data from all hauls made in February/March. Two peaks of feeding activity were noted: one in the morning and another in the evening (Table 1). Other authors mention a similar daily feeding pattern (Konstantinova, 1988; Oven *et al.*, 1990; Zalesky *et al.*, 1985). The results obtained made possible a rough estimation of the daily food intake of *E. carlsbergi* by means of the Romanova method (1958).

The mean rate of food digestion estimated by means of evaluating changes in stomach fullness index during two falls in feeding was $16.4^{o}/_{oo}$ per hour. In this case the daily food intake of *E. carlsbergi* is about 3.7% of body weight. The food digestion rate estimated for the sharpest drop in feeding was $23.1^{o}/_{oo}$ per hour with a daily food intake of about 5.6% of body weight.

Another estimate of food consumption by *E. carlsbergi* was obtained using the Winberg equation (1956) based on data on mean annual weight increment and energy metabolism rate. The energy metabolism level in Myctophidae may be assessed from the results obtained for *Myctophum nitidulum* by Abolmasova and Belokopytin (1988). The parameters of the energy metabolism equation estimated by these authors were used in the present paper. Recalculation of parameter A (see Table 2) for temperature of *E. carlsbergi* habitat was made by introducing the temperature correction factor (Winberg, 1983). Table 2 contains the basic data for estimation of the annual and mean daily food intake of fish at age 2 and 3.

The annual food intake of *E. carlsbergi* males amounted to about 76.7 kcal. Assuming the calorific value of food consumed by *E. carlsbergi* to be 0.7 kcal/g, Shushkina and Musaeva (1982) give an annual food intake of 109.6 g or 1 480% of body weight. The annual food intake of females is estimated at 86.9 kcal. This corresponds to 124.1 g of food (1 500% of body weight).

The mean daily food intake estimated on the basis of the above values was about 4% of body weight both in males and females.

Thus, according to these very rough estimates, the amount of food consumed by *E. carlsbergi* during the year in the Antarctic Convergence area is about 15 times fish body weight. Further studies including daily stations in different periods of the year are needed to refine the values derived.

REFERENCES

ABOLMASOVA, G.I. and YU.S. BELOKOPYTIN. 1988. The rate of general energy metabolism in *Myctophum nitidulum* under experimental conditions. *Ekologiya morya, 28*: 76-79.

KOZLOV, A.N. and M.I. TARVERDIEVA. 1989. Feeding of abundant Myctophidae species in different regions of the Southern Ocean. *Voprosy ikhtiologii, 29* (2): 310-317.

KONSTANTINOVA, M.P. 1988. Trophic interrelations between lantern fishes in the South Atlantic. Pitanie morskikh ryb i ispolzovanie kormovoi bazy kak elementy promyslovogo prognozirovaniya: Tezisy dokladov, Murmansk: 18-19.

NAUMOV, A.G., M.F. SVETLOV, A.N. KOZLOV and I.A. PINSKAYA. 1981. Some features of distribution and feeding of *Electrona carlsbergi* (Tåning) (*Myctophidae*) in the Scotia Sea. *Voprosy ikhtiologii, 21* (3): 467-472.

OVEN, A.S., M.P. KONSTANZINOVA and N.F. SHEVCHENKO. 1990. Some aspects of reproduction and feeding of *Myctophidae* in the Southwest Atlantic. *Voprosy ikhtiologii, 30* (2): 229-237.

REMBISZEWSKY, J.M., M. KRZEPTOWSKI and T.B. LINKOWSKI. 1978. Fishes (Pisces) as by-catch in fisheries of krill *Euphausia superba* Dana (*Euphausiacea, Crustacea*). *Polish archiv. Hydro-bio., 25* (3): 677-695.

ROMANOVA, G.G. 1958. Feeding of pikeperch fingerlings in the Rybinsky Reservoir. *Trudy biologicheskoi stantsii "Borok", 3*: 273-300.

SHUSHKINA, E.A. and E.I. MUSAEVA. 1982. Calorific value of marine zooplankton. *Okeanologiya, 22* (1): 102-107.

TARVERDIEVA, M.I. 1986. Comparative description of feeding of *Myctophidae* in various regions of the world ocean. 5 Vsesoyuznyi siezd gidrobiologicheskogo obshestva: Tezisy dokladov, part 1, *Kuibyshev*: 40-42.

WINBERG, G.G. 1956. Metabolic intensity and food requirements of fish. Izdatelstvo Belorusskogo Universiteta, Minsk, 251 pp.

WINBERG, G.G. 1983. Vant-Hoff temperature coefficient and the Arrhenius equation in biology. *Zhurnal obshchei biologii, 44* (1): 31-42.

ZASELSKY, V.S., V.D. KUDRIN, V.A. POLETAEV, and S.V. CHECHENIN. 1985. Some biological features of *Electrona carlsbergi* (Tåning) (*Myctophidae*) in the Antarctic Atlantic. *Voprosy ikhtiologii, 25* (2): 352-354.

Table 1: Daily food intake of *E. carlsbergi* estimated by taking into account the range of the index of stomach fullness variation during the day.

Local Time	Time Span (hours)	Variation in Total Index of Fullness (‰)	Amount of Consumed Food (‰)	
0.30 - 07.30	7	7.9 - 21.00	132.1[x]	(174.1)[xx]
7.30 - 09.30	2	21.0 - 47.0	60	(72)
9.30 - 10.30	1	47.0 - 50.4	20.4	(26.4)
10.30 - 12.30	2	50.4 - 4.2	-	-
12.30 - 14.30	2	4.2 - 46.0	75.8	(87.8)
14.30 - 16.30	2	46.0 - 56.5	44.5	(56.5)
16.30 - 17.30	1	56.5 - 75.5	36	(42)
17.30 - 18.30	1	75.5 - 66.0	-	(13.5)
18.30 - 20.30	2	66.0 - 17.1	-	-
20.30 - 0.30	4	17.1 - 7.9	-	(82.8)

x at a digestion rate of 16.4‰ per hour
xx at a digestion rate of 23‰ per hour

Table 2: Basic parameters for estimating food consumption by *E. carlsbergi* using the Winberg equation (1956).

Parameter	Males		Females
Mean length at age 2	72.82 mm		74.40 mm
Mean length at age 3	83.20 mm		85.60 mm
Mean weight at age 2	6.075 g		6.734 g
Mean weight at age 3	8.764 g		9.834 g
Weight increment	2.689 g		3.100 g
Gonad weight	-		0.994 g
Time span		1 year	
Calorific value		1.72 kcal/g	
Temperature of habitat		0.8 - 2.5°C	
Parameters of energy metabolism equation: $R = AW^K$		A = 0.184 K = 0.79	

Liste des tableaux

Список таблиц

Lista de las tablas

BIOMASS OF MYCTOPHIDS IN THE ATLANTIC SECTOR OF THE SOUTHERN OCEAN AS ESTIMATED BY ACOUSTIC SURVEYS

A.A. Filin, K.V. Gorchinsky and V.M. Kiseleva*

Abstract

Acoustic surveys carried out in the summer and autumn of 1987-1989 estimated the biomass of myctophids in the Atlantic sector of the Southern Ocean between 48° and 56° and from 8° to 48°W to be approximately 1.7×10^6 tonnes. Over the greater part of the surveyed area the fish were sparsely distributed. Dense concentrations consisting predominantly of one myctophid species, *Electrona carlsbergi*, were found only in some limited areas. The bulk of the surveyed biomass of myctophids was found to be within the Antarctic Convergence area.

Résumé

Les campagnes acoustiques effectuées pendant les étés et automnes de 1987-1989 ont estimé la biomasse de Myctophidae du secteur Atlantique de l'océan Austral dans la région située entre 48 et 56°S et de 8 à 48°W, à environ $1{,}7 \times 10^6$ tonnes. Sur la plus grande partie de la région prospectée, les poissons étaient épars. Leurs concentrations denses, composées principalement d'une espèce de Myctophidae, *Electrona carlsbergi*, n'étaient présentes que sur des aires restreintes. Le plus gros de la biomasse a été déclaré provenir de la région de la Convergence Antarctique.

Резюме

Оценка биомассы миктофид в атлантическом секторе Южного океана (48° - 56° ю.ш. и 8° - 48° з.д.) была получена в ходе выполнения акустических съемок в течение летних и осенних периодов 1987-1989 гг. Она составляла приблизительно 1,7 миллионов тонн. На большей части охваченной съемками площади наблюдалось незначительное количество рыбы. Плотные концентрации, в основном состоявшие из одного вида миктофид - *Electrona carlsbergi*, встречались лишь в некоторых ограниченных районах. Основная часть биомассы приходилась на район антарктической конвергенции.

Resumen

Las prospecciones acústicas llevadas a cabo durante el período de verano y otoño de 1987-1989, han estimado la biomasa de mictófidos en el sector atlántico del océano Austral - en la zona comprendida entre los 48° y 56°S y entre los 8° y 48°W - en 1.7×10^6 toneladas. En la

* Polar Research Institute of Marine Fisheries and Oceanography (PINRO), 6 Knipovich Street, Murmansk, 183763, USSR

mayor parte del área estudiada los peces se encontraban dispersos y en las pocas áreas en donde se encontraban en densas concentraciones, la especie predominante de mictófidos fue *Electrona carlsbergi.* La mayor biomasa de mictófidos ha sido registrada en la zona de la Convergencia Atlántica.

---

1. INTRODUCTION

Lanternfish, or the Myctophidae species, are typical residents of mesopelagic waters in the Southern Ocean. They occur in large numbers and their distribution is circumpolar. In certain areas they occur in dense concentrations which are accessible to commercial fishing. *Electrona carlsbergi* is the most abundant species among myctophids. A total biomass of Antarctic myctophids is presently estimated to be 70-200x10^6 tonnes (Lubimova *et al.*, 1987).

A comprehensive study of the biology and ecology of mesopelagic fish and their place in the Antarctic ecosystem becomes particularly important in view of the good prospect of commercial fishing for these resources in the Southern Ocean. For this reason, special consideration should be given to evaluating the abundance of mesopelagic fish by instrumental techniques. It is impossible to provide reliable scientific recommendations on how to manage fisheries rationally without having information on stock size and dynamics in different areas.

This paper presents estimates of the biomass of myctophids and delineates their distribution in the Atlantic sector of the Southern Ocean.

2. MATERIALS AND METHODS

Acoustic surveys for myctophids in the Atlantic sector of the Southern Ocean were conducted by the RV *Artemida* from 1987 to 1989. These surveys covered the region from 48° to 56°S and between 8° and 48°W during the southern summer and autumn. Five local acoustic surveys were conducted in the region, where concentrations of myctophids were observed.

Values of mean density of fish along the cruise track were integrated for selected intervals of the distance covered (integration intervals - **D**). Echo-integration equipment included an EK-S echosounder (SIMRAD, Norway) and a digital five-channel integrator SIORS. Their operating parameters are listed in Table 1.

An oscilloscope was used to monitor input signals and an "Iskra-226" computer was used for data processing. Ship coordinates were obtained by a satellite navigational system FSN-70 (FURUNO, Japan). Echo intensities from five depth channels (by integration intervals D=5 miles) were continuously recorded and echo recordings simultaneously identified. Control tows for determining size-species composition of fish were carried out in order to verify results of acoustic equipment. A commercial midwater trawl with a small-meshed insertion (12 mm mesh) in a trawl bag was used.

Mesh density of fish along a cruise track was estimated by means of the formulae:

$$P_N = \frac{M_0}{\sigma(L)} \quad (1)$$

or

$$P_W = \frac{M_0}{10^3 \sigma kg(L)} \quad (2)$$

then

$$\sigma_{(L)} = 4\pi \cdot 10^{0.1 \cdot TS_{(L)}} \quad (3)$$

$$\sigma kg^{(L)} = \frac{\sigma(L)}{W} \quad (4)$$

where P_N = mean density (fish per square mile),
M_0 = mean echo intensity over the transect (number of echo readings covered) (M^2/square miles),
$\sigma_{(L)}$ = "in situ" mean acoustic back-scattering cross-section for single fish of length **L** (m^2),
$TS_{(L)}$ = "in situ" mean target strength for fish of length **L** (**dB**),
$\sigma kg^{(L)}$ = mean acoustic back-scattering cross-section per 1 kg of fish weight (m^2/kg),
W = mean weight of one fish (kg),
P_W = mean density of biomass distribution (tonnes per square mile).

M_0 was estimated from:

$$M_0 = \frac{M}{n} \cdot 100 \cdot K_{TVG}(\Delta R) \cdot K_{ATT} \cdot C_I \quad (5)$$

where **M** and **N** = integrator readings and number of pulses per integration interval **D**,
K_{TVG} = TVG correction coefficient, its value depending on both the mean coefficient of sound absorption within the range surveyed and integration depth Δ **R**,
K_{ATT} = a coefficient that allows for "gaps" in the performance of the echosounder during surveying under unfavourable weather conditions,
C_I = constant of integration instruments (m^2/square miles per 100 pulses).

C_I was calculated from results of calibrations to standard target TS_{st} = -33.6 dB, completed at the beginning and at the end of each survey and 6.9 m^2/square miles in the second.

For estimation of the density of myctophids (size range within **L**=5-10 cm) expression (2) was employed, where $\sigma_{kg}(L)$ was assumed to be equal to σ_{kg} = 0.0105 (± 0.0025) m^2/kg. This value was obtained by using a relationship derived experimentally "in situ" between myctophid size and target strength at 38 kHz:

$$TS = 25.2 \lg L - 75.0 \quad (6)$$

and the length/weight relationship for these fish (Mamylov, 1988).

Mean acoustic back-scattering cross-section per kilogram of fish weight was taken to be 0.0105 m^2/kg because this value was verified during our earlier surveys of myctophids in the North Atlantic and gave a fairly stable estimate of their biomass as compared with results of control trawlings (coefficient of trawl catchability was taken to be 0.05-0.10).

3. RESULTS

Concentrations of myctophids in the area surveyed were found in the Antarctic Convergence waters and near The Shag Rocks and Black Rock. More dense concentrations were observed in the southernmost part of the Polar Frontal Zone, and particularly in areas of notable disturbances in the water thermohaline structure.

The echosounder recordings showed concentrations of myctophids as long bands or spots (isolated schools) with a height of up to 30 m (Figures 1 and 2). They were chiefly distributed between 50 and 350 m depth.

In the area surveyed, E. carlsbergi predominated almost everywhere. In the majority of cases, as shown by control tows, it accounted for more than 90% of the total catch. Besides fish, salps were also numerous. Among other species, medusas, euphausids and squids were observed.

The size structure of E. carlsbergi was fairly uniform. Specimens of 70 to 80 mm predominated.

An echometric survey for myctophids, carried out from 18 to 31 December 1987 covered the area from 48° to 54°S and between 40° and 48°W (Figure 3) (about 60 000 square miles). It estimated the biomass of fish to be 1 200 x 10^3 tonnes. Figure 4 shows the distribution of myctophids in the survey area.

In control tow catches north of 53°S *E. carlsbergi* accounted for 91 to 97% of the total biomass. The rest consisted of salps and medusas.

South of 53°S the proportion of *E. carlsbergi* was less (60 to 75%). Of other myctophids, most abundant was *Gymnoscopelus nicholsi. Electrona antarctica, Gymnoscopelus braueri* and *G. fraseri* were also encountered.

The survey was then continued from 12 to 17 January 1988 and covered the area near the Shag Rocks and Black Rock. Figure 3 shows the survey route and indicates positions of hydrological stations and control tows. The biomass of myctophids over the survey area (7 200 square miles) was estimated as being 160x10^3 tonnes. The fish were distributed chiefly over rocky slopes. Maximum density was about 350 tonne/square mile (Figure 5). Fish were more dispersed at night than in the daytime.

Over 90% (by weight) of control catches consisted of myctophids, with *E. carlsbergi* accounting for about 85%. Besides this species, *G. nicholsi, Krefftichthys anderssoni, Paradiplospinus antarcticus*, salps and medusas were also found.

In the first ten days of February 1988 an echometric survey for myctophids was conducted in the Polar Frontal Zone from 48° to 51°S and between 36° and 41°W (Figure 3). A preliminary survey in the area enabled us to to obtain an overall picture of myctophid distribution and to elaborate the most optimal survey design. The biomass of myctophids over the survey area (16 000 square miles) was estimated at 300x10^3 tonnes. The most dense concentrations of myctophids in the form of elongated strips were found in the waters of the Frontal Zone (Figure 6).

In control tow catches *E. carlsbergi* accounted for about 90% of the biomass. Of other myctophid species, most plentiful were Gymnoscopelus - *G. nicholsi, G. piabilis, Protomyctophum choriodon* and *K. anderssoni.*

In 1989 acoustic surveys for myctophids were conducted over the area from 47° and 56°S and between 8° and 44°W in the period 30 January to 10 April. The bulk of the biomass was found to be spread along the Antarctic Frontal Zone east of South Georgia. The whole area was surveyed in two stages.

Firstly, the area from 51°30' to 56°00'S and between 20°30' and 26°30'W was surveyed from 20 February to 2 March. Secondly, the area with coordinates 51°30' to 55°00'S and 8°00' to 18°30' (Figure 7) was surveyed from 20 March to 2 April. These sectors had areas of 52 600 square miles and 63 270 square miles respectively. The first survey estimated the biomass of myctophids as being 855×10^3 tonnes, the second one 829×10^3 tonnes. Control catches comprised up to 98-100% of *E. carlsbergi*. Distribution of myctophids over the area surveyed is shown in Figures 8 and 9.

4. CONCLUSIONS

Results of the surveys indicated that in the Atlantic sector of the Southern Ocean there are considerable quantities of myctophids. As estimated by acoustic surveys, the total biomass of myctophids was about 1.7×10^6 tonnes both in 1987/88 and in 1989. Bearing in mind that only the principal areas of myctophid distribution have been surveyed, their total biomass in the western part of the Atlantic sector of the Southern Ocean may be around 2×10^6 tonnes.

The fish were sparsely distributed over the greater part of the area surveyed. In 1987/88 their mean density was approximately 20 tonnes per square mile, and 15 tonnes per square mile in 1989 or 5.8 g/m^2 and 4.4 g/m^2 respectively.

Dense concentrations of myctophids were observed in some limited areas. They consisted mostly of one species - *E. carlsbergi*. The mean biomass in these concentrations was as high as 70 to 100 g/m^2. Concentrations of commercial value were found mainly in the Antarctic Convergence in the form of elongated strips.

In 1989 myctophids were found spread more to westward than in 1988. In 1989 no concentrations were found in the Frontal Zone between 30° and 40°W, whereas in 1988 dense concentrations of *E. carlsbergi* were found in the area.

The concentrations of myctophids encountered did not appear to be difficult to survey acoustically, because they were composed virtually of one species of fish of the same size. Only insignificant numbers of salps, medusas and euphausiids were found in the areas where large quantities of myctophids were present.

The design and implementation of surveys in 1987 to 1989 was seriously impeded by selection of a very large area and by the lack of sufficient information on the distribution of myctophids and their passive migrations. These parameters are highly variable and dependent on oceanographic conditions.

In future, regular annual assessments of the abundance of myctophids in the Atlantic sector of the Southern Ocean will require elaboration of standard methodology for conducting acoustic surveys. Studies of population status and dynamics is a vital element of a comprehensive study of Antarctic myctophids - an important component of the Southern Ocean ecosystem.

REFERENCES

LUBIMOVA, T.G., K.V. SHUST and V.V. POPOV. 1987. Distinctive features of the ecology of mesopelagic fishes (family Myctophidae) from the Southern Ocean. (In Russian).

Osobennosty ekologii mezopelagicheskikh ryb semeistva Myctophidae Yuzhnogo okeana. In: *Biological Resources of the Arctic and Antarctic*. Moscow: Nauka Press. pp. 320-337.

MAMYLOV, V.S. 1988. Results of "in situ" target strength measurements at 38 kHz for major commercial species in the North Atlantic. (In Russian Resultaty otsenki sily tseli "in situ" na chastote 38 kHz dlya osnovnykh promyslovykh ob'ektov Severnoi Atlantiki. In: *Instrumental Methods of Evaluation of the Stock Size of Commercially-Important Species*. Murmansk. pp. 3-18.

Table 1: Operating parameters of the echosounder and integrator.

Echosounder EK-S		Integrator SIORS	
Frequency	38 kHz	Gain	5 dB
Pulse length	0.6 ms	Discriminator	24 dB
Bandwidth	3 kHz	(integration threshold)	(50 mV_p)
Power (gross)	2.0 ÷ 2.5 kW	Integration range	10 to 500 m
TVG	(20 1gR-0)dB		
	136 ÷ 138		
Antenna	8 x 8°		

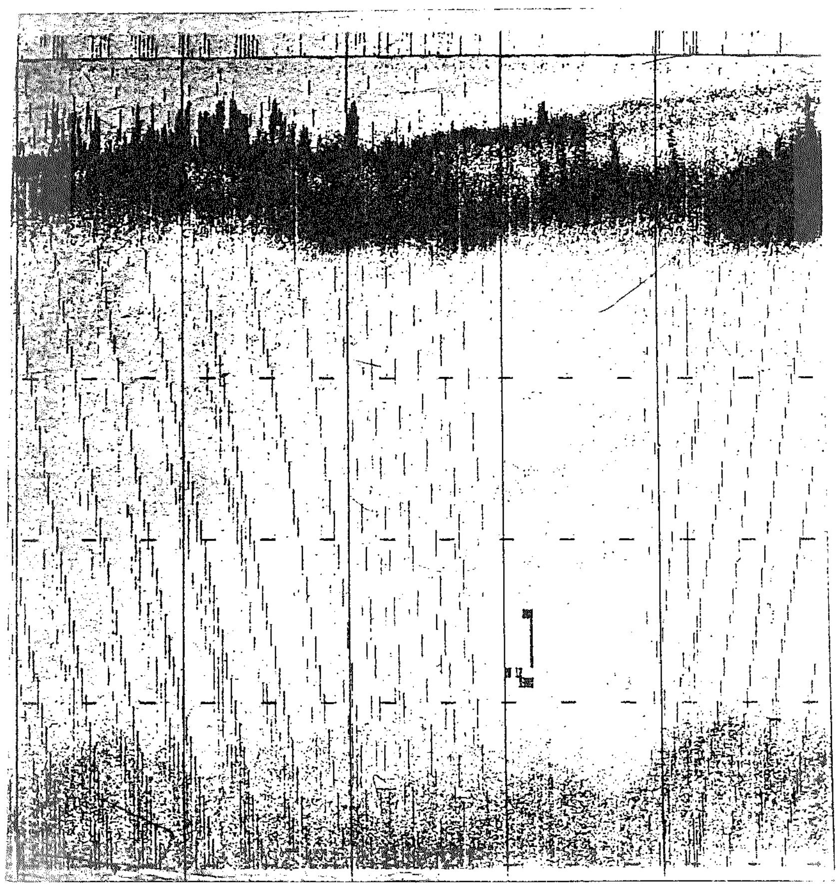


Figure 1: Typical echo recording of myctophids as a band (49°09'S, 38°17'W), 9 February 1988.

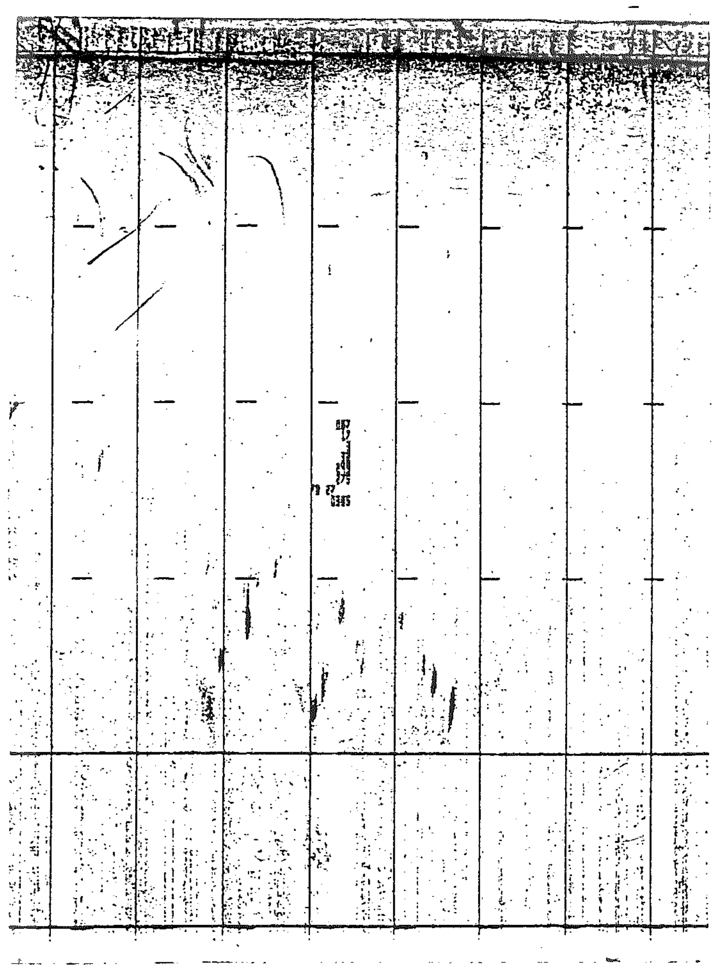


Figure 2: Typical echo recordings of myctophids as discrete schools (49°00'S, 41°30'W), 22 December 1987.

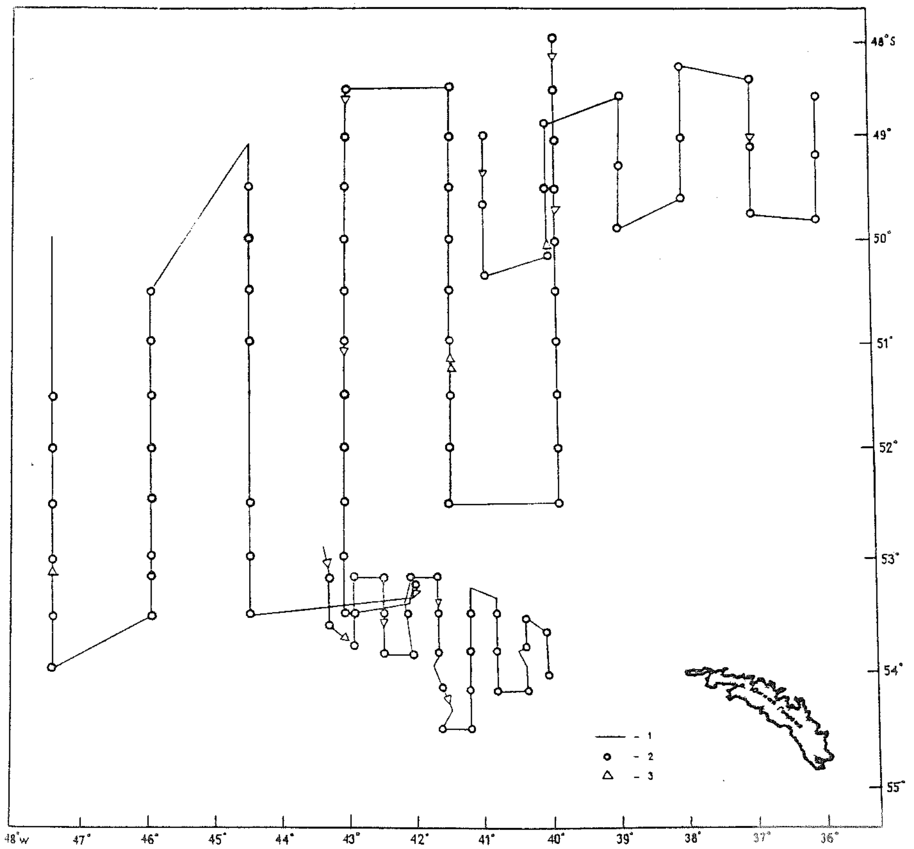


Figure 3: Chart showing the track of acoustic surveys for myctophids in 1987/88.
1 - echometric tracks
2 - hydrological stations
3 - control tows

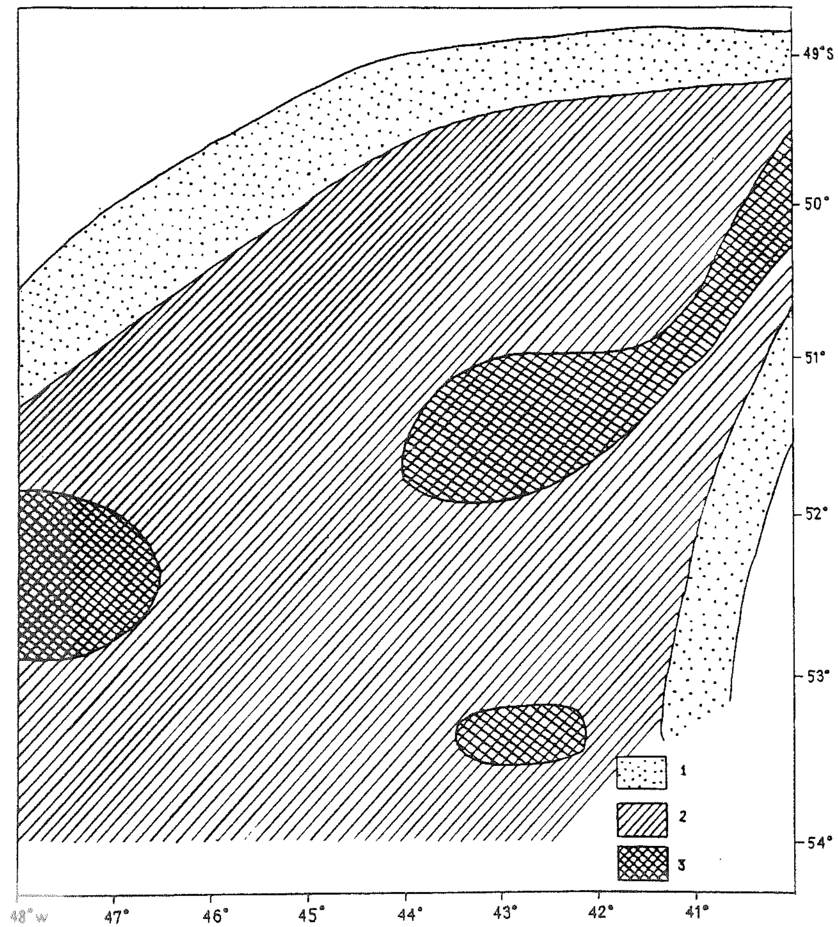


Figure 4: Density of myctophids as estimated by the echometric survey from 18 to 31 December 1987.
1 - 1 to 3 tonnes per square mile
2 - 10 to 50 tonnes per square mile
3 - over 50 tonnes per square mile

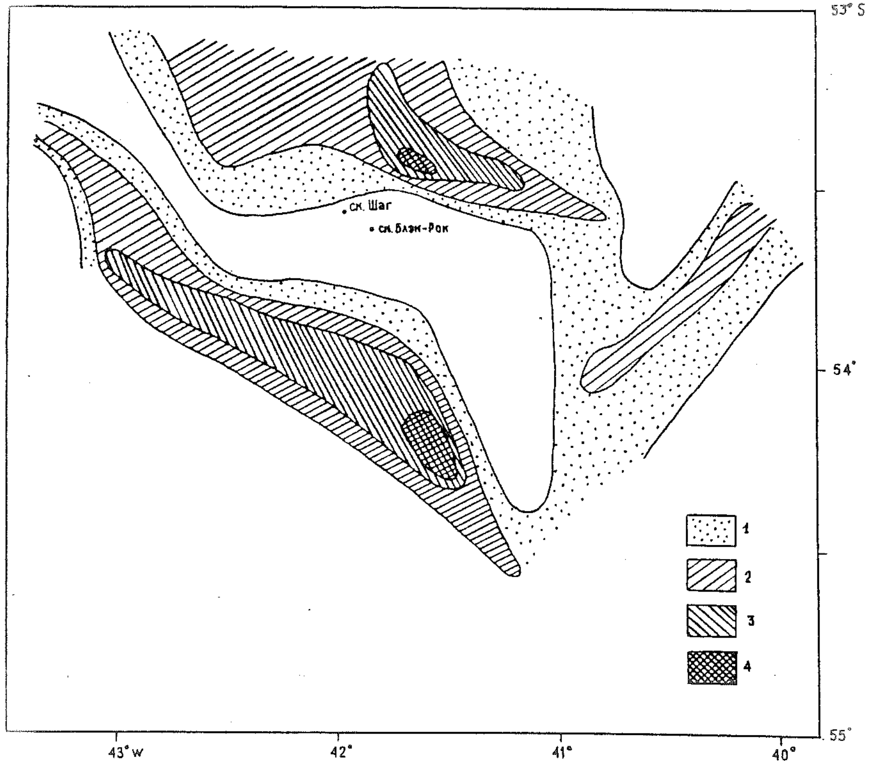


Figure 5: Density of myctophids estimated by the echometric survey near the Shag Rocks and Black Rock from 12 to 17 January 1988.
1 - 2 to 10 tonnes per square mile
2 - 11 to 40 tonnes per square mile
3 - 41 to 150 tonnes per square mile
4 - over 150 tonnes per square mile

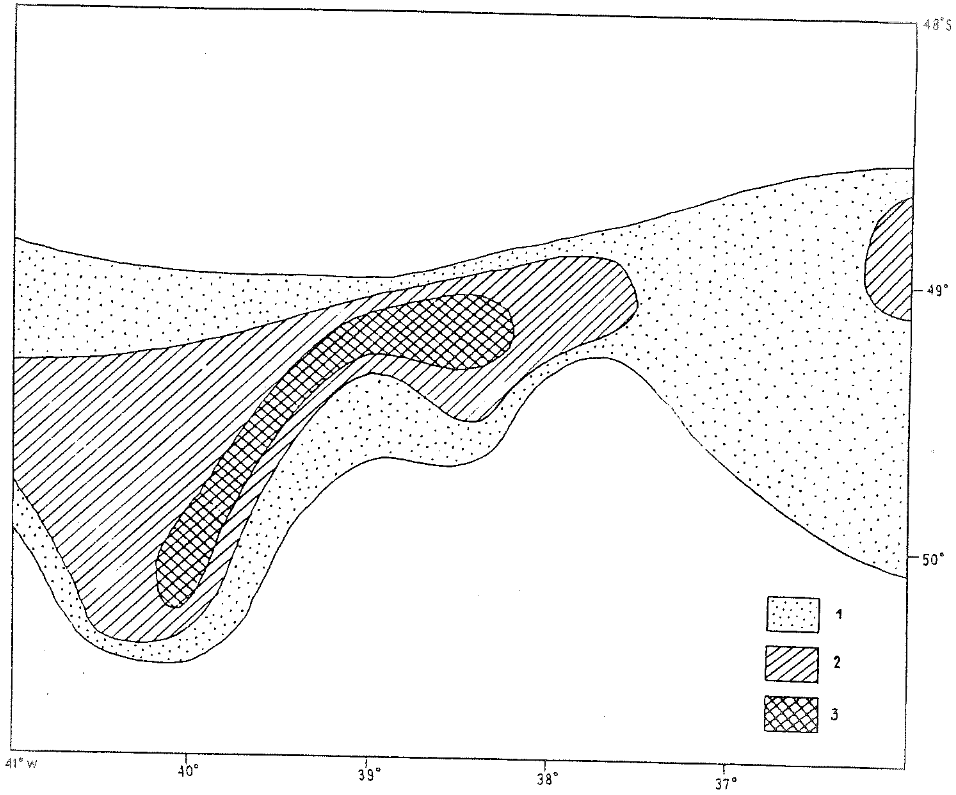


Figure 6: Density of myctophids as estimated by the echometric survey from 2 to 10 February 1988.
1 - 5 to 20 tonnes per square mile
2 - 21 to 100 tonnes per square mile
3 - over 100 tonnes per square mile

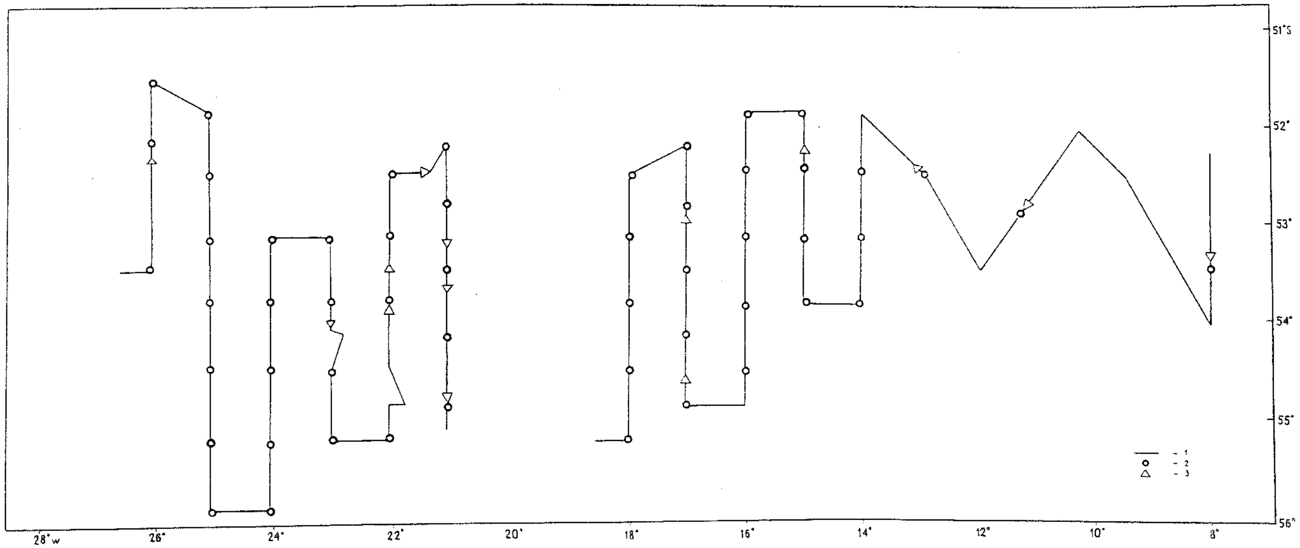


Figure 7: Chart showing the track of acoustic surveys in 1989.
1 - echometric tracks
2 - hydrological stations
3 - control tows

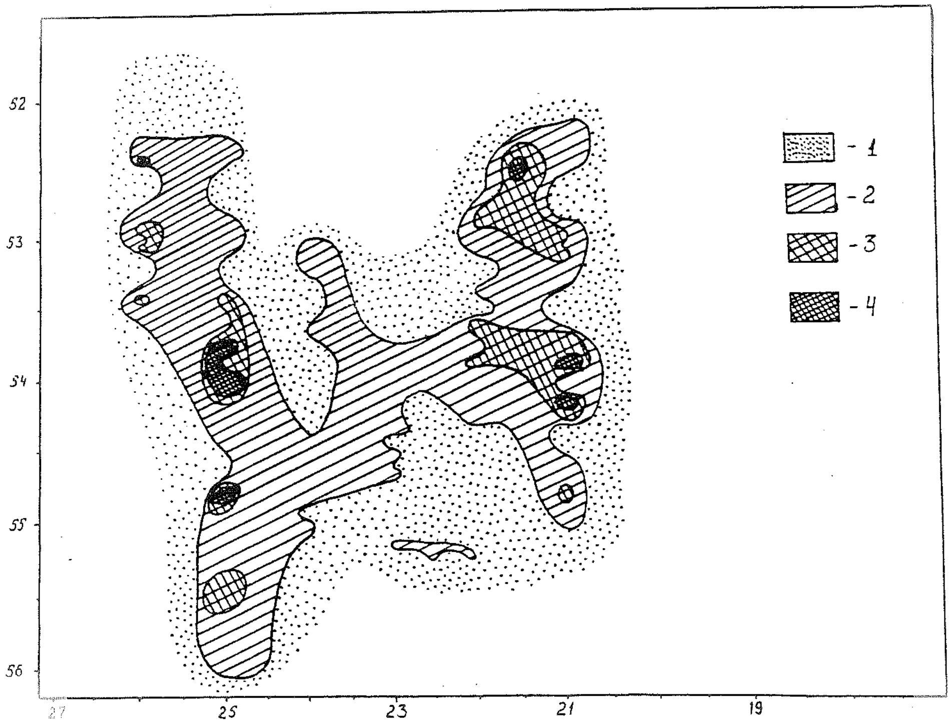


Figure 8: Density of myctophids as estimated by the echometric survey from 20 February to 2 March 1989.
1 - 1 to 10 tonnes per square mile
2 - 11 to 40 tonnes per square mile
3 - 41 to 90 tonnes per square mile
4 - 91 to 140 tonnes per square mile

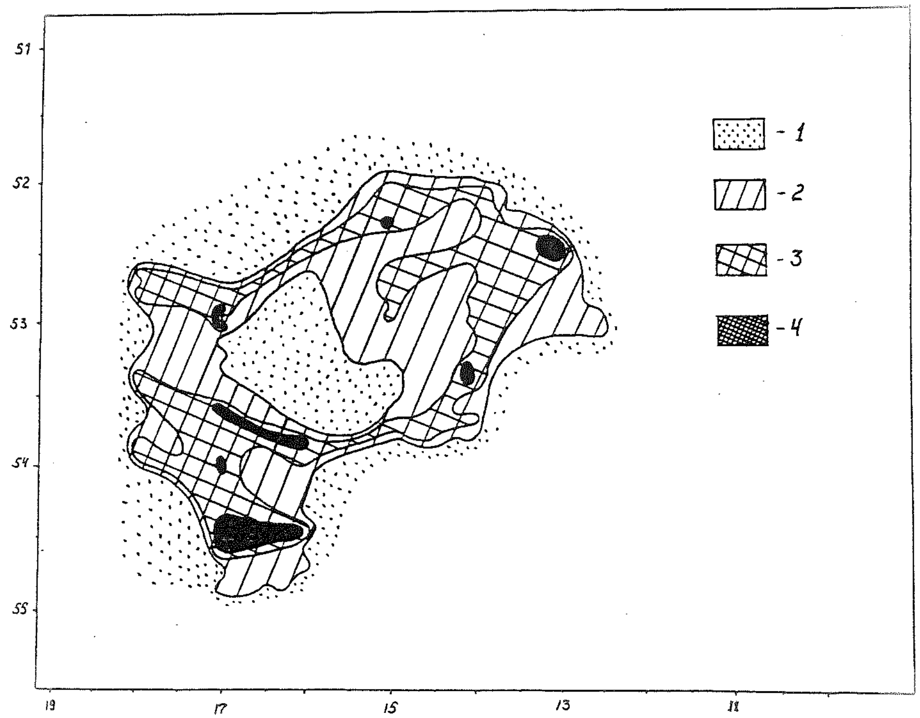


Figure 9: Density of myctophids as estimated by the echometric survey from 20 March to 2 April 1989.
1 - 1 to 10 tonnes per square mile
2 - 11 to 20 tonnes per square mile
3 - 21 to 40 tonnes per square mile
4 - 41 to 60 tonnes per square mile

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

Figura 3: Mapa de itinerarios de prospecciones acústicas de mictófidos efectuadas en 1987-1988.
1 - trayectorias ecométricas, 2 - estaciones hidrológicas, 3 - arrastres de control.

Figura 4: Densidad de mictófidos estimada de la prospección ecométrica efectuada del 18 al 31 de diciembre de 1987.
1 - 1 a 3 toneladas por milla^2, 2 - 10 a 50 toneladas por milla^2, 3 - más de 50 toneladas por milla^2.

Figura 5: Densidad de mictófidos estimada de la prospección ecométrica realizada cerca de las Rocas Cormorán y Roca Negra, del 12 al 17 de enero de 1988.
1 - 2 a 10 toneladas por milla^2, 2 - 11 a 40 toneladas por milla^2, 3 - 41 a 150 toneladas por milla^2, 4 - más de 150 toneladas por milla^2.

Figura 6: Densidad de mictófidos estimada de la prospección ecométrica efectuada del 2 al 10 de febrero de 1988.
1 - 5 a 20 toneladas por milla^2, 2 - 21 a 100 toneladas por milla^2, 3 - más de 100 toneladas por milla^2.

