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Abstract

This document contains a selection of the scientific papers presented at meetings of the Scientific Committee and Working Groups of the Scientific Committee in 1992. 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 des communications scientifiques présentées aux réunions du Comité scientifique et de ses Groupes de travail en 1992. 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 1992 г. Резюме, названия таблиц и подписи к рисункам переведены на официальные языки Комиссии (английский, французский, русский и испанский).

Resumen

Este volumen contiene una selección de los documentos científicos presentados en las reuniones del Comité Científico y de los Grupos de Trabajo en 1992. Los resúmenes de éstos y los títulos de las tablas y las figuras están traducidos a los idiomas oficiales de la Comisión (inglés, francés, ruso y español).

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CATCH-AT-AGE ANALYSIS APPLIED TO NEW FISHERIES: THE CASE OF *DISSOSTICHUS ELEGINOIDES*

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Abstract

Traditionally, the approach used in the assessment of new fisheries has been based on research surveys, making it possible to estimate the standing stock and potential yield of a resource by coarse methods. The main aim of such surveys is to monitor fishing operations in order to develop a comprehensive sampling design which will provide data in line with assessment procedures that are quite similar to those commonly used in the statistical sampling theory. These procedures are, to a certain extent, limited by the complex fishing strategies of the operators and by the movements of fish stocks, which seriously affect model assumptions. This paper demonstrates that for the new fishery, analyses using catch-at-age data derived from reseach cruises may provide an alternative to other methods of estimating the parameters of fish stocks. This alternative method is applied to the new fishery of *Dissostichus eleginoides* off the south of Chile which is being conducted in accordance with CCAMLR regulations.

Résumé

L'approche de l'évaluation des pêcheries nouvelles est traditionnellement fondée sur les campagnes de recherche, permettant ainsi l'évaluation du stock existant et du rendement potentiel par des méthodes approximatives. L'objectif principal de ces campagnes est de contrôler les opérations de pêche afin de développer un modèle d'échantillonnage détaillé, propre à fournir des données conformes à des procédures d'évaluation quasi-similaires à celles généralement utilisées par la théorie de l'échantillonnage statistique. Dans une certaine mesure, ces procédures sont limitées par les stratégies de pêche complexes des opérateurs et par les déplacements des stocks de poissons qui affectent grandement les hypothèses du modèle. Les auteurs démontrent que pour la nouvelle pêcherie, des analyses utilisant des données sur la capture à un âge donné provenant des campagnes de recherche peuvent s'avérer une nouvelle méthode d'évaluation des paramètres des stocks de poissons. Cette nouvelle procédure est appliquée à la nouvelle pêcherie de *Dissostichus eleginoides* menée conformément à la réglementation de la CCAMLR au large du sud du Chili.

Резюме

Традиционный подход к оценке новых промыслов основан на научно-исследовательских съемках и дает возможность оценить биомассу и потенциальный вылов какого-либо ресурса с применением "приблизительных" методов

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расчета. Главной целью таких съемок является проведение мониторинга промысловых операций с тем, чтобы разработать всеобъемлющую схему взятия проб, результаты которой в достаточной мере будут соответствовать процедурам расчетов, обычно используемых в статистической теории взятия проб. В какой-то степени эти процедуры ограничены сложными стратегиями промысловиков и передвижением запасов рыб, что в значительной мере влияет на допущения в моделях. Данная работа показывает, что в случае нового промысла проведение анализа с помощью данных по составу уловов по возрасту, полученных в результате научно-исследовательских рейсов, может послужить альтернативой другим методам оценки параметров рыбных запасов. Этот альтернативный метод применяется к новому промыслу *Dissostichus eleginoides* около южного побережья Чили, который ведется в соответствии с мерами АНТКОМа.

Resumen

Tradicionalmente el enfoque de la evaluación de las nuevas pesquerías ha estado basado en pescas de investigación, procedimiento que permite una estimación del "standing stock" de un recurso y su rendimiento potencial utilizando métodos crudos. Las características de estas operaciones es el control sobre las operaciones de pesca y su énfasis está en desarrollar un plan de muestreo exhaustivo, el que proporcionará información en conjunto con los modelos de evaluación que no difieren escencialmente de procedimientos comunes en la teoría estadística de muestreo. Estos métodos están, en cierta forma, limitados por las complejas tácticas de pesca de los pescadores y por los movimientos de las poblaciones de peces, que vulneran las presunciones del modelo.

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1. INTRODUCTION

At the 1990 and 1991 Meetings of CCAMLR, concerns were expressed about the problem of new and developing fisheries (SC-CAMLR, 1990; SC-CAMLR, 1991). In relation to this subject, the Working Group on Fish Stock Assessment (WG-FSA) has specified the definition of a new fishery, and also identified the information required to evaluate the initial catch level for such a fishery. Traditionally, the methods used in evaluating new fisheries are based on research fishing procedures which provide information for evaluation of the standing stock of a resource and its potential yield utilising coarse methods similar to those proposed by Gulland (1971). Typically, these evaluations require monitoring of fishing operations and implementation of a comprehensive, statistically-based sampling plan. In developed fisheries, the evaluation strategy is usually based on information obtained from long term sampling programs of commercial fisheries, managed so as to collect series of data which can be analysed in conjunction with stock dynamics models.

An interim approach is to conduct research surveys designed to find a compromise between the objectives of the commercial fishery and those of stock evaluation. Information obtained from such surveys can be used to evaluate the viability of the fishery, not only from an economic point of view, but especially in terms of its sustainability. Regarding this last aspect, conditions for conducting commercial fishery operations should be flexible, whilst maintaining

the requirement for the acquisition of information from scientific research programs. From the point of view of a developing country, this option appears to be the best way of performing scientific research in remote areas in an economically feasible manner. A common way of utilising information from a new fishery is to apply CPUE methods such as De Lury methods (Ricker, 1975). These methods are, to some extent, limited by complex fishery tactics which adversely affect model assumptions. Another way of optimising this type of research is to use evaluation methods based on catch composition data. This paper explores the application of catch-at-age analysis for the *Dissostichus eleginoides* fishery south of Chile, where a new fishery is beginning, with objectives similar to those of CCAMLR, i.e., to estimate levels of fish abundance and potential yields so as to ensure that initial levels of exploitation are potentially sustainable (de la Mare, 1986).

CCAMLRs concept of a new fishery specifically stresses the lack of information as being the distinctive attribute qualifying such a fishery. According to this concept, various fisheries can belong to this category: those that have developed in the past and for which no information has been received for at least the last two fishing seasons, as well as those based on previously unexploited stocks. The catch-at-age model proposed below relates to this last type of fishery.

2. EVALUATION MODEL

The basic assumptions of the catch-at-age model are as follows:

- the stock of *D. eleginoides* belongs to a closed population;
- the stock is in a state of equilibrium before the commencement of research surveys (recruitment = mortality); and
- fishing mortality is separable by age (Doubleday, 1976).

Catch-at-age for all recruited year classes i ($i = t_r, t_r + 1, \ldots, t_m$) can be expressed as

$$C_i = \mu_i N_i \tag{1}$$

where

$$\mu_i = \frac{F_i}{Z_i}\left(1 - e^{-\tau Z_i}\right) \tag{2}$$

$$N_i = R \exp\left(-M(i - t_r + \Delta)\right), \tag{3}$$

$$Z_i = F_i + M, \text{ and} \tag{4}$$

$$F_i = r_i F \tag{5}$$

where
- C_i = catch at age i during survey
- N_i = numbers at the beginning of the research survey
- μ_i = exploitation rate
- F_i = fishing mortality
- r_i = relative fishing mortality coefficient at age
- F = fishing mortality for completely recruited fish
- M = natural mortality
- τ = research survey duration (in years)
- R = recruitment
- t_r = age at recruitment
- t_m = terminal age
- Δ = time between the beginning of the year and the beginning of the research survey.

So as to reduce the number of parameters, the specific exploitation pattern at age, r_i, can be estimated by

$$r_i = \frac{i^a \exp(-b \cdot i)}{\max\left(i^a \exp(-b \cdot i)\right)} \tag{6}$$

where a and b are constants (Deriso *et al.*, 1985).

This function was particularly suitable for representing patterns of partial recruitment for the very old fish characteristic of longline fishing.

3. ESTIMATION OF MORTALITIES

Since the slope of the catch curve gives information on mortality, and recruitment is only a scale factor on this curve, mortality can be estimated from the proportion of the total catch of a research survey to the catches at age:

$$p_i = \frac{\frac{F_i}{Z_i} \cdot e^{(-M \cdot i)}\left(1 - e^{-\tau Z i}\right)}{\sum \frac{F_i}{Z_i} \cdot e^{(-M \cdot i)}\left(1 - e^{-\tau Z i}\right)} \tag{7}$$

The parameters of model (6) can be estimated using a non-linear least-squares approach, which minimises the function

$$SSQ = \sum_i (p_i - \hat{p}_i)^2 + \lambda P(\theta) \tag{8}$$

where λ is a penalisation factor and $P(\theta)$ is a quadratic function which represents a number of restrictions that permit the introduction of values of some estimated parameter from an independent source (e.g., M) or mark off the parametric space within the most probable range.

4. RECRUITMENT ESTIMATION

Replacing (3) in (1) and summing over all ages, we may calculate recruitment:

$$R = \frac{\sum_i C_i}{\sum_i \mu_i \exp\left(-M(i - t_r + \Delta)\right)} \tag{9}$$

5. ESTIMATION OF INITIAL TAC

A TAC for a new fishery can be calculated in the usual way, by performing the following steps:

- projecting stock size at the beginning of the fishing season, based on stock age composition estimated at the beginning of the research survey;
- estimating or calculating recommended fishing mortality level; and
- totalling catches at age by weight.

6. APPLICATION TO A NEW FISHERY SOUTH OF CHILE

During the period September 1991 to June 1992, a research survey was carried out by a fleet of seven longliners south of Chile, over the continental slope area, between parallels 47° and 57°S. This fishing operation was authorised by the Chilean Subsecretaría de Pesca de Chile, under an agreement on technical collaboration between the Instituto de Fomento Pesquero (IFOP) and national fishery companies, with the purpose of expanding the exploitation options of the southern demersal fishery, currently targeting hake (*Merluccius australis*) and pink ling (*Genypterus blacodes*).

On board each vessel, the IFOP used technical personnel to perform intensive haul-by-haul sampling of catches, with the aim of identifying the growth parameters presented in Table 1.

Catch data were available for two years (1991 and 1992), which could be analysed independently, extending the evaluation to two seasons; however, in order to illustrate the procedure, data are presented as belonging to a single season - 1991/92 (split-year).

Available information, originating from an exploratory fishery carried out previously in the same area by the longliner *Frio Sur V*, suggested the following restrictions:

- $F \geq 0$
- $M = 0.2$
- $T_c = 10$ and 10.5 years
- $b = b_o$ $(0.8 \leq b_o \leq 1.6)$

These were incorporated into the objective function

$$SSQ = \sum_i (p_i - \hat{p}_i)^2 +$$

$$\lambda\left((M-0.2)^2 + (\max(0,-F))^2 + \left(\left(t_c{}^a \exp(-b \cdot t_c)\right) \Big/ \max\left(t_c{}^a \exp(-b \cdot t_c)\right) - 0.5\right)^2 + (b-b_o)^2\right) \quad (10)$$

In order to obtain the least-square parameters, a simplex minimiser algorithm (Nelder-Mead) from the program library 386-MATLAB was used, with $\lambda = 20$ and a tolerance factor of 0.01.

The smallest residual (SSQ = 0.0014) was obtained for $t_c = 10$, F = 0.85, $a = 20.9$ and $b = 1.6$. Another satisfactory result (SSQ = 0.0052) was obtained with $t_c = 10.5$, F = 0.51, $a = 20.6$, M = 0.2 and $b = 1.5$.

A value of M = 0.15 improved the residual (SSQ = 0.0012) with other parameters constant. When natural mortality continued to decrease (e.g., M = 0.1) the residuals increased (SSQ = 0.0028). It was also observed that, for these values of natural mortality, F decreased to values close to 0.65 and the coefficient a of the exploitation pattern stabilised at a value of 20.

The recruits (calculated from equation (9)), for the estimated parameters corresponding to the residuals SSQ = 0.0014 and SSQ = 0.0012, were 1.4 and 1.0 million fish respectively.

7. DISCUSSION

This paper shows that for new fisheries, analyses using catch-at-age data derived from research cruises may provide alternatives to other methods of estimating the parameters of fish stocks.

In the absence of a time series of data, efficient use of catch-at-age methods may require additional information from the fishery in order to restrict the model parameter space to within reasonable bounds. However, the generation of the base data, catches at age, is relatively rapid given good techniques for age determination of fish, and so the total data demand may be quite modest.

When time series data or other qualitative data are available, the sums-of-squares function provides an objective way of incorporating these data in the model. On the other hand, because of the low ratio of the number of observations to the number of parameters, the sums of squares is very sensitive to the tails of age distributions. This suggests that the target function should be weighted by the variance of the data.

The ability to estimate abundance and fishing mortality at age gives the possibility of estimating the TAC early in the history of a fishery for a certain biological reference point, for example $F_{0.1}$, and of evaluating the effect of regulations on the exploitation pattern.

Regarding the results, the most interesting feature of the analysis is the detection of patterns of partial recruitment at ages greater than 12. This raises doubts about estimates of M and Z obtained from catch curves that assume a constant recruitment pattern after a certain age. In fact, this could explain the high M obtained with these methods when they are fitted to catch curves that come from virgin stock. Also, the results suggest that the most reasonable value of M would be within the range 0.1 to 0.2, perhaps very close to 0.15.

It is too early to assess the usefulness of this method at present. It is necessary to test it for other sets of data, and to analyse its operation in relation to procedural and observational errors, such as, for example, variations in the accuracy of recruitment and catch data.

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REFERENCES

DERISO, R. B., D. J. QUINN and P. R. NEAL. 1985. Catch-age analysis with auxiliary information. *Can. J. Fish. Aquat. Sci.*, 42: 815-824.

DE LA MARE, W.K. 1986. Some principles for fisheries regulation from an ecosystem perspective. *Scientific Selected Papers, 1986 (SC-CAMLR-SSP/3).* CCAMLR, Hobart, Australia: 323-339.

DOUBLEDAY, W.G. 1976. A least squares approach to analysing catch-at-age data. *Res. Bull. Int. Comm. NW Atl. Fish.*, 12: 69-81.

GULLAND, J. A. 1970. The fish resources of the ocean. *FAO Fish. Tech. Pap.*, 97: 425 pp.

RICKER, W.E. 1975. Computation and interpretation of the biological statistics of fish populations. *Bull. Fish. Res. Board Can.*, 191: 382 pp.

SC-CAMLR. 1990. Report of the Working Group on Fish Stock Assessment. In: *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX)*, Annex 5. CCAMLR, Hobart, Australia: 145-280.

SC-CAMLR. 1991. Report of the Working Group on Fish Stock Assessment. In: *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X)*, Annex 6. CCAMLR, Hobart, Australia: 205-345.

Table 1: Growth and age composition parameters of the *Dissostichus eleginoides* catches south of Chile, from the 1991/92 survey.

K = 0.066		t_o = - 0.477 years		W_∞ = 97.153 kg	
Age	Catch (N)	Age	Catch (N)	Age	Catch (N)
4	3.846	10	116.126	16	32.309
5	13.280	11	129.356	17	18.416
6	18.017	12	145.641	18	14.378
7	18.451	13	105.385	19	1.796
8	42.519	14	79.372	20	1.058
9	83.937	15	56.400		

Légende des tableaux

Tableau 1: Paramètres de croissance et de composition en âges des captures de *Dissostichus eleginoides* effectuées au cours de la campagne d'évaluation de 1991/92 au sud du Chili.

Список таблиц

Таблица 1: Параметры роста и возрастного состава в уловах *Dissostichus eleginoides*, полученных в ходе съемок на юге от Чили - съемка за сезон 1991/1992 г.

Lista de las tablas

Tabla 1: Parámetros de la composición por edad y de crecimiento de las capturas de *Dissostichus eleginoides* en el extremo sur de Chile obtenidas de la prospección realizada de 1991 a 1992.

MODELO ITERATIVO DE CONSTRUCCION DE CLAVE EDAD-LONGITUD PARA ESTIMAR LA COMPOSICION DE LA CAPTURA POR EDAD EN LA PESQUERIA INCIPIENTE DE *DISSOSTICHUS ELEGINOIDES* EN CHILE

H. Robotham V. y Z. Young U.*

Abstract

Traditional estimation of age composition of catch requires that age/length data and random length frequency have been sampled from the same population. If such sampling is not possible the estimates of the age distribution could be biased. By using an iteration algorithm it is possible to overcome this limitation. The age composition of catch for *Dissostichus eleginoides* was obtained with the application of a single age/length key to the monthly length distribution using the non-linear model (Hoenig and Heisey, 1987). We found that age distribution derived from the model is not significantly different from the one obtained by using traditional methods.

Résumé

La mortalité naturelle (M) de *Dissostichus eleginoides* a été calculée d'après Sparre (1989) à partir des données provenant de la pêcherie à la palangre chilienne dans la sous-zone 48.3 (N = 7 848). Les paramètres de croissance de von Bertalanffy obtenus indépendamment par trois auteurs ont été utilisés. Trois variables ont été examinées: le lieu de pêche, la profondeur de pêche et le type d'hameçon. Il a été établi que la valeur de M ne variait pas de manière significative lorsqu'elle était estimée en fonction de la profondeur de la pêche ou du type d'hameçon avec différents paramètres de croissance mais variait en fonction des sites de pêche. Par ailleurs, en comparant les différentes valeurs moyennes de M pour les différentes variables, on a pu observer des différences notables selon les lieux de pêche et entre les hameçons courbes Nº14 et les hameçons droits Nº 22. La valeur moyenne générale de M calculée pour les 44 situations analysées était de 0,14 ± 0,03.

Резюме

Оценка возрастного состава в уловах обычным путем требует, чтобы данные по возрасту/длине и случайной частоте длин брались из одной и той же популяции. Если это условие не соблюдается, возможно получить смещенные оценки распределения возрастных групп. Мы можем преодолеть это ограничение используя итеративный алгоритм. Возрастной состав *Dissostichus eleginoides* в уловах был рассчитан с применением одного размерно-возрастного ключа к ежемесячному распреде-

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лению длин используя нелиненую модель (Hoenig and Heisey, 1987). Полученная нами с помощью модели картина распределения возраста не отличается в значительной мере от распределения, полученного традиционными методами.

Resumen

El método de cálculo empleado comúnmente para estimar la composición de edad de la captura requiere que los datos de edad-longitud y frecuencia de longitud sean muestreados aleatoriamente de la misma población. La vulneración de esta premisa puede llevar a estimaciones sesgadas. Mediante el uso de modelos que utilizan algoritmos iterativos es posible llegar a corregir este problema. De la aplicación del modelo log-linear propuesto por Hoenig and Heisey (1987) en *Dissostichus eleginoides*, se tiene que al emplear una misma clave edad-longitud a las distribuciones de longitud mensual, se genera una composición de edad de la captura cuyo patrón es similar al obtenido con el método tradicional. Este método iterativo resulta ser una herramienta de alternativa frente a restricciones del uso del método tradicional.

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1. INTRODUCCION

La composición de edad de la captura constituye un dato de entrada relevante en la aplicación de los métodos tradicionales de evaluación de stock que se basan en la estructura etaria de la captura.

Para obtener la composición de la captura por edad, el método tradicional de construcción de la clave longitud-edad (CLE) desarrollado por Fridriksson (1934) sigue siendo un método frecuentemente usado; sin embargo, una de las principales limitantes de la CLE radica en que ésta no puede ser empleada para aplicarse a distribuciones de longitud de otras áreas o períodos distintos de la cual fue extraída la muestra (Kimura, 1977; Westrheim and Ricker, 1978). Frente a esta situación, hay desarrollos alternativos interesantes para construir claves longitud-edad mediante algoritmos iterativos (CLEI) (Kimura and Chikuni, 1987; Hoenig and Heisey, 1987).

En el presente trabajo se usa el modelo formulado por Hoenig and Heisey con el método iterativo EM (Dempster *et al.*, 1977) para estimar la composición por edad de la captura en el caso de la nueva pesquería de *Dissostichus eleginoides* que se desarrolla en el sur de Chile. La gran ventaja del método iterativo en ésta aplicación es que, disponiendo sólo de una clave para el período, es posible reconstruir la composición de la captura por edad mes a mes, permitiendo de esta manera efectuar un seguimiento más estricto del impacto de la actividad extractiva, situación que puede incluso ser casi instantánea a la obtención de la distribución de frecuencias de longitud del mes o período de interés.

2. METODO

La estructura del modelo de Hoenig and Heisey (1987), se corresponde con un modelo Log-Linear en el que se usa el algoritmo EM para cálculos iterativos de estimaciones máximo - verosímiles. Este tipo de algoritmo ha sido también empleado por Kimura and Chikuni (1987) y discutido con más detalle en Akamine and Matsumiya (1992).

El algoritmo EM consiste en usar una etapa E de esperanza seguido de una etapa M de maximización, cuando los datos son considerados como información incompleta. Esta última condición está presente en el modelo, dado que en la muestra de longitudes extraída del muestreo de la captura, los datos sólo se clasifican por categorías de longitud, omitiéndose la correspondiente lectura de edad, las que deberán ser estimadas con la clave longitud-edad previamente construida.

El modelo sostiene el supuesto que la tasa de clasificación o distribución de probabilidad a la edad P(i/j) de que un individuo de la edad j (j = 1,...a) se encuentre en la longitud i (i = 1,...n), sean iguales tanto, en la primera muestra (k = 1) usada para estimar la clave longitud-edad como, en la segunda muestra (k = 2) usada para estimar la distribución de longitudes, es decir:

$$P(i/j)_{k=1} = P(i/j)_{k=2}$$

La función de distribución del modelo propuesto se ajusta a una multinomial dada por

$$f\left(\{n_{ijk}\}\middle|\{P_{jk}\}\right) = \prod_{k+1}^{2} \frac{n_{..k}!}{\prod_{i=1}^{n}\prod_{j=1}^{a} n_{ijk}!} \prod_{i=1}^{n}\prod_{j=1}^{a} (P(i/j)P_{jk})^{n_{ijk}}$$

Tanto P(i/j), la distribución de longitud a la edad, como P_{j2}, probabilidad a la edad j en la segunda muestra deben ser estimadas por el modelo. P(i/j) incorpora la información proporcionada por las dos muestras a la estimación. Las cantidades n_{ijk} y $n_{..k}$, representan las frecuencias observadas por categorías de longitud i a la edad j en la muestra k y la frecuencia total en la muestra k, respectivamente.

3. ALGORITMO EM DE HOENIG AND HEISEY

3.1 Indices

i = 1,2,..n	Categorías de longitud
j = 1,2,..a	Categorías de edad
k = 1,2	Muestras
s = 1,2,..	Iteraciones
.	Suma sobre índices

3.2 Parámetros

n_{ij2}:	Número estimado de peces de longitud i de edad j en la segunda muestra
n_{ij1}:	Número de peces de longitud i de edad j en la primera muestra
$\hat{P}(i/j)$:	Probabilidad condicional estimada a la longitud i dada la edad j
$\hat{P}_{j2}$:	Probabilidad estimada a la edad j en la segunda muestra
L:	Logaritmo de la función de verosimilitud, sin incluir términos constantes

3.3 Etapas del algoritmo

$$n_{ij2}^{(o)} = \frac{n_{i.2}\, n_{ij1}}{n_{i.1}} \qquad (1)$$

$$\hat{P}(i/j)^{(s+1)} = \frac{\left(n_{ij1} + \hat{n}_{ij2}^{(s)}\right)}{\left(n_{.j1} + \hat{n}_{.j2}^{(s)}\right)} \tag{2}$$

$$\hat{P}_{j2}^{(s+1)} = \frac{\hat{n}_{.j2}^{(s)}}{n_{..2}} \tag{3}$$

$$\hat{n}_{ij2}^{(s+1)} = \frac{\hat{P}(i/j)^{(s+1)} \hat{n}_{.j2}^{(s)} n_{i.2}}{\sum_{j=1}^{a} \hat{P}(i/j)^{(s+1)} \hat{n}_{.j2}^{(s)}} \tag{4}$$

$$D = \left| L^{(s+1)} - L^{(s)} \right| \tag{5}$$

$$\left\{\hat{P}_j\right\} = \hat{P}_{j2}^{(s)} \tag{6}$$

En la etapa 5, si D no es menor que una magnitud de error máxima permitida, el algoritmo debe volver a la etapa 2.

El término L del logaritmo de la función de verosimilitud a maximizar sin incluir términos constantes, está dado por

$$L = \sum_{i=1}^{n}\sum_{j=1}^{a} n_{ij1} \log(\hat{P}(i/j)P_{j1}) + \sum_{i=1}^{n}\sum_{j=1}^{a} \hat{n}_{ij2} \log(\hat{P}(i/j)\hat{P}_{j2})$$

4. APLICACION EN EL RECURSO *DISSOSTICHUS ELEGINOIDES*

Entre los meses de septiembre de 1991 y junio de 1992, en el área del Pacífico Oriental entre los paralelos 47° y 57°LS, se realizó una prospección exhaustiva con la participación de una flota de 10 barcos palangreros factoría, buscando un compromiso entre los objetivos de una pesca comercial y la adquisición de datos que aporte a la evaluación de la pesquería. El estudio fue ejecutado por el Instituto de Fomento Pesquero (IFOP) y empresas pesqueras nacionales, a solicitud de la Subsecretaría de Pesca, con objeto de evaluar el recurso *D. eleginoides* en la perspectiva de expandir nuevas opciones de explotación de la Pesquería Demersal Sur Austral.

Los datos colectados por personal técnico del IFOP a bordo de las embarcaciones, permitieron disponer de muestras de escamas para lecturas de edad y de frecuencias de longitud de la captura en el período cubierto. El muestreo de escamas se basó en un muestreo aleatorio estratificado por categorías de longitud, leyéndose un total de 3.655 escamas.

En la captura de bacalao aparecieron representados 18 grupos de edad, que van desde el grupo 3 al 20. El rango de edades de los machos fluctuó entre 3 y 16 años, observándose una mayor frecuencia en los 11 años. Por su parte en las hembras, fluctuó entre los 3 y 20 años y la moda estuvo en el grupo de edad 12. En general se aprecia que los machos son más abundantes en la captura hasta la edad 13; en tanto, en las edades superiores el predominio de las hembras es evidente.

El análisis se efectuó sin diferenciar por sexo, teniendo en consideración que el crecimiento entre machos y hembras no presenta diferencias significativas (Young *et al.*, 1992).

La figura 1 muestra la distribución de frecuencias y la composición de la captura por edad en cada uno de los meses de estudio, obtenida con el modelo de Hoenig and Heisey. Se deduce que no todas las clases de edad estuvieron soportando igual esfuerzo de pesca o proporcionalmente el mismo en cada mes. En efecto, durante los 3 primeros meses la pesca de investigación, se aprecia una mayor proporción de ejemplares juveniles en la captura, período en el cual la flota operó a menor profundidad donde la proporción de ejemplares pequeños es mayor, debido a la estratificación por talla que presenta el recurso en sentido batimétrico (Young *et al.*, op cit).

La distribución total de la composición de edades de la captura para el período, se obtuvo como producto de la suma de cada mes a la respectiva edad.

La comparación de la composición de la captura por edad obtenida por el modelo iterado y el tradicional, muestra diferencias en las distribuciones (tabla 1; figura 2); no obstante, las diferencias por efecto de aplicar estos dos métodos distintos no indican la presencia de un "error estructural" importante (Rivar, 1989).

5. DISCUSION

Los resultados indican que el método propuesto constituye una alternativa interesante de explorar, principalmente en pesquerías para las cuales no existe información de clave longitud-edad para cada período y/o zona de pesca.

Este método presenta ventajas interesantes respecto al tradicional. De hecho, este método permite sin incrementar los costos que significaría obtener una clave mensual longitud-edad, reconstruir la composición por edad de la captura mensualmente y realizar un seguimiento estricto del comportamiento de la captura. Además, permite proyectarse a zonas y áreas aún más localizadas, siempre que se disponga de una adecuada distribución de frecuencia de longitud y matriz de clasificación $P(i/j)$. Si la especie no sufre alteraciones importantes en la matriz $P(i/j)$ de un período a otro, es posible mantenerla y aplicarla recursivamente (Robotham *et al.*, en prensa).

6. AGRADECIMIENTOS

Este trabajo es un resultado de aplicación de un proyecto de investigación sobre métodos de construcción de claves longitud-edad iteradas, financiado por la Universidad Diego Portales.

BIBLIOGRAFIA

AKAMINE, T. and Y. MATSUMIYA. 1992. Mathematical analysis of age-length key method for estimating age composition from length composition. *Bull. Japan Sea Natl. Fish. Res. Inst.*, 42: 17-24.

DEMPSTER, A.P., N.M. DAVID and D.B. RUBIN. 1977. Maximum likelihood via the EM algorithm. *Journal of the Royal Statistical Society Series B: Methodological*, 39: 1-22.

FRIDRIKSSON, A. 1934. On the calculation of age distribution within a stock of cod by means of relatively few age determinations as a key to measurements on a large scale. *Rapports et Procés Verbaux des Reunions, Conseil International pour Exploration de la Mer*, 86: 1-14.

HOENIG, J.M. and D.M. HEISEY. 1987. Use of a log-linear model with the EM algorithm to correct estimates of stock composition and to convert length to age. *Trans. of the American Fisheries Society*, 116: 232-243.

KIMURA, D.K. 1977. Statistical assesment of the age-length key. *Journal of the Fisheries Research Board of Canada,* 34: 317 - 324.

KIMURA, D. and S. CHIKUNI. 1987. Mixtures of empirical distributions: an iterative application of the age-length key. *Biometrics,* 43: 23-35.

RIVAR, D. 1989. Overview of the systematic, structural and sampling errors in cohort analysis. *American Fisheries Society Symposium,* 6: 49-65.

ROBOTHAM, H., V. OJEDA y W. ARANDA. 1993. Aplicación del algoritmo EM en claves longitud-edad para estimar la distribución de edad de la captura de *Merluccius australis.* En prensa.

WESTRHEIM, S.J. and RICKER, W.E. 1978. Bias in using an age-length key to estimate age-frequency distributions. *Journal of the Fisheries Research Board of Canada,* 35: 184-189.

YOUNG, Z., A. ZULETA, H. ROBOTHAM, M. AGUAYO y L. CID. 1992 Evaluación del stock de bacalao de profundidad entre las latitudes 47° y 57°S, Chile. *Informe Técnico Instituto de Fomento Pesquero*: 63 pp. y anexos.

Tabla 1: Composición de edad de la Captura de *D. eleginoides*, empleando el Método Iterado y el Método Tradicional

Edad	Método			
	Iterado	%	Tradicional	
3	485	0,06	788	0,09
4	3846	0,44	6890	0,78
5	13280	1,51	11605	1,32
6	18017	2,05	18003	2,05
7	18451	2,09	28664	3,26
8	42519	4,83	55122	6,26
9	83937	9,52	85562	9,72
10	116126	13,18	106982	12,16
11	129356	14,69	122082	13,88
12	145641	16,54	134447	15,28
13	105385	11,97	108287	12,31
14	79372	9,01	82075	9,33
15	56400	6,4	57512	6,54
16	32309	3,67	29262	3,33
17	18416	2,09	16816	1,91
18	14378	1,63	12631	1,44
19	1796	0,20	1760	0,20
20	1058	0,12	1378	0,16
Total	880772	100,00	879866	100,00

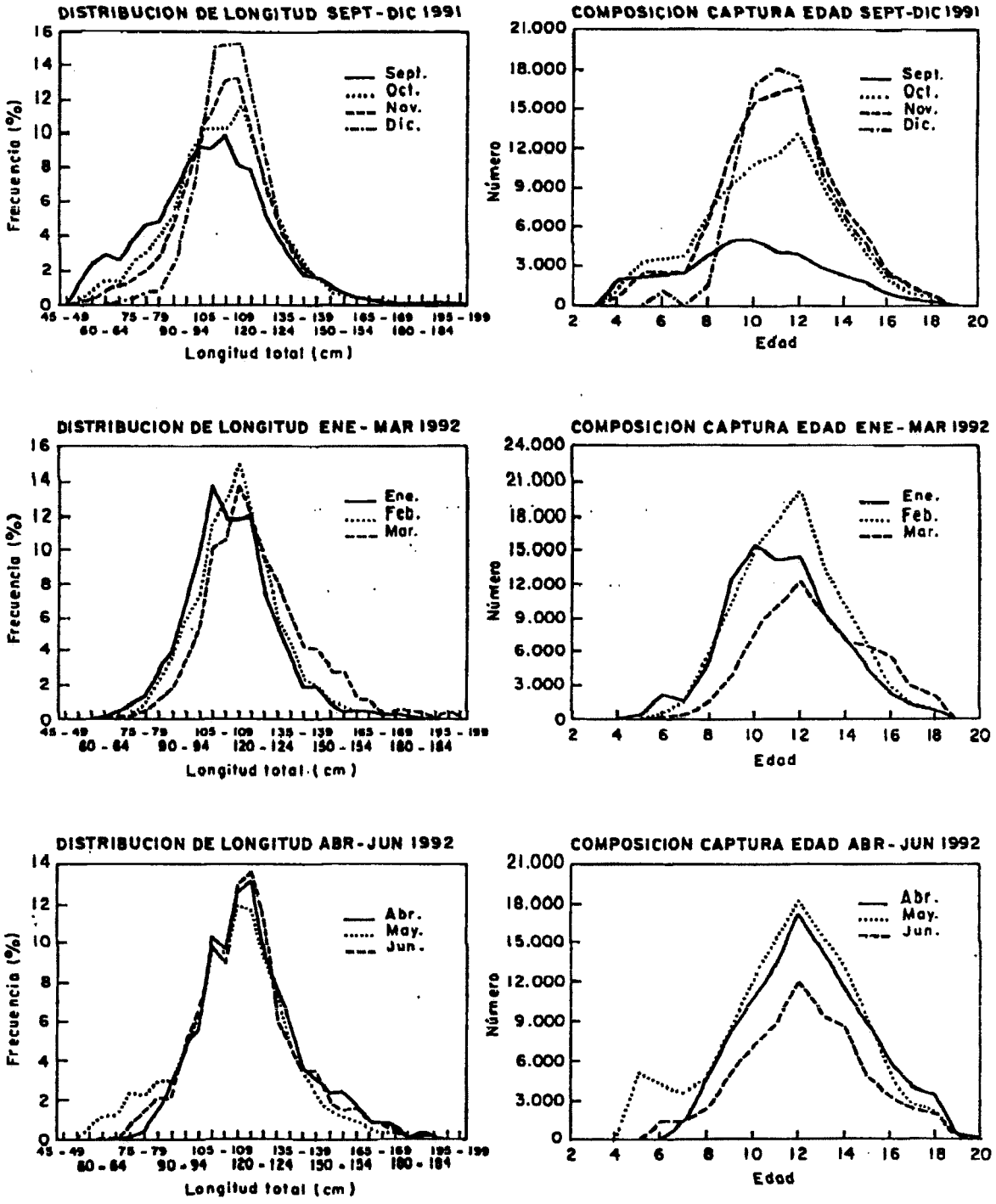

Figura 1: Composición por talla y edad de la captura de *Dissostichus eleginoides*. Sept. 1991 - Junio 1992.

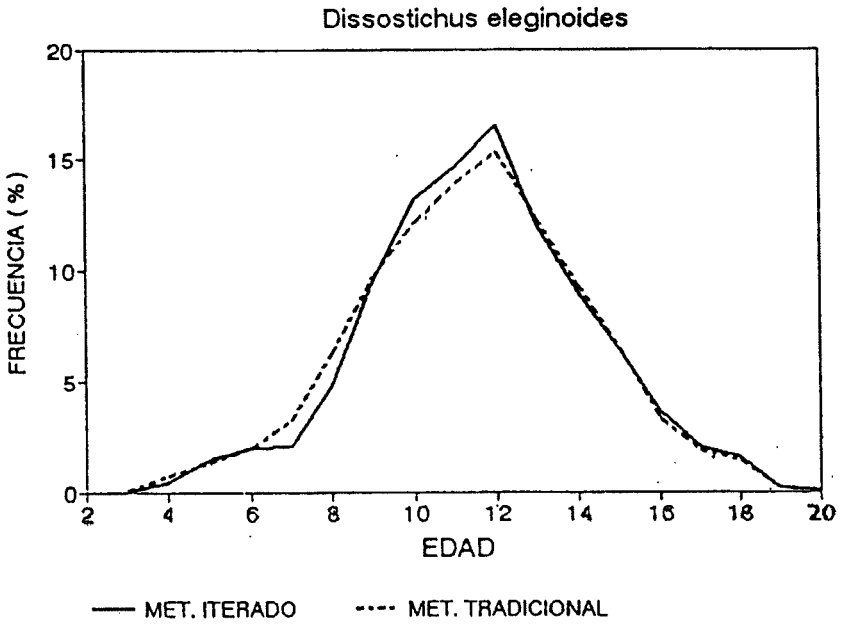

Figura 2: Composición de la captura por grupo de edad.

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NOTAS SOBRE MORTALIDAD NATURAL DE *DISSOSTICHUS ELEGINOIDES* DE LA SUBAREA 48.3

C.A. Moreno y P.S. Rubilar*

Abstract

Natural mortality (M) of *Dissostichus eleginoides* was calculated after Sparre (1989) from the data obtained during the Chilean longline fishery in Subarea 48.3 (N = 7 848). The von Bertalanffy growth parameters obtained independently by three authors were used. Three cases were considered: fishing site, fishing depth and hook type. It was determined that there were no significant differences in M estimated by fishing depth and hook type with different growth parameters although there were differences in M between fishing sites. On the other hand, when comparing various mean values of M for the different cases, it was found that there were significant differences between fishing sites and between curve hooks No. 14 and straight hooks No. 22. The general mean value of M calculated for the 44 analysed situations was 0.14 ± 0.03.

Résumé

La mortalité naturelle (M) de *Dissostichus eleginoides* a été calculée d'après Sparre (1989) à partir des données provenant de la pêcherie à la palangre chilienne dans la sous-zone 48.3 (N = 7 848). Les paramètres de croissance de von Bertalanffy obtenus indépendamment par trois auteurs ont été utilisés. Trois variables ont été examinées: le lieu de pêche, la profondeur de pêche et le type d'hameçon. Il a été établi que la valeur de M ne variait pas de manière significative lorsqu'elle était estimée en fonction de la profondeur de la pêche ou du type d'hameçon avec différents paramètres de croissance mais variait en fonction des sites de pêche. Par ailleurs, en comparant les différentes valeurs moyennes de M pour les différentes variables, on a pu observer des différences notables selon les lieux de pêche et entre les hameçons courbes Nº14 et les hameçons droits Nº 22. La valeur moyenne générale de M calculée pour les 44 situations analysées était de 0,14 ± 0,03.

Резюме

Естественная смертность (M) по данным чилийского ярусного промысла *Dissostichus eleginoides* в Подрайоне 48.3 (N = 7 848) была вычислена по методу Спарре (Sparre, 1989). Были использованы параметры роста Берталанффи, полученные тремя отдельными авторами. Были рассмотрены три случая: промысловый участок, глубина лова и тип крючка. Было установлено, что не существует

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значительных разниц в величинах M, оцененных по глубине лова и типу крючка при различных параметрах роста, но имелись разницы в величинах M между промысловыми участками. С другой стороны, сравнивая различные средние величины M для различных ситуаций наблюдалось значительное различие между промысловыми участками и между округленными крючками № 14 и прямыми крючками № 22. Общая средняя величина M для 44 проанализированных ситуаций равняется 0,14 ± 0,03.

Resumen

Se calculó la mortalidad natural (M) siguiendo a Sparre (1989), con las muestras provenientes de la pesquería chilena de palangre en la Subárea 48.3 (N = 7848). Se utilizaron los parámetros de von Bertalanffy obtenidos independientemente por 3 autores y se consideró como variables el sitio de pesca (caladero), la profundidad de pesca y el tipo de anzuelo. Se determinó que no hay diferencias significativas, en el valor de M, en los casos considerados con los diferentes parámetros de crecimiento, a excepción de entre sitios de pesca. Por otra parte, al comparar los diferentes valores promedios de M para las diferentes variables se encontró que existen diferencias significativas entre caladeros y entre anzuelos curvos N° 22 y rectos N° 14. El promedio general de los M calculados en las 44 situaciones analizadas fué de 0.14 ± 0.03.

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1. INTRODUCCION

Desde que Shust *et al.* (1990) presentaron valores de mortalidad natural (M) para la población de *Dissostichus eleginoides* de las islas Georgia del Sur entre M = 0.16 y 0.18, el grupo de trabajo de evaluación de poblaciones de peces (WG-FSA) notó que estos valores parecían altos comparados con el valor del parámetro K de crecimiento de von Bertalanffy de 0.072, implicando que muy pocos peces llegarían a la edad adulta. Antes de estos valores el grupo de trabajo utilizó además el valor obtenido por Kock, Duhamel and Hureau (1985) de M = 0.06. Durante la reunión de 1991 se volvieron a usar los mismos valores en Gasiukov *et al* (1991) y Everson (1991) respectivamente, sin que existieran nuevas evidencias para acercarse al valor más adecuado de este parámetro.

Tales discrepancias pueden tener variados orígenes; se han mencionado la selectividad de los anzuelos (SC-CAMLR, 1990) y la eventualidad de que existan diferencias espaciales de la distribución de individuos de diferentes edades, tanto verticales como a lo largo del talud que afecten la estructura de talla de las capturas, con las subsecuentes consecuencias para los valores obtenidos de mortalidad natural. Especialmente a partir de los métodos que utilizan distribuciones de talla o de edad en sus cálculos. Otra fuente potencial de variación para los valores de la mortalidad natural son las variaciones de los parámetros de las ecuaciones de crecimiento, especialmente la constante K y L_{∞}.

Una manera de explorar las causas de variación de los valores de mortalidad es haciendo un análisis, en base a una selección de métodos de entre los sugeridos por Sparre (1989), aplicados a las capturas obtenidas en diferentes caladeros (sitios de pesca) dentro de la

Subárea 48.3 cuyas estructuras de edad y tamaños son diferentes y utilizando las tres ecuaciones de crecimiento de *D. eleginoides* conocidas para esa área: la indicada por Zacharov y Frolkina (1976), Shust *et al.* (1990) y la recientemente aportada por Aguayo (1992).

2. METODOS

Los datos para los diferentes cálculos de mortalidad provienen de la serie de datos en escala fina que fueron tomados durante la temporada 1991/92 por la flota palangrera chilena en la Subárea 48.3 (véase Agnew and Moreno, 1992).

De cada lance se tomó: posición geográfica, profundidad, número y tamaño de los anzuelos, captura total y una submuestra de 30 ejemplares por lance, de los cuales se obtuvo la composición por talla de la captura, medida en cm de longitud estándar (LS). Para estandarizar los valores de las distribuciones de tallas obtenidos con los de las ecuaciones de crecimiento existentes todos los cálculos de M se hicieron en base de longitudes totales (LT).

De esta manera fué posible considerar como variables de la mortalidad:

- Tipos de anzuelo;
- Sitios de pesca (caladeros);
- Profundidad de pesca.

Las ecuaciones de crecimiento consideradas para los cálculos fueron:

- Zacharov and Frolkina (1976): $L_t = 204.3\ [1-e^{-0.0563\{t+0.545\}}]$
- Shust *et al.* (1990): $L_t = 174.8\ [1-e^{-0.07117\{t-0.0049\}}]$
- Aguayo (1992): $L_t = 210.8\ [1-e^{-0.0644\{t+0.7832\}}]$

Los algoritmos de cálculo de la mortalidad natural (M) fueron:

- Berverton and Holt (1956) (basado en edad)

$$M(=Z) = \frac{1}{\bar{t} - t'}$$

donde, t' es la edad totalmente reclutada, y $\bar{t}$ es el promedio de peces a la edad t' y más viejos.

- Beverton and Holt (1956) (basado en longitudes)

$$M(=Z) = K\frac{L\infty - \bar{L}}{\bar{L} - L'}$$

donde, L_∞ y K son parámetros de la ecuación de von Bertalanffy, L' es la longitud totalmente reclutada y $\bar{L}$ es la longitud promedio de los peces a la longitud L' y mayores.

- Robson and Chapman (1961)

$$M(=Z) = \ln\left(1 + \frac{1}{\bar{t} - t'}\right)$$

donde, t' es la edad totalmente reclutada, y $\bar{t}$ es el promedio de peces a la edad t' y más viejos.

- Alverson-Carnee según Sparre (1989):

$$M(= Z) = \frac{3K}{e^{TK} - 1}$$

donde K es la constante de Brody de la ecuación de von Bertalanffy y T es la edad donde N_t* W_t toma su valor máximo.

3. RESULTADOS

3.1 Efecto del sitio de pesca

En la tabla 1 se observan los valores calculados para los tres diferentes caladeros identificados para la flota palangrera chilena por Agnew and Moreno (1992).

Los valores calculados en Shag Rocks usando los parámetros de las tres ecuaciones de crecimiento son significativamente diferentes (Kruskall-Wallis test H = 7.2692: 2 gl y P<0.05), siendo superior los valores de M determinados con los parámetros estimados a partir de Aguayo (1992). Respecto de los valores de M calculados para el caladero norte y sur de las Georgias, no existen diferencias estadísticamente significativas al utilizar cualquiera de las tres ecuaciones de crecimiento. (KW test para el caladero Norte, H = 3.8307: 2 gl vns; KW test para el caladero Sur, H = 2.2868: 2 gl vns).

Se observa al comparar entre caladeros, que los promedios de la mortalidad natural de las poblaciones capturadas al norte y al sur de la isla Georgia son practicamente idénticos, sin embargo ambos difieren significativamente del caladero ubicado en Shags Rocks (KW test, H = 9.2988: 2 gl P<0.01) (Prueba de comparación múltiple STP = U(α =0.05) = 112.54, P<0.05: N-S SR).

3.2 Efecto del tipo de anzuelo

En la tabla 2, se presentan los valores de M calculados a partir de los parámetros de crecimiento de las 3 ecuaciones y las distribuciones de tallas de los peces separados por el tipo (forma y número) de anzuelo. Los anzuelos utilizados por la flota chilena se pueden separar en 6 categorías: Tamaños 3, 5, 7, 9 (diferentes tamaños de anzuelos semi-curvos); 14 (recto sin ojal) y 22 (curvo).

Al comparar con la prueba de comparaciones múltiples STP, se puede concluir que con un nivel de significancia de $\alpha = 0.05$, el anzuelo 14 (recto sin ojal) difiere de los tipos 22 (curvo) y de los tamaños 7 y 9 de anzuelos semi-curvos. En un nivel de $\alpha = 0.01$, sólo difieren el 14 del 22, no existiendo diferencias significativas entre éstos y los demás tipos de anzuelo en el cálculo de la mortalidad natural (M).

Dentro de cada una de las categorías de anzuelos, los valores promedios de M calculados a partir de las diferentes ecuaciones de crecimiento, no son estadísticamente diferentes.

3.3 Efecto de la profundidad de pesca

Separando las estructuras de tallas de las pescas en 1 200 m de profundidad, se observa que al comparar los resultados de los valores M calculados dentro de cada profundidad no se encontraron diferencias significativas; tanto para el caso de las profundidades menores a

1 200 m (KW test H = 5.6538: 2 gl vns) ni para el de las mayores (KW test, H = 2.00: 2 gl vns) (Tabla 3). Por otra parte, tampoco se observan diferencias significativas entre todos los valores calculados para ambas profundidades (KW test, H = 1.0800, gl = 1 vns; ANDEVA 1-22 gl F = 0.801, vns.).

El valor promedio total y su desviación típica, es decir de los diferentes métodos de cálculo de M y de las diferentes profundidades, tipos de anzuelo y sitios de pesca fué de 0.14 ± 0.0381.

4. CONCLUSIONES

Los valores de M (= Z) calculados por cuatro diferentes métodos han mostrado ser más sensibles al sitio de pesca (caladero) que a la profundidad de los lances y al tipo de anzuelo utilizado. Por otra parte, los parámetros de las ecuaciones de crecimiento utilizadas no muestran tener una gran influencia debido a que en muy pocos casos se encontró diferencias significativas dentro de cada situación, cuando la variable a comparar fué el valor de M calculado con las 3 ecuaciones de crecimiento mencionadas.

En consecuencia, no todos los factores mencionados por el WG-FSA durante la reunión de 1991, son causas importantes de variación en el valor promedio de M de *D. eleginoides* de la pesquería de palangre de la Subárea 48.3.

La razón que parece primar en las diferencias encontradas en cada caso (por ejemplo entre caladeros) fué la frecuencia de ejemplares de tallas superiores a 1 m en las distribuciones de tamaños. Eso al menos concuerda con el efecto de selectividad conocido de los anzuelos curvos (Moreno, 1991). Por otra parte, una alta frecuencia de juveniles en las capturas, influencia el valor de $\bar{L}$ y L' y consecuentemente el valor calculado de M.

El valor de M señalado por Kock *et al.* (1985) de 0,06 corresponde a la población de la Patagonia y utilizando un método indirecto cuya precisión es puesta en duda por Sparre (1989). En cambio los valores derivados por Shust *et al.* (1991) son más cercanos a los nuestros. Sin embargo, al análisis de Longevidad ($M_{1\%} = - \ln(0.01)/M$) sugiere una edad máxima de 25 años, lo cual parece poco para una población que alcanza tamaños de más de 2 metros en aguas frías, por lo cual esa mortalidad natural debe estar sobrestimada. Nuestro valor promedio de 0.14 sugiere una edad máxima de 33 años, en cambio el valor de 0.06 resulta en una longevidad de 77 años, la cual esta lejos de las experiencias de medición del crecimiento y edad.

Lo anterior sugiere, que la mayor prioridad de investigación respecto a *D. eleginoides* es validar, por métodos alternativos, los datos de edad y crecimiento obtenidos de las lecturas de escamas.

REFERENCIAS BIBLIOGRAFICAS

AGNEW, D.J. and C.A. MORENO. 1992. The 1992 *Dissostichus* Fishery in Subarea 48.3. In: *Selected Scientific Papers, 1992 (SC-CAMLR-SSP/9).* CCAMLR, Hobart, Australia. (See this volume).

AGUAYO, M., 1992. Análisis preliminar del crecimiento de *Dissostichus eleginoides* en la Zona Sur - Austral de Chile (47°00' LS - 57°00'LS) y en el Area de las Georgias del Sur. Documento *WG-FSA-92/30.* CCAMLR, Hobart, Australia.

BEVERTON, R.J.H. and S.J. HOLT, 1956. A review of methods for estimating mortality rates in exploited fish populations, with special refence to source of bias in catch sampling. Rapp. P.V. Reún. CIEM, 140: 6783 pp.

EVERSON, I., 1991. Stock Assesment of the patagonian toothfish *(Dissostichus eleginoides)* at South Georgia. Document *WG-FSA-92/20.* CCAMLR, Hobart, Australia.

GASIUKOV, P.S, R.S. DOROVSKIKH and K.V. SHUST, 1991. Assesment of the *Dissostichus eleginoides* stock in subarea 48.3 for the 1990/91 season and calculation of TAC for the 1991/92 season. Document *WG-FSA-91/24.* CCAMLR, Hobart, Australia.

KOCK, K-H., G. DUHAMEL and J.-C. HUREAU, 1985. Biology and Status of exploited Antartic Fish Stock: A Review. *BIOMASS Scientific Series* 6: VIII-143 pp.

MORENO, C.A. 1991. Hook selectivity in the longline fishery of *Dissostichus eleginoides* (Nototheniidae) off the chilean coast. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 107-119.

ROBSON, D.S and D.G. CHAPMAN. 1961. Catch curves and mortality rates. *Trans. Am. Fish. Soc.*, 90 (2): 181-189.

SC-CAMLR. 1990. Report of the Working Group on Fish Stock Assessment. In: *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX)*, Annex 5. CCAMLR, Hobart, Australia: p. 156.

SHUST, K.V., P.S. GASIUKOV, R.S. DOROVSKIKH and B.A. KENZHIN. 1990. The state of *Dissostichus eleginoides* stock and TAC for 1990/91 in Subarea 48.3 (South Georgia). Document *WG-FSA-90/34.* CCAMLR, Hobart, Australia.

SPARRE, P. 1989. Some comments on the estimation of natural mortality for *C. gunnari, N. squamifrons and P. guntheri* based on Soviet data. In: *Report of the Eighth Meeting of the Scientific Committee (SC-CAMLR-VIII)*, Annex, 5, Appendix 5. CCAMLR, Hobart, Australia: 264-271.

ZACHAROV, G.P. and Z.A. FROLKINA. 1976. Some data on the distribution and biology of the Patagonian toothfish *(Dissostichus eleginoides* Smitt) occurring in the Southwest Atlantic. *Trudy AtlantNIRO*, 65: 143-150. (In Russian.)

Tabla 1: Mortalidades naturales determinadas para 3 sectores de pesca en la Subárea 48.3 de la CCRVMA.

Parámetros de crecimiento de:			
Método	Zacharov and Frolkina (1976)	Shust *et al.* (1991)	Aguayo (1992)
SHAG ROCK			
Beverton and Holt (longitud)	0.1343	0.1184	0.1705
Beverton and Holt (edad)	0.1608	0.1514	0.1945
Robson and Chapman	0.1491	0.1410	0.1777
Alverson-Carnee	0.1709	0.1442	0.2175
		$\overline{M} = 0.1609 \pm 0.0273$	
SOUTH GEORGIA (N)			
Beverton and Holt (longitud)	0.1008	0.0911	0.1227
Beverton and Holt (edad)	0.1194	0.1235	0.1526
Robson and Chapman	0.1128	0.1165	0.1421
Alverson-Carnee	0.1526	0.1260	0.1945
		$\overline{M} = 0.1296 \pm 0.0276$	
SOUTH GEORGIA (S)			
Beverton and Holt (longitud)	0.0816	0.0688	0.1004
Beverton and Holt (edad)	0.1020	0.1004	0.1397
Robson and Chapman	0.0971	0.0957	0.1308
Alverson-Carnee	0.1709	0.1442	0.2175
		$\overline{M} = 0.1207 \pm 0.0421$	

Tabla 2: Mortalidades naturales determinadas para 6 tipos de anzuelos en la Subárea 48.3 de la CCRVMA.

Parámetros de crecimiento de:			
Método	Zacharov and Frolkina (1976)	Shust *et al.* (1991)	Aguayo (1992)
Anzuelo N° 3			
Beverton and Holt (longitud)	0.1048	0.0953	0.1275
Beverton and Holt (edad)	0.1310	0.1278	0.1575
Robson and Chapman	0.1231	0.1203	0.1463
Alverson-Carnee	0.2144	0.1872	0.2727
		$\overline{M} = 0.1506 \pm 0.0511$	
Anzuelo N° 5			
Beverton and Holt (longitud)	0.1005	0.0890	0.1226
Beverton and Holt (edad)	0.1266	0.1218	0.1258
Robson and Chapman	0.1192	0.1149	0.1525
Alverson-Carnee	0.1709	0.1448	0.2175
		$\overline{M} = 0.1338 \pm 0.0342$	
Anzuelo N° 7			
Beverton and Holt (longitud)	0.1133	0.1040	0.1376
Beverton and Holt (edad)	0.1395	0.1368	0.1677
Robson and Chapman	0.1306	0.1282	0.1550
Alverson-Carnee	0.1362	0.1095	0.1740
		$\overline{M} = 0.1360 \pm 0.0216$	
Anzuelo N° 9			
Beverton and Holt (longitud)	0.1110	0.1017	0.1349
Beverton and Holt (edad)	0.1372	0.1344	0.1650
Robson and Chapman	0.1286	0.1261	0.1527
Alverson-Carnee	0.1913	0.1645	0.2434
		$\overline{M} = 0.1492 \pm 0.0386$	
Anzuelo N° 14			
Beverton and Holt (longitud)	0.0766	0.0623	0.0946
Beverton and Holt (edad)	0.1022	0.0936	0.1240
Robson and Chapman	0.0973	0.0895	0.1169
Alverson-Carnee	0.1215	0.0946	0.1555
		$\overline{M} = 0.1024 \pm 0.0244$	
Anzuelo N° 22			
Beverton and Holt (longitud)	0.1618	0.1519	0.2044
Beverton and Holt (edad)	0.1948	0.1854	0.2351
Robson and Chapman	0.1112	0.1071	0.2112
Alverson-Carnee	0.1526	0.1260	0.1945
		$\overline{M} = 0.1749 \pm 0.0361$	

Tabla 3: Mortalidades naturales determinadas para 2 profundidades de pesca en la Subárea 48.3.

Parámetros de crecimiento de:			
Método	Zacharov and Frolkina (1976)	Shust *et al.* (1991)	Aguayo (1992)
Profundidad ≤ 1200 m.			
Beverton and Holt (longitud)	0.1075	0.0967	0.1310
Beverton and Holt (edad)	0.1337	0.1292	0.1611
Robson and Chapman	0.1255	0.1215	0.1494
Alverson-Carnee	0.1526	0.1259	0.1945
		$\overline{M} = 0.1357 \pm 0.0511$	
Profundidad > 1200 m.			
Beverton and Holt (longitud)	0.0898	0.0797	0.1096
Beverton and Holt (edad)	0.1157	0.1118	0.1394
Robson and Chapman	0.1095	0.1060	0.1305
Alverson-Carnee	0.1709	0.1443	0.2175
		$\overline{M} = 0.1270 \pm 0.0377$	

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THE 1991/92 FISHERY FOR *DISSOSTICHUS ELEGINOIDES* IN SUBAREA 48.3

D.J. Agnew[1] and C.A. Moreno[2]

Abstract

The 1991/92 longline fishery for *Dissostichus eleginoides* in Subarea 48.3 was open from 4 November 1991 to 10 March 1992. A total of 3 382 tonnes was taken by one Bulgarian, five Russian and eight Chilean vessels. The maximum catch taken in a five-day period was 375 tonnes. Catch rate was not influenced by fishing depth, time of day or soak time, but was dependent on type of hook and geographical position. Fish caught around Shag Rocks were larger than to the north and southeast of South Georgia. CPUE varied markedly among fleets and was about 1 kg/hook in the Chilean fleet, 0.2 to 0.4 in the Russian and 0.2 in the Bulgarian. These differences were probably a result of the different hook types used by the fleets.

Résumé

En 1991/92, la pêche à la palangre de *Dissostichus eleginoides* dans la sous-zone 48.3 était ouverte du 4 novembre 1991 au 10 mars 1992. Au total, 3 382 tonnes ont été capturées par un navire bulgare, cinq navires russes et huit navires chiliens. La capture maximale était de 375 tonnes pour une période de cinq jours. Le taux de capture n'était pas influencé par la profondeur de pêche, l'heure ou le temps de trempage; par contre, il était fonction du type d'hameçon et de la position géographique. Les poissons capturés étaient plus grands autour des îlots Shag qu'au nord et au sud-est de la Géorgie du Sud. La CPUE variait nettement entre les flottes: 1 kg/hameçon dans la flotte chilienne; de 0,2 à 0,4 dans la flotte russe; 0,2 dans la flotte bulgare. Les différents types d'hameçons utilisés expliquent vraisemblablement ces différences.

Резюме

В Подрайоне 48.3 ярусный промысел *Dissostichus eleginoides* был открыт с 4 ноября 1991 г. по 10 марта 1992 г. Всего было получено 3 382 тонны одним болгарским, пятью российскими и восьмью чилийскими судами. Максимальный вылов - 375 тонн за один пятидневный период. На интенсивность лова не влияли глубина лова, время суток или время нахождения яруса в воде, однако интенсивность лова зависела от типа крючка и географического местоположения лова. Более крупные особи вылавливались вокруг скал Шаг, чем в районах к северу и юго-востоку от Южной Георгии. CPUE в значительной мере колебался между промысловыми

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флотами: 1 кг/крючок у чилийского флота; 0,2-0,4 у российского флота и 0,2 у болгарского флота. Эти различия вероятно являлись следствием использования флотами крючков различных типов.

Resumen

La temporada de pesca de palangre de 1991/92 de *Dissostichus eleginoides* en la Subárea 48.3 estuvo abierta del 4 de noviembre de 1991 hasta el 10 de marzo de 1992. Un total de 3 382 toneladas fueron extraídas por un buque pesquero búlgaro, cinco rusos y ocho chilenos, dándose un máximo de captura de 375 toneladas en un período de cinco días. El nivel de captura no se vio influenciado por la profundidad de pesca, hora del día o tiempo de calado, pero sí dependió del tipo de anzuelo y de la situación geográfica. Se pescaron peces más grandes alrededor de las rocas Cormorán que al norte y sudeste de Georgia del Sur. El CPUE varió significativamente entre las flotas, siendo de 1 kg/anzuelo para la flota chilena, 0.2 a 0.4 para la flota rusa y 0.2 para la flota búlgara. Es posible que esto haya ocurrido debido a los distintos tipos de anzuelos utilizados por las flotas.

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1. INTRODUCTION

The 1991/92 fishery for *Dissostichus eleginoides* opened on 4 November 1992 with a TAC of 3 500 tonnes, and was closed on 10 March 1992 when a total of 3 364 tonnes had been taken. A further 18 tonnes was taken by Bulgaria before it ceased fishing on 24 March. The maximum catch taken in a five-day period was 375 tonnes (Figure 1).

The fishery was prosecuted by one Bulgarian, five Russian and eight Chilean vessels, fishing for different periods (see Figure 2). Vessel size was reported as 500 to 1 000 tonnes for Bulgaria and Russia, and as shown in Table 1 for Chile.

1.1 Data Sources

Catch and effort data were reported by five-day periods and in fine-scale longline format. These data were used in the following analysis. In addition, length frequency data were reported by Chile and Russia in standard format. Chilean data were extracted from logbooks and included the weight, but not the number, of fish caught, thus precluding some calculations in the following analysis.

1.2 Fishing Strategies

Two clear fishing strategies were identified in the Russian fishery. Some vessels set all their lines (usually three to four) in the early morning, and then commenced hauling; others set and hauled lines alternately to maintain a standard soak time for the lines. This lead to very different times in the water for the first group of vessels, but more consistent times for the second. These strategies are shown schematically in Figure 3.

There was no significant correlation between the time that hooks were in the water and the number of fish caught or CPUE (both in numbers and weight) for either the Bulgarian or Russian fishery. Thus, it appears that the strategies shown in Figure 3 have no bearing on

expected catch rates and are significant only for logistic reasons. However, there was a positive relationship between mean number of fish caught per haul and the number of hooks on the line for the Russian fishery over the whole season (Figure 4).

The number of hooks per line, and the size of hooks varied considerably among vessels (Tables 1 and 2). In the Chilean fleet six different hook sizes of four general types were used:

- Type I - hooks with parallel sides and in a single plane ("parallel, flat") [Mustad sizes 3 and 5; width 20 to 25 mm (Moreno, 1991)];
- Type II - hooks slightly recurving at the barb and twisting out of a single plane ("semicurved, twisted") [Japanese brand, sizes 7 and 9; width 30 to 35 mm];
- Type III - hooks fully recurving, in one plane ("curved, flat") [Mustad size 14; width 27 mm (Moreno, 1991)]
- Type IV - hooks parallel, twisting and without an eye (all the above are eyed) ("parallel, eyeless") [Japanese hooks size 22; width 28 mm].

On some vessels more than one type of hook was used, even on the same longline. This strategy was attributed to vessels moving to the *Dissostichus* fishery having recently targeted other species, such as pink ling (*Genypterus blacodes*) and hake (*Merluccius australis*) in Chilean fisheries, and to trying to determine the most effective hook for *D. eleginoides* (SC-CAMLR, 1992b). With the exception of vessel (e) (Table 2), the hooks used in the Russian fishery were probably of type I.

A number of different baits were used in all fisheries: squid *(Loligo, Ilex), Sardinops,* Mackerel and Horse Mackerel (including *Scomber*). By-catch mainly comprised skates and macrourids, reported occasionally by Russian and Bulgarian fleets. Two reports from early December by the Russian fleet indicated some incidental mortality of unidentified birds but subsequent reports indicated zero mortality.

The position of all catches is shown in Figure 5 (a to c). The Chilean fleet showed most movement between areas, with the Russian and Bulgarian fleets remaining to the north and close north-west of South Georgia. The depth of fishing for the Russian, Bulgarian and Chilean fisheries was similar, with means of 1 334 m, 1 378 m and 1 473 m respectively and distributions typically ranging from 1 000 to 1 800 m with strong modes between 1 300 and 1 400 m.

Hook size was reported for only some of the length frequencies recorded by Chilean vessels. From these data it appears that within a type of hook, larger hooks catch larger fish; however, hooks of type I caught larger fish than the larger type II hooks, and the curved hooks of type III caught markedly larger fish then any others (Figure 6).

Combining all data from the Chilean fishing season it is possible to identify three major areas of fishing, defined as northwest of South Georgia ("Shag Rocks"), north of South Georgia and southeast of South Georgia, each with a characteristic length frequency distribution (Figure 7). The mean weight of fish from the Russian fishery in the northwest area (west of 41°W) was 9.78 kg (n = 153 hauls, SD = 2.09), while from the northern sector it was 8.86 (n = 347, SD 2.48), significantly lower than in the Shag Rocks area (t test, $p<0.001$). This result is similar to that seen in Figure 7, where there is an increasing proportion of larger fish in the northwest area. Mean weights from the Bulgarian fishery showed similar, but insignificant, differences between regions (7.11 kg northwest, 6.95 kg north). However, the length frequency

data reported from the Russian fishery (Figure 8) appear to show a contrary trend, where there is an increasing proportion of larger fish in the north than the northwest areas[1].

Mean weight of fish in the Russian and Bulgarian fisheries did not change over the period of the commercial fishery, but did appear to increase during the Russian research fishery from April to June (Table 4). However, some vessels caught significantly smaller fish than others, especially vessel (a) which seemed to improve its performance later in the year.

CPUE

Daily CPUE, expressed as kg/thousand hooks for comparative purposes between fleets, is shown in Figure 9 (a to c). The CPUE for Chilean vessels was far in excess of that for Russian and Bulgarian vessels, with the former having a mean CPUE in February of about 1 000 compared to between 200 and 400 for Russian vessels and about 200 for Bulgarian vessels.

Whilst the CPUE for Chilean vessels showed a decline throughout the season, Bulgarian and Russian vessels did not experience this; on the contrary, it appears from Figure 9 that the Russian CPUE increased in late February and March. A more detailed analysis of the Russian and Bulgarian CPUE (numbers/thousand hooks) (Table 3) shows the increase in overall CPUE in March to be a result of vessel (e) entering the Russian fishery. Although the catches were in similar positions and at similar depths to catches by other vessels, vessel (e) used larger hooks and shorter lines than other vessels (Table 2). It thus appears that gear differences may have been the cause of the higher CPUE values for vessel (e), seen both in Table 3 and Figure 4.

DISCUSSION

The 1991/92 fishing season for *D. eleginoides* was rather shorter than previous seasons, primarily because of the entry into the fishery of the large Chilean fleet with its very high CPUE.

There were large differences in CPUE among and within fleets. All fleets were operating in similar areas (apart from the extra area southeast of South Georgia exploited by the Chilean fleet), at similar depths over similar times, but the line characteristics of the fleets were different. Chilean vessels used longer lines, larger hooks and a different types of hook from the other vessels. It is perhaps significant that the one Russian vessel to use a larger hook achieved a much increased CPUE over February to March. The UK reports of an attempted inspection of a Russian longliner and an inspection of the Chilean *Mar del sur III* (SC-CAMLR, 1992a and 1992b) found that the Russian longlines retained less bait and caught fewer fish than the Chilean vessels. It appears that the differences in CPUE between these two fleets may have been due to the different types and sizes of hooks used, but there is probably also a large component of fishing skipper experience in the choice of appropriate sites for setting the longlines, even within the generalised areas shown in Figure 5.

Both Russian and Chilean fleets caught larger fish in the west of the Subarea 48.3, towards Shag Rocks, than in the east. However, the average weight of fish caught by the Russian fishery was lower than the mean weight assumed for this species by the Working Group on Fish Stock Assessment (WG-FSA) in 1991 (9.14 kg compared to 10.82). Chilean and Russian CPUE have been superimposed on the data extracted from STATLANT reports by WG-FSA in 1991 (assuming 10.82 kg/fish). The Russian data appear to show a decline in CPUE for this species; however, there may be some effect of interaction among the fleets since up to now this has been a single fleet fishery. These data, supplied in haul-by-haul formats, have proved extremely useful in understanding the mechanics of the *D. eleginoides* fishery.

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[1] Reported total lengths from the Russian fishery were converted to standard length for comparison with the Chilean data using the relationship TL=1.247+1.118SL given in Kock *et al.*, (1985).

REFERENCES

KOCK, K.-H., G. DUHAMEL and J.-C. HUREAU. 1985. Biology and status of exploited Antarctic fish stocks: a review. *BIOMASS Scientific Series,* No. 6.

MORENO, C.A. 1991. Hook selectivity in the longline fishery of *Dissostichus eleginoides* (nototheniidae) off the Chilean coast. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 107-119.

SC-CAMLR. 1992a. Report of an inspection carried out under the provisions of the CCAMLR inspection system on the registered fishing vessel *Mar del sur III,* 18 January 1992. Document *CCAMLR-XI/BG/3.* CCAMLR, Hobart, Australia.

SC-CAMLR. 1992b. Report of an attempted inspection, under the provisions of the CCAMLR inspection system, of the Russian long-line vessel *Pantakopei*, 27 January 1992. Document *CCAMLR-XI/BG/5.* CCAMLR, Hobart, Australia.

Table 1: Chilean fleet characteristics, 1991/92 season.

Vessel Name	Length (m)	GRT (tonnes)	Hold Capacity (m^3)	Hook Sizes
Mar del Sur I	46	349.5	380.7	Mixed (see text)
Mar del Sur III	48.8	299.4	290	" " "
Chaval	42.5	325	350	" " "
Antonio Lorenzo	50	650	500	" " "
Isla Sofia	48.5	449	505	" " "
Cisne Verde	44.4	327.1	562	" " "
Cisne Blanco	46.7	437	457	" " "
Friosur V	54	975	746	Japanese No. 22
	47.6	466.5	473.8	

Table 2: Line characteristics of Russian and Bulgarian vessels.

Vessel	Hook Size	Hook Spacing	Number of Hooks
Russian a	20 to 25 mm	120 cm	2800 - 5600
Russian b	20 to 25 mm	120 cm	2400 - 4800
Russian c	20 to 25 mm	120 cm	2400 - 4800
Russian d	20 to 25 mm	120 cm	13500
Russian e	25 to 30 mm	120 cm	3200
Bulgarian	25 to 30 mm	120 cm	1125 - 9000
Chilean (vessel undefined)	25 to 30 mm	200 cm	11700

Table 3: CPUE and calculated mean fish weight by month.

Russia:

Month	Vessel	Mean CPUE number x 10^3 hooks	SD	Mean Wt (kg)	SD	n
12	a	29.6	(23.8)	6.70	(1.6)	50
12	b	29.0	(9.4)	10.03	(1.0)	30
12	c	29.2	(14.3)	9.02	(1.2)	25
	Total	29.3	(18.4)			105
1	a	32.9	(14.7)	5.44	(0.6)	30
1	b	28.7	(14.1)	10.87	(2.0)	30
1	c	33.8	(16.8)	9.27	(1.4)	70
	Total	32.4	(15.8)			130
2	a	25.9	(11.0)	5.52	(0.9)	42
2	c	43.8	(16.1)	9.93	(0.7)	21
2	d	20.0	(6.3)	9.02	(0.1)	7
2	e	47.6	(19.1)	9.38	(0.2)	23
	Total	34.9	(17.7)			93
3	a	34.4	(13.2)	8.05	(2.4)	10
3	c	38.7	(17.3)	10.87	(1.5)	29
3	d	14.9	(3.5)	9.00	(0.0)	9
3	e	74.7	(17.9)	9.71	(0.1)	34
	Total	50.5	(26.9)			82
4	a	40.4	(13.8)	11.67	(1.4)	8
	Total	40.4	(13.8)			8
5	a	17.0	(9.2)	9.89	(1.8)	7
5	b	28.3	(12.7)	10.53	(1.1)	10
	Total	23.6	(12.5)			17
6	a	20.3	(10.2)	12.62	(0.9)	36
6	b	40.8	(16.8)	11.12	(1.5)	29
	Total	29.4	(17.0)			65
Total	Total			9.14	(2.4)	500

Bulgaria:

Month	Vessel	Mean CPUE number x 10^3 hooks	SD	Mean Wt (kg)	SD	n
12	1	23.6	(20.9)	7.66	(1.4)	67
1	1	19.8	(12.3)	6.86	(1.3)	56
2	1	32.9	(13.1)	7.11	(1.0)	36
3	1	30.0	(16.5)	6.29	(1.1)	45
Total				7.04	(1.4)	204

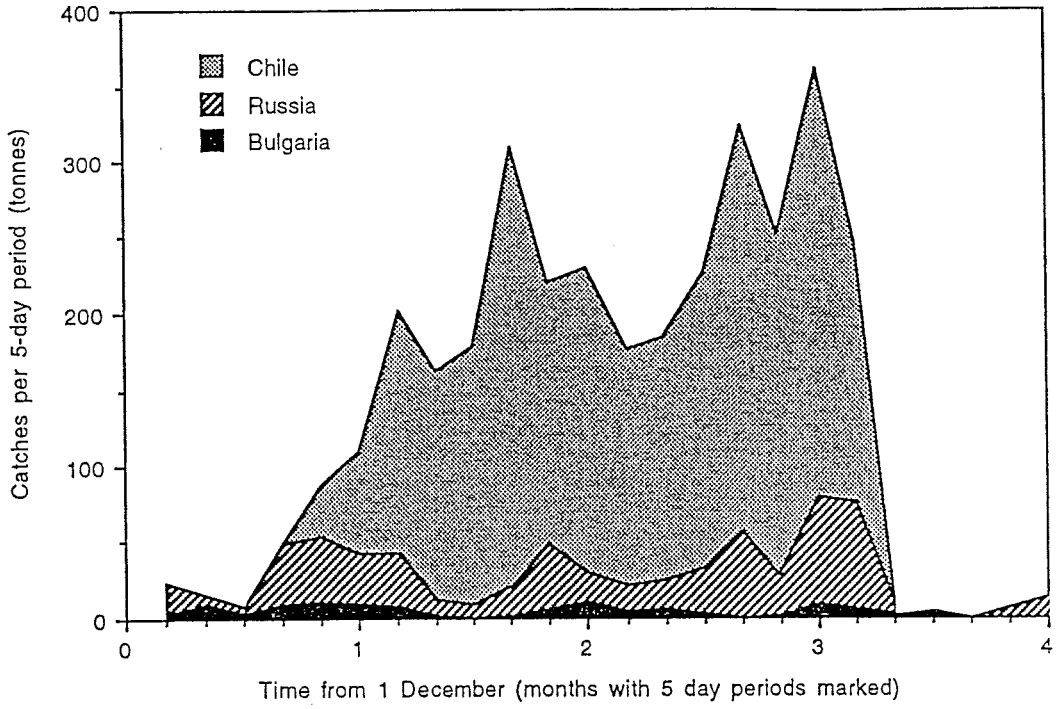


Figure 1: *D. eleginoides* fishery, 1992 season. Catches by five-day period.