Figura 7: Mapa de itinerarios de prospecciones acústicas de 1989.
1 - trayectorias ecométricas, 2 - estaciones hidrológicas, 3 - arrastres de control

Figura 8: Densidad de mictófidos estimada de la prospección ecométrica efectuada del 20 de febrero al 2 de marzo de 1989.
1 - 1 a 10 toneladas por milla^2, 2 - 11 a 40 toneladas por milla^2, 3 - 41 a 90 toneladas por milla^2, 4 - 91 a 140 toneladas por milla^2.

Figura 9: Densidad de mictófidos estimada por la prospección ecométrica desde el 20 de marzo al 2 de abril de 1989.
1 - 1-10 toneladas por milla^2, 2 - 11-20 toneladas por milla^2, 3 - 21-40 toneladas por milla^2, 4 - 41-60 toneladas por milla^2.

MESOPELAGIC FISH OF THE SOUTHERN OCEAN - SUMMARY RESULTS OF RECENT SOVIET STUDIES

E.N. Sabourenkov*

Abstract

Since 1963, Soviet research on Antarctic mesopelagic fish has been carried out as a part of the general multi-disciplinary program of research on Antarctic biological resources. Studies concentrate primarily on the following four most abundant species: *Electrona carlsbergi*, *Electrona antarctica*, *Krefftichthys (Protomyctophum) anderssoni* and *Gymnoscopelus nicholsi*. The data obtained so far are sufficient to allow a description of the general ecology and distribution of these species. Some data are available on their feeding, reproduction and age/length composition. The paper summarizes recently published results of these studies. A general description of mesopelagic myctophids is followed by more detailed information on individual species. Some details of the biological characteristics of these species are summarized in tables with details on area, season and source of data. Some data, e.g. length composition of samples, are also illustrated in figures. The importance of studies on the role of myctophids in the Antarctic ecosystem is highlighted.

Résumé

Depuis 1963, une recherche soviétique est effectuée sur les poissons mésopélagiques de l'Antarctique, dans le cadre d'un programme pluridisciplinaire de recherche sur les ressources biologiques de l'Antarctique. Les études portent tout particulièrement sur les quatre espèces les plus abondantes, à savoir: *Electrona carlsbergi*, *Electrona antarctica*, *Krefftichthys (Protomyctophum) anderssoni* et *Gymnoscopelus nicholsi*. Les données déjà obtenues sont suffisantes pour permettre la description de l'écologie et de la distribution générales de ces espèces. Quelques données sont disponibles sur leur alimentation, leur reproduction et leur composition en âge/longueur. Le présent document résume les résultats de ces études publiés récemment. La description générale des Myctophidae mésopélagiques est suivie d'informations plus détaillées sur chaque espèce. Quelques caractéristiques de ces espèces sont récapitulées dans les tableaux, y compris des détails sur la région, la saison et l'origine des données. Quelques données, telles que la composition en longueurs des échantillons, sont également illustrées dans les figures. L'importance des études sur le rôle des Myctophidae dans l'écosystème antarctique est soulignée.

Резюме

С 1963 г. советские исследования мезопелагических рыб антарктических вод проводились в рамках общей комплексной программы изучения биологических

* CCAMLR Secretariat

ресурсов Южного океана. В основном исследования сосредоточены на следующих четырех наиболее многочисленных видах: *Electrona carlsbergi, Electrona antarctica, Krefftichthys (Protomyctophum) anderssoni* и *Gymnoscopelus nicholsi*. Данные, полученные к настоящему времени, позволяют описать общую экологию этих видов и их распределение. Имеются некоторые данные по их кормлению, воспроизводству и размерно-возрастному составу. В настоящей работе суммируются недавно опубликованные результаты этих исследований. Общее описание мезопелагических видов миктофид сопровождается более подробной информацией по отдельным видам. В таблицах суммируются некоторые данные по биологическим характеристикам этих видов, при этом указан район получения, сезон и источник этих данных. Некоторые данные, напр. - размерный состав проб, также проиллюстрированы рисунками. Подчеркивается важность изучения роли миктофид в экосистеме Антарктики.

Resumen

Desde el año 1963, la Unión Soviética ha estado realizando estudios sobre los peces mesopelágicos de las aguas antárticas, como parte del programa global multidisciplinario de investigación de los recursos biológicos del océano Austral. La investigación está centrada principalmente en las cuatro especies más importantes: *Electrona carlsbergi, Electrona antarctica, Krefftichthys (Protomyctophum) anderssoni* y *Gymnoscopelus nicholsi*. La información recogida hasta ahora es suficiente para describir de modo general, la distribución y ecología de estas especies. Existe cierta información sobre su comportamiento alimentario, reproducción y composición edad/talla. En este documento se incluye un resumen de los resultados publicados recientemente, una descripción general de los mictófidos mesopelágicos, así como un detalle sobre cada especie. Algunas características biológicas se presentan en forma resumida en tablas, junto con información detallada sobre el área, temporada y fuente de datos. Algunos datos, como por ejemplo la composición por tallas de las muestras, se presentan en figuras. Se hace especial hincapié en la importancia de los estudios de mictófidos en el ecosistema antártico.

---

1. INTRODUCTION

True epipelagic fish species are nearly absent in Antarctic waters. Pelagic fish fauna of this area consists primarily of meso- and bathy-pelagic species of the families *Myctophidae*, *Paralepididae* and *Bathylagidae* inhabiting waters from 500 to 1 500 m in depth. Of these three families, species of the family *Myctophidae* are the most widely distributed and abundant, with more than 20 species found in the area. Most of them have a circumpolar distribution (Andriashev, 1964 as cited in Lubimova *et al.*, 1983b; Lubimova *et al.*,1983a).

Soviet research on mesopelagic fish in the Antarctic waters is carried out as a part of the general research program on the biological resources of the Southern Ocean. Since the first research cruise in 1963, fishery-oriented investigations have primarily been conducted by the VNIRO research institute (USSR Ministry of Fisheries) and its branches in Murmansk (PINRO), Kaliningrad (AtlantNIRO), Kerch (YugNIRO) and Vladivostok (TINRO). Research institutes of the USSR Academy of Science (Institute of Oceanology, Moscow) and of the State Committee on Meteorology (Institute of Arctic and Antarctic, Leningrad) also contribute to some aspects of this research.

This paper is summarizes major results of Soviet research on mesopelagic fish in Antarctic waters published in the last 5 to 7 years. The paper deals specifically with the following four most abundant species of *Myctophidae: Electrona carlsbergi, Electrona antarctica, Krefftichthys (Protomyctophum) anderssoni* and *Gymnoscopelus nicholsi*. A complete list of publications is attached.

2. GENERAL DISTRIBUTION AND BIOLOGY OF MYCTOPHIDAE

The data on myctophids of the Southern Ocean collected by the Soviet scientists during many years of research are adequate enough to describe the general ecology, reproduction, distribution and feeding of these mesopelagic species, as well as to identify the most abundant species and environmental conditions under which they are used to form dense concentrations.

In the sub-Antarctic area there are about 20 species of myctophids and about 13 to 14 in the Antarctic area. The most abundant species are *E. carlsbergi, E. antarctica, K. (Protomyctophum) anderssoni,* and *G. nicholsi.* These species predominate over other myctophids both in the sub-Antarctic and Antarctic, and in some places around the Southern Ocean form dense concentrations.

It has been discovered that abundant distribution of these species is limited by the waters associated with the Antarctic Circumpolar Current (ACC) which is the reproductive area for most species of myctophids, and where their eggs and larvae are found (Efremenko, 1987). Eggs and larvae of all myctophids studied are present in the waters of the Antarctic Convergence, and eggs and larvae of *E. carlsbergi* and *K. anderssoni* are observed even further north of the Antarctic Convergence, in the sub-Antarctic. The southernmost recorded distribution of eggs and larvae for *E. antarctica* was in the waters of the Secondary Frontal Zone in the Scotia Sea which are dependent on the ACC.

The circumpolar distribution of myctophids is closely dependent upon the specific oceanographical structure of Antarctic waters, i e. the zonal distribution of major water masses having uniform chemical and physiological properties. A constant flux of food (mainly copepods) is maintained in the area of their habitat (0 to 600 m depth) owing to the process of down-welling which is predominant in this area.

While myctophids inhabit mainly waters of the ACC the most abundant species are distributed as far south as the southern boundary waters of the ACC and the drift ice zone (Lubimova *et al.*, 1983b). Catches of myctophids in these waters were first recorded in the Pacific and Atlantic ocean sectors of the Southern Ocean, namely in the Scotia Sea, Drake Passage, to the north of the Lazarev and Bellingshausen seas, in the north of the Sodruzhestva, Riiser-Larseni and Ross Seas, and over the abyssal waters of the continental slope (Lubimova *et al.*, 1983a). However, such penetration to the south of abundant myctophids is always related to the distribution and activity level of the ACC, particularly of its southern boundary waters. Myctophids do not occur in the shelf waters of the Antarctic continent because their distribution is limited by the distribution of the Antarctic Deep Warm Waters which do not spread over the continental shelf. The presence of myctophids on the shelf of South Shetlands is related to a high level of meandering of the ACC in this area.

Antarctic myctophids occur in waters down to a depth of 1 500 m. Their vertical migrations can extent to epipelagic waters but these migrations are limited to waters of the same temperature gradient (Parin, 1968 as cited in Lubimova *et al.*, 1983b). In general, however, myctophids are distributed in the 200 to 600 m layer and sometimes deeper. Their vertical distribution is always related to the distribution of the Antarctic Deep Warm Waters (below 200 m) (Lubimova *et al.*, 1983a).

In spring/summer adult myctophids are found in the upper layer, but in winter-autumn they migrate to the lower levels of their vertical distribution range. They also undergo diurnal vertical migrations, spending the daylight hours in the upper 50 to 100 m layer and descending to the deep waters at night. These types of vertical migration of adult myctophids are closely related to the diurnal rhythm of their feeding activity.

In general, myctophids of the Antarctic open waters (Lubimova *et al.*, 1983b) feed all year round and have a long reproduction season, as evidenced by the distribution of eggs and larvae. Spawning of many myctophids is apparently serial as in the case of *E. antarctica.* Sampling of gonads in summer/autumn has suggested that spawning takes place in autumn/winter (Efremenko, 1987; Lisovenko, 1987).

Eggs and pre-larvae of myctophids are found predominantly in the mesopelagic Antarctic and sub-Antarctic waters. During autumn/winter, the larvae of myctophids are found in the Deep Warm Waters located south of the Antarctic Convergence. In spring/summer they move into the upper 0 to 200 m layer (Efremenko, 1987a and 1987b).

The precise location of spawning areas of particular species of myctophids has not yet discovered. The uniformity of the water structure around Antarctica provides favourable conditions for mesopelagic fish. The best feeding areas for myctophids are between the SPF and the Antarctic Divergence. *K. anderssoni* and *E. antarctica* share the same feeding and spawning areas. It appears that the spawning areas of *E. carlsbergi* and *G. nicholsi* are outside of the Antarctic Region (Zemsky, 1987). Recent studies of the development of oocytes in *E. carlsbergi* give weight to the hypothesis that spawning grounds of this species are in the notal zone, to the north of the Antarctic Convergence (Mazhirina, 1991). It has been suggested that in the South Atlantic *E. carlsbergi* breeds in the Sub-Tropical and Sub-Tropical Frontal zones (Zemsky and Zozulia, 1991).

The diet of myctophids is not particularly specialized, but varies according to area and season. The food composition of myctophids and, in particular the size of food organisms, also depends upon the size of the particular the species, and varies according to the stage of development of individual fish. A diet of myctophids in the open waters in winter-summer consists primarily of certain species of copepods. They are the staple food for *E. antarctica, E. carlsbergi* and *K. anderssoni* as copepods are widely distributed in these waters and are abundant in the surface 500 m layer. In some areas euphausiids are also found in the diet of myctophids. However, the feeding areas of myctophids do not coincide with the distribution of *E. superba,* as they generally cover waters to the south of 60°S (Lubimova *et al.*, 1983).

Myctophids of the 5 to 11 cm length group feed exclusively on small planktonic organisms. Larger myctophids as *E. antarctica* and *G. nicholsi* have also macroplanktonic organisms in their diet, including *E. superba.* In the areas where myctophids occur together with krill (South Orkney, South Shetland and South Georgia Islands) their diet is not limited to krill but also includes other food items. It is likely to be related to the distribution of krill mainly in the upper 50 m layer and hence less available to myctophids which do not reach the surface layer during their vertical migrations.

Some species of fish and squid feed on myctophids. Therefore myctophids are a part of the following food chain (Lubimova, Shust and Popkov, 1987; Podrazhanskaya and Pinskaya, 1987):

Phytoplankton→copepods→myctophids→predatory fish and squids-whales.

A preliminary assessment of natural mortality of all myctophids combined, taking into account their reproductive potential and a short life span, gave a value of up to 50%. There are some inaccuracies in such calculations because the reproductive areas of the four most abundant species do not coincide and a detailed assessment should thus be attempted for each species separately. As mentioned above, spawning and feeding of *K. anderssoni* and *E. antarctica* take place in the same area, while spawning areas of *E. carlsbergi* and *G. nicholsi* are apparently located outside of the Antarctic area (i.e., only a part of adult fish biomass of these species, is located in Antarctic waters) (Zemsky, 1987).

The data collected so far on the general biology and ecology of the most abundant species of myctophids have lead to the conclusion that at all stages of their life history they are confined to the ACC waters although each species has its own characteristic features of distribution, feeding and reproduction. *E. carlsbergi* and *K. anderssoni* are found mainly in the northern boundary waters of the ACC. The area of habitat of this species covers waters from the Southern Frontal Zone to the north to the boundary waters between ACC and High-Latitude Modified Waters to the south. Among other species the distribution of *G. nicholsi* extends furthest to the south (Scotia Sea).

The facts that myctophids are widely distributed in the ACC waters which have an adequate supply of food both for young and adult fish throughout the year, together with specific features of the reproduction of myctophids, are major factors contributing to their high abundance and creating conditions for their potential commercial utilization. The biomass of myctophids in the Antarctic Convergence area, in the Atlantic Ocean sector alone was recently assessed at about 1.7×10^6 tonnes (Filin *et al.*, 1991). Recent biomass assessments of all mesopelagic myctophids to the south of 40°S are around 337×10^6 tonnes (survey data) and $212\text{-}396 \times 10^6$ tonnes (results of calculation by modelling) (Tseitlin,1982 as cited by Lubimova *et al.*, 1983). The biomass of myctophids is about 1/3 to 1/2 of the total biomass of the Antarctic mesopelagic fish, i.e. around 70-130 and $100\text{-}200 \times 10^6$ tonnes, respectively (Lubimova, 1985a; Lubimova *et al.*, 1983a).

3. SUMMARIES OF MAJOR BIOLOGICAL CHARACTERISTICS OF ABUNDANT SPECIES OF MYCTOPHIDS

Some details of the biological characteristics of these species are summarized in the attached tables by known areas, seasons and sources of data. Some data (e.g., length composition of samples) are also illustrated in figures.

3.1 *Electrona antarctica* (Table 1)

Distribution: Inhabits primarily the Antarctic Deep Warm Waters. Distributed mainly within the Antarctic Circumpolar Current (ACC). Dominant in the area of the Polar Frontal Zone (PFZ). In the Atlantic Ocean sector of the Southern Ocean, found everywhere (except in high-latitute waters of coastal seas) from Drake Passage to Bouvet Is.

Reproduction: Spawning is serial and extended. Spawning intensity is greatest in autumn/winter. In summer, the gonads of adult specimens are at maturity Stages III and IV (Lisovenko, 1980). Larvae of *E. antarctica* are found all over the Scotia Sea (Efremenko, 1978).

Feeding: The frequency distribution of food items varies from area to area (see Table 1). The staple food of *E. antarctica* is planktonic crustaceans. Small juvenile fish feed primarily on copepods, euphausiid larvae and hyperiids. The proportion of *E. superba* and other euphausiids is increasing in the diet of larger adult fish. Data on the feeding of *E. antarctica* indicate low selectivity of food items. *E. antarctica* is an opportunistic feeder and feeds on almost any abundant food organisms.

Migrations: Seasonal vertical migrations are observed (surface layers in the summer and deeper waters in the winter). Diurnal vertical migrations are not markedly pronounced, primarily because food availability (copepods) is sufficient at any depth of the apparent range of vertical movement of *E. antarctica.*

Population parameters: Length compositions from samples taken in various areas does not vary greatly and mainly are within a range of 5.5 to 10 cm (modal length 8.5 to 9.6 cm). Size compositions of samples taken in different areas are shown in Figure 1. Maximum reported length was 12.5. Maximum age is 4 to 5 years. Age of maturity is 2 to 3 years (Shust and Kochkin, 1985). Length at maturity L_{50}=8.6 cm, L_{95}=9-10 cm (Lisovenko and Efremenko, 1982). Females were more frequent in samples (sex ratio reported by different authors is about 1:1.05 to 1.4). The sex ratio was found to be different in different size groups (Lisovenko and Efremenko, 1983).

Biomass and stock assessments: No assessments of the biomass of this species have been reported. Only assessments of a total biomass of all myctophids are available.

3.2 *Electrona carlsbergi* (Table 2)

At present this is the most studied species of the Antarctic myctophids.

Distribution: Distribution of this species covers waters to the south of the Antarctic Convergence to the Antarctic coast and also between the Antarctic and sub-Antarctic Convergences. Concentrations of this species are frequently observed in the waters close to the sub-Antarctic. The species is most abundant in the waters of the Frontal Zone which have high abundance of copepod plankton (up to 150-160 mg/m^3). Its vertical distribution is mainly affected by the position of pycnocline and the degree of illumination at various depth, and is also related to the seasonal cycle of plankton development.

Reproduction: Spawning apparently takes place at the end of winter (June/July) or at the beginning of spring (August/September). From November to May gonads of *E. carlsbergi* were found at development stage II (Konstantinova, 1988, Bouvet Is and Discovery Bank). Recent studies of the development of oocytes in *E. carlsbergi* give weight to the hypothesis that spawning grounds of this species are in the notal zone, to the north of the Antarctic Convergence (Mazhirina, 1991). Recent surveys indicate that *E. carlsbergi* breeds in the waters of the Sub-Tropical and Sub-Tropical Polar Zones (Zemsky and Zozulia, 1991). Individual fecundity is about 12 000 to 25 000 eggs (Mazhirina and Poletayev, 1990)

Feeding: Major food items: copepods (87 to 88% frequency of occurrence in stomachs), also hyperiids and euphausiids. Intensive feeding takes place during the night (23.00 to 24.00) and during the day (14.00 to 15.00) (Konstantinova, 1988, Scotia Sea). Daily food intake is about 4% of body weight (Gerasimova, 1991).

The high proportion of copepods in the diet is related to their high abundance in the areas of distribution of *E. carlsbergi*. Feeding concentrations of *E. carlsbergi* in the Atlantic Ocean sector are observed in the waters of the Antarctic Convergence and further to the north up to the Sub-Tropical Convergence (Lubimova *et al.*, 1983a). Main feeding grounds are thought to be in the Polar Frontal Zone (Zemsky and Zozulia, 1991).

Migrations: Analyses of feeding rates throughout the day revealed two peaks: an extended morning and shorter evening periods. These peaks correspond to diurnal vertical migration. In the down fish migrate up to the surface layer of 80 to 140 m depth; in the night they are found dispersed in the 5 to 100 m layer from the surface. During daylight hours fish descend to the 200 to 250 m depth layer (Zaselskiy *et al.*, 1985; Gerasimchuk, 1989).

Population parameters: Length of individuals in samples is 67 to 96 cm (Atlantic sector). Size compositions of samples taken in different areas are shown in Figure 3. Maximum age is not greater than 5 years. A slight sexual dimorphism was observed in some cases (Zaselskiy *et al.*, 1985, Gerasimchuk, 1989). Mature males and females have different structure of dorsal, caudal and anal fins as well as different body colour. Females at age 2 were found to be larger and heavier. Differences were 2 to 3 mm and 0.7 to 1.0 g ($P=0.01$). Maximum reported length was 10.5. Maximum age is 4 to 5 years. Age of maturity is 2 to 3 years (Shust and Kochkin, 1985). Sex ratio is about 1:1 with a slightly higher occurrence of females.

The mean annual growth rate was estimated to be 1.5 to 1.8 cm (Konstantinova, 1987, Atlantic sector). Growth rates during the first two years of life were found to be 30 to 36 mm per year (Zaselskiy *et al.*,1985). Growth pattern is considered to be close to isometric and described by the following Bertalanffy equations (Konstantinova, 1987, Atlantic sector):

$$L_t = 12.48\ [i - e^{-0.25}\ (t+0.68)].$$

The mean natural mortality of 0.86 was calculated from one year's data on 2- to 4-year-old fish which comprised the bulk of catches (Konstantinova, 1987, Atlantic sector)

Biomass and stocks: Concentrations of *E. carlsbergi* were observed in the Shag Rocks area from June to September (1984 to 87). Density of concentrations was two to three specimens per cubic meter (Zaselski, 1988). Surveys from 1987 to 1989 in the Atlantic sector of the Southern Ocean in the waters of the Antarctic Convergence resulted in a total biomass estimate of about 1.7×10^6 tonnes. About 90% of control catches was found to consist of *E. carlsbergi* (Filin *et al.*, 1991). Density of concentrations of the species was 70 to 100 g per square metre. Later observations in the South Georgia area gave biomass estimates of the species of 5.5-40.4 tonnes per square mile (survey area from 29.6 to 95.6 x 10^3 square miles) (Kozlov *et al.*, 1991).

Statistical analyses of the available data showed that fish from the Scotia Sea and the Antarctic Convergence areas (between 20° and 30°W) had statistically different length (SL). Apparently two different populations of *E. carlsbergi* exist in these areas: one in the waters of the anticyclonic gyre around South Georgia and Shag Rocks and another in the mixed waters of the Antarctic Convergence east of 30°W (Zaselskiy *et al.*, 1985).

Experts from the Northern Branch of the Fish Survey Board (USSR Ministry of Fisheries) attempted to forecast on a short-term basis the location of *E. carlsbergi* concentrations in the waters of the Polar Frontal Zone, taking into account position and dynamics of the atmospheric and oceanic frontal zones. Data on some selected biological parameters of *E. carlsbergi* were also used. Reliability of these forecasts was about 90 to 95% (Zemsky, 1987).

3.3 *Krefftichthys (Protomyctophum) anderssoni* (Table 3)

Distribution: Distribution is similar to *E. carlsbergi.* Found in waters to the south and to the north of the Antarctic Convergence. Concentrations of this species were observed in 1979 over the Discovery Bank in the Scotia Sea (Lubimova *et al*, 1983a).

Reproduction: Spawning and feeding areas of *K. anderssoni* is similar to those of *E. antarctica.*

Feeding: Available data are summarized in Table 3.

Migrations: Data not available.

Population parameters: Size compositions of samples taken in different areas are shown in Figure 4.

Biomass and stock assessments: Assessments of biomass of this species are not reported. Only assessments of a total biomass of all myctophids are available.

3.4 *Gymnoscopelus nicholsi* (Table 4)

Distribution: Distribution in the Atlantic Ocean sector covers waters to the south of the Antarctic Convergence up to the zone of mixing of waters of the High-Latitude Modification with waters of the Secondary Frontal Zone.

Reproduction: Spawning of this species apparently takes place within the same period as that of *E. antarctica*, i.e. at the end of autumn or in the winter (April to June).

Feeding: The diet of *G. nicholsi* consists of larger food organisms than the diet of other myctophids. Main food items are the Antarctic euphausiids, mainly *E. superba.* Intensive feeding takes place in the morning (2.00 to 4.00) and in the evening (18.00 to 19.00) (Konstantinova, 1988, Scotia Sea).

Migrations: Diurnal vertical migration is recorded for this species in spring/summer in all areas studied. In the South Shetlands area, at night *G. nicholsi* is caught by a krill midwater trawl in the 50 to 90 m layer from the surface, whereas during daylight hours it is caught only by bottom trawl at depths of 350 to 700 m. In the shelf waters of South Georgia, *G. nicholsi* was observed near the bottom at depths of 145 to 280 m.

Population parameters: This species is larger than other myctophids. Some specimens are up to 20 cm with a mean length of 16 to 18 cm. Length compositions differ considerably from area to area. Size compositions from samples taken in different areas are shown in Figure 5. Maximum age is less than 5 years. Annual growth rate is 2.7 to 3.4 cm. Growth pattern is considered to be close to isometric and described by the following Bertalanffy equations (Konstantinova, 1987):

$$L_t = 20.35[i - e^{0.28\,(t+0.14)}].$$

Mean natural mortality of 1.14 was calculated from one year's data on 2- to 4-year old fish which comprised the bulk of catches (Konstantinova, 1987, Atlantic sector).

Biomass and stock assessments: Assessments of biomass of this species are not reported. Only assessments of a total biomass of all myctophids are available.

CONCLUSION

Soviet studies of mesopelagic myctophids in the Southern Ocean are carried out as a part of the general multi-disciplinary program on Antarctic biological resources. Studies concentrate primarily on the following four most abundant species: *E carlsbergi, E. antarctica, K. (Protomyctophum) anderssoni* and *G. nicholsi.* The data obtained so far are adequate to describe the general ecology and distribution of these species. Some data are available on their feeding, reproduction and age/length composition. It has been suggested that *K. anderssoni* and *E. antarctica* have separate reproductive and feeding areas which are located within the Antarctic region. It has recently become apparent that the reproductive area of two other species, *E. carlsbergi* and *G. nicholsi*, is outside the Antarctic region, in the notal waters to the north of the Antarctic Convergence. Biomass estimates of myctophids are available for some areas in the Atlantic sector of the Southern Ocean, in particular in the South Georgia area. Some estimates of the total biomass of myctophids in the Southern Ocean are also made.

Of these four species, *E. carlsbergi,* is the most studied. This species is known to form dense localized concentrations in the Antarctic waters which can be commercially exploited. In addition to more detailed information on distribution, reproduction and feeding of the species, research effort has concentrated on studies of temporal and spatial variability of fish concentrations under different environmental conditions. It has been claimed that in some cases the available data allow for a reliable forecast of the location of fish concentrations.

However, the suggestion that, at least in the Atlantic sector of the Southern Ocean, spawning and feeding areas of *E. carlsbergi* are located in the notal zone, i.e. outside of the Antarctic region, is by no means most important. The theory claims that some part of the main population of *E. carlsbergi* located apparently in the Argentine Basin, is carried away by the Antarctic Circumpolar Current. Only fish older than one year can survive in the cold Antarctic waters, but the surviving fish never spawn because of the unfavourable environmental conditions (Gorchinsky, 1991). One of the consequences of this theory that so-called expatriated fish are considered lost as breeders and could be exploited without harming the main population in the notal zone. A catch limit on *E. carlsbergi* would be based only on ecological considerations, mainly on parameters of the importance of this species in the Antarctic food web.

This theory, if accepted, may lead to a new fishery in the Antarctic waters. However, mesopelagic myctophids represent only an intermediate level between the primary producers and high-level predators. Any exploitation at intermediate levels will inevitably have an adverse effect on high-level predators. It is known that mesopelagic fish are frequently found in the diet of some species of fish, birds and seals. Unfortunately, available information is scarce. More studies are urgently required on the importance of mesopelagic fish in the Antarctic ecosystem. Any research in the Antarctica and, in particular, research on such a geographically widespread resource as mesopelagic fish, will benefit from international cooperation. The CCAMLR Scientific Committee may wish to play an important role in coordinating future international research on the Antarctic mesopelagic fish.

ACKNOWLEDGEMENTS

I am grateful to the VNIRO Research Institute and, in particular to A.V. Zemsky (Laboratory of Antarctic Resources) for providing access to recent Soviet publications on the subject.

REFERENCES

CHINDONOVA, Y.G. 1987. Quantitative information on distribution of mesopelagic fish in the South of the Atlantic Ocean. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference, 22 to 24 September 1987*. Kerch: USSR Ministry of Fisheries. pp. 113-114. (In Russian).

EFREMENKO, V.N. 1986. Some particular aspects of distribution of eggs and larvae of fish of Myctophidae family in the Southern Atlantic. *Voprosy Ikhtiologii (Ichthyology magazine), 26*(5): 820-826. (In Russian).

EFREMENKO, V.N. 1987a. Types of reproduction areas of the Antarctic mesopelagic fish. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference, 22 to 24 September 1987.* Kerch: USSR Ministry of Fisheries. pp. 111-112. (In Russian).

EFREMENKO, V.N. 1987b. Species composition and distribution of eggs and larvae of mesopelagic fish in the Ross Sea. In: *Biological and oceanographic surveys of the Pacific Ocean sector of the Antarctic. Collection of scientific papers.* Moscow: USSR Ministry of Fisheries. pp. 186-193. (In Russian).

FILIN, A.A., K.V. GORCHINSKY and V.M.KISELEVA. 1991. Biomass of myctophids in the Atlantic sector of the Southern Ocean as estimated by acoustic surveys. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7).* Hobart, Australia: CCAMLR. (See this volume).

GERASIMOVA, O.V. 1991. Feeding and food intake of *Electrona carlsbergi* (Tåning), Myctophidae. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7).* Hobart, Australia: CCAMLR. (See this volume).

GORCHINSKY, K.V., V.M. KISELEVA, and A.A. FILIN. 1990. *Comparative Biological Characteristics of Electrona carlsbergi (Tåning) (Myctophidae) from the Notal and Antarctic Areas in the Southern Ocean Atlantic Sector.* WG-FSA-90/21. Hobart, Australia: CCAMLR.

KONSTANTINOVA, M.P. 1987. Growth and natural mortality rates of three species of myctophids from the Southern Atlantic. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference, 22 to 24 September 1987.* Kerch: USSR Ministry of Fisheries. pp. 117-118. (In Russian).

KONSTANTINOVA, M.P. 1988. Biology of *E. carlsbergi* (Tåning) (Myctophidae) from the talassobathyal zone of the South-East Atlantic. In: *Abstracts of Papers Presented at the All-Union Conference on Biological Resources of Talassobathyal Zone of the World Ocean, Rhybnoye, November 1988.* Moscow. pp. 27-28. (In Russian).

KONSTANTINOVA, M.P. 1988. Trophic relationships of myctophids of the Southern Atlantic. Abstract. In: *Feeding of seafish and their food availability as elements of fishery forecasting. All-Union Conference, 12-14 April 1988, Murmansk*: pp. 18-19 (In Russian).

KONSTANTINOVA, M.P. and P.P. FEDULOV. 1985. Biology and distribution of myctophids in the South-West and Antarctic Atlantic. In: *Studies and Rational Exploitation of Biological Resources of the Open Ocean Waters (mesopelagic fish), Collection of papers.* Moscow: VNIRO. pp. 30-36. (In Russian).

KONSTANTINOVA, M.P. and V.V. KONSTANTINOV. 1985. Some data on the biology of abundant myctophids of the eastern part of the Atlantic sector of the Southern Ocean. In: Yakovlev, V.N. (Ed.). *Integrated Studies of Biological Productivity of the Southern Ocean". Collection of Papers V. 3.* Moscow. pp. 35-52. (In Russian).

KORNILOVA, G.N. 1987. Environmental conditions for the formation of concentrations of *Electrona* species. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference 22-24 September 1987.* Kerch: USSR Ministry of Fisheries. pp. 118-120. (In Russian).

KOZLOV, A.N. and A.V.ZEMSKY. 1988. Some particular features of distribution and biology of abundant myctophids in open waters of the South-West Atlantic. In: *Quinto Simposio Cientifico, Comision Technica Mixta del Frente Maritimo. 28-30 noviembre 1988, Mar del Plata, Argentina. pp.* 24-25.

KOZLOV, A.N. and K.V. SHUST. (In press). Diet and daily feeding rhythm of *E. carlsbergi* in the Polar Frontal Zone area to the north-east of South Georgia. (In Russian).

KOZLOV, A.N., and M.I. TARVERDIEVA. 1989. Food of abundant myctophids in different areas of the Southern Ocean. *Voprosy Ichthiologii (Problems of Ichthiology), 29* (2): 310-317.

KOZLOV, A.N., K.V. SHUST and A.V. ZEMSKY. 1991. Seasonal variability in distribution of *Electrona carlsbergi* in the Southern Polar Front area with the South Georgia taken as an example. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7).* Hobart, Australia: CCAMLR. (See this volume).

LISOVENKO, L.A. 1987. Reproductive biology of Antarctic fish as related to the environmental conditions of their habitat. In: *Biological Resources of Hydrosphere and their utilisation. Biological resources of the Arctic and Antarctic.* Moscow: Nauka. pp. 337-357. (In Russian).

LISOVENKO, L.A. and V.N. EFREMENKO. 1983. Characteristic features of reproduction of abundant mesopelagic fish of the West Antarctic. *VNIRO Research Report.* Moscow. p. 36.

LUBIMOVA, T.G., K.V. SHUST, F.M. TROJANOVSKY and A.B. SEMENOV. 1983a. On the ecology of mass species of Myctophidae in the Atlantic sector of the Antarctic. In: *Soviet Committee of Antarctic Research. The Antarctic. The Committee Report 22*: 99-106. (In Russian).

LUBIMOVA, T.G., K.V. SHUST and V.V. POPKOV. 1987. Specific features of the ecology of mesopelagic fish of family Myctophidae of the Southern Ocean. In: *Biological Resources of Hydrosphere and Their Utilisation. Biological Resources of the Arctic and Antarctic.* Moscow: Nauka. pp. 320-337. (In Russian).

LUBIMOVA, T.G., R.R.MAKAROV, K.V. SHUST, L.A. LISOVENKO, V.A. ZEMSKY, and I.S. STUDENETSKAJA. 1983b. Biological resources of the Southern Ocean. Major characteristics of the oceanographic and biological structure of the Southern Ocean. Review. *Series: Fishery utilisation of the World Ocean.* TsNIITEIRKH. Moscow: USSR Ministry of Fisheries. pp. 18-32. (In Russian).

LUBIMOVA, T.G. and K.V. SHUST. 1987. Results of fish resources studies of the Southern Ocean. In: *Integrated Fishery-Related Studies of VNIRO in the World Ocean.* Moscow. pp. 19-43. (In Russian).

MAZHIRYNA, G.P. 1991. On reproduction of *Electrona carlsbergi* (Tåning). In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7).* Hobart, Australia: CAMLR. (See this volume).

MAZHIRYNA, G.P. and V.A. POLETAYEV. 1990. Distribution and some features of the biology of *E. carlsbergi* (Myctophidae) of the Atlantic Antarctic. Abstract. In: *All-Union Conference on Reserves of Biological Food Resources of the Ocean and the USSR Coastal Seas. Kaliningrad, 20-22 March 1990.* Moscow. pp. 118-120. (In Russian).

NESCHERETOV, A.B., A.V. PLETESHKOV and V.S.ZASELSKY V.S. 1985. On the possibility of a short-term forecast of spatial location of concentrations of *E. carlsbergi* in the Antarctic Convergence zone. Abstract. In: *Problems in the Long-Term Fishery Forecast and Fleet Management During Fishery. Second All-Union Conference, 15-17 October 1985, Kaliningrad.* pp. 42-44. (In Russian).

PODRAZHANSKAYA, S.G. and I.A. PINSKAYA. 1987. Trophic relationship of myctophids in the Scotia Sea. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference, 22-24 September 1987.* Kerch: USSR Ministry of Fisheries. pp. 116-117. (In Russian).

SHUST, K.V. 1987a. Subdivisions of ichthyofauna and formation of fish resources in the Antarctic waters. Abstract. In: *Resources of the Southern Ocean and Problems of Their Rational Exploitation. Second All-Union Conference, 22-24 September 1987.* Kerch: USSR Ministry of Fisheries. pp. 109-111.

SHUST, K.V. 1987b. Distribution and general biology of abundant notothenioid fish of the Antarctic. In: *Biological Resources of Hydrosphere and Their Utilisation. Biological Resources of the Arctic and Antarctic.* Moscow: Nauka. pp. 296-230. (In Russian).

SHUST, K.V. and N.P. KOCHKIN. 1985. *Age, Growth Rate and Age/Length Composition of Populations of Abundant Neritic and Mesopelagic Fish of the Southern Ocean.* Moscow: VNIRO.

SOLYANIK, G.A. 1967. The food of the *Electrona antarctica* Gunth. *Bulletin of the Soviet Antarctic Expedition, 67*: 36-39. (In Russian).

TANKEVITCH, P.B. *et al.* 1989. Notothenioid fish. In: *Biological Resources of the Hydrosphere and Their Utilisation. Biological Resources of the Indian Ocean .* Moscow: Nauka. pp. 303-310. (In Russian).

ZACEL'SKIY, V.S. 1985. Studies of distribution and biology of a myctophid species, *E. carlsbergi* (Tåning) in the Southern Atlantic. In: *Studies and Rational Exploitation of Biological Resources of the Waters of the Open Ocean (Mesopelagic Fish). Collection of Papers.* Moscow: VNIRO. pp. 30-36. (In Russian).

ZACEL'SKIY, V.S. 1988. Some ecological and biological features of the distribution of *E. carlsbergi* in winter in the Shag Rocks and Black Rocks area. In: *Abstracts of Papers Presented at the All-Union Conference on Biological Resources of Talassobathyal Zone of the World Ocean, Rhybnoye, November 1988.* Moscow. pp. 24-26. (In Russian).

ZACEL'SKIY, V.S., B.D. KUDRIN, V.A. POLETAYEV and S.V. CHECHENIN. 1985. Some features of the biology of *Electrona carlsbergi* Tåning (Myctophidae) in the Atlantic Sector of the Antarctic. *Voprosy Ikhtiologii (Problems in Ichthyology), 25*(2): 352-354.

ZAKHAROV, G.P. 1985. Parameters of back-scattering layers and echosounder records of fish in the sub-Antarctic waters of South-East Atlantic in January-February 1982. In: YAKOVLEV, V.N. (Ed.). *Integrated Studies of Biological Productivity of the Southern Ocean Waters, 3:* 19-34. (In Russian).

ZEMSKY, A.V. 1987. Studies of abundant species of myctophids in the East Pacific Sector of the Antarctic. In: *Biological and Oceanographic Surveys of the Pacific Ocean Sector of the Antarctic. Collection of Scientific Papers.* Moscow: USSR Ministry of Fisheries. pp. 193-201. (In Russian).

ZEMSKY, A.V. and S.A. ZOZULIA. 1989. Functional subdivision of the area of habitat of *E. carlsbergi* (Tåning, 1932), family Myctophidae, and its relation to the zonal structure of the Southern Ocean. In: *Sexto Simposio Cientifico, Comision Technica Mixta del Frente Maritimo. 4-6 deciembre de 1989.*

ZOZULIA, S.A and A.V. ZEMSKY. 1989. Some particular features of spatial distribution and biology of abundant myctophids in the Polar Frontal Zone area to the north of South Georgia in winter. In: *Sexto Simposio Cientifico, Comision Technica Mixta del Frente Maritimo. 4-6 deciembre de 1989.*

Table 1: Biological parameters of *E. antarctica.*

Area	Date	Sampling Technique	Mean Length (cm)	Mean Weight (g)	Sex Ratio	State of Gonad Devel.	Rate of Stomac Fullness	Frequency Distribution of Food by Items (%)	Sample Size	Reference
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
South Georgia	Dec-Feb 1975,76 and 79	Midwater trawl 30-60 m	7.8-7.9	7.3-8.2	-	III,III/IV	1.9-2.1	Copepods-95%; Euphausiids-72%; Hyperiids-54%	155	Lubimova *et al.*, 1983
South Orkneys	Dec 1974	Midwater trawl	8.8	8.5	-	III	1.4	Euphausiids-90%; Hyperiids-54%	50	Lubimova *et al.*, 1983
South Shetlands	Jan-Feb 1976,78	Midwater trawl	8.7-9.6	8.3-10.2	-	III,III/IV	1.8-2.0	Copepods-30%; Euphausiids-85%; Hyperiids-26%	217	Lubimova *et al.*, 1983
Peter I Is. (Bellingshausen Sea)	Jan 1976	Midwater trawl	9.7	10.5	-	III	3.2	Euphausiids-100%	100	Lubimova *et al.*, 1983
East of South Sandwich Is	Dec 1974	Midwater trawl	8.5	7.4	-	II-III	1.9	Euphausiids (except krill)-55%; Krill-47%; Hyperiids-31%	76	Lubimova *et al.*, 1983
Lazarev Sea	Jan-March 1978,81,84	Midwater trawl 30-70 m	3.5-10.6	–	–	–	1.8	Pteropods-14.7% Ostracods-45.0% Hyperiids-10.8% Copepods-89.1% Euphausiids-36.4%	129	Kozlov and, Tarverdieva 1989
As above	As above	Midwater trawl 380-600 m	3.5-10.6	–	–	–	2.1	Pteropods-20.7% Polychaets-3.4% Ostracods-1.7% Hyperiids-12.9% Copepods-24.1% Euphausiids-81.0%	116	Kozlov and Tarverdieva 1989

Table 1 (continued)

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
Kosmonavtov Sea	Jan-March 1978,81,84	Midwater trawl 30-70 m	4.0-9.5	–	–	–	1.2	Pteropods-2.0% Hyperiids-14.8% Copepods-84.0%	55	Kozlov and Tarverdieva 1989
As above	As above	350-540 m	4.0-9.5	–	–	–	1.6	Hyperiids-17.5% Copepods-21.0% Euphausiids-52.5%	237	Kozlov and Tarverdieva 1989
Sodruzhestva Sea	Jan-March 1978,81,84	Midwater trawl 50-80 m	4.0-9.5	–	–	–	2.5	Ostracods-2.0% Hyperiids-15.0% Copepods-95.0% Euphausiids-5.0%	100	Kozlov and Tarverdieva 1989

Table 2: Biological parameters of *E. carlsbergi*.

Area	Date	Sampling Technique	Length, Mean or Modal/ (Range) (cm)	Weight (g)	Sex Ratio	Stage of Gonad Devel.	Rate of Stomach Fullness	Frequency Distribution of Food by Items (%)	Sample Size	Reference
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
South Georgia	Oct-Feb 1979-80	–	8.3-8.8	7.3-7.5	1.27:1	II	2.32-3.12	Copepods-100%; Euphausiids-32%; Hyperiids-67%	346	Lubimova *et al.*, 1983
South Georgia, Scotia Sea and ACC waters 20-40°W	Dec 1982-Jan 1983	–	7.0-7.9 (6.8-9.6)	Max-12.1-14.6 Mean-7.5-8.8	1:1.1	–	–	Copepods-87-88%; Hyperiids-7%; Euphausiids-4%	–	Zaselhskiy, 1985; Zaselhskiy *et al.*,1985
Shag Rocks, South Georgia	June-Sept 1984-87		7.0-7.8 (6.4-9.3)	5.5-6.5	–	–	–	–	–	Zaselhskiy, 1988
Discovery Bank, Bouvet Is	–	–	(3.5-10.3)	–	–	–	–	–		Konstantinova, 1988
	spring/summer 1987-88	–	7.0-7.4	6.3-8.2	–	II	1.9-2.3	Mainly copepods	–	Kozlov and Zemskiy, 1988
North of South Georgia, Polar Frontal Zone	Oct-Jan 1987/88	-	7.0-7.4	6.3-8.2	–	II	1.9-2.3	Mainly copepods	–	
North of South Georgia	June 1989	Midwater trawl	7.9-8.36 (7.0-10.0)	–	–	II	–	–	–	Zozulia and Semskiy, 1989
Atlantic sector	Summer 1987/88, summer/autumn 1989	–	7.6-8.0 (age 2) 82-90 (age 3)	–	–	II	–	–	–	Mazhirina and Poletayev, 1990

Table 2 (continued)

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
Atlantic Sector, transects at 17° and 10° W between 37°30' and 55°30' S	20 Mar-10 Apr 1989	Midwater rope-trawl, 3600 sq. m opening	8.4 7.0-10.5 exact M and range dependent on catch latitude	7.3-11.2 depending on latitude	from 1:0.85 to 1:1.2 depending on latitude	II-V depending on latitude	0.96-1.47 depending on latitude	–	2072	Zemsky and Zozulia, 1991
Bellingshausen Sea	Jan-March 1978,81,84	Midwater trawl, 50-80 m	(7.8-9.5)	–	–	–	2.8	Pteropods-52%; Copepods-26%; Gammaroids-4.0%; Hyperiids-88%; Euphausiids-12%	50	Kozlov and Tarverdieva 1989
D'Urville Sea	Jan-March 1978,81,84	Midwater trawl, 150-200 and 4000-4400 m	(7.3-10.3)	–	–	–	1.8	Pteropods-12.2%; Ostracods-14.4%; Copepods-87.8%; Hyperiids-10.0%; Euphausiids-47.8%; Salps-14.4%	100	Kozlov and Tarverdieva 1989
Kosmonavtov Sea	Jan-March 1978,81,84	Midwater trawl, 30-70 and 240-540 m	(7.9-10.0)	–	–	–	2.1	Copepods-89.6%; Hyperiids-10.6%; Euphausiids-42.0%; Chaetognaths-16.6%	105	Kozlov and Tarverdieva, 1989

Table 3: Biological parameters of *P. anderssoni*.