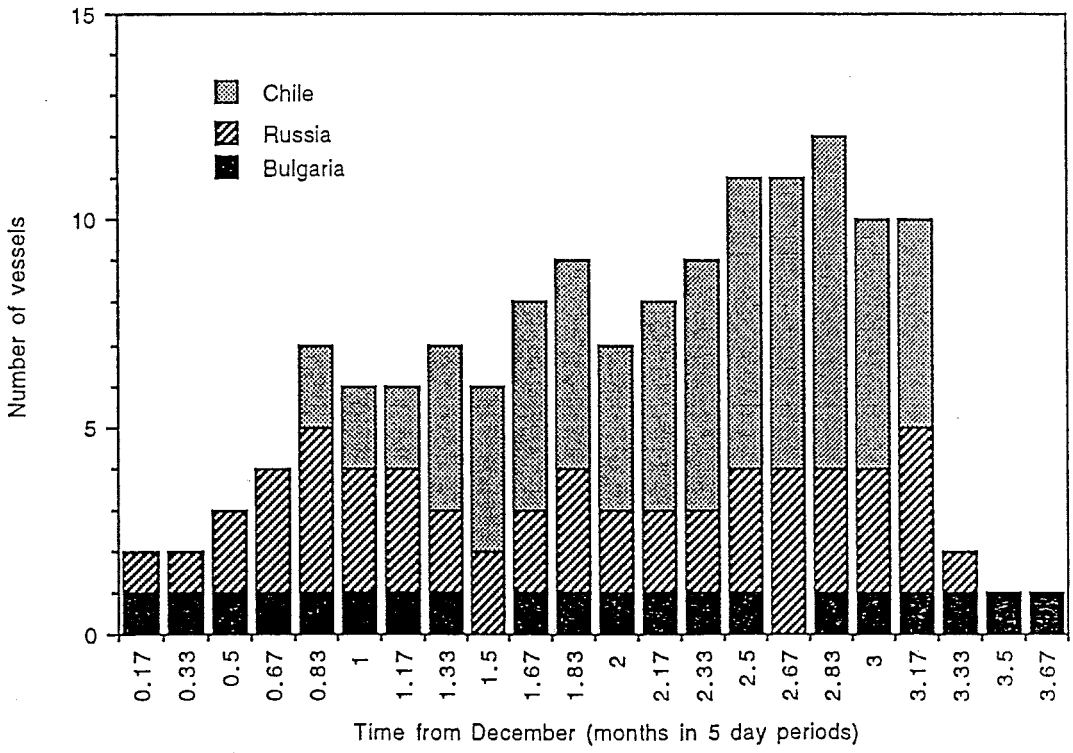


Figure 2: Number of vessels taking part in the fishery.

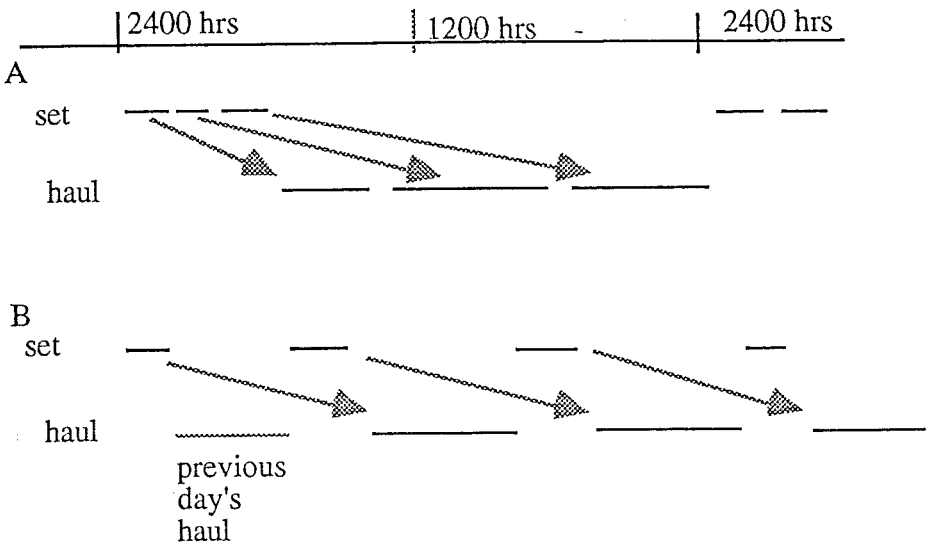


Figure 3: Schematic diagram of fishing strategies shown by the Russian and Bulgarian fleets.

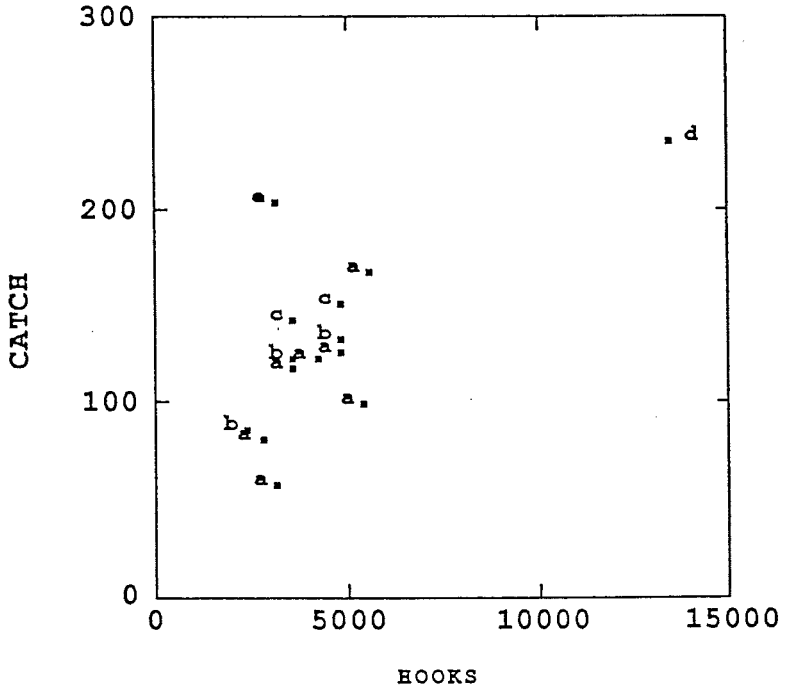


Figure 4: Relationship between catch (numbers of fish per haul, as mean over whole season) and effort (numbers of hooks per haul) for Russian vessels a - e (see Table 2).

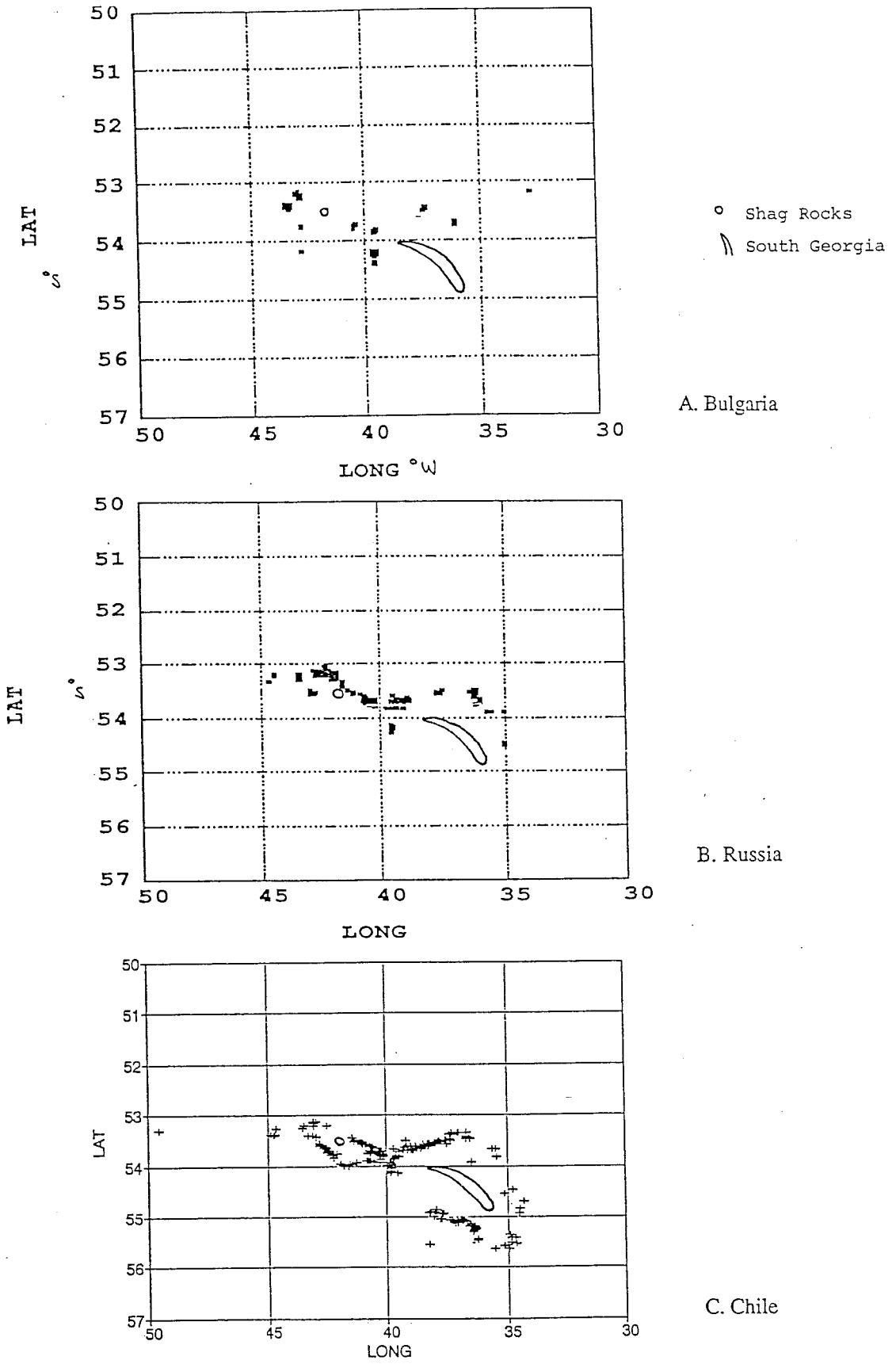
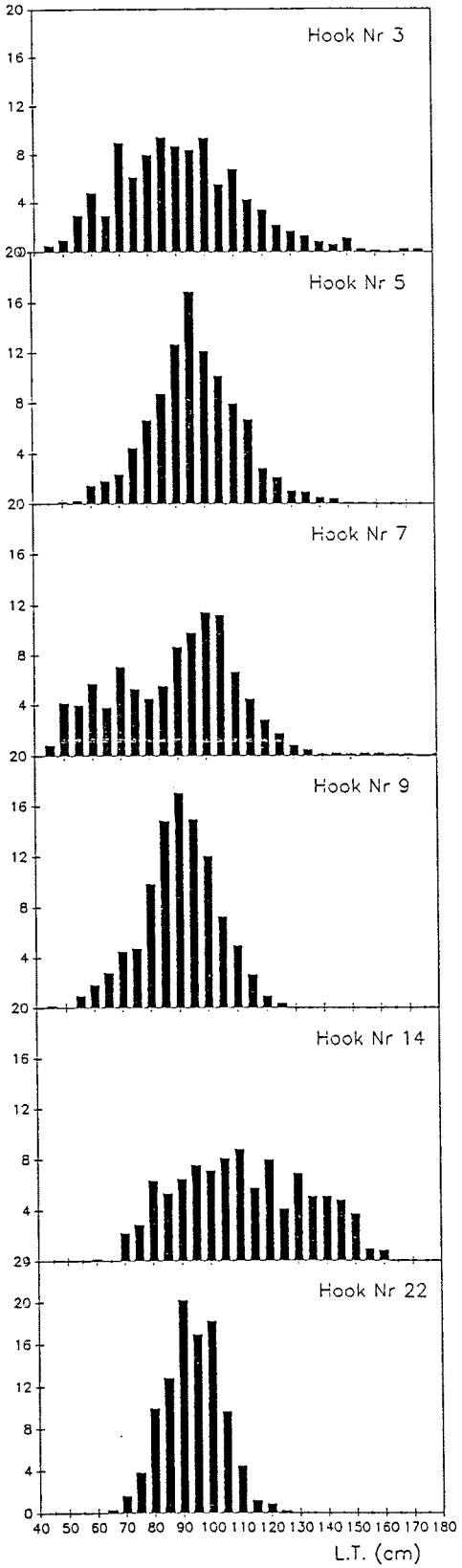


Figure 5: Position of all hauls in Subarea 48.3, 1992 season.



parallel, flat: 24mm
n=813

parallel, flat; 20mm
n=3345

semicurved, twisted; 34mm
n=981

semicurved, twisted; 30mm
n=822

curved, flat; 27mm
n=729

parallel, twisting, eyeless; 28mm
n=1008

Figure 6: Normalised length frequencies of *D. eleginoides* caught by Chilean vessels (total length converted from standard length using the relationship given in Kock *et al.* (1985)).

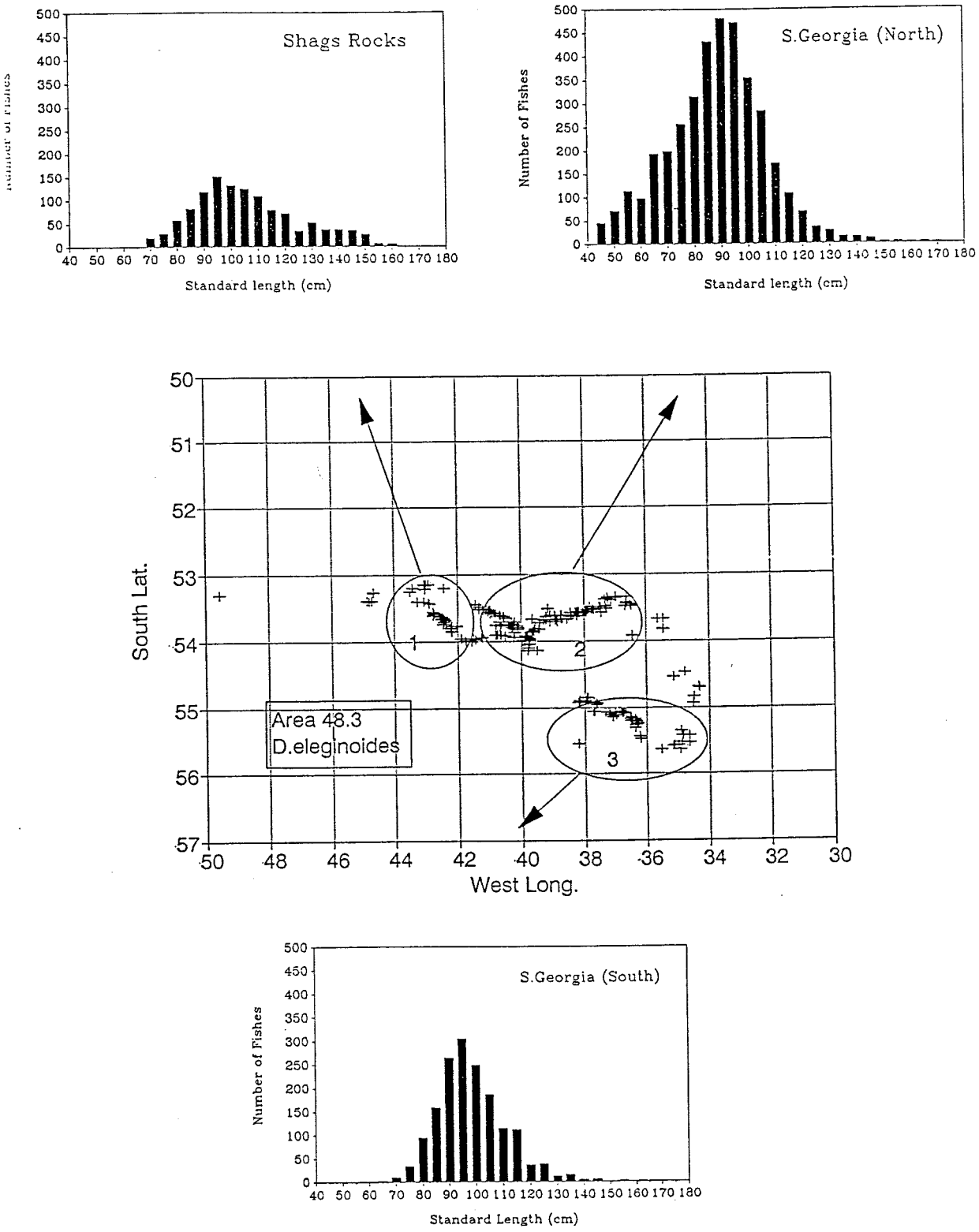
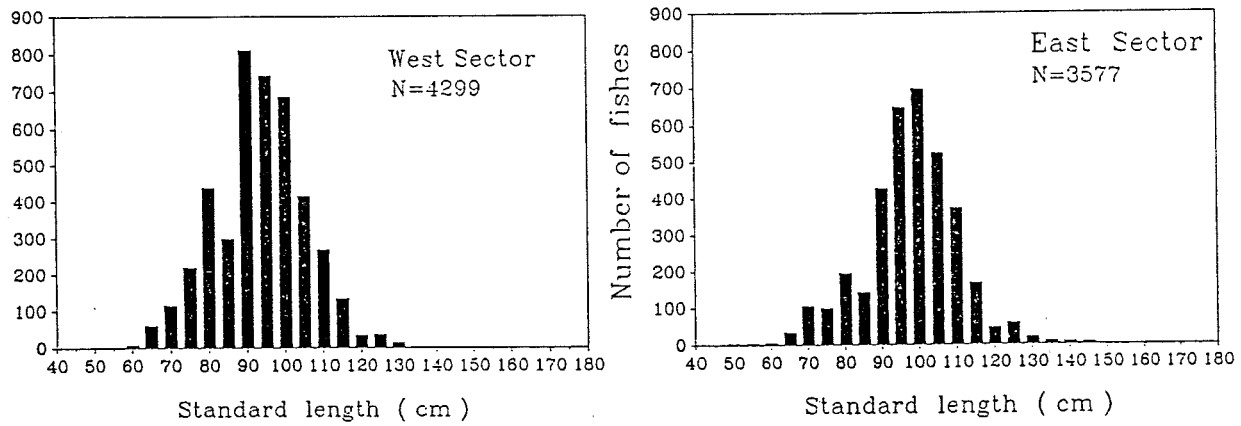
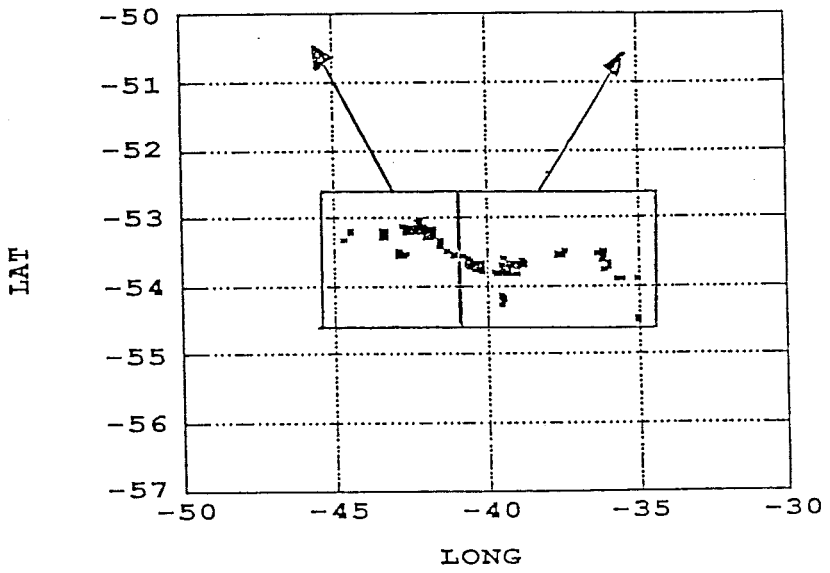


Figure 7: Length composition of *D. eleginoides* taken by Chilean vessels (reported by haul).





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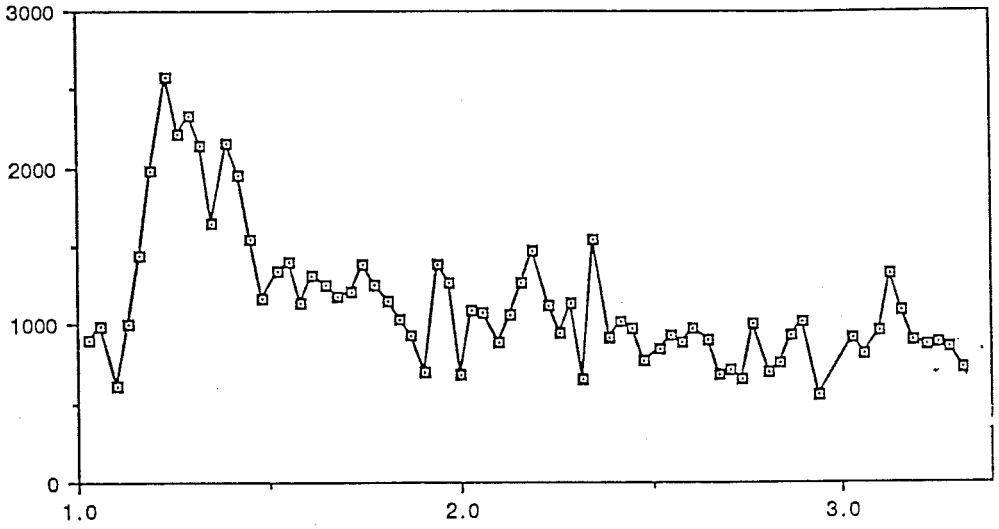

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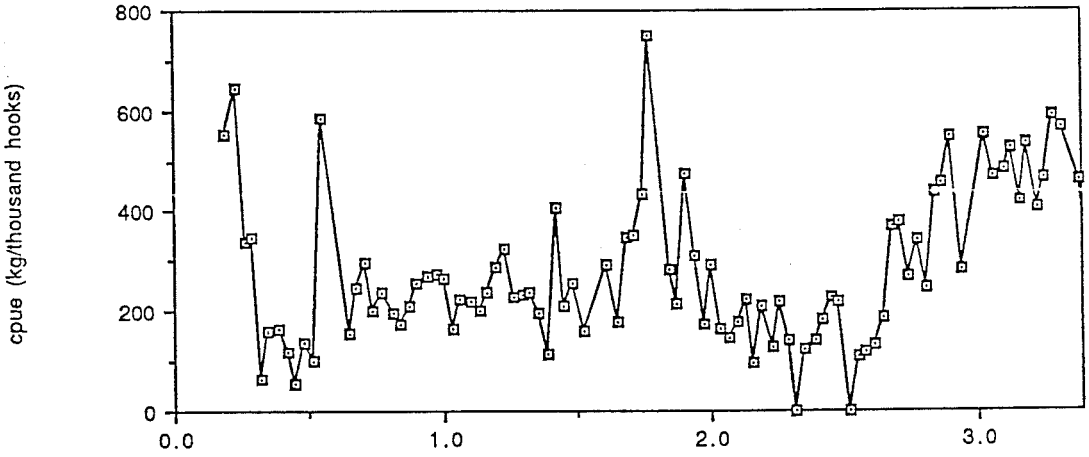

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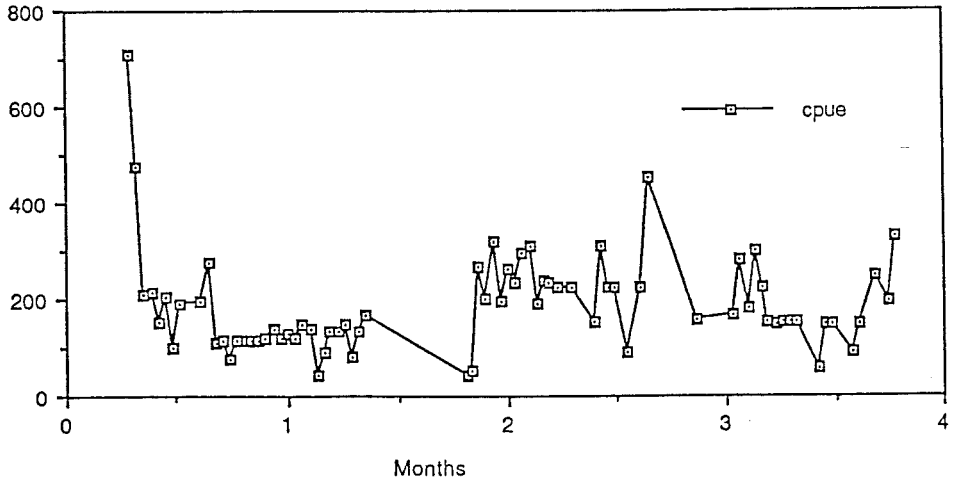

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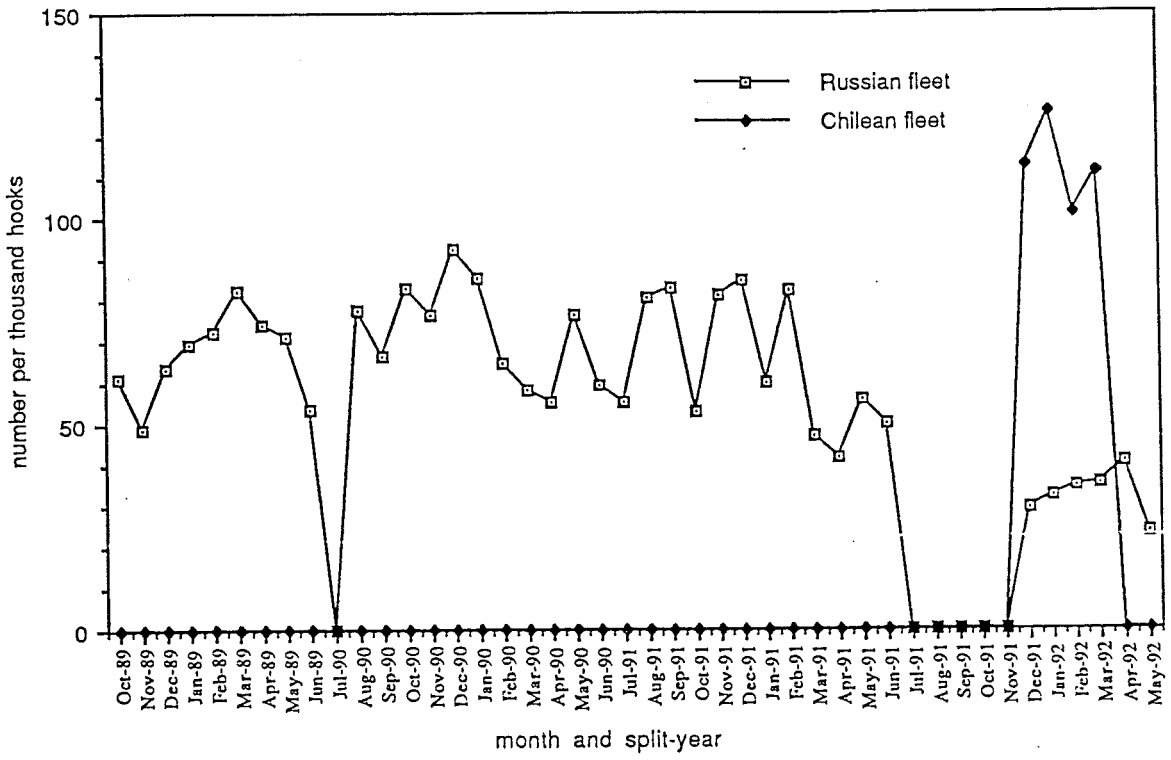

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NOTES ON THE USE OF VIRTUAL POPULATION ANALYSIS FOR STOCK ASSESSMENT OF THE MACKEREL ICEFISH, *CHAMPSOCEPHALUS GUNNARI* (LÖNNBERG, 1906) IN SUBAREA 48.3 FOR THE 1990/91 AND 1991/92 SEASONS

G. Parkes*

Abstract

Following on from the apparent failure of the CCAMLR Working Group on Fish Stock Assessment (WG-FSA) to satisfactorily assess in 1991 the status of the *Champsocephalus gunnari* population in Subarea 48.3 using VPA, attempts were made to re-work the analysis using Laurec-Shepherd and ADAPT tuning techniques, from 1991 back to 1977. The predicted age structure, dominated in recent years by the 1987 year-class (1 year olds in 1988), was quite robust, despite the use of various combinations of survey and CPUE indices for tuning. According to the VPA the population in 1991/92 was composed of a large proportion of 5 year olds, which was not observed during the survey on *Falklands Protector* in January 1992. Breakdown in the credibility of the VPA results in most recent years is attributed to the invalid assumption of constant M and contradictions in the input data. A conservative approach to management for 1992/93 is recommended, based on the results of surveys by *Falklands Protector* in 1990/91 and 1991/92.

Résumé

Suite à l'apparente incapacité du Groupe de travail de la CCAMLR chargé de l'évaluation des stocks de poissons (WG-FSA) à évaluer proprement en 1991 le statut de la population de *Champsocephalus gunnari* par la VPA dans la sous-zone 48.3, de nouvelles tentatives d'analyse ont été effectuées par les techniques d'ajustement Laurec-Shepherd et ADAPT, en remontant de 1991 à 1977. La structure d'âge prévue, dominée ces dernières années par la classe d'âge 1987 (âgés d'un an en 1988) était assez robuste, en dépit d'une ajustement effectué par plusieurs combinaisons d'indices de campagnes d'évaluation et de CPUE. D'après la VPA, la population de 1991/92 comportait une proportion importante d'individus de 5 ans, ce qui n'avait pas été observé lors de la campagne du *Falklands Protector* en janvier 1992. La baisse de crédibilité des résultats de la VPA de ces dernières années est attribuée à l'hypothèse invalide d'un M constant et aux contradictions dans les données d'entrée. Pour 1992/93, une approche conservative de gestion, fondée sur les résultats des campagnes d'évaluation du *Falklands Protector* de 1990/91 et 1991/92, est recommandée.

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Резюме

В связи с тем, что на совещании WG-FSA в 1991 г. не удалось удовлетворительно оценить состояние популяции *Champsocephalus gunnari* в Подрайоне 48.3 с использованием VPA, были предприняты попытки усовершенствовать анализ, используя методы настройки Лорека-Шеперда и ADAPT за период 1977-1991 гг. Прогнозируемая возрастная структура, в которой в последние годы преобладал годовой класс 1987 г. (однолетние особи в 1988 г.), была довольно устойчива несмотря на то, что при настройке использовались различные комбинации съемочных индексов и индексов CPUE. Судя по результатам анализа VPA популяция в 1991/92 г. содержала большую долю пятилетних особей, которая не наблюдалась в ходе съемки судна *Falklands Protector* в январе 1992 г. Неудача расчетов VPA за самые последние годы объясняется неправильным предположением о постоянной величине M и противоречиями в вводных данных. На основании результатов съемок судна *Falklands Protector*, проведенных в 1990/91 и 1991/92 гг., рекомендуется применить предохранительный подход к управлению промыслом в 1992/93 г.

Resumen

Luego del malogrado esfuerzo del Grupo de Trabajo para la Evaluación de las Poblaciones de Peces de la CCRVMA, por evaluar satisfactoriamente el estado de la población de *Champsocephalus gunnari* en la Subárea 48.3 en 1991 mediante el VPA, se trató de volver a aplicar el análisis utilizando las técnicas de ajuste de Laurec-Sheperd y ADAPT desde 1991, en regresión, hasta 1977. La distribución de edades prevista, la cual ha sido dominada por la clase del año 1987 (ejemplares de 1 año en 1988) fue muy abundante, a pesar de la utilización de distintas combinaciones de índices y de CPUE de prospecciones para el ajuste. De acuerdo al VPA, la población de 1991/92 estuvo compuesta en su mayoría de ejemplares de 5 años, lo que no se vio en la prospección del *Falklands Protector* realizada en enero de 1992. La baja credibilidad del VPA experimentada en los últimos años se atribuye al supuesto inválido de una M constante y a contradicciones en los datos de entrada. Se recomienda por tanto un planteamiento de gestión conservador durante la temporada 1992/93, basado en los resultados de las prospecciones del *Falklands Protector* en 1990/91 y 1991/92.

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1. INTRODUCTION

Attempts were made at the 1991 meeting of the CCAMLR Working Group on Fish Stock Assessment (WG-FSA-91) to assess the status of the *Champsocephalus gunnari* population in Subarea 48.3 using virtual population analysis (VPA). Two assessment papers were presented (Gasiukov, 1991; Parkes, 1991) which showed highly divergent stock sizes, largely due to differences in the use of tuning data. Two VPA runs were made at WG-FSA-91, using the Laurec-Shepherd tuning method (MAFF DFR VPA version 2.1), which followed the same general trends of the two assessments above (SC-CAMLR-X, 1991).

Despite the huge difference between estimates of the overall stock size in 1990/91, all of these VPAs indicated that the biomass that year was dominated by 4 year old fish. Negligible catch was reported for 1990/91, hence projections to 1991/92 predicted that the somewhere in the region of 40 to 50% of the fishable biomass (age 2+*) would be composed of 5 year olds. Accordingly, TAC levels based on fishing mortality $F_{0.1}$ were proposed under the assumption that these fish would form a considerable proportion of the catch. The observed age distribution from a stock assessment survey in Subarea 48.3 in January 1991 (Everson *et al.*, 1992a), however, did not confirm the age distribution estimated by the VPA for that year (Figure 1). Concern was expressed at WG-FSA-91 that the large biomass of 5 year olds predicted by the VPA for 1991/92 might be an artefact of the analysis. In the absence of this year class, the TAC would be extracted from the younger, less abundant year classes, with potentially catastrophic effects on a population already apparently under considerable stress (Everson *et al.*, 1991; Kock *et al.*, 1992). Concerns over the credibility of the VPA and resulting uncertainties in the estimation of total stock size lead to the closure of the fishery for *C. gunnari* in Subarea 48.3 for the 1991/92 season (CCAMLR, 1991).

A stock assessment survey of the same design as that in January 1991 was undertaken by the RV *Falklands Protector* in January 1992 (Everson *et al.*, 1992b). Figure 2 compares predictions of age structure in 1992 from VPAs presented to the working group in 1991 (age 2+) with that observed during this survey. The samples taken during the survey were dominated by 2 and 3 year old fish, with 5 year olds comprising less than 5% of the fishable population biomass. Assuming the survey provided a representative sample of the population, it appears that the VPAs presented to and performed at WG-FSA-91 provided a misleading representation of the current structure of the *C. gunnari* population in Subarea 48.3.

Closure of the fishery in 1991/92 resulted in no commercial catch in the most recent year, and hence no terminal Fs for the VPA. This report presents notes on a reworking of the VPA runs made at WG-FSA-91. Forwards projections to 1991/92 were made in an attempt to reconcile the estimated population structure with that observed during the UK stock assessment surveys of the last two years.

2. MATERIALS AND METHODS

Two VPA programs were used: MAFF DFR VPA version 2.1 (MAFF 1988) using the Laurec-Shepherd tuning module, written in Fortran, and a version of ADAPT VPA translated from APL and Fortran versions (authored by V.R. Restrepo and J.E. Powers) into Pascal by Dr K. Patterson (for algorithms see Gavaris, 1988).

2.1 Input Data

Input data were the same as those used at WG-FSA-91, except where indicated below.

2.1.1 Natural Mortality

Natural mortality M was fixed at 0.48 throughout the analyses. The absolute value of M was not thought to be of major concern since the initial purpose of the exercise was to compare the outputs of various runs rather than produce a definitive VPA result.

* here and below, "age 2+" means "age ≥2"

2.1.2 Survey Indices

The method of standardising the survey indices to account for variations in the commercial catch between the 'birthday' at the start of the split-year and the time of the survey used in Parkes (1991) (equation 1) was criticised at WG-FSA-91, because it included values of different dimensions. For the month of the start of the survey t (July = month 1, August = month 2 etc.), and known catches C in month i, the number of fish N of age a on 1 July was approximated to:

$$N_a = N_{at} \bullet e^{\left(\frac{t-1}{12}M\right)} + \sum_{i=1}^{t-1} C_{ai} \bullet e^{\left(\frac{i-1}{12}M\right)} \quad (1)$$

This would be valid if N were considered to be an absolute measure of abundance, however it is generally regarded to be a relative index I, such that:

$$I_{survey} = q \bullet N_{survey} \quad (2)$$

where q is the catchability. Equation (1) then becomes:

$$I_a = I_{at} \bullet e^{\left(\frac{t-1}{12}M\right)} + q_a \sum_{i=1}^{t-1} C_{ai} \bullet e^{\left(\frac{i-1}{12}M\right)} \quad (3)$$

The application of equation 3 in Parkes (1991) assumed that q was 1 (i.e., equation (1)), however, the Laurec-Shepherd tuned VPA provides estimates of predicted q_a from the series of survey indices I_a, which can be used to re-estimate values of I_a from equation (3). In running Laurec-Shepherd tuned VPAs for this report this procedure was iterated until the values of q_a and, therefore estimated abundance, stabilised.

Additional VPA runs were performed with 'raw' unstandardised survey indices for comparison with the results of those tuned using standardised indices. Raw and standardised survey abundance indices are given in Tables 2(a) and 2(b). The age distribution from the US/Polish survey in 1987/88 has been slightly amended since that presented in Parkes (1991), following the discovery of a small error in the allocation of ages 2 and 3 in the age/length key used previously (Basson *et al.*, 1989).

2.1.3 Effort Indices

VPA runs tuned to indices of CPUE used at WG-FSA-91 (Gasiukov, 1990 and 1991) were performed for comparison with the performance of survey tuning. An attempt was also made to combine the raw survey and standardised CPUE indices in one index to allow their use in a single run of the MAFF VPA. Using both survey and CPUE indices in one VPA run at WG-FSA-91 proved to be impossible, due to the absence of a CPUE index for 1991 (SC-CAMLR, 1991). A more recent version of the MAFF VPA is understood to have been written, which allows specification of separate weights for estimation of mean ln q from different tuning indices (allowing specific down-weighting of a dummy value of CPUE for 1991), however, this version was not available at the time of writing.

A standardised, combined index was simply derived as follows:

For years y and ages a with both survey indices I_{ay} and CPUE indices U_{ay}, the combined index A_{ay} was estimated as:

$$A_{ay} = \left(\frac{I_{ay}}{\overline{I_a}} + \frac{U_{ay}}{\overline{U_a}} \right) \cdot \frac{1}{2} \qquad (4)$$

where $\overline{I_a}$ is the mean survey index at age a over all years and $\overline{U_a}$ is the mean CPUE index at age a over all years.

For years with survey indices only:

$$A_{ay} = \frac{I_{ay}}{\overline{I_a}}$$

and for years with CPUE indices only:

$$A_{ay} = \frac{U_{ay}}{\overline{U_a}}$$

Equation 4 assumes equal weighting between the two indices in years when they are both available. The indices used here are shown in Table 2(c).

2.1.4 Bottom Row (Terminal Age) Fs

These are calculated in the MAFF VPA as a fixed proportion of the mean of Fs from a specified number of younger Fs for that year. The default is one times the mean of the four younger Fs (i.e., for *C. gunnari* age 1 to 6+ this represents the mean of ages 1 to 4). The bottom row Fs for the MAFF VPA runs presented here were calculated as the mean of ages 2 to 4. The bottom row Fs in the ADAPT program were population weighted averages of all younger Fs, except for the final year, which was based on the selection pattern, averaged over the four most recent years.

2.2 VPA RUNS

Several VPA runs were performed for comparison, using both Laurec-Shepherd and ADAPT tuning techniques.

2.2.1 MAFF VPA, Using Laurec-Shepherd Tuning

Survey indices were prepared for Laurec-Shepherd tuning in both raw, unstandardised form and standardised according to the method described in Section 2.1. The calculation of predicted q was either weighted by the inverse variance of the survey estimates, as in Parkes (1991), or it was unweighted. The details of inputs to individual runs are given in Table 2.

2.2.2 ADAPT VPA (Pascal Version)

Raw survey indices and standardised indices of fishing effort (Gasiukov, 1990 and 1991) were used both separately and in the same run for tuning the ADAPT VPA. Details of the inputs are also provided in Table 2. The indices were input as two fleets in the ADAPT3 run and as one combined index in the ADAPT4 run (as for run MAFF6). Initial estimates of population size in the final year for the ADAPT tuning were taken from a Laurec-Shepherd tuned VPA run with the same input data. The ADAPT procedure was constrained by limiting the possible

difference between this initial estimate and the new estimate produced by minimising the sum of squared differences between observed and predicted abundance (Gavaris, 1988). In practice this constraint was set at different levels for each set of input data to assess whether the ADAPT procedure had genuinely converged or had simply reached its limits. Diagnostics from each iteration of each run were available to monitor the progress of the analysis.

3. RESULTS OF THE VPAS

3.1 MAFF VPA Runs

The outputs from the various MAFF VPA runs described in Table 2 are summarised in Tables 3 to 8. Total biomass (age 2+) is shown in Figure 3. Of the runs tuned to survey indices only (1 to 4) all show similar patterns of dynamics with the population in the most recent years dominated by the year class spawned in late 1985/86, recruiting as 1 year olds in 1987/88. The relative strength of the year class varies between runs, being particularly strong in run MAFF1. MAFF3 is similar to run 1 in Parkes (1991). The overall biomass is slightly larger, but the revision of the standardisation method and difference in calculation of bottom row Fs have had little effect on the dynamics of the population. The effect of using the standardised survey indices with equal weighting (run MAFF4) was to greatly reduce the overall estimated abundance due to higher q values, however, the standard errors on the predicted values of ln q were the largest of the survey tuned runs by a large margin, indicating an unreliable result.

The run tuned to CPUE (MAFF5) resulted in a much larger estimated population size in recent years (up to 1990) than the survey tuned runs. The population was again heavily dominated by the year class recruiting as 1 year olds in 1987/88. Combination of the two indices in the final Laurec-Shepherd tuned VPA (run MAFF6) resulted in an abundance estimate in between runs MAFF2 and MAFF5. It was, however, much closer to the former than the latter, due to the lack of a CPUE index for the most recent year of the VPA (1991). Some weighting factor could be introduced into equation 4 to adjust the balance of influence between the two indices if required. The fishable biomass in 1990/91 was again dominated by 4 year olds, as with all of the Laurec-Shepherd tuned VPA runs.

Age distributions of the biomass, projected to 1991/92 (age 2+) from runs 1 to 5 are illustrated in Figure 6, along with the age distribution from the *Falklands Protector* survey in January 1992. The population structure predicted by the VPA appears to be fairly robust with a variety of inputs. Comparison of these predictions with the observed age distribution highlights the same problem as illustrated in Figure 2. The large proportion of 5 year olds consistently predicted by the VPA was not observed during the survey.

3.2 ADAPT Runs

ADAPT runs 1 to 4 provided no satisfactory results. The constraint was set to its maximum possible value (initial estimate ±99%), however, in all cases one or more of the age groups reached their limit of abundance, indicating that the procedure was unable to converge. Diagnostics of runs ADAPT1 and ADAPT2 are presented in Table 9 as an illustration. These tables show the abundance (numbers of fish) by age group in the projected year (1992 for ADAPT1 and 1991 for ADAPT2).

The failure of the ADAPT to produce reasonable estimates for age group 2 in the projected year is understandable, due to the uncertainty associated with the estimate of recruitment (1 year olds) in the final year of the VPA. Table 9a, however, shows that run ADAPT1 was aiming to produce estimates in excess of double those produced by Laurec-Shepherd tuning (abundance + step) and similarly predicted a large proportion of 5 year olds in 1991/92.

Table 9b shows that run ADAPT2 (tuned to effort indices) produced estimates of abundance for ages 2 and 3 within the set limits, however, age group 4 reached the lower limit of its permitted range. The initial estimates for ADAPT2 came from MAFF5 (Table 7). It appears from Table 7 that the 1987 year class (4 year olds in 1991) was probably over estimated by MAFF5, and ADAPT2 would have reached a more sensible result had it not been constrained by the lower limit for this age group. A further ADAPT run was performed (ADAPT5), with a more appropriate starting estimate and limits for the 1987 year class. This run succeeded in converging within its limits and the results are shown in Table 10, with residuals plotted in Figure 5. No attempt was made to re-run the analysis following the masking of outlying residuals.

Total biomass (age 2+) from runs MAFF5 and ADAPT5, both tuned using the standardised effort data from Gasiukov (1990 and 1991) is compared in Figure 6. ADAPT5 produced much lower estimates of abundance in the most recent years than MAFF5. The picture of year class strength, however, is consistent with other runs, and projections from the end of the VPA again predict a high abundance of 4 year olds in 1990/91, and hence 5 year olds in 1991/92.

4. DISCUSSION OF THE VPA RESULTS

All of the VPA runs presented in this document show inconsistencies between the age structure for 1991/92 and that observed during the UK survey in Subarea 48.3 in January 1992. It is not expected that these two independent estimates should coincide completely, however, had a TAC been set for 1991/92 based on the assumption that the VPA results were reliable, the fishery would have probably targeted 2 and 3 year old fish, due to the apparent absence of the predicted abundance of 5 year olds. This could have had a potentially catastrophic effect on the population, which was already under stress according to the results of the 1990/91 UK survey (Everson *et al.*, 1992a; Everson *et al.*, 1991 and Kock *et al.*, 1992). The decision taken by CCAMLR to close the *C. gunnari* fishery in Subarea 48.3 for the 1991/92 season appears to have been vindicated by the results of the recent UK survey (CCAMLR, 1991; Everson *et al.*, 1992b).

The reasons for this discrepancy are uncertain, however, a number of possible sources are potentially responsible. The VPA assumes constant M both between years and between ages over the period of the analysis. This assumption is almost certainly violated to some extent in all fish populations, however, both UK and Soviet surveys in Subarea 48.3 during 1989/90 and 1990/91 revealed that there had been a massive reduction in the standing stock of *C. gunnari* between these two seasons, in the absence of commercial fishing (SC-CAMLR, 1991).

The UK survey results between 1989/90 and 1990/91 can be used to estimate values of total mortality Z by year and age class using Baranov's method (Baranov, 1914), where:

$$Z = -\ln\left(\frac{N_{(a+1,y+1)}}{N_{a,y}}\right) \qquad (5)$$

The results are presented in Table 11. Given the large uncertainty associated with survey abundance estimates, this method should only be employed with caution, however, it is worth investigating. There has been virtually no reported catch of *C. gunnari* in Subarea 48.3 in 1990/91 and 1991/92, hence these values of Z could be considered to be indicative of either natural mortality or a loss of fish from the area by some other mechanism such as migration. Whatever the mechanism, assuming the fish will not return at some future time, they can be considered to be lost to the fishery. This could therefore be represented in the assessment as an increase in M for that particular period. These results are clearly not particularly reliable, although the values for 3, 4 and 5 year olds in 1991 and 4, 5 and 6 year olds in 1992 are

reasonably consistent, and they do serve to emphasise the magnitude of the change in apparent mortality. Changes in M were not taken into account in the VPA and may therefore represent one explanation of its failure to produce credible results for the most recent years.

There may also be problems with the catch at age data itself. The tendency for *C. gunnari* in years of high abundance to aggregate in age specific groups has been reported (Kock, 1979; Parkes *et al.*, 1990). Given the likelihood that the commercial fishery exploits aggregations as they are encountered, the exploitation pattern in a given year may depend more upon which aggregations are encountered rather than the selectivity of the trawl. During the UK survey in January 1990, for instance, commercial trawlers were observed exploiting an aggregation to the north west of South Georgia, which was sampled and found to consist almost exclusively of 3 year old fish. No length distribution from the commercial fishery was available for that period. It was necessary to use information from samples collected during the survey to produce an *ad hoc* commercial length and age distribution for the catch-at-age in that year (Parkes, 1991). Other aggregations were encountered during the same survey, however, which apparently consisted almost exclusively of 2 year olds, calling into question the validity of the assumed age distribution of the catch in that year. Similarly in other years the assumed commercial age distribution will depend upon where the length and age samples were taken from, in comparison to the actual distribution of the fishery.

The overall length distributions for the surveys are calculated by weighting samples from individual stations by the catch rate. In order for this distribution to be representative of the population in years when aggregations are encountered, it must be assumed that the catch rates encountered at the aggregations are proportional to the abundance and the length frequency samples taken are representative of the whole aggregation. The degree to which this is true is unknown, hence the overall length distribution may contain unknown bias. This may be true for the 1989/90 survey at least in terms of the proportions of 2 and 3 year olds. Unfortunately insufficient fine-scale catch and biological data is currently available through CCAMLR to investigate this further.

No aggregations were encountered during the surveys of the following two seasons hence they probably do not suffer from the same problem. It is possible that the 4 and 5 year old fish predicted by the VPA in 1990/91 and 1991/92 respectively were aggregated into patches which were missed by the surveys. There is evidence, however, from other sources that the drop in abundance between 1989/90 and 1990/91 indicated by the surveys was genuine. Commercial trawlers failed to locate any viable concentrations of *C. gunnari* in Subarea 48.3 in December/January 1990/91 and acoustic surveying between and around sampling stations during both the 1990/91 and 1991/92 did not detect any fish concentrations.

The 'background count' of *C. gunnari* biomass outside the aggregations during the 1989/90 *Hill Cove* survey was of the order of 7 600 tonnes. This indicates that there may be a 'sink' effect which draws fish spread out over the shelf in towards these areas of high abundance. The hypothesis that the 1990/91 and 1991/92 surveys missed aggregations, which were present on the shelf, suggests that the observed standing stock represented this 'background count'. Assuming the observed ratio between the background biomass and aggregated biomass in January 1990, for the two proceeding surveys to have failed to detect the aggregated biomass, the total biomass in 1990/91 and 1991/92 would have to have been of the order of 400 000 tonnes, which seems unlikely. The more plausible scenario is that the fall in standing stock indicated by the surveys is genuine and needs to be taken into account in the assessment.

5. ASSESSMENT FOR 1991/92

The VPA has apparently broken down in the most recent years due to conflicting information in the input data. It is therefore necessary to devise an alternative method of assessing the current status of the fishery and the potential effect of setting a TAC for 1992/93.

One approach is to use the results of the two most recent surveys, which show a reasonably consistent picture of total biomass, and project forwards to 1992/93 and 1993/94, assuming either no catch (maintenance of the current closure) or a catch based on a target F, such as $F_{0.1}$, in 1992/93. Projected recruitment of 1 year olds was input as a mean value with a log-normal error. Mean recruitment and the variance of $\log_e$ recruitment were taken from the VPA between 1977 and 1986, prior to the period where the analysis apparently broke down. These parameters were very consistent between runs and were taken from the MAFF6 run (898 000 individuals and 0.45 respectively). Annual recruitment, R was generated independently for each year on each run as follows:

$$R = \overline{R} \bullet e^{\left(x - \frac{\sigma^2}{2}\right)} \qquad (6)$$

where $\overline{R}$ = mean recruitment

$X = \sqrt{\sigma^2} \bullet Z$

σ^2 = variance of $\log_e$ recruitment

Z = normal (0,1) random variable

The value of σ^2 was well within the range of values listed for other marine species (Beddington and Cooke, 1983). Each projection was run 500 times to simulate recruitment uncertainty and 95% confidence limits. The results of all projections are presented in Table 12 and Figure 7.

The survey biomass estimate from January 1991 (with 1 year olds in 1991 replaced by the simulated value) was projected forwards one year and compared to the survey result in January 1992. The projected biomass of 2 to 6 year olds in 1992 was higher than that estimated from the survey, largely due to the size of the 2 year old age class. This may be an indication that the recruitment of 1 year olds in 1991 was lower than estimated using mean recruitment from the early part of the VPA. The 1992 survey estimate was then projected forwards 2 years, with the 1 year olds being replaced by a simulated value, firstly with no fishing in 1992/93 and then assuming a catch at the $F_{0.1}$ level, calculated under the same assumptions used in Parkes (1991) and at WG-FSA-91 ($F_{0.1}$ = 0.39, with knife edge selection at age 2).

In the absence of fishing the mean biomass was projected to grow to about 137 000 tonnes (95% confidence limits L_1 = 62 700, L_2 = 277 000) by 1993/94, with a healthy increase in the biomass of 4 and 5 year olds.

The $F_{0.1}$ catch level in 1992/93 was estimated to be in the region of 24 000 tonnes (95% confidence limits L_1 = 15 200, L_2 = 43 600), however, about 50% of this was composed of 2 year olds and was thus highly dependent on the estimated recruitment of 1 year olds in 1991/92. The mean recruitment from the VPA was estimated over a period when the fishery was generally in a more healthy state than it appears to be at present. Any projections relying heavily on this mean recruitment should therefore be treated with caution. Following this catch in 1992/93 the biomass was projected to grow to about 111 000 tonnes (95% confidence limits L_1 = 49 400, L_2 = 241 000) in 1993/94. The lower limit of the 95% confidence interval on the total biomass, however, was lower in 1993/94, following the catch, than it was in 1992/93.

Given the uncertainty surrounding the current status of and future recruitment to the *C. gunnari* fishery in Subarea 48.3, a conservative approach to management is appropriate in the immediate future. The wisdom of re-opening the fishery and setting a TAC in 1992/93 is questionable. A more prudent policy would be to maintain the current closure until the degree of uncertainty in the stock status is reduced. In the event that a TAC is considered appropriate,

the lower 95% confidence limit given above (15 200 tonnes) is likely to allow the stock a reasonable chance of recovery over the next few years. The proportion of 2 year olds in the projected catch in 1992/93 at this level is reduced to about 25%, thus relying less heavily on the assumed recruitment of 1 year olds in 1991/92.

6. SUMMARY

1. Attempts were made to run a satisfactory VPA on *C. gunnari* in Subarea 48.3 using Laurec-Shepherd and ADAPT tuning techniques, from 1991 back to 1977.

2. Various combinations of survey and CPUE indices were used.

3. The VPA does not account for the massive decline in population size detected by the surveys between 1989/90 and 1990/91 in the absence of fishing.

4. According to the VPA the population in 1991/92 was composed of a large proportion of 5 year olds, which was not observed during the survey on *Falklands Protector* in January 1992.

5. Breakdown in the credibility of the VPA results in most recent years is attributed to the invalid assumption of constant M and contradictions in the input data.

6. A conservative approach to management for 1992/93 is recommended, based on the results of surveys by *Falklands Protector* in 1990/91 and 1991/92.

REFERENCES

BARANOV, F.I. 1914. The capture of fish by gillnets. *Mater. Poznaniyu Russ. Rybolovstva*, 3 (6): 56-99. (In Russian.)

BASSON, M., J.R. BEDDINGTON and W. SLOSARCZYK. 1989. The status of the *Champsocephalus gunnari* stock in the South Georgia area. Document *WG-FSA-89/8 Rev. 1.* CCAMLR, Hobart, Australia.

BEDDINGTON, J.R. and J.G. COOKE. 1983. The potential yield of fish stocks. *FAO Fisheries Technical Paper*, 242: 47 pp.

CCAMLR. 1991. *Report of the Tenth Meeting of the Commission (CCAMLR-X).* CCAMLR, Hobart, Australia: 427 pp.

EVERSON, I., K-H. KOCK, S. CAMPBELL, G. PARKES, D. CIELNIASZEK, and J. SZLAKOWSKI. 1991. Reproduction in the mackerel icefish, *Champsocephalus gunnari*, at South Georgia. Document *WG-FSA-91/7.* CCAMLR, Hobart, Australia.

EVERSON, I., G.B. PARKES, K.-H. KOCK, S. CAMPBELL, Z. CIELNIASZEK and J.SZLAKOWSKI. 1992a. Fish stock assessment survey in Subarea 48.3. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 25-67.

EVERSON, I., G.B. PARKES, S. CAMPBELL, K.-H. KOCK, J. SZLAKOWSKI, Z. CIELNIASZEK, C. GOSS and S. WILHELMS. 1992b. Fish stock assessment survey in Subarea 48.3. Document *WG-FSA-92/17.* CCAMLR, Hobart, Australia.

GASIUKOV, P.S. 1990. State of stock and TAC assessment for *Champsocephalus gunnari* from the area of South Georgia (48.3) for 1990/91 season. Document *WG-FSA-90/26.* CCAMLR, Hobart, Australia.

GASIUKOV, P.S. 1991. Assessment of the status of the *Champsocephalus gunnari* stock in the South Georgia area for the 1990/91 season and TAC calculations for the 1991/92 season. Document *WG-FSA-91/27*. CCAMLR, Hobart, Australia.

GAVARIS, S. 1988. An adaptive framework for the estimation of population size. *CAFSAC Research Document* 88/29.

KOCK, K.-H., I. EVERSON, S. CAMPBELL, G.B. PARKES, Z. CIELNIASZEK and J. SZLAKOWSKI. 1991. Food and feeding of the mackerel icefish (*Champsocephalus gunnari*) around South Georgia in January/February 1991. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8)*. CCAMLR, Hobart, Australia: 15-23.

PARKES G.B. 1991. Stock assessment of the mackerel icefish, *Champsocephalus gunnari* (Lönnberg 1906) in Subarea 48.3 for the 1990/91 season, using virtual population analysis. Document *WG-FSA-91/15*. CCAMLR, Hobart, Australia.

PARKES, G.B. *et al.* 1990. Report of the UK/Polish fish stock assessment survey around South Georgia in January 1990. Document *WG-FSA-90/11*. CCAMLR, Hobart, Australia.

SC-CAMLR. 1991. Report of the Working Group on Fish Stock Assessment. In: *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X)*, Annex 6. CCAMLR, Hobart, Australia: 205-345.

Table 1: Data inputs into VPA runs.

Run Code	Period	Source of Catch-at-Age	Source of Mean Weight at Age	M	Tuning Indices	Weighting of Mean in q
MAFF1	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	Inverse variance of surveys
MAFF2	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	Equal weighting
MAFF3	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Standardised survey indices	Inverse variance of surveys
MAFF4	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Standardised survey indices	Equal weighting
MAFF5	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort indices	Equal weighting
MAFF6	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Combination of fishing and raw survey indices	Equal weighting
ADAPT1	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices	--
ADAPT2	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort	--
ADAPT3	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Raw survey indices and fishing effort	--
ADAPT4	1977 to 1991	WG-FSA-91	WG-FSA-91	0.48	Combination of fishing effort and raw survey indices	--
ADAPT5	1977 to 1990	WG-FSA-91	WG-FSA-91	0.48	Fishing effort adjusted starting value	--

Table 2: Tuning data for VPAs.

2(a) unstandardised survey indices
MAFF1 and MAFF2

Year	Effort	1	2	3	4	5	6+
1987	100	17265	298562	181115	15760	1831	257
1988	100	18858	36456	52004	5248	570	202
1989	100	364220	57940	29350	15696	2156	663
1990	100	93622	721231	164021	10382	760	1688
1991	100	190078	53809	42303	17741	1039	343

2(b) standardised survey indices with inverse variance weighting
Final iteration, MAFF3

Year	Effort	1	2	3	4	5	6+
1987	100	20361	386123	393315	19685	2952	436
1988	100	27444	40603	250980	17764	21182	5841
1989	100	464062	230921	104067	23952	18234	3958
1990	100	114350	880914	200336	12681	928	2061
1991	100	241636	68574	54401	22570	1324	437

2(c) standardised survey indices with equal weighting
Final iteration, MAFF4

Year	Effort	1	2	3	4	5	6+
1987	100	21581	558201	442349	24449	4824	747
1988	100	33312	80530	298979	51662	64483	17630
1989	100	476836	987750	122175	39959	54354	11220
1990	100	114350	880914	200336	12681	928	2061
1991	100	241636	69391	54571	22642	1332	439

2(d) combined survey and effort indices
MAFF6; ADAPT4

Year	Effort	1	2	3	4	5	6+
1981	100	1869.8	8558.9	2827.3	1985.3	1554.8	2464.6
1982	100	21280.3	17080.3	9720	25026.5	19051.3	33089.6
1983	100	25825.8	16851.1	12112	19269.2	16264	27478.7
1984	100	7496.2	20577.4	7222.9	7961.6	1311.5	411.5
1985	100	5377.2	13945.1	13715.7	7748.6	1092.3	3809.2
1986	100	10319.3	8619.6	3500.2	8119.7	2798.2	1075.9
1987	100	2706.7	8783.6	18601.3	8681.1	9053	3503.2
1988	100	3931.3	960.7	5616.6	8040.9	16145.9	19625
1989	100	21038.1	4982.9	2739.5	9163.5	21177	17410.5
1990	100	4292.8	16304.9	21237.5	7217.3	3501.3	13412.1
1991	100	13893.7	2303.5	4511.9	13683.3	8173.4	5439.3

Table 3: Output: run MAFF1.

Table 3a: Fishing Mortality F at age (Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0195	0.0572	0.1694	0.0049	0.0367	0.0846	0.0095	0.0768	0.0166	0
2	0.0136	0.9682	0.0334	0.1226	0.5333	0.2685	0.5092	0.8977	0.0569	0.0618	0.8211	0.2928	0.2612	0.0402	0.0032
3	2.8582	0.3615	0.0285	0.1615	0.1823	0.271	1.4655	1.4773	1.0712	0.1933	1.1724	1.1619	0.9779	0.116	0.0052
4	4.0118	0.8608	0.0346	0.4592	0.1085	0.4226	0.9637	2.5751	0.8839	0.1383	0.2175	0.6374	0.6427	0.8855	0.0006
5	2.2945	0.7302	0.0322	0.2478	0.2747	0.3207	0.9794	1.652	0.6816	0.133	0.737	0.6974	0.6281	0.3479	0.003
+gp	2.2945	0.7302	0.0322	0.2478	0.2747	0.3207	0.9794	1.652	0.6816	0.133	0.737	0.6974	0.6281	0.3479	0.003

Table 3b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189300	328747	684480	1260337	2267894	826719	586741	791778	1348092	756022	107093	1140116	174089	138022	463068
2	32614	117135	201166	423476	779875	1401621	501660	342878	413609	830065	450978	60894	698788	99762	83996
3	209650	19909	27526	120387	231796	283120	663053	186557	86460	241786	482837	122775	28115	333012	59296
4	228126	7443	8582	16555	63384	119529	133604	94762	26349	18328	123318	92511	23772	6543	183502
5	41615	2555	1947	5130	6472	35189	48470	31539	4465	6737	9877	61391	30262	7735	1670
+gp	4957	1400	1312	3255	4309	25674	16597	6311	1339	1307	1642	16714	6084	3762	835

Table 3c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5012	9384	19629	35701	65590	23397	17977	26119	38698	23066	3075	30292	4909	4337	13429
2	2471	9570	16511	34332	64553	113532	43990	32373	33981	72483	37060	4631	56398	8972	7453
3	32348	3312	4600	19873	39067	46694	118387	35864	14463	42990	80790	19010	4620	60981	10713
4	59151	2081	2410	4592	17952	33128	40087	30614	7407	5476	34675	24071	6565	2013	55712
5	15996	1059	811	2109	2717	14458	21559	15104	1861	2984	4117	23679	12389	3529	752
+gp	2602	793	746	1828	2471	14407	10082	4128	762	791	935	8805	3402	2344	513
age 2+	112568	16815	25078	62734	126760	222219	234105	118083	58474	124724	157577	80196	83374	77839	75143
Total	117580	26199	44707	98435	192350	245616	252082	144202	97172	147790	160652	110488	88283	82176	88572

Table 4: Output: run MAFF2.

Table 4a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0575	0.1786	0.0051	0.0378	0.0899	0.0213	0.1209	0.0313	0
2	0.0136	0.9685	0.0334	0.1227	0.5337	0.2686	0.5113	0.9057	0.0604	0.0643	0.8591	0.3151	0.7082	0.0657	0.0061
3	2.8584	0.3617	0.0285	0.1616	0.1824	0.2713	1.467	1.4935	1.0962	0.2069	1.2613	1.3156	1.1274	0.4767	0.0085
4	4.012	0.8611	0.0346	0.4595	0.1086	0.423	0.9659	2.5936	0.9135	0.1441	0.2365	0.7636	0.8834	1.3159	0.003
5	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6661	0.7014	0.1405	0.7857	0.7981	0.9064	0.6196	0.0059
+gp	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6661	0.7014	0.1405	0.7857	0.7981	0.9064	0.6196	0.0059

Table 4b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189266	328554	684062	1259483	2267011	824119	583570	753795	1297820	734238	101027	513483	112791	73883	307084
2	32602	117114	201046	423218	779346	1401075	500051	340915	390134	798957	437499	57141	311040	61846	44309
3	209646	19901	27513	120313	231636	282797	662716	185572	85283	227262	463591	114659	25801	94794	35837
4	228124	7441	8577	16547	63339	119430	133404	94570	25789	17632	114345	81263	19037	5171	36415
5	41614	2555	1946	5127	6467	35161	48409	31420	4374	6401	9447	55850	23432	4869	858
+gp	4957	1400	1311	3253	4306	25653	16576	6287	1312	1242	1571	15206	4711	2368	429

Table 4c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9379	19617	35676	65564	23324	17880	24866	37255	22402	2901	13643	3181	2322	8905.45
2	2471	9568	16501	34311	64510	113487	43849	32188	32052	69766	35952	4345	25104	5562	3932
3	32348	3311	4598	19860	39040	46641	118327	35675	14267	40407	77570	17753	4240	17359	6475
4	59151	2080	2409	4590	17939	33101	40027	30552	7250	5268	32152	21144	5257	1591	11056
5	15995	1059	810	2108	2715	14446	21532	15047	1823	2835	3938	21542	9592	2221	386
+gp	2602	792	745	1827	2469	14395	10070	4112	747	751	894	8010	2634	1475	264
age 2+	112567	16810	25063	62696	126673	222070	233805	117574	56139	119027	150506	72794	46827	28208	22113
Total	117578	26189	44680	98372	192237	245394	251685	142440	93394	141429	153407	86437	50008	30530	31018

Table 5: Output: run MAFF3.

Table 5a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0575	0.1788	0.0051	0.0378	0.0916	0.0165	0.2365	0.0182	0
2	0.0136	0.9685	0.0334	0.1227	0.5337	0.2686	0.5112	0.9053	0.0604	0.064	0.8622	0.3226	0.5032	0.1418	0.0035
3	2.8584	0.3617	0.0285	0.1616	0.1824	0.2713	1.467	1.4933	1.0952	0.2071	1.2514	1.3293	1.1837	0.2753	0.0193
4	4.012	0.861	0.0346	0.4595	0.1086	0.423	0.9659	2.5932	0.9132	0.1438	0.2369	0.7482	0.9099	1.5577	0.0015
5	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6658	0.7009	0.1404	0.7835	0.8	0.8663	0.6591	0.0082
+gp	2.2947	0.7304	0.0322	0.2479	0.2749	0.321	0.9814	1.6658	0.7009	0.1404	0.7835	0.8	0.8663	0.6591	0.0082

Table 5b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189267	328558	684070	1259502	2267031	824149	583702	753156	1303047	732554	99163	661075	60706	126617	336023
2	32603	117114	201049	423223	779358	1401087	500070	340997	389739	802192	436458	55988	402366	29652	76939
3	209646	19901	27513	120315	231639	282804	662724	185583	85333	227018	465592	114033	25091	150530	15923
4	228124	7441	8577	16547	63340	119432	133409	94574	25795	17661	114194	82428	18675	4753	70727
5	41615	2555	1946	5127	6467	35162	48410	31422	4376	6405	9464	55757	24137	4652	619
+gp	4957	1400	1311	3253	4306	25654	16576	6287	1313	1243	1574	15180	4853	2262	310

Table 5c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9379	19617	35677	65565	23324	17884	24845	37405	22350	2847	17564	1712	3979	9744.67
2	2471	9568	16501	34311	64511	113488	43851	32195	32020	70049	35867	4257	32474	2667	6827
3	32348	3311	4598	19861	39040	46642	118328	35677	14275	40364	77905	17656	4123	27565	2877
4	59151	2080	2409	4590	17939	33101	40029	30553	7252	5277	32109	21447	5157	1463	21473
5	15995	1059	810	2108	2715	14446	21532	15048	1824	2837	3945	21506	9881	2122	279
+gp	2602	792	745	1827	2469	14395	10070	4112	747	752	896	7997	2713	1410	190
age 2+	112567	16810	25063	62697	126674	222072	233810	117585	56118	119279	150722	72863	54348	35227	31646
Total	117578	26189	44680	98374	192239	245396	251694	142430	93523	141629	153569	90427	56060	39206	41391

Table 6: Output: run MAFF4.

Table 6a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0577	0.1839	0.0052	0.0384	0.0943	0.0264	0.2787	0.0998	0
2	0.0136	0.9686	0.0334	0.1228	0.534	0.2687	0.5123	0.9095	0.0624	0.0654	0.8819	0.3343	0.9769	0.1735	0.0204
3	2.8585	0.3617	0.0285	0.1617	0.1825	0.2715	1.4678	1.5018	1.1087	0.2148	1.3044	1.422	1.2774	0.9294	0.0241
4	4.0121	0.8612	0.0346	0.4596	0.1086	0.4233	0.9671	2.603	0.9293	0.1471	0.2479	0.8351	1.1187	2.1739	0.0076
5	2.2948	0.7305	0.0322	0.248	0.275	0.3212	0.9824	1.6732	0.7116	0.1446	0.8114	0.8638	1.1243	1.0923	0.0174
+gp	2.2948	0.7305	0.0322	0.248	0.275	0.3212	0.9824	1.6732	0.7116	0.1446	0.8114	0.8638	1.1243	1.0923	0.0174

Table 6b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189249	328458	683853	1259058	2266570	822803	582048	733938	1276133	722118	96451	415789	52471	23903	262146
2	32597	117103	200987	423088	779083	1400802	499237	339974	377862	785538	430000	54311	250590	24570	13386
3	209645	19898	27507	120276	231556	282635	662548	185073	84719	219670	455289	110153	24057	58374	12782
4	228123	7440	8575	16543	63316	119381	133305	94474	25506	17299	109655	76440	16443	4150	14260
5	41614	2554	1946	5126	6465	35147	48379	31360	4329	6231	9241	52955	20520	3324	292
+gp	4957	1400	1310	3252	4305	25643	16565	6275	1299	1209	1536	14417	4125	1617	146

Table 6c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5011	9376	19611	35664	65551	23286	17833	24211	36632	22032	2769	11047	1480	751	7602.25
2	2470	9567	16496	34300	64488	113465	43778	32099	31044	68595	35336	4130	20225	2210	1188
3	32347	3310	4597	19854	39026	46614	118297	35579	14172	39057	76181	17055	3953	10689	2309
4	59150	2080	2408	4589	17933	33087	39998	30521	7170	5169	30833	19889	4541	1277	4329
5	15995	1058	810	2108	2714	14440	21518	15018	1804	2760	3852	20425	8401	1516	131
+gp	2602	792	745	1827	2468	14389	10063	4104	739	731	875	7595	2307	1007	90
age 2+	112564	16807	25056	62678	126629	221995	233654	117321	54929	116312	147077	69094	39427	16699	8047
Total	117575	26183	44667	98342	192180	245281	251487	141532	91561	138344	149846	80141	40907	17450	15649

Table 7: Output: run MAFF5.

Table 7a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0111	0.0002	0	0.0012	0.0188	0.0539	0.0996	0.0035	0.0265	0.0271	0.0047	0.0562	0.0117	
2	0.0137	0.9649	0.0332	0.1217	0.5277	0.2671	0.4852	0.8174	0.0318	0.0437	0.5228	0.0829	0.1198	0.029	
3	2.8592	0.3646	0.0283	0.1602	0.1807	0.2668	1.4475	1.3077	0.855	0.1025	0.6784	0.4718	0.1768	0.0477	
4	4.0193	0.8622	0.0349	0.4561	0.1075	0.4176	0.9368	2.3754	0.6346	0.0947	0.1042	0.229	0.1385	0.071	
5	2.2974	0.7382	0.0322	0.2507	0.2719	0.3172	0.9565	1.5002	0.5071	0.0803	0.4351	0.2613	0.1451	0.0492	
+gp	2.2974	0.7382	0.0322	0.2507	0.2719	0.3172	0.9565	1.5002	0.5071	0.0803	0.4351	0.2613	0.1451	0.0492	

Table 7b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189707	331067	689494	1270696	2278520	858280	622322	1304431	1887491	1041284	325409	2323563	235716	981493	
2	32386	117387	202601	426579	786285	1408197	521190	364892	730619	1163835	627487	195972	1431084	137889	
3	209631	19768	27676	121275	233714	287043	667111	198526	99701	437933	689347	230198	111619	785586	
4	228061	7434	8495	16648	63933	120715	136025	97074	33222	26237	244595	216452	88864	57873	
5	41598	2535	1942	5076	6529	35529	49198	32985	5585	10898	14768	136369	106520	47875	
+gp	4955	1390	1308	3221	4347	25922	16846	6600	1675	2115	2456	37127	21415	23283	

Table 7c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5023	9450	19772	35994	65897	24290	19067	43031	54182	31770	9343	61735	6647	28463.3	
2	2454	9590	16628	34583	65084	114064	45703	34451	60026	101628	51565	14902	115501	12401	
3	32345	3288	4625	20019	39390	47341	119111	38165	16678	77864	115344	35642	18343	143855	
4	59134	2078	2386	4618	18108	33457	40814	31361	9339	7839	68776	56319	24541	17809	
5	15989	1051	809	2087	2741	14597	21883	15797	2327	4827	6156	52599	43607	21839	
+gp	2601	786	744	1809	2493	14546	10234	4317	954	1279	1398	19559	11974	14506	
age 2+	112523	16793	25192	63116	127816	224005	237745	124091	89324	193437	243239	179021	213966	210410	
Total	117546	26243	44964	99110	193713	248295	256812	167122	143506	225207	252582	240756	220613	238873	

Table 8: Output: run MAFF6.

Table 8a: Fishing Mortality F at age (MAFF output Table 8)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.0112	0.0002	0	0.0012	0.0196	0.0574	0.1734	0.0051	0.0371	0.0849	0.0183	0.0624	0.0171	0
2	0.0138	0.9682	0.0334	0.1226	0.5332	0.2685	0.5096	0.9018	0.0584	0.0632	0.8362	0.2942	0.574	0.0323	0.0033
3	2.8617	0.3665	0.0285	0.1615	0.1823	0.271	1.4652	1.4807	1.0839	0.1992	1.2214	1.22	0.9868	0.3361	0.0041
4	4.022	0.8658	0.0352	0.4592	0.1085	0.4226	0.9635	2.571	0.8899	0.1412	0.2257	0.7039	0.7235	0.9055	0.0019
5	2.2992	0.7411	0.0324	0.2526	0.2747	0.3207	0.9794	1.6512	0.6774	0.1345	0.7611	0.7394	0.7614	0.4246	0.0031
+gp	2.2992	0.7411	0.0324	0.2526	0.2747	0.3207	0.9794	1.6512	0.6774	0.1345	0.7611	0.7394	0.7614	0.4246	0.0031

Table 8b: Stock number at age, start of year (MAFF output Table 10)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	189301	328758	684483	1260391	2268091	826174	585116	774641	1319370	747083	106679	597966	212866	134033	359725
2	32247	117136	201173	423478	779908	1401743	501323	341872	403017	812292	445447	60638	363316	123752	81528
3	209586	19681	27526	120391	231797	283140	663128	186351	85857	235233	471841	119442	27957	126636	74140
4	228038	7414	8442	16555	63387	119530	133617	94804	26231	17972	119269	86073	21819	6449	55995
5	41588	2528	1930	5043	6472	35191	48470	31546	4485	6666	9656	58891	26347	6549	1613
+gp	4954	1386	1300	3200	4309	25675	16597	6312	1346	1293	1606	16033	5297	3185	807

Table 8c: Stock biomass at age with sop correction, start of year (MAFF output Table 14)

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5012	9385	19629	35702	65595	23382	17927	25554	37873	22793	3063	15887	6003	4212	10432
2	2444	9570	16511	34332	64556	113541	43961	32278	33111	70931	36606	4611	29323	11129	7234
3	32338	3274	4600	19873	39067	46698	118400	35825	14363	41824	78951	18494	4594	23189	13395
4	59128	2073	2371	4592	17953	33129	40091	30627	7374	5370	33537	22396	6026	1984	17000
5	15985	1048	804	2074	2717	14458	21559	15108	1869	2953	4025	22715	10786	2987	726
+gp	2601	784	739	1797	2471	14407	10082	4129	766	782	914	8446	2962	1984	496
age 2+	112496	16749	25025	62668	126764	222233	234093	117967	57483	121860	154033	76662	53691	41273	38851
Total	117508	26134	44654	98370	192359	245615	252020	143521	95356	144653	157096	92549	59694	45485	49283

Table 9a: Diagnostics from ADAPT run 1.

Iteration 1
Sum of Squares Before = 16.1489719
Sum of Squares After = 7.69898365

Age	Step	Abundance	Lower	Upper
2	758927.1	511994.7	56888.3	511994.7
3	68532.9	48967.7	5440.9	48967.7
4	61048.2	39522.2	4391.4	39522.2
5	-8464.519	13974.22	4487.748	40389.74

Iteration 2
Sum of Squares Before = 7.6989
Sum of Squares After = 7.6371

Age	Step	Abundance	Lower	Upper
2	479375.0	511994.7	56888.3	511994.7
3	87561.4	48967.7	5440.9	48967.7
4	90385.9	39522.2	4391.4	39522.2
5	18317.84	32292.07	4487.748	40389.74

Iteration 3
Sum of Squares Before = 7.6989
Sum of Squares After = 7.6247

Age	Step	Abundance	Lower	Upper
2	401364.3	511994.7	56888.3	511994.7
3	90106.2	48967.7	5440.9	48967.7
4	97896.9	39522.2	4391.4	39522.2
5	18243.62	40389.74	4487.748	40389.74

Iteration 4
Sum of Squares Before = 7.6247
Sum of Squares After = 7.6247

Age	Step	Abundance	Lower	Upper
2	421498.4	511994.7	56888.3	511994.7
3	90550.2	48967.7	5440.9	48967.7
4	98327.9	39522.2	4391.4	39522.2
5	11522.07	40389.74	4487.748	40389.74

Table 9b: Diagnostics from ADAPT run 2.

Iteration 1
Sum of Squares Before = 2.4797
Sum of Squares After = 2.0307

Age	Step	Abundance	Lower	Upper
2	114988.7	213126.1	23680.7	213126.1
3	72360.4	147940.3	16437.8	147940.3
4	-1092739.0	91727.6	91727.6	825548.1
5	-33484.48	6585.022	6585.022	59265.2

Iteration 2
Sum of Squares Before = 2.0307
Sum of Squares After = 1.7111

Age	Step	Abundance	Lower	Upper
2	102845.7	213126.1	23680.7	213126.1
3	-142262.0	16437.8	16437.8	147940.3
4	-51958.0	91727.6	91727.6	825548.1
5	8077.638	14662.66	6585.022	59265.2

Iteration 3
Sum of Squares Before = 1.7111
Sum of Squares After = 1.4163

Age	Step	Abundance	Lower	Upper
2	-41128.5	171997.6	23680.7	213126.1
3	43415.7	59853.5	16437.8	147940.3
4	-88923.5	91727.6	91727.6	825548.1
5	-3257.323	11405.34	6585.022	59265.2

Iteration 4
Sum of Squares Before = 1.4163
Sum of Squares After = 1.3283

Age	Step	Abundance	Lower	Upper
2	-65508.9	106488.7	23680.7	213126.1
3	17594.5	77447.9	16437.8	147940.3
4	-61969.6	91727.6	91727.6	825548.1
5	1087.835	12493.17	6585.022	59265.2

Table 9b (continued)

Iteration 5
Sum of Squares Before = 1.3283
Sum of Squares After = 1.2975

Age	Step	Abundance	Lower	Upper
2	-13089.2	93399.5	23680.7	213126.1
3	-14931.7	62516.2	16437.8	147940.3
4	-44679.8	91727.6	91727.6	825548.1
5	-296.8229	12196.35	6585.022	59265.2

Iteration 6
Sum of Squares Before = 1.2975
Sum of Squares After = 1.2926

Age	Step	Abundance	Lower	Upper
2	-7697.1	85702.4	23680.7	213126.1
3	7268.0	69784.2	16437.8	147940.3
4	-50192.0	91727.6	91727.6	825548.1
5	-225.2508	11971.1	6585.022	59265.2

Iteration 7
Sum of Squares Before = 1.2926
Sum of Squares After = 1.2904

Age	Step	Abundance	Lower	Upper
2	-1700.9	84001.6	23680.7	213126.1
3	-4586.5	65197.7	16437.8	147940.3
4	-45321.2	91727.6	91727.6	825548.1
5	103.072	12074.17	6585.022	59265.2

Table 10: Output: run ADAPT5.

Table 10a: Fishing Mortality F at age

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	0	0.01	0.0002	0	0.0012	0.019	0.0581	0.163	0.0049	0.0354	0.0511	0.0194	0.0787	0.0172	
2	0.0092	1.0984	0.0299	0.1227	0.5135	0.2623	0.4925	0.9174	0.0544	0.0613	0.7771	0.1643	0.6246	0.0413	
3	2.8274	0.2317	0.0351	0.1432	0.1824	0.2558	1.3853	1.351	1.138	0.1837	1.1525	1.015	0.4056	0.3841	
4	4.1552	0.8204	0.0205	0.6029	0.0947	0.4242	0.8725	1.8852	0.6895	0.154	0.2048	0.6132	0.479	0.1959	
5	3.1714	0.9092	0.0298	0.1388	0.417	0.2717	0.9871	1.21	0.2563	0.0907	0.8769	0.6358	0.5867	0.2228	
+gp	3.1714	0.9092	0.0298	0.1388	0.417	0.2717	0.9871	1.21	0.2563	0.0907	0.8769	0.6358	0.5867	0.2228	

Table 10b: Stock number at age, start of year

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	175528	365897	683090	1299238	2317218	849700	578295	820957	1359158	782804	174179	562472	169960	422354	
2	47838	108613	224157	422616	803946	1432140	515871	337632	431601	836914	467546	102406	341365	97207	
3	209897	29329	22408	134618	231305	297698	681692	195073	83473	252933	487068	133008	53766	113108	
4	227137	7685	14394	13387	72185	119259	142638	105560	31261	16552	130250	95197	29826	22178	
5	38132	2204	2093	8727	4533	40632	48285	36885	9915	9707	8780	65669	31904	11431	
+gp	4545	1206	1414	5539	3014	29624	16529	7391	2980	1881	1457	17870	6398	5565	

Table 10c: Stock biomass at age with sop correction, start of year

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	5090	10611	19810	37678	67199	24641	16771	23808	39416	22701	5051	16312	4929	12248	
2	3971	9015	18605	35077	66728	118868	42817	28023	35823	69464	38806	8500	28333	8068	
3	35473	4957	3787	22750	39091	50311	115206	32967	14107	42746	82314	22478	9086	19115	
4	64507	2183	4088	3802	20501	33870	40509	29979	8878	4701	36991	27036	8471	6299	
5	16054	928	881	3674	1908	17106	20328	15529	4174	4087	3696	27647	13432	4812	
+gp	2613	693	813	3185	1733	17034	9504	4250	1713	1082	838	10275	3679	3200	
age 2+	122617	17775.4	28174.1	68488.5	129960.05	237188	228365	110748	64695.7	122079	162646	95935.9	63000.8	41494.3	
Total	127707	28386.4	47983.7	106166	197159.37	261829	245135	134556	104111	144780	167697	112248	67929.6	53742.6	

Table 11: Estimates of Z from surveys using the Baranov method.

age in 1991 >>	2	3	4	5	6
Z 1990 to 1991	0.55	2.84	2.22	2.30	0.80
age in 1992 >>	2	3	4	5	6
Z 1991 to 1992	0.10	*	1.21	1.92	1.36

* N age 3 in 1992 > N age 2 in 1991.

Table 12: Projection results.

	Total Biomass (tonnes), age 2+, Subarea 48.3					
	1990/91 Survey	1991/92 Survey	1992/93 Projection	1993/94 Projection without catch	1992/93 Catch at $F_{0.1}$	1993/94 Projection With Catch
Upper 95%			154139	277226	43621	240564
Mean	22400 cv 16%	38000 cv 18%	87005	137350	24289	110791
Lower 95%			52065	62707	15175	49371

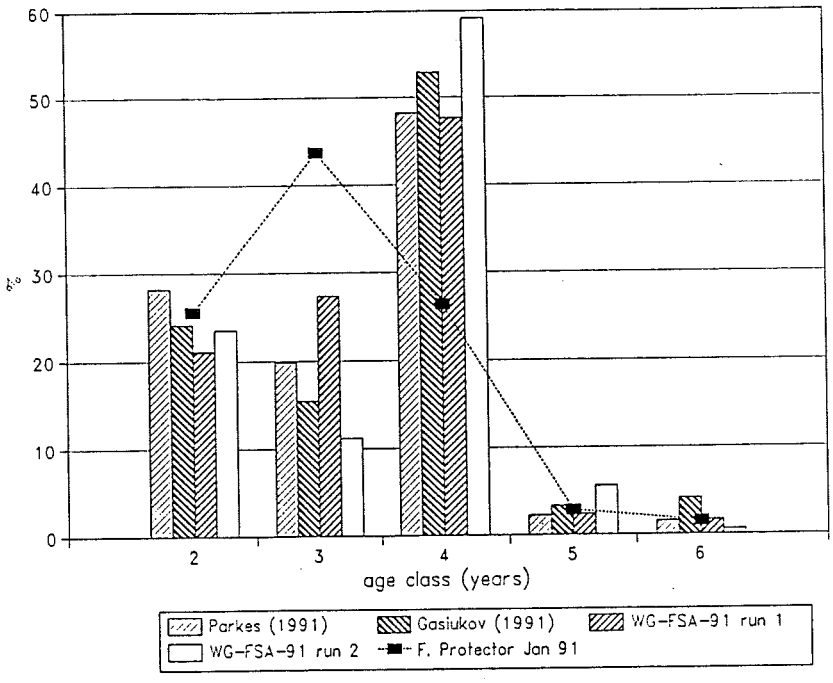


Figure 1: Age distribution of biomass (age 2+) - observed and estimated 1990/91.

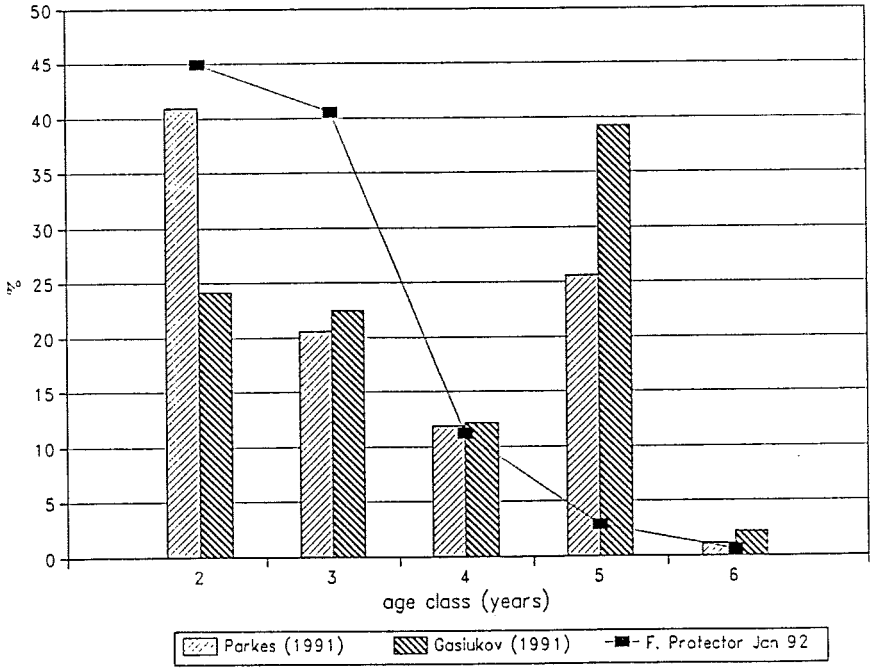


Figure 2: Age distribution of biomass (age 2+) - observed and predicted 1991/92.

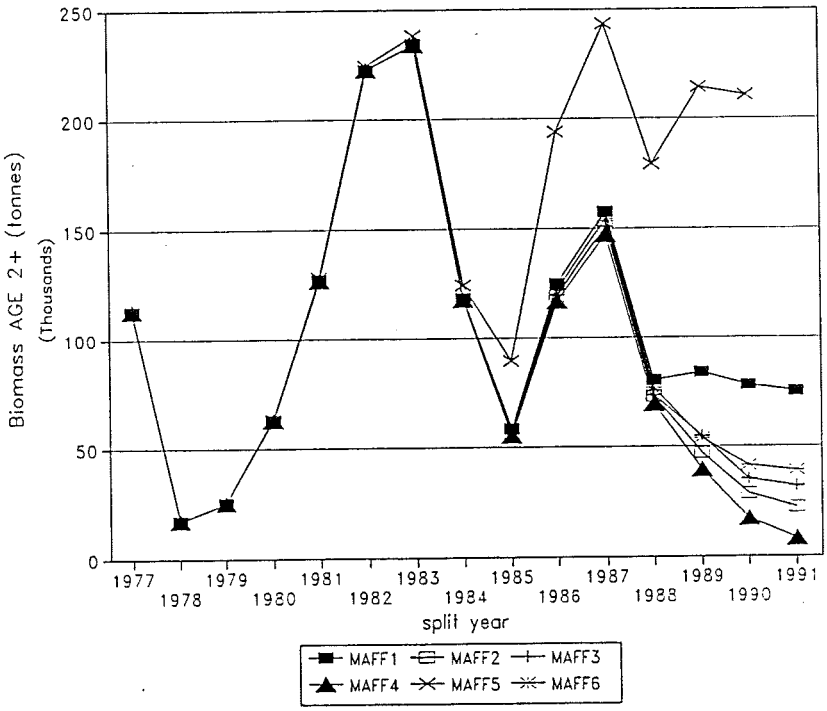


Figure 3: Comparison of VPA runs - total biomass age 2+.

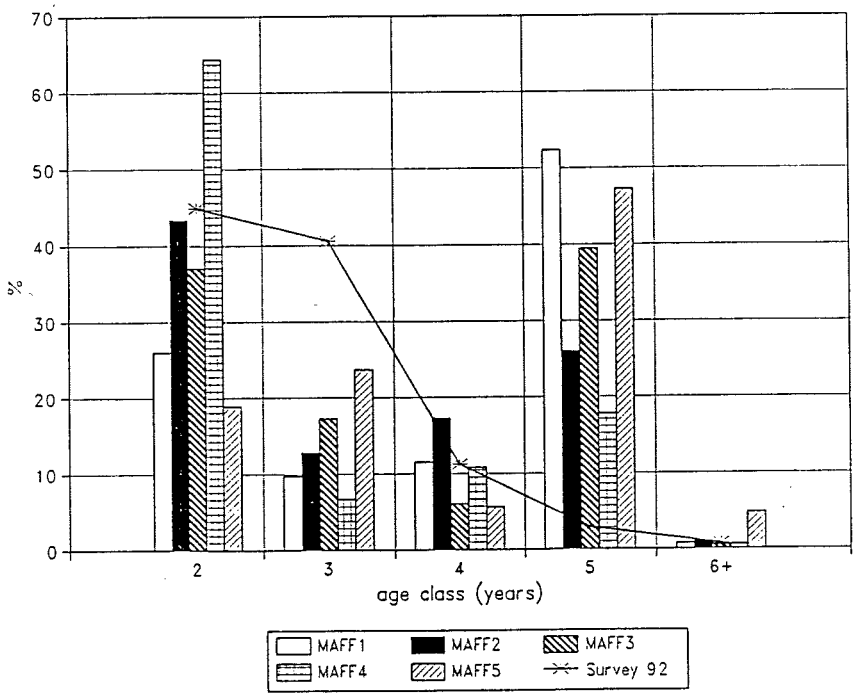
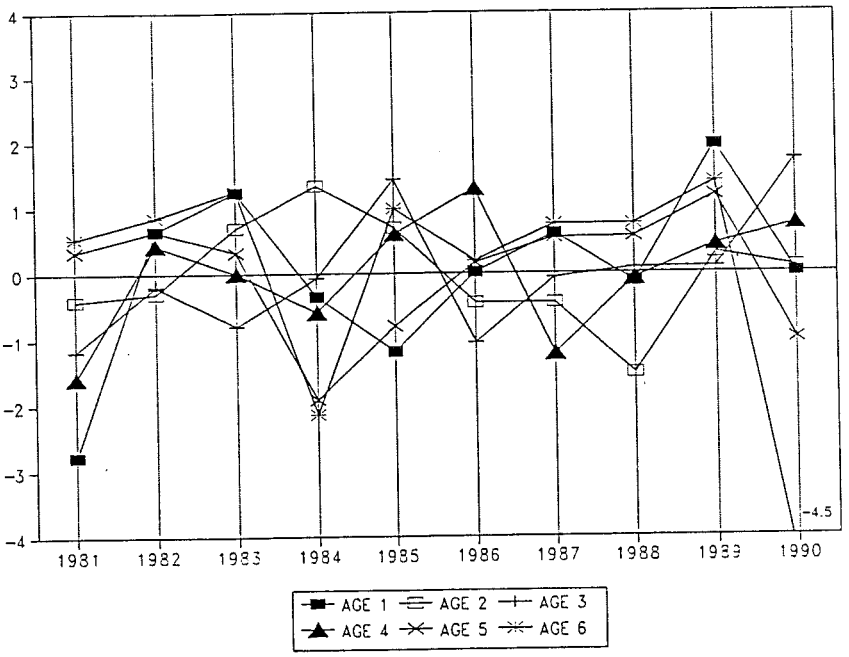


Figure 4: VPA projection and survey 1991/92. Age distribution of biomass (age 2+).



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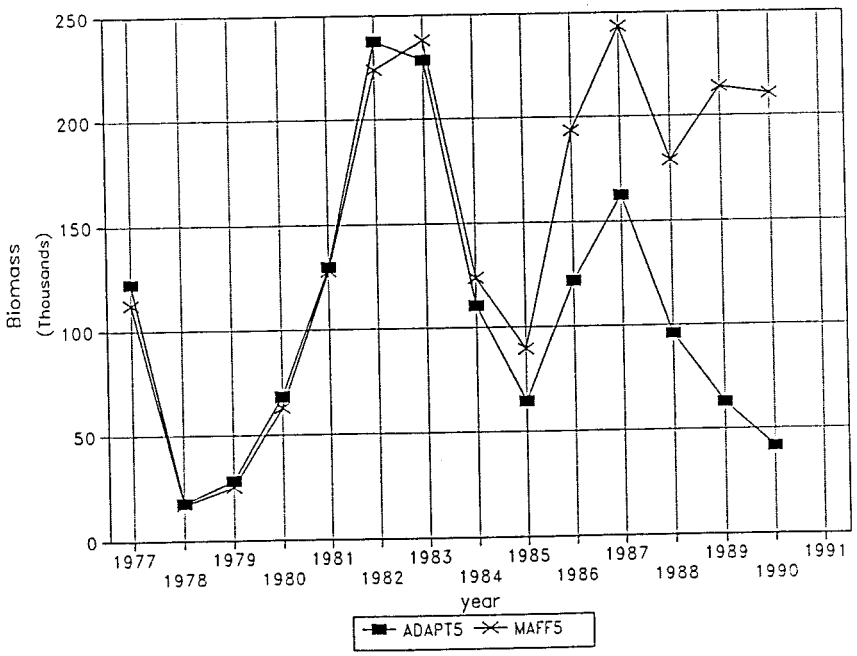

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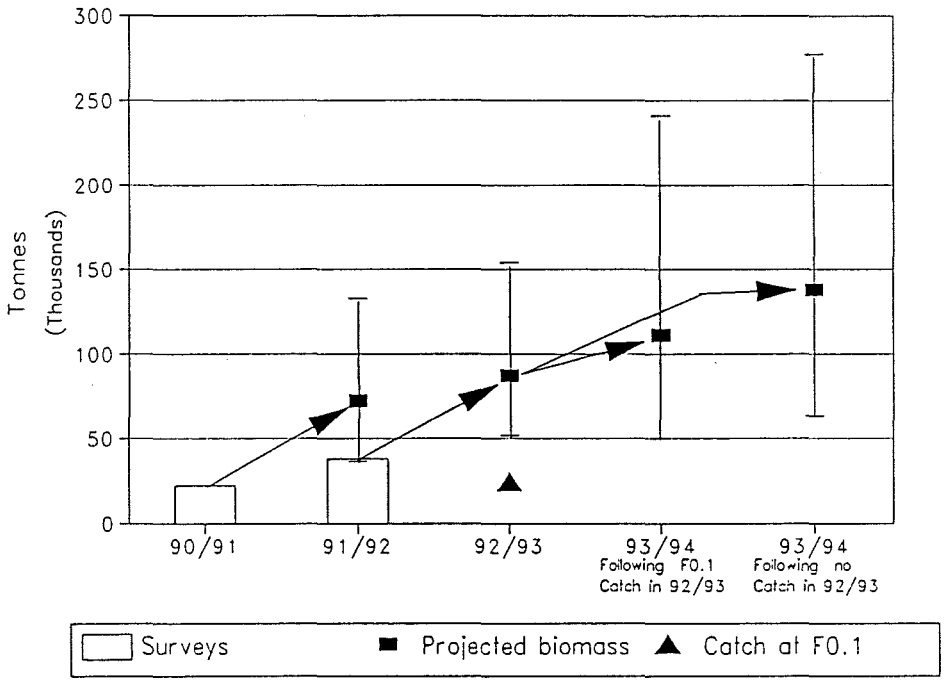

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THE CHOICE OF PROCEDURE FOR DECIDING WHEN TO CLOSE FISHERIES REGULATED BY CCAMLR: A SIMULATION MODEL

D.J. Agnew*

Abstract

The methods, described in CCAMLR Conservation Measures, used for deciding the closure date for fisheries monitored by the Secretariat of CCAMLR, have been difficult to implement because of the variation in catch rates shown by the fisheries. Non-fluctuating random and fluctuating random catch histories are simulated and the performance of four models for making closure decisions is investigated under a variety of circumstances.

The model described in the existing conservation measures is shown to have a high probability of allowing large over- or under-shoots of the TAC. The most successful model determines the trend of catch rates using linear regression over the latest four reporting periods, and closes the fishery if these rates indicate that the TAC will be taken before the next report is received by the Secretariat. The probability of large over-shoots of the TAC is reduced if reporting periods are small (five days) and the reporting delay is minimal.

It is recommended that in future conservation measures, methodologies for deciding the date of closure of fisheries should incorporate a formulation of Model 4, given in this paper.

Résumé

Les méthodes décrites dans les mesures de conservation de la CCAMLR, servant à déterminer la date de fermeture des pêcheries contrôlées par le secrétariat de la CCAMLR, sont difficiles à appliquer en raison de la variation des taux de captures des pêcheries. L'historique des captures aléatoires fluctuantes et non fluctuantes sont simulées et la performance de quatre modèles de décision de fermeture soumis à des conditions diverses est examinée.

Avec le modèle décrit dans les mesures de conservation en vigueur, le taux de capture a toutes les chances d'être bien en-dessous ou bien au-dessus du TAC. Le meilleur modèle détermine la tendance des taux de captures par une régression linéaire effectuée sur les quatre dernières périodes de déclaration; il ferme la pêche si ces taux indiquent que le TAC sera atteint avant que la prochaine déclaration ne parvienne au secrétariat. La probabilité d'un dépassement important du TAC est réduite lorsque les périodes sont courtes (cinq jours) et le délai de déclaration minime.

Il est recommandé, pour les prochaines mesures de conservation, d'inclure la description du Modèle 4 donnée dans cette communication dans toute méthodologie relative à la décision d'une date de fermeture des pêcheries.

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Резюме

В связи с колебаниями уловов в период промысла, в прошлом было сложно использовать метод расчета сроков закрытия тех промыслов, которые контролируются Секретариатом АНТКОМа. Эти метод описан в соответствующих мерах по сохранению. Сформулированы модели, описывающие случайно генерированные серии уловов с колебаниями и без колебаний. Изучена эффективность четырех моделей принятия решений о закрытии промысла в зависимости от разных обстоятельств.

Показано, что описанная в существующих мерах по сохранению модель имеет высокую вероятность получения бо̀льших превышений или недополучений ТАС. Самая эффективная модель определяет тенденцию изменения в размерах вылова с использованием линейной регрессии за последние четыре отчетные периоды и закрывет промысел в том случае, если интенсивность вылова указывает на достижение ТАС до поступления следующего отчета в Секретариат. Вероятность больших превышений ТАС меньше, если отчетные периоды коротки (пять дней) и промежуток времени до получения отчета минимален.

Рекомендуется, что в дальнейших мерах по сохранению методы принятия решений о сроках закрытия промысла должны включить в себя какую-либо формулировку Модели 4, приведенной в настоящей работе.

Resumen

Los métodos contemplados en las medidas de conservación de la CCRVMA y que han sido utilizados para decidir el cierre de las pesquerías controladas por la Secretaría de esta organización, han sido difíciles de llevar a la práctica debido a la variación en los índices de captura experimentada por la pesquería. Se simulan las capturas históricas aleatorias fluctuantes e invariables y se prueba la aplicación de cuatro modelos para decidir el cierre de las pesquerías bajo diversas condiciones. Se ha constatado que el modelo descrito en las medidas de conservación actuales tiene una alta probabilidad de permitir excesos y déficit significativos con respecto al TAC. El modelo más exitoso determina la tendencia de los índices de captura mediante una regresión lineal de los últimos cuatro períodos y determina el cierre de la pesquería cuando estos índices indican que el TAC será alcanzado antes de que la Secretaría reciba el próximo informe. La probabilidad de que se exceda el TAC de manera considerable se ve reducida si los períodos de notificación son cortos (cinco días) y el tiempo entre notificaciones es mínimo.

Se recomienda que en las futuras medidas de conservación, la formulación del Modelo 4 (presentado en el documento) sea incorporado en los métodos para decidir la fecha de cierre de las pesquerías.

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1. INTRODUCTION

CCAMLR manages fisheries in its Convention Area[1] by a number of traditional means (mesh size regulation, closed areas, Total Allowable Catches (TAC) etc.). At present CCAMLR has no rationally managed quota system for ensuring TAC control on the fisheries. Instead, TACs are administered by the CCAMLR Secretariat. Reports of catches are made to the Secretariat by all countries engaged in a specific fishery, and the Secretariat determines when the TAC has been taken.

There have now been two seasons for which the Secretariat has had to implement a closure of fisheries regulated by catch limits in Subarea 48.3. The history of these fisheries is described in CCAMLR (1990 and 1991).

TAC conservation measures set at CCAMLR-VIII and CCAMLR-IX specified that:

- catches should be reported to the Secretariat by 5-day reporting period, reports falling due at the end of the period following that in which catches are taken;
- the Secretariat should calculate the date of closure of the fishery using the catch rate from the most recent reporting period; and
- when the cumulative catch is 90% (Conservation Measure 17/VIII) or 80% (Conservation Measure 25/IX) of the TAC the Executive Secretary shall notify Members that the fishery will be closed from the date shown by his calculations to be that on which the TAC will have been taken.

The central problem in all closure methods is that it is not possible to close the fishery at exactly the same time that the TAC is reached because of the time delay between catches being reported to Member countries, those catches being reported to the Secretariat, and any notification of a closure decision being transmitted from the Secretariat to fishermen via their national management bodies. This means that the Secretariat must attempt to predict dates of closure.

The types of predictive method outlined in conservation measures to date rely upon fishing effort being constant and having low variance. In the case of the *Champsocephalus gunnari* fishery in 1989/90 and the *Dissostichus eleginoides* fishery in 1990/91, this method was inadequate for predicting the correct date of closure of the fishery. Contributing factors to this failure were:

- the variation of catch rates was quite high (coefficient of variation 0.2 to 0.3);
- the catch rates were high in the *C. gunnari* fishery in 1989/90 (about 1% of the TAC per day) and very low in the *D. eleginoides* fishery in 1990/91 (0.05 to 0.5% of the TAC per day); and
- catch rates sometimes varied in an almost cyclic way, by a factor of 10 or more.

The catch history for the 1991 *D. eleginoides* fishery is shown in Figure 1.

As a result of these factors, catches were greater than the TAC in 1990 by 1% and the method was found to be unworkable in 1991. In this latter year, a second method was developed (Model 2 in this paper) that resulted in catches being 4.3% less than the TAC.

This paper describes a simulation model constructed in order to investigate further the performance of various methods of arriving at a closure decision and to develop methods with a higher performance than those presently in use.

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[1] Except in the French EEZ around Kerguelen which is managed by France.

2. MODEL PARAMETERISATION

The model was constructed so that it would reflect the progress of a real fishery as much as possible. Whilst the fishery was modelled on a daily basis, the only information available to the Secretariat was assumed to be the catch for a single reporting period.

2.1 Catch Rates

Catch histories for fisheries were modelled on a daily basis in order to allow different reporting periods to be tested. All catches were expressed as proportions of a TAC.

Two models were used:

- Type I catch - random catch rates

$$C = \bar{c} + S_c \cdot \rho$$

where C is the catch rate for one day, $\bar{c}$ = mean catch, S_c = standard deviation (derived from the coefficient of variation cv_c), and ρ is a normally distributed random deviate; and

- Type II catch - regularly changing catch rates, modelled by a sine function overlaid with a variance that is proportional to catch rate

$$C = \bar{c} + \alpha \cdot \bar{c}, \sin(\theta) + \delta \cdot S_c \cdot \rho$$

where α is the amplitude of the sin wave, θ is the position of the sinusoidal cycle at time t computed from the equation $\theta = \theta_o + \pi / \lambda$ (t is time in days, λ = period of sin wave in days, θ_o = start position, randomly determined), and δ is an adjustment of the variance that is proportional to C.

An example of a simulated Type II catch is given in Figure 2 and can be compared with the catch history of the *D. eleginoides* fishery in 1991 (Figure 1).

2.2 Catch Reporting

The date that a catch report arrives at the Secretariat was modelled by:

$$D = P + \bar{d} + s_d \cdot \rho$$

where D is the total time from the end of a reporting period to the arrival of the report at the Secretariat in days, P = length of the reporting period in days, $\bar{d}$ = mean delay, s = standard deviation and ρ is a normally distributed random deviate.

Unless other values are mentioned in the text, the following values should be assumed for the simulation runs:

$P = 5$	(reporting period in 1990 and 1991 was 5-days)
$\bar{c} = 0.005, 0.01, 0.02$	(0.5%, 1%, 2% of TAC per day; similar to mean rates for *D. eleginoides* in 1991 (see Figure 2) and *C. gunnari* in 1990 respectively)
$cv_c = 0.2$	(coefficient of variation, slightly lower than CV of catch by period in 1989/90; see discussion under 'results')
$\bar{d} = 5$	(mean reporting delay in 1990/91)
$cv_d = 0.5$	(coefficient of variation of reporting day in 1990/91)
$\alpha = 0.5$	(amplitude of cycles in 1990/91 is approximately 0.5)
$\lambda = 80$	(period of cycles in 1990/91 is about 80 days)
$L = 0.8$	(limit for decision in Model 1 as given in Conservation Measure 25/IX)

2.3 Decision Making Models (DMM)

Four decision making models were tested:

	Decision to Close Fishery	Rate Determined By	Closure Effective From
1. Percentage model: this is the model described in the existing conservation measures	If cumulative catch is greater than a specified level L	Catch rate of most recent period	The end of the reporting period within which the predicted date[2] of TAC completion falls
2. Time delay: used as an *ad hoc* method by the Secretariat in 1990/91	If predicted date falls in the period immediately following the period in which the report was received, or sooner	Catch rate of most recent period	The end of the reporting period within which the predicted date falls, or the end of the period in which the report was received, whichever is later
3. Time delay: Modified 1	If predicted date falls before the next report is expected (taking into account the reporting delay and its variance)	Catch rate of most recent period	The predicted date, or the date that the report was received, whichever is later
4. Time delay: Modified 2	If predicted date falls before the next report is expected (taking into account the reporting delay and its variance)	Catch rate is predicted using the trend of catch rates from the last *n* reporting periods (a linear regression is performed)	The predicted date, or the date that the report was received, whichever is later

The Fortran code for these decision models is given in Appendix A.

2.4 Performance

The performance of DMMs was assessed by monitoring the final catch that would be taken by the time of the decided closure of the fishery and comparing this to the TAC. An example of a frequency distribution of these differences ("over-shoot") is given in Figure 3. Differences between the observed catch and the TAC were characterised by the mean and

[2] Predicted date means the date on which predictions show that the TAC is expected to be taken. It is calculated using the catch rate determined by the previous box and the quantity of TAC that remains to be caught. The predicted date is always rounded down, so that a predicted date of 145.56 days becomes 145 days.

standard deviation of the magnitude of the over-shoot, the proportion of runs that produced a catch greater than the TAC, i.e., greater than the TAC+5% and greater than the TAC+10%, and were calculated from 20 x 400 iterations of the simulation.

Mean over-shoot was almost always positive, and in many cases the frequency histogram of over-shoot values was quite heavily skewed (Figure 3). Over-shoots rather than under-shoots were considered as performance indicators because they are potentially more damaging to the fish stocks. The chances of similar magnitudes of under-shoot were almost always lower than for the over-shoots because of the skewed nature of the distributions.

3. RESULTS

All models were highly sensitive to catch rates as a proportion of TAC ($\bar{c}$), to the length of the reporting period (P), and to the length of the reporting delay ($\bar{d}$).

In general the mean over-shoot and its standard deviation increased with increasing catch rate. However, Model 1 showed local minima of the probability of significant over-shoot that occurred at different values of L for different levels of $\bar{c}$ (Figure 4). Best performance was attained with L = 0.9 if $\bar{c}$ was 0.005, L = 0.8 if $\bar{c}$ = 0.1 and L = 0.6 if $\bar{c}$ = 0.02. This implies that the use of Model 1 in a conservation measure must incorporate a mechanism for adjustment of the limit for a decision, L, in relation to the catch rate.

All models showed decreases in performance with increasing length of reporting period (Table 1), and this was exacerbated by increasing catch rates.

All models performed less well with the Type II catch than with Type I. However, although there was little difference between the performance of Model 1 and Model 2 at low catch rates and with Type I catches, the performance of Model 1 was significantly lower at higher catch levels and Type II catches than Model 2 (Table 2). DMMs of classes similar to Model 2 are clearly preferable to Model 1 under most circumstances.

Two refinements to Model 2 were made, creating Model 3 and Model 4 by changing the decision path and the way the rate was determined. Individual simulations established that the optimal number of periods to use for the calculation of trend for Model 4 was four. Table 4 shows that Model 4 performs more successfully with changing catch rates (Type II) than either Models 2 or 3, although it appears to perform less well with catches of Type I than Model 3.

The effect of the coefficient of variation (CV) of the mean catch rate is unpredictable. For instance, increasing cv_c from 0.2 to 0.8 with catch = 0.01 and using catch Type II with Model 4 decreases the chance of more than 5% over-shoot but increases the chance of greater than 10% over-shoot. The CV used for the simulations (0.2) is similar but slightly lower than that found for the catches of *Champsocephalus gunnari* reported by 5-day period in 1989/90. The CV of catches by period (cv_c) computed by the simulation is less than this, about 0.15, because the cv_c is applied to each catch by day, and adding catches by period removes some of this variation. However, it was considered that since no direct information on CV of catches by day was available, and vessels may change their fishing strategy by 5-day (week) periods rather than by day, that the cv_c value of 0.2 was realistic until further information becomes available.

4. DISCUSSION

There is clear evidence that Models 2 to 4 perform more successfully than Model 1. Models 2 to 4 all use a decision based on the time to completion of the TAC in relation to reporting periods, whereas Model 1 was based on a proportion of the TAC. This means that the

time interval over which it is necessary to predict catch rates is reduced. Since the uncertainties in all these models arise because they have to use information from past catch rates to extrapolate future catches up to when the TAC is taken, models that reduce the extrapolation time should reduce the over- or under-shoot in TAC.

Table 4 shows that there is a significant advantage in using a model that combines the features of short extrapolation periods with an element of trend analysis. In this case, using the past four reports to infer a trend gave the best results (but under other conditions of α and λ, for example, this could change). The decrease in probability of greater than 5% over-shoot from 0.47 to 0.27 with a change from Model 1 to Model 4 (catch = 0.01) demonstrates the increased performance of the latter model.

A fifth model was trialed, which used mean catch rates over a number of previous periods to calculate closure date (i.e., trend assumed zero). This offered no advantages over Model 3 and was not pursued further.

It must be emphasised that extrapolation of information from past catch rates will always contain an element of uncertainty, for some methods more than others. The more complex the analysis of trend the better the model might be expected to perform, but in this paper only simple linear regression techniques have been used. Large, unpredictable changes in rate such as happened at the end of the 1991 *D. eleginoides* fishery, can never be realistically anticipated by these models without further information being provided, such as anticipated changes in fleet structure.

Model 4 performs better under fluctuating conditions (Type II catches) than the others described here, although it appears to perform slightly worse than Model 3 when catches are of Type I. The choice of model may thus depend on the type of catches from the fishery. However, it should be noted that a fishery need not be cyclical to benefit from the adoption of Model 4; if a fishery starts consistently and then declines or increases effort towards the end of the season, Model 4 will perform better than others.

The latter situation can often be expected since fishermen receive feedback on the progress of the fishery from the Secretariat. If Method 4 had been used in 1991, the fishery would not have been closed when it was, but later, and would probably have avoided some of the 4.3% shortfall in catches from the TAC.

The probability of serious over- or under-shoot of a TAC can be further minimised by:

- low catch rates and coefficient of variation (at catch rates of less than 0.005, Models 3 and 4 perform similarly);
- short reporting periods (5-days); and
- short reporting delays.

The details that should be incorporated into a conservation measure based on the implementation of Model 4 are given in Appendix B.

REFERENCES

CCAMLR. 1990. Implementation of Conservation Measures in 1989/90. Document *CCAMLR-IX/BG/14*. CCAMLR, Hobart, Australia.

CCAMLR. 1991. Implementation of Conservation Measures in 1990/91. Document *CCAMLR-X/9*. CCAMLR, Hobart, Australia.

Table 1: Effect of length of reporting period on performance. Mean over-shoot and probability of greater than 5% over-shoot (in parentheses).

Model 1, catch Type I, L = 0.8	Catch[2] = 0.005	0.01	0.02
5-day reporting period	0.007 (0.027)	0.015 (0.071)	0.093 (0.715)
10-day reporting period	0.019 (0.073)	0.052 (0.511)	0.294 (0.982)

Model 2, catch Type I,	Catch = 0.005	0.01	0.02
5-day reporting period	0.005 (0.002)	0.010 (0.038)	0.018 (0.220)
10-day reporting period	0.013 (0.012)	0.023 (0.220)	0.034 (0.209)

[2] As proportion of TAC

Table 2: Performance of Models 1 and 2 with Catch Types I and II. Mean over-shoot and probability of greater than 5% over-shoot in parentheses.

Model 1, L = 0.8	Catch = 0.005	0.01	0.02
Catch Type I	0.007 (0.027)	0.015 (0.071)	0.093 (0.715)
Catch Type II	0.046 (0.435)	0.061 (0.466)	0.155 (0.817)

Model 2	Catch = 0.005	0.01	0.02
Catch Type I	0.005 (0.002)	0.010 (0.038)	0.018 (0.220)
Catch Type II	0.014 (0.073)	0.026 (0.417)	0.155 (0.521)

Table 3: Performance of Models 2, 3 and 4 under Catch Types I and II. Probability of over-shoots greater than 5% and 10% (in parentheses) (mean over-shoot is not given).

Catch Type I	Catch = 0.005	0.01	0.02
Model 2	0.002 [0]	0.038 [0.001]	0.220 [0.040]
Model 3	0 [0]	0.025 [0]	0.219 [0.025]
Model 4	0.001 [0]	0.036 [0.001]	0.230 [0.038]

Catch Type II	Catch = 0.005	0.01	0.02
Model 2	0.073 [0.001]	0.417 [0.087]	0.521 [0.341]
Model 3	0.050 [0]	0.350 [0.035]	0.478 [0.254]
Model 4	0.025 [0]	0.269 [0.023]	0.342 [0.167]

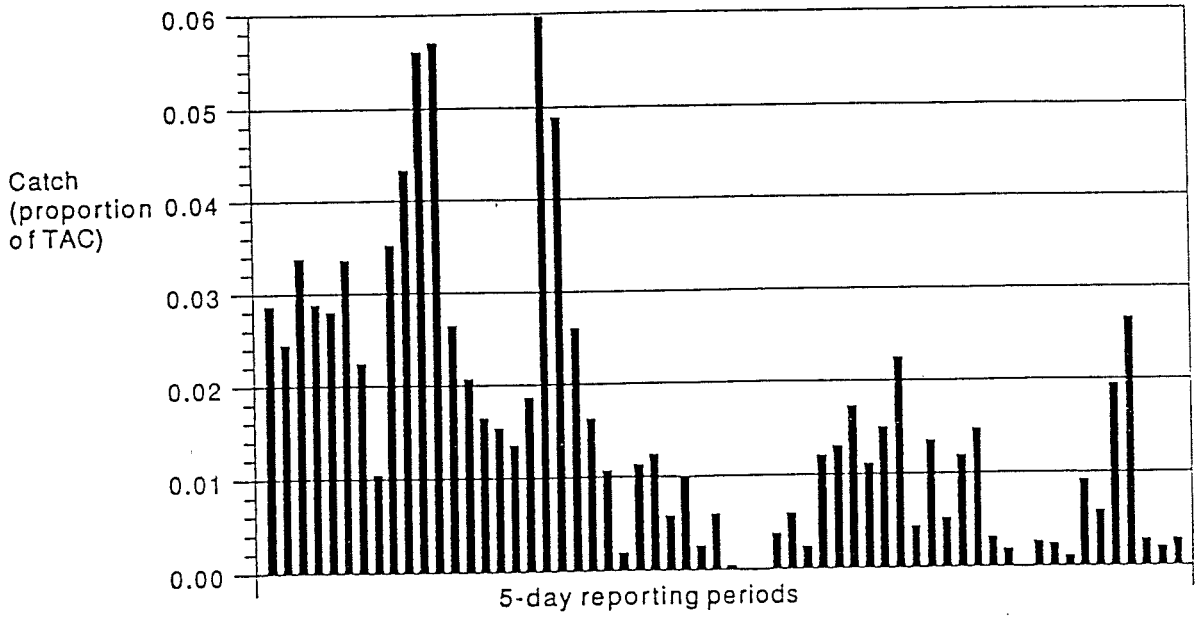

Figure 1: Progress of the *D. eleginoides* fishery in 1991. Catches are by five-day period and are expressed as a proportion of the TAC of 2 500 tonnes.

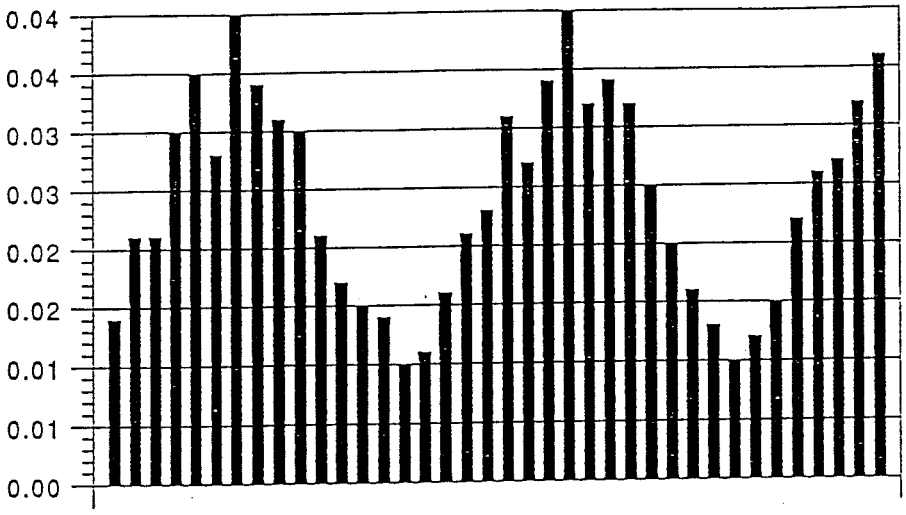

Figure 2: Simulated progress of a fishery with Catch Type II: mean catch = 0.005 of the TAC day^{-1}, with other sin parameters as given in the methods. Catches are given by five-day period.

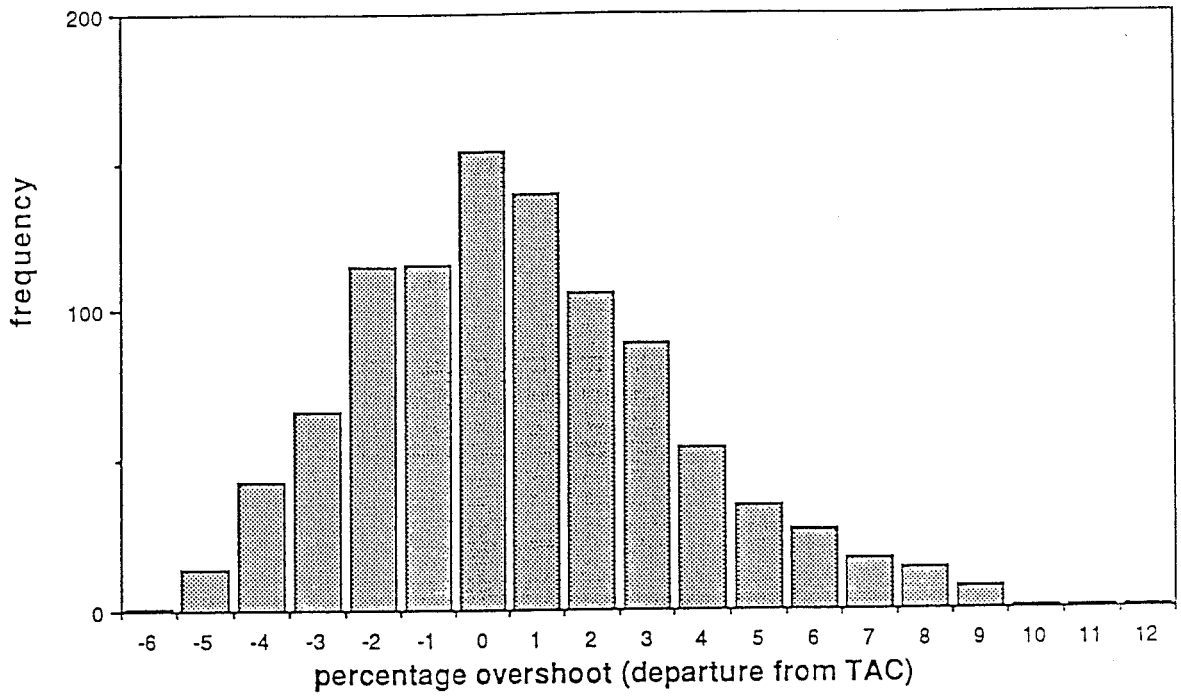

Figure 3: Frequency distribution of overshoots expressed as percentage of TAC, after 1 000 simulation runs. This was produced using Model 1, Catch Type I, $\underline{c}$ = 0.005, L = 0.70 and had the characteristics of mean and SD over-shoot = 0.0071 and 0.029 respectively, and a probability of >5% and >10% over-shoot of 0.086 and 0.002 respectively.

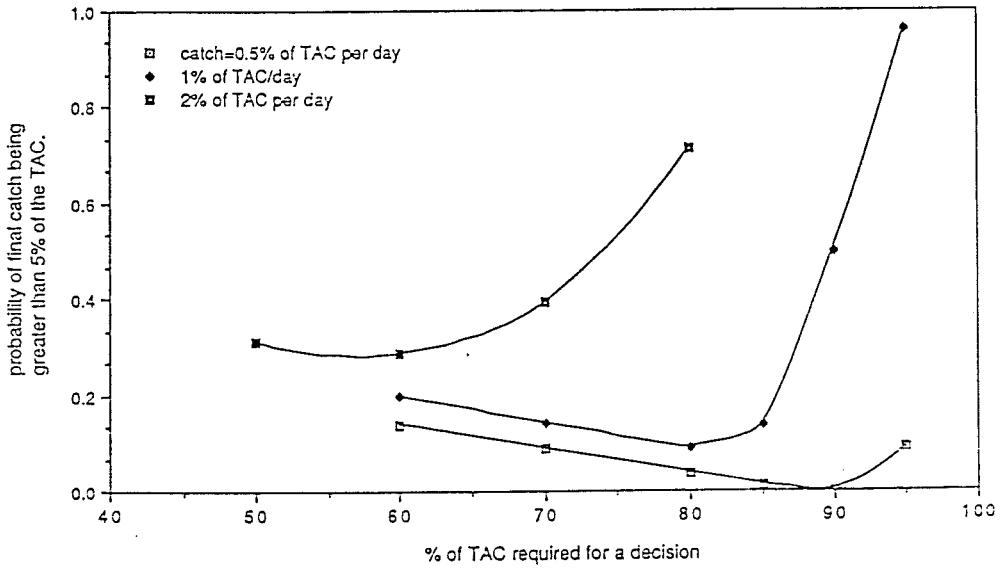

Figure 4: Model 1 (currently defined in Conservation Measure 25/IX) with Catch Type I. The effect of L, the catch limit required to trigger a closure decision, on the performance of Method 1 expressed as the probability of the final over-shoot in catch being greater than 5% of the TAC. The curves are interpolated by computer, and show local minima which occur at different values of L with different catch rates.

Légende des tableaux

Tableau 1: Répercussions de la durée de la période de déclaration sur la performance. Dépassement moyen et probabilité d'un dépassement supérieur à 5% (entre parenthèses).

Tableau 2: Performance des modèles 1 et 2 pour des captures de type I et II. Dépassement moyen et probabilité d'un dépassement supérieur à 5% (entre parenthèses).

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Figure 4: Modèle 1 (défini dans la mesure de conservation 25/IX) pour une capture de Type I. Effet de L, limite de capture à l'origine de la décision d'une fermeture, sur l'efficacité de la Méthode 1, exprimé en tant que probabilité selon laquelle le dépassement final de la capture est supérieur à 5% du TAC. Les courbes sont tracées par ordinateur et illustrent les minima localisés pour différentes valeurs de L et différents taux de capture.

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Figura 4: Modelo 1 (definido actualmente en la Medida de conservación 25/IX) con una captura de tipo I. El efecto que produce L, la captura máxima que se requiere para instituir el cierre, en el funcionamiento del modelo 1, expresado en términos de la probabilidad de exceder el objetivo final de captura superior al 5% del TAC. Las curvas fueron interpoladas por computador y muestran el mínimo local que ocurre a distintos valores de L con diferentes índices de captura.

```
      SUBROUTINE MODEL1(CUMCAT,ILASDAY,EFFRATE,IREPDAY,
     &DECLIM,IPERIOD,IENDDAY)

C cumulative catch CUMCAT assumed to be out of 1 so amount to go =1-cumcat
C ILASDAY is the day the report came in
C EFFRATE is the effective rate of catching used (calculated in main prog)
C DECLIM is the limit of catch for decisions
C IREPPER is the end date of the report period
C IEND is the end date
C IENDPER is the end date of the end period
C
C IENDDAY is the returned date of the closure; set to -1 if no closure decision
C
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD*(((IEND-1)/IPERIOD)+1)
      IREPPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+1)
C      WRITE (*,*) IEND,EFFRATE,CUMCAT,DECLIM
      IF (CUMCAT.GE.DECLIM.AND.IENDPER.GE.IREPPER) THEN
       IENDDAY=IENDPER
      ELSE IF (CUMCAT.GE.DECLIM.AND.IENDPER.LT.IREPPER) THEN
       IENDDAY=IREPPER
      ELSE
       IENDDAY=-1
      ENDIF
      RETURN
      END

C ************************************************************

      SUBROUTINE MODEL2(CUMCAT,ILASDAY,EFFRATE,IREPDAY,IPERIOD,IENDDAY)

C  cumulative catch CUMCAT assumed to be out of 1 so amount to go =1-cumcat
C  ILASDAY is the day of last catch
C  EFFRATE is the effective rate of catching used (calculated in main prog)
C  IREPDAY is the date the report was recieved by Secretariat
C  IPERIOD is the number of days in the period for reporting
C  IENDDAY is the date of the closure; set to -1 if no closure decision
C
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+2)
      IREPPER=IPERIOD*(((IREPDAY-1)/IPERIOD)+1)
      IF (IEND.LE.IENDPER.AND.IEND.GT.IREPPER) THEN
        IENDDAY=IENDPER
      ELSE IF (IEND.LE.IREPPER) THEN
        IENDDAY=IREPPER
      ELSE
        IENDDAY=-1
      ENDIF
      RETURN
      END


C ************************************************************
```

```
      SUBROUTINE MODEL3(CUMCAT,ILASDAY,EFFRATE,IREPDAY,IPERIOD,IENDDAY)

C same as model 2 except with closure date on that date rather than on
C the end of the period, and with determination by catch within next
C xx days, where xx=IPERIOD
C
      IF (EFFRATE.EQ.0.) EFFRATE=.000000001
      IEND=ILASDAY+INT((1.-CUMCAT)/EFFRATE)
      IENDPER=IPERIOD+IREPDAY
      IF (IEND.LE.IENDPER.AND.IEND.GT.IREPDAY) THEN
        IENDDAY=IENDPER
      ELSE IF (IEND.LE.IREPDAY) THEN
        IENDDAY=IREPDAY
      ELSE
        IENDDAY=-1
      ENDIF
      RETURN
      END


C ************************************************************

      SUBROUTINE MODEL4(CUMCAT,ILASDAY,ARREG,NO,
     &IREPDAY,IPERIOD,IENDDAY)

C this model fits a regression line to the last "NO" data points
C (data point = catch/period) and calculates the change in catch rates
C fitting this to estimate next catch level
C ARREG(30) holds the latest reported catch
C NO is the number of previous catch reports to be used in the regression
C IENDDAY is the returned date of closure
C
C regression model: linear
C
      REAL ARREG(30)

       SUMX=0.
       SUMY=0.
       SSUMX=0.
       SUMXY=0.

C this code fills up ARREG from the bottom with the latest "NO" catches
      DO 10 N=1,NO
       IF (N.LT.NO) THEN
         ARREG(N)=ARREG(N+1)
       ELSE
         ARREG(N)=ARREG(30)
       ENDIF
C       WRITE (*,'(5X,I5,F8.4)') N,ARREG(N)
       SUMX=SUMX+N
       SUMY=SUMY+ARREG(N)
       SSUMX=SSUMX+N**2
       SUMXY=SUMXY+N*ARREG(N)
10     CONTINUE

       IF (ARREG(1).NE.-1.) THEN
C the equation of the fitted line is Y=A+B(X)
       B=(NO*SUMXY-SUMX*SUMY)/(NO*SSUMX-SUMX**2)
       XMEAN=SUMX/NO
       YMEAN=SUMY/NO
       A=YMEAN-B*XMEAN
C find the catch rate appropriate to the first unreported period
       RATESTART=NO*B+A
C set up a safetycatch for number of periods
       MAXPERIOD=IREPDAY-ILASDAY+2
C calculate remaining catch, and find last catch=totcat2
       REMAIN=1-CUMCAT
       TOTCAT2=ARREG(NO)
C       WRITE (*,'(4F8.4)') B,A,RATESTART
       DO 20 I=1,MAXPERIOD
C use equation for uniform accelleration to calculate catch in period I
        TOTCAT1=RATESTART*I+0.5*B*(I**2)
C        WRITE (*,'(3X,I4,F8.4)') I,TOTCAT1
        IF (TOTCAT1.GT.REMAIN) GOTO 30
        TOTCAT2=TOTCAT1
```

```
20      CONTINUE
          IENDDAY=-1
          GOTO 40
C find proportion of last period at which TAC was taken
C from this find total number of periods (real) at TAC, and then days
C if limit was found, iend is the day before it was reached,
C otherwise iend is a safetycatch day, maxperiod

30      IEND=ILASDAY+INT(IPERIOD*(REAL(I)
     &-(TOTCAT1-REMAIN)/(TOTCAT1-TOTCAT2)))

C the rest is identical to Model 3
        IENDPER=IPERIOD+IREPDAY
        IF (IEND.LE.IENDPER.AND.IEND.GT.IREPDAY) THEN
          IENDDAY=IENDPER
        ELSE IF (IEND.LE.IREPDAY) THEN
          IENDDAY=IREPDAY
        ELSE
          IENDDAY=-1
        ENDIF
       ELSE
         IENDDAY=-1
       ENDIF
40       RETURN
       END
C ***********************************************************
```

CONSERVATION MEASURES INCORPORATING MODEL 4 WOULD HAVE THE FOLLOWING FEATURES:

- Catches should be reported by 5-day period to the Secretariat, the deadline being the end of the reporting period following that in which the catches are taken.
- The progress of the fishery should be reported by the Secretariat to all Members every month, and to Members fishing for that species being reported at the end of each reporting period.
- The Secretariat should calculate the trend in catches using linear regression on the last four catch reports.
- This catch rate trend should be extrapolated to calculate the "predicted date", the day on which the TAC is expected to be taken, using a rounding down function.
- If the predicted date is within one reporting period of the date on which the Secretariat received the report of the catches the fishery will close on that day or on the day on which the report was received, whichever is the later (i.e., if the calculation indicates that the TAC will be taken before another report would be received by the Secretariat [received day plus one reporting period], the fishery should close).

II. KRILL BIOLOGY AND MANAGEMENT

STATUS OF KRILL TARGET STRENGTH

K.G. Foote[1], D. Chu[2] and T.K. Stanton[2]

Abstract

Empirical estimates for the target strength of krill are extracted from publications. These are confined to measurements on aggregations of live euphausiids and should not be affected by a frequent cause of bias in single-animal measurements, namely thresholding. Theoretical estimates for the target strength are derived from the deformed-cylinder scattering model assuming specific sets of physical and orientational parameters, for which there is an empirical basis. The theoretical estimates show a non-monotonic dependence of target strength on both animal size and transmit frequency, notwithstanding admitted shortcomings. Some recent single-animal measurements of target strength for live euphausiids and euphausiid-related species, made under high signal-to-noise-ratio conditions, are consistent with the general pattern. Several specific recommendations are made for future, improved determinations of krill target strength. Based on the comparisons, general prediction curves for the target strength are presented that are applicable to a wide range of lengths, acoustic frequencies and orientation parameters.

Résumé

Les estimations empiriques de la réponse acoustique du krill sont extraites des publications. Elles sont limitées aux mesures des concentrations d'euphausiacés vivants et ne devraient pas être affectées par une cause fréquente de biais dans les mesures des individus, à savoir l'identification du seuil. Les estimations théoriques de la réponse acoustique sont dérivées du modèle de diffusion en cylindre déformé, présumant des séries spécifiques de paramètres physiques et d'orientation reposant sur une base empirique. Les estimations théoriques mettent en évidence une dépendance non monotone entre la réponse acoustique et à la fois la taille des individus et la fréquence de transmission, en dépit des limites admises. Quelques mesures de réponse acoustique prises récemment sur des individus vivants (un par un) d'espèces d'euphausiacés et d'espèces apparentées aux euphausiacés, effectuées dans des conditions dans lesquelles le rapport signal-bruit est élevée, suivent le modèle général. Plusieurs recommandations spécifiques sont avancées pour une meilleure détermination de la réponse acoustique du krill à l'avenir. Basées sur les comparaisons, les courbes générales de prédiction de la réponse acoustique présentées sont applicables à tout un éventail de longueurs, de fréquences acoustiques et de paramètres d'orientation.

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Резюме

Эмпирические оценки силы цели криля были взяты из различных публикаций. Они касаются только измерений проведенных на скоплениях живых эвфаузиид и на них не должен оказывать влияние "пороговой эффект", который часто вызывает смещение измерений, проведенных на единичных животных. Теоретические оценки силы цели получены с помощью модели рассеивания деформированным цилиндром, предполагали наличие конкретных наборов физических и ореинтационных параметров, для которых имеется эмпирическое обоснование. Несмотря на имеющиеся в расчетах недостатки, теоретические оценки указывают на отсутствие монотонической зависимости силы цели как от размера животного, так и от частоты передатчика. Несколько проведенных недавно измерений силы цели живых эвфаузиид и близких к ним видов, проделанных в условиях высокого соотношения сигнала к шуму, соответствуют общей картине. Приводится ряд конкретных рекомендаций по улучшению определения силы цели криля в будущем. На основе сравнений, даются общие прогнозируемые кривые силы цели, применяемые к широкому диапазону длин, акустических частот и ориентационных параметров.

Resumen

Los valores empíricos de la potencia del blanco del kril han sido extraídos de las publicaciones. Estos se limitan a mediciones hechas en cardúmenes de eufáusidos libres y no debieran ser afectados por una fuente de desviación frecuente experimentada en las mediciones de animales individuales, es decir, por la formación de umbrales. Los valores teóricos de la potencia del blanco son deducidos del modelo de dispersión del cilindro deformado, suponiéndose una serie específica de variables físicas y orientacionales para las cuales existe una base empírica. Los valores teóricos muestran una dependencia no-monótona de la potencia del blanco con respecto al tamaño del animal y a su frecuencia de transmisión, a pesar de las reconocidas limitaciones. Algunas mediciones recientes de potencia del blanco en eufáusidos vivos y en especies afines, hechas en condiciones de alta relación señal/ruido, son consecuentes con el modelo general. Se formulan varias recomendaciones específicas para mejorar las futuras estimaciones de potencia del blanco del kril. Sobre la base de las comparaciones, se presentan las curvas de predicción general para la potencia del blanco que son aplicables a una amplia gama de tallas, frecuencias acústicas y parámetros orientacionales.

---

1. INTRODUCTION

The echo integration method (Forbes and Nakken, 1972; MacLennan, 1990) has been applied to krill (*Euphausia superba*) in the Southern Ocean (Miller and Hampton, 1989). In order to convert measurements of echo strength to biological quantities, such as the number density of scatterers, knowledge of target strength is essential. Notwithstanding the degree of

interest in krill biomass, as witnessed, for example, by the scale of international involvement in the Biological Investigation of Marine Antarctic Systems and Stocks (BIOMASS) program, measurements of krill target strength have been quite scarce.

In fact, at the time of the Post-FIBEX Acoustic Workshop in 1984 (Anon., 1986) only several measurements on *E. superba* had been reported in the literature. In order to establish a target strength-size relationship for use in interpreting the measurements of the First International BIOMASS Experiment (FIBEX), recourse was made to measurements on other zooplankton. These included measurements on preserved, defrosted and even live specimens of other species. In many cases, the measurements were performed on single specimens. It is the authors' contention that such measurements, while being inherently difficult for weak, zooplankton scatterers, are vulnerable to the effect of thresholding.

Thresholding, or the discarding or rejection of signals as noise because of their low amplitude, low spectral level, or other inferior characteristics, has been recognised as an important phenomenon in fish-scattering measurements (Weimer and Ehrenberg, 1975; Foote *et al.*, 1986). Its recognition in zooplankton acoustics has been less common. Clearly its mention in the literature as a possible source of bias in single-scatterer measurement has been rare. The kind of review attempted here may consequently be justified for gathering together diverse, generally recent references on scattering by live euphausiids that avoid or otherwise address the effect of thresholding.

The organisation of this paper is the following. The quantities of target strength, backscattering cross section, and mean volume backscattering coefficient and strength are defined. Empirical studies of krill target strength, based on measurements of the mean volume backscattering strength are summarised, and a theoretical model for krill scattering is described. Both measurements and theory are combined. On this basis, target strength-size relationships are proposed for current use in acoustic surveys of krill aggregations or stocks. In addition to considering both the presented measurements and theoretical computations, comparisons are made with data involving individuals, and recommendations are made for improving the determination of krill target strength.

2. DEFINITIONS

Target strength gives a measure of backscattering or echo strength intrinsic to the scatterer itself. It is useful sometimes to keep in mind its origin in basic scattering physics. A plane, harmonic wave is assumed to be incident on an isolated, finite body in a homogeneous fluid medium. In terms of pressure,

$$p_{inc} = \mathrm{A} \exp\left[i(k \cdot r - \omega t)\right],$$

where A is the amplitude, k is the wave vector, r is the position where the incident pressure field is to be evaluated, ω is the angular frequency, and t is time. The scattered pressure field in the far-field of the body is typically expressed in terms of the spherical wave $\exp(ikr)/r$. Suppressing the time dependence $\exp(-i\omega t)$,

$$\lim_{r \to \infty} p_{sc} = \mathrm{A} f \exp(ikr) / r,$$

where f is the far-field scattering amplitude. The backscattering cross section, σ or σ_{bs}, is defined in terms of the far-field backscattering amplitude f_b thus:

$$\sigma = 4\pi\sigma_{bs} = 4\pi|f_b|^2. \qquad (1)$$

The quantity σ_{bs} is also called the differential scattering cross section in the backscattering direction. Because of the frequently large range in values of σ or σ_{bs} for the same or similar scatterers, a logarithmic measure is convenient. This is the target strength TS,

$$\mathrm{TS} = 10 \log \frac{\sigma}{4\pi} = 10 \log \sigma_{bs}, \tag{2}$$

where the backscattering cross section is expressed in SI units. The TS of an idealised, perfectly reflecting sphere of 2 m radius at very high frequency is 0 dB.

Theoretical and empirical studies show that it is sometimes useful to normalise the backscattering cross section by the square of the length of the body, provided of course that the body is elongated. In this paper, krill length refers consistently to the distance from the anterior end of the eye to the tip of the telson. When the length is not defined in the cited data source, it is assumed to be tantamount to this. Expression of the normalised cross section in the logarithmic domain results in the reduced target strength,

$$\mathrm{RTS} \equiv 10 \log \left\{ \sigma / \left(4\pi \mathrm{L}^2 \right) \right\} = 10 \log \left(\sigma_{bs} / \mathrm{L}^2 \right) = \mathrm{TS} - 10 \log \mathrm{L}^2. \tag{3}$$

It is convenient to represent RTS as a function of the equivalent cylindrical radius a of the body, normalised by the multiplicative factor k. The advantage of presenting RTS versus ka is that data spanning a wide range of lengths and frequencies can be compared on the same plot. The present definitions of σ, σ_{bs}, TS, and RTS apply strictly to harmonic waves. Although useful as a concept, such continuous waves are fictional. A backscattering cross section or target strength can also be defined for finite-duration waves or signals (Foote, 1982). However, the continuous-wave or harmonic-wave approximation is excellent for the several data sources considered in the next section. This is due to the fact that the distance spanned by a ping is much larger than any dimension of the animals.

The above definitions also pertain only to single realisations of the scattering from individuals. Accordingly, the state of an animal is defined by a unique combination of orientation, body shape including bend, taper and roughness, and physical properties. Adding to the complexity of the description of the scattering are the facts that (1) echoes from individual krill tend to fluctuate from ping to ping as the animals change shape and orientation, and (2) echoes from animals that are not acoustically resolved or separated, because of overlap with echoes from other animals, also tend to fluctuate from ping to ping because of the stochastic nature of the interference between the echoes from each animal. In order to describe the scattering involving the fluctuating echoes, the following averages of the above quantities are defined:

Data

$$\bar{\sigma} = \frac{1}{\mathrm{N}} \sum_{j=1}^{\mathrm{N}} \sigma_j, \tag{4}$$

Theory

$$\bar{\sigma}(\mathrm{L}) = \int_{\theta} \sigma(\mathrm{L},\theta) f_{\theta}(\theta) d\theta \quad \text{(individual)}, \tag{5}$$

$$\bar{\sigma} = \int_{\mathrm{L}} \bar{\sigma}(\mathrm{L}) f_{\mathrm{L}}(\mathrm{L}) d\mathrm{L} \quad \text{(aggregation)}, \tag{6}$$

The definitions are divided into two broad categories. Equation (4) represents the measured backscattering cross section averaged over N pings. This equation could be applied to repeated observations of the same individual or many observations of different individuals. Thus the average might involve, for example, behaviour through the tilt angle θ, or both behaviour and length through θ and L, respectively. Equations (5) and (6) are the respective theoretical counterparts, where f_X denotes the appropriate probability density function of variable X. Equation (5) is typically more appropriate for use in the laboratory where animals are studied on an individual basis, while equation (6) is more applicable in the field where an aggregation of animals over a range of lengths will typically exist. The above averages apply to both σ and σ_{bs}. All averages involve the addition of energies (cross sections) because the energy is most appropriate for describing the incoherent addition of echoes from animals in aggregations. Finally, the above theoretical averages are shown with just a few variables over which the averages are made. Generalisations are possible for inclusion of other effects, such as the degree of bend or flexure of the animal, as represented by its radius of curvature, or the degree of roughness of the body.

The "average" target strength can be defined in terms of the average backscattering cross section as

$$\overline{TS} = 10 \log \left(\overline{\sigma} / 4\pi \right) = 10 \log \overline{\sigma}_{bs}, \tag{7}$$

where the averaging is performed before the logarithm is taken. The average reduced target strength is defined in a similar manner.

The mean volume backscattering coefficient S_v is related to the mean backscattering cross section and the number density ρ of scatterers (Stanton *et al.*, 1987),

$$S_v = \rho \frac{\overline{\sigma}}{4\pi} = \rho \overline{\sigma}_{bs}, \tag{8}$$

where the usual convention of not indicating the average nature of S_v by an overhead bar is used. This quantity can be determined through the sonar equation (Urick, 1975), given knowledge of the transmit and receive conditions, including beam pattern characteristics. In the logarithmic domain,

$$S_v = 10 \log \rho + \overline{TS} \tag{9}$$

where S_v is the mean volume backscattering strength. This or similar volume scattering quantities are typically what are measured in the field, especially when the animals are not resolved by the sonar. Relating raw echo levels to S_v requires knowledge of sonar system parameters such as ping duration and beam pattern. Single animal target strengths can only be measured directly when the echoes from the different animals are not overlapping.

3. EMPIRICAL VALUES OF TARGET STRENGTH

Estimating the target strength of zooplankton is far from straightforward because of the behaviour of the animals and thresholding of the sonar system. When the animal is insonified at or near broadside incidence, the resultant echo is strong and the sonar will be most able to record it. However, at or near end-on incidence, the echo is quite weak. When measuring target strengths of (resolved) individuals in the laboratory or field, the echoes from end-on incidence may be below the noise level or "detection threshold" of the sonar, hence the echo goes unrecorded. The average from measurements of individuals will involve only the average of values above the threshold, causing an overestimate (threshold bias) of target strength. In the other case, when the animals are measured collectively, i.e., when the animals are not resolved by

the sonar, the echoes from some animals may be above the threshold while those from others may not. The resultant echo from this aggregation is detectable and an average target strength is determined by normalising the echo level (or energy) by the total number of animals regardless of whether all of them would have been detectable individually. The threshold bias in this latter case is much less than with the measurements involving individuals, hence providing a more accurate estimate of target strength, assuming that the number of animals is known.

In order to eliminate threshold bias in this study, only aggregation measurements are used. Table 1 summarises the data from the published experiments, which are more fully described in the paragraphs below. Most of the experiments were performed *in situ* on aggregations of sufficient density so that the received echoes were due to a superposition or average of echoes from many individuals of various sizes, shapes and orientations. The average target strength is thus determined from acoustic measurements of the volume scattering strength and direct measurements of numbers of animals, whose values are directly inserted into equation (9).

Pieper (1979) measured *E. pacifica in situ* at 102 kHz. The animals were distributed in layers at depths from 130 to 280 m in the San Pedro and Santa Catalina basins off southern California in, respectively, March and July 1976. Sampling was accomplished by a Tucker trawl with acoustically controlled open-close command. Other animals were caught, but *E. pacifica* was the predominant species. The target strength was inferred from acoustic measurements of S_v, with 1 ms pulse duration, and estimates of ρ determined by catching. A total of 18 TS values are given for krill of mean lengths from 11.6 to 18.6 mm and mean masses from 2.09 to 10.0 mg (dry weight). These authors accept Pieper's speculation that the effective mouth opening of the net is equal to the area of the net on the codend of the trawl. Consequently, the tabulated values of TS are here adjusted downwards by 4.8 dB.

Everson (1982) measured *E. superba in situ* at 120 kHz. The krill were in a large concentration just north of South Georgia at the time of measurement in March 1980. The entire water column, from surface to 250 m, was sampled both acoustically and physically by means of a Rectangular Midwater Trawl with 8 m^2 mouth opening (RMT8) and surface nets. The modal sizes of krill according to five RMT8 catches varied from 37 to 44 mm. Measurement of S_v, with 0.6 ms pulse duration, and determination of ρ by trawling allow solution of equation (9) for TS. Everson (1982) specifies two TS numbers: -81.3 dB in the daytime and -89.2 dB at night-time. Tabulation of S_v values, however, allows extraction of a total of two values each for daytime and night-time TS.

Artemov (1983) measured euphausiids *in situ* in the Black Sea or Atlantic Ocean at 49.5 kHz. By measuring S_v, with 0.3 ms pulse duration, and estimating ρ by trawling, equation (9) prescribes TS. The result is that TS = 84.3 dB for a euphausiid of mean length 45 mm and mean mass of 0.6 g.

Nakayama *et al.*, (1986) measured *E. superba in situ* in the Indian sector of the Southern Ocean at 200 kHz. The krill occurred near the surface, apparently with uniform density, where they were observed about one hour before sunset on 29 January 1984. The krill were measured over the depth range 13.5 to 14.5 m for three minutes and over the depth range 12 to 13 m for two minutes. The mean volume backscattering strength was measured with a 200 kHz transducer, with 0.6 ms pulse duration. A second transducer, with operating frequency of 455 kHz, was used to determine the number density of krill according to the echo counting method (MacLennan, 1990). This was facilitated by use of a pulse of 20 μs duration, hence with nominal resolving power of 15 mm. The mean densities for the two observation periods were 50 and 62 krill/m^3. These determined respective target strengths of -68.1 and -68.3 dB. The mean total length was 42.0 $\pm$ 0.28 mm and the corresponding mean mass was 0.62 $\pm$ 0.014 g.

Everson (1987) measured *E. crystallorophias in situ* in Port Foster, the caldera of Deception Island, at 120 kHz. The krill was observed in March 1985 in the daytime in compact swarms deeper than 80 m, and in the night-time in a thick diffuse layer between 20 and 40 m.

By measuring S_v, with 1 ms pulse duration, and determining the number density ρ by 8 m^2 Multiple Rectangular Midwater Trawl, the TS could be determined. Problems with net avoidance were recognised by Everson (1982), but the very large discrepancy between the sampled density and that estimated from the BIOMASS equation (Anon., 1986) suggests the following major revision: that the BIOMASS-predicted TS for the observed 22.8 mm mean length be reduced by 13 dB to -81.7 dB.