Area	Date	Sampling Technique	Length, Mean or Modal/ (Range) (cm)	Weight (g)	Sex Ratio	Stage of Gonad Devel.	Rate of Stomach Fullness	Frequency Distribution of food by items (%)	Sample Size	Reference
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
Scotia Sea, Discovery Bank	1979	Krill trawl	4.5-7.0	-	-	-	-	-	-	Lubimova *et al.* 1983
Kosmonavtov Sea	Jan-Feb 1984	Midwater trawl 30-70 m	3.0-6.9	-	-	-	2.4	Copepods-96.0% Euphausiids-19.5% Hyperiids-5.1	457	Kozlov and Tarverdieva 1989

Table 4: Biological parameters of *G. nicholsi*.

Area	Date	Sampling Technique	Length, Mean or Modal/ (Range) (cm)	Weight (g)	Sex Ratio	Stage of Gonads Devel.	Rate of Stomach Fullness	Frequency Distribution of Food by Items (%)	Sample Size	Reference
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
South Georgia	Dec 1974 Jan 1975	Bottom trawl 145-280 m	13.4-14.5	21.2-25.6	80/20	II	1.73-2.35	Mysids-85%; Hyperiids-42%; Krill-21%	115	Lubimova *et al.*, 1983
South Georgia	Feb 1979	Midwater trawl 50 m	16.7	23.5	75/25	II	2.11	Euphausiids (krill)-90%; Hyperiids-34%.	87	Lubimova *et al.*, 1983
South Orkneys	Jan 1980	Bottom trawl 315-500 m	16,7	30.2	66/34	III	1.82	Euphausiids (krill)-100%	50	Lubimova *et al.*, 1983
South Shetlands	Feb 1976 Jan 1980	Bottom trawl 360-590 m	16.8-18.4	29.3-36.2	58/42	III	1.75-2.22	Copepods-100%; Krill-92%; T.macrura (furcilia)-88%; Hyperiids-35%	150	Lubimova *et al.*, 1983
South Shetlands	Jan 1978	Midwater trawl 90 m	18.2	35.8	54/46	III	2.14	Euphausiids (krill)-96%; Hyperiids-27%	50	Lubimova *et al.* 1983
Kosmonavtov Sea	Feb 1984	Midwater trawl 340-540 m	10.0-15.8	-	-	-	1.9	Copepods-33% Euphausiids-65.9% (E.superba-60.2%) Others-7.1%	140	Kozlov and Tarverdieva 1989

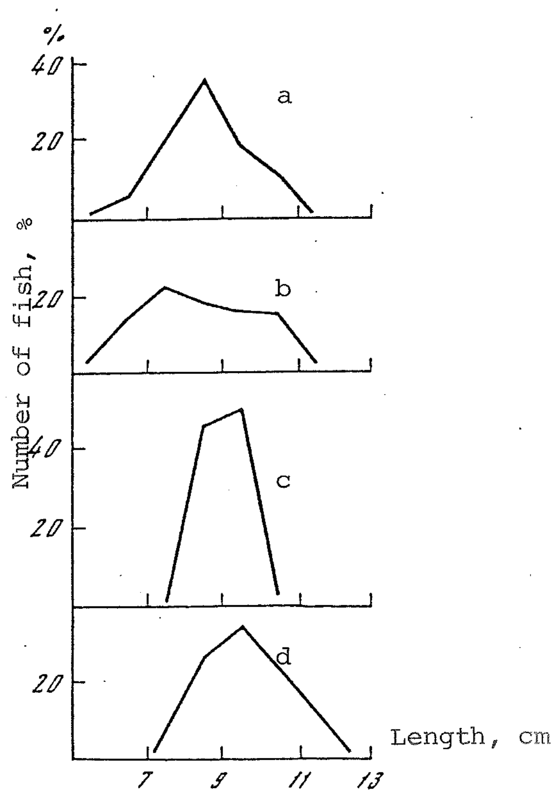


Figure 1: Size composition of *E. antarctica* catches (from Lubimova *et al.*, 1983, research surveys).
a - South Georgia, $SL_{(mode)}$=8.6 cm, n=182
b - east of South Sandwich Is, 53°05'S, 16°15'W, $SL_{(mode)}$=8.1 cm, n=1.67
c - South Shetlands, $SL_{(mode)}$=9.6 cm, n=206
d - Peter I Is, $SL_{(mode)}$=9.7 cm, n=170

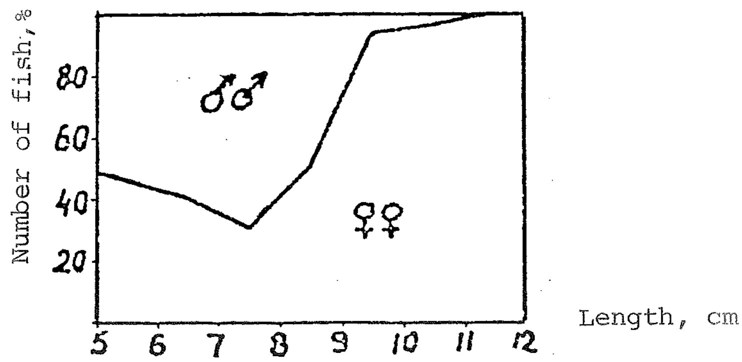


Figure 2: Sex ratio in different size groups of *E. antarctica* catches (from Lisovenko and Efremenko, 1983, research surveys).

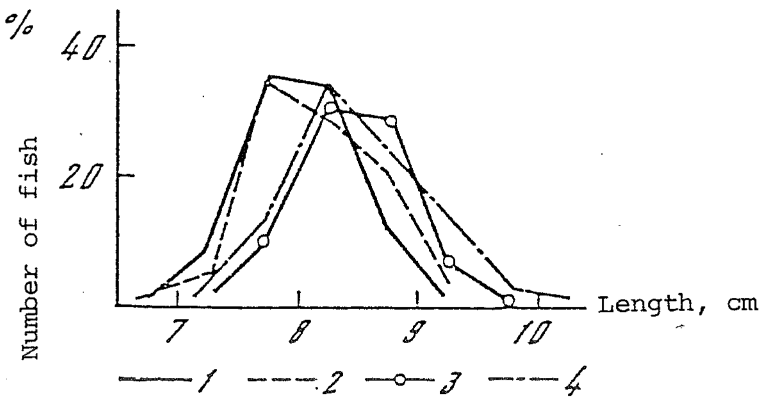


Figure 3: Size composition of *E. carlsbergi* catches (from Lubimova *et al.*, 1983, research surveys to the north of South Georgia, 1979).
1 - January, $SL_{(mode)}$=8.3 cm, n=1 670
2 - February, $SL_{(mode)}$=8.6 cm, n=1 480
3 - November, $SL_{(mode)}$=8.8 cm, n=1 380
4 - December, $SL_{(mode)}$=8.6 cm, n=516

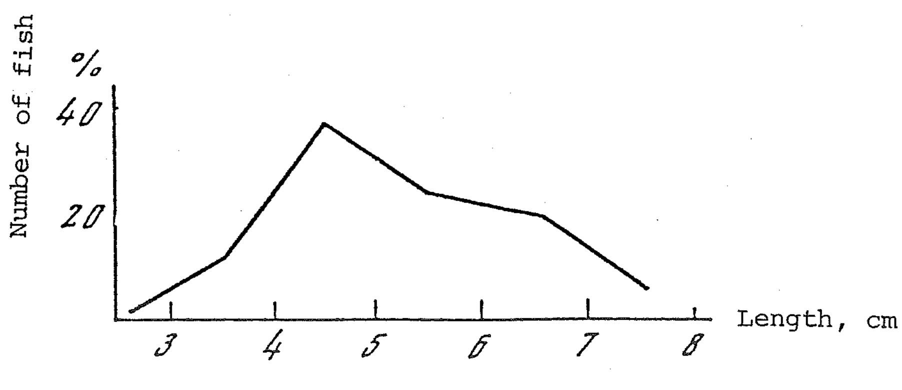


Figure 4: Size composition of *K. anderssoni* catches (from Lubimova *et al.*, 1983, research surveys). East of South Sandwich Is, 54°30'S, 18°35'W, $SL_{(mode)}$=5.3 cm, n=289.

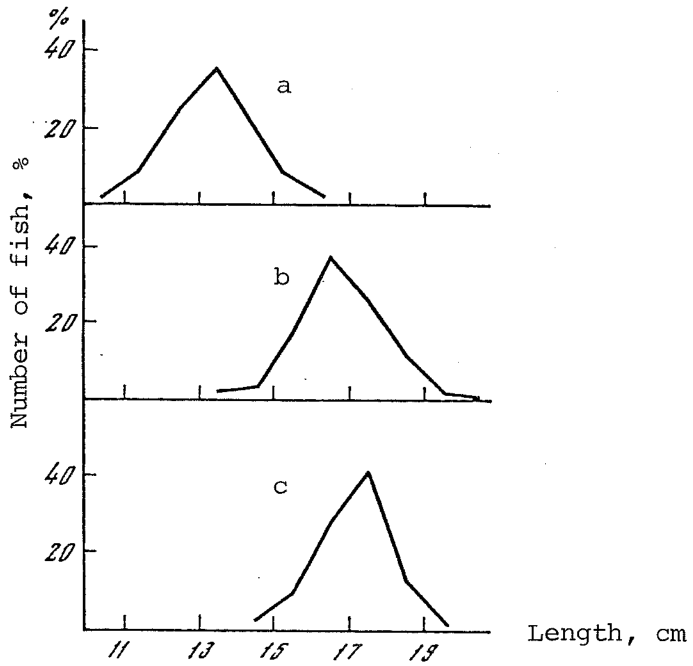


Figure 5: Size composition of *G. nicholsi* catches (from Lubimova *et al.*, 1983 research surveys).

a - South Georgia, $SL_{(mode)}$=13.4 cm, n=466
b - South Orkneys, $SL_{(mode)}$=16.7 cm, n=322
c - South Shetlands, $SL_{(mode)}$=18.2 cm, n=1 472

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

Figura 2: Proporción de sexos por intervalo de talla de *E. antarctica* (de Lisovenko y Efremenko, 1983, prospecciones de investigación)

Figura 3: Composición por tallas de las capturas de *E. carlsbergi* (de Lubimova *et al.*, 1983, prospecciones de investigación al norte de Georgia del Sur, 1979).
a - Enero $SL_{(moda)}$ = 8.3 cm, n = 1 670;
b - Febrero, $SL_{(moda)}$ = 8.6 cm, n = 1 480;
c - Noviembre, $SL_{(moda)}$ = 8.8 cm, n = 1 380;
d - Diciembre, $SL_{(moda)}$ = 8.6 cm; n = 516

Figura 4: Composición por tallas de las capturas de *K. anderssoni* (de Lubimova *et al.*, 1983, prospecciones de investigación). Al este de las islas Sandwich del Sur, 54°30'S, 18°35'W, $SL_{(moda)}$ = 5.3 cm; n = 289

Figura 5: Composición por tallas de las capturas de *G. nicholsi* (de Lubimova *et al.*, 1983, prospecciones de investigación).
a - Georgia del Sur $SL_{(moda)}$ = 13.4 cm, n = 466;
b - Orcadas del Sur, $SL_{(moda)}$ = 16.7 cm, n = 322;
c - Shetlands del Sur, $SL_{(moda)}$ = 18.2 cm, n = 1 472

AREAS OF SEABED WITHIN SELECTED DEPTH RANGES IN CCAMLR SUBAREA 48.3, SOUTH GEORGIA

I. Everson and S. Campbell*

Abstract

Areas of seabed within 50 m depth contours down to 250 m, between 250 and 500 m and deeper than 500 m have been estimated from nautical charts. The results are presented by CCAMLR fine-scale reporting areas.

Résumé

Les aires de fond marin situées à l'intérieur de courbes bathymétriques de 50 m, entre 0 et 250 m, entre 250 et 500 m et à plus de 500 m de profondeur ont été estimées à partir de cartes marines. Les résultats sont présentés par zones de déclaration à échelle précise de la CCAMLR.

Резюме

По морским картам была определена площадь участков морского дна по глубинным горизонтам от 50 до 250 метров, от 250 до 500 метров и глубже. Результаты представлены по мелкомасштабным участкам представления данных АНТКОМа.

Resumen

A partir de las cartas de navegación, se han estimado áreas de lecho marino de las curvas de profundidad de 50 a 250 m; entre 250 y 500 metros y a más de 500 m. Los resultados se presentan por áreas de notificación de la CCRVMA y a escala fina.

1. INTRODUCTION

During the 1989 Meeting of the Working Group on Fish Stock Assessment in Hobart, it was agreed that data should be available within 50 m depth contours and within CCAMLR fine-scale reporting areas. This paper contains such data for the South Georgia area, CCAMLR Subarea 48.3 and supersedes that presented in a similar paper (Everson, 1988).

* National Environment Research Council, British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, United Kingdom

2. DATA SOURCES

The main sources of data have been UK Admiralty Charts for the region. The following charts have been used:

		Reference Number
1.	Approaches to South Georgia	3596
2.	South Georgia	3597
3.	Stewart Strait	3592
4.	Harbours and Anchorages in South Georgia	3589
5.	Harbours and Anchorages in South Georgia	3585

Further information has been obtained by reference to small scale 'collector sheets'. These are charts containing all reported and validated soundings and are used to update the published charts. The areas covered by these collector sheets are listed below.

Latitude Range (degrees South)	Longitude Range (degrees West)
48°00' - 54°00'	30°00' - 45°00'
54°00' - 60°00'	30°00' - 45°00'
53°52' - 54°42'	36°25' - 37°15'
53°36' - 54°58'	35°40' - 36°10'
53°10' - 54°59'	35°38' - 36°36'
53°50' - 54°25'	37°04' - 38°27'
54°00' - 54°15'	37°35' - 38°02'
54°02' - 54°20'	37°10' - 37°56'
54°14' - 54°33'	36°53' - 37°22'
54°20' - 54°33'	36°27' - 37°05'
54°05' - 54°23'	36°10' - 36°42'
54°03' - 54°23'	35°55' - 36°32'
53°50' - 54°15'	35°55' - 36°55'

Certain of the CCAMLR fine-scale rectangles, specifically those at 54°S 37°W, 54°S 36°W and 54°30'S 36°W are divided by land. The southerly part of each of these rectangles has been designated by '(S)' in the longitude (W) column of the tables.

3. RESULTS

Areas of seabed, expressed as square kilometres, by fine-scale rectangle and within 50 m depth contours are set out in Table 1. The areas have been summed within the depth strata that are currently used for standing stock estimation and are presented in Table 2.

There is some justification for considering some fishery resources at Shag Rocks separately from those around the mainland of South Georgia. The areas of seabed within the Shag Rocks zone, defined as being between latitudes 53°S and 54°S and longitudes 40°W and 44°W have therefore been calculated. The total areas within depth strata for all Subarea 48.3, South Georgia and Shag Rocks are summarized in Table 3.

REFERENCES

EVERSON, I. 1988. Areas of seabed within selected depth ranges in the south-west Atlantic and Antarctic Peninsula regions of the Southern Ocean. In: *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4)*. Hobart, Australia: CCAMLR. pp. 49-73.

Table 1a: Areas of seabed (km²) around South Georgia between 53° and 54°30'S.

NE Corner									
S°	S'	W°	0 - 50	50 - 100	100 - 150	150 - 200	200 - 250	250 - 500	>500
53	0	43	0.0	0.0	0.0	0.0	0.0	12.0	3673.9
53	0	42	0.0	0.0	0.0	129.8	158.3	445.2	2952.6
53	0	41	0.0	0.0	88.9	116.9	41.4	26.8	3411.9
53	0	40	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	39	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	38	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	37	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	36	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	35	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	0	34	0.0	0.0	0.0	0.0	0.0	0.0	3685.9
53	30	43	0.0	0.0	0.0	0.0	0.0	0.0	3642.8
53	30	42	0.0	0.0	93.3	174.9	115.0	178.6	3081.0
53	30	41	0.0	0.0	1209.8	500.2	495.1	410.5	1027.2
53	30	40	0.0	3.8	77.7	101.3	37.6	536.9	2885.5
53	30	39	0.0	0.0	0.0	39.5	138.1	689.2	2776.0
53	30	38	51.2	105.8	363.9	819.4	340.7	640.9	1320.9
53	30	37	107.6	232.7	1025.4	585.5	246.5	732.9	690.8
53	30	36	0.0	0.0	131.0	808.2	728.6	723.1	1251.9
53	30	35	0.0	0.0	6.0	57.7	81.6	270.5	3227.0
53	30	34	0.0	0.0	0.0	0.0	0.0	0.0	3642.8
54	0	43	0.0	0.0	0.0	0.0	0.0	0.0	3599.2
54	0	42	0.0	0.0	0.0	0.0	0.0	0.0	3599.2
54	0	41	0.0	0.0	0.0	0.0	0.0	0.0	3599.2
54	0	40	0.0	0.0	0.0	0.0	0.0	0.0	3599.2
54	0	39	0.0	0.0	15.8	260.6	457.5	482.7	2382.6
54	0	38	54.0	106.7	113.1	782.7	2466.2	66.5	0.0
54	0	37	124.4	46.6	41.6	14.3	5.5	4.6	0.0
54	0	37(S)	447.6	313.6	703.4	605.3	510.9	251.3	0.0
54	0	36	138.4	313.4	447.4	309.2	414.7	176.6	0.0
54	0	36(S)	175.0	76.7	26.2	24.9	23.8	0.0	0.0
54	0	35	0.0	38.8	100.5	451.4	1261.8	528.7	1218.0
54	0	34	0.0	0.0	0.0	0.0	0.0	0.0	3599.2

Table 1b: Areas of seabed (km²) around South Georgia between 54°30' and 56°S.

NE Corner									
S°	S'	W°	0 - 50	50 - 100	100 - 150	150 - 200	200 - 250	250 - 500	>500
54	30	43	0.0	0.0	0.0	0.0	0.0	0.0	3555.5
54	30	42	0.0	0.0	0.0	0.0	0.0	0.0	3555.5
54	30	41	0.0	0.0	0.0	0.0	0.0	0.0	3555.5
54	30	40	0.0	0.0	0.0	0.0	0.0	0.0	3555.5
54	30	39	0.0	0.0	0.0	14.1	113.1	106.0	3322.3
54	30	38	0.0	0.0	0.0	542.9	715.0	273.8	2023.8
54	30	37	0.0	0.0	422.0	649.6	1034.7	455.5	993.7
54	30	36	17.9	2.6	10.3	0.0	0.0	0.0	0.0
54	30	36(S)	234.8	263.5	565.0	492.2	597.5	903.7	0.0
54	30	35	180.8	371.8	922.0	792.9	443.1	554.0	84.9
54	30	34	0.0	8.9	142.4	145.0	199.4	317.7	2742.1
55	0	43	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	42	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	41	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	40	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	39	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	38	0.0	0.0	0.0	0.0	0.0	0.0	3511.5
55	0	37	0.0	0.0	0.0	0.0	0.0	6.9	3504.6
55	0	36	0.0	4.6	22.8	262.8	94.8	178.2	2948.3
55	0	35	0.0	52.8	1321.2	810.1	586.4	457.9	283.1
55	0	34	0.0	18.1	523.9	221.0	55.5	153.4	2539.6
55	30	43	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	42	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	41	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	40	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	39	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	38	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	37	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	36	0.0	0.0	0.0	0.0	0.0	0.0	3467.1
55	30	35	0.0	0.0	0.0	0.0	0.0	18.3	3448.8
55	30	34	0.0	0.0	0.0	0.0	0.0	209.5	3257.7

Table 2a: Areas of seabed (km²) around South Georgia between 53° and 54°30'S.

NE Corner						
S°	S'	W°	50 - 150	150 - 250	250 - 500	>500
53	0	43	0.0	0.0	12.0	3673.9
53	0	42	0.0	288.1	445.2	2952.6
53	0	41	88.9	158.3	26.8	3411.9
53	0	40	0.0	0.0	0.0	3685.9
53	0	39	0.0	0.0	0.0	3685.9
53	0	38	0.0	0.0	0.0	3685.9
53	0	37	0.0	0.0	0.0	3685.9
53	0	36	0.0	0.0	0.0	3685.9
53	0	35	0.0	0.0	0.0	3685.9
53	0	34	0.0	0.0	0.0	3685.9
53	30	43	0.0	0.0	0.0	3642.8
53	30	42	93.3	289.9	178.6	3081.0
53	30	41	1209.8	995.3	410.5	1027.2
53	30	40	81.5	138.9	536.9	2885.5
53	30	39	0.0	177.6	689.2	2776.0
53	30	38	469.7	1160.1	640.9	1320.9
53	30	37	1258.1	832.0	732.9	690.8
53	30	36	131.0	1536.8	723.1	1251.9
53	30	35	6.0	139.3	270.5	3227.0
53	30	34	0.0	0.0	0.0	3642.8
54	0	43	0.0	0.0	0.0	3599.2
54	0	42	0.0	0.0	0.0	3599.2
54	0	41	0.0	0.0	0.0	3599.2
54	0	40	0.0	0.0	0.0	3599.2
54	0	39	15.8	718.1	482.7	2382.6
54	0	38	219.8	3248.9	66.5	0.0
54	0	37	88.2	19.8	4.6	0.0
54	0	37(S)	1017.0	1116.2	251.3	0.0
54	0	36	760.8	723.9	176.6	0.0
54	0	36(S)	102.9	48.7	0.0	0.0
54	0	35	139.3	1713.2	528.7	1218.0
54	0	34	0.0	0.0	0.0	3599.2

Table 2b: Areas of seabed (km²) around South Georgia between 54°30' and 56°S.

NE Corner						
S°	S'	W°	50 - 150	150 - 250	250 - 500	>500
54	30	43	0.0	0.0	0.0	3555.5
54	30	42	0.0	0.0	0.0	3555.5
54	30	41	0.0	0.0	0.0	3555.5
54	30	40	0.0	0.0	0.0	3555.5
54	30	39	0.0	127.2	106.0	3322.3
54	30	38	0.0	1257.9	273.8	2023.8
54	30	37	422.0	1684.3	455.5	993.7
54	30	36	12.9	0.0	0.0	0.0
54	30	36(S)	828.5	1089.7	903.7	0.0
54	30	35	1293.8	1236.0	554.0	84.9
54	30	34	151.3	344.4	317.7	2742.1
55	0	43	0.0	0.0	0.0	3511.5
55	0	42	0.0	0.0	0.0	3511.5
55	0	41	0.0	0.0	0.0	3511.5
55	0	40	0.0	0.0	0.0	3511.5
55	0	39	0.0	0.0	0.0	3511.5
55	0	38	0.0	0.0	0.0	3511.5
55	0	37	0.0	0.0	6.9	3504.6
55	0	36	27.4	357.6	178.2	2948.3
55	0	35	1374.0	1396.5	457.9	283.1
55	0	34	542.0	276.5	153.4	2539.6
55	30	43	0.0	0.0	0.0	3467.1
55	30	42	0.0	0.0	0.0	3467.1
55	30	41	0.0	0.0	0.0	3467.1
55	30	40	0.0	0.0	0.0	3467.1
55	30	39	0.0	0.0	0.0	3467.1
55	30	38	0.0	0.0	0.0	3467.1
55	30	37	0.0	0.0	0.0	3467.1
55	30	36	0.0	0.0	0.0	3467.1
55	30	35	0.0	0.0	18.3	3448.8
55	30	34	0.0	0.0	209.5	3257.7

Table 3: Summary of areas of seabed for Shag Rocks, South Georgia and the whole of Subarea 48.3. An asterisk (*) indicates that there are no reported soundings for this depth range.

Depth Range (m)	Area of Seabed (km²)		
	Shag Rocks	South Georgia	The Whole of Subarea 48.3
0 - 50	*	1531.7	1531.7
50 - 100	3.8	1956.6	1960.4
100 - 150	1469.7	6903.8	8373.6
150 - 200	1023.1	8689.3	9712.4
200 - 250	847.5	10515.0	11362.8
250 - 500	1610.0	8201.9	9811.9
> 500	24360.0	144798.0	169158.9
Total	29314.1	182597.6	211911.7

Liste des tableaux

Список таблиц

Lista de las tablas

SC-CAMLR-BG-IX/BG/14

REFINEMENTS TO THE STRATEGY FOR MANAGING DEPLETED FISH STOCKS BASED ON CCAMLR OBJECTIVES

W.K. de la Mare* and A. Constable**

Abstract

A method of calculating fishing mortalities which will allow depleted fish stocks to recover to levels near those giving greatest net annual increment within two to three decades is illustrated. These fishing mortalities are based on probabilistic descriptions of the future states of a depleted stock, and take into account uncertainty in assessments. Sample calculations show that applying a policy of $\mathbf{F}_{0.1}$ will not always lead to stock recovery in two to three decades, and hence that additional management policies are required for depleted stocks. The implications of these studies for defining the terms 'depleted' and 'target levels for recovery' are briefly discussed.

Résumé

Une méthode de calcul des mortalités par pêche est illustrée, selon laquelle les stocks de poissons surexploités pourront récupérer à des niveaux proches de ceux permettant un accroissement maximum net annuel dans les 20 ou 30 années à venir. Ces mortalités par pêche sont fondées sur des descriptions probabilistes de l'état futur d'un stock surexploité, et tiennent compte de l'incertitude dans les évaluations. Des calculs effectués à titre d'exemples démontrent que l'application systématique de $\mathbf{F}_{0.1}$ ne conduit pas forcément à un repeuplement du stock en 20 ou 30 ans, et que, par conséquent, les stocks surexploités devraient faire l'objet de nouvelles mesures de gestion. Les implications de ces études pour la définition des termes "surexploité" et "seuil à atteindre pour le repeuplement" sont examinées brièvement.

Резюме

Демонстрируется метод вычисления уровней промысловой смертности, позволяющих восстановление истощенных рыбных запасов на протяжении двух-трех десятилетий до уровней, близких к тем, которые обеспечивают максимальный чистый годовой прирост. При расчете этих уровней промысловой смертности, основанных на вероятностных прогнозах состояния истощенного запаса, учитывалась имеющаяся в оценках неопределенность. Пробные расчеты показывают, что применение стратегии, основанной на $\mathbf{F}_{0.1}$, не всегда приводит к восстановлению запаса через два-три

* Centre for Marine and Ecological Research, Soerlaan 33, 1185 JG Amstelveen, Netherlands

** Division for Environmental Sciences, Griffith University, Nathan, Brisbane, Queensland, Australia 4111

десятилетия, и, следовательно, необходимы дополнительные меры управления истощенными запасами. В общих чертах рассматривается значение данных исследований для уточнения значения терминов "истощенный" и "целевые уровни восстановления".

Resumen

En este documento se presenta un método para calcular la mortalidad por pesca que permitirá la recuperación de las poblaciones mermadas de peces a niveles cercanos a aquellos que producirán el mayor aumento anual neto dentro de dos a tres décadas. Estas mortalidades por pesca se basan en descripciones probabilísticas de la futura condición de una población mermada y toman en consideración las ambigüedades en las evaluaciones. Los cálculos experimentales indican que al aplicar una norma de $\mathbf{F_{0.1}}$ no siempre conducirá a una recuperación de la población dentro de de dos o tres décadas y, por lo tanto, se necesitan normas de administración adicionales para las poblaciones mermadas. Se trata brevemente como los resultados de estos estudios podrán ayudar con la definición de los términos "mermado" y "niveles objetivo para recuperación".

---

1. INTRODUCTION

In 1988 the Working Group for the Development of Approaches to Conservation (WG-DAC) suggested that the interpretation of Article II of the CCAMLR Convention would be assisted by the development of operational definitions for "depletion" and for "target levels for recovery of depleted populations" (CCAMLR-VII, paragraph 140). In 1987 the Commission adopted the yield-per-recruit fishing mortality $\mathbf{F_{0.1}}$ as the appropriate management strategy for fish stocks (CCAMLR-VI, paragraph 61). The studies in this paper explore an approach to calculating values of fishing mortality (F) which are more appropriate than $\mathbf{F_{0.1}}$ in terms of the requirements of Article II of the Convention, for fish stocks which have been reduced to low levels. This approach represents a starting point for extending the management strategy to the case of depleted fish stocks, and points to factors to be considered in formulating operational definitions of depleted and target levels for recovery.

The part of Article II directly applicable to harvesting objectives states:

"3. Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:

(a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;

(b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and

(c) prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources."

From these general objectives several key concepts relevant to the management of depleted stocks stand out.

(1) Depleted populations are below levels near to the population level giving greatest net annual increment (GNAI).

(2) The minimum population level posited to ensure stable recruitment is equated with GNAI.

(3) The effects of exploitation should be compatible with potential reversibility in two or three decades, taking into account the state of available knowledge of, *inter alia,* the direct and indirect impact of harvesting.

The general objectives need to be supplemented to render their meaning more precise for the purposes of formulating advice in the Scientific Committee. It is very unlikely that in the near term that levels of GNAI for various stocks will be able to be estimated directly. Thus, levels will probably be chosen on the basis of conventional fisheries models. Similarly, identifying stock-recruitment (S-R) relationships will also be extremely difficult, and some form of model will have to be selected which is compatible with the concepts (1), (2) and (3) above.

A further factor to be taken into consideration in some practical way is the state of available knowledge about the stocks. Inevitably assessments of the state of a stock will include uncertainty, for example due to sampling variability. This uncertainty needs to be taken into account when formulating management advice.

A framework which integrates the elementary concepts above can be formulated as follows. An assessment is made of a fish stock, using whatever methods and data are available, to estimate the current stock level and the mean stock level which would exist without fishing. If the 'best' estimate of current stock level is substantially below GNAI (expressed as a fraction of the unfished mean stock level) then it is deemed to be depleted and hence fishing mortality must be set at levels which should not preclude stock recovery to GNAI (or other target level) within two or three decades. A 'best' estimate would be the mean or median of a probability density function which incorporates the uncertainty in the quantities estimated. Using this information the following fishing mortalities are calculated using a stock projection computer program:

(i) the fishing mortality which results in a specified subjective probability that the stock will be above the current level in 20 years;

(ii) the fishing mortality which results in a subjective probability of 0.5 that the stock is at or above GNAI (or other target level) in 20 years;

(iii) the fishing mortality which results in a specified subjective probability that the stock is above GNAI (or other target level) in 30 years; and

(iv) the fishing mortality corresponding to $\mathbf{F_{0.1}}$.

A TAC (which might be a by-catch limit in practice) would be set using whichever of these fishing mortalities was lowest. The assessments would be revised as new data became available. Once the procedure has been put into effect the target years for recovery become fixed at 20 and 30 years after the procedure is first put into effect. Thus, the fishing mortalities specified above have to be calculated using shorter projections as time progresses. The fishing mortalities would also be revised as more information accrues about the status of the stock.

2. METHODS AND RESULTS

The underlying process in calculating the probabilities is illustrated in Figure 1. In year 0 an estimate is available of the biomass relative to the average unexploited biomass. Around this point estimate will lie some distribution expressing degrees of belief in alternative values for the estimate. Calculating the subjective probability of the state of the stock at a given time in the future could be done with population projections. Each interval, such as A, B, or C in the probability distribution in the current assessment of the stock, can be projected forward with given values of **F**. However, because recruitment is stochastic, (and also because of uncertainty in the population dynamics) there will be a distribution of final population sizes for each current population size projected forward, shown as A', B' and C'. The probability distribution at year 20 is the sum of the projected distributions, for the set of current stock states in the distribution associated with the current assessment, weighted by their subjective probabilities.

These calculations will most likely have to be carried out numerically, using multiple simulation projections with some parametric or empirical model for generating variability in recruitment. In addition, some form of stock-recruitment model will be required. The starting point for the projections would be the centres of a range of intervals in the distribution of the current stock status. The weight to be applied to the distribution of the projections is the area of the respective starting interval.

A computer program implementing this algorithm has been used to generate some approximate results to illustrate some of the properties of the fishing mortalities defined above. A modified version of the CCAMLR stochastic population projection program (PROJ) was used to set a deterministic initial age-structure for hypothetical fish stocks. The same model was then used with stochastic recruitment for the projections using catches by weight, however, rather than applying fishing mortality. The catches by weight were calculated using the biomass from a deterministic projection (i.e., no recruitment fluctuation) of the median of the current stock assessment. This series of catches was applied for each interval selected from the distribution about the current stock estimate. 100 projections with recruitment fluctuation were made from 20 intervals. Other sources of uncertainty, for example, in the population dynamics parameters such as natural mortality (**M**) and growth rates, could also in principle be taken into account in the assessment and in the stock projections, but this has not been attempted here.

Calculations were made for two hypothetical fish stocks with different levels of production, one relatively high, the other relatively low. The population dynamics parameters for the two stocks are given in Table 1. Two current stock states are examined, one with the population at 30% of average pre-exploitation biomass, and the other at 5%. GNAI is taken to be 50% of the average pre-exploitation biomass. Two stock-recruitment relationships are used, one with the recruitment constant (independent of stock size, denoted C in the table) and the other with recruitment declining linearly to zero for stock sizes less than 50% of the unexploited level (denoted L). These particular forms were chosen because they represent the bounds of the plausible S-R relationships which might apply below GNAI. Stochastic variation in recruitment is drawn from a lognormal distribution with median determined by the S-R relationship and a coefficient of variation of 0.4. The subjective probability distribution of the estimate of the current status of the stock is taken to be normal, with median equal to the true value of the stock assessment. CV's of 0.1 and 0.3 are used for this distribution. This leads to a total of 16 cases, with results shown in Table 2.

The fishing mortalities given in the table are those which would result in

(1) $\mathbf{F_{0.1}}$;

(2) 95% confidence in the stock being above the current level in year 20 (denoted $P_{L,20} > 0.95$ in the table);

(3) 50% confidence in the stock being above GNAI in year 20 (denoted $P_{GNAI,20} = 0.5$ in the table); and

(4) 95% confidence in the stock being above GNAI in year 30 (denoted $P_{GNAI,30} \geq 0.95$ in the table).

There are several points worth noting about the results. In most cases, the fishing mortalities required to meet all of the three criteria relating to projected outcomes in two to three decades are less than $\mathbf{F_{0.1}}$. This has clear significance for applying $\mathbf{F_{0.1}}$ for stocks below GNAI, in that it will not necessarily lead to fulfilment of the basic objective of reversibility in two to three decades. This suggests that an operational definition of depletion for fish stocks would involve the concept that the stock state is such that the application of the normal policy of applying $\mathbf{F_{0.1}}$ will not lead to the stock being restored to at or near GNAI within two to three decades.

In all these cases, the fishing mortality which gives 95% probability of exceeding GNAI is the limiting value. The value is lower for the more uncertain estimate of current stock status. A population recovery level different from GNAI might be selected for this particular criterion in light of the language of Article II 3. (a) which is couched in terms of levels "close to that which ensures" GNAI; the definitions and calculations given here are illustrative. However, the calculations point to the selection of the level to be used in such a criterion as having a significant effect on the level of fishing allowed on recovering stocks.

As might be expected, the S-R relationship plays a major role in determining the critical value of the fishing mortality. A constant S-R relationship is an implausible choice for stocks depleted substantially below GNAI. Where a more suitable form of S-R is unknown it may be appropriate to use the linear model given here, in order to determine fishing mortalities at a likely lower bound with regard to uncertainty in the S-R relationship.

Interestingly, the degree of uncertainty in the estimate of current stock status does not have a great effect on the levels of fishing mortality which would prevent further decline over 20 years or lead to median recovery to GNAI by year 20. However, the 95% probability of being above GNAI by year 30 is sensitive to the degree of uncertainty in the current stock status estimate. This uncertainty would be reduced as further data accrued, and consequent recalculation of the various fishing mortalities could lead to increased TACs at least in cases where the fishing mortality for 95% recovery by year 30 is binding.

The final column in the table shows the median value to which the stocks would be expected to recover under the lowest of the fishing mortalities calculated (i.e., 95% probability of being above GNAI in three decades). In many cases it can be seen that these levels are not greatly above GNAI, and the form of calculation suggests a procedure for selecting target levels for exploited stocks which takes into account uncertainty in estimates of stock status. This would entail managing the stocks by choosing a stock target level so that there is a given level of confidence that the stock will be maintained above GNAI (or other nearby selected value).

3. CONCLUSION AND DISCUSSION

There are important details to sort out regarding methods of estimating the status of the stock with respect to the average pre-exploitation biomass, and in particular, concerning the means of formulating a subjective probability distribution about such estimates. Consideration needs to be given to procedures to be applied in cases where the available data are too sketchy to calculate subjective probability distributions for the current assessment, or to assess variability in recruitment. The routine application of the calculations presented in this paper will require the development of a more sophisticated computer program than that used to make the illustrative calculations here.

The calculation of fishing mortalities which lead to assessments of the subjective probability of a depleted stock being in a state which conforms to the basic objectives of the Convention seems to be a promising line of enquiry for further refinement of the Commission's management policy for finfish stocks. It is shown that the current strategy of applying $\mathbf{F}_{0.1}$ would not always be sufficient to restore depleted populations to the levels envisaged in the Convention. The approach outlined here gives an objective basis for basing scientific advice on fishing mortalities which will be expected to achieve management goals with selected levels of probability. The selection of the probability level to apply is not a purely scientific question, and hence guidance from the Commission will be required. However, this will be most easily obtained if further analyses can be carried out of the merits of these or other suggestions for definitions and procedures, so that the Commission has an objective and quantitative basis for selecting management policy parameters.

ACKNOWLEDGMENT

The authors are indebted to Dr Larry Jacobson and Matt Perchard, the authors of the PROJ simulation program for the calculations presented in this paper.

Table 1: Population parameters used for the two hypothetical fish stocks.

Lower yielding stock		
Natural Mortality	=	0.15 $year^{-1}$
Von Bertalanffy **K**	=	0.12 $year^{-1}$
Von Bertalanffy $\mathbf{W_\infty}$	=	2 500 grams
Age at first fishing	=	5 years (knife-edge)
Age at first spawning	=	5 years (knife-edge)
Pooled age-class	=	20 years
Higher yielding stock		
Natural Mortality	=	0.40 $year^{-1}$
Von Bertalanffy **K**	=	0.20 $year^{-1}$
Von Bertalanffy $\mathbf{W_\infty}$	=	1 000 grams
Age at first fishing	=	3 years (knife-edge)
Age at first spawning	=	3 years (knife-edge)
Pooled age-class	=	10 years

Table 2: Fishing mortality rates consistent with each of the three criteria for managing stocks below the putative level giving greatest net annual increment. (See text for explanation of terms).

S/R	CV	Current Stock	$P_{L,20} > 0.95$	$P_{GNAI,20} = 0.5$	$P_{GNAI,30} \geq 0.95$	Stock at 30 years
			Lower Yielding Stock ($F_{0.1}$ = 0.123)			
C	0.1	0.30	0.210	0.139	0.130	0.63
L	0.1	0.30	0.044	0.041	0.029	0.75
C	0.3	0.30	0.103	0.112	0.074	0.63
L	0.3	0.30	0.012	0.041	0.008	0.92
C	0.1	0.05	0.318	0.106	0.071	0.62
L	0.1	0.05	0.044	0.	0.	0.23
C	0.3	0.05	0.197	0.104	0.067	0.65
L	0.3	0.05	0.011	0.	0.	0.23
			Higher Yielding Stock ($F_{0.1}$ = 0.336)			
C	0.1	0.30	0.304	0.340	0.150	0.69
L	0.1	0.30	0.073	0.117	0.057	0.88
C	0.3	0.30	0.302	0.340	0.150	0.69
L	0.3	0.30	0.032	0.120	0.031	0.94
C	0.1	0.05	>1.0*	0.367	0.150	0.75
L	0.1	0.05	0.087	0.	0.	0.83
C	0.3	0.05	>1.0*	0.355	0.149	0.70
L	0.3	0.05	0.011	0.	0.	0.83

* Approximate values: current version of computer program failed to converge on more accurate solution.

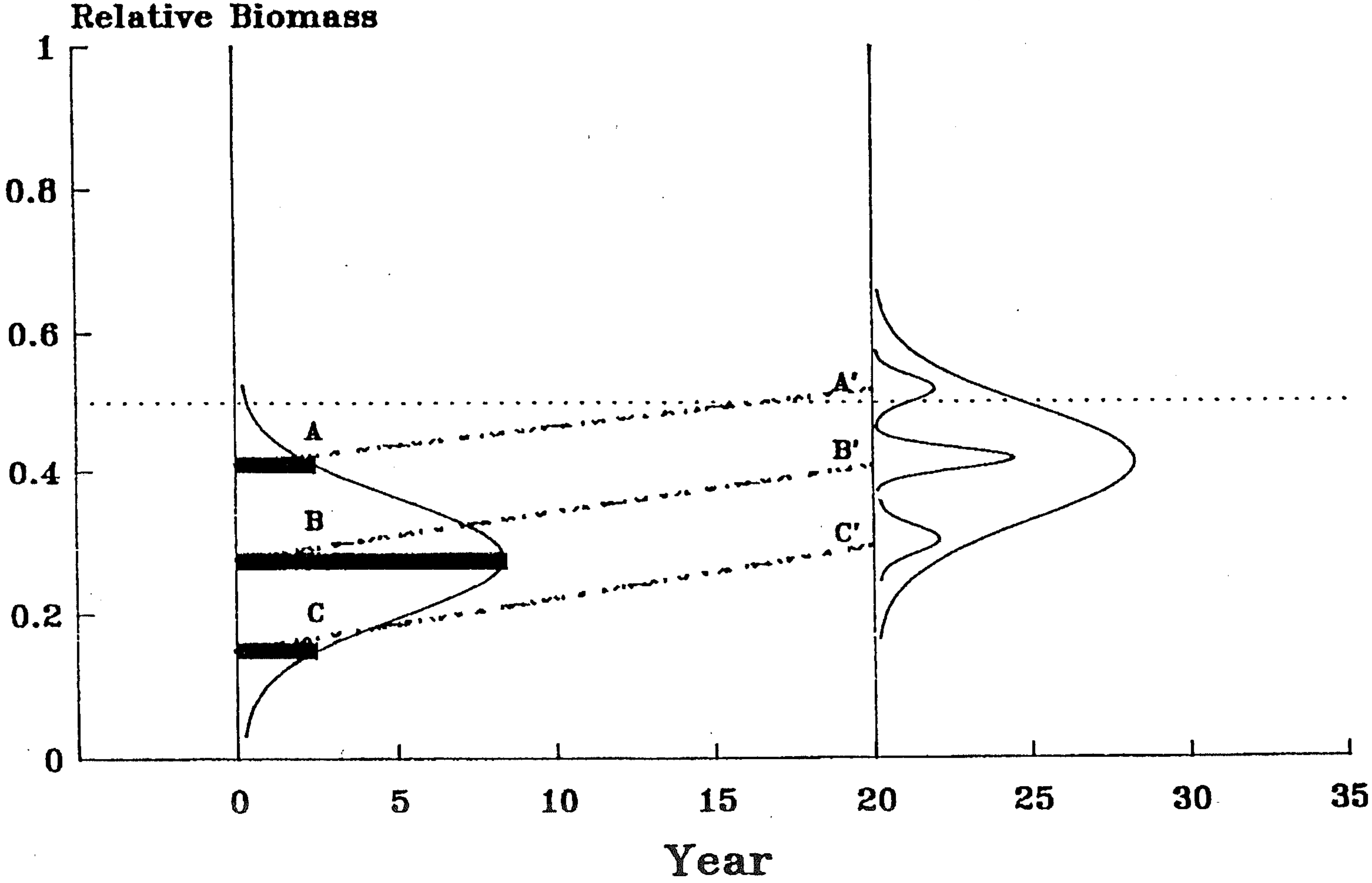


Figure 1: Schematic illustration of the method of calculating subjective probabilities of future states of a fish stock by stochastic forward projection of the subjective probability distribution associated with the current stock assessment.

Liste des tableaux

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

III. CEPHALOPODS

A PRELIMINARY ASSESSMENT OF THE STOCK OF THE OMMASTREPHID SQUID *MARTIALIA HYADESI* IN THE SCOTIA SEA BASED ON DATA FROM PREDATORS*

P.G. Rodhouse**

Abstract

Cephalopod fisheries world-wide mainly target species from two families, Loliginidae and Ommastrephidae. Fisheries for the latter have been characterized by dramatically fluctuating annual catches and frequent switches to exploit new target species. It is likely, therefore, that exploitation of the sub-Antarctic ommastrephid species *Martialia hyadesi* will be attempted in the future. This squid is an important component of the diet of several species of albatross and the southern elephant seal and is probably taken in significant quantities by several other Southern Ocean vertebrate predators. Estimated annual consumption by known predators in the Scotia Sea is 326 098 to 330 642 tonnes, 94% of which is taken by southern elephant seals, and the other species may take at least a further 51 400 tonnes. *M. hyadesi* probably has a life span of two years and a circumpolar distribution, but its biology and ecology are still virtually unknown. Given the commercial potential of the Southern Ocean stock of *M. hyadesi* and its significant role in the diet of some vertebrate predators, the species is clearly important within the context of the aims of CCAMLR and should attract greater research effort in the future.

Résumé

Les pêcheries mondiales des céphalopodes visent principalement des espèces appartenant à deux familles: les Loliginidae et les Ommastrephidae. Les pêcheries de cette dernière ont été caractérisées par des fluctuations spectaculaire des captures annuelles, et des changements fréquents ayant pour but d'exploiter de nouvelles espèces-cibles. L'exploitation de l'espèce ommastréphidée subantarctique *Martialia hyadesi* a donc de fortes chances d'être tentée. Ce calmar est un élément important du régime alimentaire de plusieurs espèces d'albatros et de l'éléphant de mer austral, et il risque d'être ingéré en quantités importantes par plusieurs autres prédateurs vertébrés de l'océan Austral. La consommation annuelle estimée de cette espèce par ses prédateurs connus dans la mer de Scotia est de 326 098 à 330 642 tonnes, dont 94% par les éléphants de mer australs; il se peut également que les autres espèces en consomment au moins encore 51 400 tonnes. Il est probable que *M. hyadesi* ait une espérance de vie de deux ans, et une répartition circumpolaire, mais sa biologie et son écologie restent pratiquement inconnues. Etant donné le potentiel commercial du stock de l'océan Austral de *M. hyadesi* et son rôle significatif dans le régime alimentaire de certains prédateurs vertébrés, il est évident que l'espèce revêt de l'importance dans le contexte des objectifs de la CCAMLR et devrait à l'avenir faire l'objet d'un effort de recherche plus intensif.

---

* This paper, in a revised form will be submitted at the International Symposium on Recent Advances in Cephalod Fishery Biology, Tokai University, Shimizu, Japan in July 1991.

** National Environment Research Council, British Antarctic Survey, Madingley Road, Cambridge, CB3 0ET, UK.

Резюме

Во всех районах мира, где ведется промысел кальмаров, в основном облавливаются кальмары, принадлежащие к семействам Lolignidae и Ommastrephidae. Промысел кальмаров семейства Ommastrephidae характеризуется значительно изменяющимся уровнем годового вылова и частыми переходами на эксплуатацию прочих видов. Таким образом вероятно, что в будущем будут сделаны попытки эксплуатации субантарктического вида *Martialia hyadesi* (сем. Ommastrephidae). Этот вид кальмара является важным элементом рациона нескольких видов альбатроса и южного морского слона и, вероятно, потребляется в значительном объеме прочими позвоночными хищниками Южного океана. Оценка объема, ежегодно потребляемого известными хищниками в море Скотия, составляет 326 098 - 330 642 тонны; 94% этого объема потребляется южным морским слоном, при этом прочие виды могут дополнительно потреблять по меньшей мере 51 400 тонн. Продолжительность жизни кальмара *M. hyadesi* вероятно составляет два года. Этот вид характеризуется циркумполярным распределением. До сих пор практически отсутствуют сведения о его биологии и экологии. Принимая во внимание коммерческий потенциал южноокеанского запаса кальмара *M. hyadesi* и важную роль, которую он играет в рационе некоторых хищных позвоночных, очевидно, что этот вид имеет большое значение для целей АНТКОМа и в будущем его изучение следует расширить.

Resumen

Las pesquerías de cefalópodos mundiales se centran casi exclusivamente en dos familias, Loliginidae y Ommastrephidae. Las pesquerías de esta última especie se han caracterizado por grandes fluctuaciones en las capturas anuales y por frecuentes cambios en la explotación de nuevas especies-objetivo. Existe pues la posibilidad de que, en el futuro, se intente explotar la especie subantártica del omastréfido *Martialia hyadesi*. Esta forma parte importante de la dieta de varias especies de albatros y del elefante marino del sur, y posiblemente otros vertebrados del océano Austral lo consumen también en cantidades importantes. Se ha estimado que los depredadores conocidos del mar de Scotia consumen anualmente entre 326 098 - 330 642 toneladas, de las cuales un 94% corresponde a las focas elefante, y es posible que las demás especies consuman otras 51 400 toneladas. Se cree que la longevidad de *M. hyadesi* es de dos años y que tiene una distribución circumpolar, pero de su biología y ecología apenas si se conoce nada. El posible interés comercial de la población de *M. hyadesi* del océano Austral y su importancia en la dieta de algunos depredadores vertebrados, coloca a esta especie dentro del contexto de objetivos de la CCRVMA y debería ser objeto de investigaciones futuras.

IV. ECOSYSTEM MONITORING

THE GENTOO PENGUIN AS A CANDIDATE SPECIES FOR THE CCAMLR ECOSYSTEM MONITORING PROGRAM

J.P. Croxall and T.D. Williams*

Abstract

Based on dietary and other biological information collected over several years at Bird Island, South Georgia and at the South Shetland Islands (both within Integrated Study Regions (ISRs) of the CCAMLR Ecosystem Monitoring Program), we suggest (and provide a full bibliography of supporting literature) that the gentoo penguin meets the specified criteria qualifying species for inclusion in the CEMP. The extensive dependence of this species in these ISRs on *Euphausia superba*, (including in winter), its residence in the ISRs in winter and its early attainment of sexual maturity are all features of special relevance to the CEMP.

Résumé

Les informations portant sur le régime alimentaire et la biologie, collectées sur plusieurs années à l'île Bird, en Géorgie du Sud, et aux îles Shetland du Sud (toutes deux dans les zones d'étude intégrée (ISR) du programme de contrôle de l'écosystème de la CCAMLR), nous amènent à suggérer (en présentant la bibliographie complète de la littérature de support) que le manchot papou répond aux critères spécifiés de sélection des espèces à inclure au CEMP. Le fait que cette espèce dépende largement d'*Euphausia superba* dans ces ISR (même en hiver), sa présence dans les ISR en hiver et sa maturité sexuelle précoce présentent un intérêt particulier pour le CEMP.

Резюме

На основании данных по рациону и других биологических данных, собранных в течение нескольких лет на острове Берд, Южная Георгия, и Южных Оркнейских островах (оба участка находятся в пределах Районов комплексных исследований по Программе АНТКОМа по мониторингу экосистемы), мы предполагаем (и представляем полный список справочной литературы), что папуасский пингвин отвечает всем необходимым критериям включения видов в Программу СЕМР. Большая зависимость этого вида от *Euphausia superba* в данных районах комплексных исследований, (включая зимний период), обитание этого вида в Районах комплексных исследований в зимний период и раннее достижение этим видом половой зрелости - все это свидетельствует о его причастности к Программе СЕМР.

* British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

Resumen

Basándose en la información dietética y biológica recopilada durante varios años en la isla de los Pájaros, Georgia del Sur y en el archipiélago de Shetlands del Sur (ambas localidades están dentro de las Regiones de Estudio Integrados (ISRs)) del Programa de Seguimiento del Ecosistema de la CCRVMA), sugerimos que el pingüino papúa satisface el criterio especificado que califica a las especies para ser incluidas en el CEMP. La elevada dependencia de esta especie de *Euphausia superba* en estas ISRs, incluso en invierno, su residencia en las ISRs durante el invierno y su madurez sexual precoz, son todas características de especial importancia para el CEMP.

1. INTRODUCTION

At the 1985 Meeting of the (*ad hoc*) CCAMLR Working Group on Ecosystem Monitoring, the criteria used to select predator species thought to be best suited for ecosystem monitoring were defined as:

(i) specialist predators on the critical prey components identified;
(ii) wide geographic distribution;
(iii) importance in the ecosystem;
(iv) feasibility of study (ease to approach, handle, observe);
(v) knowledge of general biology; and
(vi) availability of baseline data at one or more sites.

On this basis, the following species were selected as those most likely to be useful as indicators of changes in krill availability:

- crabeater seal;
- Antarctic fur seal;
- Adélie penguin;
- chinstrap penguin;
- macaroni penguin; and
- minke whale.

At the 1986 Meeting, Antarctic petrel and black-browed albatross were added. This was done despite the fact that the Antarctic petrel did not adequately meet criteria (i) - few published dietary data; krill certainly not the only significant prey, (v) - breeding biology largely unknown, or (vi) - no baseline data available; and that the black-browed albatross did not adequately meet criteria (i) - krill probably not main diet, except for South Georgia, with fish and squid also important, or (ii) - only in sub-Antarctic.

There are probably several additional species which meet the specified criteria better than the Antarctic petrel and black-browed albatross; pre-eminent amongst these is the gentoo penguin.

2. PROPOSAL

We suggest that the gentoo penguin more than adequately meets the CCAMLR criteria, expecially in relation to the South Georgia and Antarctic Peninsula Integrated Study Regions, and recommend that it should be incorporated into the CCAMLR Ecosystem monitoring Program (CEMP) as soon as appropriate standard methods and methods sheets can be prepared.

3. FULFILMENT OF CRITERIA

3.1 Specialist Predator on Harvestable Prey

In seven seasons (and over 300 samples) of investigating summer diet, of adults feeding crèched chicks, at South Georgia, Antarctic krill (*Euphausia superba*) has averaged 71% by weight of the diet (Croxall *et al.*, 1988a and unpublished data). During the incubation and brooding periods, krill is an even more important component (95%+) of the diet (Williams, unpublished data). Only in one year (1985) did the proportion of *E. superba* fall below 65%. During the winters of 1987 and 1988, *E. superba* was also the main component (c. 90%) of the diet at South Georgia (Williams, in press). Similarly, at the South Shetland Islands, studies over several summers have confirmed that krill is the main (70%+) component of the diet (Jablonski, 1985; Trivelpiece *et al.*, 1987). In both localities, the rest of the diet is almost entirely fish. In most studies, certain individual penguins appear to feed chiefly on fish, at least during single foraging trips (Jablonski, 1985; Croxall *et al.*, 1988b).

At Marion Island and Macquarie Island, *E. superba* does not occur in gentoo penguin diets. In the chick-rearing season, several species of fish, *Euphausia valentinii* and *Nauticaris marionis* are the main prey at Marion Island (LaCock *et al.*, 1984; Adams and Klages, 1989) and fish and *E. valentinii* at Macquarie Island (Hindell, 1989).

3.2 Geographical Distribution

Gentoo penguins are widely distributed at sub-Antarctic islands and on the Antarctic Peninsula breed south to 65°S. They are absent from the Antarctic Continent.

3.3 Importance (in terms of prey consumption) to the Southern Ocean System

Gentoo penguins have the second smallest total breeding population (270 000 pairs) and the lowest estimated total biomass (3 160 tonnes) of any Southern Ocean penguin (Woehler, in press). However, there are substantial breeding populations in the South Georgia and Antarctic Peninsula Study Regions (a minimum of 80 000 to 100 000 pairs and c. 50 000 pairs respectively: Woehler, in press). Because the species is resident, these populations are likely to consume significant quantities of krill each year within the Integrated Study Regions.

3.4 Feasibility of Study

At South Georgia and the South Shetland Islands, gentoo penguins are an easy species to work with. (At Indian Ocean islands, they are much more wary and difficult to observe and handle.) Being the largest of the pygoscelid penguins, they are particularly suitable for the deployment of recording and transmitting instruments.

3.5 Knowledge of General Biology

Gentoo penguins have been quite extensively studied. The major (multi-year) studies of general breeding biology are: Trivelpiece *et al.* (1987) at the South Shetland Islands, Williams (1990) at South Georgia and Bost and Jouventin (in press) at the Crozet Islands; smaller-scale studies have been conducted at Marion Island (Williams, 1980) and Macquarie Island

(Robertson, 1986). Diet and foraging ecology have been studied at South Georgia (Croxall and Prince, 1980; Croxall *et al.*, 1988a and 1988b; Williams, in press; Williams and Rothery, in press), the South Shetland Islands (Volkman *et al.*, 1980 and unpublished; Jablonksi, 1985; Trivelpiece *et al.*, 1986), Marion Island (LaCock *et al.*, 1984; Adams and Wilson, 1987; Adams and Klages, 1989) and Macquarie Island (Robertson *et al.*; 1988, Hindell, 1989). Chick growth has been studied at South Georgia (Williams and Croxall, in press a, b), the South Orkney Islands (Despin, 1977) and the South Shetland Islands (Volkman and Trivelpiece, 1980).

3.6 Availability of Baseline Data

Data on breeding population size and breeding success are available annually since 1976 at Bird Island, South Georgia (Croxall *et al.*, 1988a; Williams, 1990), and in most years since 1976 at King George Island, South Shetland Islands (Trivelpiece *et al.*, 1987). For other sites within the Antarctic Peninsula Integrated Study Region, there are accurate counts of breeding populations, often dating back to the 1950s (Croxall and Kirkwood, 1979; Jablonski, 1984; Woehler, in press). Some baseline data also exist for Marion Island, the Crozet Islands, Heard Island and Macquarie Island (Wilson, 1983). The sections above on diet and general biology indicate that multi-year data are available for South Georgia and the South Shetland Islands for many other aspects of direct relevance to CCAMLR selected parameters (e.g., chick diet, foraging trip duration, demography).

4. ADDITIONAL CONSIDERATIONS

4.1 Resident Species

Gentoo penguins remain in the vicinity of their breeding colonies year-round and come ashore frequently during the non-breeding season (Williams, in press). There are few, if any, CEMP species which are readily accessible on land throughout the year.

4.2 Early Sexual Maturity

With typical ages of first breeding being at two and three years old (Williams, 1990), gentoo penguins have the shortest period of immaturity known in penguins. This minimizes the time over which parameters such as survival from fledging to breeding are calculated and thus improve the likely accuracy of such results. The short generation time also increases the likelihood of populations showing rapid and marked responses to environmental change.

REFERENCES

ADAMS, N.J. and N.T. KLAGES. 1989. Temporal variation in the diet of the gentoo penguin *Pygoscelis papua* at sub-Antarctic Marion Island. *Colonial Waterbirds 12*: 30-36.

ADAMS, N.J. and M.-P. WILSON. 1987. Foraging parameters of gentoo penguins *Pygoscelis papua*, at Marion Island. *Polar Biology 7*: 51-56.

BOST, C.A. and P. JOUVENTIN. In press. The breeding biology of the gentoo penguin on the Crozet Islands. *Ibis*.

CROXALL, J.P. and E.D. KIRKWOOD. 1979. *The Distribution of Penguins on the Antarctic Peninsula and Islands of the Scotia Sea.* Cambridge: British Antarctic Survey.

CROXALL, J.P. and P.A. PRINCE. 1980. The food of gentoo penguins *Pygoscelis papua*, and macaroni penguins *Eudyptes chrysolophus*, at South Georgia. *Ibis 122*: 245-253.

CROXALL, J.P., R.W. DAVIS and M.J. O'CONNELL. 1988b. Diving patterns in relation to diet of gentoo and macaroni penguins at South Georgia. *Condor 90*: 157-167.

CROXALL, J.P. T.S. MCCANN, P.A. PRINCE and P. ROTHERY. 1988a. Reproductive performance of seabirds and seals at South Georgia and Signy Island: Implications for Southern Ocean monitoring studies. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Berlin: Springer-Verlag. pp. 261-285.

DESPIN, B. 1977. Croissances comparées des poussins chez les manchot du genre *Pygoscelis*. *Comptes Rendus Hebdomadaire des Seances de l'Académie des Sciences, Paris (Série, D)* 285: 1135-1137.

HINDELL, M.A. 1989. The diet of gentoo penguins *Pygoscelis papua* at Macquarie Island: winter and early breeding season. *Emu 89*: 71-78.

JABLONSKI, B. 1984. Distribution and numbers of penguins in the region of King George Island, South Shetland Islands in the breeding season 1980/81. *Polish Polar Research 5*: 17-30.

JABLONSKI, B. 1985. The diet of penguins on King George Island, South Shetland Islands. *Acta Zoologica Cracov 29*: 117-186.

LACOCK, G.D., T. HECHT and N. KLAGES. 1984. The winter diet of gentoo penguins at Marion Island. *Ostrich 55*: 188-191.

ROBERTSON, G. 1986. Population rise and breeding success of the gentoo penguin *Pygoscelis papua* at Macquarie Island. *Australian Wildlife Research 13*: 583-587.

ROBERTSON, G., B. GREEN and K. NEWGRAIN. 1988. Estimated feeding rates and energy requirements of gentoo penguins, *Pygoscelis papua*, at Macquarie Island. *Polar Biology 9*: 89-93.

TRIVELPIECE, W.Z., J.L. BENGTSON, S.G. TRIVELPIECE and N.J. VOLKMAN. 1986. Foraging behaviour of gentoo and chinstrap penguins as determined by new radio-telemetry techniques. *Auk 103*: 777-781.

TRIVELPIECE, W.Z., S.G. TRIVELPIECE and N.J. VOLKMAN. 1987. Ecological segregation of Adélie, gentoo and chinstrap penguins at King George Island, Antarctica. *Ecology 68*: 351-361.

VOLKMAN, N.J. and W.Z. TRIVELPIECE. 1980. Growth in pygoscelid penguin chicks. *Journal of Zoology, London, 191*: 521-530.

VOLKMAN, N.J., P. PRESLER and W. TRIVELPIECE. 1980. Diets of pygoscelid penguins of King George Island, Antarctica. *Condor 82*: 373-378.

WILLIAMS, A.J. 1980. Aspects of the breeding biology of the gentoo penguin, *Pygoscelis papua*. *Gerfaut 70*: 283-295.

WILLIAMS, T.D. 1990. Annual variation in breeding biology of gentoo penguins *Pygoscelis papua* at Bird Island, South Georgia. *Journal of Zoology, London.*

WILLIAMS, T.D. In press. Winter diet of gentoo penguins *Pygoscelis papua* at South Georgia: an assessment of winter krill consumption. *Ibis*.

WILLIAMS, T.D. and J.P. CROXALL. In press (a). Is chick fledging weight a good index of food availability in seabird populations? *Oikos.*

WILLIAMS, T.D. and J.P. CROXALL. In press (b). Chick growth and survival in gentoo penguins *Pygoscelis papua*: the importance of hatching asynchrony and variation in food supply. *Polar Biology.*

WILLIAMS, T.D. and P. ROTHERY. In press. Factors affecting variation in foraging and activity patterns of gentoo penguins *Pygoscelis papua* during the breeding season at Bird Island, South Georgia. *Journal of Applied Ecology.*

WILSON, G.T. (Ed.). 1983. *Distribution and Abundance of Antarctic and Sub-Antarctic Penguins: A Synthesis of Current Knowledge.* Cambridge: SCAR.

WOEHLER, E.J. (Ed.). In press. The Distribution and Abundance of Antarctic and Sub-Antarctic Penguins. Cambridge: SCAR.

SC-CAMLR-IX/BG/16

FOOD CONSUMPTION BY PREDATORS IN A CCAMLR INTEGRATED STUDY REGION

J.P. Croxall*, C. Ricketts** and A.G. Wood*

Abstract

A detailed description of the structure and mode of operation of a model for estimating food consumption of seabird predators is provided. This model is a development of earlier ones used in the South Georgia Integrated Study Region and incorporates new features, allowing for seasonal variation in predator weight (and hence energy requirements), diet composition and prey energy content. Specimen outputs are provided, illustrating the changes produced by using these new sub-models. Results of initial sensitivity analyses indicate particular sensitivity to estimation of metabolic energy requirements. The system is directly applicable also to fur seals and could be modified to incorporate phocid seal data, when available. Prey categories are readily modifiable to sub-divide krill into sexes and maturity stages. With existing empirical data on breeding population size, diet, activity-specific energy requirements and foraging ranges, it is possible to make realistic estimates of krill consumption of penguins and fur seals during their breeding seasons within specified areas.

Résumé

Sont décrits en détail la structure et le mode de fonctionnement d'un modèle destiné à évaluer la consommation de nourriture des oiseaux de mer prédateurs. Ce modèle a été élaboré sur des modèles antérieurs utilisés dans la zone d'étude intégrée de la Géorgie du Sud; de nouvelles caractéristiques qui tiennent compte de la variation saisonnière du poids des prédateurs (et donc des besoins en énergie), de la composition du régime alimentaire et de la teneur en énergie des proies, s'y trouvent incorporées. Les résultats fournis de l'étude des spécimens illustrent les changements produits par l'utilisation de ces nouveaux sous-modèles. Les résultats des premières analyses de sensibilité indiquent une sensibilité particulière à l'estimation des besoins en énergie métabolique. Ce système peut également être appliqué directement aux otaries et pourrait être modifié pour incorporer des données sur les phoques de la famille des Phocidae, lorsque celles-ci sont disponibles. Les catégories de proies peuvent être modifiées à tout moment pour subdiviser le krill par sexe et stades de maturité. A partir des données empiriques sur la taille de la population reproductrice, le régime alimentaire, les besoins en énergie selon les activités et les secteurs d'alimentation, il est possible de faire des estimations réalistes de la consommation de krill par les manchots et les otaries au cours de leur saison de reproduction dans des régions précises.

* British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

** Department of Mathematics and Statistics, Polytechnic Southwest, Drake Circus, Plymouth, Devon PL4 8AA, UK

Резюме

В настоящей работе приводится подробное описание структуры и принципа работы модели оценки потребления пищи хищными морскими птицами. Данная модель является усовершенствованным вариантом моделей, применявшихся ранее для Района комплексных исследований на Южной Георгии, и включает новые характеристики, позволяющие учитывать сезонную изменчивость веса особей хищников (и следовательно энергетических потребностей), состав рациона и калорийность потребляемых видов. Приводятся данные по отдельным особям, иллюстрирующие изменения, вызванные использованием этих новых подмоделей. Результаты исходного анализа чувствительности свидетельствуют об особенной чувствительности модели к оценке энергетических потребностей, необходимых для метаболизма. Данная система непосредственно применима и для исследования морских котиков, а также может быть модифицирована с целью включения данных по настоящим тюленям по поступлении таких данных. Категории параметров потребляемых видов легко изменимы и позволяют классифицировать криль по половой принадлежности и стадиям половозрелости. На основании имеющихся эмпирических данных по размеру размножающейся части популяции, рациону, энергетическим потребностям при различных типах активности и нагульным ареалам можно достоверно оценить потребление криля пингвинами и морскими котиками в течение периодов размножения в пределах отдельных районов.

Resumen

Se proporciona una descripción detallada de la estructura y modo de operación de un modelo diseñado para estimar el consumo de alimento de las aves depredadoras. Este modelo es una modificación de los previos modelos empleados en la Región de Estudio Integrado de Georgia del Sur e incorpora nuevas características, teniendo en cuenta la variación estacional en el peso del depredador (y por lo tanto el consumo de energía), la composición de la dieta y el contenido de energía de la especie presa. Se indican los resultados en los especímenes, que ilustran los cambios que se producen al emplear estos nuevos submodelos. Los resultados de los análisis iniciales de sensibilidad muestran una sensibilidad especial en la estimación de los requisitos de energía metabólicos. El sistema se puede aplicar directamente a los lobos finos antárticos y podría modificarse para incluir información sobre focas de la familia phocidae, cuando estuviese disponible. Las categorías de especies presa se pueden modificar facilmente para subdividir el krill por sexo y etapas de madurez. La información empírica actual sobre el tamaño de la población reproductora, dieta, el consumo de energía relacionado con actividades específicas y los rangos de alimentación, permite hacer estimaciones razonables sobre el consumo de krill de los pingüinos y los lobos finos antárticos durante sus temporadas de reproducción dentro de las áreas designadas.

1. INTRODUCTION

At SC-CAMLR-VIII requests by the Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP) for Members to synthesize data on predator population size, diet and energy budgets in order to provide estimates of krill requirements of predators in Integrated Study Regions, at least during their breeding seasons, were endorsed by the Scientific Committee (SC-CAMLR-VIII, paragraph 5.26).

The difficulties of doing these, however, were also recognized and discussion with Members and other appropriate specialists on how best to proceed towards this goal was advised (SC-CAMLR-VIII, paragraph 5.28).

This paper summarizes current progress towards these goals, in respect of the South Georgia Integrated Study Region, by the United Kingdom. This is a development of earlier work (Croxall *et al.*, 1984; Croxall and Prince, 1987), already made available to CCAMLR (SC-CAMLR-VIII/BG/12, SC-CAMLR-VIII/BG/15).

2. CONTENTS

The present paper comprises:

Part 1:
A description of the content, mode of operation and data input format of the current version of the system for estimating food consumption of breeding populations of South Georgia seabirds.

Part 2:
(a) Some selected outputs obtained from using this system, chiefly featuring results of incorporating new sub-models allowing for seasonal variation in predator weight, diet composition and prey energy content.

(b) Results of some initial sensitivity analyses.

(c) Comments on the potential applicability of the system to other predators.

(d) Comments on the potential application of the system to more detailed analyses of particular prey, e.g. krill.

PART 1: A COMPUTER PROGRAM FOR THE ASSESSMENT OF THE IMPACT OF SEABIRDS ON MARINE RESOURCES AROUND SOUTH GEORGIA

GUIDE TO THE SYSTEM

1. INTRODUCTION

The original version of this program was developed in 1982 and 1983 by Dr C. Ricketts at British Antarctic Survey (BAS), in conjunction with Dr J.P. Croxall and Mr P.A. Prince. The program was written in FORTRAN IV and implemented on the IBM 360 at Cambridge University. The program formed the basis of two papers, one referring solely to seabirds at South Georgia (Croxall *et al.*, 1984) and the other extending to seabirds and seals in the Scotia Sea (Croxall *et al.*, 1985). Unfortunately, the working version of the program was lost when BAS moved its computing away from Cambridge University. The lost program will be referred to as Version 1.0.

In 1990 there was a renewed interest in assessing the impact of seabirds on marine resources around South Georgia, partly driven by the needs of CCAMLR and partly by the Government of South Georgia and the South Sandwich Islands (GSGSSI) to develop a management and licensing strategy for finfish and krill in the South Georgia area. Version 1.0 of the program was restored to the BAS VAX computer and the PRIME computer at Polytechnic South West (PSW) from old printouts of the program source held by Dr C. Ricketts. During this process the program was updated to FORTRAN-77 and modified to include myctophids as a separate prey item and to allow the inclusion of non-breeding components of the population. The graphics output using the Cambridge University CAMPLOT routines were not implemented on the PRIME at PSW: this version of the program is referred to as Version 2.0. The graphics capability was transformed from the Cambridge University CAMPLOT system to the NERC GRAFIX system on the BAS VAX computer by Dr A.G. Wood. This version will be referred to as Version 2.10.

Subsequent developments have included:

Version 3.10:	The program can allow for seasonal variation in the calorific value of all prey items.
Version 3.20	The program can allow for seasonal variation in the composition of the diet of predators.
Version 3.30	The program can allow for seasonal variation in the body weight of predators; this is the current version.

The program will be enhanced by Dr A.G. Wood to use FORTRAN graphics from UNIRAS, probably late in 1990. This will be Version 3.40.

2. DATA PREPARATION

For all data input to the program the time-base used 1 September as day number 1.

The data preparation format for the predator data is given in Appendix 1. Note that provided that the relevant data can be manipulated into the correct form, the use of the program is not restricted to seabirds alone, but may include other predators such as seals.

The data which gives the seasonal variation in calorific value of the prey items must be held in separate files for each prey type as they are common to all predator species. The file names are prescribed and must be:

EUPHAUSI . CAL
CEPHALOP . CAL
MYCTOPHI . CAL
OTHRFISH . CAL
COPEPODS . CAL
AMPHIPOD . CAL
OTHRCUS . CAL
ODDSNSOD . CAL

Any of these files may be included as necessary; if any file does not exist then the calorific value of that prey item will be assumed constant. Within each file the data is a series of day numbers and calorific values. Only one day and calorific value may be on any line, and its is sufficient to separate the calorific value from the day number by a space. The first day number must be 1 and the last must be 365; there must be at least three lines of data. The calorific value on each day will be calculated within the program by linear interpolation. An example is given in Appendix 2.

Note that although the names within the program refer to Euphausiids, Cephalopods, etc., the use of the program is not restricted to these prey items. The eight prey items could, for example, be different maturity stages of krill: the calculations would then be appropriate to these stages of krill - only the names would be wrong! Changing the headings for output is a fairly trivial task.

3. USING THE PROGRAM

The program is presently held on the VAX computer at BAS. Potential users should contact Dr A.G. Wood who will advise them on the correct way of starting the program.

The program asks the user for two file names, some dates (again day 1 is 1 September) and the type of graphical output required. Note that the data files may be held in any directory provided that the user gives the complete file name.

4. OUTPUT FROM THE PROGRAM

The program produces both printed output and graphs of the pattern of resource utilization in either space or time.

The printed output comprises a list of all prey consumed by each component (male, female, non-breeder) of each predator species together with a grand total for the whole community of predators. The output also includes the daily impact of the community on each prey category between the dates specified by the user (again day 1 is 1 September). Between these dates the program also produces a weekly distribution of foraging impact in relation to distance offshore for those birds rearing chicks.

The graphical output provides either the distribution of the predation on each day throughout the year, or distribution of the impact of predators rearing chicks by distance offshore, or both. Examples are given in Appendix 3.

5. METHODS OF CALCULATION

The methods of calculation used in Version 1.0 were described in Croxall *et al.* (1985). For the sake of completeness (and to correct a few typographical errors!) the details are repeated here, together with details of the enhancements made to the program.

To estimate the food consumption of a seabird community throughout the year requires knowledge of the population size, dietary composition and energy requirement on each day of the year for each species in the community. Because the sizes, activity patterns and hence energy requirements of males, females and non-breeders may differ, the food consumption of each component needs to be assessed separately. Moreover, although most species complete one breeding cycle in one year, wandering, grey-headed and light-mantled sooty albatrosses breed biennially (when successful in rearing a chick) and have cycles lasting two years. The king penguin typically has two breeding attempts in three years at South Georgia. Thus the estimation procedure is based on an activity cycle which can be one, two or three years long within which there may be two breeding attempts. Here we illustrate the estimation process for a species which breeds annually; the extension to more complicated activity cycles is straightforward.

5.1 Population Size

On each day throughout the year the breeding population is divided into active breeders and failed breeders. The total breeding population **P** is divided in $\mathbf{P_1}$ **(i)** active breeders and $\mathbf{P_2}$ **(i)** failed breeders on day **i**. The number of active breeders is calculated from the rate of egg loss between the laying date (day 1) and the hatching data (day h) and the rate of chick loss between hatching and fledging date (day f). Both egg loss and chick loss are assumed to be exponential at rates $\mathbf{k_1}$ and $\mathbf{k_2}$ respectively. Thus the populations on day **i** are given by:

before laying:	$P_1 (i) = P$	$1 \leq i \leq 1$
laying to hatching:	$P_1 (i) = P_1 (l) \exp(-k (i-1))$	$1 < i \leq h$
hatching to fledging:	$P_1 (i) = P_1 (h) \exp(-k (i-h))$	$h < i \leq f$
after fledging:	$P_1 (i) = P$	$f < i \leq 365$
always:	$P_2 (i) = P - P_1 (i)$	$1 \leq i \leq 365$

5.2 Dietary Composition and Energy Content

Here we specify the dietary composition of each species as the proportion by weight of each of eight different food types. These are krill, copepod, amphipod, other crustaceans, myctophid, other fish, squid and "other". Only free-living marine prey are considered; the carrion element, which is only important in the diets of giant petrels, is ignored.

We denote the proportion of the diet of food type **k** on day **i** by **d(i,k)**. Dietary composition is assumed to change in a step-wise manner according to the data input. The dietary composition is also assumed to vary over a one-year period, irrespective of the number of years in the predator's activity cycle: diet is more likely to be determined by seasonal changes in prey availability than activity-dependent prey selection by the predator.

Default values for the energetic content of prey (**kJ** $\mathbf{g^{-1}}$) are specified as constants in the program: krill and all other crustaceans, 4.35; myctophids, 10.0; fish, 3.97; and, squid, 3.47. Otherwise the seasonal pattern of energy content is interpolated from the values given in the appropriate calorific value file (see Part 2 and Appendix 2). The energy content of each food type is assumed to be the same for each predator species. We denote the energy content of food type **k** on day **i** by **c(i,k)**. The mean energy content of the diet on day **i** is then

$$\Gamma_i = \sum_{k=1}^{8} c(i,k)d(i,k) \quad \text{kJ g}^{-1}$$

5.3 Activity Patterns

For simplicity, we assume that all members of each component of a species are performing the same activity on any one day and that they do it for the same (mean) length of time, while allowing for differences in activity between active breeders, failed breeders and non-breeders. Thus, changes from one activity to another are treated in a step-wise manner according to the data input. We have arbitrarily divided a bird's activity pattern into seven categories: absent from the population, attending at the nest site, incubating, brooding, feeding chick, foraging for self and moulting (penguins only). Failed breeders are assumed to forage for themselves only. Non-breeders may not incubate, brood nor feed chicks.

5.4 Energetic Costs

The energetic cost of each activity may be specified either as an equation of the form

$$E = aW_i^b$$

where W_i is the body weight on day **i**, or as a constant. The source of equation or constant is left to the user and may vary between species.

The energetic cost of foraging for a chick is calculated as the sum of the cost of foraging for self plus the energy content of the food delivered to the chick. Thus if **g(c)** is the daily energetic cost of feeding a chick, **g(s)** is the cost of foraging for self and **M** (grams) of food is delivered to the nest at frequency Φ (deliveries per adult per day) then

$$g(c) = g(s) + M\Gamma_i\Phi \quad \text{kJ d}^{-1}$$

where Γ_i is the energetic content of the meal on day **i**.

5.5 Food Requirements

If the energy cost of the j-th activity is denoted by **g(j)**, the total food required to fulfil activity **j** on day **i** is

$$F(j) = g(j)/\Gamma_i \quad \text{g d}^{-1}$$

The total food requirements of the population performing activity **j** on day **i** is then

$$C(i) = P_1(i)F(j) + P_2(i)F(s) \quad \text{grams}$$

where **F(s)** is food required when foraging for self. The amount of food of type **k** required on day **i** is C(i)d(k).

The food required between days t_1 and t_2 is simply

$$\sum_{i=t_1}^{t_2} C(i), \text{ or, for food type k } \quad \sum_{i=t_1}^{t_2} C(i)d(k).$$

5.6 Foraging Range

The potential mean maximum (i.e., greatest distance using mean values of parameters) foraging range of a species during the chick rearing period is calculated from the travel speed (corrected for indirect (zigzag) flight pattern), the time between feeds and proportion of that time spent on activities other than travelling (e.g., feeding or resting). If the travel speed is $\mathbf{v}$ **m** $\mathbf{s^{-1}}$ and proportion of the trip spent not travelling is τ then the maximum range is $86.4\, v(1-\tau)/2\Phi$ where again Φ is the feeding frequency: the factor 86.4 converts travel speed from **m** $\mathbf{s^{-1}}$ to **km** $\mathbf{d^{-1}}$ and the factor 2 corrects for outward and return journeys. If $\mathbf{z}$ is the correction factor for indirect flight, that is the distance flown to achieve a unit distance forward, then the corrected foraging range is

$$R = 86.4\, v\, (1-\tau)/2z\Phi \quad \text{km.}$$

5.7 Distribution of Foraging Effort and of Food Taken

For birds rearing chicks, the data on mean flight speeds, flight pattern and the time spent travelling between deliveries of food to the nest define a mean maximum foraging range.

We then classify each species as feeding primarily inshore, primarily offshore, or neither (and potentially intermediate). We assume that these intermediate species forage uniformly out to maximum range (**R**). For such species the proportion of foraging effort expended between $\mathbf{r_1}$ and $\mathbf{r_2}$ km offshore is then

$$f(r_1,r_2) = (r_2-r_1)/R \qquad 0 \le r_1 < r_2 \le R$$

$$f(r_1,r_2) = 0 \qquad R \le r_1 < r_2$$

For species which forage primarily inshore we assume that the foraging effort at the inshore end of the range is 10 times that for uniform foragers and declines exponentially over the range so that the total foraging effort remains unity. The foraging effort between distances r_1 and r_2 offshore is then

$$f(r_1,r_2) = \int_{r_1}^{r_2} (10/R) \exp(-10r/R)\, dr$$

$$= \exp(-10r_1/R) - \exp(-10r_2/R) \qquad 0 \le r_1 < r_2 < R$$

$$f(r_1,r_2) = \exp(-10r_1/R) \qquad 0 \le r_1 < r = R$$

$$f(r_1,r_2) = 0 \qquad R \le r_1 < r_2$$

This is based on the premise that inshore feeders attempt to satisfy their requirements as close to the breeding site as possible, only foraging further afield when unable to do so.

Species which forage primarily offshore are treated as the mirror image, over their range, of inshore feeders. We assume that offshore species usually travel to feeding grounds at or near their mean maximum range and only if they then fail to find food in this area do they forage closer to home.

Within the chick rearing period, that is from day **h** to day **f**, the amount of food taken on day **i** in the range $\mathbf{r_1}$ to $\mathbf{r_2}$ km offshore is

$$D(i,r_1,r_2) = C(i)f(r_1,r_2)$$

5.8 Community Food Requirements and Distribution

The food requirements of the multi-species seabird community on day **i** are calculated by summing the values of **C(i)** over all species. Similarly, the amount of food of type **k** taken on day **i** is the sum of the values of **C(i)d(k)** over all species. The distribution of the food taken by birds feeding chicks on day **i**, between $\mathbf{r_1}$ and $\mathbf{r_2}$ km offshore is the sum of the $\mathbf{D(i,r_1,r_2)}$ over all species rearing chicks on that day.

REFERENCES

CROXALL, J.P., P.A. PRINCE and C. RICKETTS. 1984. Impact of seabirds on marine resources, especially krill, of South Georgia waters. In: WHITTOW, G.C., and H. RAHN (Eds). *Seabird Energetics*. New York: Plenum. pp. 285-317.

CROXALL, J.P., P.A. PRINCE and C. RICKETTS. 1985. Relationships between prey life cycles and the extent, nature and timing of seal and seabird predation in the Scotia Sea. In: SIEGFRIED, W.R., P.R. CONDY and R.M. LAWS (Eds). *Antarctic Nutrient Cycles and Food Webs*. Berlin and Heidelberg: Springer-Verlag. pp. 137-146.

SOUTH GEORGIA SEABIRD IMPACT ASSESSMENT
DATA INPUT FORMAT

Each species is divided into two sexes whose data are entered separately to allow for sex differences in activity, diet and energy costs. Non-breeding populations can also be included. The various data types are entered on several different types of lines and allowance is made for future expansion. Although the output pertains only to one twelve-month period (starting 1 September) each species may have an activity cycle lasting up to three years, containing up to two breeding periods. Each data line is preceded by a line with a number typed in the first two columns indicating the type of data to follow. The data lines have columns 1 and 2 left blank. An example is follows.

Data Line 01

This contains the basic data for one component of one species: population size, length of activity cycle and number of breeding periods in that cycle.

Columns	Content
1-2	Blank
3-6	Species name (abbreviated to four letters).
7	Blank
8	Sex (M or F for breeders; any other character is assumed non-breeder).
9	Blank
10	Number of years to complete one activity cycle (e.g., 2 for wandering albatross). Must be 1 for non-breeders.
11	Blank
12	Number of breeding periods in one activity cycle. Must be 0 for non-breeders.
13	Blank
14-21	Total population size for this component. (For a population with a two-year activity cycle this population size will be divided by two within the program when their impact is assessed).

Data Line 02

This line contains information on the weight of each species/sex and its changes throughout the season.

Weights are interpolated between the values given on successive lines.

Note that if more than one line is entered, the day number on the last card must be the last day of the activity cycle (365 for most species, 730 for species whose cycle lasts two years, and 1 095 for king penguins).

Columns	Content
1-2	Blank
3-6	Day number (must be 0001 on first card).
7	Blank
8-12	Weight (grams)

Data Line 03

Reserved for future use.

Data Line 04

This card contains details of the dietary composition of a species/sex.

Columns	Content
1-2	Blank
3-6	Day number (must be 0001 on first card)
7-9	Percentage of diet Euphausiid
10-12	Percentage of diet Cephalopod
13-15	Percentage of diet Myctophid
16-18	Percentage of diet Other Fish
19-21	Percentage of diet Copepod
22-24	Percentage of diet Amphipod
25-27	Percentage of diet Other Crustacea
28-30	Percentage of diet Other (marine)

Data Lines 05 and 06

These data give details of the daily energetic costs of each activity the bird undertakes. Currently these activities are:

0. absent from the sea
1. "standing around at nest site"
2. incubation
3. brooding
4. foraging for chick
5. foraging for self
6. moult.

Weight to energy relationships of the form $E=aW^b$ can be used. If **b**=0 then '**a**' should be the energy consumption of a bird of average weight for that activity. The values of '**a**' are given on line 05 and the values of '**b**' on line 06. The values of **a** and **b** should be given for the weight in grams. Energetic costs should be calculated in **kJ/d**. Only activities 0, 1, 5 and 6 are used for non-breeders.

Columns	Contents
1-2	Blank
3-7	a or b for activity 1
8	Blank
9-13	a or b for activity 2
14	Blank
15-19	a or b for activity 3
20	Blank
21-25	a or b for activity 4
26	Blank
27-31	a or b for activity 5
32	Blank
33-37	a or b for activity 6

Data Line 07 (omit for non-breeders)

These data relate to one breeding period. There should be one 07-type line for each breeding period within a complete activity cycle. All dates are referred to day 1 as the first day of the activity cycle (i.e., may go from 1 to 1 095).

Columns	Contents
1-2	Blank
3-6	Laying date (number of days from start of activity cycle)
7	Blank
8-14	Egg loss rate (fraction per day)
15	Blank
16-19	Hatching data (as lay date)
20	Blank
21-27	Chick loss rate (fraction per day)
28	Blank
29-32	Fledging date (as lay date)
33	Blank
34-37	Feed size (grams delivered by one adult)
38	Blank
39-43	Feeding frequency (meals per adult per day)

Data Line 08

Lines of this type describe the activity budget of a bird throughout one activity cycle (which may include more than one breeding period and last for more than one twelve-month period). The activities are coded 1-6 or zero to indicate absence. Days are numbered from 1 September at the start of the activity cycle and may go up to 1 095 if the activity cycle covers three years. Non-breeders may only have activity codes 0, 1, 5 and 6.

As many cards as are necessary may be used but each card must be full before starting the next.