Shimadzu *et al.*, (1989) measured *E. superba in situ* in the Scotia Sea north of Livingston Island, South Shetland Islands, in January 1988 at 200 kHz. The quantity S_v was measured, with 1.2 ms pulse duration, on board the research vessel. An accompanying commercial trawler caught along the precise track of the research vessel, with monitoring of the height of the mouth opening of the trawl, nominally 28 m, to ensure operation according to design specification. The depth of the krill aggregation as measured by the depth of the ground rope varied from 35 to 80 m. The density was thus determined, and equation (9) solved for TS. Estimates varied from -71.4 to -63.1 dB, with overall mean of -66.7 dB. The average krill length was 47.5 mm, and the average mass was 0.873 g.

Foote *et al.* (1990) measured *E. superba* in a cage of 0.1 m^3 volume at 38 and 120 kHz. The cage was maintained under measurement at constant 15 m depth in the harbour of Stromness on South Georgia in January and February 1988. Since the density was known *a priori*, measurements of S_v, with 1 ms pulse duration, could be converted directly to values of TS. In 14 separate measurements series, lasting from 15 to 65 hours each, the effective mean TS varied over the range from -89 to -83 dB at 38 kHz and from -81 to -74 dB at 120 kHz. Mean lengths varied from 30.1 to 39.4 mm. Additional measurements revealed a mass density contrast of 1.0357 ± 0.0067 and sound-speed contrast of 1.0279 ± 0.0024, where the limits are those of the first standard deviation of the underlying measurements.

Hampton (1990) measured *E. superba in situ* off Coronation Island and Elephant Island, in March 1990, at 38 and 120 kHz. The mean surface backscattering strength (MSBS) was measured at both frequencies for 200 discrete krill swarms in the Coronation Island region and for 50 swarms in the Elephant Island region. The pulse duration was 0.9 ms at 38 kHz and 1.0 ms at 120 kHz. The depth range of examination was 5 to 100 m. Aimed commercial midwater trawls determined the size distribution in each region. Differences in corresponding values of MSBS were attributed to differences in TS. This has been observed to be 7.1 dB off Coronation Island and 6.9 dB off Elephant Island, with the value at 120 kHz exceeding that at 38 kHz. The mean lengths of krill for the two localities were 48.8 and 46.0 mm, respectively.

Cochrane *et al.* (1991) measured *M. norvegica in situ* in two deep basins of the Nova Scotia Shelf, in June 1988, at 50 and 200 kHz. The pulse duration at the two frequencies was 2 and 5 ms, respectively. Beamwidths, as measured between opposite -3 dB levels, were 18° and 5.4°, respectively. In Emerald Basin, S_v was measured over the depth range from 210 to 242 m. In LaHave Basin, S_v was measured from 190 to 230 m. In both cases, S_v at 200 kHz was significantly greater than that at 50 kHz. The differences were 10.5 and 7.4 dB in Emerald and LaHave Basins, respectively. Biological sampling with the Bedford Institute of Oceanography Net and Environmental Sensing System (BIONESS) established that the mean krill length was 28 mm.

Kasatkina (1991) measured *E. superba* both encaged and *in situ*. A series of cage measurements with live specimens was carried out in April 1983 in the vicinity of the South Orkney Islands at 20 kHz. For krill of mean lengths from 43.0 to 47.1 mm the effective mean TS varied over the range from -77 to -71 dB. Measurements on encaged krill at 136 kHz yielded values of the effective mean TS from -69 to -68 dB for mean lengths from 45.1 to 48.9 mm. Combined acoustic measurements of the mean area backscattering coefficient and trawl measurements of absolute number density were performed at 30 and 20 kHz. Measurements at 30 kHz were performed near Bouvet Island in December 1979 on krill of mean lengths from 53.6 to 54.2 mm, with effective mean TS from -76 to -69 dB. On the Maud Banks, in February 1980, krill with mean lengths from 36.0 to 50.0 mm were observed to have

values of effective mean TS from -82 to -71 dB. Measurements at 20 kHz were performed near the South Orkney Islands in May 1983 on krill of mean length 44.7 mm, for which the effective mean TS was observed to be -78 dB. Measurements were performed at the same 20 kHz frequency near South Georgia in June 1983 on krill of mean length 49.9 mm, with effective mean TS of -72 dB. The standard deviation of the observed length distributions was close to or less than 10% of the mean length in every case.

Watkins (1991) measured *E. superba in situ* during the night-time in swarms off South Georgia in February 1990, at 120 kHz. Concurrent *in situ* photographic observations of the respective swarms determined density values spanning the range from 13 to 186 krill/m^3. The mean krill length was 40 mm. Use of density values with the corresponding measurements of mean volume backscattering strength determined values of effective mean TS from -75 to -70 dB.

4. THEORETICAL MODELS OF TARGET STRENGTH

To date, there is no theory that adequately describes the scattering of sound by zooplankton. The animals are morphologically complex as they are elongated, bent, have legs and antennas, and are inhomogeneous in composition. Also, the animals change shape and orientation as they move through the water which further complicates the problem. Recently, the deformed cylinder solution has been applied to several sets of data with some success (Stanton, 1989; Wiebe *et al.*, 1990; Chu *et al.*, 1992; Chu *et al.*, in press; Stanton *et al.*, submitted (a); Stanton *et al.*, submitted (b)). The formulation is general enough to take into account the length, bend, taper, roughness, orientation and non-uniform composition. The modal-series-based solution used in this work is not valid for end-on or near end-on incidence. In that region, the solution predicts zero response while data show the animals to have small, but finite, scattering cross sections at that angle.

The general far-field backscatter solution to the deformed cylinder is:

$$f_b = \frac{-i}{p} \int_{\vec{r}_{pos}} \sum_{m=0}^{\infty} b_m (-1)^m \, e^{i2k\hat{r}_i \cdot \vec{r}_{pos}} \left| d\,\vec{r}_{pos} \right|, \qquad (10)$$

where $\vec{r}_{pos}$ is the position vector of the axis of the cylinder, $\vec{r}_i$ is the unit vector in the direction of the incident field, m is the modal index number to the modal series solution, and b_m is a coefficient that is determined by the (circular cylinder) boundary conditions.

The exact expression for b_m is always quite complicated and is typically expressed as the ratio of two determinants. b_m depends upon acoustic frequency, radius of cross section of body, and material properties (such as fluid surrounded by fluid or fluid-filled shell surrounded by fluid). A list of references to articles that present derivations and expressions for b_m for various boundary conditions is given in Stanton (1990).

The deformed cylinder formulation has been applied to a wide range of cases including geometries in which averages over angle of orientation and length were carried out (Cochrane, 1991; Chu *et al.*, in press; Stanton *et al.*, submitted (b)). For the analysis in this article, the average given in equation (6) is used. The most reliable distribution used in the averaging is the one involving length as it is derived from net samples or direct measurements in the laboratory scattering work. At this writing, only independent measurements were available to help estimate the distribution of orientation. Because of the importance of taking this latter quantity into account, angular distributions similar to those observed by Sameoto (1980), Kils (1979 and 1981), Endo (1989) and Kristensen and Dalen (1986) are used in this article. A distribution of bend could not be used because of the lack of data on this subject. Fortunately, calculations demonstrate that due to offsetting effects, target strength averaged over angle of orientation is relatively insensitive to bend (Stanton *et al.*, submitted (b)). Hence for the purpose of this

article, a reasonable fixed value of radius of curvature for the animals is used. In order to replicate the tapered shape of the body and also avoid spurious end effects if the ends were (unrealistically) large and flat, the calculations included tapering.

Finally, the animals are modelled as being composed of a homogeneous "weakly" scattering fluid, where the term weak refers to the fact that the mass density and speed of sound for the animal body is very close (to within several percent) of the surrounding fluid. This is a simplification of the actual body that has an outer shell and inhomogeneous (fluid-like) interior. The weak scatterer assumption can be substantiated for several reasons:

(i) the shell is very thin when compared with the wavelengths of sound typically used in acoustic studies, hence to a first approximation one can ignore the shell and only take into account the fluid-like interior (Machlup, 1952; Stanton, 1990);

(ii) the studies published by Foote *et al.* (1990) and Foote (1990) show that the compressional wave speed and density for live euphausiids are indeed only several percent different from the corresponding properties of the surrounding water; and

(iii) a new simple ray model derived by Stanton *et al.* (submitted (a)) that assumes weak scattering predicts deep nulls such as those observed by Chu *et al.* (1992).

5. COMBINATION OF TARGET STRENGTH ESTIMATES

In order to compare the scattering levels involving animals of various sizes and sonars of various frequencies, all data are presented on the dimensionless scale of reduced target strength (RTS) versus ka, where a is the estimated average cylindrical radius of the thorax section of the animals. Since in most cases a was not directly measured or reported, it is estimated in this analysis from the (total) length L by the approximate relation a = L/16, as derived from drawings of *E. superba* given in Mauchline and Fisher (1969).

The empirical data are shown in Figure 1. Because of the diversity of sources of data, the data are divided into two categories: caged (solid circle) and *in situ* (open circle). As discussed in a later section, the data involving caged animals provided more reliable estimates of target strength because the numbers of animals are precisely known. All data lie in the range $0.3 \lesssim ka \lesssim 3$ that includes the upper limit of the Rayleigh scattering region ($ka \ll 1$) and lower limit of the geometric scattering region ($ka \gtrsim 1$). These ka values are consistent with the fact that the animals are generally not detectable in the Rayleigh scattering region. Hence it is apparent that the frequencies of the sonars used by the various investigators were in accordance with the size range of the animals of interest so that the scattering would be in or near the stronger geometric region.

A subset of the data, which from the formal record is believed to be free of at least large biases, is plotted in Figure 2. Each of these data sets, like those of the entire data collection, involves a different set of animals, location, environment and behaviour. Presented with the subset of empirical data in Figure 2 is a class of theoretical curves based on the deformed cylinder model, but spanning a range of conditions. Predictions involve averages over length and angle of orientation of the backscattering from tapered bent cylinders. The taper was carefully constructed so as to resemble the taper of the krill. The cross-sectional radius decreased non-linearly from a maximum, near constant value in the thorax region to 50% of the thorax value at the tail end. In order to isolate effects due to experimental bias, environmental conditions and behaviour, a comparison between the theory and data from Foote *et al.* (1990) alone are presented in Figure 3. The entire data set is presented in the main plot while several data pairs are illustrated in the inset. For each (two-frequency) pair, all conditions such as environment, time of experiment etc. were held constant. The curves superimposed on the different pairs were generated by varying orientation parameters. A more detailed analysis of this two-frequency set of data is presented in Chu *et al.* (in press).

6. DISCUSSION

6.1 General Observations

The target strength data in Figure 1 span an implausibly wide range in target strength for similar values of *ka*. For *ka* roughly equal to 0.4 to 0.5 and near 1.5 the range is 25 dB. The only trends evident in the data occur where there are few data, for *ka* greater than about two. Clearly, as elaborated in the next section, the data are of uneven quality and their attempted comparison here may be misleading.

The subset of data presented in Figure 2 display a correlation that is generally lacking in the data of Figure 1. The empirical data presented in Figure 2 are consistent with two expected trends, namely the transition from Rayleigh to geometric scattering regimes about $ka = 1$ and constant level in the geometric regime, for $ka \lesssim 2$. The data do not, however, follow closely any single presented curve. These authors hypothesise that the source of the variability is due to:

(i) the variety of conditions and environments under which the data were collected which cause changes in animal behaviour and hence scattering levels; and

(ii) errors in the data collection/analysis specific to each experiment.

The dependence upon behaviour is illustrated in Figure 3 where there is correlation between the data from the controlled experiments of Foote *et al.* (1990) and the curves, especially when the data are presented on a case-by-case basis (Chu *et al.*, in press) as in the inset. Hence there is some promise as to the predictability of scattering levels if the behaviour of the animals is known or at least constant.

Analyses (not shown) involving the Hampton (1990) and Cochrane *et al.* (1991) data indicated the relative levels to be consistent with averaged bent tapered cylinder predictions.

Finally, while all curves predict an oscillatory pattern of RTS vs *ka*, the data were not collected at intervals that are sufficiently closely spaced in order to test the accuracy of the pattern. This behaviour is observed in laboratory data discussed in section 4 of this discussion section.

6.2 Data Quality

Of the cited eleven empirical data sources, nine involve measurement of the mean volume backscattering strength S_v. The remaining two sources consist of comparative measurements performed at different pairs of frequencies and are not considered further here.

In the majority of the data sources, the number density ρ of krill was determined by trawling. Pieper (1979) expressed doubts about the effective size of the trawl mouth opening. Everson (1982) mentioned the possibility of avoidance reactions, but attributed the large differences in target strength values between day and night to systematic differences in orientation. However, Everson (1987), using the same method of target strength determination, attributed the large observed difference in target strength between day and night to avoidance reaction, a cause of bias in the determination of ρ by trawling. This is also documented in Everson and Bone (1986). Everson (1987) states that the validity of abundance estimates derived from daytime trawl hauls must be doubted.

Artemov (1983) considered avoidance reactions in trawling to be minimal for the particular species and, presumably, circumstances of catching operations. Direct observational evidence for this in the case of small fish is offered through citation of Vyskrebentsev (1966). Shimadzu *et al.* (1989) also consider biasing in the trawl estimated of ρ, among other error

sources. They conclude that this is negligible for their particular study. Several of the studies reported by Kasatkina (1991) involved determination of krill density by trawling. No comments are made by the author on this sampling method.

In the other studies based on measurement of S_v, ρ was determined by non-trawling means. Nakayama *et al.* (1986) determined ρ by echo counting with a second transducer operating at a rather high frequency and with quite short pulse duration. Among other error sources considered by Nakayama *et al.* (1986) were those of the sampling volume and differences in target strength at the two frequencies. The cumulative effect of the several error sources was expressed through confidence limits. Shimadzu *et al.* (1989), however, have challenged the basic result because of claimed problems in determination of the beam pattern, hence sampling volume, although without sufficient detail for further critical evaluation. Watkins (1991) determined ρ by means of *in situ* photography. The reference is preliminary, however, and lacks information about the possible coincidence of acoustic and optical sampling volumes, so no assessment can be made here as to the accuracy of this density determination.

In two studies, krill were measured in cages. However, because of the degree of control implicit in cage measurements, the several problems mentioned above are avoided. In the study by Foote *et al.* (1990), ρ was determined by counting the number of encaged animals and relating this to the nominal cage volume. The cage was held in the axial region of the measurement transducers, hence the sampling volume is known. The effect of confinement on animal behaviour is not known, although visual observation by means of a low-light-level underwater television camera suggests that the effect at times, as during swarming within the cage, was negligible. The cage experiments reported by Kasatkina (1991) can be presumed to have been similar, but insufficient detail is given in the reference to state this.

In summary here, at least several of the cited empirical data sources, represented in Figure 1, are very likely biased.

6.3 Model Quality

Along with inaccuracies in the data are imperfections in the theoretical predictions. These latter drawbacks can be categorised in terms of imperfections in:

(i) the deformed cylinder model itself;
(ii) simplifications in the modelling; and
(iii) the physical parameters used in the modelling.

The deformed cylinder model, which is inherently an approximate solution, has been shown under some conditions to be most accurate when the scatterers are of very high aspect ratio ($\gtrsim$ 5:1 length to diameter ratio) and near normal incidence. Furthermore, any changes in morphological properties must be slowly varying along the lengthwise axis. At end-on incidence, the solution completely breaks down and predicts a zero response where, in fact, the animal actually does scatter sound at that angle although very little. Application of the model to krill is appropriate under some conditions. Certainly krill are elongated enough ($L/2a \sim 8:1$) to satisfy the aspect ratio condition. Also, the dominant scattering features (outer boundary of the animal) change slowly along its lengthwise axis. However, one must be cautious when applying the model to free swimming animals *in situ*, especially if a substantial fraction of the angles of incidence are far away from normal or "broadside". If the echosounder and/or animals are oriented in such a way such that the animal is never at broadside incidence, then it is likely that predictions based on the model will tend to underestimate the scattering. Thus the model under that condition would not be appropriate. If the mean angle of incidence is near broadside incidence, the model would be most accurate, even if some of the angles are far from normal simply because the more accurate near normal incidence values will dominate the other less accurate lower values arising from far off broadside. In the modelling in this paper, the animals were assumed to have a mean orientation within 40° of normal incidence which is the region in

which the model is most accurate. Under this "best" condition of near normal mean incidence, high aspect ratio body, and slowly varying features, error was introduced into the modelling due to the natural approximations in the theory.

There are simplifications in the modelling of the animals. Modelling the animals as bent cylinders with or without tapering and composed of homogeneous fluid material is a great simplification of what one sees with the eye. Studies have indicated that acoustically the animals do tend to behave like bent cylinders, but nonetheless the legs, shell and inhomogeneities of the body volume were ignored in the modelling, rendering the model as being approximate at best. It is not practical, of course, to include all body parts, but ignoring even small parts builds error into the predictions.

In addition to imperfections of the mathematical aspect of the deformed cylinder solution, the information regarding physical properties of the animals is flawed hence adding another component of inaccuracy to the predictions. In order to make predictions with the model, it is essential to know the distribution of shape and orientation of the body as well as the density and speed of sound contrast of the material of the body. There are very few data concerning the distribution of orientation and no specific information on shape. Also, the information on material properties is extremely limited. All of these parameters have a profound impact on the predictions, thus it is essential that one obtains the most reliable values of the parameters for any predictions. In this article, the most reasonable values of distribution of orientation and density and speed of sound contrast were chosen although for the most part those parameter values did not involve the animals studied in the survey, hence introducing error. The shape distribution was not known at all and effects due to changes in shape were totally ignored causing more error. However, as mentioned before, simulations have shown that when the predictions are averaged over orientation, the results are relatively insensitive to the degree of bend. Hence the shape was held fixed at a reasonable mean bend.

While an exhaustive error analysis has not been performed with respect to uncertainties in the above parameters, errors introduced by the uncertainties are large enough so that final choice of the parameters must be tested by comparing predictions with scattering data whose relevant parameters are known.

6.4 Other Data

While the empirical estimates of target strength in the article involve aggregations of animals, it is useful to compare the results with crustacean zooplankton data collected in the laboratory. Although the threshold bias is greater in this latter case and the animals are of different taxa than krill, the results are quite revealing with respect to the basic physics of the scattering process. The following paragraphs review the results of Wiebe *et al.* (1990) and Chu *et al.* (1992) and compare the measurements and modelling to the results presented above.

Wiebe *et al.* (1990) measured the backscattering of 420 kHz sound by 43 live individual macro-zooplankton and micronekton of various taxa, one of which was a euphausiid (*Euphausia pacifica*). All animals were crustaceans except for two of the taxa and we will limit our summary of their results to the crustaceans. The scattering measurements were conducted in a cage filled with filtered seawater deployed off a dock at Friday Harbor, Washington. The animals ranged in length from 5 to 90 mm. An attempt was made at maintaining the orientation of the animals so that either their dorsal or ventral sides were facing the transducer. This was aided by having anaesthetised all animals prior to the measurements and used an acoustically transparent tether on the larger animals. Hundreds of pings per animal were recorded so that the statistical nature of the target strengths could by analysed.

Complementing the research by Wiebe *et al.* (1990) is the work by Chu *et al.* (1992) where only two live individuals were involved (decapod shrimp - *Palaemonetes vulgaris*), but using a broad band sonar that covered about an octave of frequencies (300 to 650 kHz). A chirp

signal was used so that each animal could be insonified simultaneously with the entire range of frequencies before it had a chance to change orientation. The measurements were conducted in a seawater-filled laboratory tank at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. The animals were 13.5 and 19.8 mm in length and were anaesthetised and tethered so that their dorsal side was facing the transducer. As a result of using a broad band sonar and two different sizes of animals, ka, where a is the cylindrical radius of the animal, spanned the values of two to six continuously. Since the amplitude of the echoes varied from ping to ping due to changes in shape and orientation of the animals, many echoes were recorded allowing a statistical analysis to be performed.

Figures 4 and 5 summarise some of the results from the studies of Wiebe *et al.* (1990) and Chu *et al.* (1992). All data involve averages over a number of pings as the animals changed shape and orientation while at the same time maintaining a principal angle of orientation (mostly via tethering) broadside to the incident acoustic signal. A truncated bent cylinder model in which the modal series solution was truncated to include just the first two modes of vibration was used to describe the Wiebe *et al.* (1990) data. Regardless of model, both data sets show that there is structure in the data, especially in the data collected by Chu *et al.* (1992). In the latter data set, there is a distinct dip in the data at the $ka = 2$ and 3.5 values - the positions of which are predicted by the fluid cylinder theory (the dips were confirmed in a more complete experiment by Stanton *et al.* (submitted (b)). The structure in the Wiebe *et al.* (1990) data set is less pronounced although a dip is suggested in the $ka = 2$ region.

While the overall levels and/or general trends of these laboratory data sets may not coincide exactly with the target strength estimates presented in Figure 1 (the reasons possibly due to thresholding effects discussed earlier in this article and differences in animal type), the structure exhibited in the laboratory data sets is important. In a figure not presented here involving single (unaveraged) echoes, Chu *et al.* (1992) show that this dip can be quite distinct and is sometimes as much as 30 dB below the levels of the scattering at surrounding values of ka. In spite of the effects of averaging the echo over distributions of angle of orientation and length which tend to "smear" out the nulls, there is still some residual dip that is of the order 5 to 7 dB below the surrounding values. As shown in Stanton *et al.* (submitted (a)) the presence of the dips is due to interference between the echoes from the front and back interfaces of the animals. The smearing effect has been successfully modelled in Stanton *et al.* (submitted (b)). It is quite apparent from the laboratory studies that the TS/length relationship for zooplankton is not monotonic.

7. SUMMARY, CONCLUSION AND RECOMMENDATIONS

An attempt has been made to specify the target strength of krill through reference to a particular kind of measurement and by exercise of a scattering model. To avoid possible threshold-induced bias with single-animal measurements, only measurements on aggregations have been used. Many of these, however, have depended on physical sampling by trawl in order to determine the number density of observed krill. Because of the generally unknown effect of such sampling on the targeted animals, related acoustic measurements dependent on trawling must be suspected. The data collected by Kasatkina (1991) and Watkins (1991) are not considered further here because of their admitted or evident preliminary state of publication. Only some of the cited empirical data sources thus remain as candiates for use. These are those by Foote *et al.* (1990), Hampton (1990), and Cochrane *et al.* (1991). The measurement methods described by Nakayama *et al.* (1986) and Watkins (1991) are also potentially valuable, as would be the direct dual-beam or split-beam measurement methods, of which the first split-beam measurements have recently been reported by Hewitt and Demer (1991).

Numerical computation by means of the theoretical scattering model (Stanton, 1989) offers an attractive alternative to measurement, especially as the model is not limited to a particular size or frequency range. However, the model does depend on a knowledge of the animal's physical properties, e.g., mass densities of and sound speeds in muscle and other

tissue, in addition to morphometry. To relate the result of computations to measurements in the wild, it is also necessary to know something about the orientation characteristics of krill during the conditions of surveying. In the present work, values for the physical properties and orientation distribution have been assigned according to independent measurements. Unfortunately, the degree to which these parameter values are representative is unknown.

The authors thus find themselves in the classic dilemma of wanting to solve a problem - specification of the target strength of krill - for which there are few plausible direct measurements and for which a plausible theoretical model lacks basic data on its underlying parameters, which are required for its proper exercise. A provisional resolution is, however, suggested.

The empirical data collected by Foote *et al.* (1990) seem to escape the major problems associated with many other data on krill target strength. The cited data apply strictly to encaged *E. superba.* Hampton (1990) has performed extensive, comparative measurements on the same species *in situ* and at the same frequencies of 38 and 120 kHz. The difference in target strength at the two frequencies is the same for the measurements on encaged and wild aggregations. Additional *in situ* measurements, performed at 50 and 200 kHz on *Meganyctiphanes norvegica* by Cochrane *et al.* (1991), support the same general finding. Given that the model calculations with averaging show a fair agreement with these measurements, the following conclusion is drawn.

7.1 Conclusion

For the time being, in the absence of new data, the target strength of krill may be determined from the curves shown in Figure 2. Since this displays the reduced target strength as a function of ka, an absolute target strength must be derived for the particular application, hence frequency and animal size, according to equation (3). Lacking more detailed data, the size parameter a may be determined from the measured total length L by the relation $a \approx L/16$.

To address the various shortcoming noted above, the following recommendations are made for improved determinations of krill target strength in the future:

(i) measurements of the kinds reported by Foote *et al.* (1990), Hampton (1990), and Cochrane *et al.* (1991) should be repeated for a wider range of animal sizes and frequencies;

(ii) measurements of the kind reported by Nakayama *et al.* (1986) should be performed with particular care being given to the sampling volume of the second, high-frequency, short-pulse transducer used to determine number density by echo counting;

(iii) measurements should be made using dual-beam or split-beam echo sounding systems;

(iv) the physical properties of krill should be measured: (a) whenever possible to determine the range of variation in such properties and causative mechanisms; and, (b) in conjunction with studies performed along the lines of recommendations (i) to (iii); and

(v) the orientation and shape characteristics of krill should be determined whenever possible, especially under conditions when the animal would be surveyed.

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REFERENCES

ANON. 1986. Report on Post-FIBEX Acoustic Workshop, Frankfurt, 3-14 September 1984. *BIOMASS Report Series*, 40: 126 pp.

ARTEMOV, A.T. 1983. Determination of the acoustic backscatter cross section of small pelagic organisms in aggregations. *Oceanology*, 23: 264-266.

CHU, D., T.K. STANTON AND P.H. WIEBE. 1992. Frequency dependence of sound backscattering from live individual zooplankton. *ICES Journal of Marine Science*, 49: 97-106.

CHU, D., T.K. STANTON AND K.G. FOOTE. (In press). Further analysis of target strength measurements of Antarctic krill at 38 kHz and 120 kHz: comparison with deformed cylinder model and inference of orientation distribution. *Journal of the Acoustical Society of America.*

COCHRANE, N.A., D. SAMEOTO, A.W. HERMAN AND J. NEILSON. 1991. Multiple-frequency acoustic backscattering and zooplankton aggregations in the inner Scotian Shelf basins. *Canadian Journal of Fisheries and Aquatic Science*, 48: 340-355.

ENDO, Y. 1989. Swim angles of *Euphausia pacifica*. *Proc. NIPR Symposium on Polar Biology*, 2: 219 pp.

EVERSON, I. 1982. Diurnal variations in mean volume backscattering strength of an Antarctic krill (*Euphausia superba*) patch. *Journal Plankton Research*, 4: 155-162.

EVERSON, I. 1987. Some aspects of the small scale distribution of *Euphausia superba*. *Polar Biology*, 8: 9-15.

EVERSON, I. and D.G. BONE. 1986. Effectiveness of the RMT8 system for sampling krill (*Euphausia superba*) swarms. *Polar Biology*, 6: 83-90.

FOOTE, K.G. 1982. Optimising copper spheres for precision calibration of hydroacoustic equipment. *Journal of the Acoustical Society of America*, 71: 742-747.

FOOTE, K.G. 1990. Speed of sound in *Euphausia superba*. *Journal of the Acoustical Society of America*, 87: 1 405-1408.

FOOTE, K.G., A. AGLEN and O. NAKKEN. 1986. Measurement of fish target strength with a split-beam echosounder. *Journal of the Acoustical Society of America*, 80: 612-621.

FOOTE, K.G., I. EVERSON, J.L. WATKINS and D.G. BONE. 1990. Target strengths of Antarctic krill (*Euphausia superba*) at 38 kHz and 120 kHz. *Journal of the Acoustical Society of America*, 87: 16-24.

FORBES, S.T. and O. NAKKEN. 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. *FAO Man. Fish. Science,* 5: 1-138.

HAMPTON, I. 1990. Measurements of differences in the target strength of Antarctic krill (*E. superba*) swarms at 38 and 120 kHz. In: *Selected Scientific Papers, 1990. (SC-CAMLR-SSP/7).* CCAMLR, Hobart, Australia: 75-86.

HEWITT, R.P. and D.A. DEMER. 1991. Krill abundance. *Nature,* 353: 310 pp.

KASATKINA, S.M. 1991. Target strengths of krill at 136 and 20 kHz. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 141-157.

KILS, U. 1979. Preliminary data on volume, density and cross section area of Antarctic krill, *Euphausia superba. Meeresforsch,* 27: 207-209.

KILS, U. 1981. The swimming behaviour, swimming performance and energy balance of Antarctic krill, *Euphausia superba. BIOMASS Science Series,* 3: 122 pp.

KRISTENSEN, A. and J. DALEN. 1986. Acoustic estimation of size distribution and abundance of zooplankton. *Journal of the Acoustical Society of America,* 80: 601-611.

MACLENNAN, D.N. 1990. Acoustical measurement of fish abundance. *Journal of the Acoustical Society of America,* 87: 1-15.

MACHLUP, S. 1952. A theoretical model for sound scattering by marine crustaceans. *Journal of the Acoustical Society of America,* 24: 290-293.

MAUCHLINE, J. and L.R. FISHER. 1969. The biology of euphausiids. In: RUSSEL, F.R. and M. YONGE (Eds.). *Advances in Marine Biology.* Chapter 7. Academic Press, London.

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

NAKAYAMA, K., K. SHIRAKIHARA and Y. KOMAKI. 1986. Target strength of krill *in situ* at the frequency of 200 kHz. *Memorial National Institute of Polar Research,* Special Issue 40: 153-161.

PIEPER, R.E. 1979. Euphausiid distribution and biomass determined acoustically at 102 kHz. *Deep-Sea Research,* 26: 687-702.

SAMEOTO, D.D. 1980. Quantitative measurements of euphausiids using a 120 kHz sounder and their *in situ* orientation. *Canadian Journal of Fisheries and Aquatic Science,* 37: 693-702.

SHIMADZU, Y., T. KIOKE and T. SUGURO. 1989. Target strength estimation of Antarctic krill, *Euphausia superba* by cooperative experiments with commercial trawler. Document *SC-CAMLR-VIII/BG/30.* CCAMLR, Hobart, Australia: 10 pp.

STANTON, T.K. 1989. Sound scattering by cylinders of finite length. III. Deformed Cylinders. *Journal of the Acoustical Society of America,* 86: 691-705.

STANTON, T.K. 1990. Sound scattering by spherical and elongated shelled bodies. *Journal of the Acoustical Society of America,* 88: 1619-1633.

STANTON, T.K., C.S. CLAY and D. CHU. Submitted (a). Ray representation of sound scattering by weakly scattering deformed fluid cylinders: simple physics and application to zooplankton. *Journal of the Acoustical Society of America.*

STANTON, T.K., D. CHU, P.H. WIEBE and C.S. CLAY. Submitted (b). Average echoes from randomly-oriented random-length finite cylinders: zooplankton models. *Journal of the Acoustical Society of America.*

STANTON, T.K., R.D.M. NASH, R.L. EASTWOOD and R.W. NERO. 1987. A field examination of acoustical scattering from marine organisms at 70 kHz. *IEEE Journal of Oceanic Engineering* OE-12: 339-348.

URICK, R.J. 1975. *Principles of Underwater Sound.* 2nd Edition. McGraw-Hill, New York: 384 pp.

VYSKREBENTSEV, B.V. 1966. Observations of the operations of trawl nets in the Black Sea. *Tr. Okeanograf. kommissii AN USSR,* 14: 187-196.

WATKINS, J.L. 1991. Krill target strength estimated by underwater photography and acoustics. Document *WG-Krill-91/40.* CCAMLR, Hobart, Australia.

WEIMER, R.T. and J.E. EHRENBERG. 1975. Analysis of threshold-induced bias inherent in acoustic scattering cross-section estimates of individual fish. *Journal of the Fisheries Research Board Canada,* 32: 2547-2551.

WIEBE, P.H., C.H. GREENE, T.K. STANTON and J. BURCZYNSKI. 1990. Sound scattering by live zooplankton and micronekton: empirical studies with a dual-beam acoustical system. *Journal of the Acoustical Society of America,* 88: 2346-2360.

Table 1: Summary of empirical data involving aggregations of krill.

The target strengths are estimated from measurements of S_v and ρ. v is echo sounder frequency, $\bar{l}$ mean length, ρ number density, S_v volume scattering strength, and TS estimated average target strength.

Investigators	v (kHz)	$\bar{l}$ (mm)	ρ (m^{-3})	S_v (dB)	TS (dB)	*ka*	RTS (dB)
Pieper (1979)	102	17.0	1.14	-75.8	-76.4	0.47	-41.0
		14.7	1.75	-74.3	-76.7	0.41	-40.0
		16.0	2.26	-72.3	-75.8	0.44	-39.9
		15.0	0.38	-79.2	-75.0	0.41	-38.5
		18.0	3.29	-68.0	-73.2	0.50	-38.3
		17.4	6.38	-64.4	-72.4	0.48	-37.2
		17.2	14.87	-66.0	-77.7	0.48	-42.4
		18.6	8.33	-67.2	-76.4	0.51	-41.8
		14.9	0.24	-78.3	-72.1	0.41	-35.6
		16.6	1.25	-72.3	-73.3	0.46	-37.7
		12.4	2.03	-80.3	-83.5	0.34	-45.4
		12.6	0.90	-79.0	-78.5	0.35	-40.5
		14.1	0.32	-79.5	-74.6	0.39	-37.6
		12.5	1.38	-78.1	-79.6	0.35	-41.5
		11.6	1.10	-78.8	-79.8	0.32	-40.5
		11.6	2.62	-76.5	-80.7	0.32	-42.0
		18.2	0.17	-82.7	-75.2	0.50	-40.4
		18.6	0.13	-83.2	-74.5	0.51	-39.9
Everson (1982)	120	44	12.5	-74.3 (day)	-85.3	1.43	-58.2
		37	8.61	-86.8 (night)	-96.2	1.20	-67.5
		39	7.75	-78.9 (night)	-87.8	1.27	-59.6
		37	11.48	-78.9 (night)	-89.5	1.20	-60.9
		37	11.78	-78.9 (night)	-89.6	1.20	-61.0
Artemov (1983)	49.5	45			-84.3	0.60	-57.4
Nakayama *et al.* (1986)	200	42.0	50.0	-51.0	-68.1	2.27	-40.5
		42.0	61.6	-50.4	-68.3	2.27	-40.8
Everson (1987)	120	16.8			-84.3	0.55	-48.8
		17			-84.2	0.55	-48.8
		19			-83.3	0.62	-48.8
		21			-82.4	0.68	-48.8
		23			-81.6	0.75	-48.8
		25			-80.9	0.81	-48.8
		27			-80.2	0.88	-48.8
		29			-79.6	0.94	-48.8
Shimadzu *et al.* (1989)	200	47.48			-66.7	2.57	-40.2
Foote *et al.* (1990)	38	39.4	4769		-84.1	0.41	-56.0
		31.8	2365		-82.6	0.33	-52.6
		33.8	3375		-82.8	0.35	-53.4
		30.9	7231		-87.8	0.32	-57.6
		30.1	3750		-83.6	0.31	-53.2
		35.3	4404		-85.1	0.36	-56.1
		32.2	13154		-85.5	0.33	-55.7
		31.2	7567		-88.0	0.32	-57.9

Table 1 (continued)

Investigators	ν (kHz)	$\bar{l}$ (mm)	ρ (m^{-3})	S_v (dB)	TS (dB)	*ka*	RTS (dB)
		33.5	3827		-87.6	0.34	-58.1
		32.8	15317		-89.1	0.34	-59.4
		31.5	8173		-86.6	0.32	-56.6
		38.4	7846		-84.2	0.40	-55.9
		31.5	3788		-86.9	0.32	-56.9
		31.3	7635		-88.3	0.32	-58.2
	120	39.4	4769		-75.9	1.28	-47.8
		31.8	2365		-74.5	1.03	-44.5
		33.8	3375		-76.2	1.10	-46.8
		30.9	7231		-77.3	1.00	-47.1
		30.1	3750		-74.6	0.98	-44.2
		35.3	4404		-74.8	1.15	-45.8
		32.2	13154		-75.6	1.05	-45.8
		31.2	7567		-76.5	1.01	-46.4
		33.5	3827		-77.0	1.09	-47.5
		32.8	15317		-79.7	1.07	-50.0
		31.5	8173		-78.0	1.02	-48.0
		38.4	7846		-75.4	1.25	-47.1
		31.5	3788				
		31.3	7635		-80.7	1.02	-50.6
Kasatkina (1991)	20 (cage)	43.0			-76.6	0.23	-49.3
		47.1			-71.3	0.26	-44.7
		46.5			-72.9	0.25	-46.2
		47.1			-72.6	0.26	-46.0
		44.7			-75.2	0.24	-48.2
		44.0			-76.4	0.24	-49.2
		43.9			-76.2	0.24	-49.0
		45.3			-72.4	0.25	-45.5
		45.3			-71.3	0.25	-44.4
Kasatkina (1991)	20 (*in situ*)	44.7			-77.8	0.24	-50.8
		49.9			-72.3	0.27	-46.3
	30	53.6	1.43	-69.7	-71.8	0.44	-46.4
		53.7	5.6	-67.7	-75.7	0.44	-50.3
		53.9	1.3	-74.3	-75.4	0.44	-50.0
		54.2	0.14	-77.5	-69.0	0.44	-43.7
		47.3	3.6	-72.5	-78.3	0.38	-51.8
		50.0	1.24	-70.0	-70.9	0.41	-44.9
		46.4	16.2	-70.3	-82.2	0.38	-55.5
		47.7	2.4	-71.7	-75.5	0.39	-49.1
		38.1	3.49	-74.7	-80.1	0.31	-51.7
		36.0	164.6	-60.3	-82.4	0.29	-53.5
	136	47.1			-68.1	1.73	-41.6
		46.5			-68.5	1.71	-41.8
		47.1			-68.1	1.73	-41.5
		46.4			-68.5	1.71	-41.8
		46.3			-68.9	1.71	-42.2
		47.1			-68.5	1.73	-41.9
		48.9			-67.9	1.80	-41.7
		45.9			-68.8	1.69	-42.1
		47.7			-68.1	1.76	-41.6
		45.1			-68.8	1.66	-41.9
		46.2			-68.5	1.70	-41.8

Table 1 (continued)

Investigators	ν (kHz)	$\bar{l}$ (mm)	ρ (m^{-3})	S_v (dB)	TS (dB)	*ka*	RTS (dB)
Watkins (1991)	120	40.0	31.5	-58.7	-73.6	1.30	-45.6
		40.0	37.4	-57.9	-73.6	1.30	-45.6
		40.0	27.1	-58.1	-72.4	1.30	-44.4
		40.0	15.7	-59.2	-71.2	1.30	-43.2
		40.0	25.1	-60.5	-74.4	1.30	-46.4
		40.0	13.0	-60.2	-71.3	1.30	-43.3
		40.0	14.7	-58.8	-70.4	1.30	-42.4
		40.0	185.7	-52.0	-74.6	1.30	-46.6

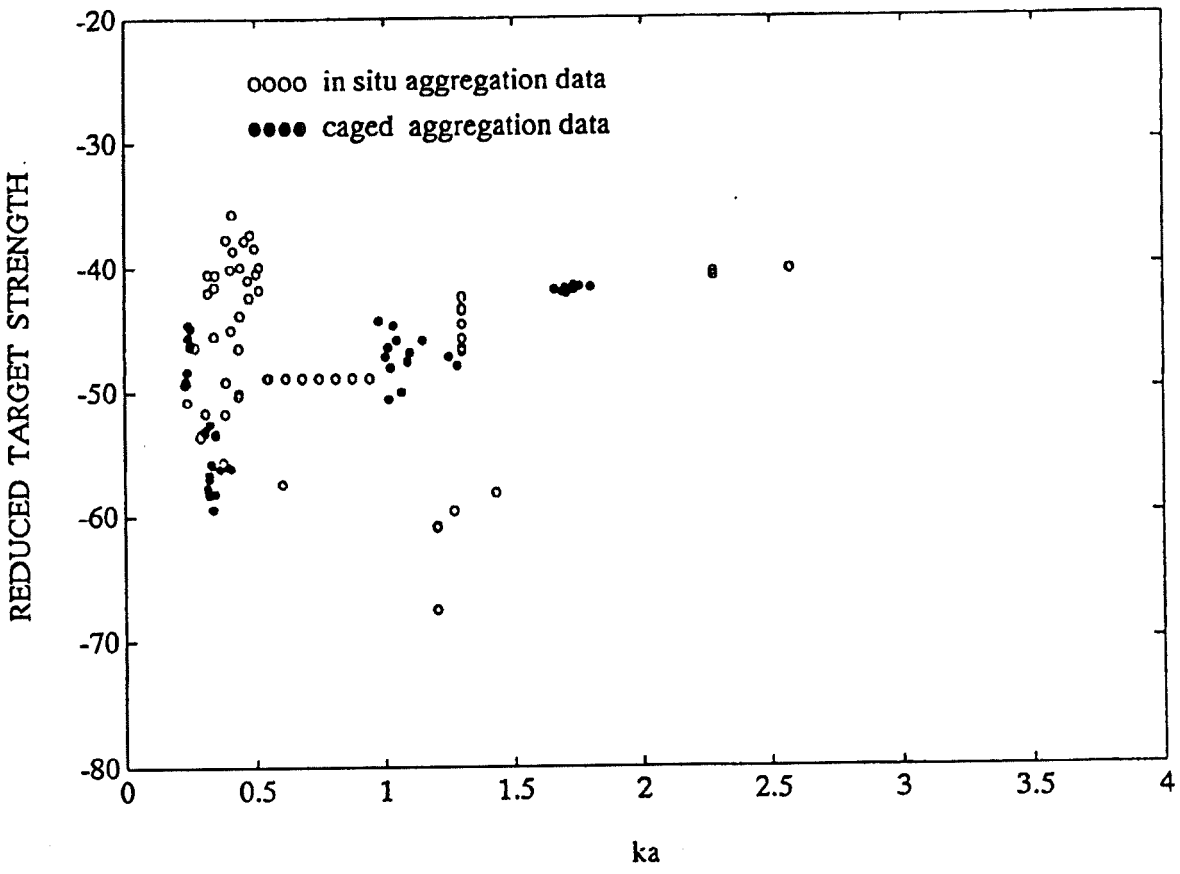

Figure 1: Backscatter data assembled from nine publications involving a variety of sonar types and frequencies and a wide range of animal lengths.

The data were put onto the dimensionless scale of (average) reduced target strength versus *ka* for comparison where *a* is the estimated radius of the thorax of animals. All target strengths were estimated from volume scattering strength (typically involving overlapping echoes from multiple individiuals) normalised by the number of individuals (equation (9)). The number was estimated from net data, echo counting, specimen counting, or *in situ* photography (more details in Table 1 and text).

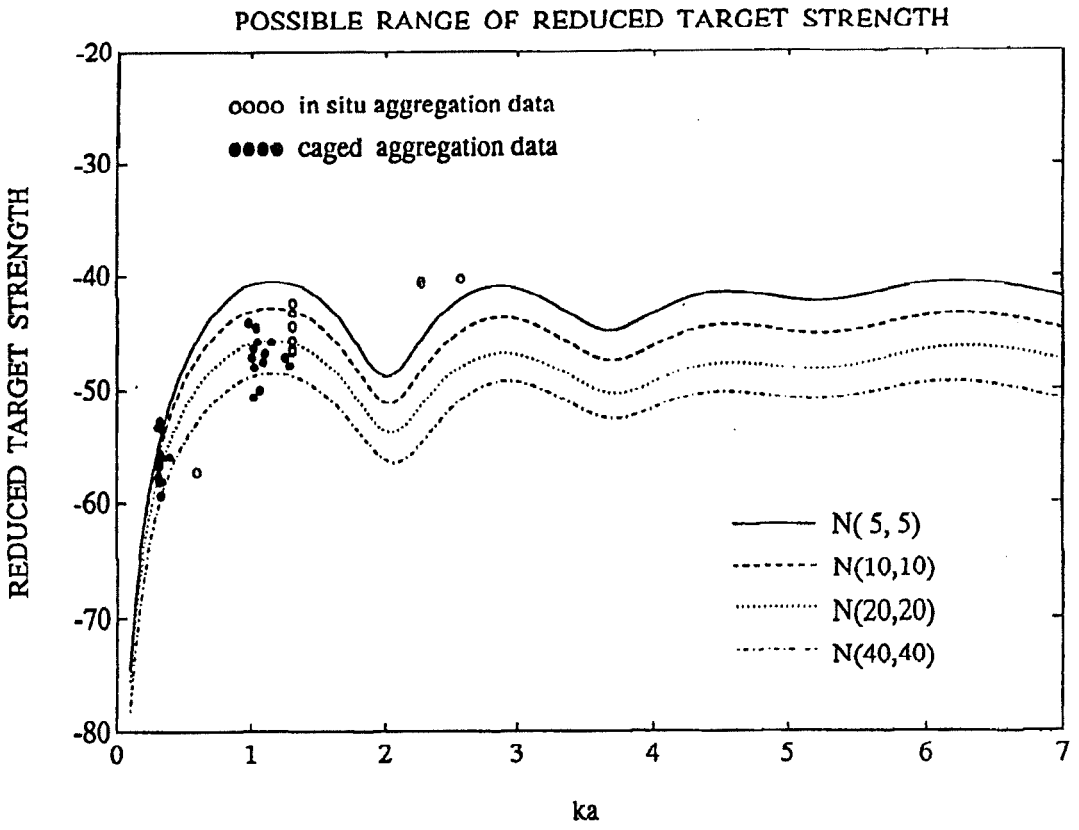

Figure 2: Examples of several sets of predictions using the bent tapered fluid cylinder superimposed on a subset of data from Figure 1.

These data are derived from the following sources: Artemov (1983), Nakayama *et al.* (1986), Shimadzu *et al.* (1989), Foote *et al.* (1990) and Watkins (1991). Each curve represents the average scattering levels due to different animal behaviour where the average is with respect to Gaussian distributions of tilt angle N[mean angle, standard deviation] and length [standard deviation = 0.1 x mean length]. The integrations to calculate the averages spanned the range ±2 standard deviations about the mean of each variable. The radius of curvature relative to the length ρ_c/L = 3.0 for each curve. The relative mass density and speed of sound of the animals was assumed to be 1.0357 and 1.0279, respectively. The modal series solution is converged in each case. The theoretical values of RTS were adjusted by adding 20 log (L_b/L) to them (L_b = total length - length of telson, L = total length) to account for the fact that the thin telson most likely does not contribute substantially to the scattering. Since the TS data were normalised by 20 log L, the adjustment was required to compare similar scattering bodies. A value of L_b/L = 0.76 is used for each curve.

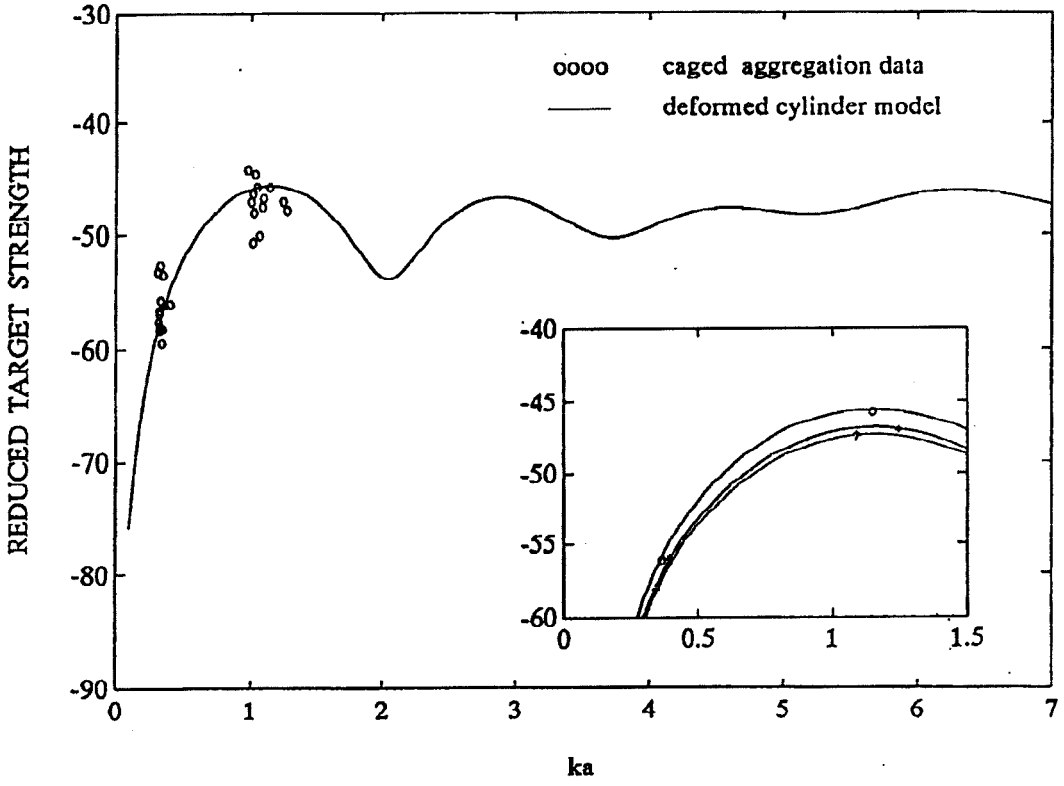

Figure 3: Backscatter data from Foote *et al.* (1990) where the aggregation of animals was encaged.

The entire set of data is shown with a single curve in the main portion of the plot while subsets from single experiments are displayed along with best-estimate curves in the lower right corner. Each pair of points represents data from the 38 kHz and 120 kHz systems. The distributions of (mean angle, standard deviation) are (20, 20), (20, 20), (27, 27) and (30, 30) for the curve in the main plot and upper, middle and lower curves in the inset, respectively. Most data pairs not shown follow trends similar to those illustrated in the inset.

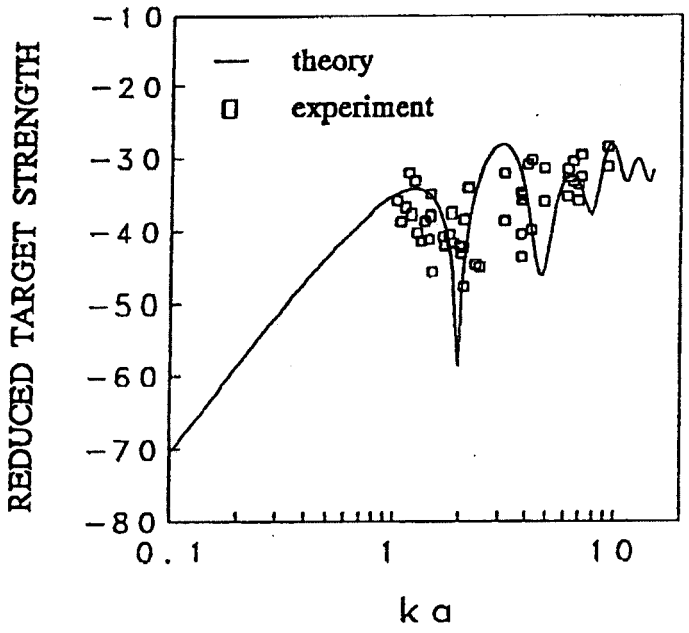

Figure 4: Backscatter data at 420 kHz and model from Wiebe *et al.* (1990).

The data from 39 individual crustaceans of different sizes were averaged, plotted and compared with the bent cylinder model. The modal series solution was truncated with the hypothesis that the rough animals do not support higher modes of vibration.

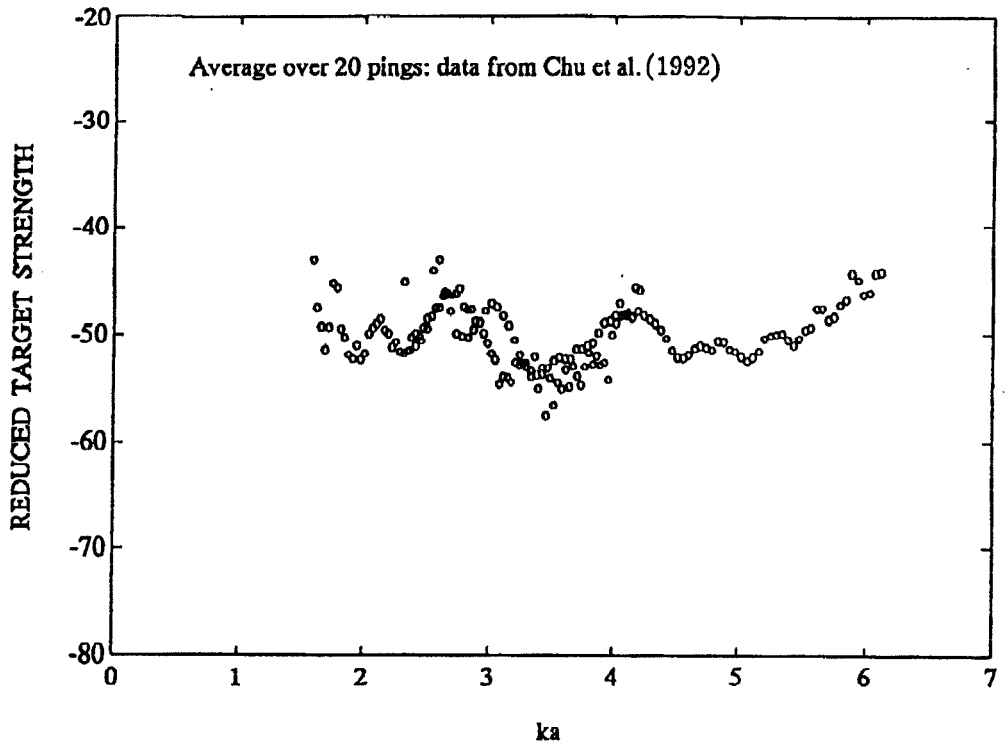

Figure 5: Backscatter data in the range 300 to 650 kHz from Chu *et al.* (1992).

The data from two individuals of different sizes were shown from an average of 20 realisations. The data illustrate the structure of the scattering regardless of the averaging process.

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Tableau 1: Récapitulation des données empiriques concernant les concentrations de krill.

Légende des figures

Figure 1: Données de rétrodiffusion provenant de neuf publications concernant différents types et fréquences d'échosondeurs et un intervalle important de longueurs d'animaux.

Figure 2: Exemples de plusieurs jeux de prédictions utilisant le cylindre de fluide coudé et en fuseau, superposé à un sous-jeu de données de la Figure 1, à savoir celles dérivées des sources suivantes: Artemov (1983), Nakayama *et al.* (1986), Shimadzu *et al.* (1989), Foote *et al.* (1990) et Watkins (1991).

Figure 3: Données de rétrodiffusion de Foote *et al.* (1990) lorsque les concentrations étaient en enceinte.

Figure 4: Données de rétrodiffusion à 420 kHz et modèle de Wiebe *et al.* (1990) dans lequel on a établi la moyenne, on les a tracées et comparées des données de 39 individus de crustacés de tailles différentes au modèle de cylindre coudé.

Figure 5: Données de rétrodiffusion comprises dans l'intervalle de 300 à 650 kHz de Chu *et al.* (1992) dans lesquelles les données de deux individus de différentes tailles sont présentées sur une moyenne de 20 essais.

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Рисунок 2: Примеры нескольких вариантов прогнозов с использованием деформированного цилиндра, наложенных на частичный набор данных из Рисунка 1. Были использованы данные следующих авторов: Artemov (1983), Nakayama *et al.* (1986), Shimadzu *et al.* (1989), Foote *et al.* (1990) и Watkins (1991).

Рисунок 3: Данные по акустическому рассеиванию из работы Фут и др. (Foote *et al.*, 1990) - скопление особей находилось в садке.

Рисунок 4: Данные по акустическому рассеиванию на частоте 420 кГц и модель из работы Вибе и др. (Wiebe *et al.*,1990) - были усреднены, нанесены на график и сравнены с моделью рассеивания деформированных цилиндром. Данные по 39 отдельным рачкам разного размера.

Рисунок 5: Данные по акустическому рассеиванию в диапазоне 300 - 650 кГц из работы Чу и др. (Chu *et al.*, 1992) - показаны данные по двум особям разного размера, осредненные по результатам 20 прогонов. Несмотря на используемое усреднение эти данные иллюстрируют структуру рассеивания.

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CALIBRATION OF AN ACOUSTIC ECHO-INTEGRATION SYSTEM IN A DEEP TANK, WITH SYSTEM GAIN COMPARISONS OVER STANDARD SPHERE MATERIAL, WATER TEMPERATURE AND TIME

D.A. Demer*[1] and R.P. Hewitt[1]

Abstract

This paper outlines the theory and procedures for calibrating an echo integration acoustic system with a standard sphere. It presents the results of an extensive calibration of a Simrad EK500 scientific echosounder with a 120 kHz split-beam transducer in a refrigerated 10 m deep tank. Calibration parameters are studied in relation to sphere material (WC and Cu), water temperature (0.5 to 5.5°C), transmitted pulse length (0.1, 0.3 and 1.0 ms), target depth (0.8 to 7.5 m), and time (149 days). The total range in TS gain, including the effects of temperature, standard sphere and time, is 2.9 dB. Gain values calibrated with the Cu sphere are, with the exception of the long pulse length, lower than those from the WC sphere. The general trends are consistent between $S_{A\_}$ gain and TS gain. The total spread in $S_{A\_}$ gain, including the effects of temperature, standard sphere and time, is 2.1 dB. Thus, the accuracy of the standard sphere as a reference TS value, the pulse length, the water temperature range, and equipment instabilities during the duration of a survey can contribute significant errors to the accuracy and precision of an echo integration acoustic survey. To minimise these effects, the TS gain and $S_{A\_}$ gain parameters should be meticulously measured, measured frequently, and matched to the pulse length used and the water temperature in the survey area.

Résumé

L'auteur expose la théorie et les procédures d'étalonnage d'un système d'écho-intégration acoustique avec une sphère standard. Il présente les résultats de l'étalonnage extensif d'un échosondeur scientifique Simrad EK500 équipé d'un transducteur à faisceau fractionné de 120 kHz dans un réservoir réfrigéré de 10 m de profondeur. Les paramètres d'étalonnage sont étudiés en fonction du matériau de la sphère (WC et Cu), de la température de l'eau (de 0,5 à 5,5°C), de la durée de la pulsation transmise (0,1, 0,3 et 1,0 ms), de la profondeur de la cible (de 0,8 à 7,5 m) et de la durée (149 jours). L'intervalle total du gain TS, tenant compte des effets de la température, de la sphère standard et de la durée est de 2,9 dB. Les valeurs du gain calibrées avec la sphère de Cu sont, sauf dans le cas de la durée de la pulsation, inférieures à celles de la sphère de WC. Les tendances générales sont régulières entre les gains de $S_{A\_}$ et TS. L'étendue totale du gain de $S_{A\_}$, y compris les effets de la température, la sphère standard et la durée, est de 2,1 dB. Ainsi, la précision de la sphère standard en tant que valeur de référence de réponse acoustique, la durée de la pulsation, l'intervalle de températures de l'eau et l'instabilité de l'équipement tout au long d'une campagne peuvent contribuer à former des erreurs significatives en matière de

* Supported by the John and Fannie Hertz Foundation

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justesse et de précision d'une campagne acoustique par échosondages. Pour réduire ces effets au minimum, les paramètres des gains de TS et de $S_{A\_}$ devraient être mesurés méticuleusement et fréquemment et ajustés à la durée de la pulsation utilisée et à la température de l'eau dans la zone concernée.

Резюме

Настоящая работа описывает теорию и процедуру калибровки акустической системы эхо-интеграции с помощью стандартного шара. Представлены результаты всесторонней калибровки научного эхолота типа Симрад EK 500 с помощью преобразователя с расщепленным лучом в охлаждаемом садке глубиной 10 м. Параметры калибровки изучаются по отношению к материалу шара, (вольфрамовый карбид - WC; и медь - Cu), температуре воды (0,5-5,5°C), продолжительности передаваемого пульса (0,1, 0,3 и 1,0 мс), глубине нахождения цели (0,8-7,5 м) и времени (149 дней). Общий диапазон TS-усиления, включая влияния температуры, стандартного шара и времени, составляет 2,9 дБ. Величины усиления, калиброванные с помощью шара из Cu, за исключением длительного по продолжительности импульса, ниже чем в случае шара из WC. Общие тенденции между $S_{A\_}$ и TS-усилением были последовательными. Общий диапазон $S_{A\_}$-усиления, включая влияния температуры, стандартного шара и времени, составляет 2,1 дБ. Таким образом точность стандартного шара как контрольное значение TS, продолжительность пульса, диапазон температуры воды и неустойчивость приборов во время съемки могут привести к допущению значительных ошибок в точности акустической съемки с использованием эхо-интеграции. В целях сведения к минимуму таких последствий следует тщательно и часто измерять параметры TS и $S_{A\_}$-усиления и делать поправку на используемую продолжительноcть импульса и температуру воды в районе съемки.

Resumen

En el presente trabajo se describen la teoría y la práctica de la calibración de un sistema de ecointegración acústica con una esfera estándar. Se explica la calibración de un ecosondas Simrad EK500 con un transductor de haz doble a 120 kHz, en un tanque refrigerado de 10 m de profundidad. Se han estudiado los parámetros de calibración respecto del material de la esfera (WC y Cu), temperatura del agua (0.5 a 5.5°C), duración del impulso transmitido (0.1, 0.3 y 1.0 ms), profundidad del blanco (0.8 a 7.5 m), y tiempo (149 días). El valor total de TS gain, que comprende el efecto de la temperatura, la esfera estándar y el tiempo, es 2.9 dB. Los valores de ganancia calibrados con la esfera de Cu son menores que con la esfera WC, exceptuando el impulso más largo. Los valores de $S_{A\_}$ gain y TS gain son coherentes. La amplitud total de $S_{A\_}$ gain, incluyendo el efecto de la temperatura, esfera estándar y tiempo, es 2.1 dB. Por consiguiente, la precisión de la esfera estándar como valor de referencia de TS, duración del impulso, gama de

temperatura del agua, y la variabilidad instrumental durante la realización del estudio pueden ocasionar errores importantes en la prospección acústica ecointegrada. Para reducir este efecto, los parámetros de TS gain y de S_A gain deberán medirse con cuidado y frecuencia, ajustándolos a la duración del impulso y a la temperatura del agua de la zona.

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1. INTRODUCTION

Successful management of fisheries invariably requires accurate information about fish size, distribution and abundance. To acquire this information over large survey areas, echo integrating instruments are commonly used. Hydroacoustic instruments are attractive to researchers due to cost, survey speed and apparent ease of data analysis. However, a practical application of echo integration theory requires a meticulous and cautious interpretation of the data with respect to the many theoretical assumptions. The main contributions of bias in an echo integration acoustic survey are due to errors in calibration and target strength measurements (Tesler, 1989). Therefore, if a quantitative hydroacoustic study is to produce results of adequate accuracy, a highly accurate calibration is necessary.

Outlined first is a currently accepted methodology for calibrating a hydroacoustic system with a standard sphere (Johannesson and Mitson, 1983). The theory and procedures have been adapted to the Simrad EK500 scientific echosounder, a commonly used instrument in fish stock assessment. Both the electrical and acoustic parameters pertinent to the calibration are defined. Then, the results of an extensive calibration experiment, performed in a deep tank, are presented. Possibilities for improving the calibration equipment and procedures are suggested. Finally, the ramifications of the results on the accuracy of a hydroacoustic study are discussed.

2. CALIBRATION

Calibration is the process of standardising a measuring instrument. Typically it is performed by determining the deviation from a standard so as to ascertain the proper correction factors. In the context of hydroacoustic instruments, a popular method of calibration is to insonify a standard target on the beam axis and at a prescribed depth, calculate the difference between the standard and the measured target strength (TS), and adjust the system gain parameters to compensate for the discrepancy. Spherical standards are commonly used for fisheries calibration because the TS remains stable, they are independent of orientation, and no additional electronic equipment is required (Blue, 1984). Furthermore, the method is repeatable, thus allowing performance changes for the entire system to be monitored over time.

In order to realise the potential accuracy of the standard target technique, considerable care must be taken to position the target on the acoustic axis of the survey transducer (Robinson, 1984). Then, unless the beam pattern is known, the resulting calibration refers only to the axis. Knowledge of the transducer beam pattern permits relative gain compensation algorithms to be effected off axis. Calibration should be performed under the complete range of operating conditions and equipment settings. It should be performed with no effect from the water column boundaries so that only spherical waves reflecting from the target return to the transducer. The water should be homogeneous and isotropic. The water temperature and salinity should be measured to correct for absorption losses. The standard target must be held stable, but spatially adjustable, in the acoustic far-field.

$$\text{far-field} > \frac{2L^2}{\lambda}$$

where L is the longest dimension of the transducer face and λ is the wavelength of the transmitted pulse. The factor of two is commonly included in quantitative acoustics to be certain of far-field operation. Finally, the ambient noise level must be low.

Standard targets are solid elastic spheres typically made from tungsten carbide or high purity copper. The sphere diameter is selected to provide a desired target strength and to minimise the temperature dependence on TS. Operating at 120 kHz, the optimal sphere diameter for commercial, high purity copper was suggested by a preliminary investigation to be 30.05 mm (Foote, 1981). Improved knowledge of the elastic properties has recently enabled better sphere designs (Foote, personal correspondence). Electrical grade copper (Cu) resists corrosion in sea water and is inexpensive and machineable (Foote, 1984a and b). Tungsten carbide (WC) is extremely hard and therefore has highly elastic acoustic characteristics. Due to its extreme hardness, it is sintered into a spherical shape rather than machined. Consequently, the diameters of WC spheres are commonly more precise than those of Cu spheres.

To suspend and move the sphere in the beam, a typical set-up includes multiple monofilament lines connected to the sphere and manipulated using fishing reels, stepping motors, or similar apparatus. Attaching the lines to the sphere without affecting its acoustic properties is difficult, but a fine mesh nylon bag or monofilament net is commonly used. Before deploying, the surface of the sphere should be cleaned and deaerated in a solution of soap and fresh water.

Calibration data is normally supplied with a new transducer. This data usually includes the leakage resistance, beam pattern, beam width, impedance, directivity index, transmitting response, receiving sensitivity, and electro-acoustic efficiency. The manufacturer may test the transducer in a configuration completely different than that used in the actual deployment. It may be tested with a different transmission cable length, mounting configuration, water temperature and salinity, transmitted power, and/or pulse length. The electrical and material properties of the transducer are susceptible to changes over temperature and time.

Ideally, all of the calibration parameters should be re-checked under the actual operating configuration, over the entire range of anticipated survey settings and conditions, and as often as possible. In usual practice, however, only the leakage resistance, beam axis and beam width are tested explicitly while the remaining factors are either accepted from the manufacturer's specifications (beam pattern, effective beam width and directivity index), or lumped into the system gain settings (impedance, transmitting response, receiving sensitivity, and electro-acoustic efficiency).

Leakage resistance refers to the sum of electrical resistances between the hull of the ship and the transducer cable screen and between the individual transducer leads and the cable screen. These resistances should be measured with the deck and/or towing cable(s) attached to the transducer. Leakage resistance values should be many MΩ. A low leakage resistance may cause excessive noise due to ground loops. The resistance of the transducer (single-beam), or each transducer section (dual- or split-beam), should also be checked between each pair of transducer leads. Transducer resistances should be measured at all accessible points along the connecting cable (i.e., pig-tail, winch slip-rings, back of echosounder, etc.). If repeated frequently, these measurements will warn of connectivity problems - a concern particularly in towed systems.

To measure the beam width, TS data should be collected from the on-axis signal level of the main lobe to a level less than 6 dB down in both alongship and athwartship directions (Simmonds, 1984a and b). A two-dimensional polynomial is fit to these data to approximate the angle between half power points and to determine the offset angles of the beam axis. Another method of estimating beam angles and offsets is to fit a surface of TS data points to a modified Bessel function (Ona, 1990).

The impedance, transmitter response, receiving sensitivity, and electro-acoustic efficiency are typically measured collectively while calibrating with a standard sphere to adjust the overall system gain. The EK500 processes the signal digitally immediately following the receiver front end. Therefore, changes in gain are effected by altering software parameters (TS gain and volume scattering strength gain, S_V gain), rather than an analog gain.

To be thorough, the transducer impedance, transmitter frequency, pulse length, pulse repetition rate, and transmitted power can also be tested. The impedance of the transducer should be measured in the survey configuration (i.e., all connecting cables, slip-rings, etc. attached). Transducers made of piezoelectric ceramic materials are capacitive, and the impedance has one maximum at the nominal resonance frequency. Ideally they are tuned at this frequency, using a coil and transformer, to be purely resistive. Practically, however, the complex impedance of the cable plus transducer will exhibit some phase difference between the voltage and the current. Although the impedence of transducers is usually tuned in the factory to be 60 Ω at the nominal operating frequency, the true impedance with the cable attached may be significantly different.

As electronic settings drift over time, the transmitter operating frequency, pulse length (PL), and pulse repetition rate (PRR) may also move outside the specified limits. However, Foote (1981) measured the effect of modulating the centre frequency and the transmit pulse duration by ±1% and ±0.5 ms to total less than ±0.05 dB on the TS of one sphere.

3. EQUIPMENT AND PROCEDURES

An extensive calibration was performed on a Simrad EK500 echosounder with a 120 kHz split-beam transducer in a deep tank facility at Scripps Institution of Oceanography (Figure 1). Calibration parameters were studied in relation to sphere material (WC and Cu), water temperature (0.5 to 5.5°C), transmitted pulse length (0.1, 0.3, and 1.0 ms), target depth (0.8 to 7.5 m), and time (pre- and post-cruise). The calibration was in preparation for an acoustic survey of Antarctic krill (*Euphausia superba*) in a study area around Elephant Island.

The deep tank is a cylindrical steel structure, approximately 10 m deep by 3 m in diameter. It was filled with ocean water pumped from the end of Scripp's pier. A pump and refrigeration unit allowed the water inside the tank to be chilled from ambient ocean temperature (~15°C) to 0.5°C. A second pump was used to vertically circulate the tank water, keeping it well mixed so that temperature strata would not develop. The outside of the tank is fully insulated and fitted with multiple observation ports. Before each set of measurements, a calibrated thermistor (YSI 44008 30K) was used to profile the tank temperature at 1 m depth intervals from the surface to 10 m. Uniform temperature profiles (target temperature (T_t) ±0.2°C) were achieved over most of the tank (2 to 10 m). The temperature of the surface water (0 to 2 m) varied from the T_t±0.2 to T_t±1°C depending on the time of day.

The main components of the acoustic system included a Simrad echo integration system (EK500), a UNIX work station for postprocessing (Sun Sparc Station 1+), and a Simrad 120 kHz split-beam transducer (ES120). The transducer was tethered radially with three nylon cords in the centre of the tank at a depth of 0.5 m. It was connected to the EK500 through a 50 m towing cable, a 13-conductor slip-ring set, and a 75 m deck cable.

The acoustic characteristics of a 33.17 mm (specified as ~33 mm) WC sphere from Biosonics and a 30.05 mm (specified as 30.05 mm) Cu sphere from Simrad were compared versus temperature, pulse length, and time. In successive trials, each sphere was suspended and controlled by three monofilament lines connected to three fishing reels. The lines were attached to the WC sphere by a monofilament knotted bag and to the Cu sphere by a loop of monofilament nylon affixed into a single shallow bore. The effect of the bore is still undetermined in the case of the 120 kHz echosounder (Foote, 1981).

The nominal equipment and environmental parameters were:

Transducer model:	Simrad ES120 (split-beam)
Frequency (kHz):	119.047 (centre)
Pulse Length (ms):	0.1 short, 0.3 med, 1.0 long
Pulse Rep. Freq. (Hz):	1
Bandwidth (kHz):	12.0 (Wide), 1.2 (Narrow)
Transmit power (kW):	1 (Normal)
Angle Sens. (deg.):	17.0
2-Way Beam Angle (deg.):	-18.5
3-dB Beamwidth (deg.):	9.0
Sample Distance (cm):	3
Sampling Freq. (kHz):	50
Nom. Water Temp. (°C):	5.5, 5.0, 3.5, 3.0, 1.0, 0.5
Salinity (‰):	34.0 (±0.5)

A wide receiver bandwidth was used with the short and medium pulse lengths and a narrow bandwidth was used with the long pulse length. For all three pulse lengths, the noise margin was 0 dB, the depth range was 10 m, and the time varied gain (TVG) was set to 40log(r).

Temporal variations were evaluated by repeating parts of the experiment pre- and post-cruise. The pre-cruise calibration experiments were conducted from 16 to 19 November 1991, and the post-season experiments were performed from 17 to 18 April 1992, a 149 day separation.

4. DATA ANALYSIS

To determine the centre of the main lobe and to estimate the effective beamwidth, pre-cruise TS measurements were recorded from the WC sphere at 5±1 m depth, over ±6.0° alongship and athwartship angles, and at 0.5° C (Figure 2). By maintaining near zero offset (±1°) in one of the two directions, the alongship and athwartship data were independently fitted, in the least squares sense, with second-order polynomials.

$$TS_{alongship} = 0.40\Theta^2_{alongship} - 0.11\Theta_{alongship} - 44.23$$

$$TS_{athwartship} = 0.38\Theta^2_{athwartship} - 0.01\Theta_{athwartship} - 44.27$$

The maximum value of these equations provides a good estimate of the beam axis location. Therefore, the beam is centred at -0.1° alongship and 0.0° athwartship angles. The echosounder was adjusted for this slight offset. Since a target was measured, rather than a microphone, the total gain is a product of the transducer's transmit and receive gains. Therefore, solving the equations for the -6 dB points indicates a beam widths of 7.8° and 7.9° alongship and athwartship, respectively. The vendor specified beamwidth at half-power points for this transducer is a symmetrical 9.4°. However, since the measurements of angle are made by the same sounder as is calibrated, the actual beam width and the measured beamwidth may differ. In fact, the angle sensitivity parameter, or the conversion factor between electrical and mechanical angles, will change the measured beam width.

The theoretical near-field / far-field transition distance is approximately 1.02 m from the transducer ($\lambda \cong 1.25$ cm, $L \cong 8$ cm). Pre-cruise TS measurements taken from the WC sphere at 0.5°C and distances of 0.8 to 7.5 m confirmed that transition occurs at a distance of approximately 1.1 m (Figure 3). Beyond the transition range, however, the maximum target strength values taken on-axis had a large range of 1.1 dB (-43.9 to -42.8 dB). It is unclear whether this spread is inherent in the system and target or if the Deep Tank boundaries are

causing significant reverberation from the side-lobes. Range uncertainty, due to the 3 cm sampling distance, may also be suspect. To minimise the effect of this variation, a constant target depth of 5 m was chosen for the remainder of the measurements.

The target strength measurement (TS) is based upon the maximum sample value of the standard sphere echo:

$$\text{TS gain}_{new} = \text{TS gain}_{old} + \frac{\text{TS}_{measured} - \text{TS}_{sphere}}{2}$$

TS gain_{old} was held at a constant reference value of 23.0 dB throughout all of the testing. The TS_{sphere} values are from the vendor supplied data sheets at the appropriate sound velocity. Biosonics claims the TS accuracy to be within ±0.2 dB for pulse lengths of 0.5 ms or more. Simrad's data sheet (TS versus sound velocity) included no claim about accuracy. The sound velocity was calculated at each temperature and at a depth of 5 m and a salinity of 34‰ (Mackenzie, 1981). TS_{comp} values are the maximum sample values of the echo from the sphere, taken on-axis (Table 1 and Figure 4). On-axis stability decreased with increasing pulse length. Therefore, if no data were collected exactly on axis, the nearest data to the axis were used after being multiplied by a beam pattern compensation factor.