Columns	Contents
1-2	Blank
3-6	0001 (day 1)
7	activity on day 1
8-11	day start next activity
12	activity
13-16	day start next activity
17	activity
18-21	day start next activity
..	
..	
..	
68-71	day start next activity
72	activity
73-80	blank

Data Line 09 (omit for non-breeders)

These data describe the foraging range and pattern of the adults during the chick-rearing part of the activity cycle. There must be one card for each breeding period (e.g., two for king penguins). A foraging trip is defined here as the time between feeds, and is calculated from the feeding frequency.

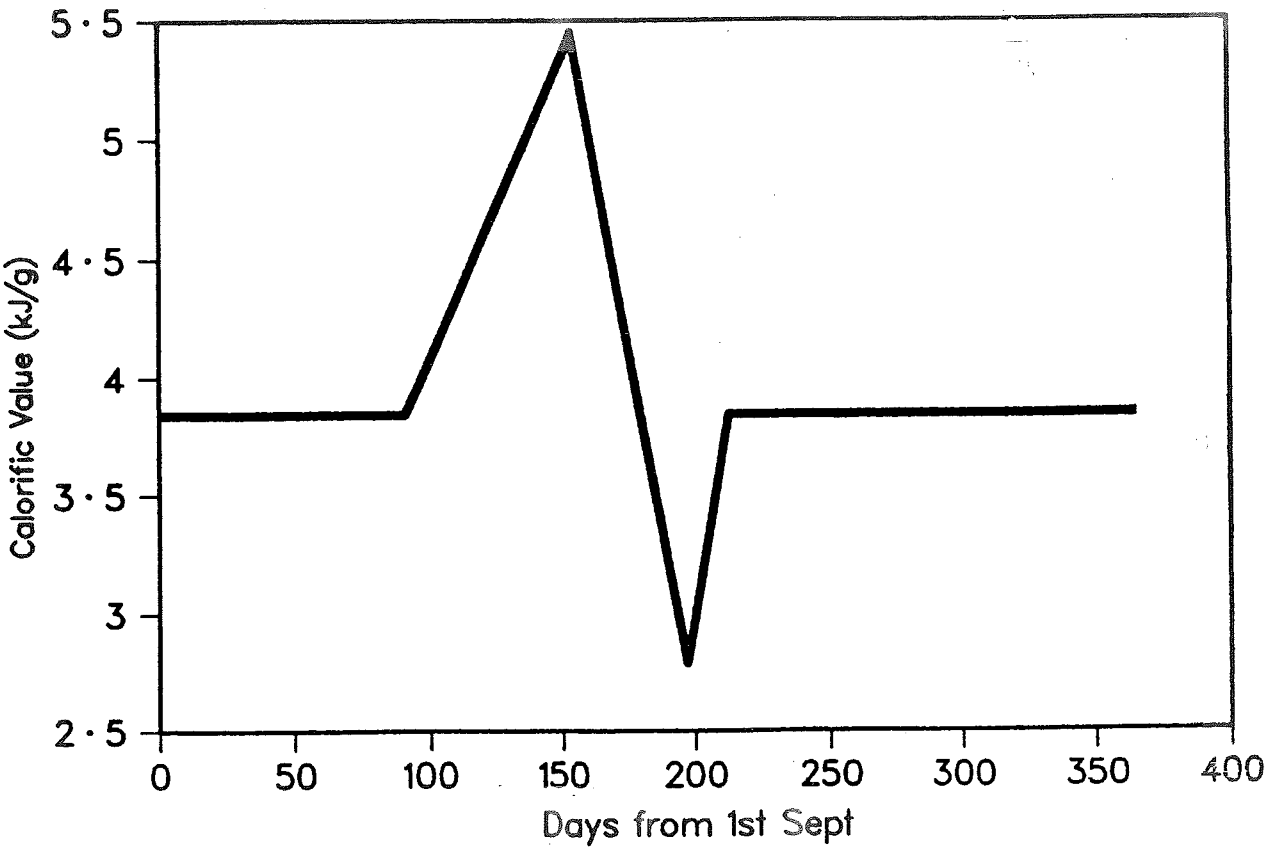
Columns	Content
1-2	Blank
3-6	Flight speed (m/s)
7	Blank
8-11	Zigzag factor (distance flown to achieve unit distance forward)
12	Blank
13-16	Proportion not travelling (e.g., proportion of a foraging trip spent on water for flying birds, or on land for penguins)
17	Blank
18	Foraging type: 1 = uniform, 2 = inshore, 3 = offshore

(a) Data giving seasonal changes in calorific value of krill (from file name EUPHAUSI . CAL).

Day No.	Calorific Value (kJ/g)
001	3.84
091	3.84
154	5.45
197	2.79
213	3.84
365	3.84

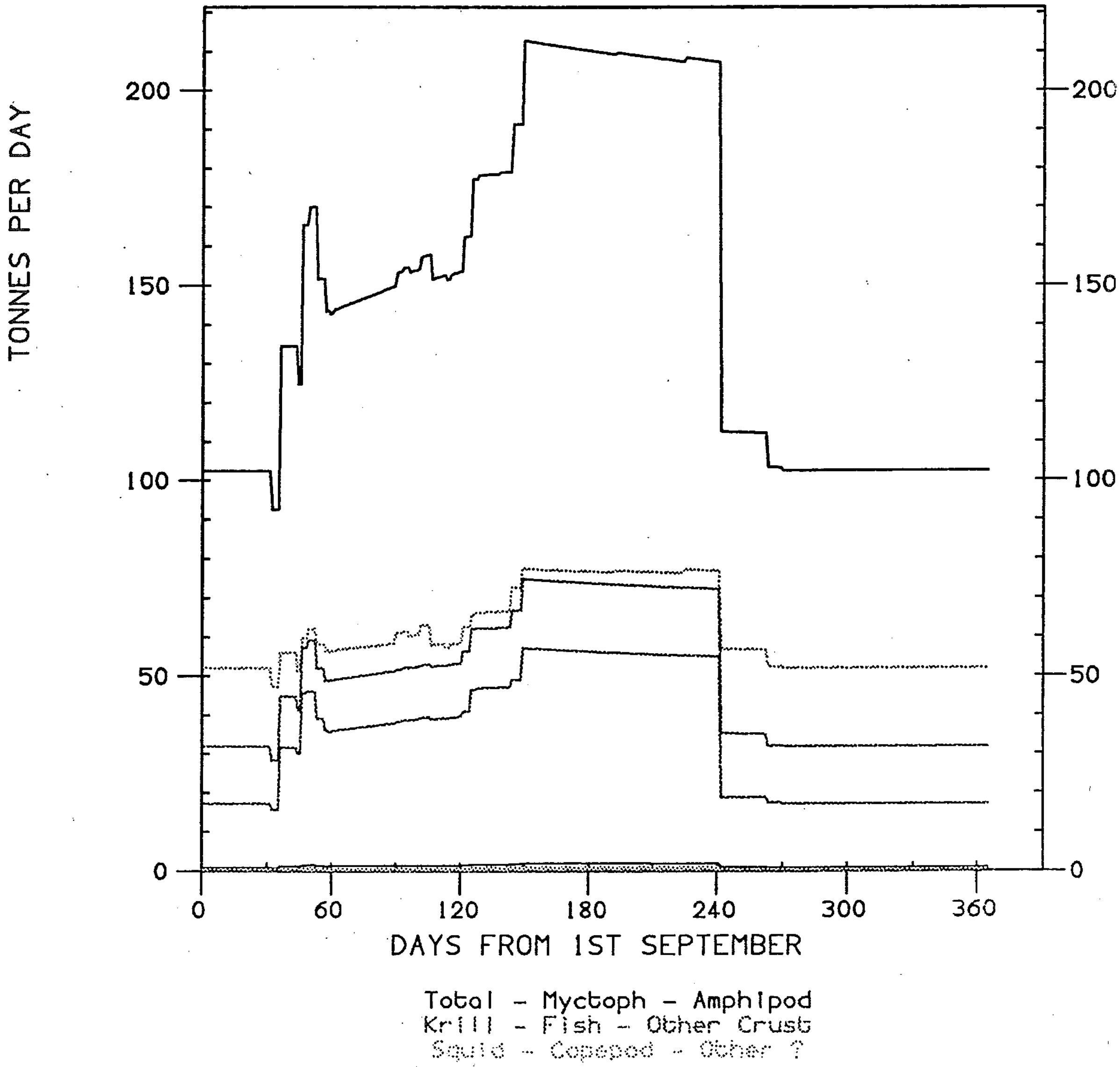
(b) Interpolated seasonal pattern.

Seasonal change in calorific value of krill

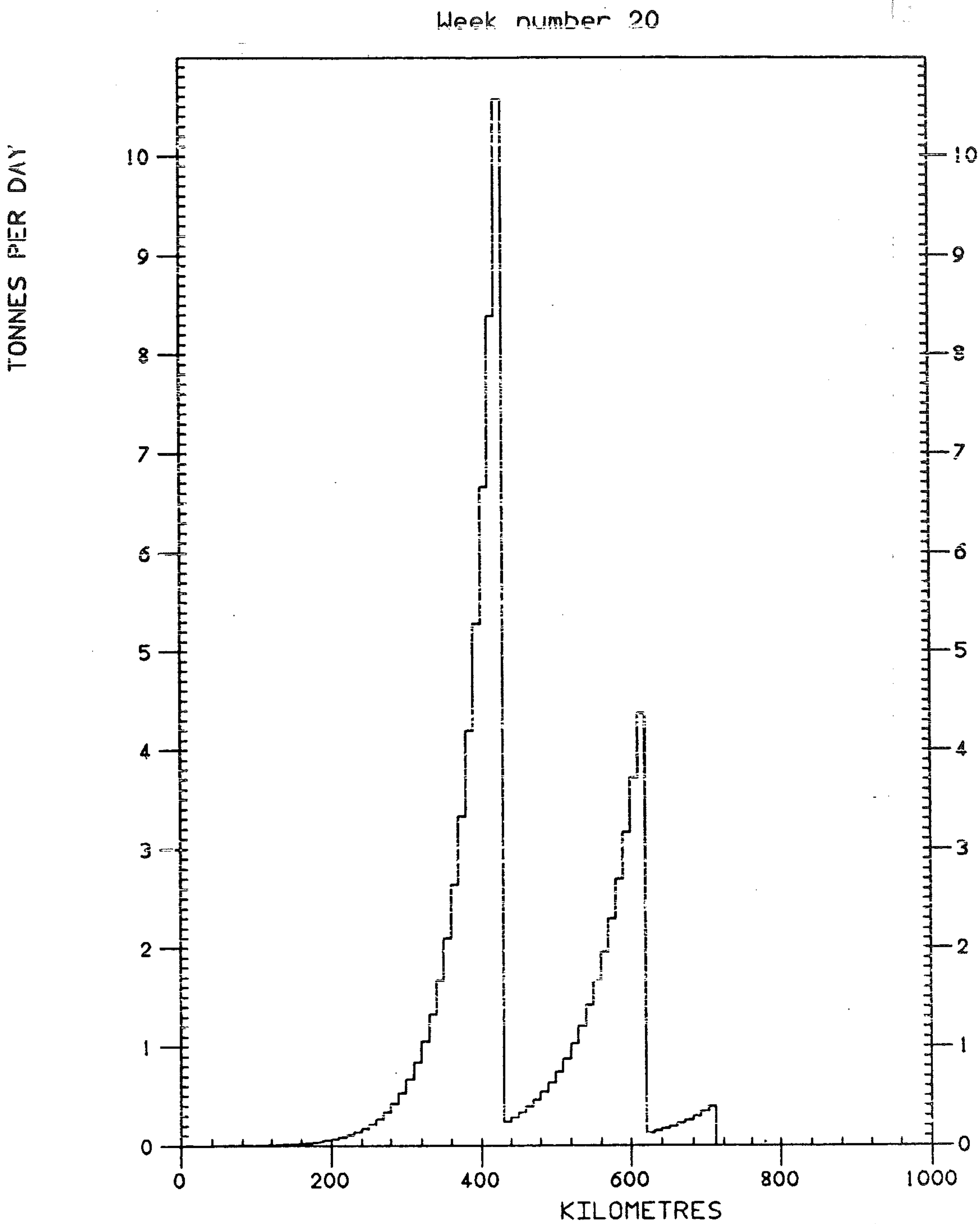


GRAPHICAL OUTPUT FROM THE PROGRAM
(Produced by Dr A.G. Wood)

(a) Plot of daily food consumption throughout the year.



(b) Plot of food consumption per 10 km band offshore on day 140 (week 20).



PART 2: SELECTED OUTPUTS FROM SEABIRD IMPACT ASSESSMENT PROGRAM

This document contains outputs resulting from:

1. Running a new version of the original model incorporating the (few) changes to parameter values.

2. Running the new sub-models (for seasonal changes in predator weight, diet composition and prey energy content) and comparing these with the original version which lacks these.

3. Sensitivity analyses.

4. Comments on the potential applicability of the system to other predators and to more detailed analyses of prey such as krill.

1. Running Version 3.30 of the System

The changes to the data used in the original system are as follows:

(a) Total population estimate for king penguins is now 188 000 pairs (Croxall *et al.*, 1988a).

(b) Diet of king penguins is now 13% cephalopod, 86% myctophid, 1% other fish (Adams and Klages, 1987).

(c) Diet of Wilson's storm petrel is now 35% krill, 2% cephalopod, 28% myctophid, 30% amphipod, 3% other crustacea, 2% other (Croxall *et al.*, 1988b).

(d) fish prey of Antarctic (dove) prion, blue petrel, white-chinned petrel and black-bellied storm petrel is now all myctophid (Croxall and Prince, unpublished data).

The selected outputs are as follows:

(a) Annual food consumption (tonnes) of seabirds breeding at South Georgia (Table 1). Note that this treats the sexes separately and does not incorporate the necessary correction for an assimilation efficiency coefficient of 75%.

(b) Seasonal changes in food consumption by the combined breeding population of all South Georgia seabirds (Figure 1).

(c) Food consumption, in terms of distance offshore, of the active breeding seabird population (i.e., all birds still engaged in rearing chicks) in mid-February (day 196) is shown in Figure 2. Note that all macaroni penguin chicks have fledged. The main peaks in Figure 2 correspond to:

   (i) inshore-gentoo penguin, giant petrels, Wilson's storm petrel, Antarctic prion;

   (ii) at 400 km - black-browed albatross;

   (iii) at 600 km - grey-headed albatross; and

(iv) at 1 000 km - light mantled sooty albatross and white-chinned petrel (wandering albatrosses are incubating at this time).

(d) food consumption, in terms of distance offshore, of the active breeding seabird population in mid-January (day 168) of gentoo penguin (small peak close inshore) and macaroni penguin only (Figure 3). Note the differences in both scales from Figure 2.

2. New Sub-Models

(a) Predator weight change

Figure 4a shows seasonal changes in food consumption by breeding macaroni penguins assuming constant weight. Figure 4b shows the effect of including seasonal changes in weight using data for macaroni penguins from Croxall (1984, Figure 25). Note particularly the new peak prior to the moult fast ashore.

(b) Diet composition change

Figure 5a shows seasonal changes in krill and fish consumption by breeding gentoo penguins, assuming constant diet composition (68% krill, 32% fish). Figure 5b shows the effect of varying the composition of the diet using also data from Williams (in press) for times of the year outside the chick-rearing period. Note the elevated consumption of krill, due to its high contribution in the winter diet. The 'step' changes in Figure 5a solely reflect changes in food consumption associated with different activities. The step changes which only occur in Figure 5b are those which reflect changes due to diet composition.

(c) Predator energy content change

Figure 6a shows seasonal changes in chinstrap penguin krill consumption, assuming that krill have constant energy content. Figure 6b incorporates the effect of varying krill energy content using data in Clarke (1980) as portrayed in Figure 6c.

(d) General

We have portrayed the effects of changes in each of these three parameters independently. In the system they can all be combined together, subject only to data availability.

3. Sensitivity Analyses

Analyses were conducted to compare the sensitivity of the model to specify changes in values for each of the key parameters. The results of one such analysis, using macaroni penguin data, are shown in Table 2. Note the overwhelming effect of changes in the exponent of the energetic equation.

Running the model using standard general equations for e.g., penguin incubation and moult energy costs, rather than empirical values for the species concerned, resulted in a 30% decrease in food consumption for male macaroni penguins. This reinforces the importance of obtaining accurate energetic data from field studies of Antarctic species.

We also examined the effect of the changes induced by the three new sub-models. Allowing for the changes in macaroni penguin weight produced a 12% decrease in food consumption compared with the assumption of constant weight.

Allowing for seasonal changes in gentoo penguin diet composition produced a 1.5% decrease in food consumption compared with extrapolating the diet in the chick-rearing period through the whole year.

Allowing for seasonal changes in krill energy content produced a 10% increase in food consumption by chinstrap penguins compared with the assumption that krill energy content remains constant year-round.

4. Application of System to Other Predators

Provided that the relevant data can be manipulated into the correct form, the use of the program and system is not restricted to seabirds alone, but may include other predators such as seals. In incorporating Antarctic fur seals into the system the following problems were encountered.

(a) Values for daily energy consumption and mass of male seals exceeded the maximum currently allowed (five digits). This could be resolved by using **kg** and **MJ** and making concomitant changes.

(b) It is necessary to equate pup birth date with chick hatching date and to insert dummy data for the pre-birth period (equivalent to the laying period in seabirds). Weaning equates to fledging.

(c) Although determining feeding frequency in fur seals is straightforward (based on known foraging trip durations) estimation of meal size is currently difficult because it requires knowledge of the amount of milk transferred per attendance period and the conversion efficiency of krill into milk. Research is currently in progress to determine these.

(d) Data line 09 would be completed using activity budget data from TDR studies, as in penguins.

The system might also be applied to other (e.g., phocid) seals but at present for most such species there are too many data deficiencies to make this feasible.

For southern elephant seals at South Georgia, however, recent studies on population size, diet, bioenergetics and diving activity patterns have provided most relevant data - including the ability to make rough estimates of energy costs of swimming.

This means that elephant seal activities could be regarded as belonging to one of two basic categories: ashore (i.e., breeding and moult period) and at-sea (rest of year). If periods ashore, when the animals are fasting, were regarded as involving no food consumption, the estimated at-sea daily energy costs could be assumed to include acquisition of any 'extra' food before and after the periods ashore. This would allow data lines 05, 06 and 08 to be completed and require 07 to be filled with dummy data. Data line 09 would be completed using data from TDR studies.

5. Application of System to Krill Prey Alone

The system and program currently allow analysis of up to eight prey categories, which are currently different species groups. However, these eight prey categories could easily be different components of one prey species, e.g. sex and maturity stages/age classes of krill. All the calculations within the program would be appropriate; the names of the eight prey categories would simply need to be altered within the program.

REFERENCES

ADAMS, N.J., and N.T. KLAGES. 1987. Seasonal variation in the diet of the king penguin (*Aptenodytes patagonicus*) at sub-Antarctic Marion Island. *Journal of Zoology, London 212*: 303-324.

CLARKE, A. 1980. The biochemical composition of krill *Euphausia superba* from South Georgia. *Journal of Experimental Marine Biology and Ecology 43*: 221-236.

CROXALL, J.P. 1984. Seabirds. In: LAWS, R.M. (Ed.). *Antarctic Ecology* 2: 533-619. London: Academic Press.

CROXALL, J.P., T.S. MCCANN, P.A. PRINCE and P. ROTHERY. 1988a. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands 1976-1986: Implications for Southern Ocean monitoring studies. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Berlin: Springer-Verlag.

CROXALL, J.P., H.J. HILL, R. LIDSTONE-SCOTT, M.J. O'CONNELL and P.A. PRINCE. 1988b. Food and feeding ecology of Wilson's storm petrel, *Oceanites oceanicus* at South Georgia. *Journal of Zoology, London 216*: 83-102.

WILLIAMS, T.D. In press. Winter diet of gentoo penguins, *Pygoscelis papua*, at South Georgia: An assessment of winter krill consumption. *Ibis 133*.

Table 1: Total annual consumption of each category of prey by South Georgia breeding seabird populations.

Species	Sex	Weight (kg)	Population (pairs)	Food Consumption (tonnes)								Total
				Euphausids	Cephalopods	Myctophids	Fish	Copepods	Amphipods	Other Crustaceans	Oddsnsods	
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
KINP	M	13.450	188000	0	7727	51122	594	0	0	0	0	59445
KINP	F	13.760	188000	0	7622	50427	586	0	0	0	0	58636
GENP	M	5.890	100000	22902	0	0	10777	0	0	0	0	33680
GENP	F	5.890	100000	23032	0	0	10838	0	0	0	0	33871
CHP	M	4.000	4000	992	0	0	0	0	0	0	0	992
CHP	F	3.600	4000	914	0	0	0	0	0	0	0	914
MACP	M	5.000	5000000	1480640	0	0	30217	0	0	0	0	1510857
MACP	F	4.600	5000000	1423880	0	0	29058	0	0	0	0	1452939
WALB	M	10.580	4732	116	930	0	116	0	0	0	0	1163
WALB	F	9.020	4732	105	843	0	105	0	0	0	0	1054
BBA	M	3.922	60000	3183	1759	0	3267	83	83	0	0	8378
BBA	F	3.694	60000	3013	1665	0	3092	79	79	0	0	7930
GHA	M	3.751	60000	2369	7741	0	5529	0	157	0	0	15799
GHA	F	3.624	60000	2350	7678	0	5484	0	156	0	0	15671
LMS	M	2.840	8000	669	850	0	217	0	0	0	72	1808
LMS	F	2.840	8000	680	864	0	220	0	0	0	73	1838
SGP	M	5.035	5000	1083	180	0	90	0	0	0	0	1354
SGP	F	3.798	5000	921	153	0	76	0	0	0	0	1152
NGP	M	4.902	3500	599	239	0	79	0	0	0	0	918
NGP	F	3.724	3500	537	214	0	71	0	0	0	0	824
CAPE	M	0.442	20000	1163	0	0	205	0	0	0	0	1368
CAPE	F	0.407	20000	1126	0	0	198	0	0	0	0	1325
SNOW	M	0.340	3000	144	18	0	18	0	0	0	0	180
SNOW	F	0.286	3000	135	16	0	16	0	0	0	0	169
DOVE	M	0.168	22000000	509935	8791	17583	0	272551	70335	0	0	879199
DOVE	F	0.168	22000000	472034	8138	16277	0	252294	65108	0	0	813851
BLUE	M	0.193	70000	2309	28	225	0	112	140	0	0	2816
BLUE	F	0.193	70000	2140	26	208	0	104	130	0	0	2609
WCP	M	1.368	2000000	56801	98876	50490	0	0	2103	0	0	208272
WCP	F	1.368	2000000	57755	100537	51338	0	0	2139	0	0	211771

Table 1 (continued)

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
WISP	M	0.034	600000	1013	57	810	0	0	926	86	0	2895
WISP	F	0.034	600000	832	47	666	0	0	761	71	0	2379
BBSP	M	0.053	10000	90	0	10	0	80	20	0	0	200
BBSP	F	0.053	10000	84	0	9	0	74	18	0	0	187
CDP	M	0.133	3800000	20778	0	0	0	94195	23548	0	0	138522
CDP	F	0.133	3800000	18800	0	0	0	85230	21307	0	0	125339
SGDP	M	0.107	2000000	49171	0	0	0	12939	2587	0	0	64699
SGDP	F	0.107	2000000	45005	0	0	0	11843	2368	0	0	59218
BES	M	2.867	7500	0	337	0	1179	0	0	168	0	1685
BES	F	2.473	7500	0	310	0	1085	0	0	155	0	1550
ANTT	M	0.151	2600	16	0	0	53	16	21	0	0	107
ANTT	F	0.151	2600	15	0	0	50	15	20	0	0	100

Table 2: The change in food consumption of male macaroni penguins induced by changes of 10% in each key parameter.

Parameter	Change in Food Consumption for:	
	10% Decrease	10% Increase
Weight	-7%	+6%
Energy coefficient **a** in $\mathbf{E = aW^b}$	-10%	+10%
Energy exponent **b** in $\mathbf{E = aW^b}$	-43%	+76%
Egg loss	+<1%	-<1%
Chick loss	+<1%	-<1%
Chick meal size	-<1%	+<1%
Chick meal frequency	-<1%	+<1%

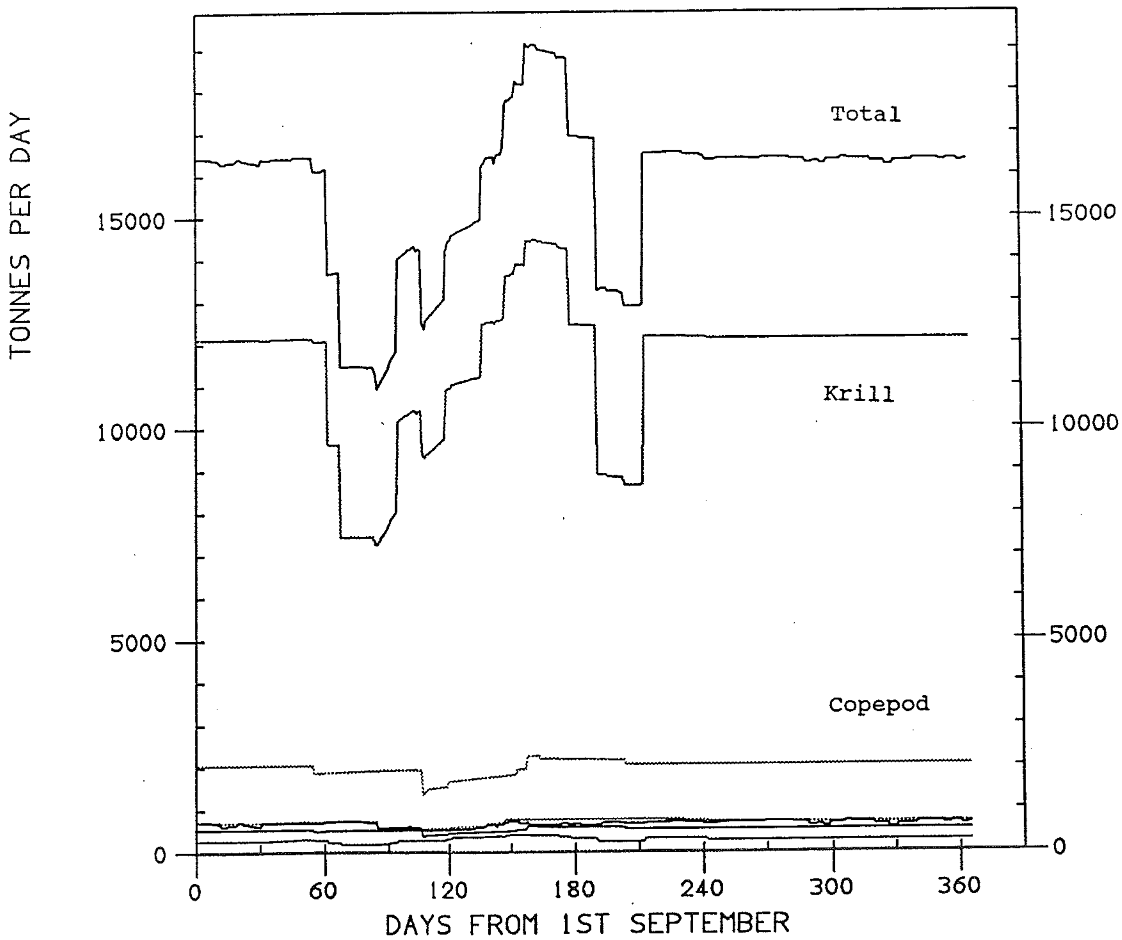


Figure 1: Annual food consumption all breeding South Georgia seabirds.

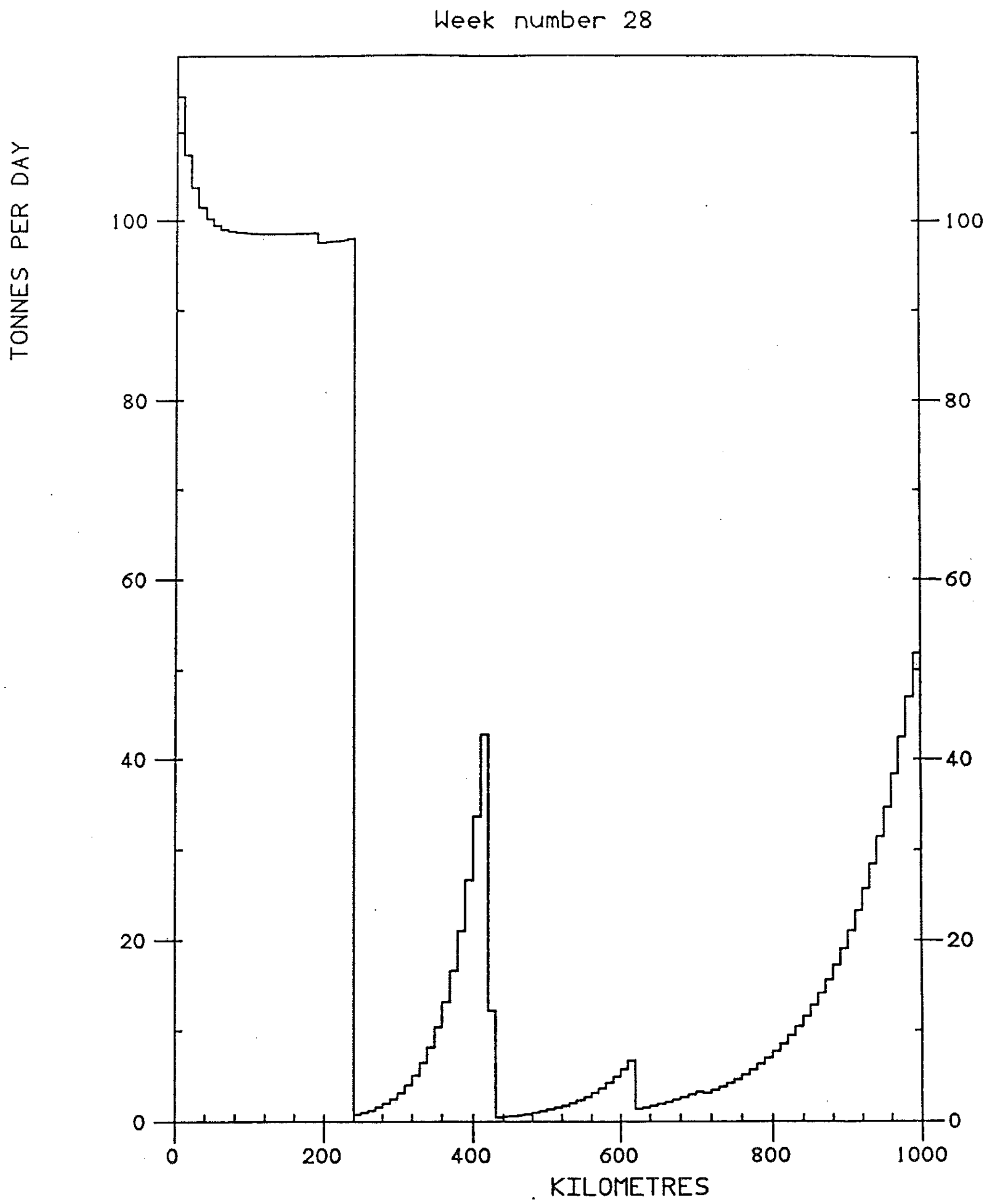


Figure 2: Distribution of food consumption (all seabirds), mid-February.

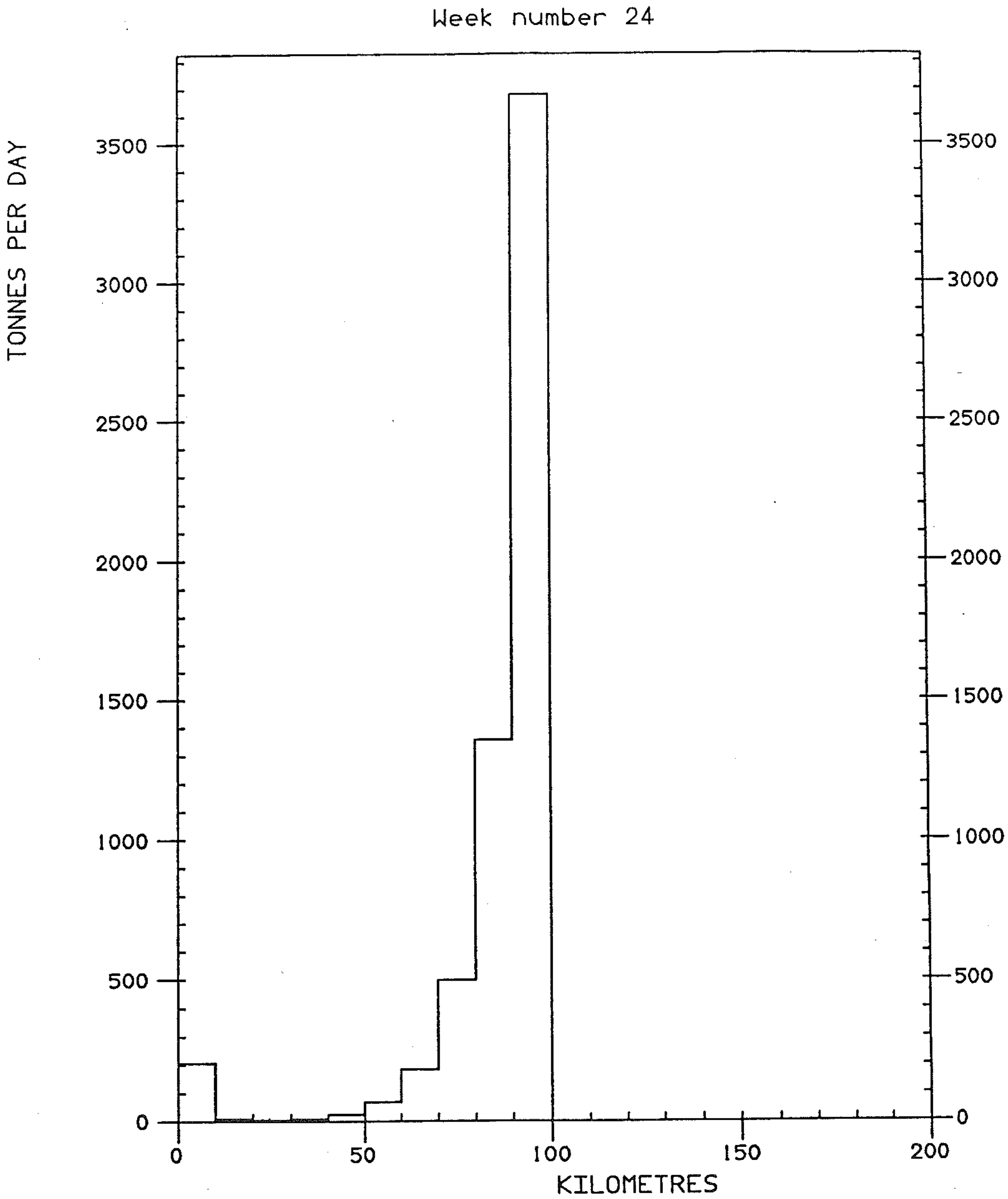


Figure 3: Distribution of food consumption, macaroni and gentoo penguins, mid-January.

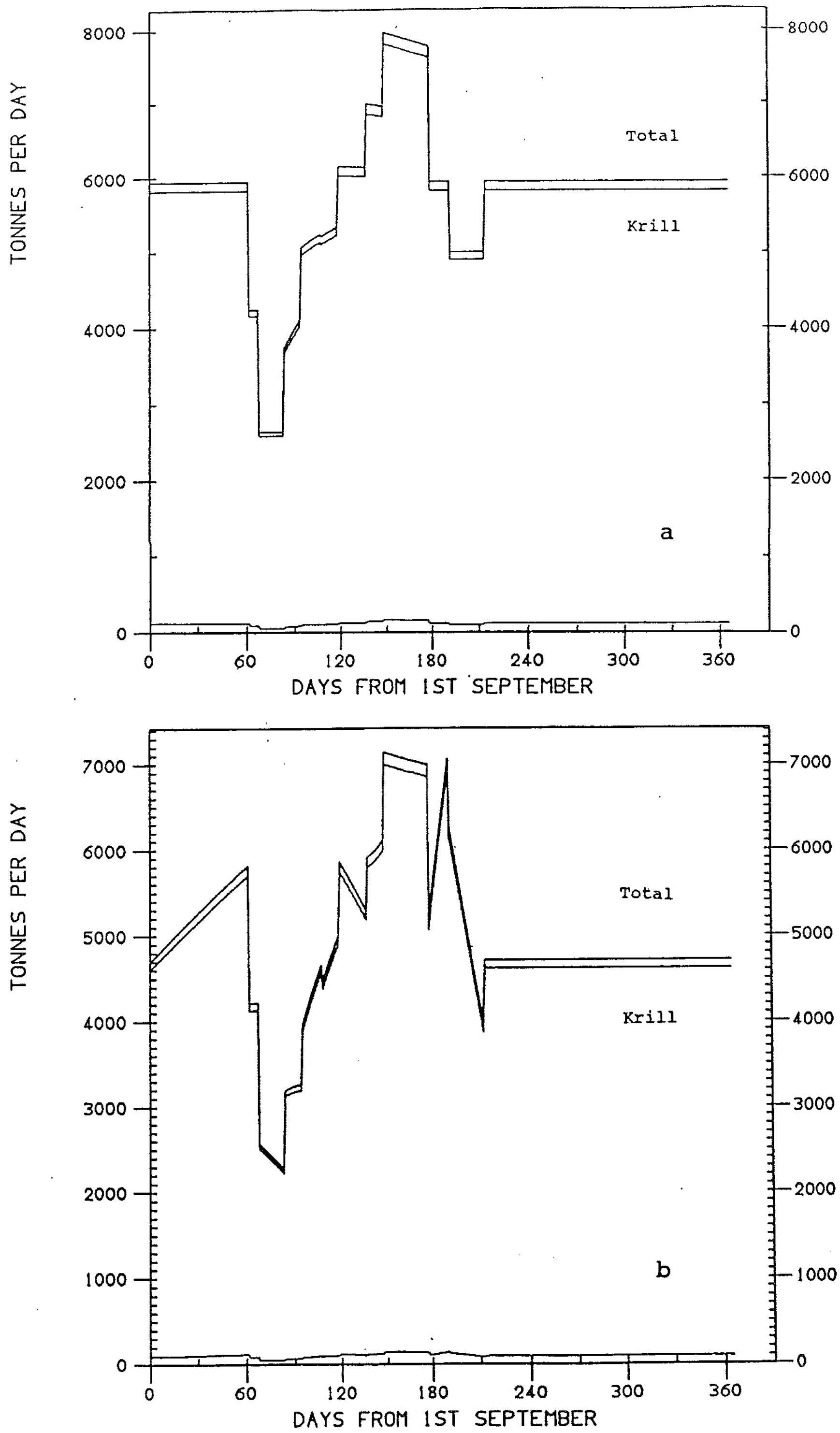


Figure 4: Food consumption in macaroni penguins without (Figure 4a) and with (Figure 4b) allowance for seasonal change in weight.

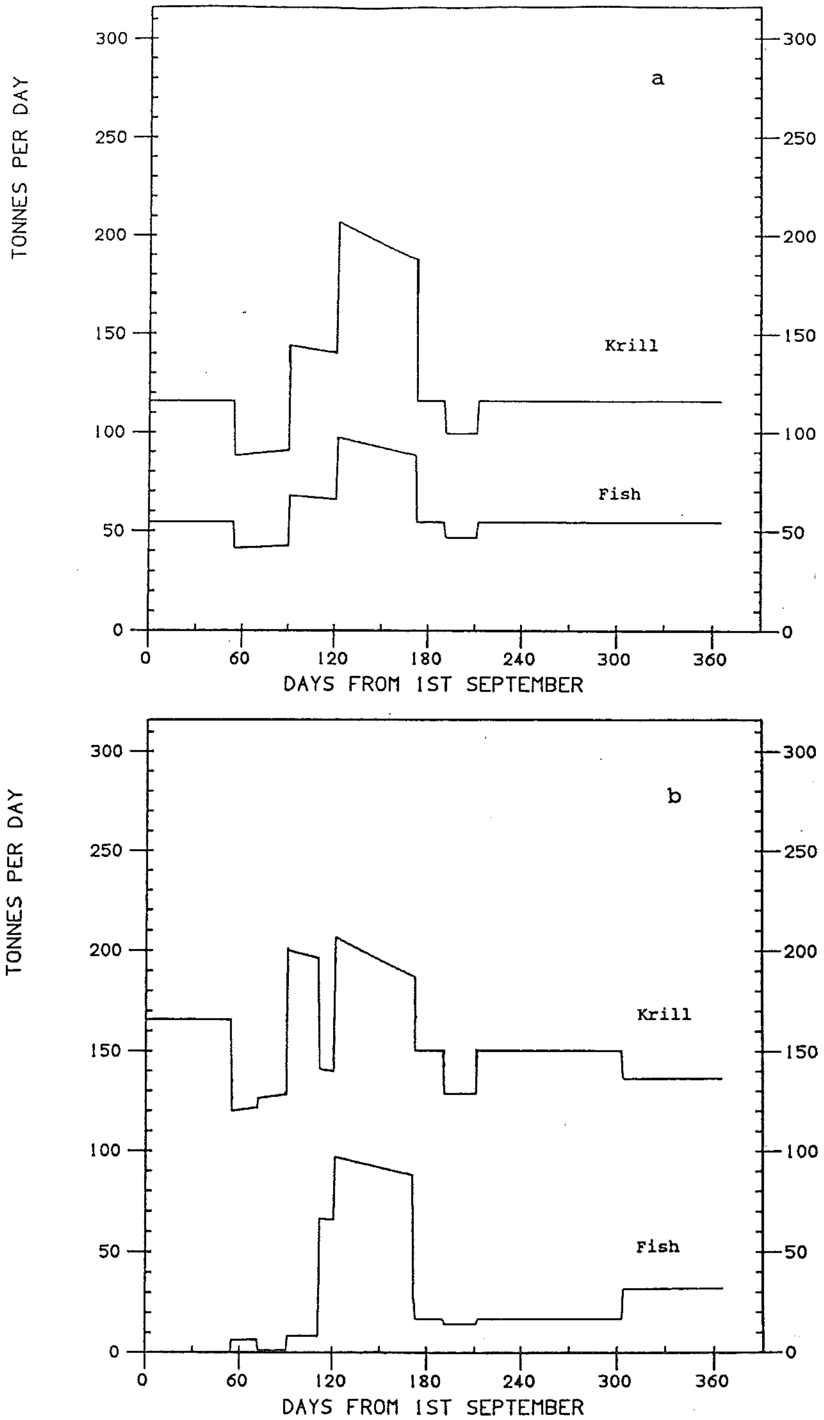


Figure 5: Food consumption in gentoo penguins without (Figure 5a) and with (Figure 5b) allowance for seasonal change in diet composition.