There is a possible trend of increasing TS gain values with increasing pulse length (PL). This trend is consistent between the short and medium PL gains. However, with the small number of data points and the possible range of TS_{sphere} values (0.4 dB) , this cannot be stated with any certainty. The gain values associated with the long PL have the greatest variance. TS gain exhibits a flat, if not slightly increasing trend over the 5°C temperature range. This is consistent with the observation by Foote (1984a and b) who reported the TS of a tungsten carbide and a copper sphere to vary by ±0.2 dB and ±0.1 dB from 0 to 30°C, respectively. TS gain values were higher for short PL than for medium PL. The total spread in TS gain, including the effects of temperature, standard sphere and time, is 2.9 dB.

Gain values calibrated with the Cu sphere are, with the exception of the long PL, lower than those from the WC sphere. Since the WC sphere diameter was slightly larger than specified, the true TS_{sphere} may be different from that reported by Biosonics. Foote (1984) calculated the effect of a ±0.1 mm variation in sphere diameter to be ±0.02 dB on TS. This corresponds to an increase of TS_{sphere} by approximately 0.04 dB.

The integrated backscattering area (S_A) is based upon integrated and averaged echo samples. The theoretical value, used as a calibration reference, is:

$$S_{A_{theory}} = \frac{4\pi r_0 \sigma_{bs} (1852\text{m}/\text{nm})^2}{\Psi r^2}$$

where r_0 is the standard reference distance for backscattering (1 m), σ_{bs} is the backscattering cross-section of the sphere, Ψ is the equivalent two-way beam angle, and r is the target range. The calibrated integration gain is:

$$S_{A\_}\text{ gain}_{new} = S_{A\_}\text{ gain}_{old} + \frac{10\log\left(S_{A_{measured}} / S_{A_{theory}}\right)}{2}$$

$S_{A_{measured}}$ is the average of three or more measurements taken while the target sphere was stable on the beam axis (±0.2 for short, ±0.4° for medium, and ±1.0 degree for long PL).

The general trends are consistent between $S_{A\_}$ gain and TS gain (Table 2 and Figure 5). Again, the gain values for the medium PL are consistently higher than those for the short PL,

those associated with the long PL have the greatest variance, and the values for the Cu sphere are generally lower than those from the WC sphere. The total spread in $S_{A\_}$ gain, including the effects of temperature, standard sphere and time, is 2.1 dB, i.e., 0.8 dB less than the total range of TS gain.

Resistances (Ω) of the deck-cable, slip-rings, tow-cable, and transducer quadrant were:

Quadrant:	1	2	3	4
Pre-cruise:	8.5	8.4	8.4	8.4
Post-cruise:	8.9	8.8	8.9	8.9

All leakage resistance values were greater than 32 MΩ both pre- and post-cruise.

Summarising, the ranges of both the TS gain and the $S_{A\_}$ gain have been tabulated versus temperature (5.5 to 0.5°C), time (~149 days), and sphere material (WC, Cu) for each of the three pulse lengths (Table 3). Over the 5°C temperature spread, the ranges of TS gain and $S_{A\_}$ gain were greatest for the long PL (1.2 and 1.1 dB, respectively). This may be due to second echo interference or reverberation from the tank walls. Both TS gain and $S_{A\_}$ gain were consistently higher for short PL than for medium PL. Temporal drift of the system calibration ranged from -0.1 to -1.3 dB for TS gain and -0.2 to -1.2 dB for $S_{A\_}$ gain, including the effects of PL and standard sphere. In general, the drift in gain increased with increasing pulse length and all of the changes were negative. The increase in resistance for each quadrant is consistent with the latter observation. TS gain and $S_{A\_}$ gain differed between spheres by as much as 1.5 and 1.0 dB, respectively.

5. DISCUSSION

Foote *et al.* (1984a and b) stated that precision calibrations to within 0.5 dB are possible by means of standard calibration spheres. Assuming an accuracy of 0.5 dB for calibration with a standard target, the error of estimating mean target strength will be 1 dB (Tesler, 1989). Robinson and Hood (1984) asserted that if the specifications of the best currently available equipments are used, and assuming that the equivalent beamwidth can be measured to ±0.1 dB, it is currently only possible to state that an acoustic system can be calibrated to within ±0.6 dB (95% confidence). He stated that the acoustic absorption coefficient is not known to better than ±5 dB/km at 120 kHz. Thus, calibration accuracies at a range of 50 m, influenced by this parameter alone, can be no better than ±0.5 dB. At greater ranges, the biases are proportionally larger (Robinson, 1984).

The results of this experiment indicate that variations in PL, time and choice of standard sphere can cause corresponding variations in the system gain of 1.2, 1.3, and 1.5 dB, respectively, all else being equal. Therefore, while using a currently accepted procedure for calibrating, a commonly used echosounder and a short pulse length, the error in mean target strength estimates of animals in 0.5°C water could be as high as 3.0 dB. This error due only to one's choice of calibration sphere.

However, the reader should note that multiple changes in the experimental equipment and procedures may provide less troubling results. For instance, if the ES120 transducer is used, an angle sensitivity of 15.7 is a better factor to match the mechanical angles with the measured phase angles (Ona, personal correspondence). Simrad currently supplies a 23.0 mm Cu sphere with a nominal TS of -40.5 dB to calibrate at 120 kHz. This sphere exhibits a smaller TS change with temperature. If WC is to be used, Foote (personal correspondence) currently recommends a 38.1 mm diameter sphere. Also, if calibrations are performed in a tank, the sphere should be suspended just outside the near-field/far-field transition zone. A closer range than used throughout these experiments may reduce or eliminate the effects of side-lobe and second-echo reverberation from the tank boundaries.

6. CONCLUSIONS

Calibration of an echo integration system for use in biomass estimation is critical for understanding and quantifying the accuracy and precision of the resulting measurements. The calibration must be performed with the system configuration used during the survey and over the range of equipment settings used and water temperatures encountered during the survey. The calibration should be repeated at least twice, before and after the survey. The results of the calibration should be included in the statistical analysis of the biomass estimates.

The accuracy of the standard sphere as a reference TS value, the pulse length, the water temperature range, and equipment instabilities during the duration of a survey can contribute significant errors to the calibration accuracy of an echo-integration acoustic system. To minimise the effects of these parameters on the accuracy and precision of an acoustic survey, the TS gain and S_A gain parameters should be meticulously measured, measured frequently, and matched to the pulse length used and the water temperature in the survey area. Furthermore, additional comparative studies should be performed to understand the practical, opposed to theoretical, accuracies and precisions of the two most commonly used calibration sphere materials (WC and Cu). Particular attention should be paid to variations in calibrated gains versus water temperature.

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REFERENCES

BLUE, J.E. 1984. Physical Calibration. *Rapp. P. -v. Reun. Cons. Int. Explor. Mer.*, 184: 19-24.

FOOTE, K.G., H.P. KNUDSEN, and G. VESTNES. 1981. Improved calibration of hydroacoustic equipment with copper spheres. *Int. Council Explor. Sea, C.M.*, B:20.

FOOTE, K.G. 1982. Optimising copper spheres for precision calibration of hydroacoustic equipment. *J. Acoust. Soc. Am.*, 71 (3): 742-747.

FOOTE, K.G. 1983. Maintaining precision calibrations with optimal copper spheres. *J. Acoust. Soc. Am.*, 73 (3): 1054-1063.

FOOTE, K.G., and D.N. MACLENNAN. 1984a. Comparison of copper and tungsten carbide calibration spheres. *J. Acoust. Soc. Am.*, 75 (2): 612-616.

FOOTE, K.G., and D.N. MACLENNAN. 1984b. Use of elastic spheres as calibration targets. *FAO Fish. Rep.*, 300: 52-58. (Contribution No. 31).

FOOTE, K.G., H.P. KNUDSEN, G. VESTNES, D.N. MACLENNAN, and E.J. SIMMONDS. 1987. Calibration of acoustic instruments for fish density estimates: a practical guide. *ICES Co-op. Res. Rep.*, 144.

FOOTE, K.G. 1990. Spheres for calibrating an eleven-frequency acoustic measurement system, *J. Cons. Int. Explor. Mer.*, 46: 284-286.

JOHANNESSON, K.A. and R.B. MITSON. 1983. Fisheries Acoustics: a practical manual for aquatic biomass estimation. *FAO Technical Paper*, No. 240: 249 pp.

MACKENZIE, K.V. 1981. Nine-term equation for sound speed in the ocean. *J. Acoust. Soc. Am.*, 70: 807-812.

MACLENNAN, D.N. and S.T. FORBES. 1984. Fisheries acoustics: a review of general principles. *Rapp. P. -v. Reun. Cons. Int. Explor. Mer.*, 184: 7-18.

NIELSON, R.L., I. HAMPTON, I. and I. EVERSON. Calibration of hydro-acoustic instruments. *BIOMASS Handbook*, No. 1.

ONA, E. 1990. Optimal acoustic beam pattern corrections for split-beam transducers. *ICES, B:30 Sess. R.*

ROBINSON, B.J. 1984. Calibration of equipment subject group C. *Rapp. P. -v. Reun. Cons. Int. Explor. Mer.*, 184: 62-67.

ROBINSON, B.J., and C.R. HOOD. 1984. A procedure for calibrating acoustic survey systems, with estimates of obtainable precision and accuracy. *FAO Fish. Rep.*, 300: 59-62. (Contribution No. 87).

SIMMONDS, E.J. 1984a. A comparison between measured and theoretical equivalent beam angles for seven similar transducers. *J. Sound Vib.*, 97: 117-128.

SIMMONDS, E.J. 1984b. The effect of mounting on the equivalent beam angle of acoustic survey transducers. *ICES CM1984/B:32*: 5 pp (mimeo).

TESLER, W.D. 1989. Bias and precision in acoustic biomass estimation. *Proc. I.O.A.*, Vol. 11, Part 3.

Table 1: Calibration data for TS gain.

Date	Sphere Mat.	Pulse Length (ms)	Temp. (c)	TScomp (dB)	Depth (m)	Along (deg.)	Athwart (deg.)	Sound Speed (m/s)	TS sphere (dB)	TS gain (dB)
11/16/91	WC	0.1	5.5	-42.5	5.1	0.0	0.0	1514	-40.7	22.1
11/16/91	WC	0.3	5.5	-42.9	5.1	0.0	0.0	1514	-40.7	21.9
11/16/91	WC	1.0	5.5	-41.2	5.2	0.0	1.5	1514	-40.7	22.8
11/16/91	WC	0.1	5.0	-42.7	5.1	0.0	0.0	1512	-40.7	22.0
11/16/91	WC	0.3	5.0	-43.2	5.1	0.0	0.0	1512	-40.7	21.8
11/16/91	WC	1.0	5.0	-41.7	5.2	-0.2	0.0	1512	-40.7	22.5
11/17/91	WC	0.1	3.0	-42.6	5.2	0.0	0.0	1503	-40.6	22.0
11/17/91	WC	0.3	3.0	-43.1	5.2	0.0	0.0	1503	-40.6	21.8
11/17/91	WC	1.0	3.0	-41.2	5.3	0.0	0.0	1503	-40.6	22.7
11/17/91	WC	0.1	2.5	-42.6	5.2	0.0	0.0	1501	-40.6	22.0
11/17/91	WC	0.3	2.5	-43.2	5.2	0.0	0.0	1501	-40.6	21.7
11/17/91	WC	1.0	2.5	-43.4	5.3	-0.7	0.3	1501	-40.6	21.6
11/18/91	WC	0.1	1.0	-42.9	5.2	0.0	0.0	1495	-40.6	21.9
11/18/91	WC	0.3	1.0	-43.0	5.2	0.0	0.0	1495	-40.6	21.8
11/18/91	WC	1.0	1.0	-43.0	5.3	0.0	-0.2	1495	-40.6	21.8
11/19/91	WC	0.1	0.5	-43.4	5.1	0.0	0.0	1492	-40.6	21.6
11/19/91	WC	0.3	0.5	-43.6	5.1	0.0	0.0	1492	-40.6	21.5
11/19/91	WC	1.0	0.5	-42.5	5.3	0.0	0.0	1492	-40.6	22.1
04/18/92	WC	0.1	0.5	-43.7	5.1	0.0	0.0	1492	-40.6	21.5
04/18/92	WC	0.3	0.5	-43.9	5.1	0.0	0.0	1492	-40.6	21.4
04/18/92	WC	1.0	0.5	-43.1	5.2	0.0	0.5	1492	-40.6	21.8
11/19/91	Cu	0.1	0.5	-41.4	5.1	0.0	0.0	1492	-36.2	20.4
11/19/91	Cu	0.3	0.5	-40.2	5.1	0.0	0.0	1492	-36.2	21.0
11/19/91	Cu	1.0	0.5	-38.2	5.2	0.0	0.0	1492	-36.2	22.0
04/18/92	Cu	0.1	0.5	-42.3	5.0	0.0	0.0	1492	-36.2	20.0
04/18/92	Cu	0.3	0.5	-42.4	5.0	0.0	0.0	1492	-36.2	19.9
04/18/92	Cu	1.0	0.5	-40.9	5.1	0.7	-0.3	1492	-36.2	20.7

Table 2: Data used to calculate calibrated $S_{A\_}$ gain.

Date	Sphere	Pulse Length (ms)	Temp. (c)	Depth (m)	$S_{A\_}$ measured (m^2/nm^2)	$S_{A\_}$ theory (m^2/nm^2)	$S_{A\_}$ gain (dB)
11/16/91	WC	0.1	5.5	5.1	6155.0	9318.6	22.1
11/16/91	WC	0.3	5.5	5.1	5541.0	9318.6	21.9
11/16/91	WC	1.0	5.5	5.2	4534.0	8963.7	21.5
11/16/91	WC	0.1	5.0	5.1	5907.0	9318.6	22.0
11/16/91	WC	0.3	5.0	5.1	5346.0	9318.6	21.8
11/16/91	WC	1.0	5.0	5.2	7402.0	8963.7	22.6
11/17/91	WC	0.1	3.0	5.2	5829.0	9172.4	22.0
11/17/91	WC	0.3	3.0	5.2	5536.0	9172.4	21.9
11/17/91	WC	1.0	3.0	5.3	4436.0	8829.6	21.5
11/17/91	WC	0.1	2.5	5.2	5972.0	9172.4	22.1
11./17/91	WC	0.3	2.5	5.2	5089.0	9172.4	21.7
11/17/91	WC	1.0	2.5	5.3	5738.0	8829.6	22.1
11/18/91	WC	0.1	1.0	5.2	5779.0	9172.4	22.0
11/18/91	WC	0.3	1.0	5.2	5407.0	9172.4	21.9
11/18/91	WC	1.0	1.0	5.3	6057.0	8829.6	22.2
11/19/91	WC	0.1	0.5	5.1	5359.0	9535.7	21.7
11/19/91	WC	0.3	0.5	5.1	5164.0	9535.7	21.7
11/19/91	WC	1.0	0.5	5.3	4758.0	8829.6	21.7
04/18/92	WC	0.1	0.5	5.1	4767.0	9535.7	21.5
04/18/92	WC	0.3	0.5	5.1	4627.0	9535.7	21.4
04/18/92	WC	1.0	0.5	5.2	2947.0	9172.4	20.5
11/19/91	Cu	0.1	0.5	5.1	10086.0	26263.4	20.9
11/19/91	Cu	0.3	0.5	5.1	10202.0	26263.4	20.9
11/19/91	Cu	1.0	0.5	5.2	11959.0	25263.0	21.4
04/18/92	Cu	0-.1	0.5	5.0	8709.0	27324.5	20.5
04/18/92	Cu	0.3	0.5	5.0	9039.0	27324.5	20.6
04/18/92	Cu	1.0	0.5	5.1	10417.0	26263.4	21.0

Table 3: Ranges in gain over sphere material, pulse length, water temperature, and time.

Ranges over temperature:

TS gain:

	0.1 ms	0.3 ms	1.0 ms
WC	0.5	0.4	1.2

$S_{A\_}$ gain:

	0.1 ms	0.3 ms	1.0 ms
WC	0.4	0.2	1.1

Ranges over spheres:

TS gain:

	0.1 ms	0.3 ms	1.0 ms
WC	-0.1	-0.1	-0.3
Cu	-0.4	-1.1	-1.3

$S_{A\_}$ gain:

	0.1 ms	0.3 ms	1.0 ms
WC	-0.2	-0.3	-1.2
Cu	-0.4	-0.3	-0.4

Ranges over time:

TS gain:

	0.1 ms	0.3 ms	1.0 ms
Pre	1.2	0.5	0.1
Post	1.5	0.5	1.1

$S_{A\_}$ gain:

	0.1 ms	0.3 ms	1.0 ms
Pre	0.8	0.8	0.3
Post	1.0	0.8	0.5

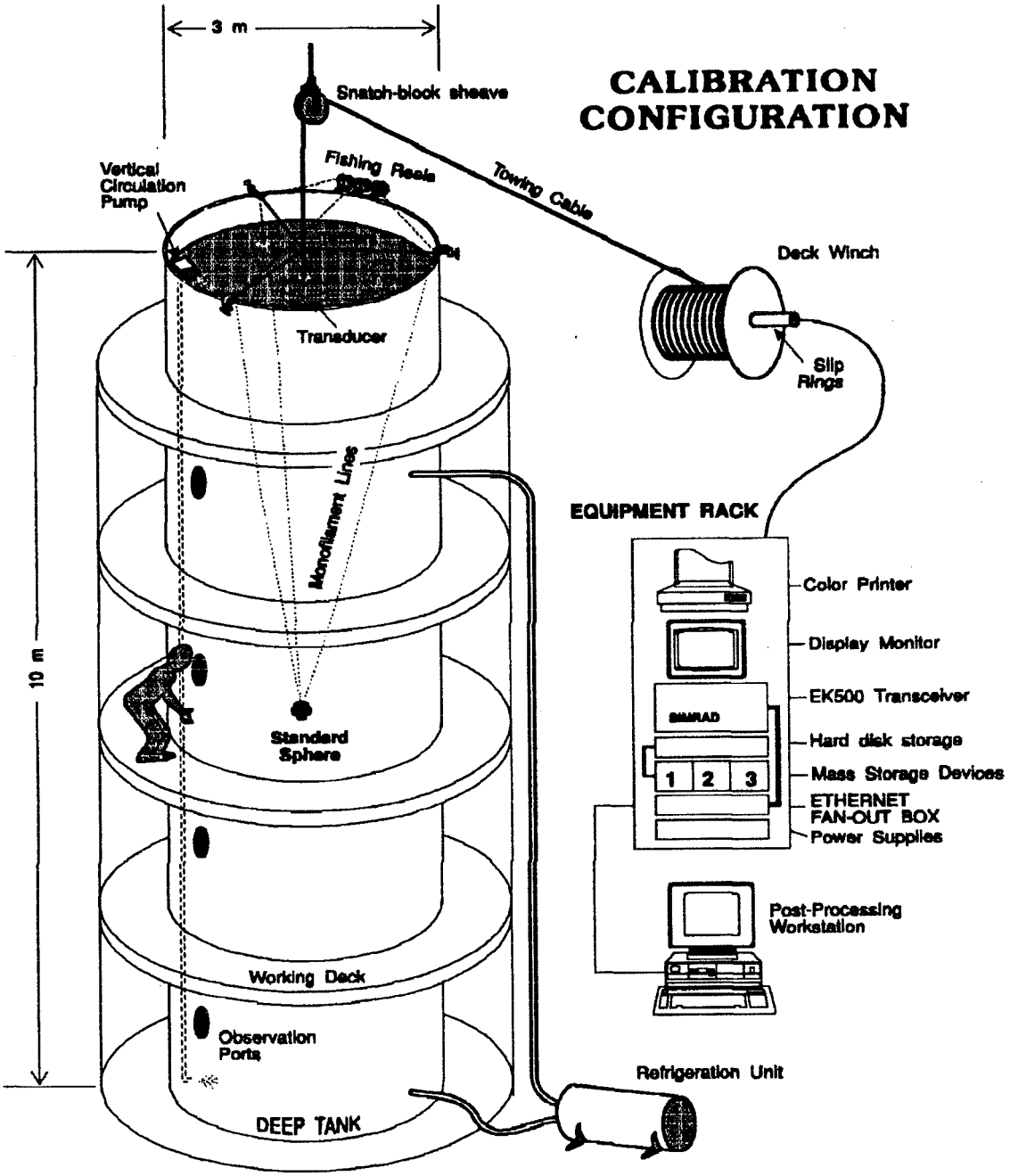

Figure 1: Calibration configuration.

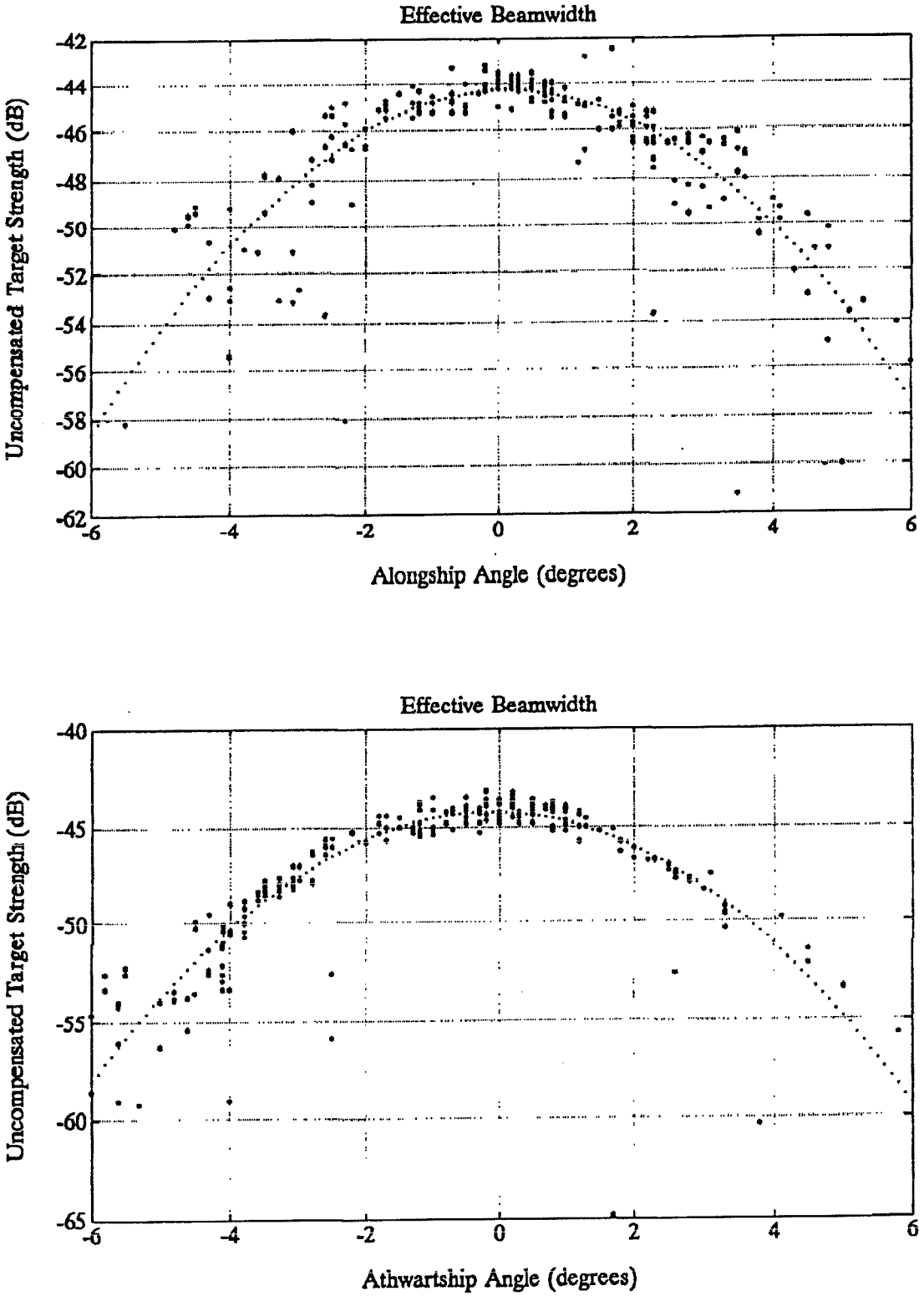

Figure 2: Beam width and offset angle determination.

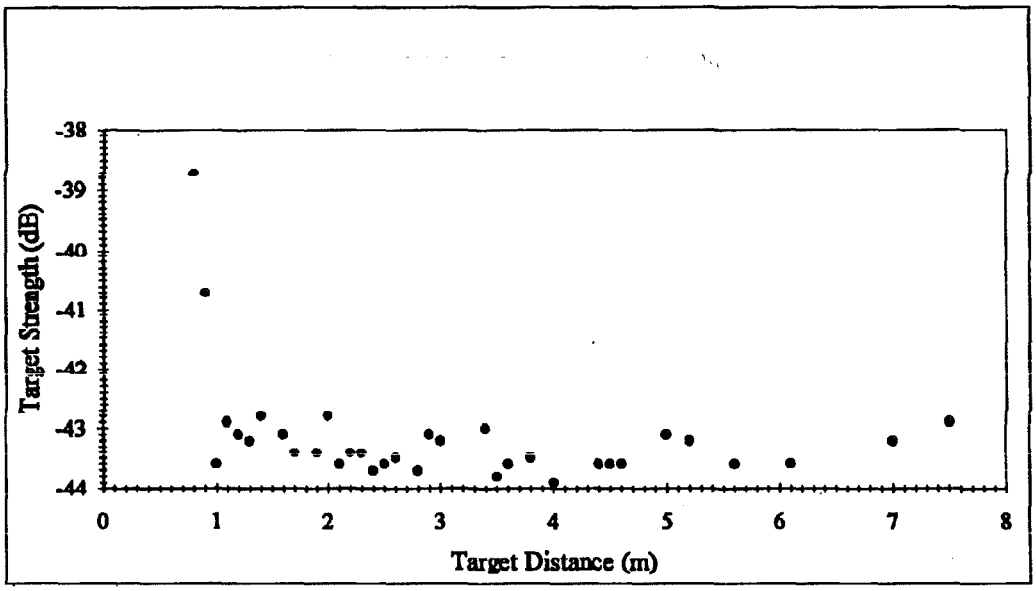

Figure 3: Near-to-far-field transition map.

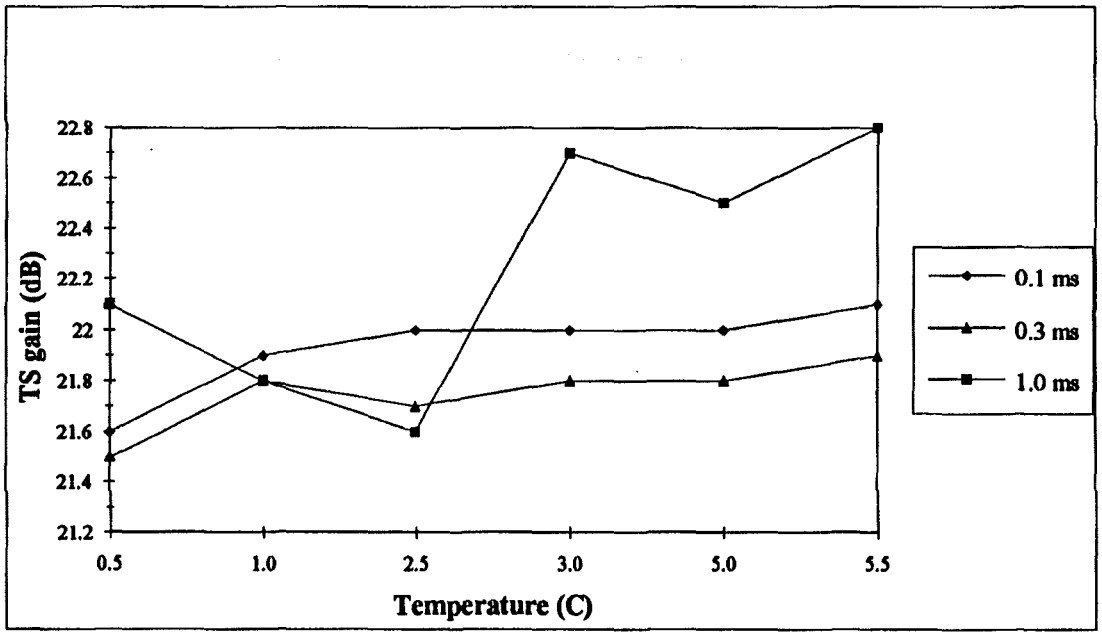

Figure 4: TS gain versus temperature.

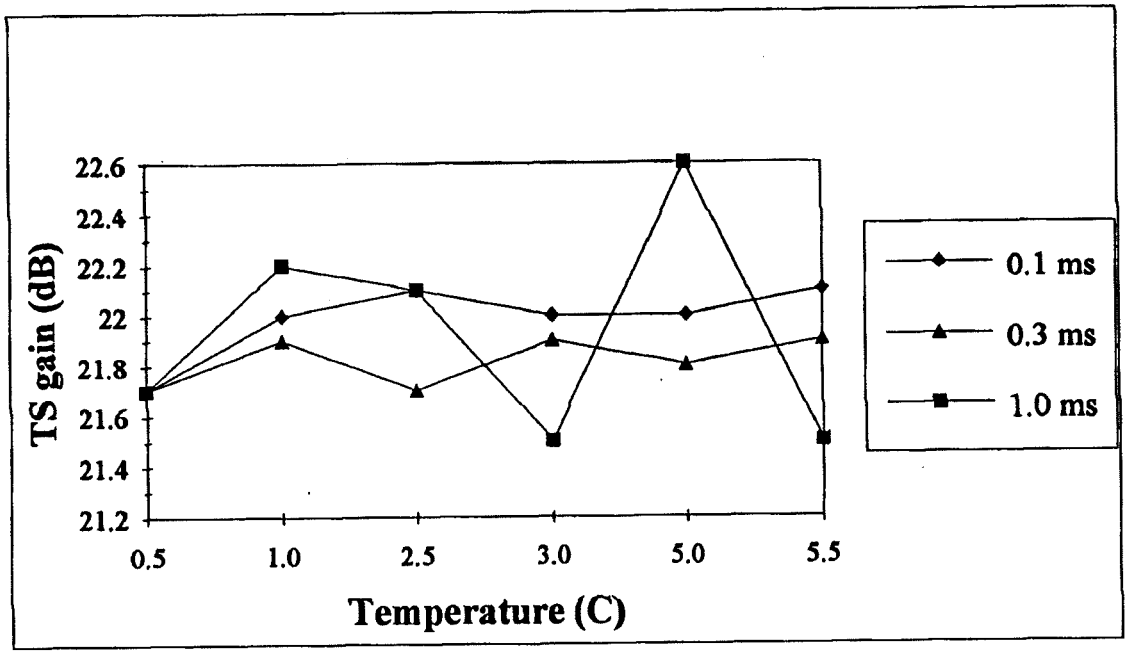

Figure 5: $S_{A\_}$ gain versus temperature.

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REVIEW OF LENGTH-WEIGHT RELATIONSHIPS FOR ANTARCTIC KRILL

V. Siegel*

Abstract

Length-weight relationships for krill, *Euphausia superba* (as well as relationships for other Antarctic euphausiid species), are listed for ash-free dry weight, dry weight, and wet weight. The accuracy of length-weight relationship calculations is improved when information on sex and dominant maturity stages is taken into account. The influence of seasonal changes on length-weight relationship parameters is discussed. Recommendations for possible uses of reviewed length-weight relationships are presented.

Résumé

Les relations longueur-poids du krill, *Euphausia superba*, (ainsi que les relations relatives aux autres espèces d'euphausiacés antarctiques) sont données pour le poids sec sans cendres, le poids sec et le poids humide. Toute information sur le sexe et les stades de maturité dominants permet d'améliorer la précision des calculs des relations longueur-poids. L'influence des variations saisonnières sur les paramètres des relations longueur-poids fait l'objet d'une discussion. Des recommandations sont présentées pour les utilisations possibles des relations longueur-poids révisées.

Резюме

Отношения "длина/вес" для криля, *Euphausia superba*, а также для других видов антарктических эвфаузиид, даны по категориям беззольного сухого веса, сухого веса и мокрого веса. Принятие во внимание информации о половой принадлежности и доминантных стадиях половозрелости улучшает точность вычислений отношений "длина/вес". Обсуждается влияние сезонных изменений в параметрах "длина/вес". Дается ряд рекомендаций по использованию приведенных отношений "длина/вес".

Resumen

Se presenta una lista de las relaciones talla-peso para el kril, *Euphausia superba* (así como las relaciones para otras especies de eufáusidos antárticos), en función del peso seco sin ceniza, peso seco, y peso húmedo. Los cálculos de estas relaciones son más fiables cuando se toman en cuenta la información sobre sexos y las fases de madurez predominantes. Se discute la influencia de los cambios estacionales en las variables de la relación talla-peso y se dan recomendaciones para el posible empleo de las relaciones talla-peso revisadas.

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1. INTRODUCTION

A knowledge of length-weight relationships of aquatic organisms is useful for a variety of studies related to fisheries biology. Biomass and production estimates from net samples and hydroacoustic surveys are expressed as wet weight and are derived from length frequency data. Physiological studies usually convert length into dry or ash-free dry weight. Length measurements can easily and rapidly be carried out on board vessels during surveys, while a direct precise measurement of weight of sorted species or specimens is often difficult and time-consuming. Various length-weight relationships have been established over the years for Antarctic krill *Euphausia superba*, but this information is widely spread throughout published scientific literature.

A comprehensive assessment of length-weight relationships has already been carried out by Morris *et al.* (1988), who also investigated the importance of maturity stages in improving the precision of calculating weight from length data. Since Morris *et al.* (1988) did not consider possible seasonal variations in weight, it would be helpful to summarise published length-weight relationships from the point of view of their seasonal variations.

2. DISCUSSION

Tables 1 to 4 summarise the available length-weight relationships for *E. superba* by season and contain information on the dominant maturity stages of krill. Table 5 lists the few data available for other Antarctic euphausiids. Most length measurements were made using total length AT (front of the eye to the tip of the telson), while other length categories are indicated in the respective tables. Another length measurement sometimes used is TT (tip of the rostrum to tip of the telson). Since this is not significantly different from AT (in *E. superba*), the results are directly comparable and are not listed separately in the tables. A few authors have used different kinds of length measurements (e.g., S1, S2, S7, BT; for definitions see Mauchline, 1980), but these are not included in Tables 1 to 4. Additional information was often collected during laboratory experiments and may be difficult to compare with field data, however the reader may refer to Morris *et al.* (1988) which contains a detailed reference list. Some data were published as the linearised logarithmic version of the regression function. These results have been re-calculated to facilitate direct comparison with other published coefficient values.

Tables 1 and 2 show the regression parameters for ash-free dry weight and dry weight relationships respectively, while Tables 3 and 4 contain wet weight data. In most cases krill were separated according to sex. In their comprehensive study, Morris *et al.* (1988) analysed the improvement in the precision of predictions using length-weight relationships. They split their samples into single maturity stages or sexes and compared the goodness of fit tests of the regressions by examining their variances. They found that the simple classification of 'males', 'gravid females' and 'non-gravid females' increases the precision in prediction for both dry weight (Table 2) and wet weight (Table 3).

Morris *et al.* (1988) noted that 'surprisingly, the simple division of krill into male and female categories is of little practical use in improving the precision of any prediction of weight'. However, Morris *et al.* (1988) only analysed samples taken over a short period during the spawning season (end of February to beginning of March 1985), when most adult krill were still in the gravid maturity stage. The result they obatined was to be expected, because for the spawning season, covariance analyses of length-weight relationships indicated no differences between male and female krill (Siegel, 1986a and 1989). Gravid-stage males and females were of the same weight.

The situation changes throughout the year, i.e., during the annual maturity cycle of krill. Morris *et al.* (1988) applied various published length-weight relationships to data obtained from a single acoustic survey around South Georgia and found great differences in the estimated total

biomass (25% for wet weight and a 35% deviation for dry weight between the results obtained for different length-weight relationships). However, they did not take into account the seasonal or dominant maturity stage composition factor which underlies length-weight relationships. A simple example which uses coefficients from overall length-weight relationships (see Table 4) demonstrates the seasonal change in krill weight. For different months (with different dominant adult maturity stages) a 50 mm krill would attain the following weights:

October	resting stage	787 mg
December	most gravid	927 mg
January	gravid + spent	913 mg
February	all gravid	931 mg
February	all spent	912 mg
March	spent	860 mg
June	resting stage	796 mg

Data for February were collected in different years and indicate the timing of spawning varies from year to year. The seasonal variation in krill weight clearly shows that the results may differ by 15% when using length-weight relationships for krill at different dominant maturity stages. Siegel (1986a and 1989) has already noted that length-weight relationships during the post-spawning and winter seasons are significantly different from those obtained during the spawning season, with minimum weight during winter. This seasonal variability partly explains the variation in estimated biomass obtained by Morris *et al.* (1988). Moreover, a difference in the weight of both sexes has been noted by Nemoto *et al.* (1981), Retama and Quintana (1982) and Siegel (1986a), with males being heavier than females at similar sizes. However, this difference in weight between males and females is statistically significant only during the post-spawning period, when females have shed their eggs (Siegel, 1989). After the ovaries had recovered and during the winter resting stage there was no significant deviation between the weight (length-weight relationship) of males and females.

Based on the above observations, it is recommended that:

(i) when data are available on stock composition by size, sex and maturity stage:

  (a) during the summer spawning period use separate length-weight relationships for males, gravid females and non-gravid females (Table 3);

  (b) during the post-spawning period use separate length-weight relationships for males, gravid females, non-gravid females and spent females (Table 3);

  (c) during the winter and pre-spawning periods use general length-weight relationships (Table 4, depending on month, although differences between months are not significant during this period);

(ii) when data are available on stock composition by size and sex, but no information can be obtained for maturity stages:

  (a) during the late spawning and post-spawning periods use separate length-weight relationships for males and females (Table 3);

  (b) for other periods use general length-weight relationships (Table 4); and

(iii) when data are available on population composition only by size:

  (a) for all periods use general length-weight relationships based on data collected during a minimum period of one month (Table 4).

Because spawning may occur in different months during different years, dominant maturity stage is more important than month in choosing the correct length-weight relationship.

REFERENCES

CHEKUNOVA, V.I. and T.I. RYNKOVA. 1974. Energy requirements of the Antarctic crustacean *Euphausia superba* Dana. *Oceanology,* 14: 434-440.

CLARKE, A. 1976. Some observations on krill (*Euphausia superba* Dana) maintained alive in the laboratory. *British Antarctic Survey Bulletin,* 43: 111-118.

JAZDZEWSKI, K., J. DZIK, J. POREBSKI, S. RAKUSA-SUSZCZEWSKI, Z. WITEK and N. WOLNOMIEJSKI. 1978. Biological and populational studies on krill near South Shetland Islands, Scotia Sea and South Georgia in the summer 1976. *Polskie Archiwum Hydrobiologii,* 25: 607-631.

KILS, U. 1979. Schwimmverhalten, Schwimmleistung und Energiebilanz des antarktischen Krills, *Euphausia superba. Berichte Institut für Meereskinde Kiel,* 65: 1-58.

LOCKYER, C. 1973. Wet weight, volume and length correlation in the Antarctic krill, *Euphausia superba. Discovery Reports,* 36: 152-155.

MAUCHLINE, J. 1980. Measurement of body length of *Euphausia superba* Dana. *BIOMASS Handbook* 4: 9 pp.

MILLER, D.G.M. 1986. Results from biological investigations of krill (*Euphausia superba*) in the southern Indian Ocean during SIBEX I. *Memoirs National Institute Polar Research,* Spec. Issue 40: 117-139.

MORRIS, D.J., J.L. WATKINS, C. RICKETTS, F. BUCHHOLZ and J. PRIDDLE. 1988. An assessment of the merits of length and weight measurements of Antarctic krill *Euphausia superba. British Antarctic Survey Bulletin,* 79: 27-50.

NEMOTO, T., T. DOI and K. NASU. 1981. Biological characteristics of krill caught in the Southern Ocean. In: EL-SAYED, S. (Ed.). *Biological Investigations of Marine Antarctic Systems and Stocks.* Volume II. SCAR, Cambridge: 47-63.

RAKUSA-SUSZCZEWSKI, S. 1981. Polish Antarctic expedition 1975/76. In: EL-SAYED, S. (Ed.). *Biological Investigations of Marine Antarctic Systems and Stocks.* Vol. II. SCAR, Cambridge: 151-155.

RAKUSA-SUSZCZEWSKI, S., R. STEPNIK. 1980. Three species of krill from Admiralty Bay (King George, South Shetlands), in summer 1978/79. *Polskie Archiwum Hydrobiologii,* 27: 273-284.

RETAMAL, M.A. and R. QUINTANA. 1982. Basic biological studies relating to the population dynamics of krill *Euphausia superba* Dana 1850. *Cer. Sci. INACH* , 28: 175-190.

ROJAS, O., C. MARTINEZ and C. GUISADO. 1981. Analisis de la estructura poblacional del krill antartico (*Euphausia superba* Dana), obtenido en Febrero y Marzo de 1975. *Boletin Museum Nacional Histologia Natural Chile,* 38: 85-104.

SAHRHAGE, D. 1978. Zur Längen-Gewichts-Beziehung beim antarktischen Krill (*Euphausia superba*). *Meeresforschung,* 26: 47-49.

SIEGEL, V. 1986a. Untersuchungen zu Biologie des Antarktischen Krill, *Euphausia superba,* im Bereich der Bransfied Strasse und angrenzender Gebiete. *Mitteilungen Institut für Seefischerei Hamburg,* 38: 1-244.

SIEGEL, V. 1986b. Structure and composition of the Antarctic krill stock in the Bransfield Strait (Antarctic Peninsula) during the Second International BIOMASS Experiment (SIBEX). *Archiv. für Fischereiwissenschaft,* 37: 51-72.

SIEGEL, V. 1989. Winter and spring distribution and status of the krill stock in Antarctic Peninsula waters. *Archiv. für Fischereiwissenschaft,* 39: 45-72.

STRELNIKOVA, V.M. 1985. Weight-length relationship and calorific value of Antarctic krill. Translated from *Biologiya Morya,* 5: 45-49.

Table 1: Length-weight relationship for krill (*Euphausia superba*) males (M) and females (F), $W_{AFD} = a \cdot L^b$ for ash-free dry weight (in mg) and total length (AT in mm).

Month	Sex	Regression Coefficient a	b	Size Range (mm)	Number of Krill	Dominant Adult Maturity Stages	Reference
October	M	0.0005	3.022	13-58	138	3A resting stage	Siegel (1986a)
	F	0.0008	2.906	13-59	141	3A resting stage	
December	M	0.00011	3.527	23-60	114	3B gravid	Siegel (1986a)
	F	0.00014	3.460	23-60	114	3C, D gravid	
January	M	0.00029	3.277	23-60	114	3A, B gravid-spent	Siegel (1986a)
	F	0.00066	3.041	23-60	114	3D/E gravid-spent	
February	M	0.00007	3.720	16-58	129	3A spent	Siegel (1986a)
	F	0.00026	3.205	16-59	132	3E spent	

Table 2: Length-weight relationship for krill (*Euphausia superba*) males (M) and females (F), and total ALL, $W_D = a \cdot L^b$ for dry weight (in mg) and total length (AT in mm).

Month	Sex	Regression Coefficient a	b	Size Range (mm)	Number of Krill	Dominant Adult Maturity Stages	Reference
Feb/Mar	ALL	0.00010	3.799		145		Jazdzewski *et al.* (1978)
Jan/Feb	ALL	0.00007	3.760	28-58	114	prespawning-gravid	Kils (1979)
October	M	0.00060	3.030	13-58	138	3A resting stage	Siegel (1986a)
	F	0.00080	2.971	13-59	141	3A resting stage	
November	M	0.00076	3.071	10-57	406	3A resting stage	Siegel (unpubl. data)
	F	0.00105	2.965	10-57	458	3A resting stage	
December	M	0.00019	3.435	23-60	114	3B gravid	Siegel (1986a)
	F	0.00025	3.357	23-60	114	3C, D gravid	
January	M	0.00036	3.277	23-60	114	3A, B gravid-spent	Siegel (1986a)
	F	0.00075	3.066	23-60	114	3D/E gravid-spent	
February	M	0.00009	3.694	16-58	129	3A spent	Siegel (1986a)
	F	0.00031	3.306	16-59	132	3E spent	
Feb/Mar	M	0.00238	2.93	34-57	1861	gravid	Morris *et al.* (1988)
	F	0.00024	3.55	37-58	1404	gravid-spent	
	(F)	0.00139	3.0737	37-58	933	only non-gravid females	
	(F)	0.00199	3.0438	41-58	471	only gravid females	
	ALL	0.00106	3.15	31-58	3265	gravid-spent	

Table 3: Length-weight relationship for krill (*Euphausia superba*) males (M) and females (F), $W_W = a \cdot L^b$ for wet weight (in mg) and total length (AT in mm). Length classes indicated by * refer to Standard 2 body length of Mauchline (1980).

Month	Sex	Regression Coefficient a	b	Size Range (mm)	Number of Krill	Dominant Adult Maturity Stages	Reference
Several	M	0.0034	3.1761	3-61		all stages	Lockyer (1973)
years	F	0.0009	3.5792	3-61		all stages	
Several	M	0.00128	3.428			all stages	Nemoto *et al.* (1981)
years	F	0.00352	3.144			all stages	(one example out of several stations)
Jan/Feb	M	0.00423	3.170	31-55	92	3B gravid	Retamal and Quintana (1982)
	F	0.00573	3.080	31-55	58	3B prespawning	
Dec/Feb	M	0.0019	3.36				Strelnikova (1985)
	F	0.0009	3.56				
Feb/Mar	M	0.00265	3.464	23-47*	2325		Rojas *et al.* (1981)
	F	0.00531	3.256	23-46*	2757		
October	M	0.00236	3.251	13-58	138	3A resting stage	Siegel (1986a)
	F	0.00242	3.247	13-59	141	3A resting stage	
November	M	0.00315	3.207	10-57	406	3A resting stage	Siegel (1989)
	F	0.00430	3.102	10-57	458	3A resting stage	
December	M	0.00083	3.561	15-59	114	3B gravid	Siegel (1986a)
	F	0.00115	3.457	15-59	114	3C, D gravid	
January	M	0.00156	3.403	23-60	114	3A, B gravid-spent	Siegel (1986a)
	F	0.00282	3.234	23-60	114	3D/E gravid-spent	
February	M	0.00111	3.507	16-58	129	3A spent	Siegel (1986a)
	F	0.00211	3.302	16-59	132	3E spent	
June	M	0.00328	3.176	21-59	380	3A resting stage	Siegel (1989a)
	F	0.00441	3.084	21-55	340	3A resting stage	
Feb/Mar	M	0.00613	3.0776	34-57	1882	gravid	Morris *et al.* (1988)
	F	0.00289	3.270	31-58	1417	gravid + spent	
	(F)	0.01088	2.9077	31-58	940	only non-gravid females	
	(F)	0.00975	2.9809	41-58	477	only gravid females	
	(F)	0.03548	2.590	39-56	65	only spent females	

Table 4: Length-weight relationship for krill (*Euphausia superba*) not separated for males and females, $W_W = a \cdot L^b$ for wet weight (in mg) and total length (AT in mm). Length classes indicated by * refer to Standard 2 and ** to Reference body length of Mauchline (1980).

Month	Regression Coefficient a	b	Size Range (mm)	Number of Krill	Dominant Adult Maturity Stages	Reference
Several months	0.00056	3.62	24-58	30/mm		Chekunova and Rynkova (1974)
Jan/March	0.00229	3.35	22-42**	49	mostly adolescent	Clarke (1976)
April	0.0018	3.3436	20-61	1085	spent	Sahrhage (1978)
Feb/March	0.0018	3.3831		145		Jazdzewski *et al.* (1978), identical to Rakusa-Suszczewski (1981)
Jan/Feb	0.00158	3.40	28-58	114	prespawning-gravid	Kils (1979)
Feb/March	0.00298	3.4232	23-47*	5082		Rojas *et al.* (1981)
Feb/March	0.00385	3.20	26-59	3299	gravid-spent	Morris *et al.* (1988)
April	0.0017	3.4327	20-60	708	probably spent	Miller (1986)
October	0.00236	3.251	13-58	279	resting stage	Siegel (1986b)
December	0.00086	3.551	15-59	250	gravid	Siegel (unpubl. data)
January	0.00205	3.325	23-60	228	gravid-spent	Siegel (unpubl. data)
February	0.00083	3.561	13-60	228	gravid	Siegel (unpubl. data)
February	0.00165	3.380	16-59	261	spent	Siegel (1986a)
March	0.00193	3.325	30-62	143	spent	Siegel (1986b)
June	0.00353	3.151	21-59	339	resting stage	Siegel (unpubl. data)

Table 5: Length-weight relationship for other Antarctic euphausiid species than krill (*Euphausia superba*). $W_W = a \cdot L^b$ for wet weight (in mg) and total length (in mm).

Month	Sex	Regression Coefficient a	b	Size Range (mm)	Number of Krill	Dominant Adult Maturity Stages	Reference
Thysanoessa macrura							
Dec-Feb	ALL	0.00482	3.063	11-28	68	(resting?)	Rakusa-Suszczewski and Stepnik (1980)
Euphausia crystallorophias							
Dec-Feb	M F	0.0113 0.0055	2.79 3.04		118 129	(spent-resting?)	Rakusa-Suszczewski and Stepnik (1980)
November	ALL	0.0017	3.373	17-37	150	prespawning-gravid	Siegel (unpubl. data)
Euphausia frigida							
March	ALL	0.040	2.339	8-23	80	resting stage	Siegel (unpubl. data)
Euphausia triacantha							
May	ALL	0.0383	2.495	13-38	115	resting stage	Siegel (unpubl. data)

Légende des tableaux

Tableau 1: Relation longueur-poids pour le krill (*Euphausia superba*) mâle (M) et femelle (F), $W_{AFD} = a \cdot L^b$ pour le poids sec sans cendres (en mg) et la longueur totale (AT en mm).

Tableau 2: Relation longueur-poids pour le krill (*Euphausia superba*) mâle (M) et femelle (F), et total (ALL), $W_D = a \cdot L^b$ pour le poids sec (en mg) et la longueur totale (AT en mm).

Tableau 3: Relation longueur-poids pour le krill (*Euphausia superba*) mâle (M) et femelle (F), $W_W = a \cdot L^b$ pour le poids humide (en mg) et la longueur totale (AT en mm). Les classes de longueur indiquées par * se rapportent à la longueur du corps Standard 2 de Mauchline (1980).

Tableau 4: Relation longueur-poids pour le krill (*Euphausia superba*), mâle et femelle combinés, $W_W = a \cdot L^b$ pour le poids humide (en mg) et la longueur totale (AT en mm). Les classes de longueurs indiquées par * se rapportent au Standard 2 et ** à la référence de longueur du corps de Mauchline (1980).

Tableau 5: Relation longueur-poids pour les espèces d'euphausiacés antarctiques autres que le krill (*Euphausia superba*). $W_W = a \cdot L^b$ pour le poids humide (en mg) et la longueur totale (en mm).

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Таблица 2: Отношение "длина/вес" для самцов (M), самок (F) и обоего пола (ALL), криля (*E. superba*), $W_D = a \cdot L^b$ в случае сухого веса (в мг) и общей длины (AT в мм).

Таблица 3: Отношение "длина/вес" для самцов (M) и самок (F) криля (*E. superba*), $W_w = a \cdot L^b$ в случае мокрого веса (в мг) и общей длины (AT в мм). Размерные классы, обозначенные *, относятся к измерениям Стандартной длины 2 (Mauchline, 1980).

Таблица 4: Отношение "длина/вес" для криля (*E. superba*) обоего пола, $W_w = a \cdot L^b$ в случае мокрого веса (в мг) и общей длины (AT в мм). Размерные классы, обозначенные *, относятся к измерениям Стандартной длины 2, и ** - Контрольной длины (Mauchline, 1980).

Таблица 5: Отношение "длина/вес" для видов антарктических эвфаузиид помимо криля (*E. superba*). $W_w = a \cdot L^b$ в случае мокрого веса (в мг) и общей длины (AT в мм).

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Tabla 2: Relación talla-peso del kril (*Euphausia superba*) macho (M) y hembra (F), y combinados (ALL), $W_D = a * L^b$ para peso seco (en mg) y longitud total (AT en mm).

Tabla 3: Relación talla-peso del kril (*Euphausia superba*) macho (M) y hembra (F), $W_W = a \cdot L^b$ para peso húmedo (en mg) y longitud total (AT en mm). Las clases de talla indicadas con un * se refieren a la talla estándar 2 de la talla corporal de referencia de Mauchline (1980).

Tabla 4: Relación talla-peso del kril (*Euphausia superba*) combinada para machos y hembras, $W_W = a \cdot L^b$ para peso húmedo (en mg) y longitud total (AT en mm). Las clases de talla indicadas con un * se refieren a la talla estándar 2, mientras que las marcadas con dos ** , a la talla corporal de referencia de Mauchline (1980).

Tabla 5: Relación talla-peso de otras especies de eufáusidos antárticos aparte de kril (*Euphausia superba*). $W_W = a \cdot L^b$ para peso húmedo (en mg) y longitud total (en mm).

KRILL BIOMASS IN AREA 48 AND AREA 58: RECALCULATIONS OF FIBEX DATA

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Abstract

FIBEX acoustic and length frequency data held in the BIOMASS database were used to provide estimates of mean density and biomass for the Indian Ocean sector and the West Atlantic sector as well as for FAO Statistical Area 41, and CCAMLR Subareas 48.1, 48.2, 48.3, 48.6 and Division 58.4.2. Density estimates were calculated using the target strength relationships used at the original FIBEX acoustic workshop. Estimates for the different areas were also calculated using the target strength relationships of Green *et al.* (1990). The new estimates were on average 4.76 times larger than the old estimates for those cruises (seven out of the nine considered) that used an echosounder frequency of 120 kHz.

Résumé

Les données acoustiques et de fréquence des longueurs provenant de la FIBEX et stockées à la banque des données BIOMASS ont fourni les estimations de densité et de biomasse moyennes pour les secteurs de l'océan Indien et de l'Atlantique ouest, de même que pour la zone statistique 41 de la FAO et les sous-zones 48.1, 48.2, 48.3, 48.6 et la division 58.4.2 de la CCAMLR. Les estimations de densité ont été calculées au moyen des rapports de réponse acoustique utilisés lors du premier atelier acoustique FIBEX. Pour les diverses zones, les estimations ont également été calculées à l'aide des rapports de réponse acoustique de Green *et al.* (1990). Les nouvelles estimations étaient en moyenne de 4,76 fois plus élevées que les anciennes estimations des campagnes (sept sur les neuf examinées) qui utilisaient une fréquence d'échosondeur de 120 kHz.

Резюме

Акустические данные и данные по размерному составу криля, полученные в период FIBEX и хранящиеся в базе данных БИОМАСС, были использованы с целью получения оценок средней плотности и биомассы в индоокеанском и западноатлантическом секторах, а также Статистическом районе ФАО 41 и подрайонах 48.1, 48.2, 48.3, 48.6 и Участке 58.4.2 АНТКОМа. Оценки плотности были вычислены используя величины отношения силы цели к длине криля, принятые на первоначальном рабочем семинаре FIBEX по акустике. Оценки по этим районам также были вычислены с

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использованием величин отношений силы цели, приведенных в работе Грина и др. (Green *et al*, 1990). В среднем новые оценки были в 4,76 раза больше старых оценок, полученных в результате рейсов (семь из девяти), в ходе которых использовалась частота эхолота 120кГц.

Resumen

Se utilizaron los datos acústicos y de frecuencia de tallas de FIBEX archivados en la base de datos BIOMASS para obtener valores de la densidad media y biomasa en los sectores del océano Indico y del Atlántico occidental, así como para el Area estadística 41 de la FAO y las Subáreas 48.1, 48.2, 48.3, 48.6 y la División 58.4.2 de la CCRVMA. Los valores de densidad fueron estimados a partir de las relaciones de potencia del blanco utilizadas en el primer taller de acústica de FIBEX. También se calcularon valores para las distintas zonas mediante las relaciones de potencia del blanco de Green *et al.* (1990). Los nuevos valores fueron, en promedio, 4.76 veces superiores a los antiguos valores para aquellas campañas (siete de las nueve consideradas) que emplearon una frecuencia de sonido de 120 kHz.

1. INTRODUCTION

In 1991 the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) set precautionary catch limits for krill in Statistical Area 48 (Conservation Measure 32/X). These limits were based on calculations undertaken by the Scientific Committee's Working Group on Krill (WG-Krill) (SC-CAMLR, 1991a) using estimates of krill biomass established from results of the First International BIOMASS Experiment (FIBEX) (Anon., 1986).

An important parameter in the estimation of krill abundance from acoustic survey data is acoustic target strength (TS) (*cf.* Miller and Hampton, 1989). Krill TS has recently been re-assessed (Foote *et al.*, 1990) and there is now a general consensus that the TS values used during the FIBEX analysis (reported in Anon., 1986) were too high, thereby resulting in unrealistically low biomass estimates (Everson *et al.*, 1990). WG-Krill has recommended that a revised TS/length relationship should now be used (SC-CAMLR, 1991b) for analysing acoustic survey data.

In order to refine the krill biomass and subsequent yield estimates used to set the precautionary catch limits, SC-CAMLR has requested that the FIBEX data should be re-analysed using the most recent TS estimates (SC-CAMLR, 1991b) (Task 1). This re-analysis should not only calculate krill biomass by statistical subareas within Area 48 (West Atlantic) but should also be extended to other statistical areas, subareas or divisions wherever possible (Task 2). This paper presents the results of these analyses.

2. MATERIALS AND METHODS

The original FIBEX analysis was carried out by the BIOMASS Acoustic Working Group in September 1984. The report of that workshop (Anon., 1986) and other archived material (listed in Anon., 1986 - Appendix I) were used extensively for primary reference. The analysis reported here was undertaken at the BIOMASS Data Centre, British Antarctic Survey, Cambridge, UK.

2.1 Data Availability

A list of areas surveyed by the 11 vessels concerned is given in Table 1. Survey areas in relation to statistical subarea divisions are depicted in Figures 1 and 2.

2.1.1 Length Data

Length frequency data were available from net hauls for all cruises except *Kaiyo Maru* and *Nella Dan.* A single mean length was available for the *Kaiyo Maru* (41.4 mm) (Anon., 1986 - p. 46), but no information was available for the *Nella Dan.*

2.1.2 Acoustic Data

Data were available as the acoustic parameter Mean Volume Backscattering Strength (MVBS) for all cruises except *Odissey* and *Dr Eduardo L. Holmberg*, where krill densities were expressed in tonnes • n mile^2. To ensure that all data were available in equivalent units prior to analysis, MVBS values for these two cruises were calculated following the procedures outlined in Appendix I of this paper. Correspondence with Dr K. Yudanov and Dr W. Tesler (USSR) indicated that the methods described in archived material from Anon. (1986) were appropriate for *Odissey*. Correspondence with Lic. E. Marschoff (Argentina) and a subsequent visit to Argentina by Dr I. Everson (UK) established that the original data from *Dr Eduardo L. Holmberg* could not be used. The original FIBEX acoustic echocharts were therefore examined by Dr A. Madirolas (Argentina) and Dr Everson and the deflection in millimetres determined. These deflections were subsequently converted to MVBS following the approach outlined in Appendix I of this paper.

The *Umitaka Maru* and *Melville* cruises comprised only single transects. These data sets could be used to provide a mean but not a variance and therefore were not included in the calculations of total biomass reported in Anon. (1986). They were not considered further in the present analyses.

The final analyses were based upon a total transect length of 22 131 km, surveyed by nine vessels during the period 16 January to 12 March, 1981.

2.2 Data Analyses Carried Out

Every attempt was made to ensure that the current analyses were comparable with those of Anon. (1986). Wherever possible, the original analysis methodologies and area definitions were used. As a check, the FIBEX results were recreated using original TS values and strata prior to undertaking any analysis with new TS values and area definitions. The analyses themselves were carried out as follows so as to address the two tasks outlined above.

2.2.1 Task (1) - Recalculation of FIBEX Results

Phase 1: Krill densities by individual cruise were calculated and Table VIII in Anon. (1986) was recreated. The TS relationships used by Anon. (1986) and the new relationships specified by WG-Krill (SC-CAMLR, 1991b) were incorporated into separate calculations. This allowed for comparison between the original FIBEX results in Anon. (1986), recalculated results using the original FIBEX TS values and results derived from the new TS values.

Phase 2: Krill densities within strata (where strata were based upon geographic area and were originally defined in Table IX of Anon., 1986) were calculated using the new TS values. Estimates for the overall biomass in the Indian Ocean sector and in the West Atlantic sector were calculated.

2.2.2 Task (2) - Extension of New TS Analysis to Statistical Subareas

Most cruise survey transects ran meridionally and therefore could be allocated to new strata on the basis of longitude (with the exception of *Walther Herwig* where further division on the basis of latitude was necessary). These new strata were assigned to statistical areas or subareas and densities and biomass estimates by area or subarea were calculated.

2.3 Analysis Details

Analyses followed those described in Anon. (1986) (for a full description of their statistical basis see also Jolly and Hampton, 1990).

2.3.1 Length (l) to Weight (w) Relationship

The following length-weight relationship (Anon., 1986 - equation 15) was used to calculate mean weight from length frequency data:

$w = 0.000925l^{3.55}$ (w in mg, l in mm).

2.3.2 Target Strength (TS) to Length (l) Relationship

The following TS/length relationships were used in the calculation of mean weight density (gm^{-2}) from available MVBS values for the original FIBEX analysis reported in Anon. (1986) and were also used in this report in the recalculations carried out for comparison with the original results. Some of these TS/length relationships are shown in Figure 3.

120 kHz
$TS = 19.9\log l - 95.7$ (Anon., 1986 - equation 11)

50 kHz
$TS = 19.9\log l - 90.5$ (Anon., 1986 - p. 46)

200 kHz
The *Kaiyo Maru* mean weight densities reported in Anon. (1986) were derived using a TS value of -68.10 dB for a mean animal length of 41.4 mm for the cruise. Since no length frequency data were available for *Kaiyo Maru*, this TS value was based on information collected during the Second International BIOMASS Experiment (SIBEX). These same values were used to recalculate density estimates for comparison with the original results reported in Anon. (1986).

The new TS/length relationship recommended by WG-Krill (SC-CAMLR, 1991b) is that of Greene *et al.* (1990). This new relationship was used to calculate new mean weight density estimates (gm^{-2}). This TS/length relationship is shown in Figure 3.

120 kHz
$TS = 34.85\log l - 127.45$ (Greene *et al.*, 1990)

50 kHz

In the absence of new information on krill TS at 50 kHz the method of Greene *et al.* (1990) was used to estimate an adjustment factor (-10 • log(120/50) = -3.80) to provide the following revised TS/length equation at 50 kHz.

$$TS = 34.85 \log l - 131.25$$

The TS/length relationship at 50 kHz given in Klindt and Zwack (1984), which corresponds to a TS of -63.86 dB for a 40 mm krill, was also used for comparative purposes.

$$TS = 0.21l - 72.26 \qquad \text{(Klindt and Zwack, 1984)}$$

200 kHz

No new information was available from experimental studies at 200 kHz. The method of Greene *et al.* (1990) was therefore applied to estimate the appropriate adjustment factor (that is -10 • log(120/200) = + 2.22). This provides a new TS/length relationship at 200 kHz.

$$TS = 34.85 \log l - 125.23$$

For the *Kaiyo Maru*, with a mean animal length of 41.4 mm, this gives a TS of -68.85 dB. This new TS is very close to that used for *Kaiyo Maru* in Anon. (1986).

2.4 Areas and Strata

The area estimates for strata were obtained from Table VIII in Anon. (1986) and with the exception of *Walther Herwig* values were not recalculated (see Table 5 and the discussion below).

In accordance with the procedure outlined in Anon. (1986), strata were defined by cruise unless the areas overlapped. Areas of overlap identified in Anon. (1986) were present in the Drake Passage (*Itzumi* and *Professor Siedlecki* cruises) and the Bransfield Strait (again *Itzumi* and *Professor Siedlecki*).

Stratification of the Bransfield Strait caused few problems. The area covered by each stratum was taken from Table VIII of Anon. (1986). Survey strata were allocated to the "Central Bransfield" area (*Itzumi* Transects 1-16: Area = 24 900 km^2, *Professor Siedlecki* Transects 12-21: Area = 29 100 km^2) and to the "East Bransfield" area (*Itzumi* Transects 17-24: Area = 8 600 km^2).

The definition of strata reported in Anon. (1986) for the Drake Passage was more complex and required the division of individual transects surveyed by the *Professor Siedlecki*, however, the criteria for this division were not recorded. However, the mean density for the three Drake Passage strata calculated from both the *Professor Siedlecki* and the *Itzumi* was 0.39 gm^{-2} (Anon. 1986 - Table IX) compared to 0.39 gm^{-2} for the *Professor Siedlecki* stratum alone (Anon., 1986 - Table VIII). Given this similarity, and the difficulty of objectively dividing the *Professor Siedlecki* transects, the mean density from the *Professor Siedlecki* data was taken as representative of the Drake Passage stratum as a whole. Therefore, *Itzumi* transects falling within the Drake Passage stratum were not included in the area estimation of biomass (see Table 3 below) although they were included in the estimation of biomass by cruise (see Table 2 below).

Only data collected during the daytime were used in analyses by strata. Transect length was calculated by summing the lengths of the relevant echo-integrator[1] intervals. This is in keeping with the original FIBEX approach (Anon., 1986).

2.5 Calculation of Biomass

The mean weight density for each echo-integrator interval was calculated using equation 1 in Appendix II (this report). In the original FIBEX analysis (Anon., 1986) length frequency data from individual net hauls were assigned to specific echo-integrator resets. Since the criteria for such assignments were not archived it was impossible to recreate exactly the results reported in Anon. (1986). To avoid some of the sampling problems highlighted by Watkins *et al.* (1990), the present analyses utilised acoustic data from each stratum together with the combined length frequency distribution from all net hauls (excluding neuston net catches) taken in a cruise. Integrator interval densities were combined for each transect and weighted by echo-integrator reset length using equation 2 in Appendix II (this paper) (Anon., 1986 - equation 3) to provide an estimate for transect density (ρ_k). The mean density by stratum (ρ_A) weighted by transect length, was then calculated using equation 3 in Appendix II (this report), and biomass derived through multiplication by stratum area. The within-stratum density variance was estimated using equation 4 in Appendix II of this paper (Anon., 1986 - equation 4).

As described above, the Central Bransfield Strait was the only stratum in the current analysis where two survey sections overlapped. A single stratum value for (ρ_A) was obtained by combining the individual survey section densities, having weighted these by the inverse of their variance using equations 5 and 6 in Appendix II of this paper.

3. RESULTS AND DISCUSSION

3.1 Task (1) - Recalculation of FIBEX Results

Phase 1: The first task assigned by SC-CAMLR was the recalculation of density and biomass by cruise and region (SC-CAMLR, 1991b). Table 2 shows density by cruise taken from Table VIII of Anon. (1986) compared with results recalculated using the TS/length relationships from Anon. (1986) and the new TS/length relationships recommended by WG-Krill (SC-CAMLR, 1991b). The recalculated densities using the old TS/length relationships were mostly close (±10.0%) to those reported in Table VIII of Anon. (1986) with the exception of *Itzumi* in the Drake Passage, *Odissey* around South Georgia and *Dr Eduardo L. Holmberg* in the Scotia Sea.

Since the allocation of transects for *Itzumi* and *Odissey* were recreated exactly, it is impossible to determine the exact cause of the large differences observed. It is assumed that only small differences would have been brought about by variations in the krill length frequency distributions within individual nets allocated to particular echo-integrator resets in the analysis reported in Anon. (1986).

For the *Dr Eduardo L. Holmberg* the very large difference may be attributed to the very different methods used for providing density estimates. The original estimate, the derivation of which is described in Anon. (1986) Appendix G, was based upon a conversion factor determined from targeted net hauls. Examination of the details of the method, together with the

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[1] The amount of acoustic energy returned from krill for an interval (set either on the basis of time or on distance steamed) of ship's track was measured by analogue or digital echo-integration. MVBS values were then stored in the BIOMASS database for individual Echo-Sounder Distance Units (ESDU) corresponding to specific echo-integrator resets by time or distance.

difficulties of reproducing the calculations, suggested that the method described in Appendix I (this paper), was more reliable and that the associated estimate was probably a better assessment of the biomass in the strata.

By contrast, a much wider range of differences between density estimates using the old TS values and the new TS values are apparent; these varied from 0.98 times for *Kaiyo Maru* to 40.92 times in the case of *Walther Herwig*. For the *Kaiyo Maru*, the similarity can be accounted for by the minor difference between the 200 kHz TS value used in Anon. (1986) and the value derived from Greene *et al.* (1990). For the *Walther Herwig*, the large increase can be accounted for by the major difference between the TS value used in Anon. (1986) and the new value. For a 40 mm krill this reflects a change in TS value at 50 kHz from -58.62 dB to -75.35 dB. The density estimated using the 50 kHz TS value given in Klindt and Zwack (1984) (see above) was somewhere between that from using the TS value given in Anon. (1986) and that from using the value derived from Greene *et al.* (1990), but somewhat closer to the former (see Figure 3). Reservations have been expressed that extrapolating individual TS values to frequencies below 120 kHz may give spurious results (Greene *et al.*, 1990). Furthermore, extrapolation over a wide range of frequencies using an approach similar to that of Greene *et al.* (1990) may result in spurious projections since the backscattering amplitude varies dramatically (Chi *et al.*, 1992). Nevertheless, a new 50 kHz TS value somewhat lower than that used in Anon. (1986) and less than that at 120 kHz appears reasonable.

In the absence of krill length frequency information, it was not possible to recalculate mean weight density estimates for *Nella Dan* (see Table 2). This problem was further compounded by a lack of acoustic data essential to the determination of the coefficients of variation for the recalculated results and for the results using the new TS values. Consequently, new density estimates were not made. However, a multiplication factor was calculated from the ratio of ρ_A [new]/ρ_A [recalculated] from all other cruises using 120 kHz (N = 11 strata from Table 2) and was applied to the results for *Nella Dan* reported in Anon. (1986). The results reported here (see Tables 2, 4 and 6) use the original Anon. (1986) estimates of density and biomass for *Nella Dan* unless otherwise indicated. The same is also true for estimates of the coefficient of variation.

For 120 kHz, the average new mean density estimate is 4.86 times the recalculated estimate using the TS values from Anon. (1986). This difference supports the conclusions of Foote *et al.* (1990) and Everson *et al.* (1990) that the TS values originally used in Anon. (1986) led to significant underestimates of krill biomass. For 120 kHz the mean difference (4.86 times) between the new and old estimates is close to the multiplication factor (5.7 times) used by WG-Krill (SC-CAMLR, 1991a) to account for differences in older TS values (e.g., Anon. 1986) and used by WG-Krill in the conversion of FIBEX biomass estimates to absolute values.

Phase 2: To eliminate problems associated with the estimation of biomass in areas where cruise survey areas overlapped new strata were used (Table 3). Areas of overlap occurred between the *Marion Dufresne* and *Kaiyo Maru* cruises as well as between the *Professor Siedlecki* and *Itzumi* cruises. The recalculated densities using the old TS values are similar to those given in Table IX of Anon. (1986).

The results from combining strata to provide total estimates of biomass for the West Atlantic and Indian Ocean sectors are given in Table 4. Table 4 is comparable with Table X in Anon. (1986). In the West Atlantic the recalculated estimate of biomass using the old TS value is larger (1.5 times higher) than that reported in Anon. (1986), however, the substantial increase in the estimate for the area surveyed by *Dr Eduardo L. Holmberg* largely accounts for this. In comparison, the estimate for the West Atlantic using the new TS values is even higher (8-times higher) and is due solely to the changed TS values. In the Indian Ocean sector the recalculated estimate using the old TS value is very similar to the estimate reported in Anon. (1986), whilst the new estimate is only twice the old figure. The relatively small increase obtained using the new TS values in the Indian Ocean sector is largely due to the very small changes in TS value at 200 kHz.

For the estimates using the new TS values, some of the large difference in the West Atlantic sector is attributable to the large change in TS value at 50 kHz. The *Walther Herwig* surveyed a large area and so even a small difference in TS will exert a large influence on the calculated biomass. In the absence of more precise estimates of TS at 50 kHz and further information concerning the distribution of krill within the area surveyed by *Walther Herwig*, extreme caution needs to be exercised in further interpretation of these particular results. Taken together these uncertainties underline the need for more information on the TS of krill at 50 kHz.

3.2 Task (2) - Extension of New TS Analysis to Statistical Subareas

The second task assigned by SC-CAMLR was the calculation of density and biomass by statistical subarea (SC-CAMLR, 1991b). Most cruise survey transects ran meridionally and hence could be allocated to statistical subareas on the basis of longitude. Part of the *Walther Herwig* survey however, contained transects which extended beyond the limits of CCAMLR Subareas 48.1 and 48.2 into FAO Statistical Area 41. These transect sections were allocated into a new stratum (Table 5).

The overall combined biomass estimates for particular subareas using the new TS relationships are presented in Table 6. These results can be compared with similar estimates for Subareas 48.1, 48.2 and 48.3 undertaken by Everson (1991). Multiplying Everson's biomass indices (Everson, 1991 - Table 2) by the mean density increase (4.86 times) attributable to the most recent TS value from Greene *et al.* (1990) indicates that the current estimate for Subarea 48.3 is more or less directly comparable, the current estimate for Subarea 48.2 is about twice that expected and the current estimate for Subarea 48.1 is about three times that expected. These differences are largely due to two factors, firstly, the large change in TS at 50 kHz, the frequency used by *Walther Herwig* for surveying one of the largest areas of the FIBEX programme and secondly, the large increase in biomass attributable to the area surveyed by *Dr Eduardo L. Holmberg* following recalculation of the MVBS values.

4. SOME IMPLICATIONS ARISING FROM RE-ANALYSIS OF THE FIBEX RESULTS

In carrying out the re-analysis of the FIBEX survey results a number of issues are highlighted. These include:

(i) appraisal of the survey design and whether it was appropriate;

(ii) assessment of the analysis methods reported in Anon. (1986) and whether they were correct, or whether a more suitable method should have been utilised;

(iii) consideration of whether the survey was truly synoptic or whether it actually covered an extended period;

(iv) estimation of whether the survey area was representative of the known distribution of krill and the densities actually observed;

(v) and lastly, estimation of whether the survey area is typical of the areas where the precautionary catch limits were set.

Most easily appraised are the survey design and the correctness of the analysis methods used. The design of the survey is considered unbiased (Anon., 1980) and the method of analysis appropriate (Jolly and Hampton, 1990), to the extent that this method was utilised in this paper for the re-analysis.

That the survey was quasi-synoptic and covered a large area, were attributes that were emphasised by WG-Krill as being important in order to account for krill advection between subareas (SC-CAMLR, 1991a). The start of the FIBEX survey was 16 January 1981 and the end was 12 March 1981 (excluding *Umitaka Maru* and *Melville*) a period of 56 days (Anon., 1986 - Table 1). Within the limitations of a large-scale multi-ship survey this time interval is probably as close as it is possible to get, to a truly synoptic survey for such a large area.