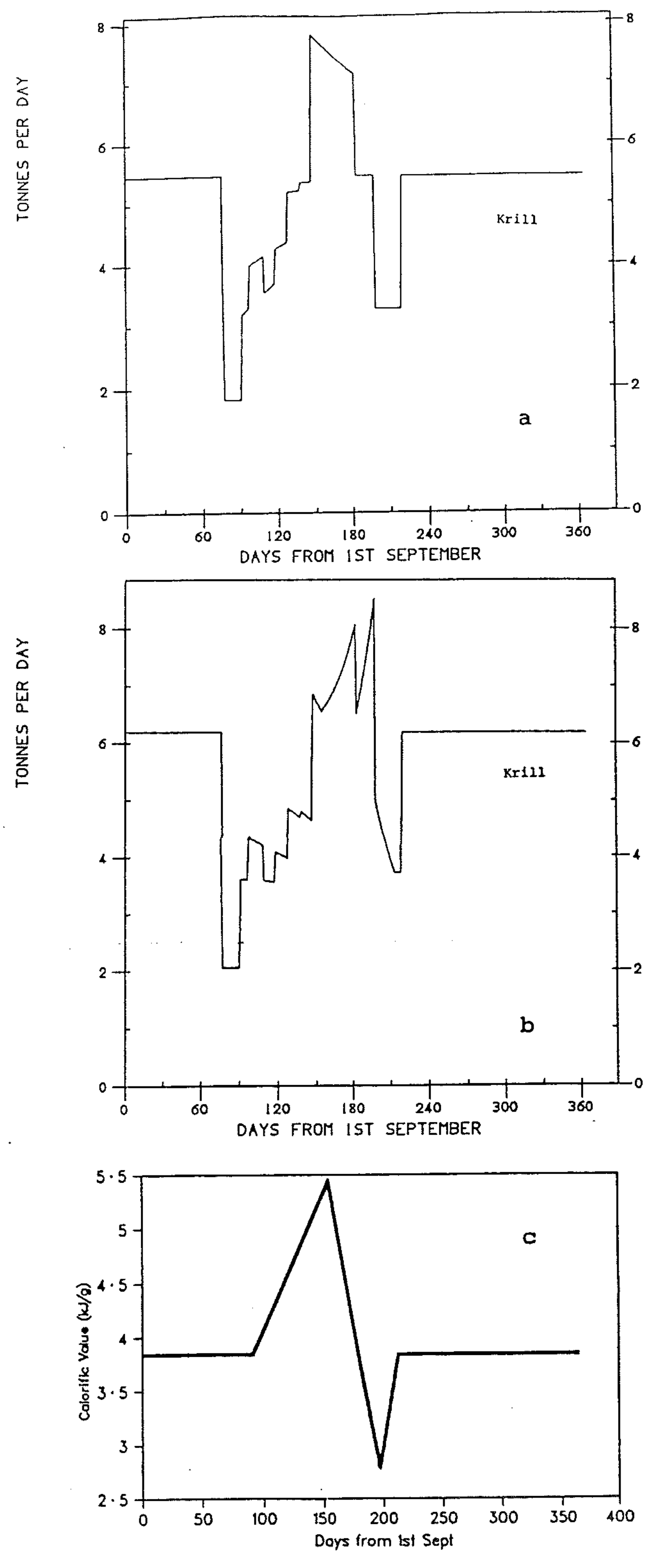


Figure 6: Food consumption in chinstrap penguins without (Figure 6a) and with (Figure 6b) allowance for seasonal change in krill energy content, as shown in Figure 6c.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

OBSERVATION OF SEABIRDS IN THE SOUTHERN OCEAN IN 1988/89

A.V. Vagin and V.V. Popov*

Abstract

This paper examines the numerical and species distribution of birds in the sub-Antarctic area of the Southern Ocean to the south of 60°S. Thirty minute observations were made daily during daylight hours at 8:00; 12:00, 16:00 and 20:00 ship-time, while sailing between Antarctic stations and while en route to ports of call. Maps summarize the distribution of 14 bird species as well as of the individual species: Antarctic, snow, and cape petrels and the southern fulmar. Ice distribution patterns prevailing over the study period are discussed as is the wide variability of numerical and species distribution in each oceanic sector of Antarctica.

Résumé

Cette communication examine la répartition numérique et spécifique des oiseaux dans la zone subantarctique de l'océan Austral au sud de 60° S. Tous les jours, des observations d'une durée de trente minutes ont été effectuées, à la lumière du jour, à 8h00, 12h00, 16h00 et 20h00, heure du bord, en naviguant entre les stations antarctiques et en route pour les ports d'escale. Des cartes récapitulent la répartition de 14 espèces d'oiseaux ainsi que celle des espèces particulières : pétrel antarctique, pétrel des neiges, pétrel du Cap et fulmar antarctique. Les tendances dominantes de la répartition de la glace au cours de l'étude sont discutées de même que la grande variabilité de la répartition numérique et spécifique dans chaque secteur océanique de l'Antarctique.

Резюме

В данной работе рассматривается количественное распределение и видовое распространение птиц в приантарктической (к югу от 60° ю.ш.) области Южного океана. Наблюдения, по 30 мин. каждое, выполнялись ежедневно в светлое время суток 8, 12, 16, 20 часов по судовому времени, во время переходов судна между антарктическими станциями и при следовании в порты захода. Приводятся карты общего распределения 14обнаруженных видов птиц, а также распределения отдельных видов - антарктического, снежного, серебристо-серого буревестников и глупыша. Рассмотрены особенности распространения льдов в исследуемый период. Показана значительная неравномерность количественного распределения и видового распространения птиц в каждом секторе Антарктики.

* VNIRO, 17 V. Krasnoselskaya, Moscow 107140, USSR

Resumen

Este documento examina la distribución numérica y de las especies de aves en el área subantártica del océano Austral al sur de los 60°S. Se realizaron observaciones diarias de treinta minutos de duración a las 8:00, 12:00, 16:00 y 20:00 horas (hora del barco), mientras se navegaba entre las estaciones antárticas y puertos escalas. Los mapas resumen la distribución de 14 especies, además de la distribución de las especies individuales de: petreles antárticos, dameros, nevados y plateados. Se debaten los patrones de distribución del hielo predominantes durante el período de estudio y también la gran variabilidad de la distribución numérica y de las especies en cada zona oceánica de la Antártida.

1. INTRODUCTION

The CCAMLR Ecosystem Monitoring Program (CEMP) includes the observation of sea-bird numbers and species composition. So far a great deal of information has been gathered together on bird behaviour, distribution and nesting sites. Unfortunately, the marine stage of these birds' life cycle remains a virtual mystery. As a result it is impossible to learn their migration routes, distribution patterns, the makeup of their diet and feeding behaviour at sea. It was therefore considered appropriate to investigate the numerical distribution and species composition of seabirds to the south of 60°S during the second Antarctic cruise of the RV *Akademik Fedorov*.

2. METHOD OF OBSERVATION

Observations were made while the vessel was in transit between the following stations:

- Bellingshausen and Druzhnaya (11 to 28 December 1988);
- Druzhnaya and Molodezhnaya (28 December 1988 to 3 January 1989);
- Molodezhnaya and Bunger Hills (10 January to 2 February 1989);
- Russkaya and Leningradskaya (26 February to 12 March 1989);
- Bunger Hills and Molodezhnaya (9 to 20 April 1989)

as well as en route to ports of call. The survey route is shown in Figure 1.

Observations lasting 30 minutes each were carried out during the daylight hours at 8:00, 12:00, 16:00 and 20:00 ship-time. As the periods of daylight became shorter (March/April), the number of observations was reduced to three or even two. The average speed was about 15 knots and the distance between two sequential observations was approximately 60 miles. When it was necessary to negotiate large ice massifs, the speed of the vessel decreased and there was less distance between observation points. A total of 175 half-hour observations were made during the voyage.

The observer was positioned in the stern section on the second deck of the superstructure (about 12 m above the sea surface) facing the wake of the vessel and had a 180° range of vision. Each observation was preceded by the recording of coordinates, course and speed of the vessel as well as environmental conditions such as visibility, type of precipitation and ice cover, which have a direct impact on bird behaviour. At the end of the observation the maximum number of birds of each species sighted at one time during a particular shift was recorded. The appearance of large flocks or new species between observation shifts was also noted. Observations were carried out regularly and interrupted only in cases of extremely poor visibility, heavy fog, snow or blizzard. Binoculars with a magnification of 7x50 were used for species identification of birds a long way from the vessel.

Considering that of all environmental factors the sea ice cover has the greatest impact on bird behaviour and migration, this paper shall deal only with ice distribution patterns over the observation period. According to the data obtained, ice conditions in the Southern Ocean during the 1988/89 season were reckoned to be close to average.

3. RESULTS OF OBSERVATIONS

During the cruise of RV *Akademik Fedorov* to the south of 60°S in the Southern Ocean, 14 species of birds were identified:

- wandering albatross (*Diomedea exulans*)
- black-browed albatross (*Diomedea melanophris*)
- sooty albatross (*Phoebetria palpebrata*)
- giant petrel (*Macronectes giganteus*)
- southern fulmar (*Fulmarus glacialoides*)
- Antarctic petrel (*Thalassoica antarctica*)
- cape petrel (*Daption capensis*)
- snow petrel (*Pagodroma nivea*)
- blue petrel (*Halobaena caerulea*)
- Wilson's petrel (*Oceanites oceanicus*)
- Dominican gull (*Larus dominicus*)
- Antarctic tern (*Sterna vittata*)
- southern polar skua (*Stercorarius skua maccormicki*)
- white-chinned petrel (*Procellaria aeguinoctialis*)

Observation results showed a distinct variability in the numerical and species distribution of birds. The most obvious feature was the absence of some species over vast areas. In the Atlantic sector, for example, the white-chinned petrel was not encountered, while in the Indian Ocean sector, the Dominican gull and in the Pacific Ocean sector the Antarctic tern, the Dominican gull and the white-chinned petrel were absent. Moreover, significant fluctuations in species composition were noted within the confines of a single sector. In general this was observed when the vessel was sailing from ice-free areas or areas close to the ice-edge to regions of vast ice massifs. In the western part of the Atlantic sector, for example, between 10 and 12 bird species were regularly observed near the ice-edge. In the region of the ice massif in the Weddell Sea the number of species fell to between four and five. Although this paper will not explore in depth the reasons for such significant variability in the distribution of species composition, it is worth noting that the absence of a particular species in one or another area may be due to the season in which observations were carried out or ecological factors which govern the migration patterns of that particular species of bird.

The numerical distribution of sea birds was even more uneven. An interesting fact here was that the fluctuation in species composition (an increase or decrease in the number of species) was not connected with fluctuations in the abundance of birds in a particular area.

The most prolific flocks, which consisted of several thousand birds, were observed in the Indian Ocean sector. Large flocks of birds were also typical here in autumn.

The number of birds in the Atlantic sector during the period of observations was in the order of a few hundred individuals, while in the Pacific Ocean sector it never exceeded a few dozen per observation shift.

Earlier studies also frequently mentioned the wide spatial fluctuations in the numerical distribution of birds in Antarctica (FIBEX Seabird Data Interpretation Workshop, Cape Town, South Africa, 10 to 18 April, 1985. BIOMASS Report Series 44). Despite the long duration of the observation period, these past results create a basis for assuming that the numerical distribution patterns which emerged in our study are close to the real situation.

Significant variations in quantitative distribution of seabirds occurred in each sector of Antarctica. The greatest abundance of birds in the Atlantic sector was witnessed near the ice-edge in the South Orkney, South Shetland and South Sandwich Islands area (Figure 2), where their numbers reached more than 100 during a single observation shift. Abundance was less to the east of the South Sandwich Islands and did not exceed 50 birds during a shift. The number of birds at the ice massif generally did not exceed 10 individuals (between 60°S, 11°W and the Antarctic continent) despite such favourable feeding conditions as broken ice and numerous patches of ice-free water. Bird numbers increased again only in very close proximity to the Antarctic continent where ice density was between 9 and 10 points and where small polynyas had formed. Separate observations put their numbers at 50 specimens.

A more even distribution of birds was typical for the area between Druzhnaya and Molodezhnaya Stations (Figure 3). Birds were observed here at every shift though their numbers never exceeded 10. Only once, on 30 December 1988, when the vessel was sailing across an area of virtually ice-free water where only strips of finely broken ice occurred, were large flocks consisting of more than 100 individuals of different species observed. The main species in these flocks were the Antarctic and cape petrels. Bird behaviour here was interesting: they did not fly above the ship's wake in the usual manner, but rather along the sides and in front.

Larger flocks were observed between Molodezhnaya and Bunger Hills Stations (Figure 4). A huge mass of birds consisting of more than 3 000 individuals was observed on 14 January 1989 in the Sodruzhestva Sea (67°S, 73°45'W). Flocks contained between 100 and 300 birds and were almost evenly distributed along the survey route of the vessel. The Antarctic petrel (about 70%) and southern fulmar (about 30%) were the most common species here although the giant, Wilson's and snow petrels were also present. As the vessel neared birds sitting in the water and on ice-floes, they flew away to the side or another 100 to 200 m ahead of the ship. Ice cover density in this area was from one to three points; the ice was almost entirely broken up and consisted of snowy chunks. Ice-floes measuring 2x3 m or 3x5 m were sighted only occasionally. Large flocks, consisting mainly of white-chinned petrels which had been encountered only in the Indian Ocean sector, were witnessed in the area of Bunger Hills Station near the ice-edge. During repeat observations (9 to 20 January 1989) very large flocks were encountered again, this time their numbers exceeded 1 000 specimens (Figure 5). Antarctic and snow petrels were the most common species in this mass of birds and in many instances their percentage ratio was equal. It was only in the Sodruzhestva Sea (63°45'S, 72°14'W) that the predominance of the Antarctic petrel re-emerged. Its abundance was more than 1 000 in mixed flocks while the numbers of snow petrel did not exceed 200 individuals. It ought be noted that for the most part the vessel was sailing in an area of new pan-ice from 10 to 15 cm thick; ice density was from 8 to 10 points.

The smallest number of birds observed over the period was in the Pacific Ocean sector (Figure 6). Undoubtedly, this could have been due to the season (late summer/early autumn) as well as severe ice conditions. In this region even the number of birds in ice-free water was not more than a handful. As a rule, snow, Antarctic and giant petrels were observed at the same time. No birds were encountered while the vessel sailed in the area of the Pacific Ocean ice massif (ice density - 9 to 10 points). It was only while the ship was at anchor near the Russkaya Station that several Antarctic petrels and skuas were observed near a polynya which had formed there. Birds were typically absent as the vessel sailed from the Russkaya Station to the eastern part of the Ross Sea along the Antarctic coast. It should be noted that thin new ice with an ice density of 10 points covered the entire route of the vessel. Flocks of more than 100 birds which were comprised of snow and Antarctic petrels were only sighted in the area bounded by the coordinates 77°16'S and 175°32'W; single skuas were also observed. An iceberg measuring 100x30 km was located in this area. Near the iceberg a small polynya played host to between fifteen and twenty whales and some seals.

4. SPECIES DISTRIBUTION PATTERNS

The wandering albatross (*Diomedea exulans*) was observed in the Atlantic and Indian Ocean sectors in areas to the north of 60°S. Individual specimens were sighted at 66°S in the Pacific Ocean sector (65°50'S, 153°50'W, 25 February 1989). The number of birds per observation generally did not exceed one or two. A slight increase of wandering albatrosses to the north was observed in the autumn; in April 1989 the species was not encountered further south than 56°S in the Indian Ocean sector.

The black-browed albatross (*Diomedea melanophris)* was also observed in small numbers in the Atlantic and Indian Ocean sectors to the north of 60°S. In the Pacific Ocean sector individual specimens were sighted at 63°S.

The sooty albatross (*Phoebetria palpebrata*) was generally encountered further south than the the wandering and black-browed albatross. It was observed at 65°S in the Indian sector and at 73°30'S in the Pacific sector. Most often single birds were observed and it was rare for two to be seen together.

The giant petrel (*Macronectes giganteus*) was practically always encountered, with one or two birds sighted per shift, in all of the study areas. It was only absent from the vast ice massif in the Pacific Ocean sector. However, to the west of 176°W in the Ross Sea this species formed small flocks of four or five birds.

The blue petrel (*Halobaena caerulea*) was mainly observed in ice-free areas. The greatest number of birds (eleven) in the Atlantic sector occurred to the south of the South Sandwich Islands. In the Indian Ocean sector the blue petrel only was observed to the east of 75°W. The largest congregations of this species (approximately 300 specimens) occurred in the northern part of the Mawson Sea (61°S, 108°W). In the Pacific sector only small numbers (one or two) of birds were encountered. In autumn the blue petrel was observed in the Indian Ocean sector to the north of 65° to 63°S and its numbers on occasion reached 15 to 17 specimens. A flock of between 100 and 150 birds was noted on 24 April 1989 at 63°S and 31°W in the Atlantic sector.

Wilson's petrel (*Oceanites oceanicus*) generally occurred in small numbers of between one and three birds in the Atlantic sector. The number of birds was only as high as twenty in the South Orkney and South Shetland Island areas of the Scotia Sea. It is noteworthy that this species, like many others, was absent from the Weddell Sea ice massif, although it was observed near the Risser-Larsen glacier where there were many small polynyas. Two or three specimens would follow in the ship's wake which enabled them to feed on cryoplankton which was constantly abundant in sub-surface drift-ice. One to three specimens of Wilson's petrel were almost always present in the Indian Ocean sector, while in the Pacific sector they appeared only occasionally. Single birds were encountered only twice; on 24 February 1989 (62°S, 166°W) and 11 March 1989 (72°34'S, 173°W). A repeated survey of the Indian Ocean sector in autumn revealed that one or two birds were only present to the north of 61°S on the way to Bunger Hills Station. Wilson's petrel was not encountered in the other survey areas of the Indian or Atlantic Ocean sectors.

The southern polar skua (*Stercorarius skua maccormiki*) was observed primarily near the Antarctic continent and islands (one or two birds). The greatest number of birds recorded at one observation shift was 17 near Molodezhnaya Station. Four to five specimens were regularly observed near Russkaya Station in the Pacific sector. This species was absent from the survey areas in the Indian and Atlantic Ocean sectors in the autumn.

The Antarctic tern (*Sterna vittata*) was observed periodically and in small numbers only in the Atlantic and Indian Ocean sectors. A small flock, comprising twelve of these birds, was seen only once, in the western part of the Indian Ocean sector on 31 December 1988 (63°26'S, 29°08'W). This particular flock was migrating south towards the Antarctic continent. The Antarctic tern was absent from the Pacific sector and during repeat surveys of the Indian and Atlantic sectors in the autumn.

The Dominican gull (*Larus dominicus*) was observed only as individual birds in the Atlantic sector between Bellingshausen Station and 32°W. The greatest number of birds, 28, was recorded in the South Shetland Islands area, although this species was sighted at 71°S, 11°W near the Antarctic continent (five birds).

The white-chinned petrel (*Procellaria aeguinoctialis*) was encountered only in the Indian Ocean sector. Large flocks of up to 20 birds were common in summer to the east of 74°W. The number observed at one shift exceeded 200 only in the Mawson Sea at 64°S, 100°W. In the autumn the highest number of birds (100 at one observation shift) was recorded in the Mawson Sea. It should be noted that between two and seven specimens per shift were sighted near the Molodezhnaya Station where they were absent in summer. The presence of a large number of this species over a prolonged period (three to four months) in one area, the Mawson Sea, indicated that this may be its permanent feeding ground and possibly, breeding area.

The snow petrel (*Pagodroma nivea*) was sighted almost everywhere in the ice massifs and in ice-free water near the ice-edge. This species generally formed small flocks of between 3 or 4 and 10 birds. Individual specimens of the snow petrel were observed in the Scotia Sea near the South Shetland Islands (Figure 7). This species was regularly sighted to the east of 20°W, near the ice-edge and in the ice massif of the Weddell Sea. Moreover, on some days the snow petrel was the only species of flying bird present. The number and frequency of encounters with the snow petrel between Druzhnaya and Molodezhnaya Stations decreased as the vessel got further away from the Antarctic continent (Figure 8). During some observations near Molodezhnaya Station this species again predominated in mixed flocks. In the Indian Ocean sector single specimens of the snow petrel were only sighted in the Sodruzhestva Sea (Prydz Bay) and the Davis Sea on the way to Mirny Station. It is possible that these birds were sighted so infrequently because of considerably low ice density (one to three points). Another reason may be the changed biological condition of the birds who were at that time breeding on the Antarctic continent. Moreover, it is significant that the snow petrel was again one of the most abundant species in the area near Bunger Hills Station. Repeated surveys of the area between Bunger Hills and Molodezhnaya Station in the autumn revealed an increase in the number of snow petrels (Figure 10); in some cases more than 200 specimens were observed (in the western part of Prydz Bay). Such a large concentration of birds may be explained in two ways. Firstly, a considerable compaction of the ice took place in April and ice density was 9 to 10 points over a large part of the Indian Ocean sector. The ice-edge shifted north to 64°S, and in some places, to 63°S. These severe ice conditions made it impossible for the snow petrel to remain within the ice massif near the Antarctic continent. This necessitated the concentration of birds near the ice-edge. A second reason may be the departure of young birds from the nest which released older and parent birds from their duties (Brown, 1966). The snow petrel was sighted occasionally in the vicinity of the Pacific Ocean ice massif near Russkaya Station where there was a large polynya in the western part of the Ross Sea during the research period. Between 5 and 10 birds were recorded per observation shift. The number of snow petrels per shift reached 50 only in the eastern part of the Ross Sea as the vessel departed a zone of high ice density (8 to 10 points) near an enormous iceberg where there were patches of ice-free water. Food availability in the area seems to have been the main reason for the formation of such a large flock. This is supported by the fact that petrels were absent from the area near the Antarctic coast between Russkaya Station and 172°W where ice density was 10 points over the entire area.

The Antarctic petrel (*Thalassoica antarctica*) was one of the most common species observed near the Antarctic continent during the cruise of RV *Akademik Fedorov*. Birds tended to form flocks consisting of 15 to 20 birds and were sighted in ice massifs near Antarctic stations and in areas of ice-free water. Individual specimens were observed in the Atlantic sector to the east of 20°W (Figure 7). An interesting fact is that the Antarctic petrel was not encountered in the Scotia Sea in December 1988 when the vessel's survey route passed by the Antarctic continent and numerous islands. The Antarctic petrel was constantly observed between Druzhnaya and Molodezhnaya Stations and its numbers decreased only to the east of 15°W. In the Kosmonavtov Sea the species was sighted periodically (Figure 8), although in the Indian Ocean sector it was more abundant. Flocks of Antarctic petrels consisting of hundreds of birds were observed here practically daily (Figure 9). The greatest number of birds (over 3 000) was recorded on 14 January 1989 in Prydz Bay at 67°18'S, 74°W. Surface water temperature in this area was minus 2°C. Birds congregated together so closely on ice-floes and in the water that it was almost impossible to see some of the smaller ice-floes. As the vessel neared them, some of the birds flew away and settled 200 to 300 m ahead of the ship. Abundant flocks of Antarctic petrels were also observed in the Sodruzhestva Sea during surveys in the Indian Ocean sector in the autumn (Figure 10). Swarms of hundreds of birds were sighted here each day. In the Pacific Ocean sector the Antarctic petrel was only encountered near the ice-edge and no more than a few dozen were observed at a time (Figure 11).

The cape petrel (*Daption capensis*) was most widely distributed in the Atlantic sector (Figure 7) and the most abundant flocks were observed near the Antarctic peninsula, the South Orkney and South Sandwich Islands. More than 100 birds were recorded at separate observations in these areas. One of the features of the numerical distribution of this bird is the significant decrease in abundance or even complete absence from areas of ice massifs. Individual specimens of the cape petrel were encountered only now and again in the ice massif of the Weddell Sea (Figures 7 and 8). Ice density in this area varied widely - from ice-free water to 10 points. This species was observed regularly only to the east of 30°W (Figure 9) where 10 to 15 birds were recorded per observation shift. The high abundance of the cape petrel in Prydz Bay is apparently caused by low ice density (one to three points) and a rich food supply in the shape of krill. This species formed smaller flocks of between 5 and 10 birds in the Pacific sector near the edge of the ice massif and in the area of Leningradskaya Station and the Balleny Islands (Figure 11). In autumn larger flocks of cape petrel in the Indian Ocean sector were recorded to the north of 62° to 63°S (Figure 10). Its abundance dropped sharply closer to the ice-edge and only individual birds were sighted.

The southern fulmar (*Fulmarus glacialoides*) was observed mainly in small numbers of two to three, although in some cases groups of five or six were encountered. The greatest number of this species was recorded in the Balleny Islands area on 21 March 1989. As a rule the southern fulmar was sighted in localized areas over a one or two-day period. This species was first observed in the South Shetland and South Sandwich Islands areas (Figure 7). In the Kosmonavtov Sea the southern fulmar was only observed on the way to Molodezhnaya Station (Figure 8) after which it was sporadically sighted in Prydz Bay and in the area of Mirny Station (Figure 9). This species was observed in the Pacific sector in open ocean (60° to 61°S, 158° to 160°W) and in the Balleny Islands area. The distribution pattern of the southern fulmar remained virtually unchanged in the Indian Ocean sector during the autumn. It was encountered infrequently and in small numbers (Figure 10).

5. CONCLUSIONS

Our study demonstrates the significant variability in the distribution of birds in Antarctica by numbers and species. The most abundant flocks were recorded in the Indian Ocean sector of the Southern Ocean where flocks of more than 3 000 birds were sighted. The second most prolific sector was the Atlantic Ocean sector and the third was the Pacific Ocean sector.

One reason for the existence of such large numbers of birds in the Indian Ocean sector is probably the close proximity of nesting areas and the presence of a plentiful and readily accessible food supply.

Many bird species did not form large flocks and tended to gather in small groups of between one and five specimens. Only the Antarctic, snow, white-chinned and cape petrels flocked together in their hundreds and even thousands.

The cape petrel was the dominant bird species over the greater part of the Atlantic Ocean sector over the observation period. In the Indian Ocean sector it was the Antarctic petrel and in the Pacific Ocean sector, the snow and Antarctic petrels.

The number of birds in the areas of the Weddell and Ross Sea ice massifs was much lower compared to areas free of ice and near the ice-edge.

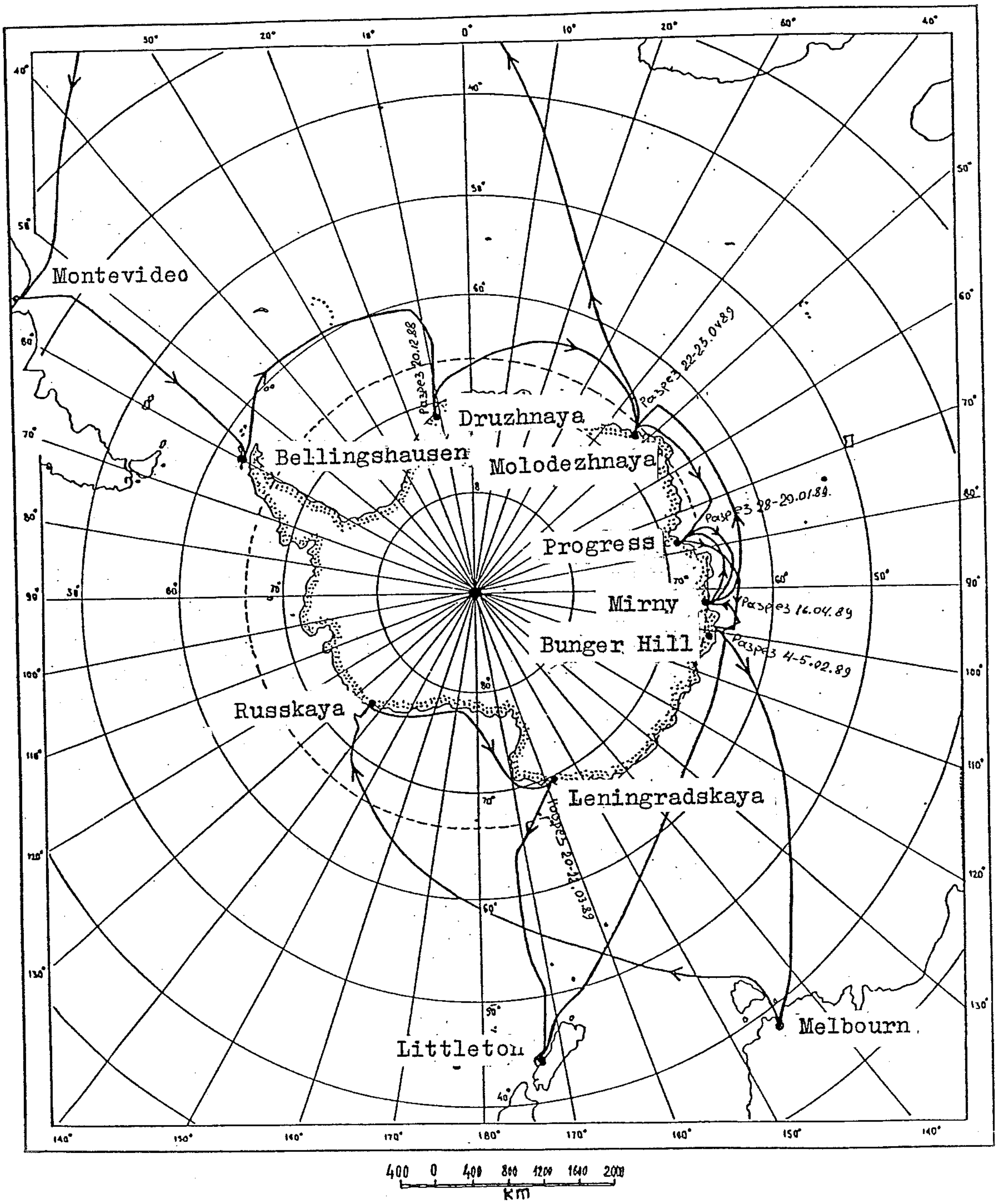


Figure 1: Cruise track of the RV *Akademik Fedorov* (1 November 1988 to 29 May 1989).

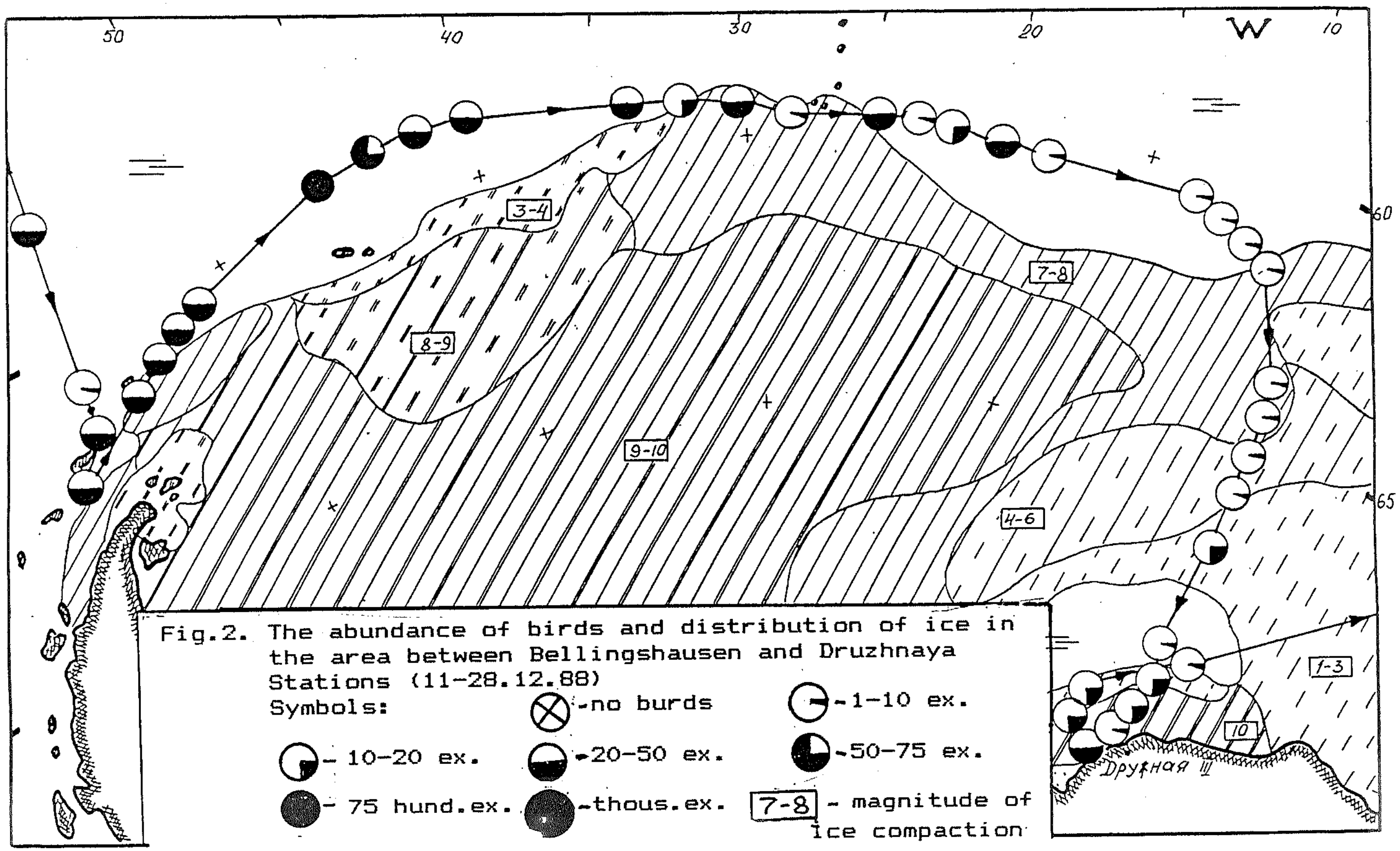


Figure 2: Bird abundance and ice distribution between Bellingshausen and Druzhnaya Stations (11 to 28 December 1988). Key: (1) no birds present; (2) 1 to 10 specimens; (3) 10 to 20 specimens; (4) 20 to 50 specimens; (5) 50 to 75 specimens; (6) 75 to hundreds of specimens; (7) thousands of specimens; (8) degree of areal ice density.

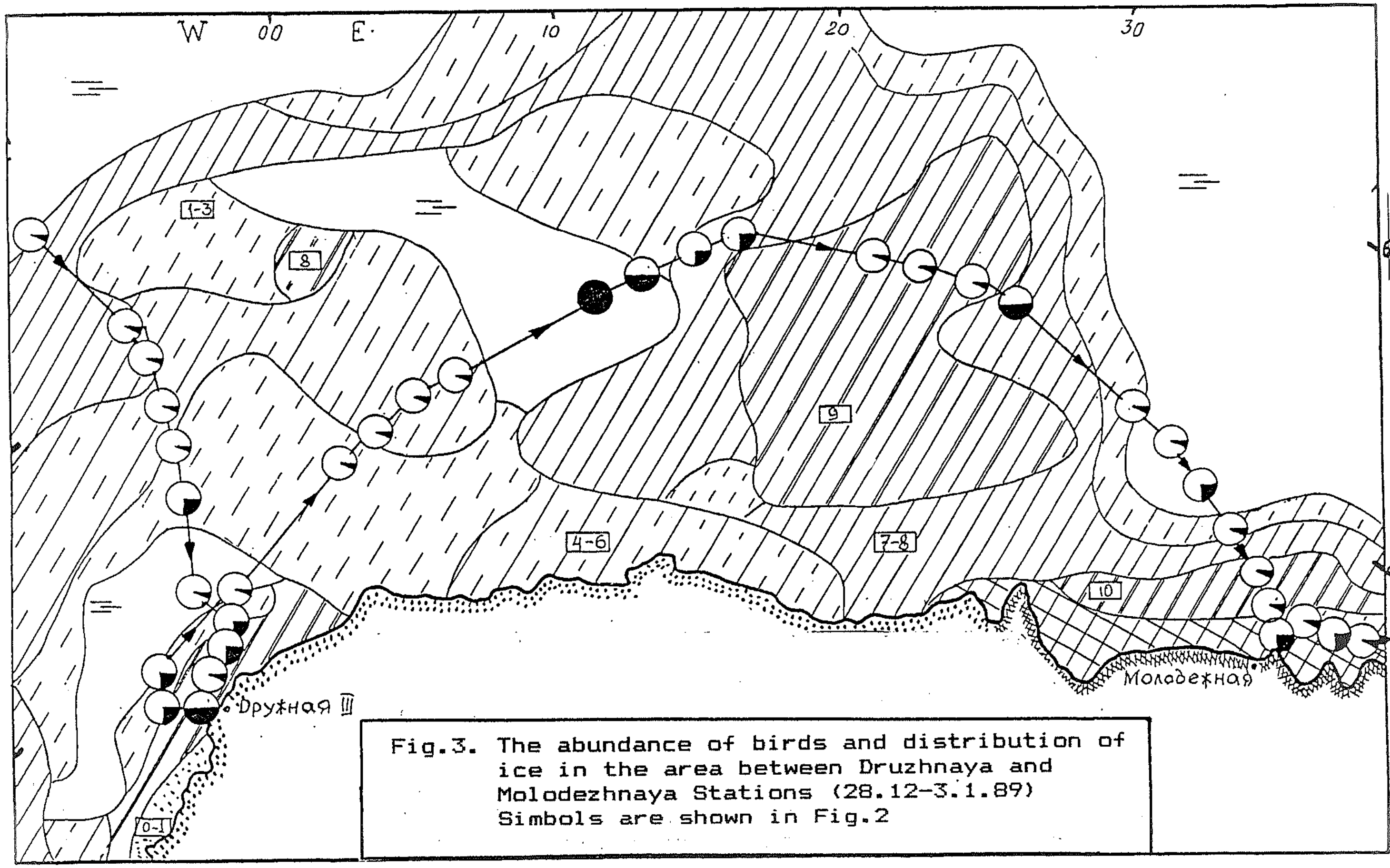


Figure 3: Bird abundance and ice distribution between Druzhnaya and Molodezhnaya Stations (28 December 1988 to 3 January 1989). (See Figure 2 for key).

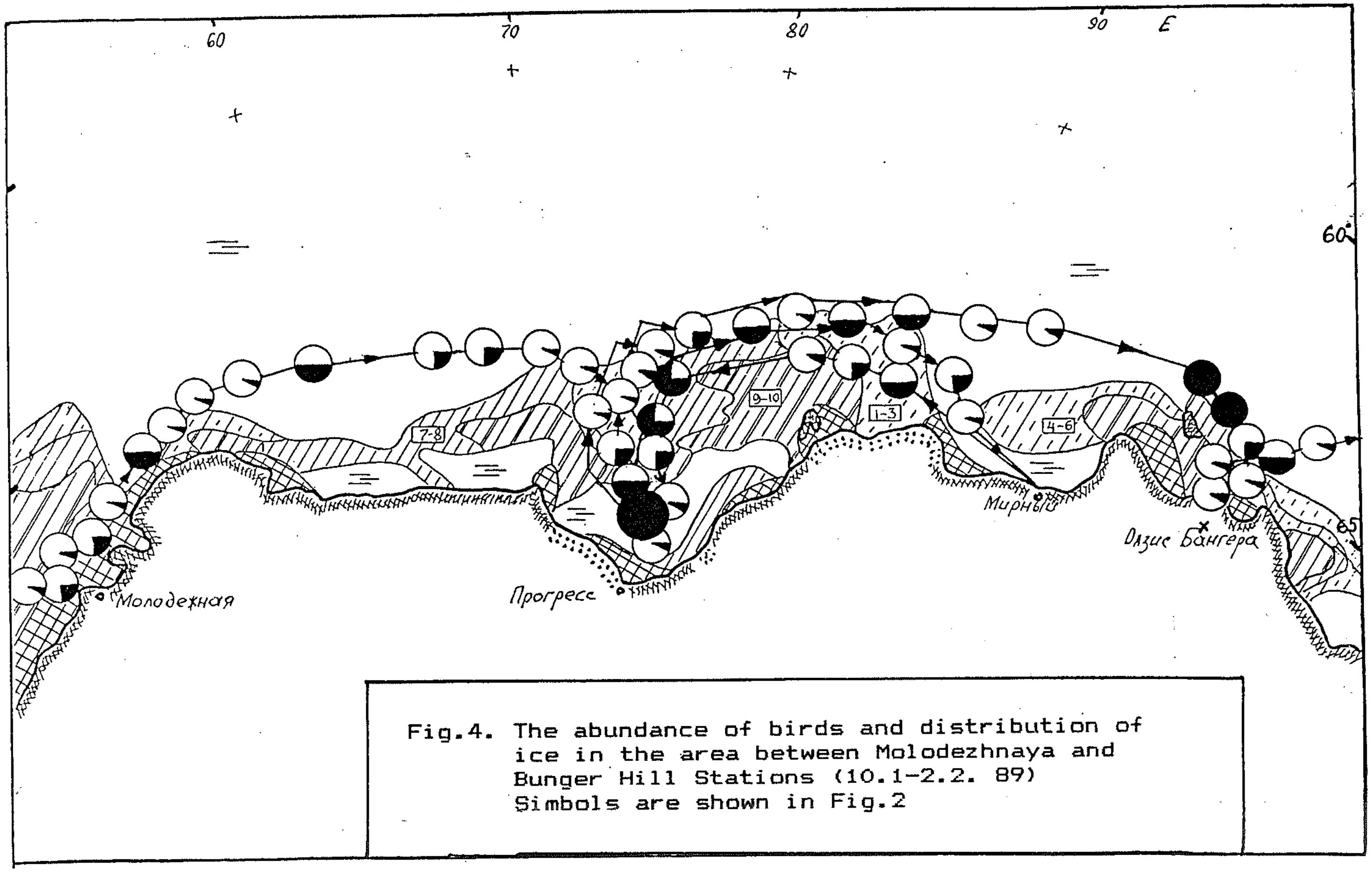


Fig.4. The abundance of birds and distribution of ice in the area between Molodezhnaya and Bunger Hill Stations (10.1-2.2. 89) Simbols are shown in Fig.2

Figure 4: Bird abundance and ice distribution between Molodezhnaya and Bunger Hills Stations (10 January to 2 February 1989). (See Figure 2 for key).

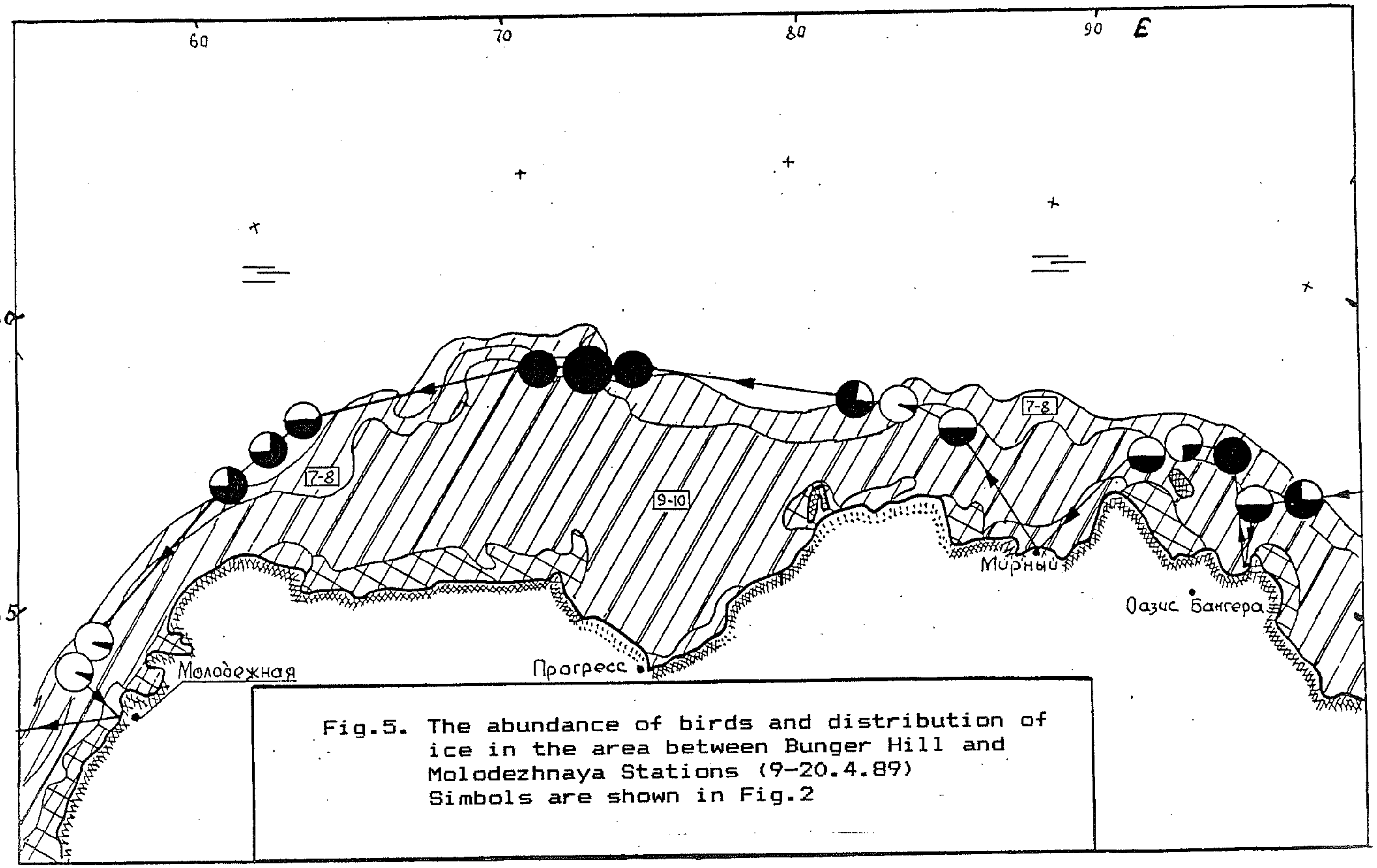


Fig.5. The abundance of birds and distribution of ice in the area between Bunger Hill and Molodezhnaya Stations (9-20.4.89) Simbols are shown in Fig.2

Figure 5: Bird abundance and ice distribution between Bunger Hills and Molodezhnaya Stations (9 to 20 April 1989). (See Figure 2 for key).