When assessing whether the FIBEX survey is representative of the known distribution of krill and of the densities actually observed, it should be emphasised that the FIBEX survey was limited to only one season and was carried out over a decade ago. In contrast, there are now several national data sets from specific areas within Statistical Area 48 which span a number of years (some of these have been summarised in Everson 1988; Nast *et al.*, 1988; Siegel 1988). In general, it would appear that:

(i) biomass estimates may vary within single surveys depending upon the sampling techniques or interpretation method being applied (e.g., Klindt and Zwack, 1984; Klindt 1986; Nast *et al.*, 1988);

(ii) there may be an order of magnitude in variation of biomass which is attributable to seasonal effects (e.g., Siegel, 1988; Everson, in press); and

(iii) year-to-year variability is hard to assess given that surveys may also have been taken at different times of the season, but for some years it may be substantial, for example, Priddle *et al.* (1988) present evidence of large scale fluctuations in the annual biomass of krill around South Georgia.

When estimating whether the FIBEX survey area is representative of the areas where krill precautionary catch limits were set by CCAMLR, it should be stressed that the area covered by FIBEX is substantially less than that of the CCAMLR subareas (Figures 1 and 2). Furthermore, the FIBEX survey covered areas that were thought to be regions of krill abundance (Anon., 1979). Everson and Goss (1991) have demonstrated that high concentrations are to be found on the shelf, or close to it and this has been confirmed by more recent studies in Subarea 48.1 (Ichii *et al.*, 1991; Marín *et al.*, 1991). This would indicate that most of the krill biomass in Subareas 48.1, 48.2 and 48.3 was within the geographic limits set for the FIBEX survey. This supports the original FIBEX survey strategy, at least in the West Atlantic, which assumed that the areas outside the FIBEX survey were areas that were characterised by low krill abundance (Anon., 1979).

The biomass estimate used to set the precautionary catch limit contained in Conservation Measure 32/X, (SC-CAMLR, 1991a - paragraph 6.54) was based upon the best scientific information then available. The re-analysis undertaken here, however, has highlighted various problems so that there now appears to be some justification in exploring ways to improve upon the current results. Important considerations in this regard are:

(i) whether further large-scale surveys such as FIBEX are necessary; and

(ii) and whether FIBEX results can be more meaningfully applied to specific ecological or fishing areas as opposed to statistical areas or subareas.

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REFERENCES

ANON. 1979. Acoustic estimation of krill - II. *BIOMASS Rept Ser.*, 9: 14 pp.

ANON. 1980. FIBEX acoustic survey design. *BIOMASS Rept Ser.*, 14: 11 pp.

ANON. 1984. Meeting of Working Party on Acoustics to Prepare for Post-FIBEX Acoustic Workshop. *BIOMASS Rept Ser.*, 37: 60 pp.

ANON. 1986. Post-FIBEX Acoustic Workshop. *BIOMASS Rept Ser.*, 40: 106 pp.

CHI, D., T.K. STANTON and P.H. WIEBE. 1992. Frequency dependence of sound backscattering from live individual zooplankton. *ICES J. Mar. Sci.*, 49: 97-106.

EVERSON, I. 1988. Can we satisfactorily estimate variation in krill abundance? In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin Heidelberg: 199 pp.

EVERSON, I. 1991. Precautionary catch limits for krill. Document *SC-CAMLR-X/10*. CCAMLR, Hobart, Australia: 6 pp.

EVERSON, I. In press. Managing Southern Ocean krill and fish stocks in a changing environment. *Proc. Roy. Soc.*

EVERSON, I. and C. GOSS. 1991. Krill fishing activity in the southwest Atlantic. *Antarctic Science*, 3 (4): 351-358.

EVERSON, I., J. WATKINS, D.G. BONE and K.G. FOOTE. 1990. Implications of a new acoustic target strength for abundance estimates of Antarctic krill. *Nature*, 345: 338-340.

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

GREENE, C.H., T.K. STANTON, P.H. WIEBE and S. MCCLATCHIE. 1990. Acoustic estimates of Antarctic krill. *Nature*, 349: 110 pp.

ICHII, T., H. ISHII and M. NAGANOBU. 1991. Krill (*Euphausia superba*) distribution in relation to water movement and phytoplankton distribution off the northern South Shetland Islands. Document *WG-Krill-91/22*. CCAMLR, Hobart, Australia.

JOLLY, G.M. and I. HAMPTON. 1990. A stratified random transect design for acoustic surveys of fish stocks. *J. Fish. Aquat. Sci.*, 47: 1282-1291.

KLINDT, H. 1986. Acoustic estimates of the distribution and stock size of krill around Elephant Island during SIBEX I and II in 1983, 1984 and 1985. *Arch. FischWiss.*, 37: 107-127.

KLINDT, H. and F. ZWACK. 1984. A method for acoustic estimation of krill - (*Euphausia superba* Dana) abundance applied to FIBEX data. *Arch. FischWiss.*, 34: 121-144.

MARÍN, V.H., A. MUJICA and P. EBERHARD. 1991. Chilean krill fishery: analysis of the 1991 season. Document *WG-Krill-91/39*. CCAMLR, Hobart, Australia.

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill: a review *BIOMASS Sci. Ser.*, 9: 166 pp.

NAST, F., K.-H. KOCK, D. SAHRHAGE, M. STEIN and J.E. TIEDTKE. 1988. Hydrography, krill and fish and their possible relationships around Elephant Island. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin, Heidelberg: 183 pp.

PRIDDLE, J., J.P. CROXALL, I. EVERSON, R.B. HEYWOOD, E.J. MURPHY, P.A. PRINCE and C.B. SEAR. 1988. Large-scale fluctuations in distribution and abundance of krill - a discussion of possible causes. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin, Heidelberg: 169 pp.

SC-CAMLR. 1991a. Report of the Third Meeting of the Working Group on Krill. In: *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X)*, Annex 5. CCAMLR, Hobart, Australia: 107-204.

SC-CAMLR. 1991b. *Report of the Tenth Meeting of the Scientific Committee. (SC-CAMLR-X).* CCAMLR, Hobart, Australia: 427 pp.

SIEGEL, V. 1988. A concept of seasonal variation of krill (*Euphausia superba*) distribution and abundance west of the Antarctic Peninsula. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin, Heidelberg: 219 pp.

SIMRAD. 1975. SIMRAD QM Echo Integrator Operator's Manual P574E. Simrad, Etterstad, Oslo, Norway.

WATKINS, J.L., D. MORRIS, C. RICKETTS and A.W.A. MURRAY. 1990. Sampling biological characteristics of krill: effect of heterogenous nature of swarms. *Mar. Biol.*, 107: 409-415.

Table 1: Ships, areas and acoustic frequencies used during FIBEX.

Ship	Country	Area	Echosounder Frequency (kHz)
Walther Herwig	Germany	48	50
Dr Eduardo L. Holmberg	Argentina	48	120
Itzumi	Chile	48	120
Odissey	USSR	48	120
Professor Siedlecki	Poland	48	120
*Melville**	USA	48	50
SA Agulhas	South Africa	48	120
Kaiyo Maru	Japan	58	200
Marion Dufresne	France	58	120
Nella Dan	Australia	58	120
*Umitaka Maru**	Japan	88	120

* Not used in present analysis (see text for explanation).

Table 2: Mean density and biomass estimates from FIBEX acoustic survey cruises, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in $gm^{-2} = \rho A$; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = CV].

Ship/Strata	Transect Number	TL	Area	ρ_A			Ratio ρA	Bw			CV		
				BIO	OLD	NEW	OLD:NEW	BIO	OLD	NEW	BIO	OLD	NEW
Walther Herwig	1-13	3549.5	220.7	1.7	1.7	70.1	40.92	372.0	381.8	15479.2	28.0	27.9	27.9
Dr Eduardo L. Holmberg	1-22	2627.4	83.8	2.8	18.6	82.8	4.45	234.0	1559.4	6937.4	55.0	34.9	34.9
Itzumi (Bransfield)	1-24	1440.9	26.5	32.3	32.6	159.6	4.89	854.0	864.3	4228.7	20.0	19.7	19.7
Itzumi (East Drake)	34-40	313.0	8.3	8.8	13.7	66.9	4.89	73.0	113.5	555.2	94.0	65.0	65.0
Itzumi (West Drake)	26-33	240.08	4.7	24.0	18.8	91.9	4.89	112.0	88.3	432.1	34.0	43.1	43.1
Odissey (South Georgia)	51-58	497.8	25.3	15.6	12.6	59.7	4.76	395.0	317.8	1511.1	38.0	37.9	37.9
Odissey (Scotia A)	1-13	2196.0	68.3	17.3	18.8	89.3	4.76	1185.0	1284.0	6102.5	23.0	20.1	20.1
Odissey (Scotia B)	14-15	322.1	33.3	3.5	3.5	16.8	4.76	115.0	117.3	557.9	7.0	7.5	7.5
Prof. Siedlecki (Bransfield)	12-21	520.4	29.1	4.7	5.2	21.9	4.24	136.0	150.5	638.2	42.0	37.7	37.7
Prof. Siedlecki (Drake)	1-11	2245.9	160.1	0.4	0.4	1.5	4.24	62.0	56.4	239.2	31.0	31.1	31.1
SA Agulhas	1-9	3037.3	576.0	1.1	1.2	8.0	6.78	610.0	682.6	4626.4	19.0	22.9	22.9
Marion Dufresne	1-3	1493.1	240.3	0.2	0.2	1.0	4.84	50.5	50.2	242.9	43.0	41.1	41.1
Kaiyo Maru	1-6	1894.6	537.5	4.3	4.4	4.3	0.98	2310.0	2300.0	2230.0	28.0	30.5	30.5
*Nella Dan**	-	3000.2	1091.6	1.5	-	7.1*	4.86*	1578.0	-	7696.9*	38.0	-	-

Difference in TOTAL Bw is ± 2.1%; BIO = 6.27 • 10^6 tonnes; OLD = 6.41 • 0^6 tonnes (excluding *Nella Dan* and *Dr Eduardo L. Holmberg*).

* For *Nella Dan* the NEW ρ_A is derived by multiplying the BIO estimate by the mean incrase due to the new TS value (see text for details).

Table 3: Mean density and biomass estimates for various strata from FIBEX acoustic survey cruises, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = Cv].

Ship/Strata	Transect Number	TL	Area	ρA			Bw			CV		
				BIO	OLD	NEW	BIO	OLD	NEW	BIO	OLD	NEW
CENTRAL BRANSFIELD												
Central Bransfield	-	1431.6	24.9	6.3	6.8	28.2	155.9	170.1	703.1	31.0	73.8	88.7
Itzumi	1-16	911.2	24.9	32.3	35.3	172.8	854.6	935.8	4302.2	20.0	22.9	22.9
Prof. Siedlecki	12-21	520.4	29.1	4.7	5.2	21.9	136.0	150.5	638.2	42.0	37.7	37.7
EAST BRANSFIELD												
Itzumi	17-24	529.7	8.6	27.2	28.0	136.9	234.1	240.6	1177.0	41.0	41.5	41.5
DRAKE PASSAGE												
Prof. Siedlecki	1-11	2245.9	160.1	0.4	0.4	1.5	62.0	56.4	239.2	31.0	31.1	31.1
INDIAN OCEAN												
Marion Defresne	2-3	800.2	81.7	0.1	0.1	0.5	8.0	8.7	41.9	45.0	28.2	28.2

Table 4: Mean density and biomass estimates from FIBEX acoustic survey cruises for the West Atlantic sector and the Indian Ocean sector, with original BIOMASS results (BIO), recalculated results (OLD) and re-analysis using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^6; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^6; coefficient of variation (%) = CV].

Sector/Strata	TL	Area	ρA			Bw			CV		
			BIO	OLD	NEW	BIO	OLD	NEW	BIO	OLD	NEW
West Atlantic	13399.87	0.63	4.46	6.60	52.33	2.65	4.13	32.71	14.00	23.60	16.67
Indian Ocean	8732.29	2.29	1.97	2.03*	3.74*	4.51	4.63*	8.55*	19.70	24.02*	20.79*

* Uses BIO density and variance estimates for *Nella Dan* - see text for details

Table 5: Mean density and biomass estimates for three strata [Subarea 48.1 (southwest), Subarea 48.2 (east) and Statistical Area 41 (northwest) from FIBEX *Walther Herwig* acoustic survey cruise, using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^3; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^3; coefficient of variation (%) = CV].

Ship/Strata	Transect Number	TL	Area	ρA NEW	Bw NEW	CV NEW
Walther Herwig (East)	6-7	773.1	56.5	35.6	2008.7	40.1
Walther Herwig (South West)	1-5 8-13 (South of 60°S)	1892.4	89.4	94.2	8420.4	38.0
Walther Herwig (North West)	1-5 8-13 (North of 60°S)	884.0	74.8	48.9	3657.4	29.6

Table 6: Mean density and biomass estimates for strata combined according to statistical areas and subareas from FIBEX acoustic survey cruises, using new CCAMLR TS (NEW). See text for further details. [Transect length in km = TL; area in km^2 = AREA • 10^5; density in gm^{-2} = ρA; biomass in tonnes = Bw • 10^6; coefficient of variation (%) = CV].

Area/Subarea/Strata	Ship/Strata	TL	Area	ρA	Bw	CV
41	*Walther Herwig* (North West)	884.0	0.75	48.90	3.66	29.57
48.1	*Walther Herwig* (South West)	6099.5	2.83	37.24	10.54	35.00
	Central Bransfield					
	East Bransfield					
	Drake Passage					
48.2	*Walther Herwig* (East)	5918.6	2.42	64.52	15.61	22.19
	Dr Eduardo L. Holmberg					
	Odissey (Scotia A)					
	Odissey (Scotia B)					
48.3	*Odissey* (South Georgia)	497.8	0.25	59.73	1.51	37.95
48.6	*Agulhas*	3037.3	5.76	8.03	4.63	22.95
58.4.2*	*Marion Dufresne*	5695.0*	17.11*	2.29*	3.93*	32.00*
	Kaiyo Maru					
	*Nella Dan**					

* Uses BIO density and variance estimates for *Nella Dan* - see text for details.

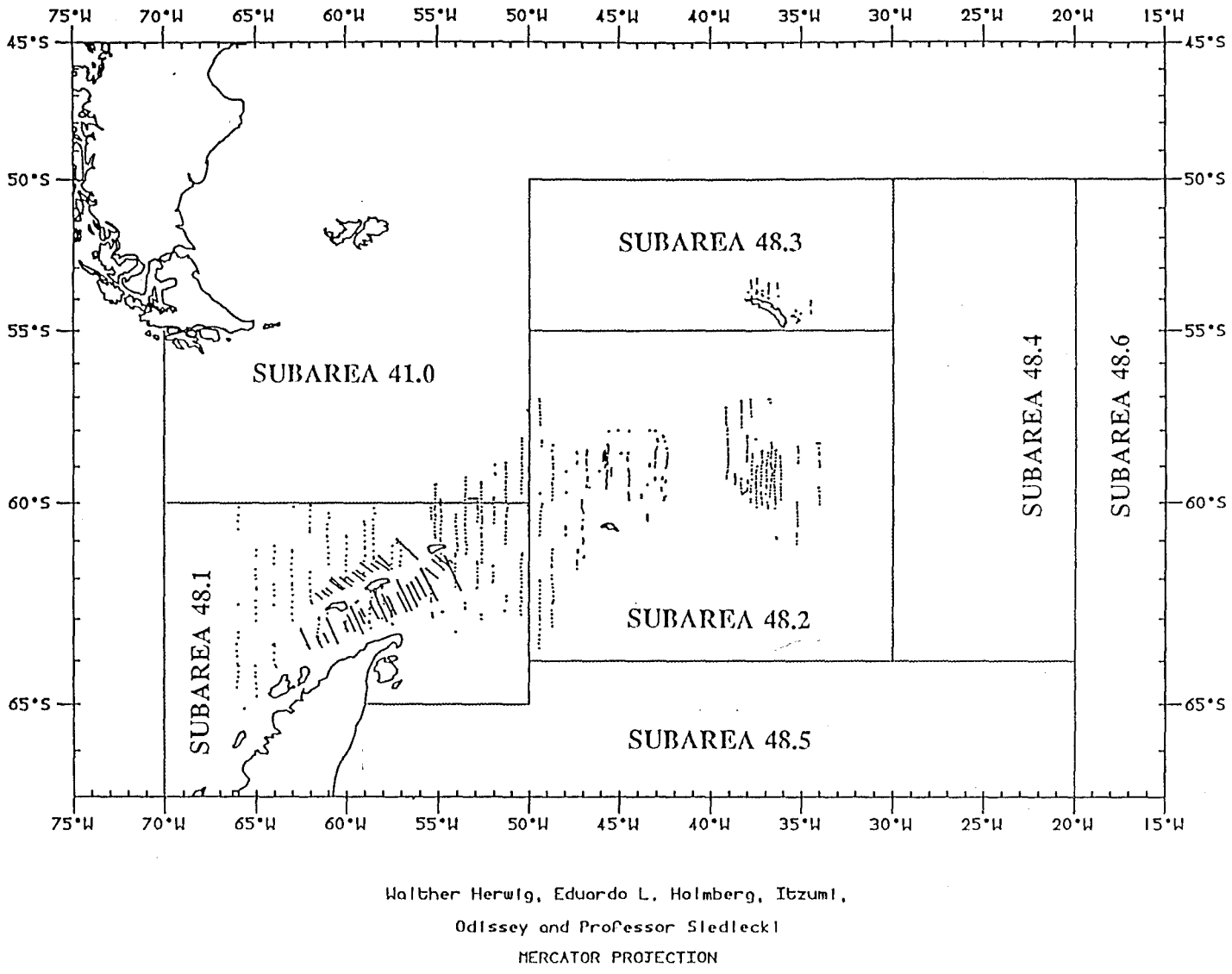

Figure 1: FIBEX survey areas and CCAMLR statistical subareas in the West Atlantic sector.

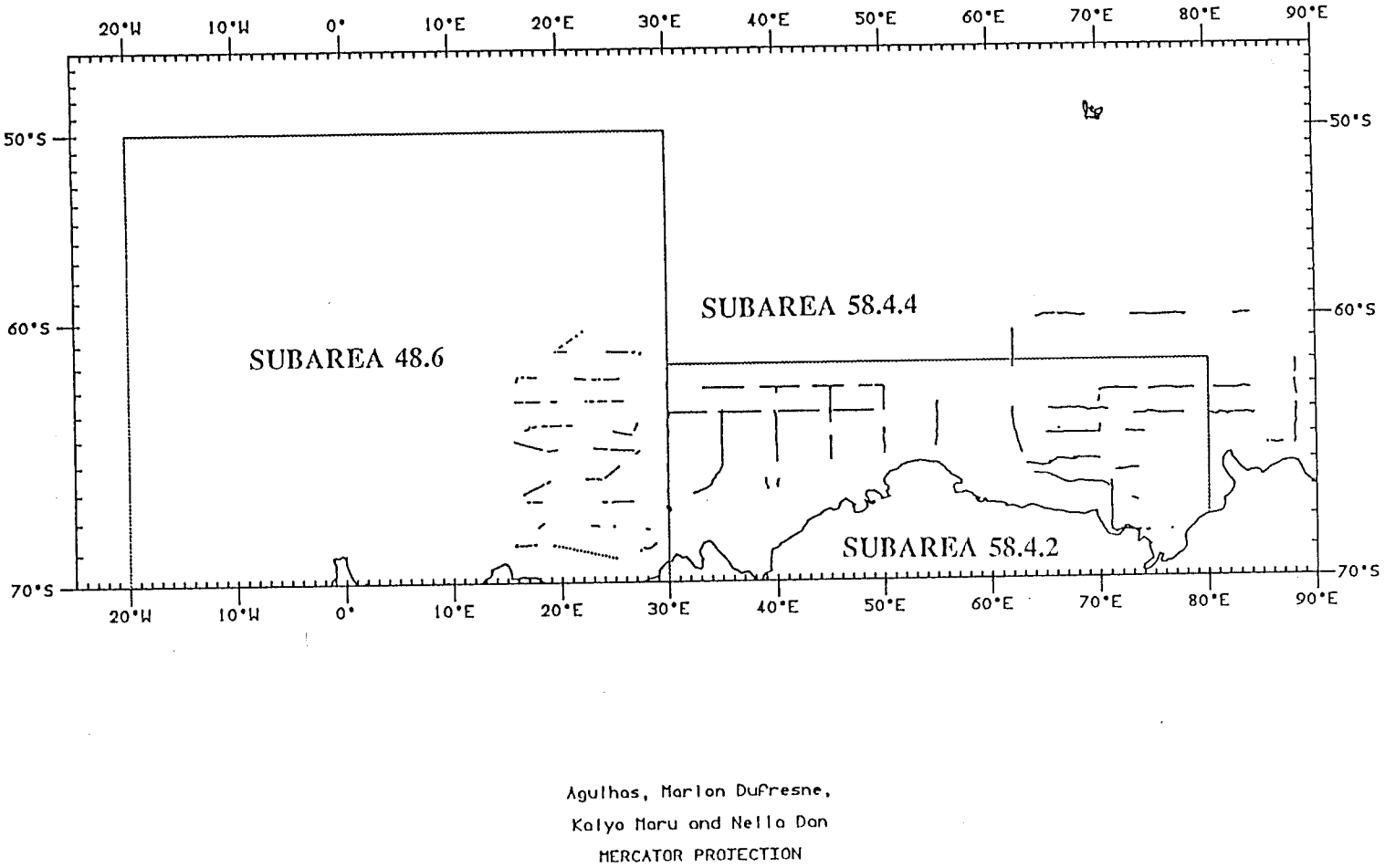

Figure 2: FIBEX survey areas and CCAMLR statistical subareas in the Indian Ocean sector.

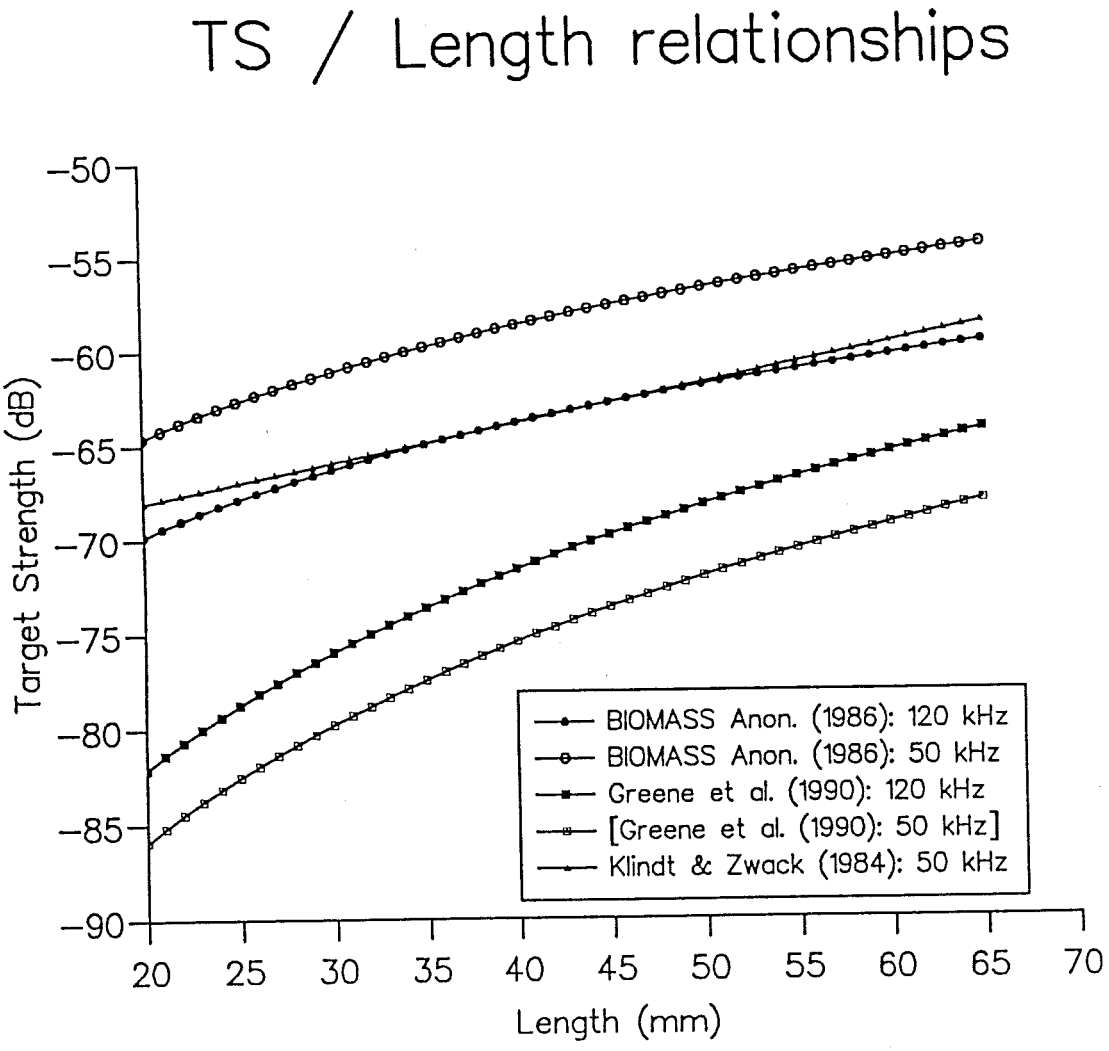

Figure 3: Relationship between krill target strength (TS) and krill length.

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Tableau 1: Navires, zones et fréquences acoustiques utilisés pendant la FIBEX.

Tableau 2: Densité moyenne et estimations de biomasse à partir des campagnes d'évaluation acoustique FIBEX, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en $gm^{-2} = \rho A$; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 3: Densité moyenne et estimations de biomasse de diverses strates à partir des campagnes d'évaluation acoustique FIBEX, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en $gm^{-2} = \rho A$; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 4: Densité moyenne et estimations de biomasse à partir des campagnes d'évaluation acoustique FIBEX pour les secteurs de l'Atlantique Ouest et de l'océan Indien, avec les résultats originaux de BIOMASS (BIO), les résultats à nouveau calculés (OLD) et la nouvelle analyse utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^6; densité en $gm^{-2} = \rho A$; biomasse en tonnes = Bw x 10^6; coefficient de variation (%) = CV].

Tableau 5: Densité moyenne et estimations de biomasse pour trois strates [sous-zone 48.1 (sud-ouest), sous-zone 48.2 (est) et zone statistique 41 (nord-ouest)] à partir de la campagne d'évaluation acoustique du *Walther Herwig* de la FIBEX, en utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^3; densité en $gm^{-2} = \rho A$; biomasse en tonnes = Bw x 10^3; coefficient de variation (%) = CV].

Tableau 6: Densité moyenne et estimations de biomasse pour des strates combinées selon les zones et sous-zones statistiques à partir des campagnes d'évaluation acoustique FIBEX en utilisant la nouvelle réponse acoustique CCAMLR TS (NEW). Se référer au texte pour davantage de précisions. [Longueur de la radiale en km = TL; aire en km^2 = AREA x 10^5; densité en $gm^{-2} = \rho A$; biomasse en tonnes = Bw x 10^6; coefficient de variation (%) = CV].

Légende des figures

Figure 1: Secteurs d'étude FIBEX et sous-zones statistiques de la CCAMLR du secteur Atlantique occidental.

Figure 2: Secteurs d'étude FIBEX et sous-zones statistiques de la CCAMLR du secteur de l'océan Indien.

Figure 3: Rapport entre la réponse acoustique (TS) et la longueur du krill.

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RECREATION OF *ODISSEY* AND *DR EDUARDO L. HOLMBERG* MVBS DATA

ODISSEY

Density values (ρ_s) expressed in tonnes • n mile^2 were used to calculate MVBS values (Sv) following the reverse of the procedure given in archived material from Anon. (1986).

$$Sv = 10 \bullet \log_{10}(\rho_v) + TS$$

where the following 120 kHz TS/length relationship applies:

$$TS = 20\log l - 77.2 \ (l \text{ in cm})$$

and

$$\rho_v = \frac{\rho_s}{(3.43w\Delta R)}$$

and the conversion from n mile^2 to km^2 is 3.43 (1.852^2), and ρ_v is density in gm^{-2}, ρ_s is density in tonnes • n mile^2, w is mean weight (g) and ΔR is the integration depth range.

The following constants were used for particular regions:

for South East Scotia Sea: $w = 0.61$ g, $l = 4.3$ cm
for South Georgia: $w = 0.36$ g, $l = 3.7$ cm.

DR EDUARDO L. HOLMBERG

The integrator deflections, D, measured from the *Dr Eduardo L. Holmberg* acoustic echocharts archived from the FIBEX cruise were substituted into the following equation (SIMRAD, 1975) and re-arranged to give MVBS (Sv):

$$Sv = 10\log D - 10\log R - SL - VR + TVG - 10\log\psi - 10\log L + 10\log C - G$$

where the QM integrator with a 50 mm full scale deflection required an integration factor, E, of 3.8 in order to convert echogram integration values to 50 mm scale; the integration range (deep - shallow: 100 - 4 = 96 m) is R; the source level, SL, is 215.0 dB; the voltage response, VR, is -108.1 dB; the maximum time varied gain, TVG, is 47.0 dB; the velocity of sound in seawater, c, is 1 500 m s^{-1}; the pulse duration, τ, is 0.6 ms; the beam pattern factor, 10 log ψ is -18.0 dB; the integration distance is L; the conversion factor C, needed to convert the integrator deflection on a 50 mm scale to V^2 per n mile • m^{-1} is 1.54; and the integrator gain, G is 10 dB.

EQUATIONS USED DURING CURRENT ANALYSES OF FIBEX RESULTS

EQUATION 1: MEAN WEIGHT DENSITY PER ECHO-INTEGRATOR INTERVAL

The mean weight density per echo-integrator interval, ρ_i is:

$$\bar{\rho}_i = c\Delta R_i 10^{0.1\bullet\left[(\bar{S}v)_i - D\right]} \frac{\sum_{j=1}^{N} n_j l_j^a}{\sum_{j=1}^{N} n_j l_j^{0.1\bullet B}}$$

where a and c are constants in the length/weight expression:

$$\text{Weight} = c\, l^{\,a} \qquad \text{(a)}$$

and B and D are constants in the TS/length relationship:

$$TS = B \log l + D \qquad \text{(b)}$$

and l is length, ΔR is the depth range (deep - shallow), i is the reset interval, j is the length class, n_j is the number of animals in length class j, Sv is the MVBS. Note also $0.1B = b$ and $10^{0.1D} = d$ where b and d are constants in the equation relating mean reflectivity of scatterers to length (see Anon., 1986 - Appendix A).

EQUATION 2: COMBINATION OF RESET DENSITIES WEIGHTED BY RESET LENGTH

The mean weight density for transect k, ρ_k is:

$$\bar{\rho}_k = \frac{1}{L_k} \sum_{i=1}^{M_k} (\rho_k)_i (D_k)_i$$

where ρ_{ki} is the mean weight density for the i-th reset interval on transect k, M_k is the number of intervals in the k-th transect, D_{ki} is the length of the i-th interval on the k-th transect and the length of the k-th transect, L_k, over which data is selected (i.e., during the daytime), is given by:

$$L_k = \sum_{i=1}^{M_k} (D_k)_i$$

EQUATION 3: MEAN DENSITY BY STRATUM WEIGHTED BY TRANSECT LENGTH

The mean density for a stratum, ρ_A is:

$$\bar{\rho}_A = \frac{\sum_{k=1}^{K} \bar{\rho}_k L_k}{\sum_{k=1}^{K} L_k}$$

Biomass is derived through multiplication by the stratum area. Densities from overlapping strata (i.e., Central Bransfield Strait) were combined with separate density estimates being weighted by the inverse of their variance.

EQUATION 4: VARIANCE OF DENSITY IN STRATUM

The variance of density in a stratum was estimated using equation 4 of Anon. (1986):

$$\mathrm{Var}(\bar{\rho}_A) = \frac{K}{K-1} \frac{\sum_{k=1}^{K} (\bar{\rho}_k - \bar{\rho}_A)^2 L_k^2}{\left(\sum_{k=1}^{K} L_k \right)^2}$$

EQUATIONS 5 AND 6: CALCULATION OF COMBINED MEAN WEIGHT DENSITY FOR OVERLAPPING STRATA

The mean weight density for overlapping strata, ρ_c is:

$$\bar{\rho}_c = \sum_{i=1}^{N} w_i (\bar{\rho}_A)_i$$

where the weight, w_i, for each separate density estimate is:

$$w_i = \frac{\frac{1}{\mathrm{Var}(\bar{\rho}_A)_i}}{\sum_{i=1}^{N} \frac{1}{\mathrm{Var}(\bar{\rho}_A)_i}}$$

ABUNDANCE, SIZE AND MATURITY OF KRILL (*EUPHAUSIA SUPERBA*) IN THE KRILL FISHING GROUND OF SUBAREA 48.1 DURING THE 1990/91 AUSTRAL SUMMER

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

Abstract

Acoustic and net sampling surveys for krill were conducted in the krill fishing ground north of the South Shetland Islands from 18 January to 3 February 1991. Distinct offshore-inshore heterogeneities in abundance and maturity of krill were observed. The survey area was divided into four zones: oceanic, slope frontal, neritic and nearshore zones. The mean density of krill was low in the oceanic zone (8.5 g/m^2), intermediate in the frontal (37.3 g/m^2) and neritic (28.1 g/m^2) zones, and extremely high in the nearshore zone (134.7 g/m^2). The last zone corresponds to the shelf break or the shelf area where topographic eddies were generated, suggesting that hydrodynamic convergence might be responsible for accumulation of krill in this zone. The total biomass over the survey area was estimated to be 1.59±0.45 million tonnes (95% confidence limit), of which 1.22±0.42 million tonnes was concentrated in the fishing ground (frontal + neritic + nearshore zones). Information from other studies indicated that krill biomass in this region had been lower than expected until early February 1991. As for maturity stages of krill, spawning krill (modal body length 49 mm) were dominant in the oceanic and frontal zones, whereas less mature krill (modal length 45 mm) dominated in the neritic and nearshore zones. Juveniles, which were scarce in the survey described, were found restricted mainly to the nearshore zone. Gravid females were exceedingly abundant in the slope frontal zone, having a mean density of 23.9 g/m^2 (411 000 tonnes), as contrasted with a low 3.7 g/m^2 (163 000 tonnes) in the oceanic zone. Gravid females were nearly absent in the neritic and nearshore zones. This indicates that slope frontal features may be important for the formation of favourable conditions for krill spawning.

Résumé

Des campagnes d'évaluation du krill par méthode acoustique et par échantillonnage au filet ont été menées dans le lieu de pêche de krill situé au nord des îles Shetland du Sud du 18 janvier au 3 février 1991. Une hétérogénéité distincte est apparue en matière d'abondance et de maturité du krill entre le large et la côte. L'aire considérée a été divisée en quatre zones: la zone océanique, celle du bord de la pente, la zone néritique et la zone proche de la côte. La densité moyenne du krill était faible dans la zone océanique (8,5 g/m^2), intermédiaire dans les zones frontale (37,3 g/m^2) et néritique (28,1 g/m^2) et extrêmement haute dans la zone côtière (134,7 g/m^2). Cette dernière zone correspond à la bordure du plateau ou à la région du plateau d'où provenaient les

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tourbillons topographiques, ce qui laisse entendre que la convergence hydrodynamique pourrait être responsable de l'accumulation du krill dans cette zone. La biomasse totale de la zone considérée à été estimée à 1,59 ± 0,45 million de tonnes (intervalle de confiance de 95%), dont 1,22 ± 0,42 million de tonnes étaient concentrées dans le lieu de pêche (zones frontale + néritique + côtière). Des informations provenant d'autres études indiquaient qu'avant début février 1991, la biomasse de krill avait été plus faible qu'on aurait pu s'y attendre dans cette région. En ce qui concerne les stades de maturité du krill, le krill reproducteur (longueur modale du corps, 49 mm) était prédominant dans les zones océanique et frontale, alors que le krill à un stade de maturité moins avancé (longueur modale, 45 mm) dominait dans les zones néritique et côtière. Les juvéniles, rares dans la campagne d'évaluation décrite, étaient généralement restreints à la zone côtière. Les femelles gravides de la zone du bord de la pente, d'une densité moyenne de 23,9 g/m^2 (411 000 tonnes), étaient extrêmement abondantes par rapport à la faible densité de 3,7 g/m^2 (163 000 tonnes) observée dans la zone océanique. Les femelles gravides étaient pratiquement absentes des zones néritique et côtière. Ceci met en évidence l'importance potentielle des caractéristiques du bord de la pente dans la formation de conditions favorables à la reproduction du krill.

Резюме

С 18 января по 3 февраля 1991 г. проводились акустические съемки и выборочные траловые съемки на участке промысла криля к северу от Южных Шетландских о-вов. Наблюдались четкие неоднородности в численности и половозрелости криля в прибрежных водах и в открытом море. Съемка делилась на четыре зоны: океаническая, фронтального склона, неритическая и прибрежная. Средняя плотность криля была низкой в океанической зоне (8,5 г/м^2), средней в фронтальной (37,3 г/м^2) и неритической (28,1 г/м^2) зонах и очень высокой в прибрежной зоне (134,7 г/м^2). Последняя зона совпадает с границей шельфа или районом шельфа, где образовались топографические водовороты. Это указывает на то, что накопление криля в этой зоне возможно вызвано гидронамической конвергенцией. Оценка общей биомассы в районе съемки - 1,59 ± 0,45 миллиона тонн (доверительный интервал - 95%), из чего 1,22 ± 0,42 миллиона тонн было сконцентрировано на промысловом участке (фронтальная + неритическая + прибрежная зоны). Полученная в результате других исследований информация указывает на то, что до начала февраля 1991 г. биомасса криля в данном районе была ниже ожиданной. Что касается стадий зрелости криля, в океанической и фронтальной зонах преобладал нерестующий криль (модальная длина - 49 мм), тогда как "менее" зрелый криль (модальная длина - 45 мм) доминировал в неритической и прибрежной зонах. Молодь, численность которой была низкой в ходе описанной съемки, в основном ограничивалась прибрежной зоной. Икряные самки были исключительно многочислены в зоне фронтального склона, где средняя плотность составила 23,9 г/м^2 (411 000 тонн). По сравнению с этим, в океанической зоне средняя плотность была

низкой - 3,7 г/м^2 (163 000). Икряные самки почти отсутствовали в неритической и прибрежной зонах. Это указывает на то, что особенности фронтального склона могут играть важную роль в формировании благоприятных условий для нереста криля.

Resumen

Del 18 de enero al 3 de febrero de 1991 se realizaron prospecciones acústicas y de muestreo mediante redes en la zona de pesca de kril al norte del archipiélago de las Shetland del Sur. Se observaron claras diferencias en la abundancia y madurez del kril entre las aguas de alta mar y las cercanas a la costa. El área de estudio se dividió en cuatro zonas: oceánica, talud frontal, nerítica y cercana a la costa. La densidad media del kril fue baja en la zona océanica (8.5 g/m^2), intermedia en la zona frontal (37.3 g/m^2) y nerítica (28.1 g/m^2), y extremadamente alta cerca de la costa (134.7 g/m^2). La última zona corresponde al borde de la plataforma continental o al área de la plataforma en donde se generan remolinos por accidentes topográficos, lo que sugiere que la convergencia hidrodinámica puede ser la causa de que el kril se acumule en esta zona. La biomasa total sobre el área estudiada se estimó en 1.59 ± 0.45 millones de toneladas (límite de confianza del 95%), de la cual 1.22 ± 0.42 millones de toneladas se concentraron en la zonas de pesca (frontal + nerítica + cercana a la costa). Según la información que se tenía de esta zona, de otros estudios realizados, la biomasa de kril fue menor de lo previsto hasta principios de febrero de 1991. En lo que respecta a los estados de madurez del kril, predominó el kril en desove (longitud modal de 49 mm) en las zonas océanica y frontal, mientras que el kril menos maduro (longitud modal de 45 mm) predominó en las zonas nerítica y cercana a la costa. Los juveniles, que resultaron escasos en la prospección estudiada, se limitaron a la zona cercana a la costa. Se encontró una gran cantidad de hembras grávidas en la zona del talud frontal con una densidad media de 23.9 g/m^2 (411 000 toneladas), comparado con una baja densidad (3.7 g/m^2) en la zona océanica (163 000 toneladas). Casi no se encontraron hembras grávidas en las zonas nerítica y cercana a la costa. Esto supone que las características del talud frontal podrían ser importantes en la formación de condiciones favorables para el desove del kril.

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1. INTRODUCTION

The Antarctic Peninsula region is known as a region rich in krill and has been actively studied. Siegel (1988) has provided the following information on the distribution and abundance of krill in this region: "In spring, as the pack ice retreats, krill abundance increases. In late December to early January it reaches its highest levels which last until the beginning of March. Interestingly, the krill stock shows a distinct spatial segregation in the maturity stages during the spawning season. Gravid and spawning adults occur along the continental slope and in oceanic waters, while nearer to the coast subadult krill dominate and juveniles are confined to coastal shelf waters."

In the Antarctic Peninsula region the krill fishing has regularly been conducted in the waters north of the South Shetland Islands, which corresponds to spawning and feeding grounds for adult and subadult krill (e.g., Siegel, 1988). As this area potentially overlaps with foraging grounds for krill-dependent predators during summer it has now become one of the "hot-spots". This paper presents information on biomass estimates and stock structure of krill in this fishing area during the 1990/91 summer, and also discusses mechanisms for the formation of persistent concentrations of krill by examining the relationship between the pattern of krill distribution and oceanographic structure.

2. MATERIALS AND METHODS

The cruise of RV *Kaiyo Maru* was conducted in two stages (Ichii *et al.*, 1991), although this paper deals only with research activities of the second leg. Leg 2 covered the waters from the north of Elephant Island to the north of Livingston Island from 18 January to 3 February 1991 (Figure 1). Transects ran in an offshore-inshore direction with 20 n miles between the transects. A zig-zag transect pattern in the offshore region of Livingston Island was caused by weather conditions which hampered operations. The cruise tracks running along the coast corresponded to the depth contour of approximately 150 m.

2.1 Oceanographic Observation

Oceanographic data were collected using a Sea-Bird SBE-19 CTD. CTD station depths were down to 1 000 m or closer to the sea bottom in shallower water.

For the study of subsurface current patterns around the islands, four drifting buoys (model C-2243, TOYOCOM, Japan) were released and tracked using the ARGOS system carried on TIROS-N and NOAA-A satellites. Typically, twelve locations per day were recorded for each buoy with an accuracy less than several hundred metres. From the 1987/88 survey krill were reported to be most abundant over the depth range of 30 to 40 m in this region (Anon., 1989). Therefore each buoy was deployed with a curtain drogue (4 m x 1 m) at 30 m depth to assess this subsurface circulation.

2.2 Hydroacoustic Survey

The echo sounder used was an FQ-50 with a digital integrator (Furuno Electric, Japan) operating at 200 kHz. The operating parameters of the acoustic system are summarised in Table 1. Throughout the survey period, excluding time spent on stations and towing sampling nets, the Mean Volume Back-Scattering Strength was continuously measured at the constant horizontal integration interval of 1 n mile for the depth range of 10 to 200 m or 10 m to bottom if shallower. The top depth of integration (10 m) was changed sometimes to 20 m to avoid surface noise. The target strength of krill used as a default value was -66.1 dB per 1 g wet weight of krill (Shimadzu *et al.*, 1989). The actual length compositions of krill during the current survey were fairly close to the length composition derived from target strength measurements.

The echo-integrator was calibrated with a hydrophone at the port of Tokyo before (29 October 1990) and after (26 March 1991) the cruise. Two calibration experiments showed little reduction in source level and receiving sensitivity.

2.3 Net Sampling

Samples of krill were collected by a rectangular frame trawl (the *Kaiyo Maru* Midwater Trawl (KYMT)), which has a mouth area of 9 m^2 and mesh size of 3.4 mm. The trawl was towed

obliquely from a depth of about 100 m to the surface at a speed of about 3 knots, at pre-determined fixed locations (blind tows). When a dense swarm of krill was detected acoustically, the KYMT was towed horizontally at swarm depth (aimed tows).

A sample from each haul was preserved in a 10% (buffered) formalin-seawater solution for later examination in the laboratory ashore. 150 individuals of krill were randomly selected from each sample for measurement of body length and determination of maturity stage; all individuals were analysed for small catches of ≤150 krill. Body length was measured to the nearest millimetre from the tip of the rostrum to the end of the telson. All measurements were carried out by a single observer to avoid methodologically biased differences in length frequency data (Watkins *et al.*, 1985). Maturity stages were identified according to the classifications of Makarov and Denys (1981). The size and maturity stage compositions from each sample were weighted by their respective mean density, estimated acoustically over 10 n miles along the transect near its respective sampling station before being pooled.

3. RESULTS

3.1 Oceanographic Features

Figure 2 shows horizontal salinity distribution at 10 m depth. Three different regions were clearly distinguished: the oceanic (deeper than approximately 3 000 m), slope frontal (≈ 500 to 3 000 m depth) and inshore (≈ 150 to 500 m) region (Figure 3). The frontal region, known as CBW (Continental Boundary Waters), is characterised by a relatively sharp increase in salinity towards the south (from 33.7 to 34.2 ‰) and is restricted to a band along the island shelf slope.

The tracks of four buoys demonstrated subsurface current patterns in each region (Figure 4). In the oceanic region buoy 1 moved continuously towards the northeast on meandering and eddying currents, reaching as far as the South Georgia region, and then became trapped in the shelf break area west of South Georgia. In the frontal region buoys 2 and 3 drifted eastward at first, then became entrained in the inshore waters adjacent to Elephant and Livingston/King George Islands, respectively. These buoys demonstrated the existence of complex eddies along the shelf break or on the shelf to the north of South Shetland Island. Buoy 4 was deployed in the inshore region and became entrained in an erratically rotating current along the shelf break, before becoming trapped in Barclay Bay on the northern side of Livingston Island. Thus, all the buoys exhibited a distinct tendency to be trapped in topographical complex eddies generated along the shelf break or on the shelf.

3.2 Hydroacoustic Surveys

3.2.1 Stratification of Survey Region

Figure 5 shows the distribution of krill density along the transects. Krill density tended to decrease oceanward. In the oceanic region only occasional occurrences of dispersed aggregations were observed, while in the frontal region dispersed aggregations or small swarms were frequently detected. The inshore region was characterised by large and dense swarms concentrated along the shelf breaks or on the shelf where topographical eddies were generated. In order to reduce the variance in the biomass estimate for the inshore region, this region was divided into two zones: neritic and nearshore (Figure 6). The latter zone was defined as narrow bands along the 150 m depth contour where krill were frequently concentrated. The width of the nearshore zone was assumed to be 3 n miles because the area of high density appeared to be formed at least over this width along the coast. Consequently, for the estimation of total krill biomass over the survey region, this area was divided into four zones: oceanic, slope frontal, neritic and nearshore.

3.2.2 Day/Night Differences in Krill Density

Because of krill's tendency to migrate at night towards the surface, where they can be undetectable acoustically, the difference in overall mean density between day and night was checked using pooled data (densities over integration intervals) for each zone. Day and night densities were 7.9 and 10.7 g/m^2; 37.2 and 40.0 g/m^2; 25.7 and 39.7 g/m^2; and 165.0 and 72.6 g/m^2 in the oceanic, frontal, neritic and nearshore zones, respectively. Since no significant day/night difference in mean density was observed for each zone, all day- and night-time data were combined for subsequent analyses.

3.2.3 Estimation of Mean Density and Biomass

Mean density and sampling variance were estimated using a transect-based method adopted at the second post-FIBEX acoustic workshop (Anon., 1986). This method assumes that the transect means are independent, that the regression of expected number of animals on transect length should pass through the origin, and that the variance of the number of animals is proportional to transect length.

Mean density (g/m^2) for each zone, the variance (Var) of the mean and 95% confidence limits (CL) about the mean were calculated from:

$$\bar{d}_i = \frac{\sum_{k=1}^{N_i} d_{ik} L_{ik}}{\sum_{k=1}^{N_i} L_{ik}}$$

$$\mathrm{Var}(\bar{d}_i) = \frac{N_i}{N_i - 1} \frac{\sum_{k=1}^{N_i} (d_{ik} - \bar{d}_i)^2 L_{ik}^2}{\left(\sum_{k=1}^{N_i} L_{ik} \right)^2}$$

$$\mathrm{CL}(\bar{d}_i) = \pm t\,(N_i - 1, 0.05) \sqrt{\mathrm{Var}(\bar{d}_i)}$$

where $\bar{d}_i$ = mean density for i-th zone
d_{ik} = mean density for k-th transect in i-th zone
L_{ik} = length of k-th transect in i-th zone
N_i = number of transects in i-th zone
$t(\mu, \alpha)$ = student's t-distribution with μ degrees of freedom and proportion α in both tails.

Biomass (tonnes) for each zone, the variance and 95% confidence limits of the biomass were given by:

$$B_i = A_i \bar{d}_i$$

$$\mathrm{Var}(B_i) = A_i^2 \mathrm{Var}(\bar{d}_i),$$

$$\mathrm{CL}(B_i) = \pm t(N_i - 1, 0.05) \sqrt{\mathrm{Var}(B_i)}$$

where B_i = biomass for i-th zone
A_i = area for i-th zone.

The total biomass (B_t) for an area consisting of M zones, and the variance of the total biomass were computed as the sum of the zonal biomass $\left(\sum_{i=1}^{M} B_i\right)$ and variance $\left(\sum_{i=1}^{M} \mathrm{Var}(B_i)\right)$, respectively. 95% confidence limits of the total biomass were estimated from:

$$\mathrm{CL}(B_t) = \pm t\left(\sum N_i - M, 0.05\right)\sqrt{\mathrm{Var}\left(\sum_{i=1}^{m} B_i\right)} \text{ (Mackett, 1973).}$$

The estimates of mean density and biomass for each zone are shown in Table 2. The mean density was as high as 135.1 g/m^2 in the nearshore zone, while only 8.5 g/m^2 in the oceanic zone, with intermediate values of 37.3 and 28.1 g/m^2 in the frontal and neritic zones, respectively. The coefficient of variation (CV) was higher in the nearshore zone (33%) than other zones (24 to 26%) due to the extremely patchy distribution of krill and the smaller number of transects in this zone. The total biomass over the survey region was estimated to be 1.59±0.45 million tonnes (95% confidence limit), of which 1.22±0.42 million tonnes was concentrated in the areas of fishery operation ("frontal" + "neritic" + "nearshore"). A statistically valid CV (14%) was obtained for the total biomass.

3.2.4 Spatial Distribution of Lengths and Maturity Stages of Krill

The krill stock showed a distinct offshore-inshore separation in size and maturity classes (Figure 7). Large krill (modal length 49 mm) were dominant in the oceanic and slope frontal zones, whereas medium-sized krill (modal length 45 mm) dominated in the neritic and nearshore zones. Small krill (modal length 30 mm) were scarce except in the nearshore zone where they represent about 30% of the stock. According to the growth curve for krill (Siegel, 1987), length modes of 45 mm and 30 mm correspond approximately to ages 3+ and 1+ years respectively. The 49 mm length mode is possibly composed of mostly age 4+ and older, considering the clear difference in maturity stages between krill with modal lengths of 49 and 45 mm (Figure 7).

All krill were at the spawning stage in the oceanic and frontal zones. Almost all females were gravid (stage IIID) and all males had fully developed spermatophores (IIIB). On the other hand, krill were less mature in the neritic and nearshore zones: females were not gravid (IIIBC), and a large component (35 to 45%) of males were immature (IIA1-IIA3). Juveniles were generally restricted to the nearshore zone where they constituted 27% of the stock. The percentages of gravid females in the population were 43%, 64%, 4% and 3% in the oceanic, slope frontal, neritic and nearshore zones respectively. Multiplying the mean densities of krill by these percentages, mean densities of gravid specimens were calculated to be extremely high in the slope frontal zone (23.9 g/m^2), as contrasted with the lower values (3.7 g/m^2) in the oceanic zone, while such krill were virtually absent from the neritic and nearshore zones (Table 3). Gravid biomass amounted to 594 000 tonnes over the survey region, of which as much as 411 000 tonnes was concentrated in the slope frontal zone.

4. DISCUSSION

The present study divided the inshore region into the two zones ("neritic" and "nearshore"). This clearly reduced the coefficient of variation of the biomass estimate for the inshore region (from 38% to 21%), with only a small change in the biomass estimate (decrease

by 10%). Since the inshore region showed great spatial variability in krill abundance, the number of transects should be increased (e.g., by setting cruise tracks diagonally across depth contours) to obtain more reliable estimates.

Krill density and biomass in the 1990/91 season for this region were at lower levels until early February, approaching normal levels from mid-February onward (AMLR, 1991). This low density in early summer influenced krill-eating predators at Seal Island: 20% decline in the number of penguins occupying nests compared to last season, and longer feeding trips of Antarctic fur seals in early January (five to nine days) compared to late February (one to three days) (AMLR, 1991). Ichii *et al.* (1991) also reported that the density at the localised fishing ground north of Livingston Island was approximately less than half of that three years ago (149 g/m^2 in 3 February 1991 vs 342 g/m^2 in 21 January 1988). Later in this season (late February to early March) krill biomass in the Elephant Island region was estimated to be as much as 2.12 million tonnes, the same level as in the previous season (AMLR, 1991). Hence, the estimate of total krill biomass obtained in this study should be regarded not as an underestimation but as a true reflection of lower biomass at the end of January in the 1990/91 season.

The krill stock showed distinct offshore-inshore heterogeneities in abundance and biological characteristics, which evidently resulted from both biological and hydrographic factors:

(i) low values of Chl *a* were observed in the oceanic zone compared to the other three zones during the survey (Ichii *et al.*, 1991). This implies that the least favourable feeding environment might be responsible for the lower krill density in this zone;

(ii) the krill spawning stock distribution was closely associated with the slope frontal zone, indicating that krill use this zone as spawning grounds. In the Indian Ocean sector a spawning ground appeared to coincide with the continental slope front region (Ichii, 1990). The slope region is favourable for spawning for the following reasons. Firstly, spawning must be much more successful in deeper waters (the frontal and oceanic zones) than in the shallow coastal region (the neritic and nearshore zones) because in the shallow region sinking krill eggs would soon reach the seabed and become exposed to predation by benthic animals, resulting in a lower survival rate. Secondly, comparing the two deeper zones (slope frontal and oceanic) the former zone may be more favourable in that the upwelling deep water may assist upward movement of early larval stage krill (Marr, 1962) and that the higher phytoplankton concentration may provide a better feeding environment for spawning krill;

(iii) the neritic and nearshore zones are characterised by sluggish circulation around the islands. Areas of dense krill concentration tended to coincide with the shelf break or be on the shelf, where topographic convergent eddies were generated. The hydrodynamic convergence, therefore, might be responsible for aggregating krill into the nearshore zone. This mechanical accumulation might also cause the frequent occurrence of juveniles, which are poorer swimmers than adults, in this zone.

Krill trawlers which had been operating over the frontal, neritic and nearshore zones during the study period operated only in the last two zones by the end of February, 1991. Post-spawned krill were observed in their catches (Kawaguchi, personal communication). Siegel (1988) and Brinton (1991) suggested that, after spawning, adult krill leave the oceanic and frontal zones where larvae occur at that time in surface waters, and migrate into the neritic and nearshore zones. It is therefore considered that toward the end of the spawning season more and more post-reproductive krill were moving into the neritic and nearshore zones, probably leading to a considerable part of the krill biomass aggregating in those zones.

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REFERENCES

AMLR. (ROSENBERG, J. and R. HEWITT, Eds). 1991. AMLR 1990/91 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-91-18. Document *WG-CEMP-91/11*. CCAMLR, Hobart, Australia: 97 pp.

ANON. 1986. Post-FIBEX Data Interpretation Workshop. Frankfurt, Federal Republic of Germany. September 1984.

ANON. 1989. Showa 62-nendo Kaiyo-maru chousa koukai houkokusho (Report of *Kaiyo maru*'s fifth Antarctic research cruise). Fisheries Agency of Japan: 301 pp.

BIOMASS. 1984. *Report Series*, 40: 106 pp.

BRINTON, E. 1991. Distributon and population structures of immature and adult *Euphausia superba* in the western Bransfield region during the 1986/87 summer. *Deep Sea. Res.*, 38 (8/9): 1169-1193.

ICHII, T. 1990. Distribution of Antarctic krill concentrations exploited by Japanese krill trawlers and minke whales. *Proc. NIPR Symp. Polar Biol.*, 3: 36-56.

ICHII, T., H. ISHII and M. NAGANOBU. 1991. Krill (*Euphausia superba*) distribution in relation to water movement and phytoplankton distribution off the northern South Shetland Islands. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8)*. CCAMLR, Hobart, Australia: 123-140.

MACKETT, D.J. 1973. Manual of methods for fisheries resource survey and appraisal; Part 3 - standard methods and techniques for demersal fisheries resource survey. *FAO Fish. Tech. Pap.*, 124: 39 pp.

MAKAROV, R.R. and C.J. DENYS. 1981. Stages of sexual maturity of *Euphausia superba* Dana. *BIOMASS Handbook*, 11: 1-13.

MARR, J.W.S. 1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). *Disc. Rep.*, 32: 33-464.

SHIMADZU, Y., T. KOIKE and T. SUGURO. 1989. Target strength estimation of Antarctic krill, *Euphausia superba* by cooperative experiments with commercial trawler. Document *SC-CAMLR-VIII/BG/30*. CCAMLR, Hobart, Australia: 10 pp.

SIEGEL, V. 1987. Age and growth of Antarctic Euphausiacea (Crustacea) under natural conditions. *Mar. Biol.*, 96: 483-495.

SIEGEL, V. 1988. A concept of seasonal variation of krill (*Euphausia superba*) distribution and abundance west of the Antarctic Peninsula. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin Heidelberg: 219-230.

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

Table 1: Operating parameters of the echosounder Furuno FQ-50.

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

* The top depth integration was changed to a maximum of 20 m when the sea was rough.

Table 2: Mean density and biomass of krill in each zone.

Zone	Area ($10^3 km^2$)	Mean Density (g/m^2)			Biomass (10^3 tonnes)			CV %	n
		E	V*	CL	E	V**	CL		
Oceanic	44.0	8.5	4.2	4.7	374	8131	204	24	10
Frontal	17.2	37.3	91.5	21.6	642	27069	372	26	10
Neritic	10.3	28.1	47.3	15.9	289	5018	163	24	9
Nearshore	2.1	135.1	2020.6	124.8	284	8911	262	33	5
Total	73.6				1589	49129	453	14	34

E - Mean, V - Variance, CL - 95% confidence limit, CV - coefficient of variation, n - number of transects, * g^2/m^4, ** 10^6 tonnes.

Table 3: Mean density and biomass of gravid krill in each zone.

Zone	% of Gravid Krill in the Population	Mean Density (g/m^2)	Biomass (10^3 tonnes)
Oceanic	43	3.7	163
Frontal	64	23.9	411
Neritic	4	1.1	11
Nearshore	3	4.1	9
Total	37		594

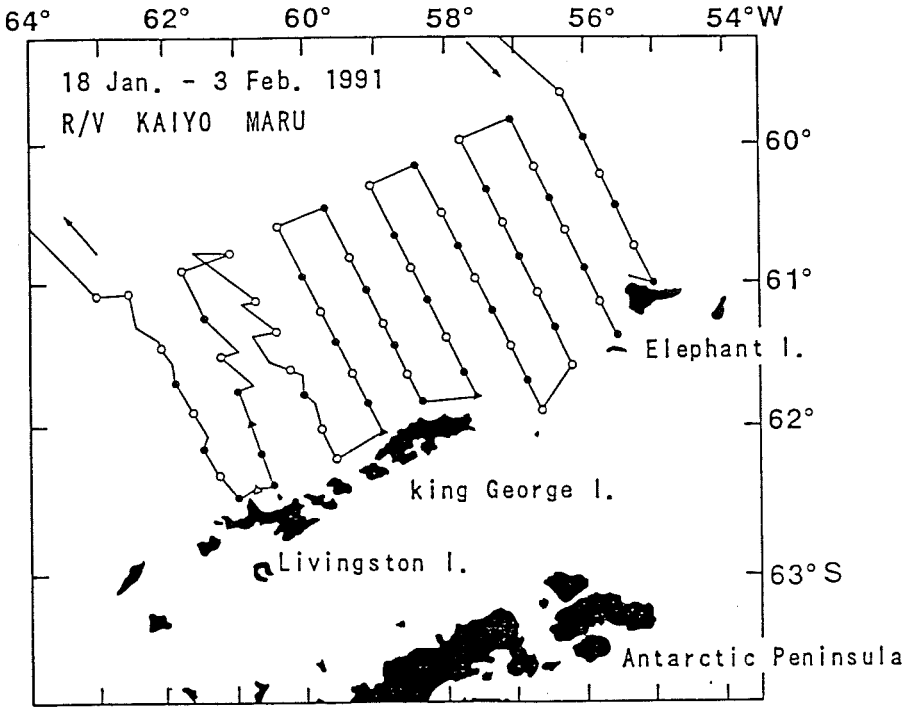


Figure 1: Cruise track and stations off the South Shetland Islands.

- o CTD stations
- • CTD and KYMT (blind tow) stations
- Δ KYMT (aimed tow) station
- ▲ CTD and KYMT (aimed tow) stations

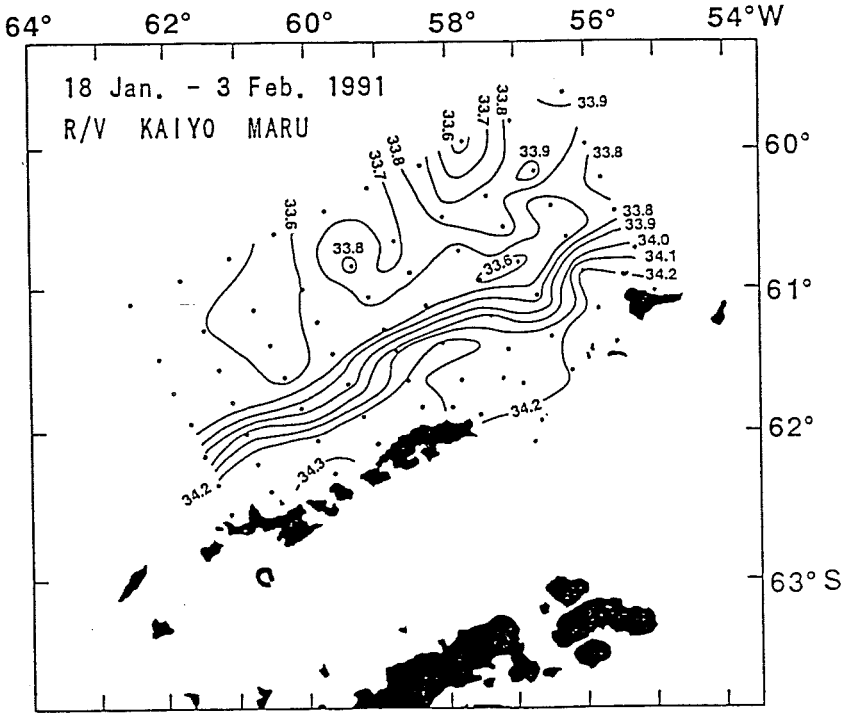


Figure 2: Distribution of salinity at 10 m depth.

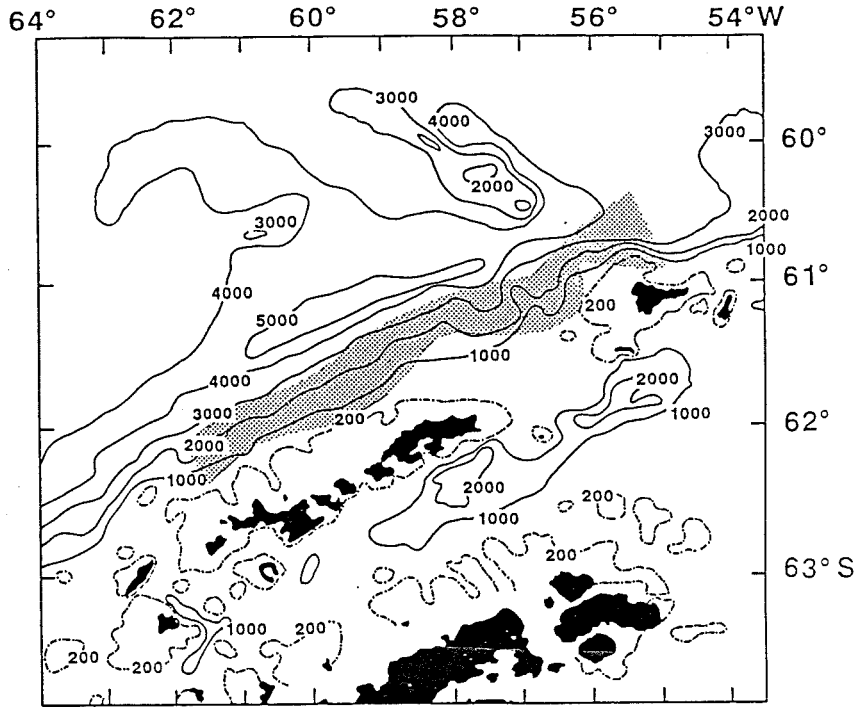


Figure 3: Bathymetric chart around the South Shetland Islands. Depth in metres. Shaded area indicates the slope frontal zone.

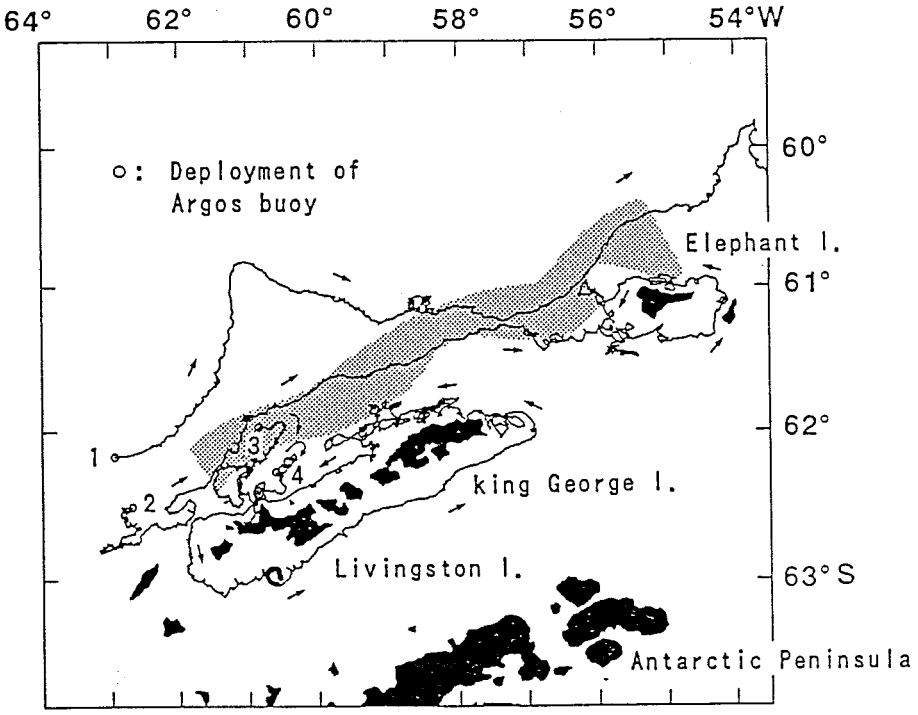


Figure 4: Subsurface (30 to 35 m depth) circulation derived from the paths of four satellite-tracked buoys. Shaded area indicates the slope frontal zone.

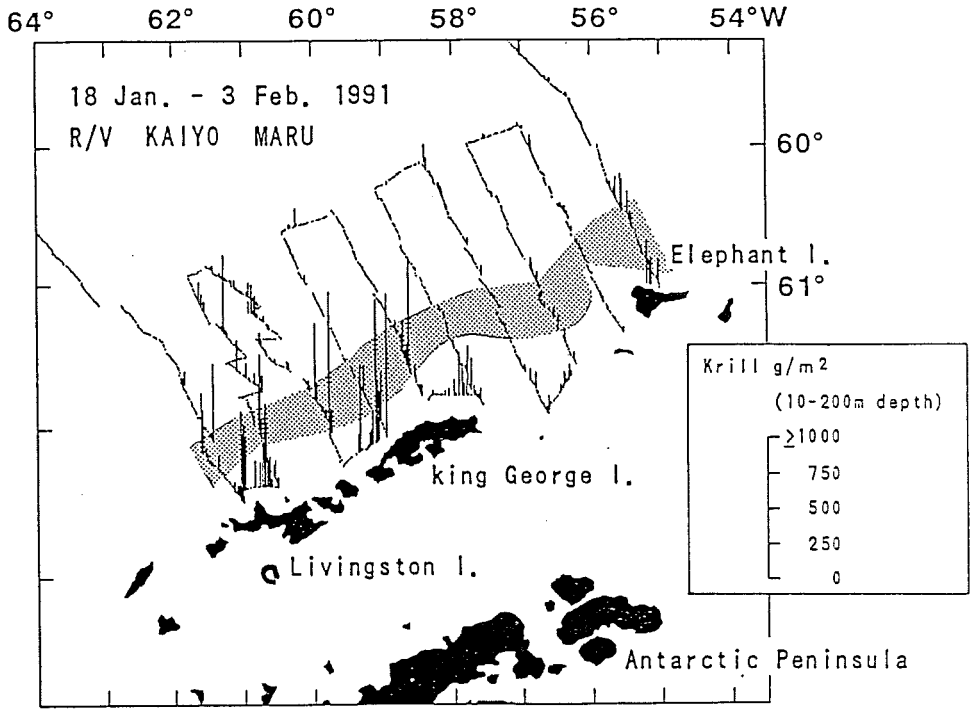


Figure 5: Mean densities of krill per n mile of the transect. Shaded area indicates the slope frontal zone.

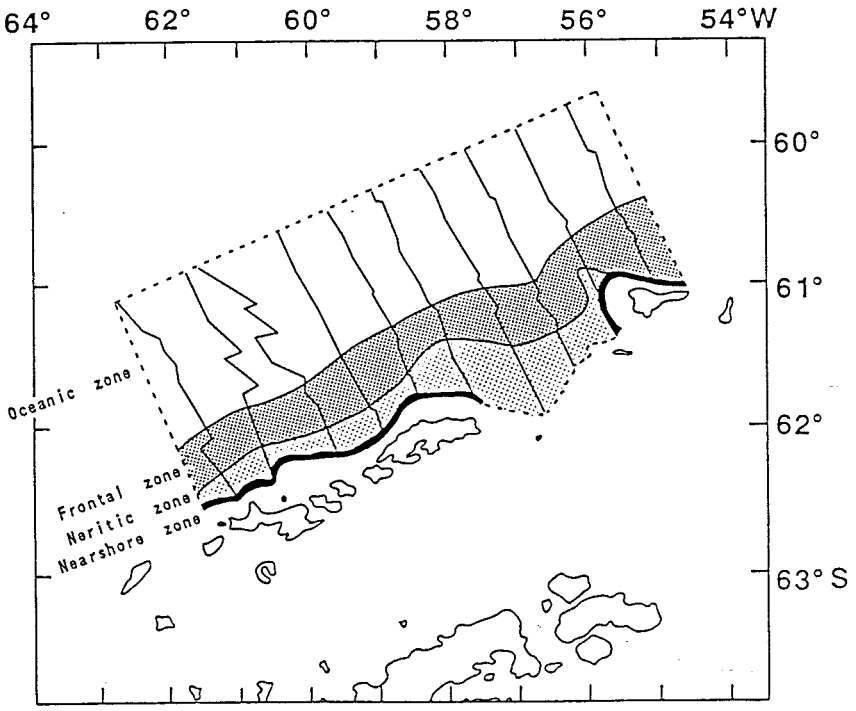
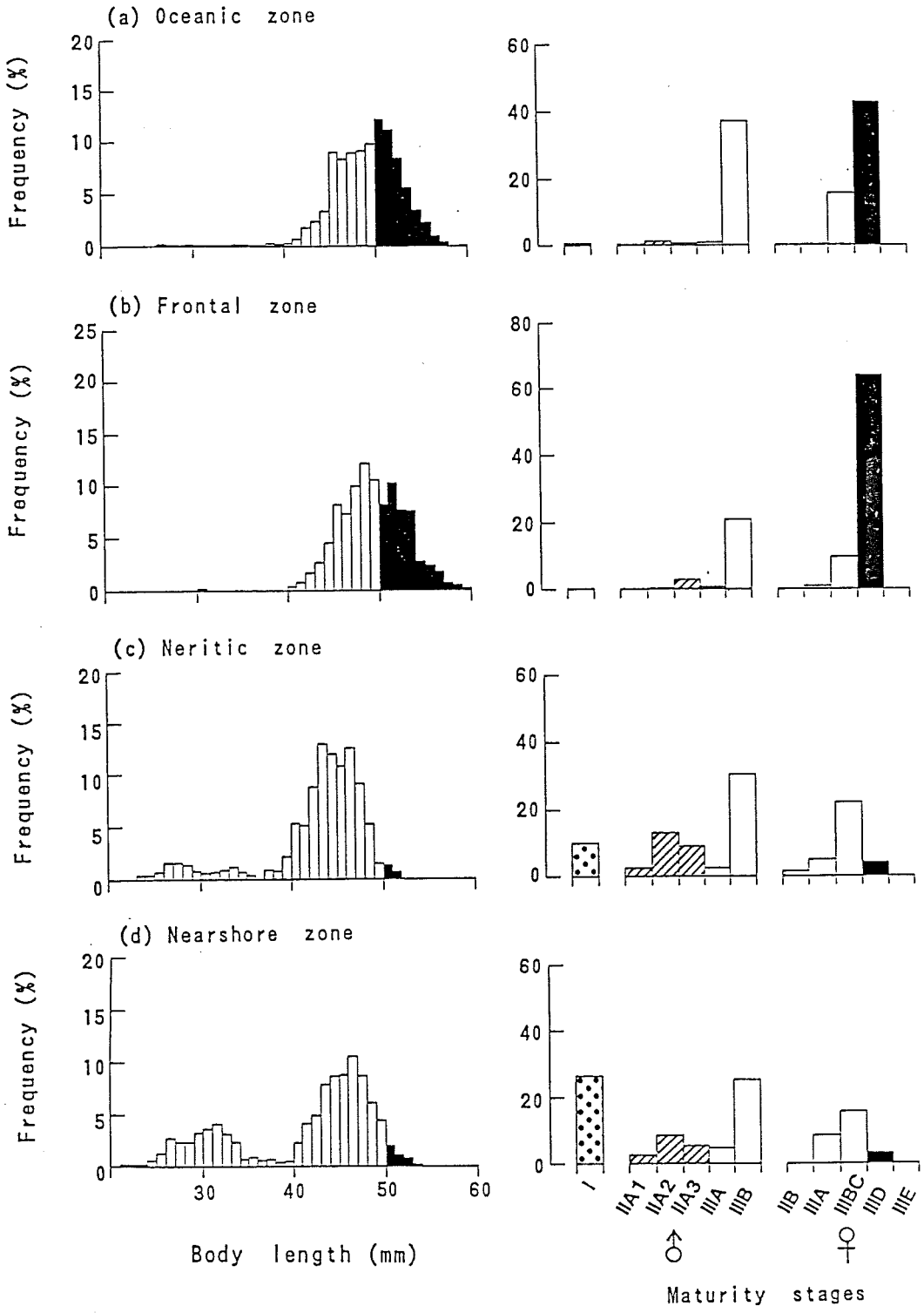


Figure 6: Stratification of the survey area and transects for each zone. The nearshore zone is defined as 3-n mile wide belts along the 150 m depth contour. Cruise tracks along these narrow belts were used as transects for the nearshore zone.