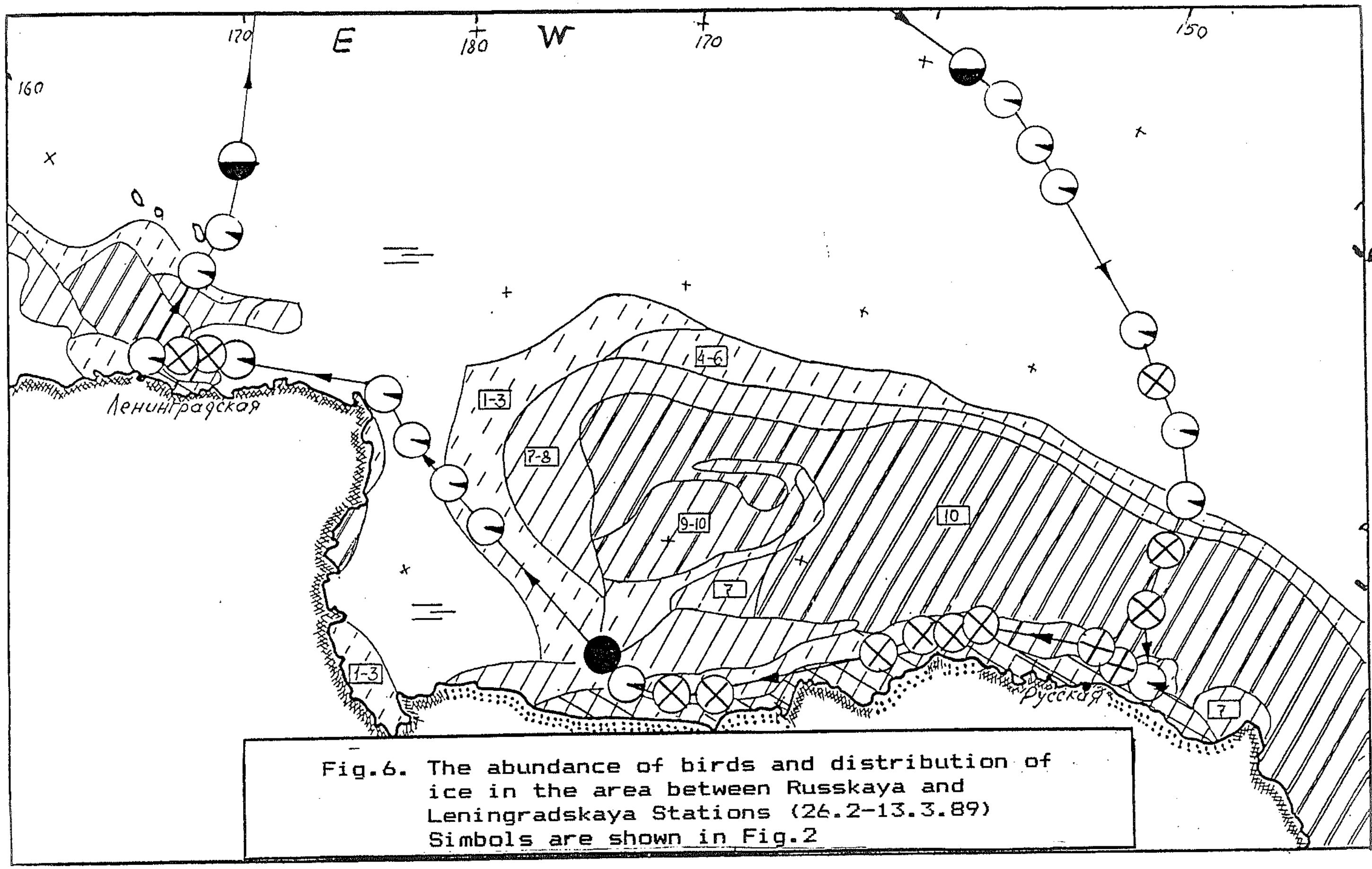


Fig.6. The abundance of birds and distribution of ice in the area between Russkaya and Leningradskaya Stations (26.2-13.3.89) Simbols are shown in Fig.2

Figure 6: Bird abundance and ice distribution between Russkaya and Leningradskaya Stations (26 February to 12 March 1989). (See Figure 2 for key).

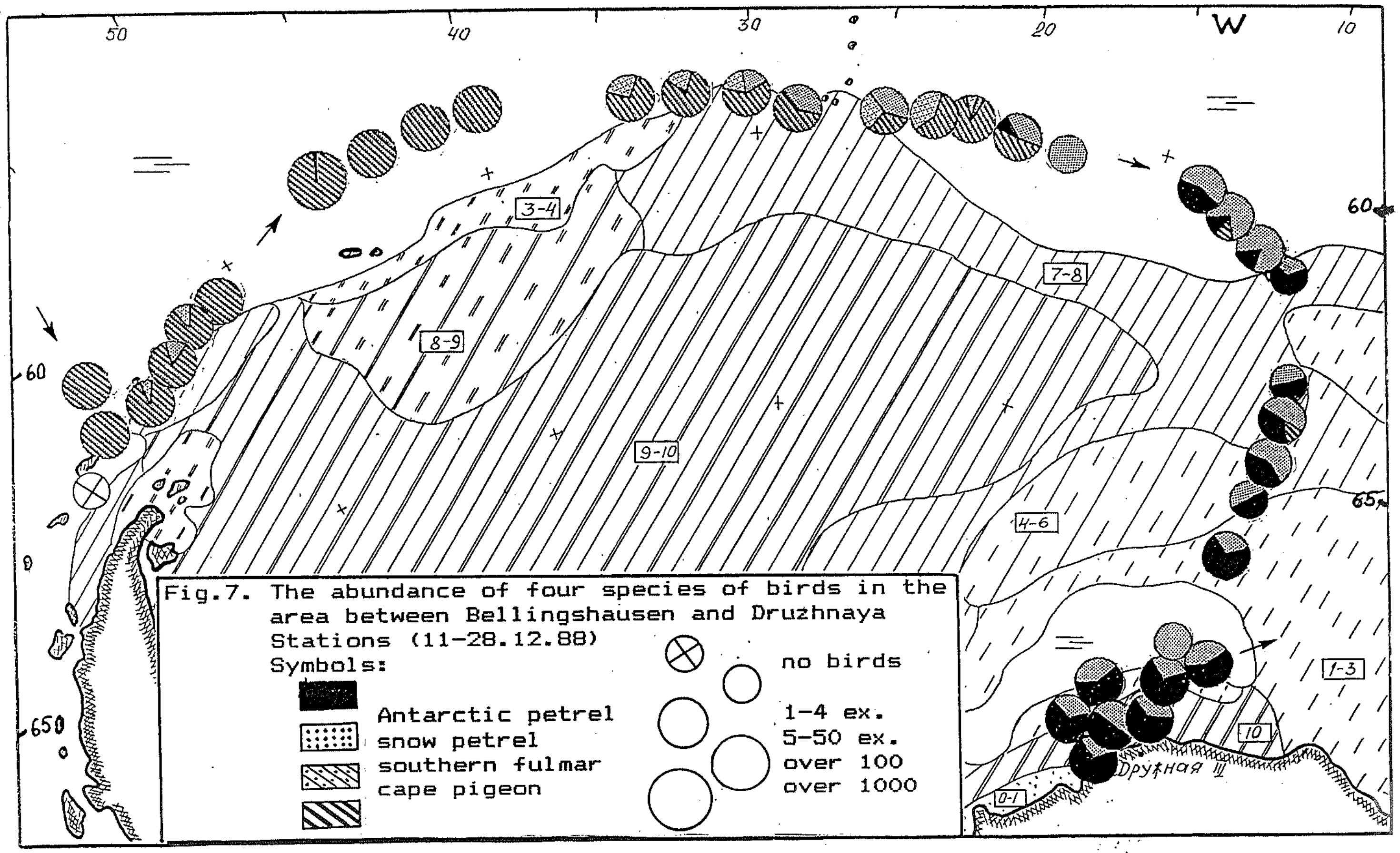


Figure 7: Ratio of abundance among four species of birds between Bellingshausen and Druzhnaya Stations (11 to 28 December 1988). Key: (1) Antarctic petrel; (2) snow petrel; (3) southern fulmar; (4) cape petrel; (5) no birds present; (6) 1 to 4 specimens; (7) 5 to 50 specimens; (8) over 100 specimens; (9) over 1 000 specimens.

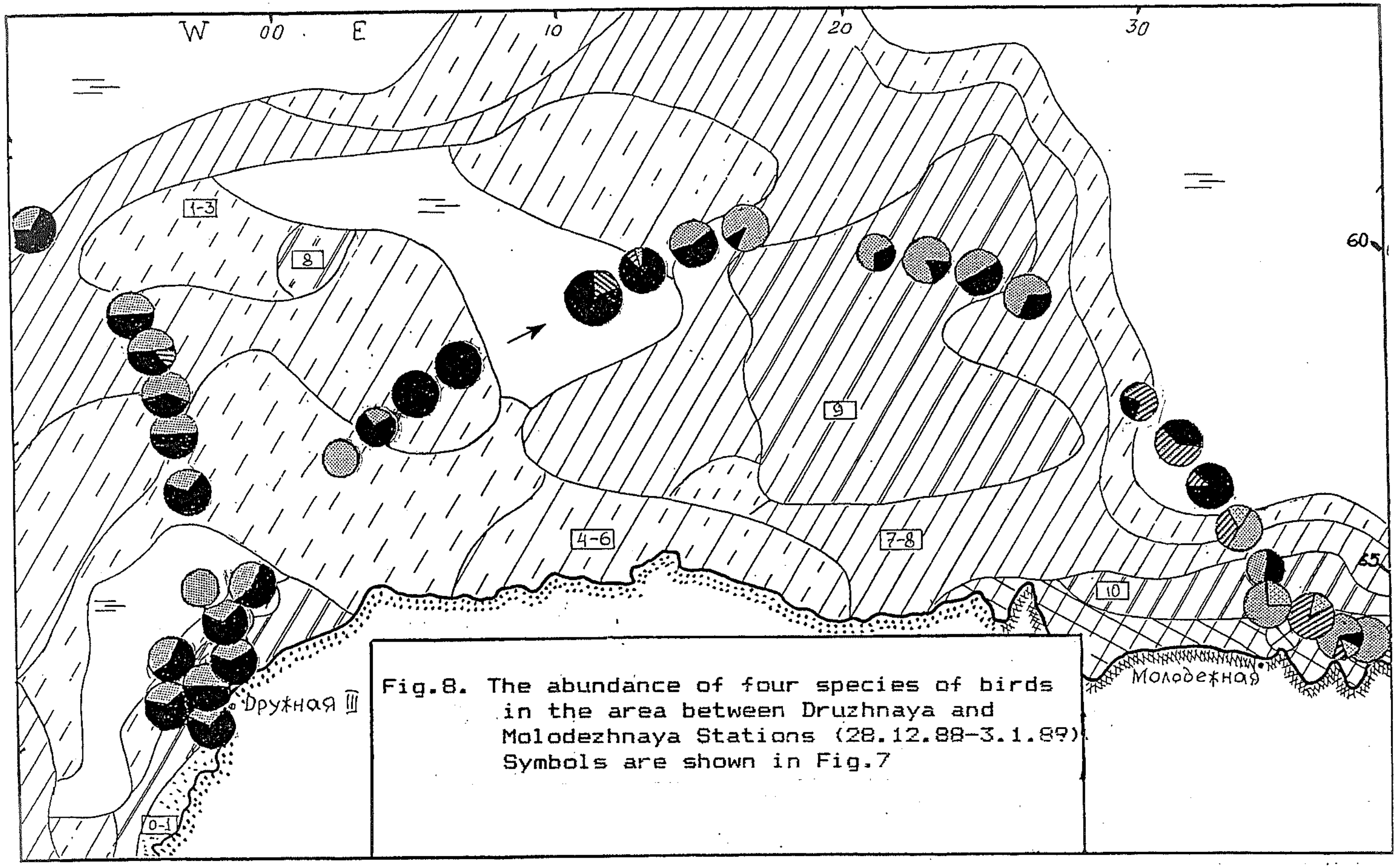


Figure 8: Ratio of abundance among four species of birds between Druzhnaya and Molodezhnaya Stations (28 December 1988 to 3 January 1989). (See Figure 7 for key).

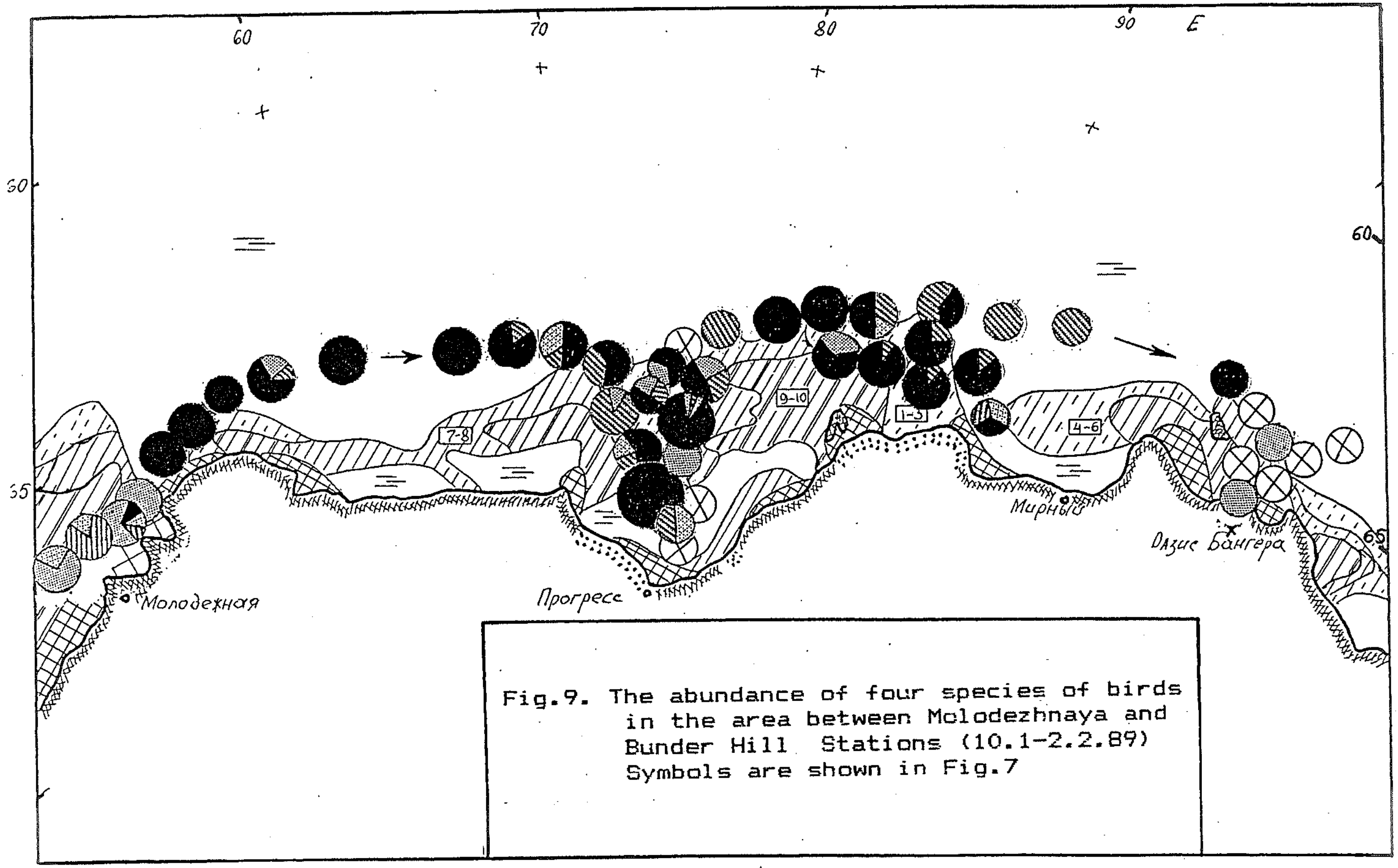


Figure 9: Ratio of abundance among four species of birds between Molodezhnaya and Bunger Hills Stations (10 January to 2 February 1989). (See Figure 7 for key).

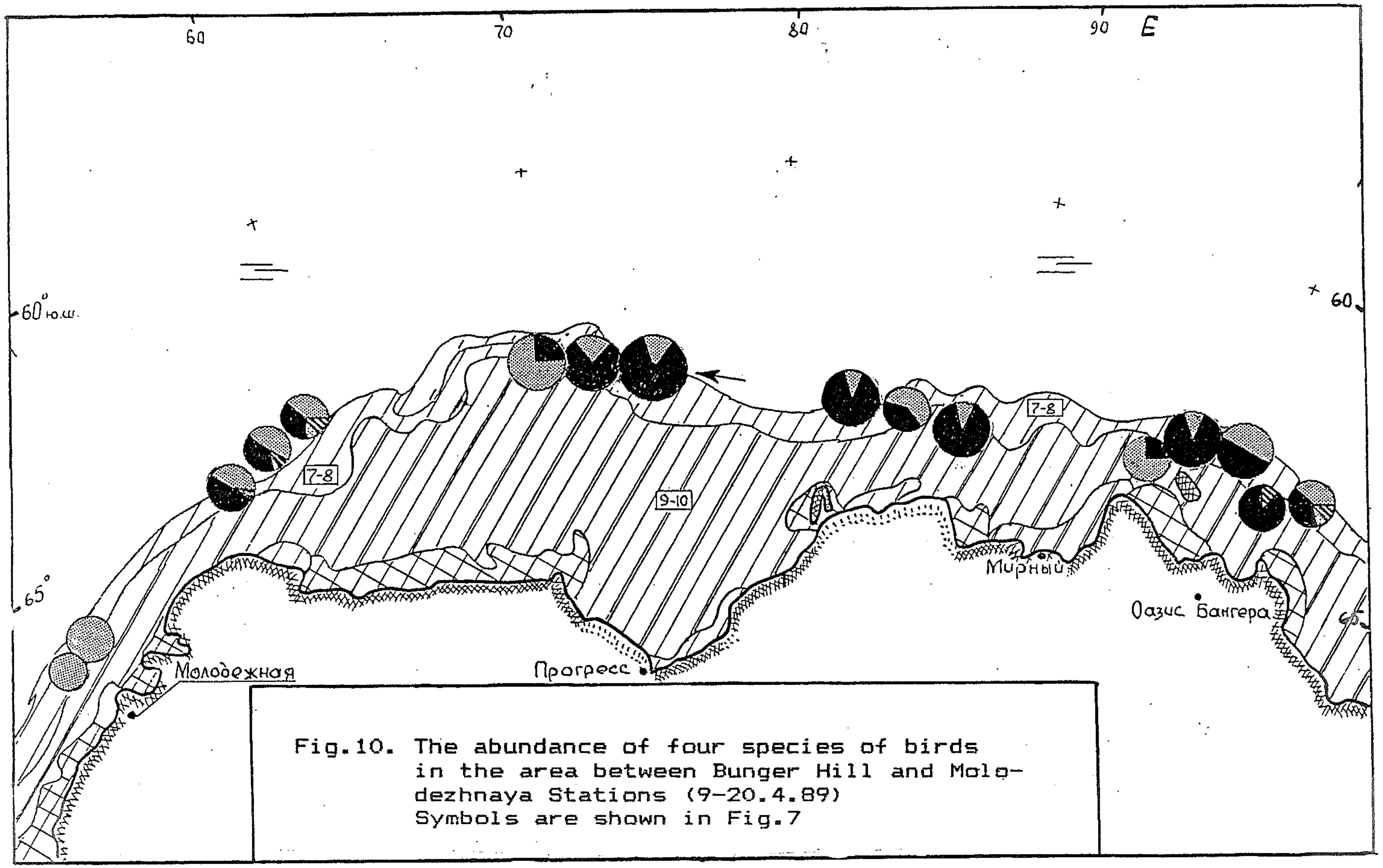


Fig.10. The abundance of four species of birds in the area between Bunger Hill and Molodezhnaya Stations (9-20.4.89) Symbols are shown in Fig.7

Figure 10: Ratio of abundance among four species of birds between Bunger Hills and Molodezhnaya Stations (9 to 20 April 1989). (See Figure 7 for key).

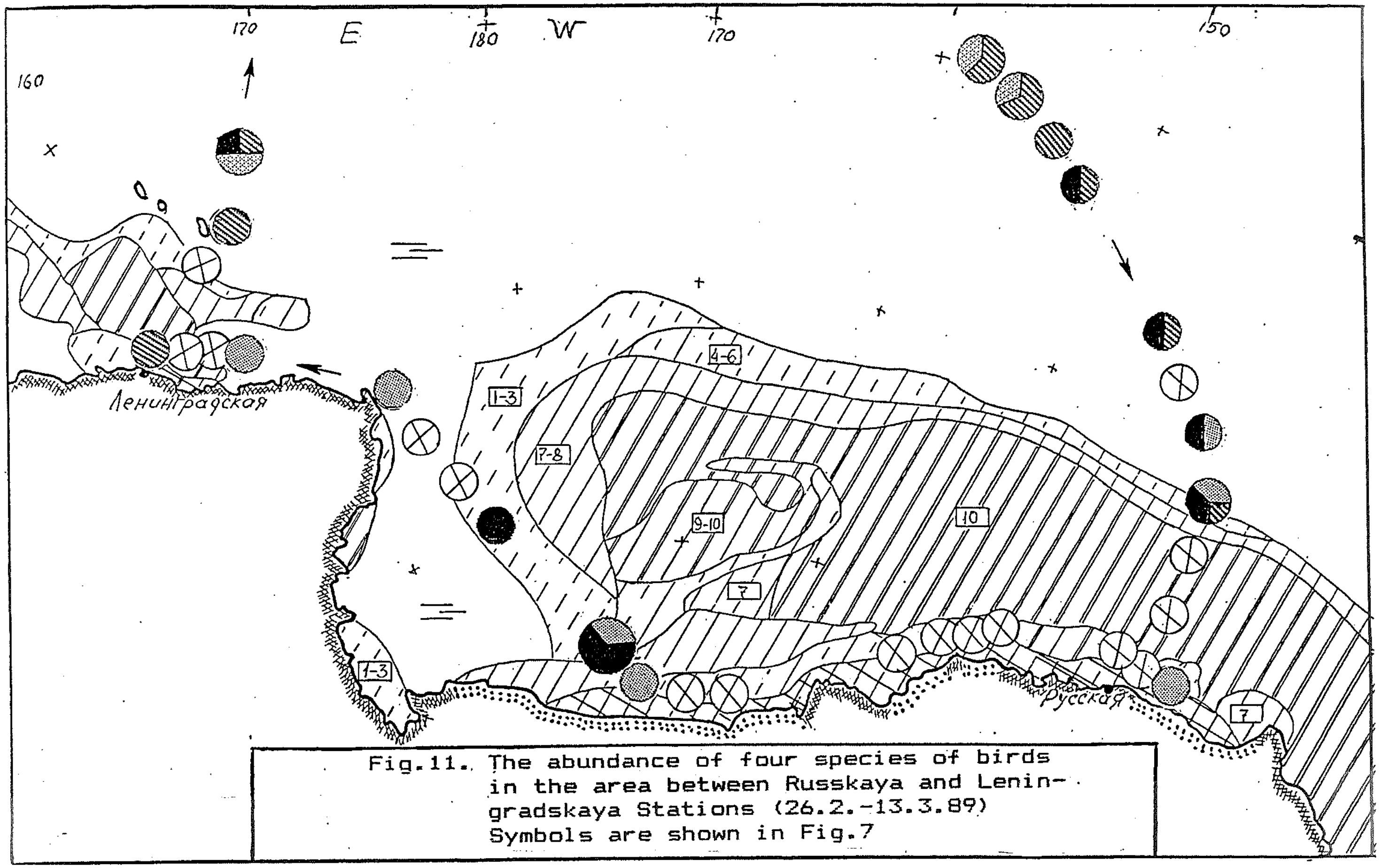


Fig.11. The abundance of four species of birds in the area between Russkaya and Leningradskaya Stations (26.2.-13.3.89) Symbols are shown in Fig.7

Figure 11: Ratio of abundance among four species of birds between Russkaya and Leningradskaya Stations (26 February to 12 March 1989). (See Figure 7 for key).

Liste des figures

Список рисунков

Рисунок 2: Численность птиц и распределение льдов на участке станция Беллингсгаузена - станция Дружная (11 - 28 декабря 1988 г.).
Условные обозначения: (1) - птиц нет; (2) - 1-10 экземпляров; (3) - 10-20 экземпляров; (4) - 20-50 экземпляров; (5) - 50-75 экземпляров; (6) - 75 - сотни экземпляров; (7) - тысячи экземпляров; (8) - сплоченность льдов.

Рисунок 3: Численность птиц и распределение льдов на участке станция Дружная - станция Молодежная (28 декабря 1988 - 3 января 1989гг.). (Условные обозначения - см. Рисунок 2).

Рисунок 4: Численность птиц и распределение льдов на участке станция Молодежная - станция Оазис Бангера (10 января - 2 февраля 1989г.). (Условные обозначения - см. Рисунок 2).

Рисунок 5: Численность птиц и распределение льдов на участке станция Оазис Бангера - станция Молодежная (9 - 20 апреля 1989 гг.). (Условные обозначения - см. Рисунок 2).

Рисунок 6: Численность птиц и распределение льдов на участке станция Русская - станция Ленинградская (26 февраля - 12 марта 989 гг.). (Условные обозначения - см. Рисунок 2).

Рисунок 7: Соотношение численности четырех видов птиц на участке станция Беллингсгаузена - станция Дружная (11 - 28 декабря 1988г.).
Условные обозначения: (1) - антарктический буревестник
(2) - снежный буревестник (3) - серебристо-серый буревестник
(4) - капский голубок (5) птиц нет (6) - 1-4 экземпляра; (7) - 5-50 экземпляров; (8) более 100 экземпляров; (9) более 1000 экземпляров.

Рисунок 8: Соотношение численности четырех видов птиц на участке станция Дружная - станция Молодежная (28 декабря 1988 - 3января 1989 гг.) (Условные обозначения- см. Рисунок 7).

Рисунок 9: Соотношение численности четырех видов птиц на участке станция Молодежная - станция Оазис Бангера (10 января - 2февраля 1989 г.) (Условные обозначения - см. Рисунок 7).

Рисунок 10: Соотношение численности четырех видов птиц на участке станция Оазис Бангера - станция Молодежная (9-20 апреля 1989г.). (Условные обозначения - см. Рисунок 7).

Рисунок 11: Соотношение численности четырех видов птиц на участке станция Русская - станция Ленинградская (26 февраля-12 марта 1989 г.) (Условные обозначения - см. Рисунок 7).

Lista de las figuras

Figura 1: Ruta del BI *Akademik Fedorov* (1° de noviembre de 1998 al 29 de mayo de 1989).

Figura 2: Distribución del hielo y la abundancia de aves entre las estaciones Bellingshausen y Druzhnaya (11 al 28 de diciembre de 1988).
Clave: (1) ausencia de aves; (2) 1 a 10 especímenes; (3) 10 a 20 especímenes; (4) 20 a 50 especímenes; (5) 50 a 75 especímenes; (6) 75 a 100 especímenes; (7) miles de especímenes; (8) grado de densidad del hielo en el área.

Figura 3: Distribución del hielo y la abundancia de aves entre las estaciones Druzhnaya y Molodezhnaya (28 de diciembre de 1998 al 3 de enero de 1988). (para la clave refiérase a la figura 2).

Figura 4: Distribución del hielo y la abundancia de aves entre las estaciones Molodezhnaya y Bunger Hills (10 de enero al 2 de febrero de 1989). (para la clave refiérase a la figura 2).

Figura 5: Distribución del hielo y la abundancia de aves entre las estaciones Bunger Hills y Molodezhnaya (9 al 20 de abril de 1989). (para la clave refiérase a la figura 2).

Figura 6: Distribución del hielo y la abundancia de aves entre las estaciones Russkaya y Leningradskaya (26 de febrero al 12 de marzo de 1989). (para la clave refiérase a la figura 2).

Figura 7: Razón de abundancia entre las cuatro especies de aves entre las estaciones Bellingshausen y Druzhnaya (11 al 28 de diciembre de 1988).
Clave: (1) petrel antártico; (2) petrel nevado; (3) petrel plateado; (4) petrel damero; (5) ausencia de aves; (6) 1 a 4 especímenes; (7) 5 a 50 especímenes; (8) más de 100 especímenes; (9) más de 1 000 especímenes.

Figura 8: Razón de la abundancia entre cuatro especies de aves entre las estaciones Druzhnaya y Molodezhnaya (28 de diciembre de 1988 al 3 de enero de 1989). (Para la clave refiérase a la figura 7).

Figura 9: Razón de la abundancia entre cuatro especies de aves entre las estaciones Molodezhnaya y Bunger Hills (10 de enero al 2 de febrero de 1989). (Para la clave refiérase a la figura 7).

Figura 10: Razón de la abundancia entre cuatro especies de aves entre las estaciones Molodezhnaya y Bunger Hills (9 al 20 de abril de 1989). (Para la clave refiérase a la figura 7).

Figura 11: Razón de la abundancia entre cuatro especies de aves entre las estaciones Russkaya y Leningradskaya (26 de febrero al 12 de marzo de 1989). (Para la clave refiérase a la figura 7).

SEXING OF ADULT ADELIE PENGUINS BY DISCRIMINANT ANALYSIS OF MORPHOMETRIC MEASUREMENTS

J.A. Scolaro*, Z.B. Stanganelli**, H. Gallelli* and D.F. Vergani**

Abstract

Discriminant analysis of eight morphometric measurements was used to determine the sex of Adélie penguins. A sample of 46 adult birds was taken for measurement from the breeding population at Stranger Point (King George/25 de Mayo Is., South Shetland Islands). The sex of each bird had been determined earlier by means of observing the birds' breeding behaviour (first incubation shift). It was found that the combination of flipper breadth, bill depth and length of the middle toe gave the most accurate sex discrimination (87% correct). Using measurements of flipper breadth and bill depth only also gave good results (80% correct).

Résumé

Une analyse discriminante de huit mensurations morphométriques a servi à identifier le sexe des manchots Adélie. Un échantillon de 46 adultes provenant des stocks reproducteurs de Stranger Point (île du Roi George / île 25 de Mayo, îles Shetland du Sud) a été mesuré. Le sexe de chaque oiseau a été précédemment déterminé par l'observation du comportement reproducteur (premier tour d'incubation). La combinaison de la largeur de l'aileron, de la hauteur du culmen et de la longueur du doigt médian a donné le facteur de discrimination du sexe le plus précis (correct à 87%). Si seules sont utilisées la largeur de l'aileron et la hauteur du culmen, la discrimination s'est également montrée satisfaisante (correcte à 80%).

Резюме

Для определения половой принадлежности пингвинов Адели использовался дискриминантный анализ результатов восьми морфометрических замеров. Измерялась выборка, состоящая из 46 половозрелых особей, взятая из размножающейся популяции, обитающей на мысу Стрейнджер-Пойнт острова Кинг-Джордж (острове 25-го Мая), Южные Шетландские острова. Половая принадлеж-ность каждой особи была предварительно установлена в результате наблюдений за поведением воспроизводства (первая инкубационная смена). Было установлено, что половую принадлежность птиц можно наиболее точно определить по комбинации замеров ширины крыла, высоты клюва и длины среднего пальца (87-процентная точность). При использовании только замеров ширины крыла и высоты клюва также были получены хорошие результаты (80-процентная точность).

* Centro Nacional Patagónico, Argentina

** Instituto Antártico Argentino, CERLAP, Calle 8 Number 1467, 1900 La Plata, Argentina

Resumen

Se utilizó un análisis discriminante de ocho medidas morfométricas para identificar el sexo de los pingüinos adelia. Se escogió una muestra de 46 aves adultas de las poblaciones reproductoras de Stranger Point (King George / isla 25 de Mayo, Islas Shetlands del Sur). El sexo de cada ave había sido determinado anteriormente mediante la observación del comportamiento reproductivo (primer turno de incubación). El conjunto de las mediciones del largo del dedo medio de la pata, la anchura de la aleta y el grosor del pico proporcionaron la determinación del sexo más precisa (87% certeza). Al utilizar solamente las mediciones de anchura de la aleta y del grosor del pico, también proporcionó buenos resultados (80% certeza).

1. INTRODUCTION

Penguins do not have any clear sexual dimorphism. Determination of penguin sex has been performed by using several techniques.

- Observation of birds' behaviour - Sladen, 1958 (Adélie penguins, *Pygoscelis adeliae*).
- External cloacal examination and observation of copulatory behaviour - Richdale, 1957 (yellow-eyed penguins, *Megadypted anitpodes*).
- Internal cloacal examination - Ainley *et al.*, 1983 (Adélie penguins), Samour *et al.*, 1983 (five species of penguins).

In Adélie penguins significant differences between sexes was also found in bill size (Ainley *et al.*, 1983).

The techniques listed above are very useful but during the breeding season they can be applied only after egg-laying. In many studies it would be necessary to know the sex of penguins on their arrival at the breeding colony.

A technique of sex determination in adult, fledgling and yearling Megellanic penguins, *Spheniscus magellanicus*, using discriminant analysis of morphometric measurements, was described by Scolaro, Hall and Ximenez (1983) and Scolaro (1987). In this paper the technique is extended to cover sex determination in adult Adélie penguins.

2. DESCRIPTION OF THE TECHNIQUE

A sample of 46 adult birds was used for the selection of appropriate morphometric variables for discriminant analysis. A sample was taken from a colony of Adélie penguins at Stranger Point (62°14'S, 58°40'W, King George/25 de Mayo Is., South Shetland Islands). The sex of birds (28 males and 18 females) was determined earlier by observing their breeding behaviour (first incubation shift).

For each individual, eight measurements were taken following the "Standard of Birds' Measurements" proposed by Baldwin *et al.* (1931) with some modifications suggested by Warham (1975). They were: flipper length of open wing (FL), flipper breadth at the widest point near the cubito-carpal joint (FB), length of the middle toe including nail (LM), arc between eyes from upper edges of eyes over the crown (AE), forehead arc between front of both eyes over the forehead at the base of the bill (FA), bill length equivalent to length of exposed culmen (LC), bill depth measured vertically at the nostrils (BD), bill width measured transversely at the nostrils (Figure 1).

Most variables were selected by their power to discriminate on a single canonical axis between two groups, males and females.

To obtain the discriminant function and the discriminant score between sexes the BMDP computer program (Dixon, 1981) was used for discriminant analysis.

BD (bill depth) was found to be the most significant discriminant variable followed by FB (flipper breadth) and LM (length of the middle toe). These three variables are uncorrelated and all have higher values for males. They could be related to behavioural differences between the sexes during the breeding season (Ainley *et al.*, 1983). In order to improve sex determination in the field and to eliminate non-relevant variables, a stepwise method was used for obtaining the smallest possible subset of significant variables for discriminating between sexes.

In practice, this means that the sex of an individual Adélie penguin can be determined simply by taking two or three standard measurements, combining them in a simple formula, and comparing the results with the constants shown in Table 1.

To verify the validity of this analysis, all the data were grouped and checked against the individual measurements of the sexed birds. This validation showed that 89.3% of the males and 83.3% of the females were classified correctly. Chi-square tests comparing predicted and observed results of sex identification gave highly significant estimates for all subsets considered ($P < 0.0001$).

In gentoo penguins, *Pygoscelis papua*, discriminant analysis of bill measurements gave 95.5% accuracy of correct determination (Williams, 1990). In Adélie penguins bill dimensions are not as useful as in gentoo penguins, and the discriminant analysis indicated that the best measurements for sex identification are flipper breadth (FB) and length of middle toe (LM).

Males can be distinguished from the females by bill, flipper and middle toe measurements. The larger bill size of males is doubtless related to its role in attack, defense and nest construction as it was found in other penguins (Stonehouse, 1971; Warham, 1975 and Scolaro, 1987).

ACKNOWLEDGEMENTS

We wish to thank C.A. Aguirre, R. Fontana and G. Soave for the measurements, M. Lucesole for the graphics, R. Kirkwood for the revision of the manuscript, J.P. Croxall for his comments and suggestions, and CERLAP for its assistance.

REFERENCES

AINLEY, D.G. and W.B. EMISON. 1972. Sexual dimorphism in Adélie penguins. *Ibis 114*: 267-271.

AINLEY, D.G., R.E. LARESCHE and W.J.L. SLADEN. 1983. *Breeding Biology of the Adélie Penguin.* USA: University of California Press.

BALDWIN, S.P., H.C. HOBERHOLSER and L.G. WORLEY. 1931. Measurements of birds. *Scientific Publications of the Cleveland Museum of Natural History* 2: 1-165.

DIXON, W.J. 1981. *BMDP Biomedical Computer Programs*. USA: University of California Press.

RICHDALE, L.E. 1957. *A Population of Penguins*. UK: Oxford Clarendon Press.

SAMOUR, H.J., M. STEVENSON, J.A. KNIGHT, A.J. LAWRIE. 1983. Sexing penguins by cloacal examination. *The Veterinary Record*. pp. 84-85.

SCOLARO, J.A., M.A. HALL and I.,. XIMENEZ. 1983. The Magellanic penguin (*Spheniscus magellanicus*): Sexing adults by discriminant analysis of morphometric characters. *Auk 100*: 221-224.

SCOLARO, J.A. 1987. Sexing fledglings and yearlings of Magellanic penguins by discriminant analysis of morphometric measurements. *Colonial Waterbirds, 10*(1): 50-54.

SLADEN, W.J.L. 1958. The pygoscelid penguins. I: Methods of Study, II. The Adélie penguin, *Pygoscelis adeliae* (Hornbrom and Jaquinot). *Falkland Is. Depend. Surv. Sci. Rep. 17*: 1-97.

STONEHOUSE, B. 1971. The Snares Islands penguin *Eudyptes robustus*. *Ibis 113*: 1-7.

WARHAM, J. 1975. The crested penguins. In: STONEHOUSE, B. (Ed.). *The Biology of Penguins*. UK: Macmillan Press. pp. 189-269.

WILLIAMS, T.D. 1990. Annual variation in breeding biology of gentoo penguins, *Pygoscelis papua*, at Bird Island, South Georgia. *Journal of Zoology*, London. p. 222.

Table 1: Results of sex determination in adult Adélie penguins by means of discriminant analysis.

Variables	FB (Flipper Breadth) BD (Bill Depth)	FB (Flipper Breadth) BD (Bill Depth) LM (Length Middle Toe)
Discriminant function	W = 0.428 FB + 1.40 BD	W = 0.348 FB + 1.46 BD + + 0.311 LM
Discriminant function score	C = 49.64	C = 70.52
% of correctly classified birds	80.4%	87.0%

If W > C the sex is male
If W < C the sex is female
If W = C the sex is indeterminate

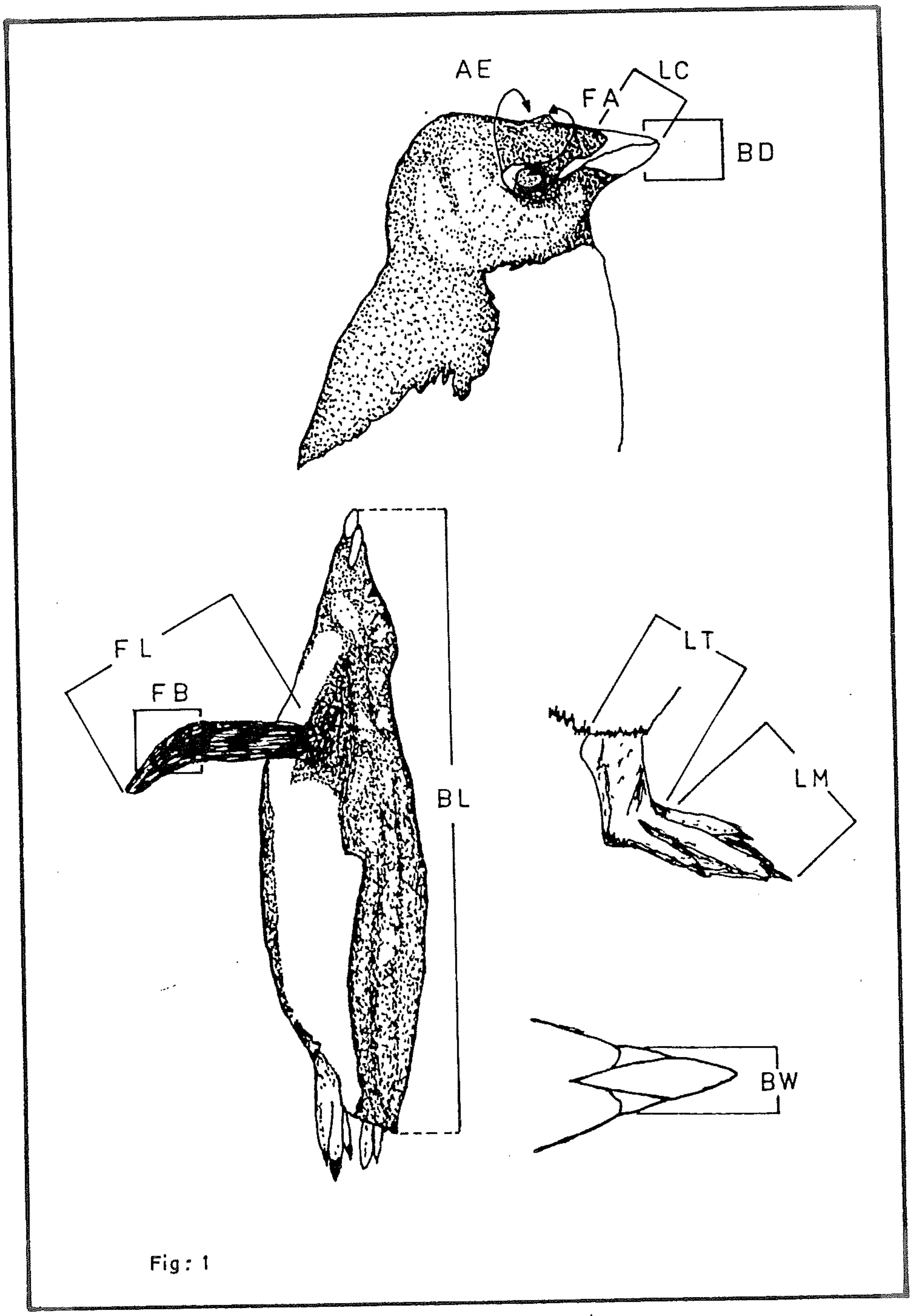


Figure 1: Adélie penguin, schematic illustration of variables measured to differentiate sex. BL - body length, FL - flipper length, FB - flipper breadth, LT - tarsus length, LM - length of middle toe, AE - arc between eyes, FA - forehead arc, LC - bill length, BD - bill depth, BW - bill width.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras

OPTIMIZATION OF SURVEY SAMPLING DESIGN IN THE DETECTION OF INTERANNUAL VARIABILITY AND PREY SIZE SELECTIVITY IN THE DIET OF PENGUINS

E. Marschoff and B. Gonzalez*

Abstract

Based on the preliminary results of a survey of prey size in Adélie penguins, sampling designs intended for the detection of interannual variations in mean prey size and penguin size-related selectivity were analyzed in order to find the optimal allocation of observations at each level in nested ANOVA designs. The optimal numbers of penguins and krill to be used in the detection of interannual variability in the parameters concerned are recommended and a required sampling protocol is suggested.

A table of minimal numbers of penguins to be sampled as a function of number of sampling dates and magnitude of the variance component is given, under the assumptions of balanced design and the variance component of "penguin-by-date" interaction equal to the variance component of "penguin-within-dates" obtained from a previous study in Bahía Esperanza.

Restrictions have been fixed in accordance with the recommendations of the fourth meeting of WG-CEMP: minimum interannual variation for mean prey size is fixed at 10%; the test power is taken as 0.9 and Type I errors fixed at 0.1.

Cost values of manpower required are based on Argentinian logistics.

Résumé

Les modèles d'échantillonnage destinés à la détection des variations interannuelles de la taille moyenne des proies et de la sélectivité en fonction de la taille des manchots sont analysés sur la base des résultats préliminaires de la taille des proies chez les manchots Adélie, pour une allocation optimale des observations à chaque niveau des modèles ANOVA à emboîtement. Le nombre optimal de manchots et d'individus de krill à utiliser pour la détection de la variabilité interannuelle est recommandé, et un protocole d'échantillonnage suggéré.

Un tableau du nombre minimal de manchots à échantillonner en fonction du nombre de dates d'échantillonnage et de l'ampleur de la variance est donné, en présumant : un modèle équilibré et l'interaction d'une variance des "manchots-par-dates" égale à la variance des "manchots-individuels-sur-un-même-jour" obtenue à Bahia Esperanza, lors d'une étude antérieure.

* Instituto Antártico Argentino, Dirección Nacional del Antártico, Cerrito 1248, 1010 Buenos Aires, Argentina

Des restrictions ont été établies conformément aux recommandations de la quatrième réunion du WG-CEMP : la variation interannuelle minimale de taille moyenne des proies est fixée à 10%; la puissance du test est fixée à 0.9 et les erreurs de type I à 0.1.

Les coûts de la main-d'œuvre sont fonction des normes argentines.

Резюме

На основании предварительных результатов исследования размерного состава видов, потребляемых пингвином Адели, схемы сбора проб в целях выявления межгодовых изменений среднего размера потребляемых видов и размерной селективности пингвинов анализируются с точки зрения оптимальной интенсивности наблюдений на каждом уровне гнездовых схем. Предлагаются оптимальные размеры проб криля и выборок пингвинов для выявления межгодовой изменчивости рассматриваемых параметров и схема взятия проб.

Приведена таблица, в которой указывается зависимость минимального размера выборки пингвинов и количества дней сбора проб, а также величина коэффициента изменчивости, исходя из того, что схема сбалансирована и изменчивость связи "количество пингвинов в выборке - количество дней сбора проб" равна изменчивости элемента "количество пингвинов, обследованное в течение определенного периода", выявленной в ходе предыдущего исследования в заливе Эсперанза.

Ограничения были установлены в соответствии с указаниями Четвертого совещания Рабочей группы по СЕМР: минимальное межгодовое изменение среднего размера потребляемых видов было установлено на уровне 10%; чувствительность принята за 0,9 и уровень погрешностей типа I - 0,1.

Стоимость необходимой рабочей силы основана на данных по аргентинскому материально-техническому обеспечению.

Resumen

Basándose en los resultados de estudios preliminares del tamaño de las especies-presa en la dieta de los pingüinos adelia, para encontrar la asignación óptima de las observaciones para cada nivel de los diseños anidados ANOVA, se han analizado los diseños de muestreo dirigidos a la detección de las variaciones interanuales entre el tamaño medio de la presa y la selectividad correspondiente de acuerdo al tamaño del pingüino. Se recomiendan las cantidades óptimas de pingüinos y de krill que han de emplearse para la detección de la variabilidad interanual en los parámetros relacionadso y se sugiere un protocolo de muestreo.

Se presenta una tabla detallando la cantidad mínima de pingüinos de los cuales se deben tomar muestras en función del número de fechas de muestreo y de la magnitud del componente de varianza, suponiendo que: el diseño está equilibrado y el factor de varianza de la interacción del "pingüino a la fecha" es igual al factor varianza del "pingüino entre fechas" obtenido de un previo estudio realizado en la bahía Esperanza.

Las limitaciones han sido fijadas de acuerdo a las recomendaciones de la cuarta reunión del WG-CEMP: la variación mínima interanual para el tamaño medio de las especies-presa se fija en un 10%; la prueba de potencia se considera en 0.9 y los errores Tipo I se fijan en 0.1.

El costo del personal requerido se basan en la logística argentina.

1. INTRODUCTION

In a previous paper (Marschoff and Gonzalez, 1989) a preliminary analysis of stomach contents of Adélie penguins from Bahía Esperanza was made using a nested ANOVA design with data grouped by dates, "penguins-within-dates" and "krill-within-penguins". These data do not allow detection of the variability due to penguin selectivity because the design used was not intended to calculate the "penguin-by-dates" interaction. Taking account of the 1989 deliberations of the Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP), the present paper develops a sampling protocol for the optimal allocation of observations at each sampling level.

Noting that penguin selectivity not only might affect monitoring results but also has a biological interest of its own, a suitable sampling design for its detection is also discussed.

2. DETECTION OF INTERANNUAL VARIATIONS IN THE MEAN SIZE OF KRILL EATEN BY PENGUINS

At the 1989 Meeting of WG-CEMP, the desirable minimum size of changes to be detected was set at 10% of the parameter values. A value of 0.9 was suggested for the test power (probability of obtaining a significant result).

In the nested ANOVA design, discussed in Marschoff and Gonzalez (1989), comparison between years results naturally in a new level added at the top. Exact **F** tests are obtained dividing the mean square for "years" group by the mean square for "dates-within-years" group.

Given the costs of sampling at each level, it is possible to define a sampling protocol achieving the desired test power while minimizing cost. We will present the calculations made for the completely balanced case, along the lines discussed in Bliss (1967). The resulting design should be adjusted for different cost structures and ancillary objectives of the field work. In the present calculations manpower in Antarctica was estimated as four times as expensive as on the mainland.

In our design (4-level nested Model II ANOVA), the expected mean square for "years" group is:

$$E(MSY) = \sigma^2_{KCP} + n_K \cdot \sigma^2_{PCD} + n_p \cdot n_K \cdot \sigma^2_{DCY} + n_D \cdot n_P \cdot n_K \cdot \sigma^2_Y \quad (1)$$

where σ^2_{KCP} is the variance component of the "krill-within-penguins" group,

n_K is the number of krill measured in each penguin sampled,
σ^2_{PCD} is the variance component of "penguins-within-dates" group,

n_P is the number of penguins sampled each day,
σ^2_{DCY} is the variance component of "dates-in-years" group,

n_D is the number of sampling days, and
σ^2_Y the variance component due to differences between years.

The expected values for the variance components and their 80% confidence intervals have been extracted from Table 3 of Marschoff and Gonzalez (1989):

Variance Component	Expected Value	80% Confidence Lower	Interval Limits Upper
σ^2_{KCP}	44.1661	42.54	45.93
σ^2_{PCD}	10.2986	7.33	14.98
σ^2_{DCY}	32.6738	12.91	51.62

The cost associated with each determination of the annual mean results from the sum of costs at the different levels. We included the additional cost for the first unit of sub-samples (first sample from a penguin during the day or first sample of a "krill-within-a-penguin" group) at the higher sampling level.

The yearly cost (C) of estimating the mean size of krill eaten by penguins at a given site is:

$$C = n_D \,.\, C_D + n_D \,.\, n_P \,.\, C_P + n_D \,.\, n_K \,.\, C_K$$

where C_D is the cost associated with each sampling day; not related to the number of penguins sampled. It is dependent on the location of colonies, other sampling programs to be carried out on the same colonies, etc. For Esperanza Base it was estimated on the basis of two people working for two and a half hours;

C_P is the cost of catching, sampling of a stomach content and labelling a penguin. Depending on methods, experience, etc, for Esperanza Base it was estimated based on two people working for 20 minutes; and the laboratory time was one person working for one hour to sort and clean the well-preserved fraction of stomach content; and

C_K is the cost of measuring and processing the measurements of one krill specimen. Actually it takes us about four to five minutes, but by means of automating the recording procedure reduces this to two and a half minutes.

C should also include costs which are not directly dependent on the design, e.g. transportation, food, etc.

The optimal numbers of penguins and krill (those yielding maximum information at a fixed cost) were calculated from:

$$n_P^* = \sqrt{\frac{C_D \cdot \sigma^2_{PCD}}{C_P \cdot \sigma^2_{DCY}}} = 1.89$$

$$n_K^* = \sqrt{\frac{C_P \cdot \sigma^2_{KCP}}{C_K \cdot \sigma^2_{PCD}}} = 20.71$$

These optimal numbers are sensitive to errors in a ratio between variance components. For this reason, 80% confidence limits were used in order to achieve the desired power of the test. In our case, the upper limit for optimal numbers has been calculated using the following expressions, where sub-indices **u** and *l* indicate the upper and lower limits of confidence intervals respectively:

$$n_P^* \leq \sqrt{\frac{C_D . \sigma^2_{PCD,u}}{C_P \cdot \sigma^2_{DCY,l}}} = 2.63 \leq 3$$

$$n_K^* \leq \sqrt{\frac{C_P . \sigma^2_{KCP,u}}{C_K \cdot \sigma^2_{PCD,l}}} = 25.03 \leq 26$$

A 10% change in the mean of two years results in the following variance component due to interannual differences:

$$\sigma^2_Y = 2(0.05\,\hat{\mu})^2$$

The parametric mean length (μ) of "krill-within-penguins" group, was estimated for Bahía Esperanza as 38.41 mm. This means that the value of σ^2 which we wish to detect will be 7.350.

From (1) the σ^2_Y can be expressed as a function of $\mathbf{n_D}$ and the expected mean square for "dates" group E(MSD):

$$E(MSD) = \sigma^2_{KCP} + n_K \cdot \sigma^2_{PCD} + n_P \cdot n_K \cdot \sigma^2_{DCY}$$

Using the formulae for confidence intervals of variance components in an iterative procedure (Bliss, 1967, p. 259), the minimal value of $\mathbf{n_D}$ yielding a 90% confidence interval for σ_Y^2 resulted in n=16. This value defines the size of sub-samples at the year level assuring a test power of 0.9 for the detection of a 10% variation in the mean size of krill eaten by penguins. Finally, the suggested sampling protocol is:

> Sample during the crèche period on 16 selected days at random. On each day, three stomach contents of randomly selected penguins should be obtained including at least 26 well-preserved krill specimens the measurements of which are to be recorded.

The value obtained for $\mathbf{n_K}$ (number of krill in a stomach) seems to be relatively low. As these data might be used for other purposes, we recommend that either all krill present be recorded or that the sample be kept for further use. This model should be revised in view of the results of the penguin selectivity analysis.

3. TESTING PENGUIN SELECTIVITY

If extant, size selectivity of krill by penguins will result in a significant random factor. When isolated in an appropriate Model II design, this factor will yield a variance component for penguins significantly different from zero (σ_P^2).

A suitable design for such analysis is the two way Model II ANOVA where dates and penguins are crossed; the mean squares of factors should be tested against the mean squares of the "penguin-by-dates" interaction. The expressions for the expected mean squares are:

$$E(MSD) = \sigma_K^2 + n_K \cdot \sigma_{PXD}^2 + n_P \cdot n_K \cdot \sigma_D^2$$

$$E(MSP) = \sigma_K^2 + n_K \cdot \sigma_{PXD}^2 + n_D \cdot n_K \cdot \sigma_P^2$$

$$E(MSPxD) = \sigma_K^2 + n_K \cdot \sigma_{PXD}^2$$

$$E(MSE) = \sigma_K^2$$

We estimated that the variance component due to "krill-within-penguins" interaction as σ_K^2=44.1661 (Marschoff and Gonzalez, 1989) and the upper limit for the "penguins-by-dates" variance component as:

$$\sigma_{PXD}^2 \leq \sigma_{PCD}^2$$

We assumed that $\sigma_{PXD}^2 \leq \sigma_{PCD}^2$ in the estimation of sample sizes would result in a test power at least equal to that required. The sample sizes obtained should therefore be considered as upper limits for the optimal values. Table 1 was constructed for different values of the penguin variance component based on the abovementioned assumption.

It is to be noted that this design requires all penguins involved to be sampled on the same dates. As this is not possible because of the differences in penguin return dates, the actual design will be incomplete. This results in a test power loss which cannot be estimated without the actual values (return date is in itself a random variable) and using more complicated designs. Therefore, $\mathbf{n_P}$ and $\mathbf{n_D}$ values should be considered only as a guide for field work.

The cross-classification Model II ANOVA might also be used for the comparison between fresh and digested fractions of stomach contents. In this case we have an extra component of variance coming from variation in meal times. This component will be a part of the interaction and cannot be assessed without direct information on its magnitude. Thence, at least a preliminary set of field data is needed to proceed with this line of investigation.

REFERENCES

BLISS, C.I. 1967. *Statistics in Biology. Vol I.* McGraw Hill Book Company.

MARSCHOFF, E. and B.N. GONZALEZ. 1989. The use of penguin stomach contents for the simultaneous study of prey and predator parameters. In: *Selected Scientific Papers, 1989 (SC-CAMLR-SSP/6)*. Hobart, Australia: CCAMLR. pp. 367-376.

Table 1: Numbers of penguins to be sampled as a function of number of sampling dates and variance component due to differences between penguins. Test power fixed at 0.9.

Variance Component	Number of Sampling Dates														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10.298	13	6	4	3	3	2	2	2	2	2	2	2	2	2	2
7.3750	19	8	5	4	3	3	2	2	2	2	2	2	2	2	2
3.2674	60	22	13	8	6	5	4	4	3	3	3	3	2	2	2
1.0298	434	150	78	48	34	25	19	16	13	11	10	9	8	7	6

Liste des tableaux

Список таблиц

Lista de las tablas

INVESTIGATIONS OF REQUIRED SAMPLING REGIMES FOR ENVIRONMENTAL PARAMETERS

D.J. Agnew*

Abstract

The sensitivity of different sampling regimes in identifying interannual changes in environmental parameters was investigated using environmental data from Davis Station, Antarctica, from 1985 to 1987. Strong daily, depressional (4 to 5 days) and yearly cycles were seen in temperature, wind speed and pressure. Sampling daily maxima and minima would be sufficient to detect a 2 to 3°C change in monthly mean temperature over two years with a significance α of 0.05 and a power **P** of 0.8. Sampling wind speed continuously or as daily maxima and minima would be sufficient to detect a 10 to 20% change in monthly mean log-transformed wind speed α of 0.05 and **P** of 0.9.

Résumé

La sensibilité des différents régimes d'échantillonnage pour l'identification des changements interannuels dans les paramètres de l'environnement a été examinée à l'aide des données de l'environnement de la station Davis, Antarctique, de 1985 à 1987. D'importants cycles journaliers, dépressionnaires (4 à 5 jours) et annuels ont été notés pour la température, la force du vent et la pression atmosphérique. Il suffirait d'échantillonner les températures journalières maximales et minimales pour déceler une variation de 2-3°C dans la température mensuelle moyenne sur deux ans avec une signification α de 0.05 et P de 0.8. Un relevé continu de la force du vent ou des vitesses maximales et minimales journalières suffirait à déceler un changement de 10-20% dans la vitesse moyenne du vent transformée par calcul logarithmique avec α de 0.05 et P de 0.9.

Резюме

Чувствительность различных режимов регистрации данных при выявлении межгодовых изменений параметров окружающей среды была изучена на примере данных, полученных на станции Дейвис, Антарктика, за период с 1985 по 1987 гг. Изменения температуры, скорости ветра и атмосферного давления характеризовались ярко выраженными суточными, депрессионными (4-5 дней) и годовыми циклами. Регистрации ежедневных максимальных и минимальных показателей достаточно для выявления изменения среднемесячной температуры в 2-3°C на протяжении двух лет при значимости α в 0,05 и **P** в 0,8. Для того, чтобы выявить 10-20% изменения в среднемесячном

* CCAMLR Secretariat, 25 Old Wharf, Hobart, Tasmania, 7000

логарифме скорости ветра при α=0,05 и **P**=0,9 достаточно постоянно регистрировать скорость ветра или регистрировать ежедневные минимальные и максимальные показатели скорости ветра.

Resumen

A partir de los datos ambientales de los años 1985 a 1987 procedentes de la estación antártica de Davis, se analiza la sensibilidad de distintos métodos de muestreo para determinar los cambios interanuales de los parámetros del medio ambiente. Se observan marcados ciclos diarios, anticiclónicos (4 a 5 días) y anuales de la temperatura, la velocidad del viento y la presión. El muestreo diario de la máxima y mínima bastaría para detectar un cambio mensual en la temperatura mínima media de 2-3°C en un período de más de dos años, con una significación α de 0.05 y una potencia **P** de 0.8. El muestreo continuo de la velocidad del viento o de la máxima y mínima sería suficiente para detectar un cambio de un 10 a 20% en la velocidad media mensual del viento, transformada logarítmicamente, con una significación α de 0.05 y una potencia **P** de 0.9.

---

1. INTRODUCTION

Monitoring of selected environmental parameters is one of the basic components of the CCAMLR Ecosystem Monitoring Program (CEMP). This monitoring should be designed in such a way as to provide the information necessary to distinguish between changes in the monitored system induced by harvesting of particular species (especially krill) and changes resulting from environmental variability (SC-CAMLR-V, Annex 6, paragraph 40).

Two categories of environmental parameters were defined by WG-CEMP (1989): those which have a direct affect on the predators and those which affect predators indirectly through their influence on the distribution and abundance of prey. Within the first category the WG-CEMP selected sea ice cover, snow cover and local weather (air temperature, atmospheric pressure, wind direction and speed) for monitoring at land-based CEMP study sites (SC-CAMLR-VIII, Annex 7, Table 6).

Sampling strategies for weather conditions should be defined so that changes in environmental parameters can be confidently identified. Sample size and frequency should be chosen so that α, the probability of making a Type I error (rejecting the null hypothesis when there is no effect) and β, the probability of making a Type II error (accepting the null hypothesis when there is an effect) are both minimised. Type II errors are especially important in studies affecting conservation issues, where the penalty of not detecting a real effect may be the serious depletion of a protected resource (Peterman, 1990). The CEMP Working Group (1989) suggested that sampling strategies should be able to detect a 10% or 20% change in a parameter with a significance level $\alpha \leq 01$ and a statistical power of **P** $(=1-\beta) \geq 0.8$.

This paper examines several meteorological parameters measured at Davis Station, collected by the Australian Bureau of Meteorology. I will investigate the characteristics of the data and suggest sampling regimes that are sufficiently sensitive to changes in meteorological parameters.

2. METHODS

Data for 1985 to 1987 describing air temperature (dry bulb), atmospheric pressure, wind speed and direction were obtained from the Australian Bureau of Meteorology for Davis Station, Antarctica. The data were recorded at three hour intervals throughout the whole day at 0200, 0500, 0800, 1100, 1400, 1700, 2000 and 2300 (eight samples per day).

The data were first examined for general temporal characteristics, and in particular the presence of cyclic phenomena. Subsequently, sensitivity analyses were performed on the data assuming that the means and standard deviations calculated from the available data were approximations for the population mean and standard deviation, μ and σ. These analyses involve the calculation of the required sample size such that a certain level of change would be detectable at a significance level of α and at a power of **P**. The method of Sokal and Rohlf (1981) was used along the guidelines suggested in WG-CEMP-89/13. The required sample size, **n** was obtained from

$$n \geq 2(\sigma/\delta)^2(t\alpha[v]+t_2(1-P)[v])^2$$

where σ is the true standard deviation, δ is the smallest true difference that it is desired to detect, **v** the degree is of freedom (**=r(n-1)**, where **r** is the number of years or replicates over which the effect is detected), $t\alpha[v]$ and $t_2(1-P)[v]$ are obtained from a two-tailed **t** table with **v** degrees of freedom.

Temperature and wind speed were chosen for this analysis since they are probably the two most directly influential on predators; they were examined for the months of December, January, February and March, the months most important to predators. The period of a month was chosen for inter-seasonal comparisons (i.e., as the time period over which the calculations of μ and σ were made) for reasons that will be discussed later. Wind direction was not investigated since it requires a different type of analysis (Mardia, 1980).

3. TEMPORAL CHARACTERISTICS OF ENVIRONMENTAL PARAMETERS

All environmental parameters can be expected to display one or more of three temporal cycles: Daily, "Depressional" and Yearly. Daily cycles are triggered by daily heating and cooling. "Depressional" cycles are associated with the regular passage of depressions around the Antarctic continent. Yearly cycles are those associated with seasonal variation. Cycles of greater period are not considered here.

Figure 1 shows the variation in minimum daily temperature in January for 1985 to 1987. The 4- to 5-day depressional cycles are clearly seen. Figure 2 shows the same phenomenon in a plot of maximum daily pressure reading for January 1985. Figure 3 shows maximum daily wind speed in January for 1985 to 1987, demonstrating the effect of the depressional cycles and showing a strong gale in 1985. Figure 4 details wind speed data for January 1985 by three hour sampling period, and shows the daily cycle and its overlaid depressional cycle.

The occurrence of cyclic phenomena at Davis Station, including the suspected occurrence of cycles in other parameters, is shown in Table 1.

4. TEMPERATURE

Mean and standard deviation were calculated for minimum and maximum temperatures in January. Data for January 1985 and 1987 were combined for this calculation because they have similar mean values; data for January 1986 were not used because temperatures in that year were lower than for the other two years (see Figure 1). Maximum and minimum temperatures had means of 3.62 and -0.48 and standard deviations of 1.931 and 1.488 respectively (**n**=62). Sensitivity analysis for January, for two years of monitoring, is shown in Table 2. Summary information for the months December to March, taking α=0.05 and **P**=0.8, is given in Table 3.

These results indicate that with a sample size of about 30 maximum and minimum temperature readings (1 per day), a mean temperature change of ±2°C in December and January could be reliably detected at Davis Station, but that in later months, when temperature starts falling rapidly, a mean temperature of ±3°C would be the smallest change reliably detected.

5. WIND SPEED

These data were first analysed using all the 1985 to 1987 data, i.e. data determined using a sampling regime of eight samples per day. The readings of wind speed at Davis Station for January 1986 and 1987 showed an approximately log-normal distribution with a mean of 1.99 (=7.32 kn) and standard deviation of 0.707 (**n**=496). Sensitivity analysis is shown in Table 4. This shows that sampling on a regular basis with about 250 samples per month (about eight per day) would be sufficient to identify changes of 10% in log mean wind speed.

The analysis above does not take into account the fact that there is a daily cycle in wind speed at Davis Station (see Figure 4). An alternative regime for sampling under these conditions is to record maxima and minima, in which case the sample size is fixed at 30 to 31 per month. The results of sensitivity analyses, conducted on log maximum daily wind speeds (kn) calculated from Davis Station data for 1985 to 1987 are shown in Table 5.

These results suggest that sampling maximum wind speed with one sample per day (**n**~30 per month) may produce data sufficient to identify 10% changes in maximum wind speed in January but would only identify changes of 20% in other months.

6. DISCUSSION AND CONCLUSIONS

Three possible sampling regimes that could be adopted for recording weather conditions are as follows:

(**A**) single 'spot' sampling once or twice a day at specified times;
(**B**) repeated sampling throughout the day at regular intervals; and
(**C**) sampling of daily maximum and minimum information alone.

It is evident that where a strong daily cycle is present method (**A**) will be inadequate to sample environmental parameters because it cannot be assumed that the daily pattern will duplicate itself exactly between days, seasons or years. Use of method (**B**) will yield most information and will also produce estimates for the values obtained using method (**C**). Thus for most parameters regime **B** is the most sensible regime since we know that daily cycles in the parameters do occur.

It is also evident that for parameters that do not exhibit daily cycles, increased frequency of spot sampling should increase the power to detect inter-seasonal changes in parameters.

In order to compare the local weather conditions in different breeding seasons, it is necessary to choose a time interval for which to calculate an index of an environmental parameter. For instance, spring temperature in 1989 may be compared with spring temperature in 1990. Because there is a great deal of seasonal change in Antarctic environmental conditions, choice of periods shorter than a few months is necessary. However, the presence of 4- to 5-day depressional cycles in many of the parameters studied here means that the time interval chosen should be greater than a few of these cycles. It is suggested that the choice of one month as a time interval may be sufficient to avoid spurious results associated with depressional cycles yet short enough to avoid significant seasonal influences.

The results of sensitivity analyses of temperature and maximum wind speed at Davis Station are given in Table 6. These results suggest that sampling temperature using regime **(C)** and wind speed with regime **(B)** would provide data that was sensitive to changes in conditions between years (i.e., changes in the parameters of the stated magnitudes could be detected with acceptably low probabilities of Type I and Type II errors).

The following are suggested regimes for the other environmental parameters:

Pressure	**(A)** or **(C)**	- daily cycles are unlikely in barometric pressure;
Wind direction	**(B)**	- spot sampling and max/min information have no meaning here;
Ice type	**(A)**	- daily cycles are unlikely;
Ice cover	**(A)** or **(C)**	- daily cycles are unlikely;
Snow cover	**(A)**	

Diurnal variability is one of the most significant causes of variation in environmental data. If parameters do show diurnal variation, the effective sample rate can be no more than one per day. Seasonal variability is also extremely important, especially in high latitudes and comparisons of weather conditions between years must take this into account. I have suggested that the shortest period that can be used to compare conditions between years at Davis Station is one month; shorter periods will be influenced by the depressional cycles identified in the data. This means that a sample size of about 30 readings is likely to be the most convenient to use in these studies, but this is sufficient to detect changes of only 2° to 3°C in temperature and 10 to 20% in wind speed. For example, the slightly lower mean maximum temperature in January 1986 (2.6°C compared with 3.7°C and 3.6°C for 1985 and 1986 respectively) would not have been detected with the required levels of significance and power.

The results of this study apply to the environmental conditions specific to Davis Station. Whilst the general principles of the effect of daily and depressional cycles may hold for other sites, analyses similar to this one should be carried out in other areas to investigate the effects of sample size on the expected detection efficiency before a particular sampling regime is chosen.

ACKNOWLEDGEMENTS

I would like to thank Dr E. Sabourenkov for constructive suggestions throughout the progress of this work, and for helpful criticism of the manuscript. I would also like to thank the Australian Bureau of Meteorology for making this data available.

REFERENCES

MARDIA, K.V. 1980. *Statistics of Directional Data.* Academic Press.

PETERMAN, R.M. 1990. The importance of reporting statistical power: the forest decline and acidic deposition example. *Ecology 71* (5): 2024-2027.

SC-CAMLR. 1989. *Instructions for the Preparation of Sensitivity Analyses.* WG-CEMP-89/13. Hobart, Australia: CCAMLR.

SC-CAMLR. 1990. *Standard Methods for Monitoring Environmental Parameters (Methods F1 to F4)*. WG-CEMP-90/5. Hobart, Australia: CCAMLR.

SOKAL, R.R. and F.J. ROHLF. 1981. *Biometry*, Second Edition. New York: W.H. Freeman and Company. pp. 859.

Table 1: Occurrence of cyclic phenomena at Davis Station. Suspected occurrence of other parameters is shown in parentheses.

Parameters	Cycles		
	Daily	Depressional	Yearly
Temperature	+	+	+
Pressure		+	+
Wind Speed	+	+	+
Wind Direction	(+)	(+)	(+)
Snow cover	(+)	(+)	(+)
Ice type			(+)
Ice cover			(+)

Table 2: Sample size required to detect a change in January mean daily maximum temperature over two years of monitoring at Davis Station.

δ	α=0.1			α=0.05		
	P=0.6	**P=0.8**	**P=0.9**	**P=0.6**	**P=0.8**	**P=0.9**
1°C	27	47	65	37	60	80
2°C	7	12	16	10	15	20
3°C	5	5	7	6	8	10

Table 3: Sample size required to detect a change in maximum and minimum temperature at Davis Station monitored over a two-year period, at α=0.05 and **P**=0.8. Mean and standard deviations calculated using data from 1985 and 1987. Changes are shown as absolute changes in the mean temperature.

	Mean	Standard Deviation		Change	
			1°C	2°C	3°C
December max	2.273	1.812	53	13	7
December min	-2.253	1.738	48	12	7
January max	3.621	1.931	60	15	8
January min	-0.482	1.488	35	10	6
February max	-0.848	2.890	132	33	15
February min	-5.141	3.304	172	44	19
March max	-5.473	3.495	193	49	22
March min	-11.574	3.846	233	59	27

Table 4: Sample size required to detect a change in January mean wind strength over two years of monitoring at Davis Station.

δ	α=0.1			α=0.05		
	P=0.6	P=0.8	P=0.9	P=0.6	P=0.8	P=0.9
10%	93	157	217	125	199	266
20%	23	40	55	32	50	68
30%	10	18	24	14	22	30

Table 5: Sample size required to detect a change in log maximum wind speed at Davis Station monitored over a two-year period, at α=0.05 and **P**=0.8 or 0.9. Mean and standard deviations were calculated using data from 1985 and 1987. Changes are shown as percentage changes in the mean log maximum wind speed.

	Mean	Standard Deviation	P=0.8 Change 10%	P=0.8 20%	P=0.9 10%	P=0.9 20%
December	2.750	0.466	46	11	62	15
January max	2.635	0.368	31	9	42	10
February max	2.703	0.437	42	10	56	14
March max	2.624	0.514	62	15	82	21

Table 6: Results of analyses of temperature and wind speed data from Davis Station.

Parameter	Sampling Regime	Sample Size Per Month	Target Change Observed	Sensitivity
Temperature	max/min daily information	**n**~30	2-3°	High power of detection
Wind speed	daily multiple recording	**n**=8 per day for one month	10-20%	High
	daily multiple recording or max/min information	**n**~30	10-20%	High

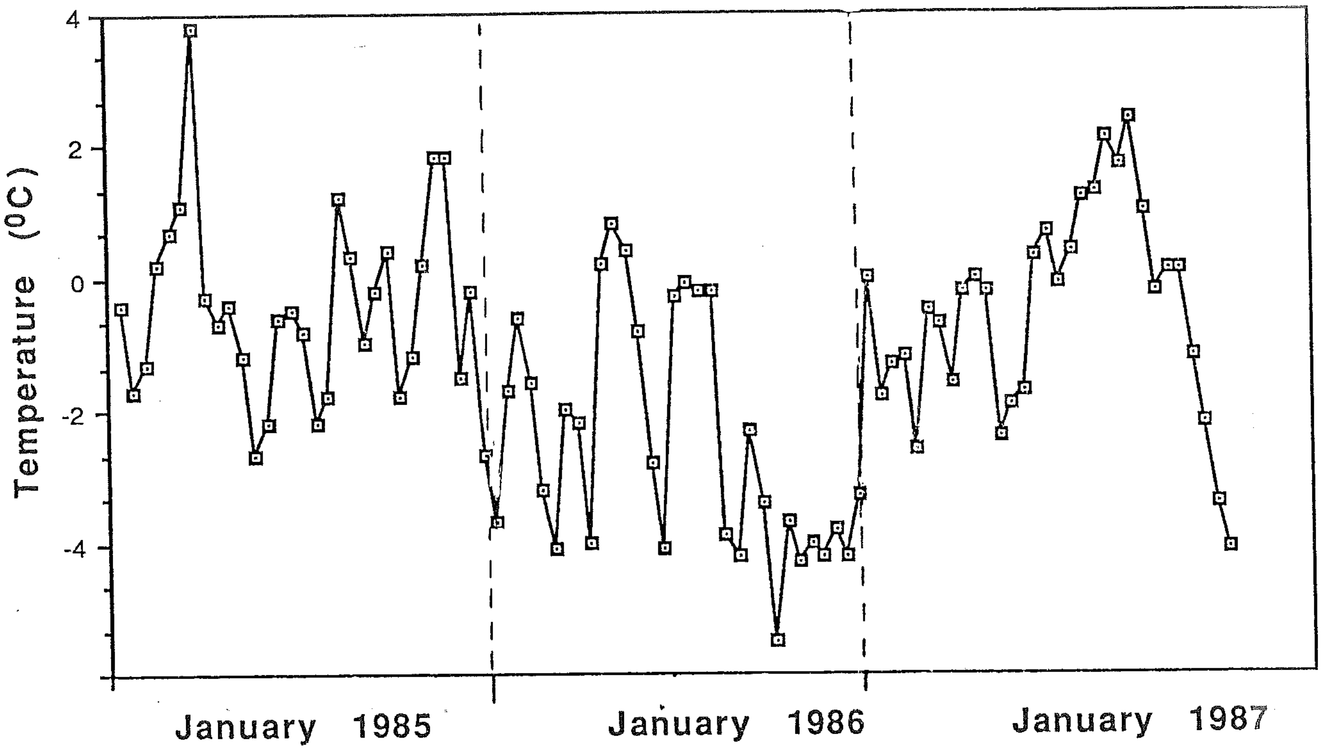


Figure 1: Mean daily temperature in January for 1985 to 1987, Davis Station, showing the effect of depressional cycles.

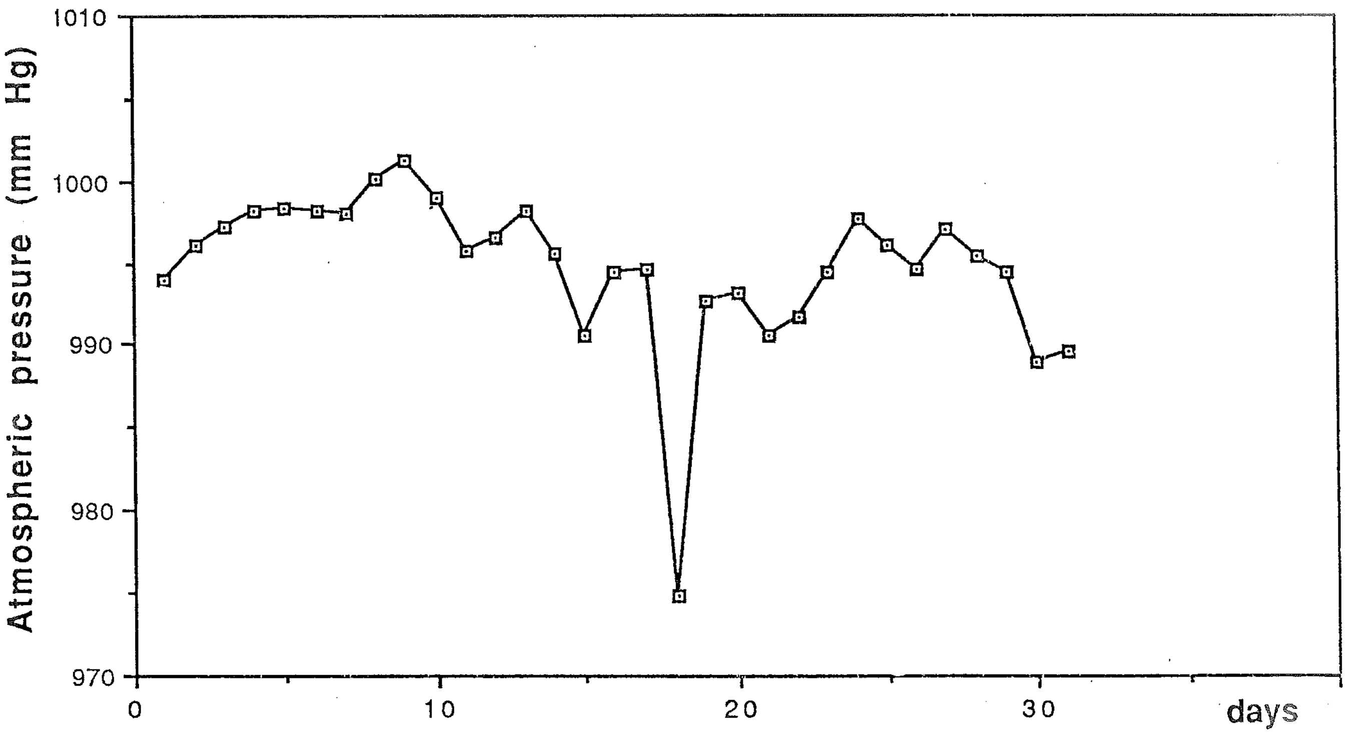


Figure 2: Maximum daily pressure for January 1985, Davis Station, showing the effect of depressional cycles.

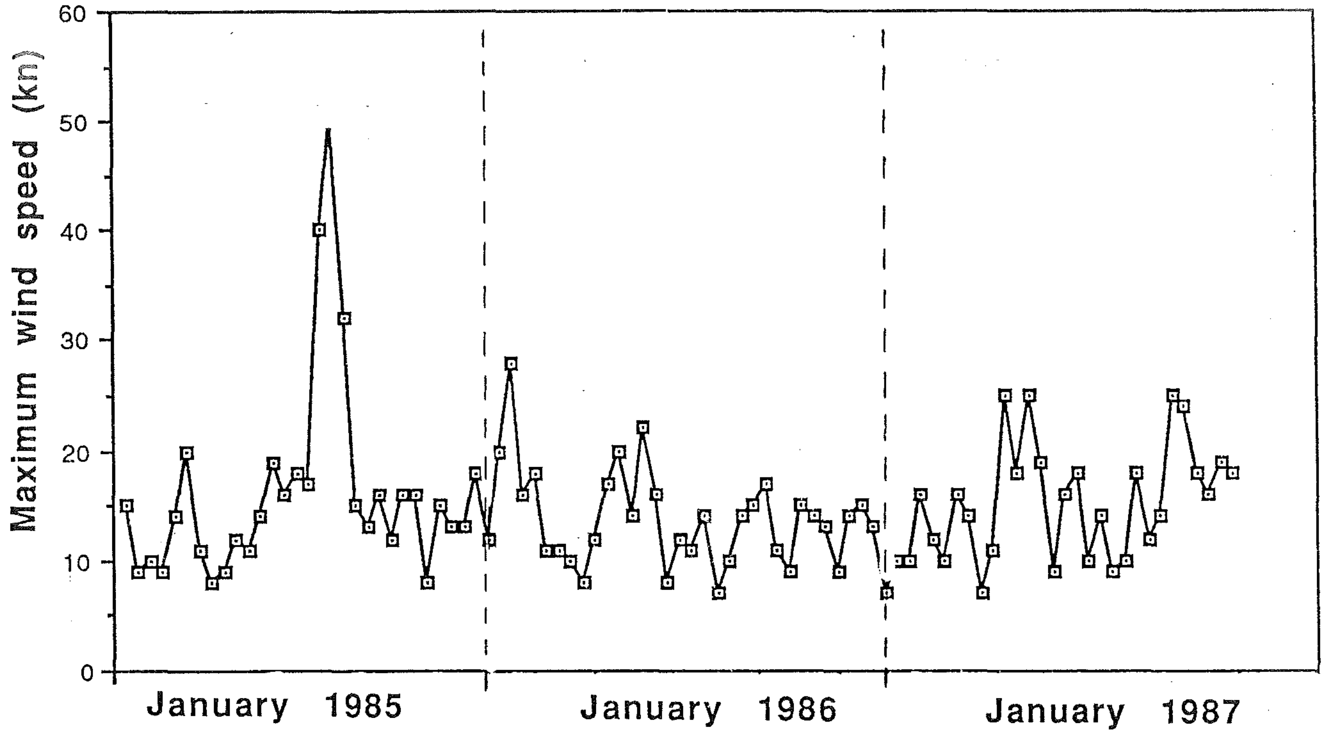


Figure 3: Maximum daily wind speed in January for 1985 to 1987, Davis Station, showing the effect of depressional cycles.

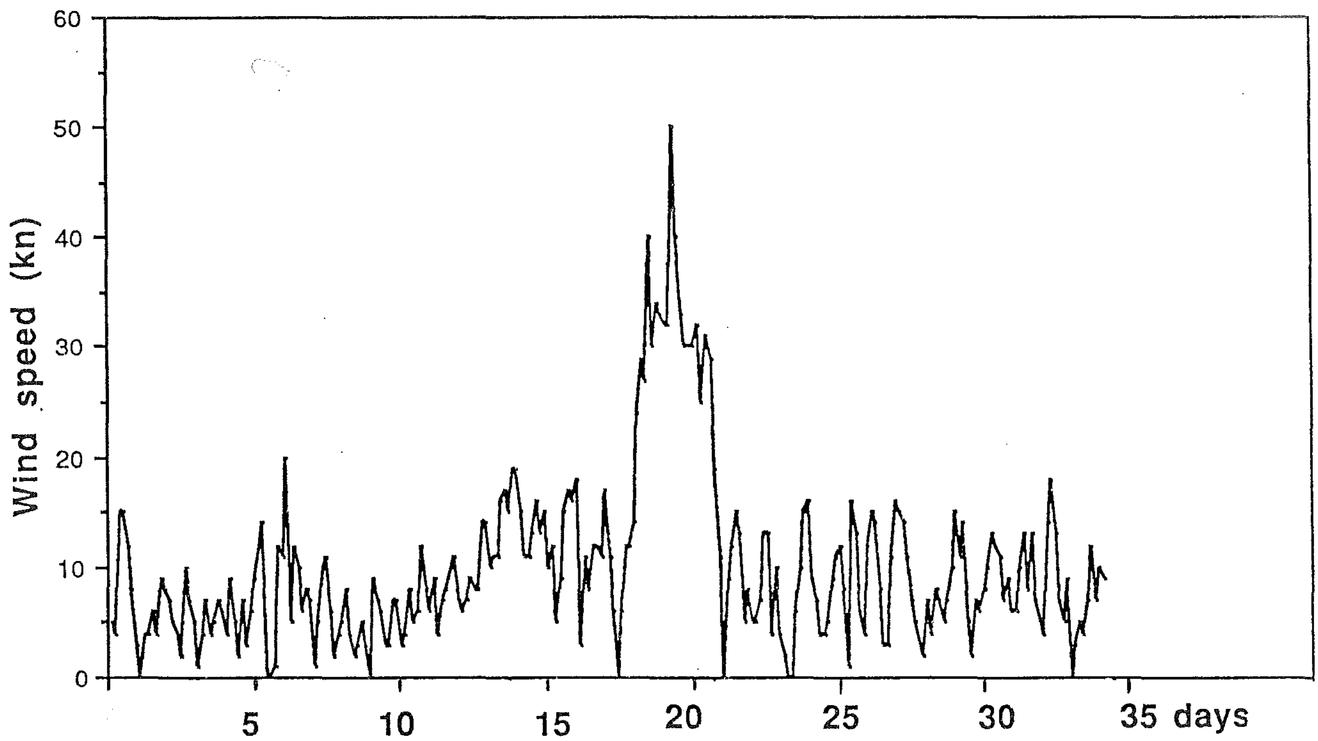


Figure 4: Daily wind speed by three hour sampling period for January 1985, Davis Station, showing daily cycles.

Légende des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Tabla 4: Número de mediciones requerido para detectar cambios en la intensidad media del viento en enero durante un período de estudio de 2 años en la estación Davis.

Tabla 5: Número de mediciones requerido para detectar cambios en el logarítmo de la intensidad máxima del viento, estudiada durante un período de 2 años en la estación Davis, con α=0.05 y **P**=0.8 ó 0.9. La desviación media y estándar fueron calculadas utilizando los datos de 1985 y 1987. Se presentan los cambios como porcentajes de cambios en la media del logarítmo de la intensidad máxima del viento.

Tabla 6: Resultados de los análisis de los datos de temperatura y velocidad del viento en la estación Davis.

Lista de las figuras

Figura 1: Temperatura media diaria de enero, desde 1985 a 1987, en la estación Davis. Se pueden observar los efectos de los ciclos anticiclónicos.

Figura 2: Presión máxima diaria registrada en el mes de enero, de 1985 a 1987, en la estación Davis. Se pueden observar los efectos de los ciclos anticiclónicos.

Figura 3: Velocidad máxima diaria del viento de enero, desde 1985 a 1987, en la estación Davis. Se pueden observar los efectos de los ciclos anticiclónicos.

Figura 4: Velocidad diaria del viento registrada durante un período de tres horas, en enero 1985, en la estación Davis. Se pueden observar los ciclos diarios.