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- • stations de CTD et KYMT (chalutage non contrôlé)
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- ▲ stations de CTD et KYMT (trait dirigé)

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Figure 7: Composition en longueurs et en fonction de la maturité du krill par zones.
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A droite : les barres en caractères gras pointillées, hachurées ou pleines correspondent respectivement aux juvéniles, aux mâles subadultes et aux femelles gravides.

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DIURNAL VARIATIONS IN BIOLOGICAL CHARACTERISTICS OF KRILL, *EUPHAUSIA SUPERBA* DANA, TO THE WEST OF THE SOUTH ORKNEY ISLANDS, 24 MARCH TO 18 JUNE 1990 - BASED ON DATA REPORTED BY A BIOLOGIST-OBSERVER

A.V. Vagin, R.R. Makarov and L.L. Menshenina*

Abstract

Investigations of diurnal variations in the size composition of *Euphausia superba* were carried out on the commercial trawler *Grigory Kovtun* near the South Orkney Islands from March to June 1990. Observations at six daily stations were carried out in various locations inside the fishing area. Each station consisted of a series of catches made using a standard commercial trawl (9 to 12 tows per station, over one day). An increase in the total average size of animals caught in periods of light or darkness was noted at several stations. Increases in the proportion of males in the catch, as well as an increased difference between average length of males and females in the layer fished were indicative of these variations. Diurnal variations of females size composition were usually less evident. These changes were related to diurnal vertical migrations of krill which were noted on echosounder recordings. Trawling depths usually corresponded to the depth of the largest concentration of krill. Within swarms males initiate diurnal vertical migrations. In the absence of diurnal migrations (particularly late in the season), diurnal variations in size composition of krill catches were less evident or non existent. The significance of these observations in relation to krill size composition data obtained from standard surveys (only one sample of krill per station) is discussed. A gradual decrease in the average size of krill from the end of March to June was observed in the fishing area. The following three causes of the observed variations in krill composition are considered: (i) post-spawning mortality of large specimens; (ii) body shrinkage of krill due to a decrease in food availability; and (iii) size selectivity of krill by commercial fisheries.

Résumé

Des études des variations diurnes de la composition en tailles de *Euphausia superba* ont été menées à proximité des îles Orcades du Sud de mars à juin 1990 à bord du chalutier industriel le *Grigory Kovtun*. Des observations ont été effectuées à six stations quotidiennes en divers emplacements dans la zone de pêche. A chaque station, une série de captures a été réalisée au moyen d'un chalut industriel standard (de 9 à 12 traits par station, sur une journée). A plusieurs stations on a observé une augmentation de la taille moyenne totale des animaux capturés en des périodes de jour ou de nuit. On a constaté que ces changements étaient dûs d'une part à une augmentation de la proportion de mâles dans la capture et d'autre part à une différence croissante de longueur moyenne entre les mâles et les femelles dans la couche de pêche. Les variations diurnes de la composition en tailles des femelles

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n'étaient pas aussi évidentes. Ces changements dépendaient des migrations verticales diurnes du krill, qui apparaissaient sur les enregistrements par échosondeur. La profondeur de chalutage correspondait en général à celle de la plus grande concentration de krill. Les mâles dans les essaims sont à l'origine des migrations diurnes verticales. En l'absence de migration diurne (notamment tard dans la saison), les variations diurnes de la composition en tailles des captures de krill étaient moins évidentes où même inexistantes. Les auteurs examinent l'importance de ces observations par rapport aux données sur la composition en tailles du krill provenant de campagnes d'évaluation standard (seul un échantillon de krill par station). De fin mars à juin on a observé une diminution progressive de la taille moyenne du krill dans la zone de pêche. On a examiné les trois causes suivantes des variations observées dans la composition du krill: i) mortalité de grands spécimens en période de post-ponte; ii) contraction du corps du krill causée par une diminution de la nourriture disponible; et iii) sélectivité de la taille du krill par les pêcheries commerciales.

Резюме

Исследования дневных изменений в размерном составе *Euphausia superba* проводились с марта по июнь 1990 г. на борту промыслового судна *Григорий Ковтун*, работавшего на промысловом участке около Южных Оркнейских о-вов. Наблюдения выполнялись на шести суточных траловых станциях в пределах промыслового участка. Каждая станция состояла из серии уловов, полученных стандартным коммерческим тралом (9-12 тралений за станцию, в течение суток). На нескольких станциях наблюдалось увеличение среднего размера особей, выловленных при дневном свете или в темноте. Было установлено, что эти изменения были связаны с возрастающей долей самцов, а также с разницей средней длины самцов и самок в облавливаемом слое. Дневные изменения в размерном составе самок обычно были менее очевидными. Эти изменения были связаны с дневными вертикальными миграциями криля, которые регистрировались эхолотом. Глубины траления обычно совпадали с глубиной наибольшей концентрации криля. Во время дневных вертикальных миграций самцы первыми начали миграцию передвигаясь внутри скоплений. Когда суточная миграция не наблюдалась (в частности в конце сезона) дневные изменения в размерном составе в уловах криля были менее явны или вообще не обнаруживались. В настоящей работе рассматривается значение этих наблюдений в отношении данных по размерному составу криля, полученных в результате стандартных съемок (только одна выборка за станцию). С конца марта по июнь на промысловом участке наблюдалось постепенное снижение среднего размера криля. Рассматриваются следующие причины отмеченных изменений в составе криля: (i) посленерестовая смертность крупных особей; (ii) сужение криля в результате уменьшения кормовой базы; и (iii) промысловая селективность криля.

Resumen

Desde marzo a junio de 1990, se llevó a cabo un estudio de las variaciones diurnas en la composición por talla de *Euphausia superba* a bordo del arrastrero comercial *Grigory Kovtun*, cerca de las islas Orcadas del Sur. Estas observaciones se realizaron en seis estaciones diarias ubicadas dentro de la zona de pesca, y consistieron de una serie de capturas realizadas mediante un arrastre comercial estándar (de nueve a 12 arrastres por estación en un día). En varias de estas estaciones se constató un aumento en la talla promedio de los animales capturados durante el día o en períodos de oscuridad. Se obtuvo una indicación de estas variaciones por el aumento en la proporción de machos en las capturas, así como por la gran diferencia entre la talla promedio de los machos y hembras del estrato de pesca. Generalmente las variaciones diurnas en la composición por talla de las hembras fueron menos evidentes. Estos cambios están relacionados con las migraciones verticales diurnas del kril, que fueron registradas mediante una ecosonda. Normalmente las profundidades de arrastre correspondieron a la profundidad de la mayor concentración de kril. Dentro de las concentraciones, los machos son los que comienzan la migración vertical diurna. A falta de las migraciones diurnas (especialmente hacia el final de la temporada), las variaciones diurnas en la composición por talla de las capturas de kril fueron menos evidentes, o no existentes. Este documento estudia la importancia de estas observaciones en relación a la composición por talla del kril obtenida de prospecciones estándar (solo una muestra de kril por estación). Desde el final de marzo hasta junio, se observó una disminución gradual de la talla promedio del kril en la zona de pesca. Se consideran los tres factores siguientes como causales de la variación observada en la composición del kril: (i) mortalidad de los ejemplares grandes después de la puesta; (ii) reducción de la talla del kril debido a la disminución de alimento; y (iii) selectividad del tamaño del kril por las pesquerías comerciales.

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1. INTRODUCTION

Routine investigations of the state of the *Euphausia superba* population which are carried out during standard surveys, consist of only one sample per station. These samples are collected on different days and at different times of the day. Therefore, during size-composition comparisons doubts remain as to whether krill specimens belong to a single or several statistical sub-populations. This problem is especially so for different areas of various frontal zones. Until now the only way to resolve these doubts has been by size composition analysis. Moreover, euphausiids captured in the same place but at different times of the day can show notable size differences. Diurnal variations of this type are well known. Diurnal variations in *E. superba* swarm density have been determined from hydroacoustic studies (Hampton, 1985; Miller and Hampton, 1989), and net sampling data (Nast, 1982). The situation in respect of diurnal variations in *E. superba* size composition is not clear. This information is not normally obtained from standard surveys.

Diurnal variations in the size composition of krill catches were studied by a biologist-observer in March to June 1990 on board the Russian trawler *Grigory Kovtun* near the South Orkney Islands. Results of his observations are discussed below.

2. MATERIALS

Six 24 hour stations were carried out by the fishing vessel *Grigory Kovtun* in the fishing area near the South Orkney Islands from the end of March to the middle of June, 1990 (Table 1). At each station a series of catches was made using a standard commercial trawl. From every catch one hundred specimens of *E. superba* were examined and subjected to biological analysis. Field observations were carried out by the biologist-observer, Dr A.V. Vagin.

The location of each station is shown in Figure 1. The starting and finishing points of every haul were recorded. The stations covered quite a large area and extended from northwest to southeast. Stations I, IV and V overlapped, as did Stations III and VI. Station II was located further south.

3. RESULTS

3.1 Diurnal Variations in the Composition of *E. superba*

Data on average body size of *E. superba* per haul (for all stations) are given in Figure 2. These data show different average sizes of *E. superba* obtained for each station. Measurements for Stations I to VI were: 45.8 - 44.4 - 43.5 - 41.9 - 41.1 - 43.1 mm. Despite the complexity of the curves this pattern can be also seen in Figure 2 which compares the size curves relative to the ordinate on each graph. It is also clearly visible, that the average body size of animals changes during the day. Size differences for Stations I to VI were: I - 2.3, II - 6.5, III - 2.4, IV - 2.7, V - 4.7, VI - 4.00 mm. These differences were estimated using a chi-square criterion at a confidence level of 0.9.

Differences in total average size of *E. superba* among stations is also related to the geographical position of the stations (see Figure 1). For example, Stations II, III and VI characterised by the intermediate average body size of krill, were positioned along the southern and western periphery of the regions, whereas Stations IV and V with the smallest specimens were located inshore. However, areas of the last two stations coincided with the area of Station I (which contained the largest specimens).

Comparison of length curves for each stations shows, that the average size of animals is most variable during the light period of a day (Figure 2). All stations may be subdivided into two groups. Stations I, II, IV and VI tended towards an increase in krill average size. Stations III and VI did not demonstrate such a tendency or it was not clearly evident (Station VI).

Comparison shows that the similarity of the length curves for Stations III and VI may not be coincidental, because these stations are located close to each other. In the eastern area, where all other stations were carried out, diurnal variations in the average size of *E. superba* were predominant. Data from Stations I, IV and V are particularly similar. These stations were carried out practically in the same area (Figure 1).

3.2 Consideration of the Possible Causes of Diurnal Variations in the Size Composition of *E. superba* Catches

Variations in the size composition of *E. superba*, described above, are not straightforward. In the case of random distribution of krill swarms the length curves should be irregular and dissimilar. The very regularity and similarity of the curves from most stations prove the regularity of trends and related processes in the *E. superba* population.

Analysis shows that the sex ratio and the average size of males change invariably in the samples (Figure 2). Several examples of this trend may be seen in Figures 3a, b and c. At Station I variations in the size composition of males were much stronger than for females over periods from 0 to 2, 2 to 4 and 6 to 8 hrs (the proportion of males was 27.0, 49.5 and 31.5% respectively). The same is typical for Station II over periods from 8 to 10, 12 to 14 and 22 to 24 hrs (the proportion of males was 29.8, 41.2 and 33.3% respectively), however more obvious variations in the size composition of females were also observed. At Station IV variations in total size composition of *E. superba* were mainly connected with variations in size composition of males (proportion of males was 32.0, 38.3 and 33.3% respectively) over periods from 6 to 8, 12 to 14 and 18 to 20 hrs. Some changes were also observed in females, but they were less evident than at Station II.

Similar trends were observed in data from other stations. As a rule, variations in size composition of males and females took place non-synchronously - but changes were clearly evident, whereas variations in size composition of females were less obvious.

During late autumn/winter the average size of males was consistently larger than that of females (Makarov, 1991). It should be stressed that 50% level of sex ratio of *E. superba* for all samples from every station corresponded with particular size intervals: 47 to 48 mm for Station I, 43 to 44 or 45 to 46 mm for Station VII (see Figure 4) and so on.

Variations in the average size of *E. superba* in trawls catches was found to be unrelated to changes in rate and difference in size composition between males and females. Graphs for all size stations and for all hauls further demonstrate these trends. These graphs (Figure 5) show the relationship between total average size of animals for each catch (sample), size difference between males and females and proportions of males (% males). Some sets of data were scaled in order to assist their comparison (see explanation in Figure 5).

Correlation between the total average sizes and the proportion of males is clearly visible for Stations I and II and more or less clear correlation can be seen on the graphs for Stations III and V. Correlation is rather weak for Stations IV and VI. Correlation between the total average sizes and variation in size values between males and females is evident from the data for Stations I and V, and partially for Station II, however there is no such correlation at the other stations.

Changes in the proportion of males usually corresponds to variations in average size of *E. superba.*

The most complex situation was observed at Stations III, IV and VI. For most of the day all three curves on each graph showed poor correlation. Analysis showed that during the first part of the day (Station III), and during the second part of the day (Station VI) the curve of total average size was influenced by variations in the average size of females (see Figure 6). The last curve corresponds to the curve of total average size.

Disagreement between curves for the second part of the day at Station III may be explained by opposing trends of size variation between males and females on the one hand and the proportion of males on the other.

A very different pattern emerged at Station IV. Agreement between curves occurred in the middle of the day. As may be seen in Figure 5, curves for most stations increased their complexity towards the end and at the beginning of the day. This irregularity is possibly typical at Station IV during the larger part of the day.

One may conclude that the main factor determining variations in total average size of *E. superba* in the study area over a one day period is a change in the ratio of males, because in most cases both of these parameters show synchronous variations.

Variations in the average size of males also determine the total average size of all krill.

The third factor, namely variations in the average size of females, is only sometimes a significant factor.

In the course of analysis it is necessary to keep in mind trawling depth. As a rule, trawling depth corresponds to the layer of maximum aggregation density of *E. superba.*

Data on this subject are given in Figure 7. Curves of depth changes are shown and are compared with total average size and the proportion of males.

Three trawling regimes were employed:

(i) surface towing during the night and under surface towing during the day (Stations II, IV and V);

(ii) surface towing during the day and under surface towing during the night (Station III); and

(iii) towing in a more or less constant layer throughout a 24 hour period (Stations I and VI).

At Station I hauls were conducted near the surface, while at Station VI hauls were made in a deeper layer. This difference reflects the seasonal migration of *E. superba* to the deeper layers (see Table 1 for the timing of stations). According to the hydroacoustic data krill (at Stations II, IV and V) tended to occupy surface layers at night, but during the day krill moved downwards (100 to 200 m depth was the upper boundary of swarms). At Station III diurnal migrations of swarms showed the opposite pattern.

The combination of diurnal variations in total average size of *E. superba* and variations in trawling depth does not show complete correlation, which indicates that both parameters are comparatively independent (Stations II, IV and V). A direct relationship between these parameters was observed at Station I, however, the relationship was inverse. The average size of *E. superba* decreased as trawling depth increased and vice versa. The same is true for values of the percentage of males. At Station III some increases in trawling depth was accompanied by an increase in the total average size during the first light period of the day but the total average size remained unchanged in the middle of the night (in spite of a considerable increase in trawling depth). Finally, irregular variations in trawling depth around Station VI did not influence average size values for *E. superba.*

Larger animals first tended to form aggregations when swarms of *E. superba* moved into deeper water during the light part of the day at Stations II, IV and V. This segregation is weaker if swarms are distributed near the surface (Station I), although large specimens also tended to concentrate here. Diurnal variation in average size were not observed when migration of *E. superba* showed the opposite pattern (e.g., at Station III). In the case of non-migrating krill which occupy deep layers, the segregation by size does not occur (Station VI).

It may be concluded that specimens of various size are distributed initially uniformly. In the case of migrating swarms larger specimens move up or smaller specimens move down more quickly (males at first) and larger krill aggregate first. At night they mix with smaller specimens, which tends to lower total average size of night catches.

Our task was not to compare our results with previously obtained information on this subject. Here we only refer to a study of Watkins *et al.,* (1986) who dealt with rather small krill. They reported diurnal variations in total average length of *E. superba,* i.e., an increase in this parameter during the night.

4. CONCLUSION

The above data on changes in various demographic parameters of *E. superba* swarms demonstrate a connection between these changes and diurnal vertical migrations of *E. superba.* Differences in average size can be as large as 6.5 mm during the day. This fact must be taken into account in the routine investigation of *E. superba.* Vertical migrations gradually end at the beginning of winter and krill form stable concentrations at a certain distance from the surface.

Observed diurnal variations in total average size of *E. superba* as well as changes in other demographic parameters, are quite interesting from a methodological point of view. They show, that this fact should keep in mind when comparing data on size composition of *E. superba* captured in different places. Oblique tows through a rather large water volume are recommended for reliable krill sampling. Single or serial horizontal towing inside a specific layer only would produce incomparable data (e.g., see data on swarms near Elephant Island (Watkins *et al.,* 1986)).

Diurnal differences in demographic parameters may be more noticeable in other seasons e.g., in summer, when *E. superba* spawns. Krill exhibit much more diverse physiological characteristics during this period.

Biological investigations carried out on commercial vessels would allow studies on some aspects of krill biology which cannot be studied during a standard survey. These investigations should also include collection of relevant information on the environment which is of real significance when explaining various biological features of *E. superba.*

Our data also showed that the average size of *E. superba* decreased during a two and a half month period in a comparatively small area (cf. data on Stations I, IV and V, whose positions overlap). There may be several causes of this decrease (see also Vagin, 1991 - Figure 2). It may be connected with post-spawning mortality of larger specimens. Moreover, this is possibly a season when body shrinkage of *E. superba* is taking place (Ikeda and Dixon, 1982) due to a decrease of food availability. Finally, the possibility of the selective capture of large specimens of *E. superba* as a result of commercial fishing activity should not be excluded. Such selectivity affects animals of intermediate size (Brinton and Antezana, 1984). This problem, however, is very complex.

These three explanations are not contradictory. However, if spatial differences in the size composition of *E. superba* inside the area being fished is taken into account, together with the possibility of swarm drifting with the current, one may conclude that there is a real possibility of drift influence (see also Brinton and Antezana, 1984). The time interval between Stations I and V is sufficient for such a passive movement of swarms to occur. *E. superba* size distribution is irregular and, moreover, in a region of dense swarms size distribution is highly variable (see also Watkins *et al.,* 1986). Therefore sampling at a limited number of stations cannot give a suitable answer as to the reasons for the gradual decrease of *E. superba* size over the whole study area.

REFERENCES

BRINTON, E. and T. ANTEZANA. 1984. Structures of swarming and dispersed populations of krill (*Euphausia superba*) in Scotia Sea and South Shetland waters during January-March 1981, determined by Bongo net. *J. Crust. Biol.,* 4 (Spec. No. 1): 45-66.

HAMPTON, I. 1985. Abundance, distribution and behaviour of *Euphausia superba* in the Southern Ocean between 15° and 30°E during FIBEX. In: SIEGFRIED, W.R., P.R. CONDY and R.M. LAWS (Eds). *Antarctic Nutrient Cycles and Food Webs.* Springer-Verlag Berlin, Heidelberg: 294-303.

IKEDA, T. and P. DIXON. 1982. Body shrinkage as a possible overwintering mechanism of the Antarctic krill *Euphausia superba* Dana. *J. Exp. Mar. Biol.*, 62 (2): 143-151.

MAKAROV, R.R. 1991. Size composition of males and females in the course of the life cycle of *Euphausia superba*. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7)*. CCAMLR, Hobart, Australia: 3-16.

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill (*Euphausia superba* Dana): a review. *BIOMASS Sci. Ser.*, 9: 1-166.

NAST, F. 1982. The assessment of krill (*Euphausia superba* Dana) biomass from a net sampling programme. *Meeresforsch.*, 29 (3): 54-165.

VAGIN, A.V. 1991. Report of the biologist-observer on board the commercial trawler *Grigory Kovtun* in the 1989/90 season. Document *WG-Krill-91/12*. CCAMLR, Hobart, Australia: 8 pp.

WATKINS, J.L., D.J. MORRIS, and C. RICKETTS. 1985. Nocturnal changes in the main length of a euphausiid population: vertical migration, net avoidance, or experimental error? *Mar. Biol.*, 86 (2): 123-127.

WATKINS, J.L., D.J. MORRIS, C. RICKETTS and J. PRIDDLE. 1986. Difference between swarms of Antarctic krill and some implications for sampling krill population. *Mar. Biol.*, 93 (1): 137-146.

Table 1: Details of sampling stations (South Orkney Islands, 24 March to 16 June, 1990).

Station Number	Time	Number of Hauls (samples)
I	27 to 29 March	10
II	10 to 11 April	12
III	10 to 11 May	9
IV	26 May	12
V	9 to 10 June	11
VI	16 June	10

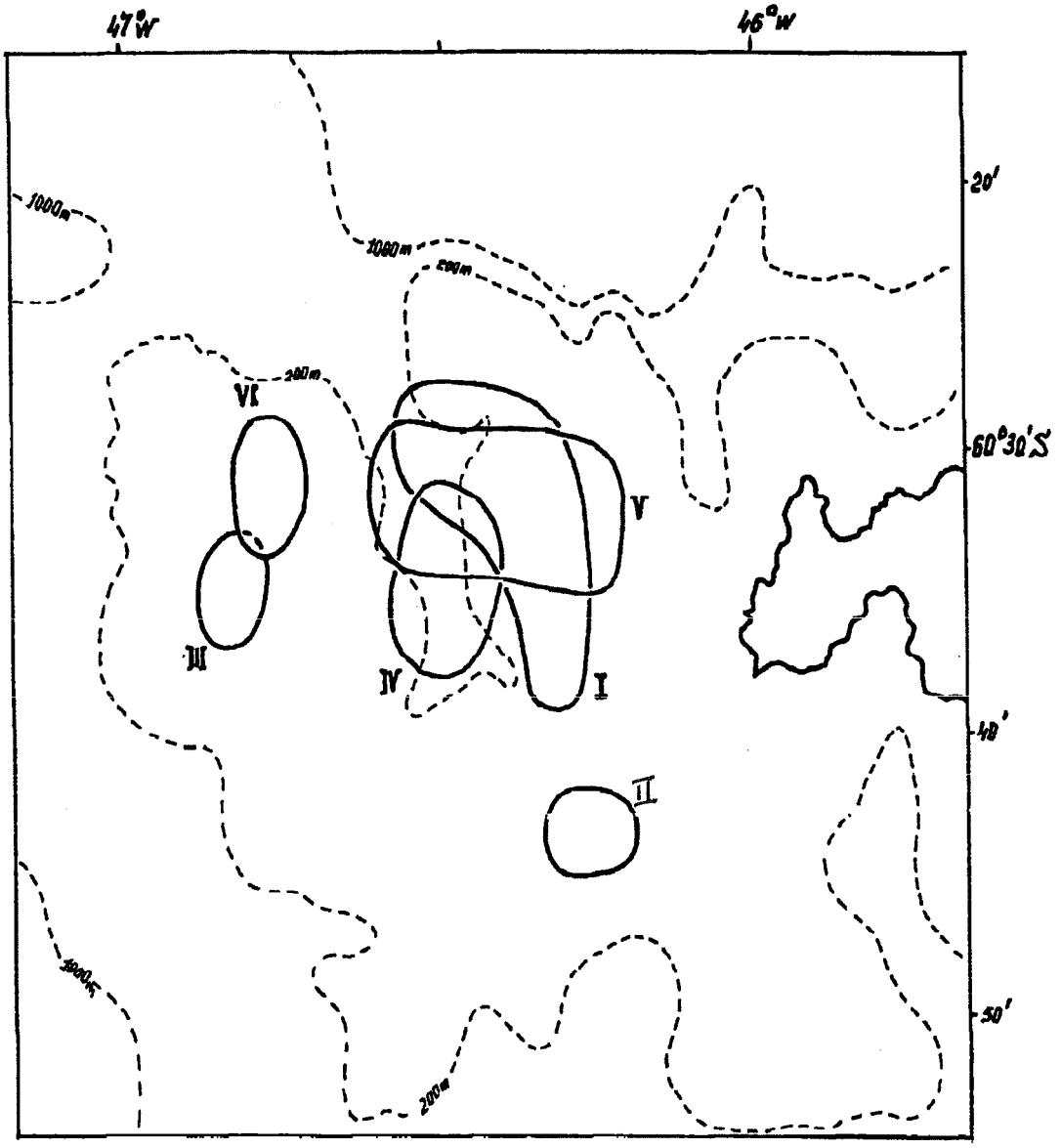


Figure 1: Location of sampling stations.

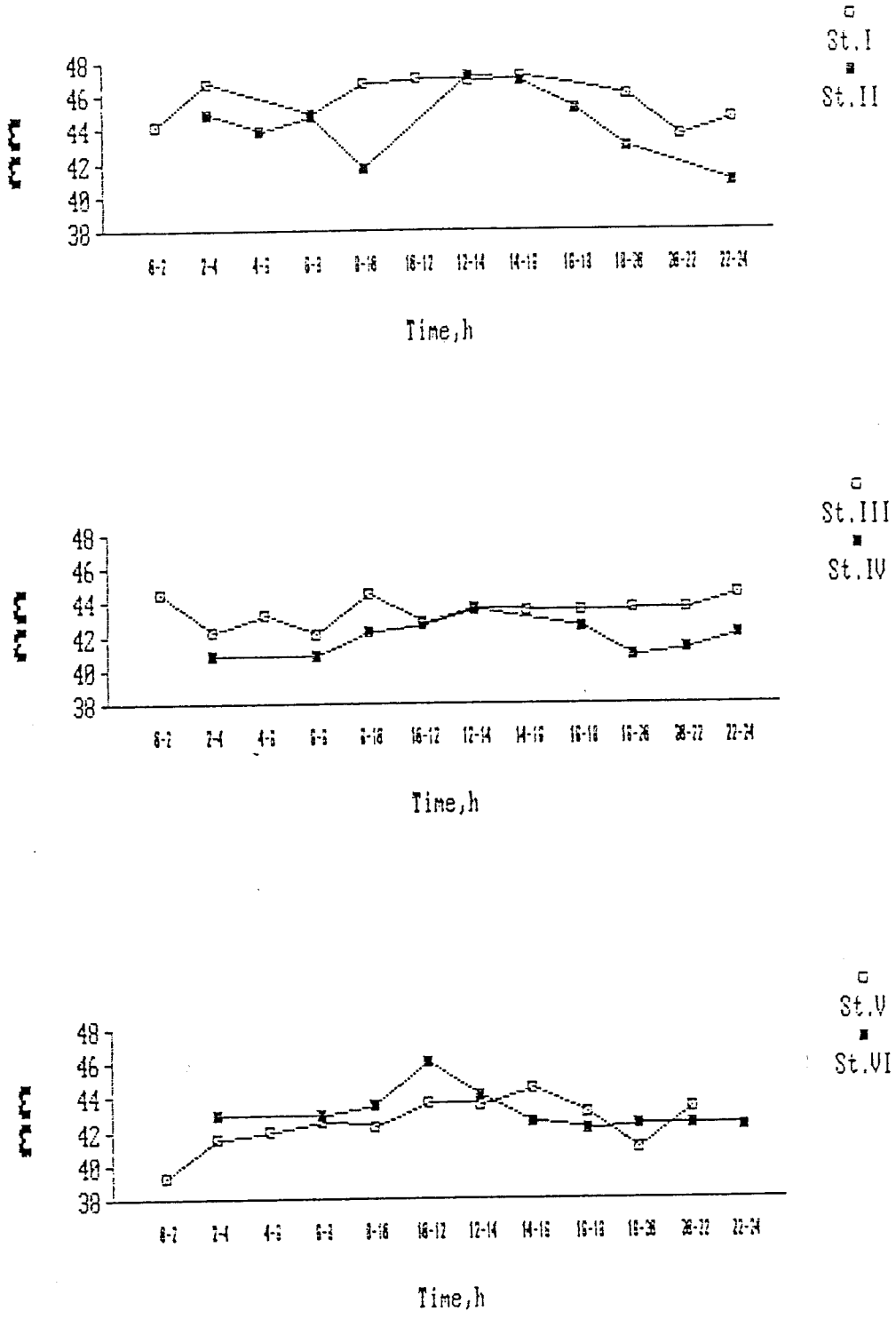


Figure 2: Average total length of *E. superba* at sampling stations.

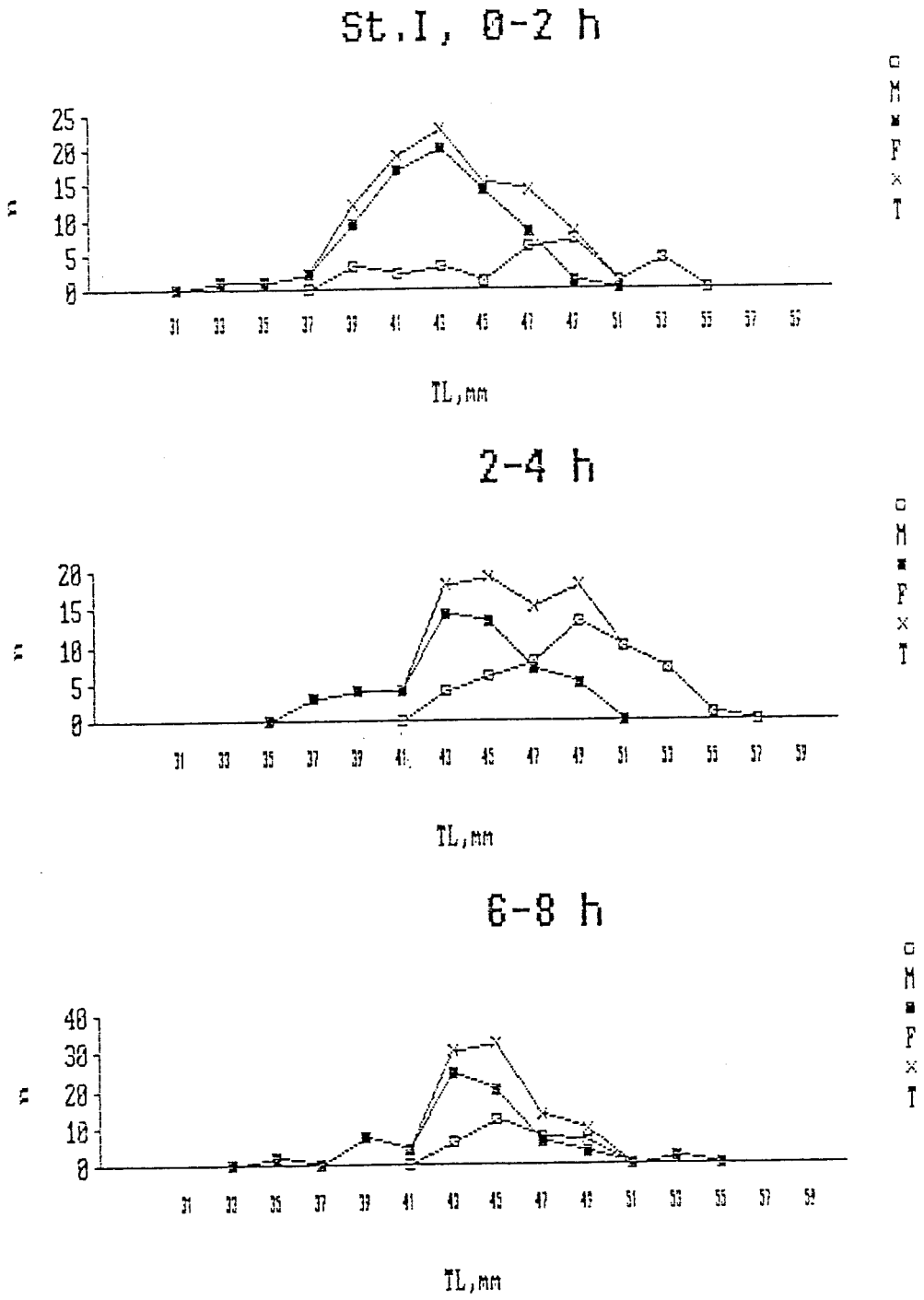


Figure 3a: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station I.

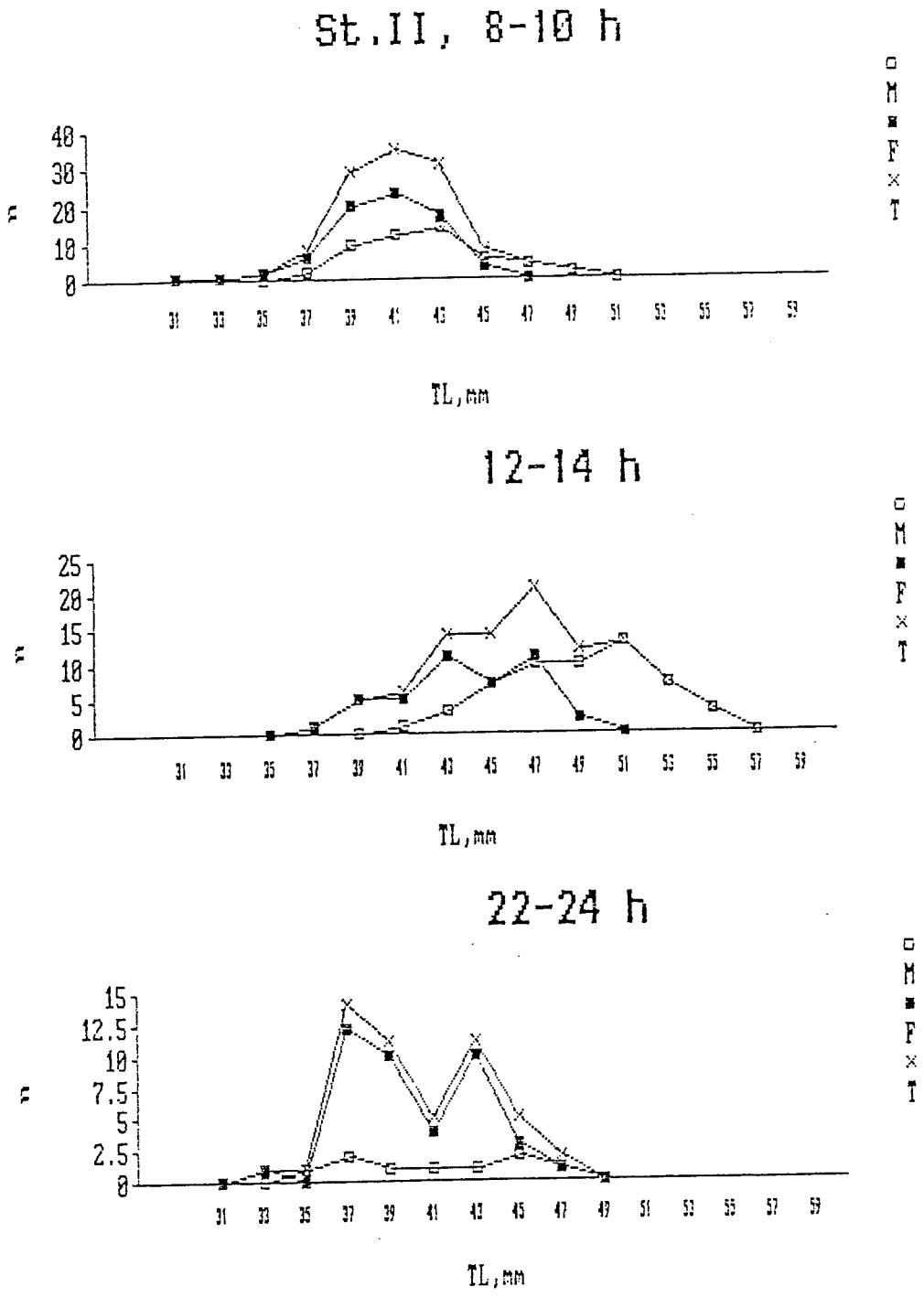


Figure 3b: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station II.

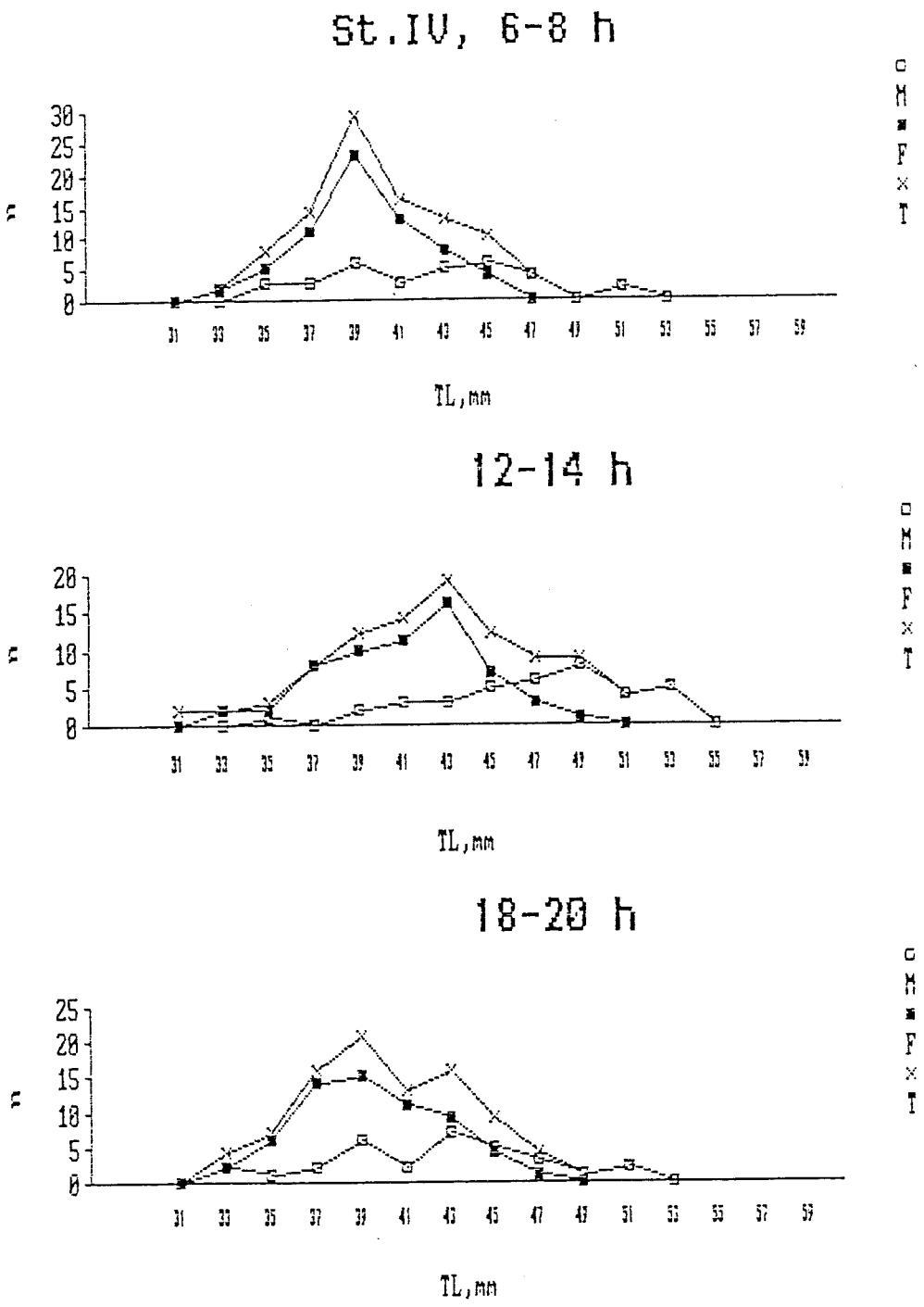


Figure 3c: Example of size composition of *E. superba*: T - total, M - males, F - females at selected points of Station IV.

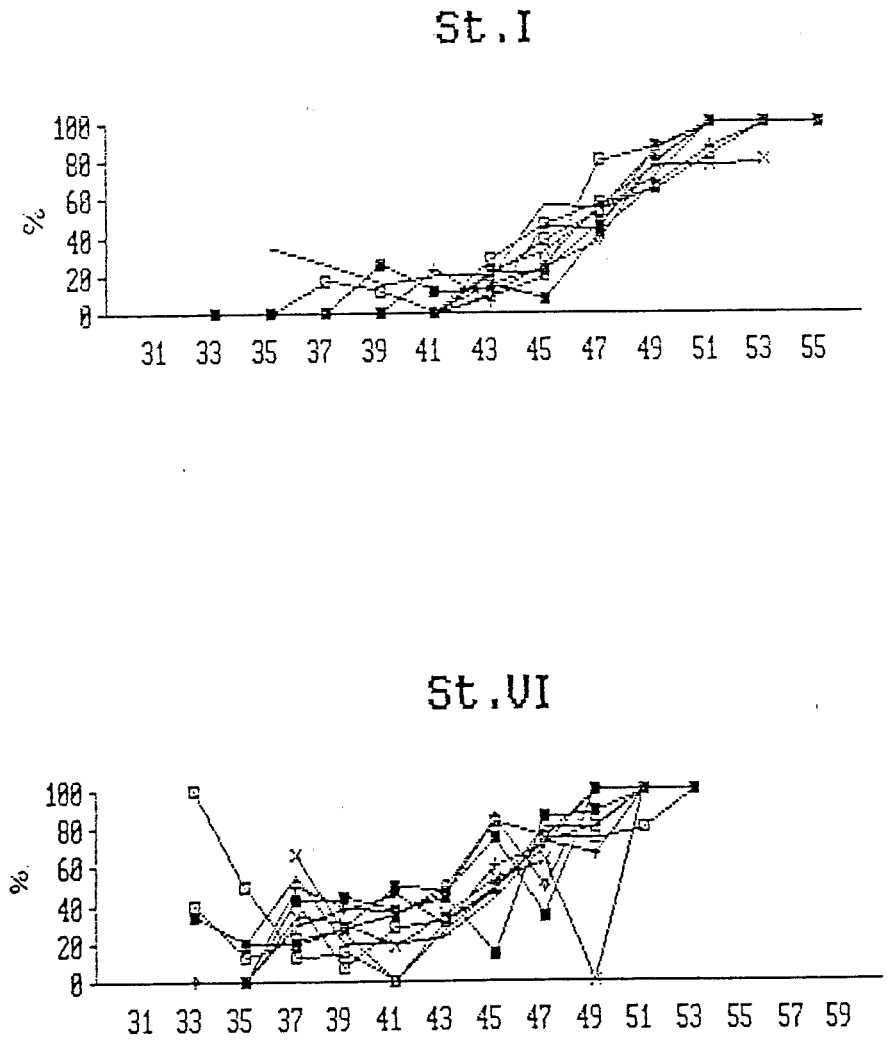


Figure 4: Changes of sex ratio of *E. superba* for Stations I and IV (% of males).

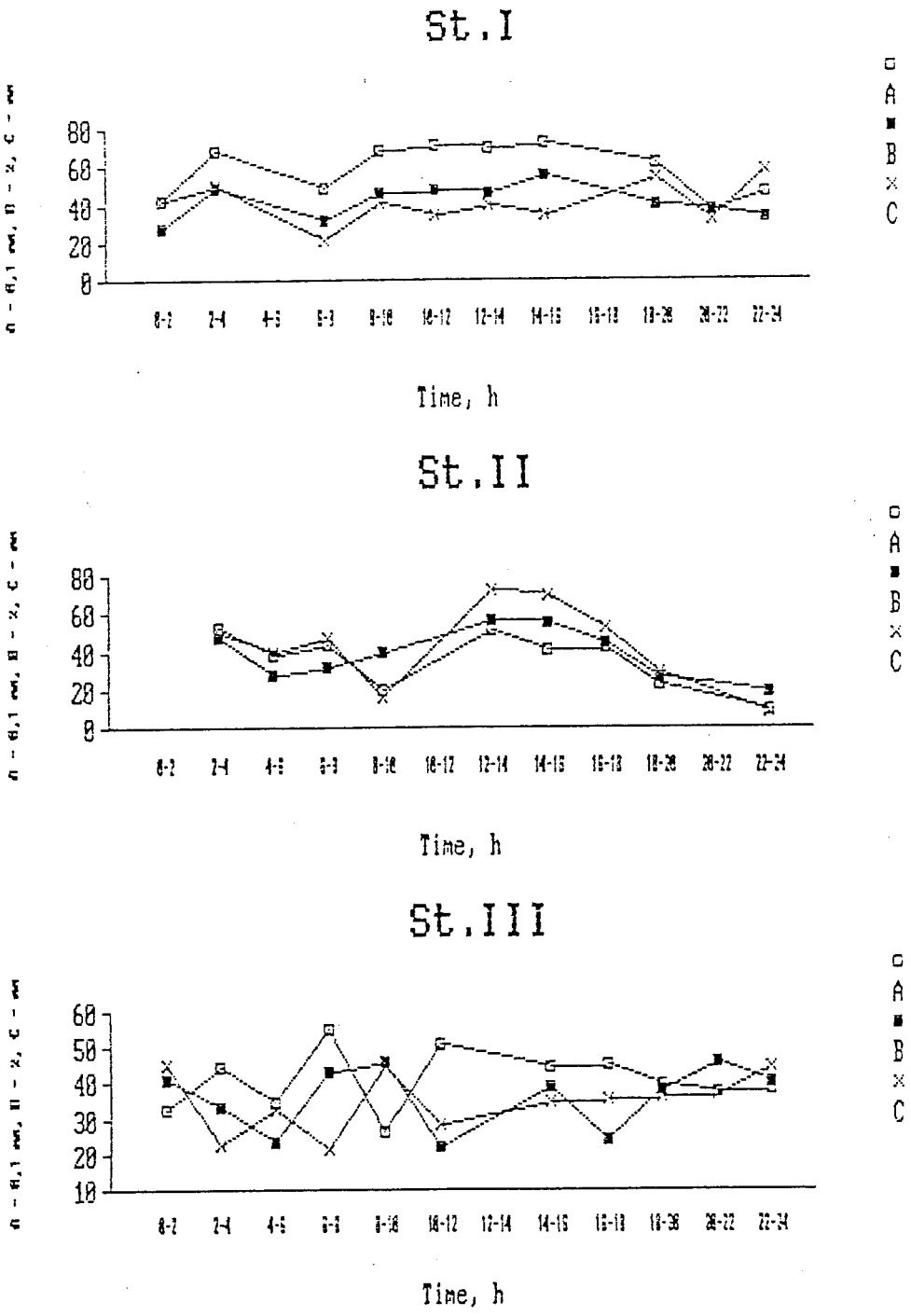
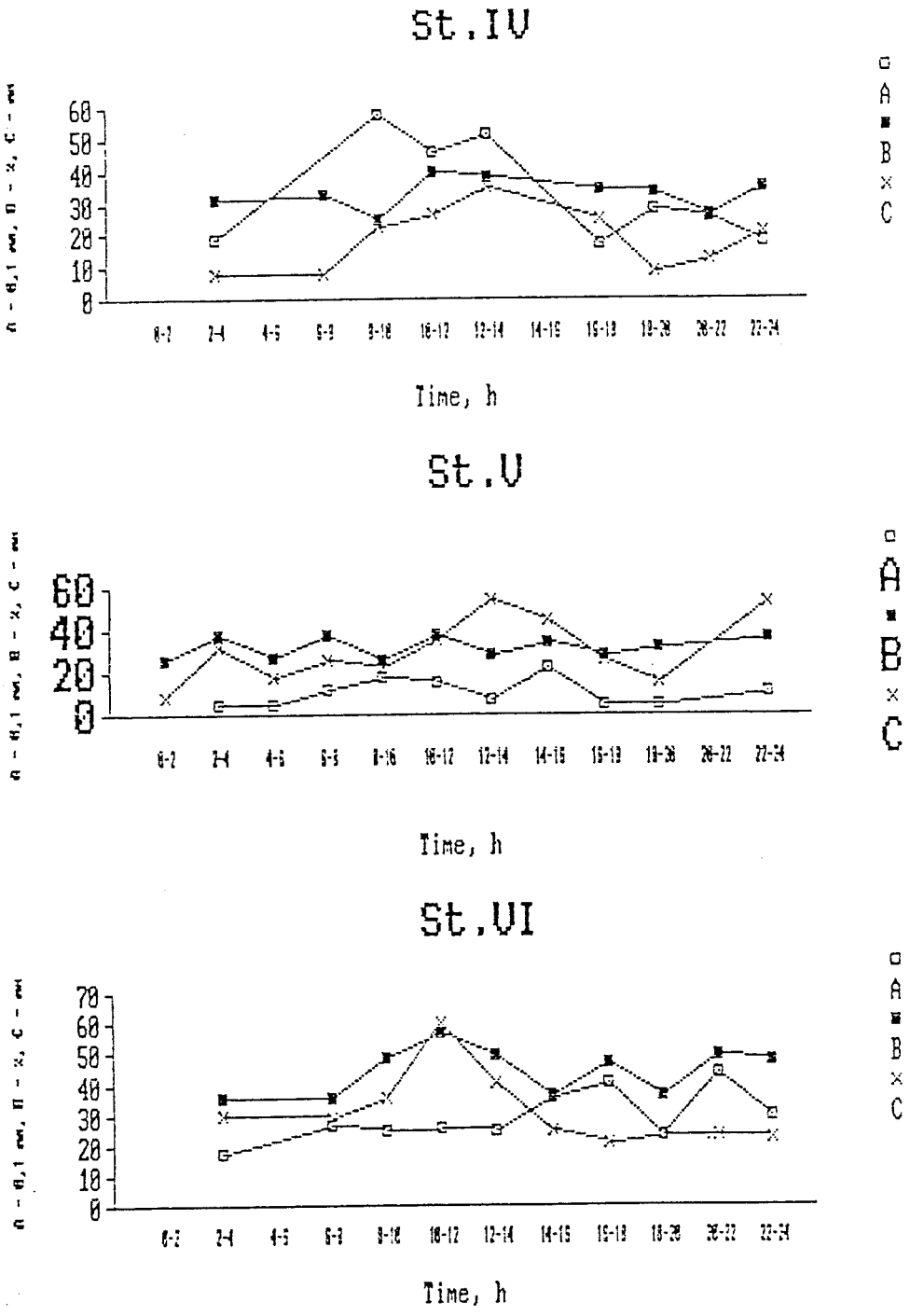


Figure 5: Diurnal variations in the size composition of *E. superba* at each station. A - average length of males - average length of females x 10; B - % of males; C - total average length (TL - 40) x 10.



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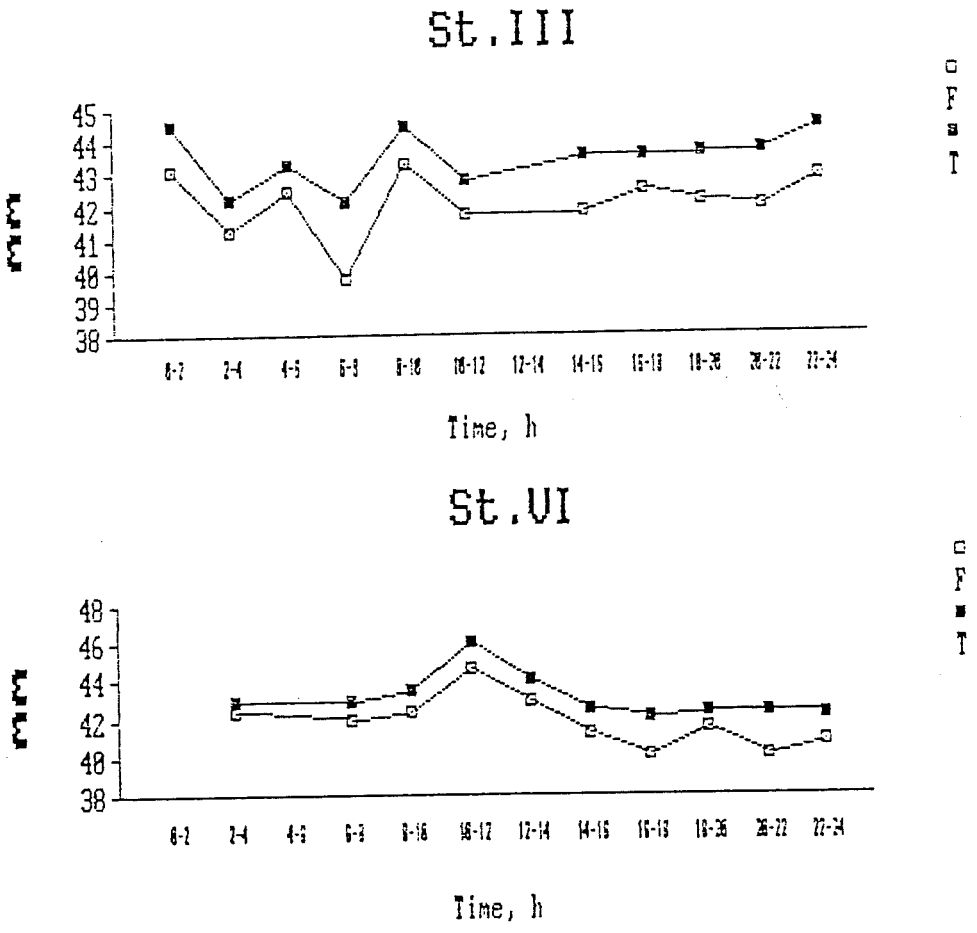

Figure 6: Total average length (T) and average length of females (F) of *E. superba* at Stations III and VI.

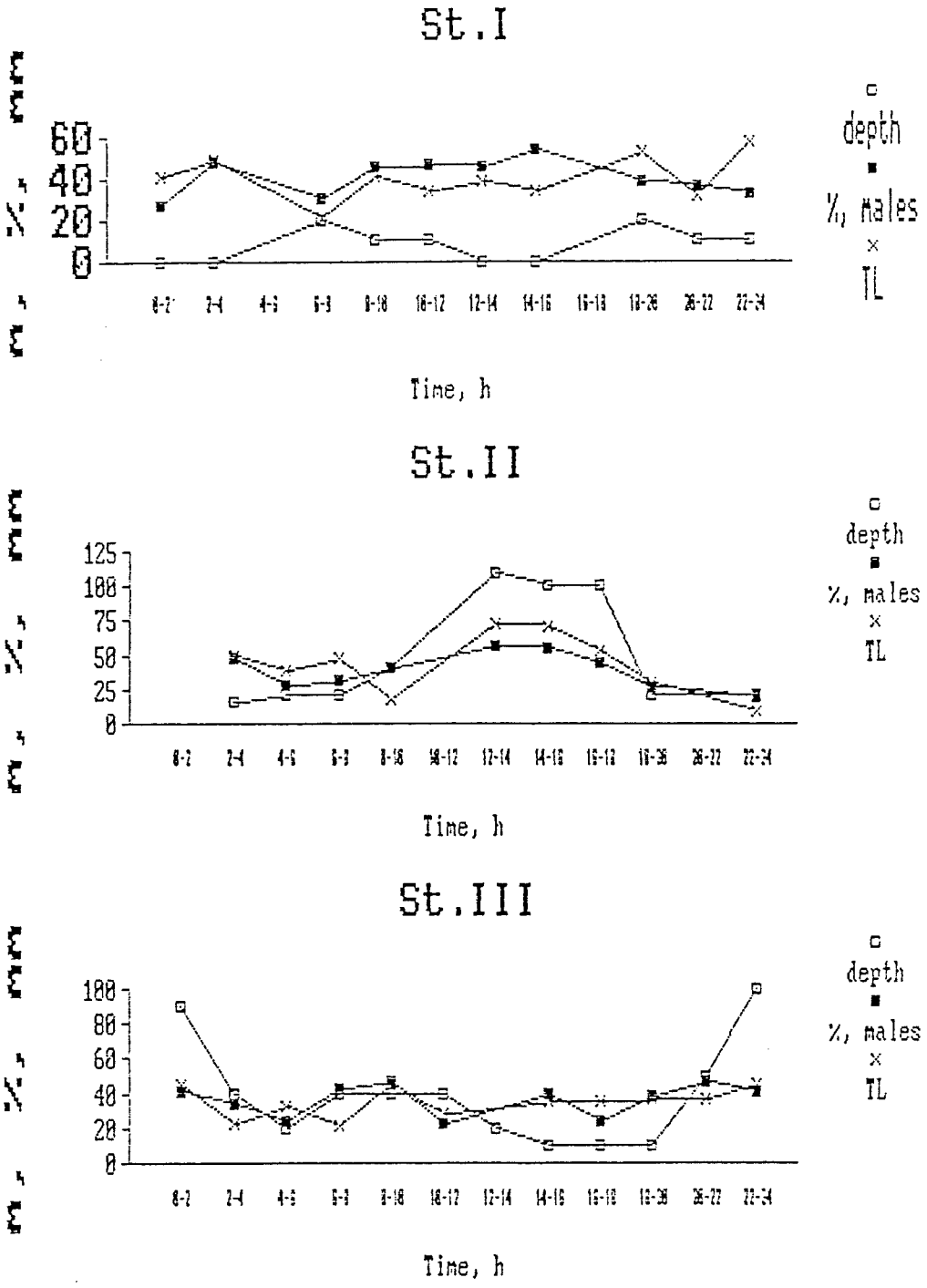

Figure 7: Catch depth, % of males and total average length of *E. superba* at each station. Depth at Station V is scaled by 1:10.

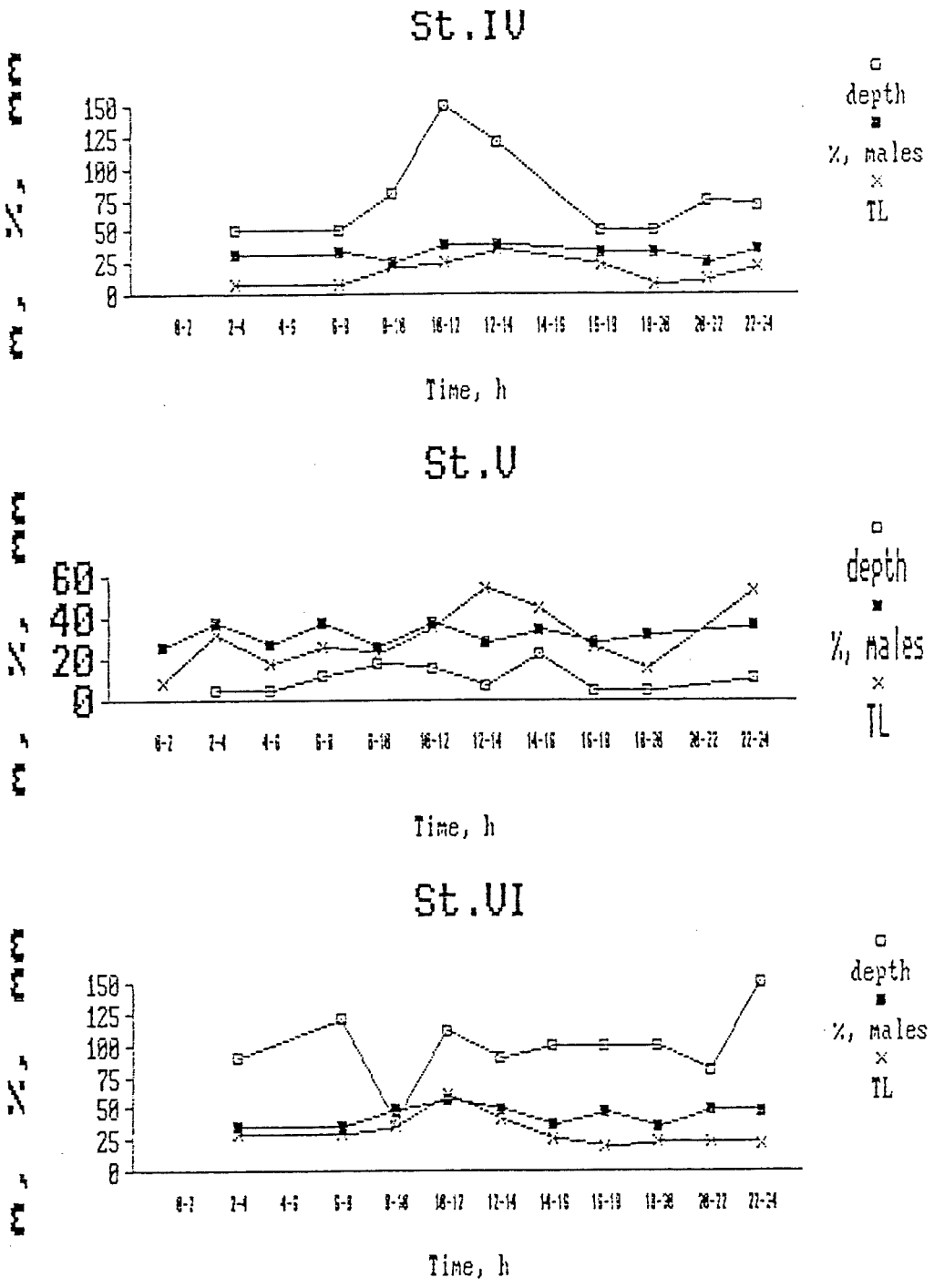

Figure 7 (continued)

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KRILL POPULATION BIOLOGY DURING THE 1991 CHILEAN ANTARCTIC KRILL FISHERY

A. Mujica R., E. Acuña S. and A. Rivera O.*

Abstract

Population biology of Antarctic krill, *Euphausia superba*, was studied from samples taken in 1991 during krill fishing operations around the South Shetland Islands on board the Chilean factory vessel *Kirishima*. Hauls were made using a commercial midwater trawl (mouth area approximately 40 x 40 m and mesh size from 1.5 to 3 cm). Two subsamples of 100 specimens each were taken from 50 samples and analysed. The fishing ground was divided into two areas: Area A, north of the South Shetland Islands; and Area B, north of Elephant Island. The samples were grouped by time of capture: daytime, twilight and night-time. The specimens were measured (total length, TL) to the nearest millimetre and weighed (wet weight) to the nearest 0.01 g. Mean catch-per-hour and mean catch-per-towing time were determined from a total of 419 hauls. In Area A, a unimodal size frequency distribution was found; the size range was between 30 and 55 mm TL, with a mean TL of 45 mm for females and 48 mm for males. A very weak mode for juvenile specimens between 26 and 36 mm TL was also found. The sex composition was 65.1% females, 34.4% males and 1.4% juveniles. Of the females sampled, 25.2% bore spermatophores. Although the smallest specimen found with a spermatophore had a 36.5 mm TL, 80% of the females with spermatophores had a TL larger than 45 mm. In Area B, a bimodal size frequency distribution and a larger size range were found, with one mode between 32 and 55 mm TL (mean length 43 mm for females and 46 mm for males), and the other (modal length 32 mm) for juvenile specimens between 20 and 39 mm TL. Females comprised 47.1%, males 40% and juveniles 12.9%. Of the females sampled, 27.1% bore spermatophores, with a size range between 35.4 and 56 mm TL, although 80% of them had a TL larger than 45 mm. The size frequency distribution showed no significant differences between the three time periods. However, when the sex composition is considered, males are more abundant in night-time catches while females are more abundant during daytime catches, thus showing a different trend. Considering all catches, the yield in terms of tonnes-per-mile and tonnes-per-hour was higher during the daytime than during twilight and night in both fishing areas. These daytime catches were also made at consistently greater depths. Research was financed by INACH (Chilean Antarctic Institute).

Résumé

Etude de la biologie des populations du krill antarctique, *Euphausia superba*, fondée sur des échantillons prélevés en 1991 au cours des opérations de pêche de krill autour des îles Shetland du Sud à bord du navire-usine chilien le *Kirishima*. Les traits ont été effectués au chalut

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pélagique (surface de l'ouverture d'environ 40 x 40 m et maillage de 1,5 à 3 cm). Deux sous-échantillons de 100 spécimens chacun ont été prélevés de 50 échantillons, puis analysés. Le lieu de pêche était divisé en deux secteurs: la zone A, au nord des îles Shetland du Sud, et la zone B, au nord de l'île Eléphant. Les échantillons ont été groupés selon l'heure de capture: de jour, en période de demi-jour et de nuit. Les spécimens ont été mesurés (longueur totale, TL) au millimètre près et pesés (poids humide) au 0,01 g près. La capture moyenne par heure et la capture moyenne par heure du chalutage ont été déterminées à partir des 419 traits. Dans la zone A, une distribution unimodale de fréquences de tailles a été observée; la TL variait de 30 à 55 mm, dont une TL moyenne de 45 mm pour les femelles et de 48 mm pour les mâles. On a également observé un mode très faible pour les spécimens juvéniles d'une TL de 26 à 36 mm. La composition par sexe a révélé 65,1 % de femelles, 34,4% de mâles et 1,4% de juvéniles. Des femelles échantillonnées, 25,2% portaient des spermatophores. 80% des femelles portant des spermatophores était d'une TL supérieure à 45 mm, le plus petit spécimen étant pourtant d'une TL de 36,5 mm. Dans la zone B, on a observé une distribution bimodale de fréquences de tailles et une gamme de tailles plus étendue, avec un mode pour le groupe d'une TL de 32 à 55 mm (longueur moyenne de 43 mm pour les femelles et de 46 mm pour les mâles), et un mode (longueur modale de 32 mm) pour les spécimens juvéniles d'une TL de 20 à 39 mm. 47,1% étaient des femelles, 40% des mâles et 12,9% des juvéniles. Parmi les femelles échantillonnées de 35,4 à 56 mm de TL, mais dont 80% excédaient toutefois 45 mm, 27,1% portaient des spermatophores. La distribution de fréquences de tailles n'a révélé aucune différence majeure entre les trois périodes. Toutefois, si la composition par sexes est prise en compte, on remarque que les mâles sont plus abondants dans les captures de nuit, alors que les femelles prédominent dans celles de jour, ce qui indique donc une tendance différente. Compte tenu de toutes les captures, le rendement dans les deux lieux de pêche, en termes de tonnes par mille et de tonnes par heure, était plus élevé de jour qu'au crépuscule ou de nuit. De plus, les captures effectuées de jour étaient régulièrement réalisées à des profondeurs plus importantes. Les recherches ont été financées par l'INACH (l'Institut antarctique chilien).

Резюме

Биология популяций антарктического криля *Euphausia superba* изучалась по пробам, взятым в ходе промысла криля у Южных Шетландских о-вов чилийским плавзаводом *Kirishima*. Траления проводились коммерческим среднеглубинным тралом с площадью устья приблизительно 40x40 м и размером ячеи 1,5 - 3 см. Из 50 проб были взяты и проанализированы две подвыборки, состоящие из 100 особей. Промысловый участок был разделен на два района: Район А - к северу от Южных Шетландских о-вов и Район В - к северу от о-ва Элефант. Пробы были сгруппированы в соответствии с временем вылова: днем, в сумерках и ночью. Особи измерялись (общая длина, TL) до ближайшего миллиметра и взвешивались (мокрый вес) до ближайшего 0,01 г. Всего было выполнено 419 тралений. Определились средний вылов за час и средний вылов за время траления. В Районе

Анаблюдалось одномодальное распределение частоты длин с диапазоном размеров между 30 и 55 мм TL, средней общей длиной 45 мм у самок и 48 мм у самцов. Также наблюдалась очень слабая модальная длина у молоди, общая длина которой была 26 - 36 мм. Половой состав: самки - 65,1%; самцы - 34,4%; и молодь - 1,4%. 25,2% обследованных самок имело сперматофоры. Несмотря на то, что общая длина наименьшей особи, имеющей сперматофоры, составляла 36,5 мм, общая длина 80% самок, имеющих сперматофоры, превысила 45 мм. В Районе И было отмечено бимодальное распределение частоты длин и больший диапазон длин - одна мода между 32 и 55 мм ЕД (средняя для самок - 43 мм и для самцов - 46 мм); другая мода была 32 мм в случае молоди, TL которой была между 20 и 39 мм. Половой состав: самки - 47,1%; самцы - 40%; и молодь - 12,9%. 27,1% обследованных самок имело сперматофоры и находилась в диапазоне длин 35,4 - 56 мм TL, хотя у 80% особей TL превысила 45 мм. Распределение частоты длин не указало на значительные расхождении между тремя периодами. Тем не менее, если принять во внимание половой состав, бо̀льшее количество самцов встречается в ночных уловах, а бо̀льшее самок - в дневных уловах. Учет всех уловов показывает, что вылов в единицах "тонны/милю" и "тонны/час" был выше при дневном свете, чем в сумерках или ночью в обоих промысловых районах. Дневные уловы также регулярно были получены в более глубоких водах. Научные исследования финансировал Чилийский антарктический институт.

Resumen

Se realizó un estudio biológico del stock de kril antártico *Euphausia superba,* a partir de la muestras recogidas en 1991 por el buque factoría chileno *Kirishima* durante sus operaciones pesqueras realizadas en las aguas del archipiélago de las Shetland del Sur. Se empleó un arrastre pelágico comercial (abertura de unos 40 x 40 m y luz de malla de 1.5 a 3 cm). De un total de 50 muestras, se separaron 2 submuestras de 100 especímenes cada una para ser analizadas. Los caladeros se dividieron en dos zonas: el Area A, al norte de las Shetland del Sur y el Area B al norte de la isla Elefante. Las muestras se agruparon según la hora de recogida: diurnas, crepusculares o nocturnas. Los especímenes se midieron al milímetro más próximo (TL, longitud total) y se pesaron (peso húmedo) al 0.01 g más próximo; también se calcularon las medias de captura por hora y por arrastre de los 419 lances realizados. Para el Area A, la distribución de frecuencia de TL fue unimodal y osciló entre 30 y 55 mm, siendo 45 mm la media para las hembras y 48 mm para los machos. La moda de TL para los juveniles era baja, entre 26 y 36 mm. La composición de sexos fue de un 65.1% de hembras, 34.4% de machos y 1.4% de juveniles. De las hembras muestreadas el 25.2% tenía espermatoforas. Aunque la TL más pequeña era 36.5 mm, en el 80% de los casos la talla superaba los 45 mm. En el Area B, la distribución de frecuencia de TL era bimodal con una gama de tallas más amplia; una moda oscilaba entre 32 y 55 mm (43 mm de media para las hembras y 47 mm para los machos) y la otra para ejemplares juveniles entre 20 y 39 mm (con una moda de 32 mm). Las hembras constituían el 47.1%, los machos el 40% y los juveniles el 12.9%. De las hembras

muestreadas el 27.1% tenía espermatoforas, con una gama de TL que oscilaba entre 35.4 y 56 mm, aunque el 88% superaba los 45 mm. La distribución de frecuencia de tallas no mostró diferencias significativas entre los tres horarios. Sin embargo, al examinar la composición de sexos resultó que los machos eran más abundantes en las capturas nocturnas, mientras que las hembras lo eran en las diurnas, lo que representa la tendencia contraria. Cuando se consideró la captura total realizada se vió que el rendimiento en términos de tonelada por milla y por hora fue mayor durante el día que en las horas crepusculares o nocturnas en ambas zonas de pesca. Las capturas diurnas se realizaron a mayor profundidad. Este estudio estuvo subvencionado por el INACH (Instituto Antártico Chileno).

1. INTRODUCTION

CCAMLR has determined that since krill, (*Euphausia superba*), is by far the most abundant marine living resource in Antarctic waters, the major task of its Working Group on Krill (WG-Krill) should be analysis of the krill fishery. Obtaining information about the size, distribution and composition of commercial krill catches is one of the key aspects of the work of WG-Krill. Marín *et al.* (1991) made a preliminary analysis of the haul-by-haul data collected during 1991 in the fishing grounds near Livingston Island, Robert Island, Nelson Island and Elephant Island.

During the 1991 fishing season, scientific observers on board the Chilean factory vessel *Kirishima* belonging to the company Empresa de Desarrollo Pesquero (ENDEPES), collected biological information on krill catches. The main objective of this article is to present an analysis of that information, in particular in respect of *E. superba* population biology.

2. MATERIALS AND METHODS

Samples were taken (20 February to 25 March, 1991) from 50 fishing tows of a total of 419, on board *Kirishima* which operated in the Drake Passage off the South Shetland Islands (Figure 1).

Catches were obtained using a commercial midwater trawl, (mesh size 1.5 to 3 cm and mouth area approximately 40 x 40 m), which was towed at a mean velocity of 2.65 knots for 5 to 95 minutes, at minimum depths between 25 to 100 m determined by a netsonde device mounted on top of the net.

In order to determine size frequency distribution and sex ratio, two subsamples of 100 specimens were taken from each haul; a total of 10 000 specimens was analysed. Each specimen was sexed and measured (Total Length, TL and Cephalothorax Length, CL) to the nearest millimetre and weighed (wet weight) to the nearest 0.01 g and its maturity stage determined.

Krill diurnal distribution was analysed using values obtained for mean catch-per-hour and mean catch-per-distance towed (n miles) from the 419 tows and by dividing the fishing grounds into areas A and B (see Figure 1) and the catches into three time categories (daytime, from 90 minutes after sunrise to 90 minutes before sunset; twilight, from 90 minutes before to 90 minutes after sunrise and sunset; and night-time, from 90 minutes after sunset to 90 minutes before sunrise).

The tow number, time of tow, date, position, towing velocity and minimum depth of the tows where samples were taken are shown in Table 1.

3. RESULTS

In Area A north of the South Shetland Islands, close to unimodal size frequency distribution was found with the main length mode of specimens between 30 and 55 mm TL, a mean TL of 45 mm for females and 48 mm for males, and a very small mode for juvenile specimens (sex undetermined) between 26 and 36 mm TL (Figure 2). The sex composition of the samples from this area was 65.1% females, 34.4% males and 1.4% juveniles or specimens of undetermined sex. Of the total number of females sampled, 25.2% bore spermatophores, and although the smallest specimen found with a spermatophore was 36.5 mm TL, 80% of these females were between 45 and 53.7 mm TL with a mode of 46.5 mm TL (Figure 3).

In Area B north of Elephant Island, a clear bimodal size frequency distribution and a larger size range were found, with one mode of specimens between 32 and 55 mm TL, (mean TL of 43 mm for females and 46 mm for males), and the other (32 mm) for juvenile specimens (sex undetermined) between 20 and 39 mm TL (Figure 4). Females were also more abundant in this area (47.1%), while males (40%) and juveniles or specimens of undetermined sex (12.9%) were much more abundant than in Area A. Of the total number of females sampled, 27.1% bore spermatophores with a size range between 35.4 and 56 mm TL, although 80% of them were larger than 45 mm TL, with the largest modes between 46 and 47 mm TL (Figure 5).

The analysis of the size frequency distribution of catches taken during the three different time periods showed no significant differences among them; sizes were between 20 and 55 mm TL and a bimodal distribution was found. Two maximum frequencies were around 48 mm TL and between 32 and 34 mm TL for juveniles during the three time periods (Figure 6). However, when sex ratio is considered, males tended to be more abundant in night-time catches while females were more abundant in daytime catches (Figure 7), showing a different trend i.e., the percentage of males in the catches increases from daytime to night-time while the percentage of females decreases.

Considering all catches, the yield in terms of tonnes/mile (Figure 8) and tonnes/hour (Figure 9) was higher during the daytime than during twilight and at night in both fishing areas. These daytime catches were also made at consistently greater depths.

REFERENCES

MARIN, V.H., A. MUJICA and P. EBERHARD. 1991. Chilean krill fishery: analysis of the 1991 season. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8)*. CCAMLR, Hobart, Australia: 273-287.

Table 1: Tow number, time of tow, date, position, towing velocity and minimum depth of tows containing a fish by-catch during krill fishing.

Tow	Time	Date	Position		Towing Velocity	Minimum Depth
			Latitude	Longitude		
			AREA A			
9	10:00	21.02.91	62°01,2'	60°29,0'	2.70	50
10	12:30	21.02.91	62°06,2'	59°57,3'	3.10	30
13	19:25	21.02.91	62°08,0'	59°55,3'	2.60	58
14	21:30	21.02.91	62°08,1'	59°51,5'	2.40	50
20	09:30	22.02.91	62°08,9'	59°56,4'	2.60	84
24	17:45	22.02.91	62°08,9'	59°54,5'	2.80	55
25	19:55	22.02.91	62°08,7'	59°55,2'	2.80	50
33	12:10	23.02.91	62°23,6'	60°40,5'	2.20	50
36	16:10	23.02.91	62°31,8'	61°09,0'	2.50	45
40	23:20	23.02.91	62°30,5'	61°21,0'	3.20	52
44	07:05	24.02.91	62°31,3'	61°24,2'	3.60	50
46	11:30	24.02.91	62°31,5'	61°26,8'	3.70	45
47	13:30	24.02.91	62°32,6'	61°28,2'	3.10	45
48	15:35	24.02.91	62°32,8'	61°28,2'	3.30	45
54	16:00	25.02.91	62°29,1'	61°03,2'	3.00	50
62	06:30	26.02.91	62°40,6'	61°46,0'	3.20	34
63	08:05	26.02.91	62°40,9'	61°46,5'	3.40	50
74	08:50	27.02.91	62°40,3'	61°35,6'	3.80	48
77	14:50	27.02.91	62°39,5'	61°37,5'	2.70	50
93	21:25	28.02.91	62°27,6'	60°58,2'	2.70	50
05	19:15	01.03.91	62°26,8'	60°26,8'	3.20	40
16	18:20	02.03.91	62°19,2'	60°51,5'	2.50	50
28	14:40	03.03.91	62°27,6'	61°17,6'	2.70	50
30	18:20	03.03.91	62°26,0'	61°17,8'	2.80	40
39	08:30	04.03.91	62°33,5'	61°22,7'	2.90	35
57	21:05	05.03.91	62°34,8'	61°27,3'	2.40	40
66	15:55	06.03.91	62°40,5'	61°26,3'	2.60	40
68	18:40	06.03.91	62°40,5'	61°26,0'	2.60	40
81	17:10	07.03.91	62°41,0'	61°21,5'	2.70	40
90	10:20	08.03.91	62°40,0'	61°24,6'	3.00	50
91	11:15	08.03.91	62°40,5'	61°24,6'	2.80	50
95	17:40	08.03.91	62°39,9'	61°33,3'	2.70	40
04	07:35	09.03.91	62°32,7'	61°22,4'	2.50	35
47	18:10	12.03.91	62°00,9'	59°18,7'	2.20	40
60	19:00	13.03.91	61°54,5'	58°41,8'	3.10	40
			AREA B			
75	07:00	15.03.91	60°51,2'	55°35,2'	2.60	45
82	18:15	15.03.91	60°50,7'	55°34,7'	2.20	50
90	07:05	16.03.91	60°52,6'	55°37,5'	2.30	35
04	07:50	17.03.91	60°52,8'	55°35,4'	2.10	50
44	04:30	20.03.91	60°59,5'	55°10,4'	2.70	70
59	05:50	21.03.91	60°52,7'	55°22,1'	2.50	50
12	06:10	25.03.91	60°50,2'	55°50,2'	2.10	60

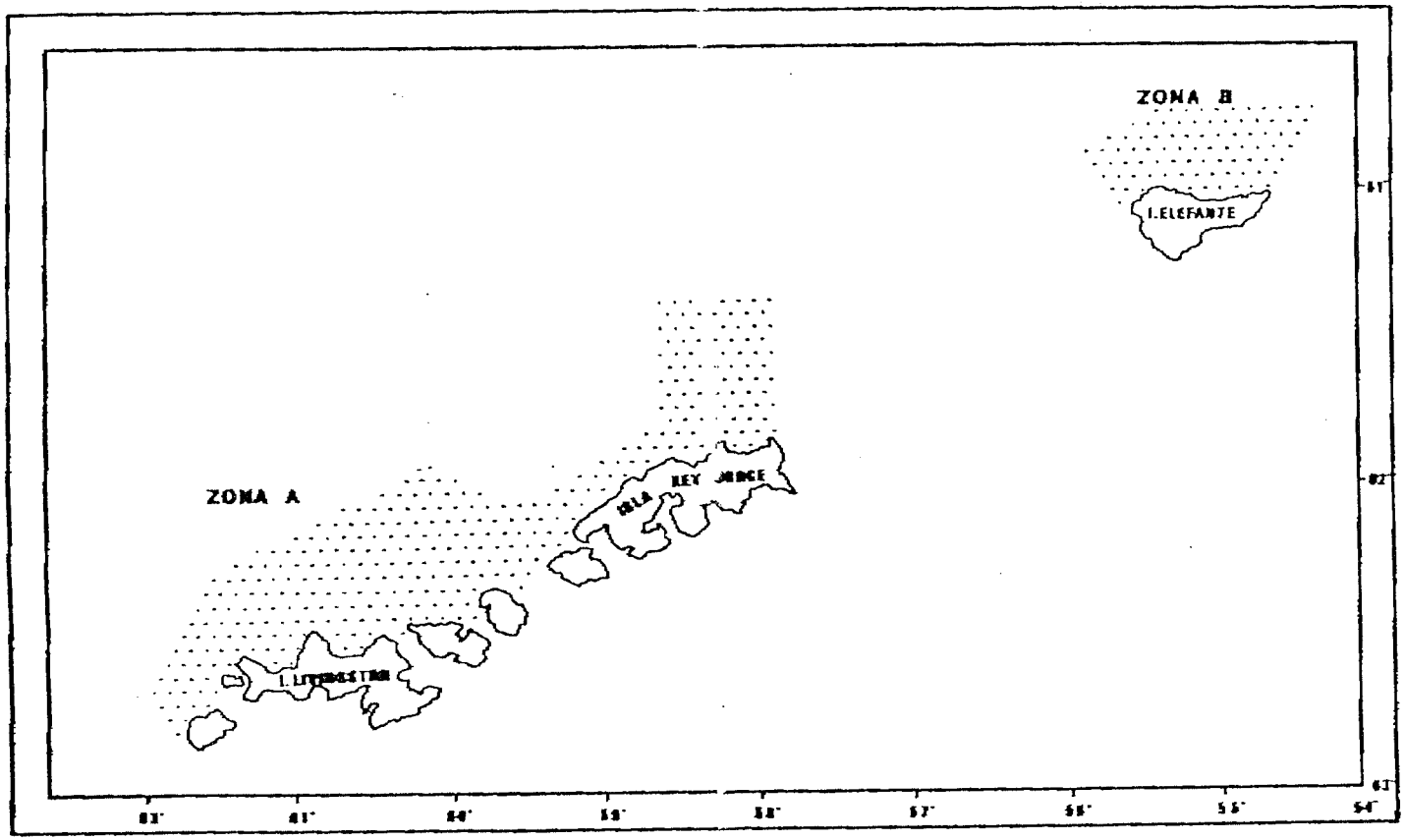

Figure 1: Chilean krill fishing grounds.

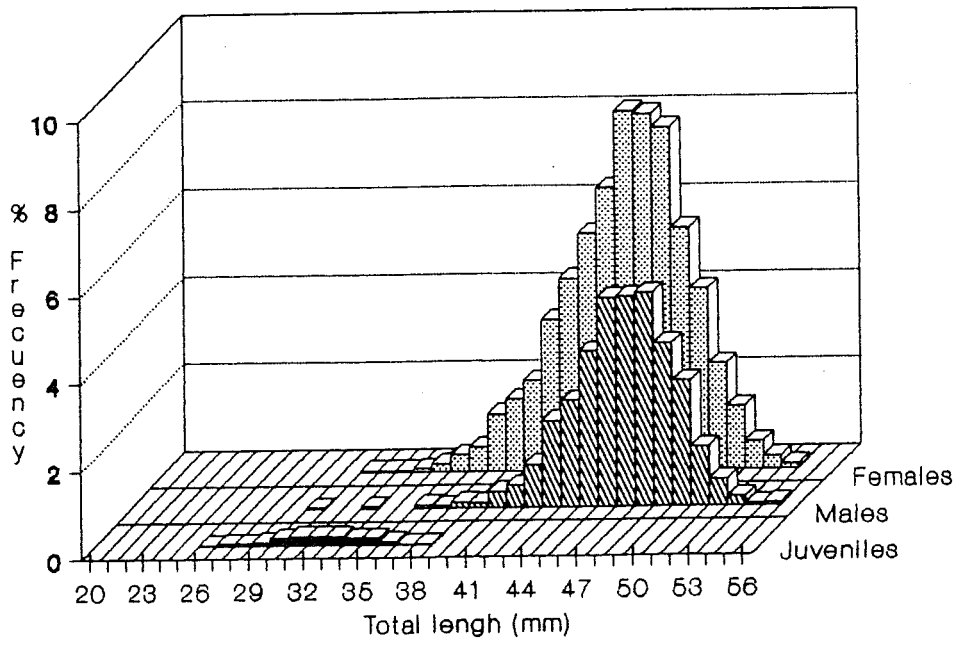

Figure 2: Size frequency distribution of *E. superba* juveniles, males and females in Area A.

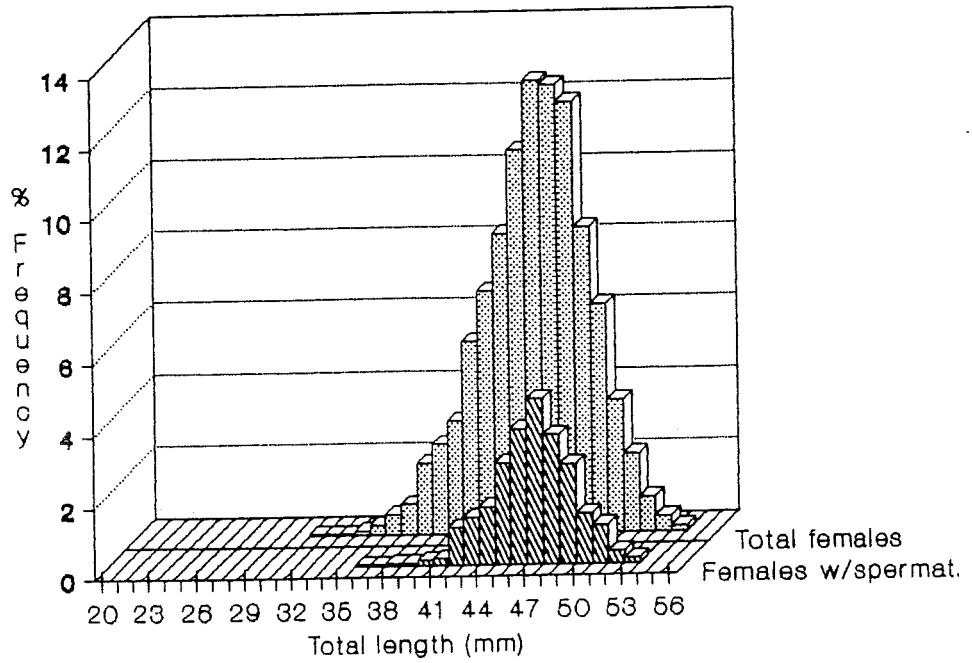

Figure 3: Size frequency distribution of total females and females with spermatophores in Area A.

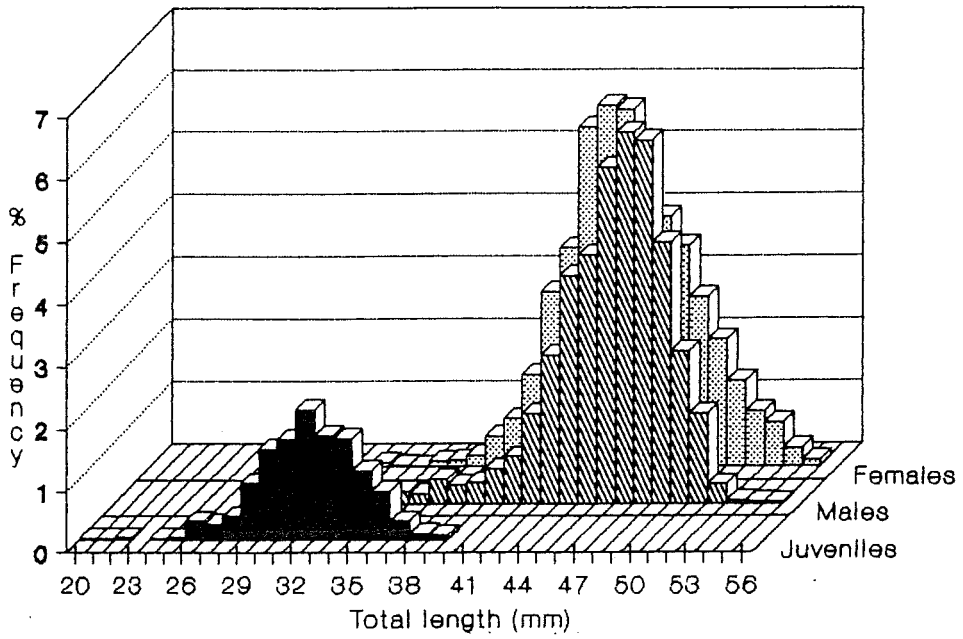

Figure 4: Size frequency distribution of *E. superba* juveniles, males and females in Area B.

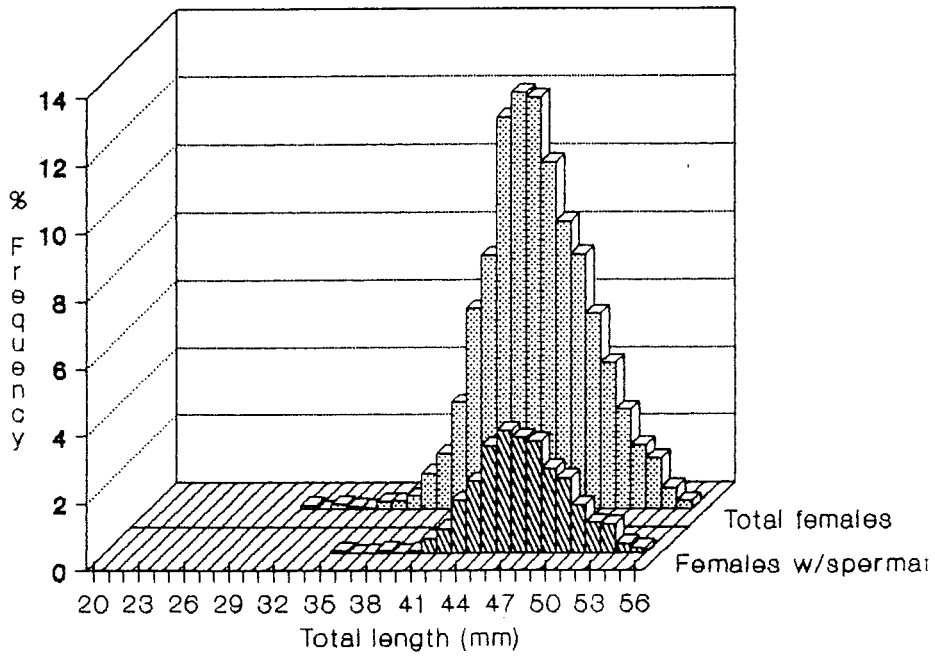

Figure 5: Size frequency distribution of total females and females with spermatophores in Area B.

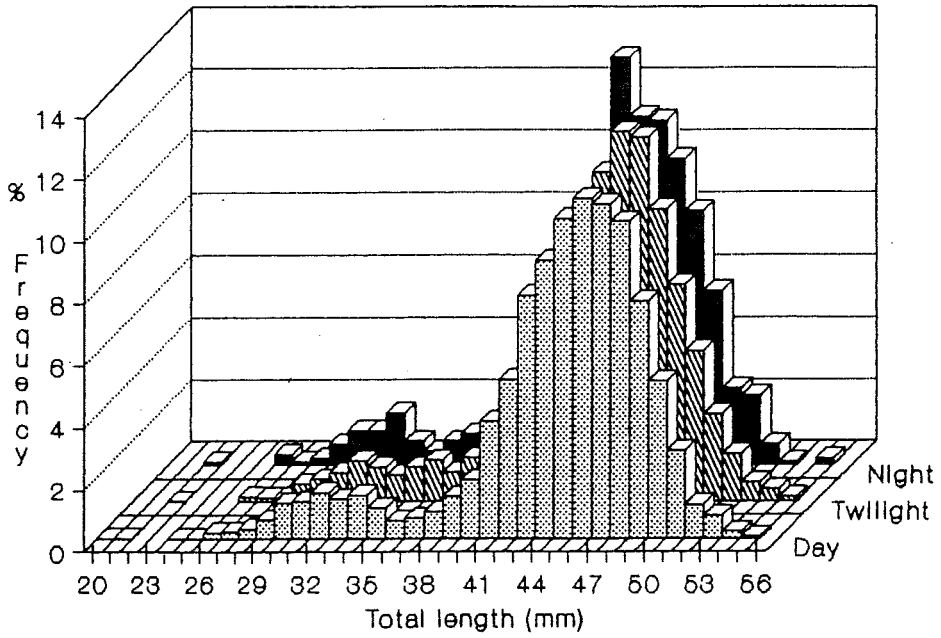

Figure 6: Size frequency distribution of *E. superba* during the daytime, twilight and night-time.

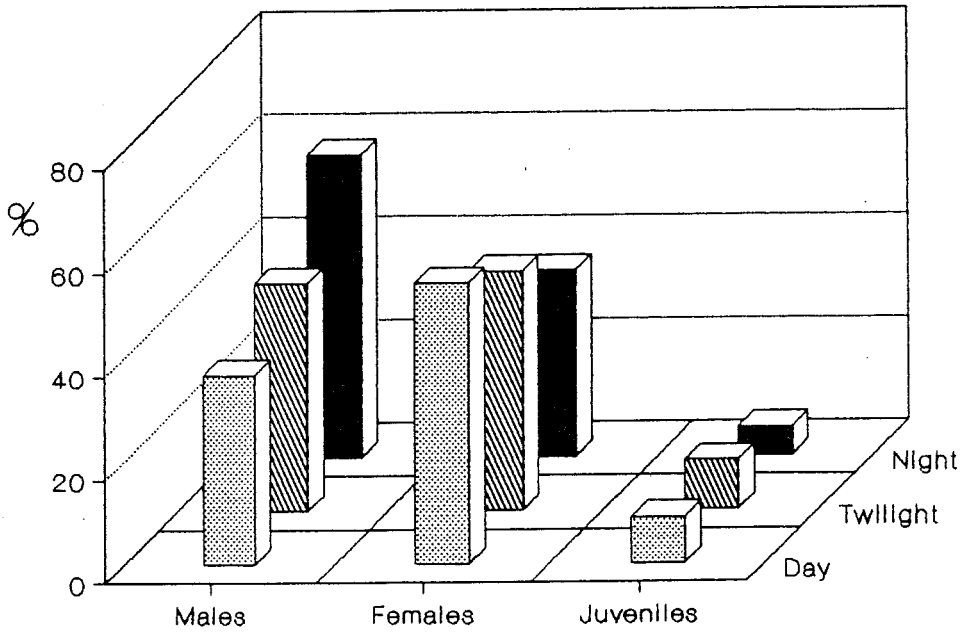

Figure 7: Sex composition of *E. superba* in the three time periods.

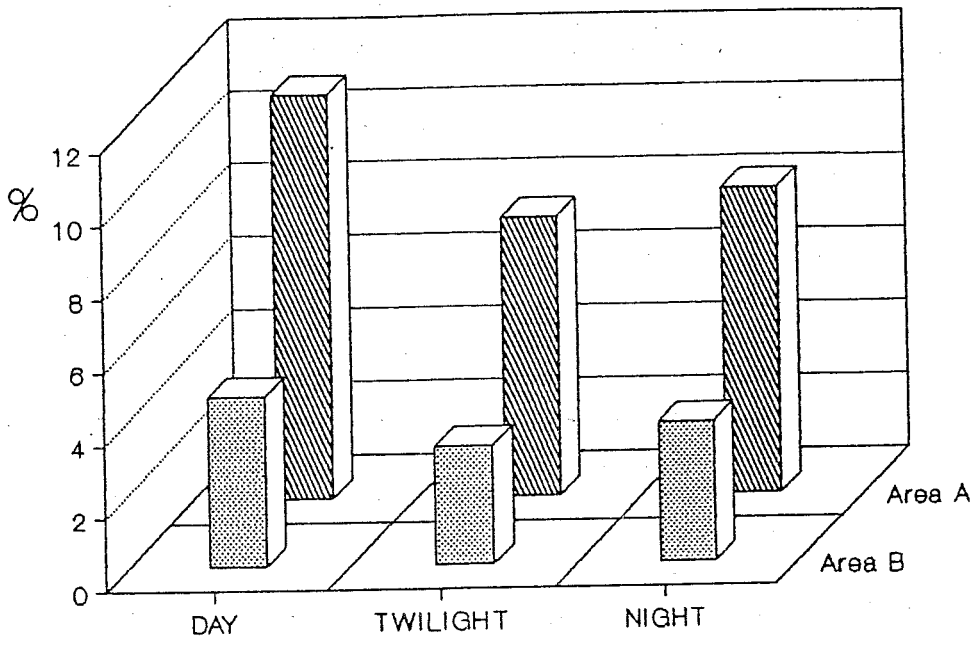

Figure 8: Total catch (tonne/mile) in both areas during the three time periods.

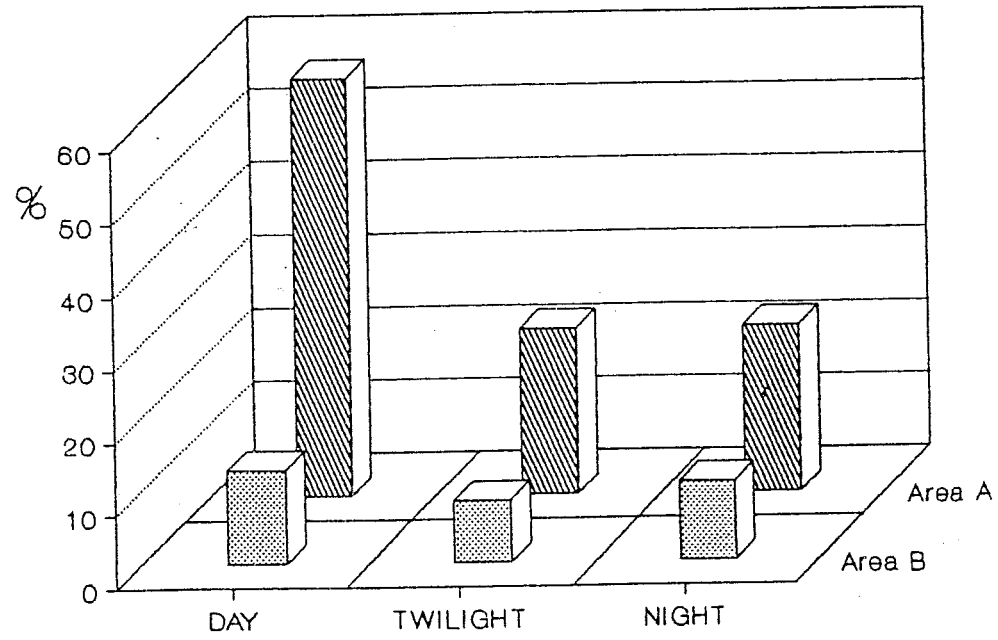

Figure 9: Total catch (tonne/hrs) in both areas during the three time periods.

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ALTERNATIVE METHODS FOR DETERMINING SUBAREA OR LOCAL AREA CATCH LIMITS FOR KRILL IN STATISTICAL AREA 48

G. Watters and R.P. Hewitt*

Abstract

CCAMLR Conservation Measure 32/X sets a 1.5 million tonne precautionary catch limit on krill (*Euphausia superba*) in Statistical Area 48. The measure also implies an application in future of precautionary limits to subareas or local areas of this area. Nine alternative methods of determining subarea or local area krill catch limits are evaluated relative to six criteria: (i) the degree to which information on biological relationships is considered; (ii) the cost of data collection; (iii) the reliability of required information; (iv) the ease of enforcement; (v) the effects on current fishing patterns; and (vi) the potential for delay in implementing the alternative. An alternative is less likely to adversely impact dependent species (e.g., penguins and seals) if the ecological relationships between krill and their predators are explicitly considered and the potential for delayed implementation is low. Therefore, we consider the following tradeoff to be important: choosing a biologically explicit alternative and delaying implementation, or choosing a biologically unrealistic alternative and implementing a management scheme immediately. We recognise that other tradeoffs may be equally important. Alternatives that allocate the 1.5 million tonne limit by evenly dividing the catch among subareas or by using historical catches to set limits can be categorised as having a low potential for delaying implementation, but they ignore information on biological relationships. Alternatives based on protective zones, critical periods, predator censuses, and predator-prey models include large amounts of biological information, but may not be practical in the near future. Alternatives based on continental shelf area, simple pulse fishing, and krill surveys are not biologically explicit and result in delayed implementation. None of the alternatives are categorised as being both biologically explicit and immediately available for implementation. However, two of the alternatives (i.e., protective zones and critical periods) are unsatisfactory only because they would alter current fishing patterns. These two alternatives could be implemented immediately if the CCAMLR Member nations are willing to tolerate changes in current fishing patterns.

Résumé

La mesure de conservation 32/X de la CCAMLR fixe la limite préventive de capture de krill (*Euphausia superba*) de la zone statistique 48 à 1,5 million de tonnes. Cette mesure implique également l'application prochaine de limites préventives aux sous-zones et aires localisées de cette zone. Neuf nouvelles méthodes de détermination des limites de capture de krill dans les sous-zones ou aires localisées sont évaluées, relativement à six critères: i) jusqu'à quel point sont prises en compte les informations sur les relations biologiques; ii) le coût de la collecte

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des données; iii) la fiabilité des informations requises; iv) la facilité de la mise en application; v) les effets sur les tendances de pêche actuelles; et vi) le risque d'un délai dans la mise en place d'une nouvelle méthode. Une nouvelle méthode risque de ne pas avoir autant d'effets néfastes sur les espèces dépendantes (telles que les manchots ou les phoques) si les relations écologiques entre le krill et ses prédateurs sont prises en considération et si sa mise en place est peu susceptible d'être retardée. Ainsi nous reconnaissons l'importance du compromis suivant: soit choisir une méthode explicite sur le plan biologique et retarder sa mise en place, soit choisir une méthode peu réaliste sur le plan biologique et mettre en place immédiatement un système de gestion. Nous reconnaissons que d'autres compromis peuvent être tout aussi importants. Les méthodes allouant la limite de 1,5 tonne soit à parts égales entre les sous-zones soit en basant les limites sur les captures anciennes peuvent être classées dans une catégorie à risques réduits de mise en place tardive, mais elles ne tiennent pas compte des informations sur les relations biologiques. Les méthodes fondées sur les zones de protection, les périodes critiques, les recensements des prédateurs, et les modèles prédateurs-proies comportent un grand nombre d'informations biologiques, mais risquent de ne pas être pratiques dans un proche avenir. Les méthodes reposant sur la zone du plateau continental, la pêche par à-coups ordinaire et les campagnes d'évaluation du krill ne sont pas explicites sur le plan biologique et se soldent par un retard dans la mise en place. Aucune de ces méthodes n'est à la fois explicite sur le plan biologique et prête à être mise en place dans l'immédiat. Toutefois, deux des méthodes (à savoir zones de protection et périodes critiques) sont peu satisfaisantes uniquement du fait qu'elles modifieraient les tendances de pêche actuelles. Ces deux méthodes pourraient être applicables dans l'immédiat si les pays membres de la CCAMLR acceptaient de tolérer des changements dans les tendances de pêche actuelles.

Резюме

Мера по сохранению 32/X устанавливает предохранительное ограничение на вылов криля (*Euphausia superba*) в Статистическом районе 48 размером 1,5 миллиона тонн. Данная мера также предусматривает распространение в будущем предохранительных ограничений на подрайоны или локальные районы этого района. Оцениваются девять альтернативных методов установления ограничений на объем вылова криля по подрайонам или локальным районам относительно шести критериев: (i) степень учета информации о биологических взаимосвязях; (ii) стоимость сбора данных; (iii) достоверность требуемой информации; (iv) степень осуществимости контроля за промыслом; (v) последствия для промысловых режимов, применяемых в настоящее время; и (vi) возможность задержок в применении того или иного метода. Та альтернатива окажет меньшие отрицательные воздействия на зависящие от криля популяции (например, пингвины и тюлени), которая учитывает экологические взаимосвязи между хищниками и потребляемыми видами и которая имеет низкую вероятность задержки в применении. В связи с этим мы считаем важным следующий компромисс: либо выбрать биологически очевидную альтернативу и отложить

осуществление, либо выбрать биологически нереальную альтернативу и сразу же внедрить систему управления. Мы признаем, что и другие компромиссы могут быть одинаково важными. Хотя альтернативы, которые равномерно распределяют вылов в 1,5 млн. тонн между подрайонами или используют промысловые данные за предыдущие сезоны с целью установления ограничений на вылов, можно охарактеризовать как имеющие низкий потенциал задержки в применении, они все-таки не принимают во внимание информацию о биологических связях. Альтернативы, основанные на закрытых районах, критических периодах, учетах хищников и моделях "хищник/потребляемый вид", предусматривают наличие большего количества биологической информации, однако они могут оказаться непрактичными в ближайшем будущем. Альтернативы, основанные на площади континентального шельфа, обыкновенном пульсирующем промысле и учетах криля, биологически не обоснованы и влекут за собой задержки в их применении. Ни одна из альтернатив не может быть охарактеризована как биологически обоснованную и готовую к применению. Тем не менее, две альтернативы (т.е. закрытые районы и критические периоды) являются неудовлетворительными лишь потому, что их применение изменило бы настоящий промысловый режим. Эти две альтернативы могли бы быть применены, если бы страны-Члены АНТКОМа согласились с изменением в существующих промысловых режимах.

Resumen

La Medida de conservación 32/X establece un límite de captura precautorio para el kril (*Euphausia superba*) de 1.5 millones de toneladas en el Area estadístisca 48. Esta medida también supone una futura aplicación de límites de captura precautorios a subáreas o zonas específicas en este área en el futuro. Se evalúan nueve métodos alternativos para determinar los límites de captura de kril por subárea o zona específica en conexión a seis principios: (i) la medida en que se considera la información sobre las relaciones biológicas; (ii) el coste de recopilación de datos; (iii) la fiabilidad de la información requerida; (iv) la facilidad de ejecución; (v) los efectos en los regímenes de pesca actuales; y (vi) la posibilidad de retrasar la puesta en marcha del método alternativo. Un método alternativo tiene menos probabilidades de dañar a las especies dependientes (p.ej. pingüinos y focas) si se toman en cuenta explícitamente las relaciones ecológicas entre el kril y sus depredadores y si la probabilidad de retrasar su aplicación es baja. Por lo tanto, consideramos relevantes las siguientes compensaciones: elegir una alternativa biológicamente detallada con un retraso en su aplicación, o elegir una alternativa biológicamente poco realista poniendo en marcha un sistema de gestión inmediato. Reconocemos que otras compensaciones podrían ser igualmente válidas. Aquellas alternativas que desglosan el límite de 1.5 millones de toneladas en partes iguales entre las subáreas o las que emplean los historiales de captura para fijar límites se pueden considerar con pocas posibilidades de retrasar la puesta en marcha, aunque se desconozca la información sobre las relaciones biológicas. Aquellas alternativas basadas en las zonas protegidas, en períodos críticos, en censos de depredadores, y en los

modelos depredador-presa, incluyen muchos datos biológicos pero pueden ser inútiles a corto plazo. Por otra parte, las alternativas centradas en la zona de la plataforma continental, en la pesca por pulso simple, y en las prospecciones de kril no contienen información biológica detallada y resultan en una ejecución tardía. Ninguna de las alternativas se clasifican a la vez como biológicamente detalladas y disponibles para ser aplicadas inmediatamente. Sin embargo, dos de las alternativas (p.ej. zonas protegidas y períodos críticos) son inapropiadas por el solo hecho de que pueden alterar los regímenes de pesca actuales. Estas dos alternativas podrían ser aplicadas de inmediato si los Estados miembros de la CCRVMA estan dispuestos a aceptar cambios en los regímenes de pesca existentes.

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1. INTRODUCTION

In November, 1991, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) adopted Conservation Measure 32/X. This conservation measure sets a 1.5 million tonne precautionary catch limit on krill, *Euphausia superba*, in Statistical Area 48 (CCAMLR, 1991a). Conservation Measure 32/X also requires CCAMLR's Scientific Committee to provide the Commission with advice on how the 1.5 million tonne limit could be allocated between subareas or local areas if the total catch in Subareas 48.1 (Antarctic Peninsula), 48.2 (South Orkney Islands), and 48.3 (South Georgia) exceeds 620 000 tonnes in any fishing season.

It is important to consider alternative methods for estimating subarea or local area catch limits before the total krill catch in Statistical Area 48 totals 620 000 tonnes. Reactive management is not an acceptable, long-term strategy for managing the krill fishery (SC-CAMLR, 1991). Considering alternative catch allocation strategies before 620 000 tonnes of krill are caught in Statistical Area 48 helps prevent reactive krill management.

The primary goal of any catch allocation scheme should be to minimise the probability of adversely impacting species that depend on krill as a primary food source (e.g., penguins and seals); this is mandated by Article II of the CCAMLR Convention. The probability of adverse impact is affected by our understanding of the relationships between krill, their predators, and their environment, and the degree to which this understanding can be incorporated into specific management terms. The probability of adverse impact is also affected by practical considerations, such as the reliability of information used by the alternative, the complexity of the management rules, the disruption of current fishing strategies, and, ultimately, the delay in implementing an effective allocation scheme.

We used the following criteria to evaluate nine alternative schemes for allocating krill catches among subareas or local areas:

(1) Amount of information on biological interactions explicitly considered in the alternative: Presumably, as more information is incorporated into an allocation scheme, the probability of adversely impacting dependent species will decrease. This may not be the case, particularly if functional relationships are incorrectly specified or if there is high variability in the data, but, as a first approximation, we will ignore these concerns.

(2) Longterm costs of collecting the data required to implement the alternative: Cost will increase if frequent surveys are required or if sampling effort must be increased to achieve a desired level of precision. Short-term costs associated with initial implementation of an alternative are not considered.

(3) Reliability of the information used in the alternative: Both precision and accuracy are important. Reliability is high if the required quantities/parameters can be estimated precisely and without bias.

(4) Ease of enforcing the alternative: Enforcement is difficult when the allocation scheme is complex and when catch allocations are frequently changed (these make it harder to maintain consensus in the Commission).

(5) Change to current fishing patterns: Allocation schemes differ in the degree to which they would change the historical distribution of fishing effort and in the amount of discretion given to the fishing vessels. Schemes that alter current fishing patterns usually lead to management delays (see below).

(6) Delay in implementing the alternative: Delays may be caused by political resistance towards altering current fishing patterns or by data unavailability. We assume that delay in implementing the alternative increases the probability of adverse impact on dependent species.

The nine alternatives for allocating krill catches among subareas are:

(1) Historical catches,
(2) Even division among subareas,
(3) Shelf area,
(4) Simple pulse fishing,
(5) Protective zones,
(6) Critical periods,
(7) Predator censuses,
(8) Krill surveys, and
(9) Models of predator-prey interactions.

This paper is intended to initiate a discussion about alternative methods of allocating the 1.5 million tonne precautionary catch limit in Statistical Area 48 between subareas or local areas. Since krill catches are usually concentrated near predator breeding colonies (Agnew 1991; Everson and Goss 1991), an allocation scheme is necessary to protect vulnerable predator populations and maintain CCAMLR's ecosystem perspective. The list of alternative allocation strategies presented in this paper is not exhaustive. The examples discussed in this paper focus on methods that limit krill catches directly; we do not consider methods to limit the catch by controlling fishing effort or fishing efficiency.

2. COMPARISON OF ALTERNATIVE ALLOCATION STRATEGIES

2.1 The Historical Catch Alternative

One of the initial proposals for setting a precautionary catch limit on krill in Statistical Area 48 was to base this limit on historical catches (SC-CAMLR, 1991). This type of strategy could also be used to allocate the catch between subareas or local areas. Between 1981 and 1991, about 18%, 48%, and 34% of the total krill catch in Statistical Area 48 was taken from Subareas 48.1, 48.2, and 48.3, respectively (CCAMLR, 1991b). Estimating precautionary catch limits according to historical catches gives a limit of 270 000 tonnes for Subarea 48.1 (1 500 000 tonnes x 0.18 = 270 000 tonnes), 720 000 tonnes for Subarea 48.2, and 510 000 tonnes for Subarea 48.3.

The historical catch alternative does not consider interactions between krill and dependent predators. The data used to calculate the historical catch distribution are probably reliable. There are no costs associated with data collection. The management scheme is not

complex and is easy to enforce. Fishing patterns can be maintained because past behavior is used to set current catch limits. Finally, this management scheme could be implemented immediately. These points are summarised in Table 1.

2.2 The Even Division Alternative

The precautionary limit of 1.5 million tonnes can be evenly divided between subareas or local areas. For example, the catch limits for Subareas 48.1, 48.2, and 48.3 could be set at 500 000 tonnes each (1 500 000 tonnes/3 = 500 000 tonnes). The catch can be further divided between local areas. For example, if the catch limit for Subarea 48.1 was 500 000 tonnes, then localised catch limits for Smith Island, Livingston Island, King George Island, and Elephant Island areas could be set at 125 000 tonnes each (500 000 tonnes/4 = 125 000 tonnes).

Evenly dividing the total catch between subareas or local areas does not consider interactions between krill and dependent predators. This alternative does not require data collection, so data reliability and collection costs are not important concerns. The simplicity of the even division alternative makes it easy to enforce. This alternative might not affect current fishing patterns because the largest catch ever taken from a single subarea is just over 250 000 tonnes (CCAMLR, 1991b). However, if fishing effort continues to be distributed according to historical proportions some of the catch will have to be redistributed from Subarea 48.2 to Subarea 48.1 (compare 500 000 tonnes per subarea to the limits prescribed by the historical catch alternative). Thus, for the even division alternative, it is difficult to evaluate the effects on current fishing patterns. The even division method can be implemented immediately. These points are summarised in Table 1.

2.3 The Shelf Area Alternative

Krill catch limits can be based on the area of continental shelf (say depth 250 m) within each subarea or local area. The basis of such an allocation scheme is to evenly distribute the catch throughout the areas where land-based predators and fisheries are most likely to interact. The total area of seabed in Subareas 48.1, 48.2, and 48.3 less than or equal to 250 m in depth is about 208 861 km^2 (Everson, 1987; Everson and Campbell, 1990). Approximately 52% of the total is from Subarea 48.1, 32% from Subarea 48.2, and 16% from Subarea 48.3. Using these proportions, catch limits for Subareas 48.1, 48.2, and 48.3 would be 780 000 tonnes (1 500 000 tonnes x 0.52), 480 000 tonnes, and 240 000 tonnes, respectively.

The shelf area alternative does not explicitly consider the relationships between krill and dependent predators. The seabed area data presented in Everson (1987) and Everson and Campbell (1990) are reliable. There are no data collection costs for this alternative, and enforcement would be easy. The shelf area method would significantly alter current fishing patterns. Historically, the krill fishery has taken the bulk of its catch from Subareas 48.2 and 48.3 (CCAMLR, 1991b), but the greatest proportion of shelf area is in Subarea 48.1 (Everson, 1987; Everson and Campbell, 1990). Therefore, allocating catches according to shelf area will concentrate krill catches on the southern edge of the historical fishing grounds. This redistribution of catch could have adverse impacts on the fishery (e.g., shorter fishing seasons during years with increased ice cover). The shelf area alternative could be effected immediately, but, since current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.4 The Simple Pulse Fishing Alternative

A simple pulse fishing strategy could be used to temporally cycle the krill catch between subareas by allowing all 1.5 million tonnes to be taken from a single subarea in a single year. Then, for the following two years, that subarea would be closed to fishing. For example, if

1.5 million tonnes of krill were taken from Subarea 48.1 this year, it would be closed to fishing during the two following years while Subareas 48.2 and 48.3 were subsequently opened and closed. We do not know if 1.5 million tonnes of krill can be taken from a single subarea, every three years, without adversely impacting dependent predator populations.

The simple pulse fishing alternative does not make an explicit consideration of krill-predator interactions, so data collection costs and problems with data reliability are not significant. This type of allocation scheme would be relatively difficult to enforce because fishing regulations would have to be changed annually (this would require international consensus at each meeting of the Commission). Pulse fishing would alter current fishing patterns. Fishing vessels would have limited flexibility areas when Subareas 48.2 and 48.3 are closed and ice is abundant. A pulse fishing strategy could be effected immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.5 The Protective Zone Alternative

This alternative creates protective zones around specific predator breeding colonies. For example, krill fishing could be prohibited within a 100 nautical mile radius of any island where fur seals (*Arctocephalus gazella*) are known to breed. Protective zones provide a spatial refuge for breeding predators and their prey. Under this alternative, no allocation would be made among subareas.

The protective zone alternative accounts for interactions between krill and predators by considering the foraging range of the farthest ranging predator. Foraging range data is usually collected with radio tracking equipment (see Amos *et al.*, 1990; AMLR, 1991 for examples), and this makes initial data collection costs high. However, since foraging ranges only need to be measured once, there would be no recurring, long-term data collection costs. The data are also highly variable (some animals swim farther than others), so reliability is a concern. Enforcing protective zones would be easy, although current fishing patterns would be drastically altered. Agnew (1991) and Everson and Goss (1991) have clearly shown that krill catches are concentrated near islands where predators breed. Closing island zones to fishing will force the fishing vessels farther offshore where krill will be more difficult to find. Vessels would probably spend considerably more time searching for fishable concentrations of krill. On the other hand, fishing vessels would not be restricted by subarea catch limits and could freely pursue operations in those subareas that are most economical. Protective zones could be prosecuted immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.6 The Critical Period Alternative

The krill fishery can be closed during "critical periods" corresponding to certain portions of the predators' reproductive cycles. This alternative is similar to the protected zone approach, but the catch limitation is based on temporal rather than spatial considerations. This method provides a temporal refuge for predators and their prey.

The critical period alternative accounts for interactions between krill and land-breeding predators during the predators' reproductive phases. Data are already available to describe the duration of this period for most predator species, so data collection costs will not be significant. The available data are also reliable. Enforcement of critical periods would be easy because the management scheme is relatively simple. However, management according to critical periods would significantly alter current patterns of fishing. Historically, some of the largest catches in Subareas 48.2 and 48.1 were taken when land-breeding predators were rearing their young (Everson and Goss, 1991), but these important fishing times would be closed according to the

critical period alternative. The critical period alternative could be effected immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.7 The Periodic Predator Census Alternative

Krill catch limits can be set for subareas or local areas by periodically censusing predator populations at important breeding sites and adjusting the catch according to some relationship between predator abundance (or predator condition) and harvestable krill biomass. This alternative considers predators as indicator species. The Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP) has made significant progress towards determining when predators are most vulnerable to competition from commercial fishing and how this vulnerability may be manifested (e.g., in lowered chick and pup survival rates). WG-CEMP is also making progress towards defining the prey requirements of many predators (Croll, 1990; Croxall, 1990; SC-CAMLR, 1991). Thus, it is apparent that much of the information necessary to implement this alternative is already being collected. However, more data needs to be collected in order to know how predators respond to temporal changes in prey availability (i.e., we need a time series of observations that covers a wide range of krill densities). It may take several years to arrive at a preliminary understanding of how predators respond to krill fishing.

Using predator censuses to estimate krill catch limits explicitly considers the interactions that occur between some of the major components of the Antarctic marine ecosystem. There will be an initial cost to collect the data necessary for defining the impacts to predators caused by changing prey availability, but, in the long term, we expect the most significant cost to be associated with conducting periodic predator censuses. Annual or semi-annual predator censuses should not be required because there will probably be a lag before population level responses to prey availability can be detected and because some predators are fairly long lived. The reliability of predator census data is probably good. This alternative would be relatively difficult to enforce because catch limits would have to be periodically changed in order to respond to changes in predator abundance or condition. There is potential for this alternative to change current fishing patterns, but this potential is difficult to evaluate. The periodic predator census alternative could be implemented immediately. These points are summarised in Table 1.

2.8 The Frequent Krill Survey Alternative

Krill catch limits can be set as some proportion of the krill biomass surveyed in a particular subarea or local area. It would be simple to determine a harvest rate based on some arbitrary notion. For instance, we might say that the harvest rate for krill in any subarea or local area could not be greater than the annual survival rate of krill in that area. Then, if the instantaneous rate of natural mortality for krill is 0.8 (the annual survival rate of krill is 0.45), and a survey determined that 200 000 tonnes of krill were present in a small, local area, the catch limit for krill in that area would be 90 000 tonnes (200 000 tonnes x 0.45 = 90 000 tonnes).

Using frequent krill surveys to determine catch limits does not explicitly consider predators; this is essentially a single-species alternative. Frequent estimates of krill biomass are necessary because patterns of krill abundance and distribution are highly variable in time and space (see Hewitt and Demer, 1992 for one example). This is in direct contrast to the frequency of surveys required by the periodic predator census alternative. Allocating catch limits according to estimates of krill biomass requires more frequent sampling because krill distributions are more dynamic in time and space than predator distributions. Thus, estimating catch limits from survey estimates of krill biomass will incur substantial long-term costs associated with data collection. It is also important to note that estimates of the instantaneous rate of natural mortality rate for krill are highly variable (Miller and Hampton, 1989). Thus, using this rate (or some derivative of it) may introduce uncertainty into estimates of catch limits. Enforcement will be difficult because the catch limits will be frequently changed. Current

fishing patterns might be altered if fishermen have to wait until the krill surveys are completed before they can start fishing. CCAMLR's Working Group on Krill (WG-Krill) has made substantial progress towards refining survey design and estimating krill target strength (SC-CAMLR, 1991); therefore, the krill survey alternative could be implemented immediately. However, because current fishing patterns are likely to change, actual implementation would probably be delayed. These points are summarised in Table 1.

2.9 The Model Alternative

Simulation models can be used to estimate subarea or local area krill catch limits. Consider a simple model with the following form:

> local TAC = (local krill biomass) - (local number of predators • per capita predator demand) - "safety factor"

where the "safety factor" is some number that ensures future krill recruitment. This simple model has substantial information requirements. It requires both predator surveys and krill surveys to estimate predator numbers and krill biomass, respectively, and to provide periodic updates for these estimates. It requires information about krill recruitment, immigration, and emigration in order to calculate a reasonable "safety factor". Information about per capita predator demand for krill is also necessary. Also, since most of the data are likely to be spatially and/or temporally variable, it would be necessary to collect information from every subarea or local area of interest and to collect this information for a number of years.

Currently, CCAMLR does not have all of the information that a simple model like the one described above would require. It is important to note, however, that models can be formulated in the absence of information and gradually updated as more information is obtained. Preliminary models can be very useful for guiding research or making provisional management decisions. CCAMLR does have some information (although more information would be required) on subarea and local area predator abundance and krill density (Shuford and Spear, 1988; Bengtson *et al.*, 1990; Hewitt and Demer, 1992), and WG-Krill is currently working on problems associated with krill movement and recruitment (SC-CAMLR, 1991). WG-CEMP plans to develop some preliminary estimates of predator demand by the summer of 1993 (SC-CAMLR, 1991). In general, however, it will take a number of years for CCAMLR to collect all of the information necessary to successfully model interactions between predators, krill, and fishermen. During the first few years of data collection, some of the information that is obtained may not be very reliable (producing uncertainty in any model's estimation of a catch limit). Again, to account for this variability, data will need to be collected over a period of years and for a number of areas. The commitment to data collection may be further increased if we consider that some species are long lived; it may take several generations to detect how krill fishing impacts predator populations.

There are several advantages associated with using models to estimate subarea or local area krill catch limits. Models, when formulated successfully, allow large amounts of data to be incorporated into the management scheme. This is advantageous because including all of the relevant biological and physical information into a catch allocation strategy meets CCAMLR's goal of maintaining an ecosystem perspective. Incorporation of economic factors can also account for changes in fishing dynamics. Simulation techniques (e.g., bootstrapping) can be used to estimate parameter uncertainty and evaluate management costs (i.e., risk) before CCAMLR institutes a conservation measure. Thus, models can be used to avoid reactive management policies.

Estimating subarea or local area catch limits with models incorporates large amounts of biological information. Data collection will obviously be expensive, and we should expect uncertainty from model results. Enforceability and effects on current fishing patterns will be difficult to evaluate until a specific model is proposed. Implementation of the model alternative

will be significantly delayed while CCAMLR Member nations collect data and debate model specification. These points are summarised in Table 1.

3. DISCUSSION

Choosing from the list of alternatives is difficult because the choice involves tradeoffs; none of the alternatives are perfect. Alternatives that require large amounts of information are good because they represent an ecosystem approach, but it takes time to collect and analyze this information. This results in delayed management, and predator populations can be adversely impacted during this time. Alternatives that do not require much information can be implemented more quickly to prevent uncontrolled expansion of the fishery, but these alternatives are not biologically realistic.

In choosing an allocation scheme that minimises the probability of adverse impact to dependent species, we believe that one of the principal tradeoffs is between the amount of biological information explicitly considered and the potential for delayed implementation. Essentially, we feel that the following questions are important: "Should CCAMLR select an alternative that considers interactions between krill and predators even though the delays caused by data collection and resistance to alter current fishing patterns, may have adverse impacts on dependent predator populations? Or, should CCAMLR select an alternative that controls expansion of the krill fishery without being biologically explicit?" The nine alternatives were arranged in a tradeoff matrix (Table 2). Alternatives based on even division among subareas and historical catches can be categorised as having a low potential for delaying implementation, but they ignore information on biological relationships. Alternatives based on protective zones, critical periods, predator censuses, and predator-prey models include a large amount of biological information, but may not be practical in the near future. The shelf area, simple pulse fishing, and krill survey alternatives are not biologically explicit and result in delayed implementation. None of the alternatives were categorised as being both biologically explicit and immediately available for implementation (this reiterates the point that none of the alternatives are perfect). However, two of the alternatives (i.e., protective zones and critical periods) are unsatisfactory only because they would alter current fishing patterns. These two alternatives could be implemented immediately if the member nations to CCAMLR are willing to tolerate changes in current fishing patterns.

Perhaps CCAMLR should consider two time horizons as it allocates the total catch in Statistical Area 48 to subareas or local areas. In the short-term CCAMLR should be concerned with controlling the expansion of the krill fishery. Conservation Measure 32/X, combined with a provisional catch allocation scheme based on protective areas and/or critical periods, would be an important step in this direction. Data collection should continue, however, and, in time, sufficient data would be available to adjust krill management according to the biological goals outlined in Article II of the CCAMLR Convention.

Finally, we would like to reiterate this paper's intent. This paper is intended to provide a basis for discussion and a template for evaluating other alternative allocation schemes. We hope that people will feel free to add new alternatives (columns) and new criteria (rows) to Table 1, develop new tradeoff matrices like Table 2, and make their own evaluations of the various allocation schemes.

REFERENCES

AMLR. 1991. ROSENBERG, J. and R. HEWITT (Eds). AMLR 1990/91 Field Season Report: Objectives, Accomplishments, and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-91-18. Document *WG-CEMP-91/11*. CCAMLR, Hobart, Australia: 97 pp.

AMOS, A., J. BENGTSON, O. HOLM-HANSEN, V. LOEB, M. MACAULAY, and J. WORMUTH. 1990. Surface water masses, primary production, krill distribution and predator foraging in the vicinity of Elephant Island during the 1989-90 austral summer. Document *WG-CEMP-90/11*. CCAMLR, Hobart, Australia: 65 pp.

AGNEW, D. 1991. Krill catches and consumption by land-based predators in relation to distance from colonies of penguins and seals in the South Shetlands and South Orkneys. Document *WG-CEMP-91/25*. CCAMLR, Hobart, Australia: 14 pp.

BENGTSON, J., L. FERM, T. HARKONEN, and B. STEWART. 1990. Abundance of Antarctic Fur Seals in the South Shetland Islands, Antarctica, during the 1986/87 Austral Summer. In: KERRY, K. and G. HEMPEL (Eds.). *Antarctic Ecosystems. Ecological Change and Conservation*. Springer-Verlag, Berlin Heidelberg: 265-270.

CCAMLR. 1991a. *Schedule of Conservation Measures in Force*. CCAMLR, Hobart, Australia: 26 pp.

CCAMLR. 1991b. *Statistical Bulletin,* Vol. 3 (1981-1990). CCAMLR, Hobart, Australia: 119 pp.

CROLL, D. 1990. Estimation of the energy and prey requirements of predators breeding on the South Shetland Islands. Document *WG-CEMP-90/30 Rev. 1*. CCAMLR, Hobart, Australia: 24 pp.

CROXALL, J. 1990. Food consumption by predators in CCAMLR integrated study regions. Document *WG-CEMP-90/31*. CCAMLR, Hobart, Australia: 21 pp.

EVERSON, I. 1987. 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)*. CCAMLR, Hobart, Australia: 49-73.

EVERSON, I. and S. CAMPBELL. 1990. Areas of seabed within selected depth ranges in CCAMLR Subarea 48.3, South Georgia. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7)*. CCAMLR, Hobart, Australia: 459-466.

EVERSON, I. and C. GOSS. 1991. Krill fishing activity in the southwest Atlantic. *Antarctic Science*, 3 (4): 351-358.

HEWITT, R. and D. DEMER. 1992. Distribution and abundance of krill in the vicinity of Elephant Island in the 1992 austral summer. Document *WG-CEMP-92/15*. CCAMLR, Hobart, Australia: 19 pp.

MILLER, D. and I. HAMPTON. 1989. Biology and ecology of the Antarctic Krill (*Euphausia superba* Dana): a review. *Biomass Scientific Series*, 9: 166 pp.

SC-CAMLR. 1991. *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X)*. CCAMLR, Hobart, Australia: 427 pp.

SHUFORD, W. and L. SPEAR. 1988. Surveys of breeding Chinstrap Penguins in the South Shetland Islands, Antarctica. *British Antarctic Survey Bulletin*, 81: 19-30.

Table 1: Characteristics of nine alternatives for allocating the 1.5 million tonne precautionary catch limit in Statistical Area 48 between subareas or local areas. See the text for a more detailed description of the evaluation criteria and the allocation alternatives.

	ALTERNATIVES								
CRITERIA	Historical Catch	Even Division	Shelf Area	Pulse Fishing	Protective Zones	Critical Periods	Predator Censuses	Krill Surveys	Models
Krill-Predator Interactions Considered?	NO	NO	NO	NO	YES	YES	YES	NO	YES
Data Reliability	HIGH	–	HIGH	–	LOW	HIGH	HIGH	HIGH	HIGH
Long-Term Data Collection Costs	LOW	LOW	LOW	LOW	LOW	LOW	HIGH	HIGH	HIGH
Easy to Enforce?	YES	YES	YES	NO	YES	YES	NO	NO	?
Alter Current Fishing Patterns?	NO	?	YES	YES	YES	YES	?	YES	?
Delay to Implement?	NO	NO	YES	YES	YES	YES	YES	YES	YES

Table 2: Tradeoff matrix characterising krill catch allocation schemes based on the amount of biological information explicitly considered and the potential for delay in implementation. The probability of adverse impact on dependent species is minimised when a high amount of biological information is considered and the potential for delay is low.

Potential Delay in Implementation	Biological Information Explicitly Considered	
	Low	High
Low	• even division • historical catches	
High	• shelf area • pulse fishing • krill surveys	• predator censuses • predator-prey models • protected zones • critical period closure

Légende des tableaux

Tableau 1: Caractéristiques de neuf méthodes d'allocation de la limite préventive de capture de 1,5 million de tonnes dans la zone statistique 48 aux sous-zones ou aux aires localisées. Se reporter au texte pour la description plus détaillée des critères d'évaluation et les méthodes d'allocation.

Tableau 2: Matrice des compromis caractérisant les systèmes d'allocation de la capture de krill basée sur le nombre d'informations biologiques examinées explicitement et le risque de retard dans la mise en place. La probabilité d'effets nuisibles sur les espèces dépendantes est réduite au minimum lorsque la quantité d'informations biologiques examinée est élevée et le risque de retard dans la mise en place est faible.

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Таблица 1: Характеристики девяти альтернативных вариантов распределения предохранительного ограничения на вылов (1,5 миллиона тонн) в Статистическом районе 48 между подрайонами или локальными районами. Более подробное описание критериев оценки и альтернатив распределения дается в тексте.

Таблица 2: Матрица расчета различных схем распределения вылова криля, основанная на объеме непосредственно учитываемой биологической информации и возможности отложения осуществления. Вероятность отрицательных последствий для зависимых видов минимальна если рассматривается большое количество биологической информации и возможность задержок низка.

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Tabla 1: Características de nueve alternativas para distribuir el límite de captura precautorio de 1.5 millones de toneladas en el Area estadística 48 por subáreas o zonas específicas. Refiérase al texto para obtener una descripción detallada del criterio de evaluación y las alternativas de distribución.

Tabla 2: Matriz de compensación que caracteriza los sistemas de distribución de capturas de kril basada en la cantidad de información biológica considerada en detalle y la posible demora de la puesta en marcha. La probabilidad de dañar a las especies dependientes se ve reducida cuando se considera gran cantidad de información biológica y la posibilidad de retraso es mínima.

III. SPECIES INTERACTIONS AND CONSERVATION

HOMOGENEITY OF ADELIE PENGUINS AS KRILL SAMPLERS

E. Marschoff[1] and B. Gonzalez[2]

Abstract

A nested ANOVA design was used to measure the variance component due to differences between individual Adélie penguins in the length of krill eaten, using data from Esperanza Bay. The variance component -0.26 was not significantly different from zero (F = 0.093; P = 0.54). This finding supports the argument for using individual penguins to estimate parameters of the prey population without discriminating by sex, weight or other factors pertaining to the predator.

Résumé

A partir de données de la baie Esperanza, on s'est servi d'un modèle ANOVA à emboîtements pour mesurer l'élément de variance dû à la différence de longueur du krill ingéré par des individus de manchots Adélie. L'élément de variance -0,26 n'était pas très différent de zéro (F = 0,093; P = 0,54). Cette découverte soutient l'argument selon lequel pour ne pas discriminer les sexes, le poids ou d'autres facteurs relatifs au prédateur, les paramètres de la population de proies doivent être estimés à partir d'individus de manchots.

Резюме

Компонент вариации, вызванный разницей в длине криля, съеденного отдельными пингвинами Адели измерялся с помощью гнездового метода ANOVA и с использованием данных из проб, собранных в бухте Эсперанза. Компонент вариации (-0,26) не отличался значительно от нуля (F=0,093; 3 = 0,54). Этот результат поддерживает довод в пользу использования проб криля из пищи пингвинов для оценки параметров популяции криля, не делая различия по полу, весу или другим факторам, как в случае других хищников.

Resumen

A partir de los datos de bahía Esperanza, se utilizó un diseño inclusivo ANOVA para medir el componente de variancia del kril de distintas longitudes consumido por algunos pingüinos adelia. El componente de variancia -0.26 obtenido variaba poco de cero (F = 0.093; P = 0.54). Este dato corrobora la tesis de utilizar pingüinos individuales para estimar los parámetros de las poblaciones de presas, sin discriminar sexo, peso u otros factores propios de los depredadores.

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1. INTRODUCTION

The size of krill eaten by penguins is probably an important factor in assimilation rates and energetic requirements of these birds. The analysis of length distributions of krill eaten by penguins will also provide information on the degree of overlap between commercial catches and predator needs. Unfortunately, the analysis of length distributions obtained from random samples of a patchy target population is statistically complex.

One of the problems is that krill occur in swarms and are not randomly distributed. This patchiness determines that, for statistical purposes, individual specimens in a given sample cannot be considered independent because their lengths are spatially correlated. Sampling strategies to estimate the population frequencies in each length class should take into account this fact. Heterogeneity between the lengths of krill in different swarms also has implications on sampling protocols aimed to the estimation of population parameters (Watkins *et al.*, 1986). Frequency distributions might prove to be impossible to calculate without knowledge of the relative volume occupied by the different patches sampled, and the bias introduced will depend on the relation between sample size, number of samples and properties of the sampling gear.

Using an appropriate sampling design however, Marschoff and Gonzalez (1989 and 1990) have shown that it is possible to obtain estimators for mean lengths from samples obtained from a patchy distribution. These might be used in the assessment of penguin energetic requirements as well as to statistically compare the lengths of krill eaten by penguins under different conditions. In order to do this it is necessary to determine if all penguins might be considered as yielding homogenous samples of their food or if these samples are affected by varying prey selection at the individual penguin level.

In this paper, we will not attempt to estimate overall krill population parameters or frequency distributions, but will aim to detect possible sources of variation originating from differences between penguins.

Finally, we will test the hypothesis that Adélie penguins are uniform with respect to prey selection.

2. MATERIALS AND METHODS

During summer 1989/90, 27 Adélie penguins from the Bahía Esperanza rookery were marked after obtaining a sample of their stomach contents as part of the CEMP related work being carried out there. Successive recaptures of these specimens yielded replicate samples of the stomach contents of the same penguins. The experimental design followed the proposal of Marschoff and Gonzalez (1990). Sources of variation were arranged in a nested ANOVA as follows:

Level 2:	"Penguins" group;
Level 1:	"Days-within-Penguins" subgroup;
Level 0:	Replications ("Krill-within-Days" subgroup).

This design allows the calculation of the components of variance at each level and testing of the null hypotheses that the variance component added at each particular level is zero (Bliss, 1967).

The power of the test to detect differences in krill lengths taken by different penguins whilst maintaining the days-within-penguins variation was evaluated using a simulation procedure which consisted in adding a fixed value (c) to the lengths of krill from five penguins. These were randomly selected from the original set of 11 birds. The variance component due to penguins was then recalculated with different values of c until a significant result was obtained.

3. RESULTS

A total of 11 marked Adélie penguins (Level 2) were recaptured at least once during the experiment, yielding a total of 23 samples (Level 1) and 1 062 individual specimens of krill measure (Level 0).

Table 1 shows the date of sampling, mean length, variance and number of specimens measured for each stomach content.

The nested ANOVA performed on these data (Table 2) showed that the differences between sizes taken by different penguins had a null contribution to total variance while differences due to days-within-penguins were highly significant ($P < 0.001$).

In the simulation approach, the variance component due to penguins gradually increased as the krill lengths of the five penguins were increased, until it became significantly different from zero for $C = 2.83$ mm, equivalent to 7% of the mean size.

4. DISCUSSION AND CONCLUSIONS

The null variance component due to penguins found in this study implies that at the Esperanza rookery, from 5 January to 2 February 1990, all penguins seemed to be eating similar sized krill. Mean lengths derived from stomach contents of penguins are formally equivalent to mean lengths derived from net samples in the sense that, while bias might exist it is the same for all penguins in the same way as it is the same for all nets of the same design and use. No significant sources of variation exist other than those pertaining to the food itself. However, it should be stressed that this result is valid within the limits of the power of the test used and does not mean that krill were being randomly selected by penguins.

The fact that a significant difference appears with a relatively small variation in the input data indicates that the method is powerful enough to detect size preferences in penguin food and might be used to explain changes found in other parameter; that is to say that changes in krill size eaten by penguins will reflect changes in food rather than individual variations of penguins due to factors like sex, age, weight, etc.

REFERENCES

BLISS, C.J. 1967. *Statistics in Biology*, Vol. 1. 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)*. CCAMLR, Hobart, Australia: 367-376.

MARSCHOFF, E. and B.N. GONZALEZ. 1990. Optimisation of survey sampling design in the detection of interannual variability and prey size selectivity in the diet of penguins. In: *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7)*. CCAMLR, Hobart, Australia: 551-560.

WATKINS, J.L., D.J. MORRIS, C. RICKETTS and J. PRIDDLE. 1986. Difference between swarms of Antarctic krill and some implications for sampling krill populations. *Biol.*, 93 (1): 137-146.

Table 1: Mean length and variance of krill taken from each stomach sampled.

Penguin	Number of Specimens	Date Sampled	Mean	Variance
1	74	09/1/90	44.26	23.82
1	71	28/1/90	41.18	16.53
2	52	12/1/90	41.60	32.16
2	66	23/1/90	40.48	26.84
2	70	31/1/90	43.79	20.32
3	19	09/1/90	39.07	13.19
3	27	31/1/90	39.98	27.10
4	30	09/1/90	42.65	14.75
4	25	19/1/90	32.11	31.78
5	41	18/1/90	40.02	15.18
5	39	24/1/90	29.09	19.62
6	66	05/1/90	41.30	26.93
6	73	29/1/90	40.34	17.07
7	42	07/1/90	44.67	21.47
7	63	23/1/90	37.66	64.44
8	32	12/1/90	41.46	23.15
8	31	02/2/90	40.27	19.49
9	60	13/1/90	39.79	22.46
9	51	23/1/90	40.44	27.12
10	44	18/1/90	41.48	14.23
10	38	28/1/90	41.50	24.17
11	19	20/1/90	39.23	14.45
11	29	29/1/90	37.93	94.74

Table 2: Nested ANOVA of krill-within-days-within-penguins.

Level	Degrees of Freedom	Mean Square	F	Prob.	Variance Components	
					Value	Percent
Penguins	10	460.68	0.9270	0.54	-0.26	0.00
Days-within-penguins	12	496.95	18.8230	<0.001	10.15	27.76
Krill-within-days	1039	26.40			26.40	72.24

Légende des tableaux

Tableau 1: Longueur moyenne et variance du krill prélevé dans chaque estomac échantillonné.

Tableau 2: ANOVA à emboîtements du krill groupé par jour et par manchot.

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Таблица 1: Средняя длина и вариация размера криля в каждом обследованном желудке.

Таблица 2: Гнездовой анализ (ANOVA) количества съеденного пингвинами криля по дням.

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Tabla 1: Talla media y variancia del kril procedente de los estómagos muestreados.

Tabla 2: ANOVA inclusiva de kril, por fechas y pingüinos.

III. SPECIES INTERACTIONS AND CONSERVATION

CAN WE USE DISCRIMINANT FUNCTION ANALYSIS TO SEX PENGUINS PRIOR TO CALCULATING AN INDEX OF A MORPHOMETRIC CHARACTERISTIC?

D.J. Agnew*

Abstract

In sexually dimorphic species, morphometric characteristics have separate distributions for males and females, and these often overlap. Whilst discriminant analysis can be used to determine the sex of individuals, it is only able to correctly sex a certain proportion of birds. Two overlapping normal distributions are used to show that there is a difference between the real mean characteristic for a sex, and the apparent mean derived by sexing the birds using discriminant analysis.

When discriminant functions are able to correctly determine the sex of birds with greater than 80% success, the difference between the true and apparent mean is likely to be undetectable when fewer than 600 birds are sampled.

Therefore, under most normal sampling regimes a discriminant function with greater than 80% success may be used to derive statistically robust estimates of male and female characteristics.

Combining all data for both sexes is considered as a procedure for avoiding the necessity of sex determination. However, uncertainty in sex ratios can lead to considerable Type I and Type II errors. Lack of knowledge about the sex ratio between years makes combining the data a very doubtful procedure and use of a discriminant function to determine sex is recommended as being most practically robust.

Résumé

Chez les espèces à dimorphisme sexuel, les caractéristiques morphométriques ont pour les mâles et les femelles des distributions distinctes qui se chevauchent souvent. Alors que l'analyse discriminante peut servir à déterminer le sexe des individus, elle n'y parvient que pour un certain pourcentage d'oiseaux. Deux distributions de Gauß se chevauchant mettent en évidence la différence entre la moyenne réelle d'une caractéristique d'un sexe et la moyenne apparente dérivée de la détermination du sexe des oiseaux par l'analyse discriminante.

Lorsque les fonctions discriminantes parviennent à déterminer correctement le sexe de plus de 80% des oiseaux, la différence entre la moyenne réelle et la moyenne apparente risque d'être impossible à déceler si l'échantillon porte sur moins de 600 oiseaux.

Par conséquent, sous la plupart des régimes d'échantillonnage normaux une fonction discriminante ayant un taux de succès de plus de 80% peut

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être utilisée pour obtenir des estimations statistiquement robustes des caractéristiques se rapportant aux mâles et aux femelles.

Il n'est plus nécessaire de déterminer les sexes si l'on utilise la procédure qui consiste à combiner les données des deux sexes. Toutefois, les incertitudes liées au sex ratio peuvent conduire à des erreurs considérables de Type I ou II. Le manque d'informations sur le sex ratio des différentes années rend douteuse la procédure qui combine les données, et il est recommandé d'utiliser la fonction discriminante qui est la procédure la plus robuste à l'usage.

Резюме

У видов, имеющих половой диморфизм, морфометрические параметры самцов и самок имеют различные распределения, которые часто в какой-то мере совпадают. Хотя дискриминантный анализ можно использовать для определения половой принадлежности отдельных птиц, он дает возможность правильно определить половую принадлежность лишь какой-либо части птиц. Используются два частично совпадающих нормальных распределения с тем, чтобы показать существование разницы между истинной средней величиной параметра какого-либо пола и наблюдаемой средней, полученной при определении половой принадлежности птиц с помощью дискриминантного анализа.

Если дискриминантная функция дает возможность определять половую принадлежность птиц со степенью точности более 80%, то имеется низкая вероятность того, что при выборке меньше 600 птиц разница между истинной и наблюдаемой средней останется незамеченной.

Поэтому, обычно при нормальных режимах сбора проб для получения статистически устойчивых оценок характеристик мужского и женского полов можно использовать дискриминантную функцию, уровень точности которой свыше 80%.

Рассматривается возможность объединения всех данных по обоему полу для избежания необходимости определения половой принадлежности. Однако неопределенности в численном соотношении полов могут привести к существенным ошибкам Типа I и Типа II. Пробелы в знаниях о численном соотношении полов в разные годы делают объединение данных весьма сомнительной процедурой. Рекомендуется использовать дискриминантную функцию для определения половой принадлежности, так как она дает наиболее устойчивые результаты.

Resumen

En especies que presentan dimorfismo sexual, las características morfométricas tienen distintas distribuciones para machos y hembras, y éstas a menudo se superponen. Aunque los análisis discriminantes

pueden ser utilizados para determinar el sexo de algunos individuos, sólo pueden acertar en el sexado de una proporción de las aves. Se utilizan dos distribuciones normales superpuestas para demostrar que existe una diferencia entre la media real de una característica para un sexo dado, y la media aparente deducida al sexar las aves mediante un análisis discriminante.

Cuando las funciones discriminantes pueden determinar correctamente el sexo de las aves con un éxito superior al 80%, la diferencia entre la media aparente y la real es casi imperceptible cuando se muestrean menos de 600 aves.

Por lo tanto, en casi todos los regímenes normales de muestreo se puede utilizar una función discriminante que tenga un éxito superior al 80%, para deducir valores de ciertas características masculinas y femeninas que sean válidos estadísticamente.

Se considera que se podría evitar esta determinación combinando la totalidad de la información de ambos sexos aunque la incertidumbre en cuanto a las proporciones de sexos puede producir errores significativos del Tipo I y II. La falta de información sobre la proporción de los sexos en distintos años hace que la combinación de los datos sea un procedimiento bastante dudoso, por lo que se recomienda - como un criterio más valedero - el uso de una función discriminante en la determinación del sexo.

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1. INTRODUCTION

In sexually dimorphic species, morphometric characteristics (such as the CEMP characteristic A1, "weight on arrival") have separate distributions for males and females, and these often overlap. Whilst discriminant analysis can be used to determine the sex of individuals, it is only able to correctly sex a certain proportion of birds. The WG-CEMP has recognised this problem, in 1991 noting that analyses by Scolaro *et al.* (1990) and Kerry *et al.* (1992) had determined discriminant functions for Adélie penguins that correctly identified the sex of 87 to 89% of birds. Concern was expressed that it may be necessary to know the sex of birds with absolute accuracy, and that discriminant analysis may not be sufficient for this purpose (SC-CAMLR, 1991 - paragraphs 4.8 to 4.12). A suggestion was made that one way to avoid the problem of sex determination would be to combine males and females for the calculation of an index.

This paper evaluates the suggestion that male and females should be combined when monitoring certain CEMP parameters, such as penguin weight at arrival, if sex is not easily determined. I approach this problem from two directions:

(i) A characteristic such as bill depth has equal variance in males and females but the means are sufficiently close that there is some overlap between the distributions. If a discriminant function is used to identify males and females with a certain error, is this likely to give us a false estimate of the characteristic?

(ii) We are required to monitor a characteristic so that we can detect changes in it. With distributions as (i), if we combine the data from males and females will we still be able to detect changes in the characteristic with the same sensitivity as if we considered males and females separately?

2. METHODS

For the purposes of this analysis, I consider distributions of the morphometric characteristics bill length, depth and body weight to behave similarly. Thus we may separate sexes on bill characteristicistics in order to monitor body weight. From now on, then, I make reference only to an undescribed "characteristic". This work is mostly theoretical but in the cases where real data are used illustratively these were supplied by Dr Knowles Kerry (Australian Antarctic Division) to whom I am grateful. These data were collected between 22 and 31 December 1990 at Bechervaise Island, Mawson Base (67'36°W 62'49°E) by Judith Clarke and Grant Else, and comprise measurements of bill, head, flipper and toe dimensions and body weight of 34 females and 37 males. Birds were sexed by cloacal examination. The measurements and full methodology are described in Kerry *et al.*, 1992.

In identifying a discriminant function for these data, Kerry *et al.* (1992) established that the following criteria for discriminant analysis were met (Klecka, 1980):

(i) no characteristics were linear combinations of each other;

(ii) correlation coefficients between characteristics used for the final discriminant function were less than 0.60; and

(iii) the variance - covariance matrices were not significantly different: Box's M statistic (Pearson and Hartley, 1976) = 55.49: $\chi^2_{(45)} = 43.14$, $F_{(45,5460)} = 0.9586$, $P > 0.5$;

and discriminant functions are derived using bill length and depth (correct prediction of sex of 87% of birds) and an additional factor, flipper width (89%).

3. IMPLICATIONS OF SEXING PENGUINS USING DISCRIMINANT ANALYSIS

Let us assume that we measure a characteristic, x, (such as bill length) which varies with the discriminant function and is normally distributed in both males and females ($\mu_{females}<\mu_{males}$), with equal variance, and that there is some overlap between the male and female distributions of the characteristic (Figure 1). We can consider this to be a representation of a single factor discriminant function with a mean discriminant score equal to v on Figure 1. We are interested in the mean and variance in males and females, where sex is determined using discriminant analysis with a proportion of correct identification of sex ($=p$). It is therefore important to us to know whether, with the sampling size chosen, the discriminant function will give us mean values for the characteristic that are significantly different from the true means of that characteristic in the population.

Consider the case of females in Figure 1, with true mean μ and standard deviation σ. Only those females with $x<v$ will be identified as females by the discriminant function, and therefore the success of the discriminant function (p) is equal to the proportion of area under the normal curve for females with $x<v$, where v can be expressed in units of standard deviation. The apparent population of females is that part of both female and male distributions to the left of v. The mean and standard deviation of the apparent populations μ_1,σ_1 can be found by integrating both distributions over $x = -\infty$ to v, finding the weighted mean of x, and can be expressed in terms of the true mean and standard deviation:

$$\mu_1 = \mu - c\sigma \quad \text{for females,} \quad \mu_3 = \mu' + c\sigma \quad \text{for males} \qquad (1)$$
$$\sigma_1 = d\sigma$$

where c, d are constants. Table 1 shows the c and d calculated for different p.

Although the variance of the apparent population is obviously lower than that of the true population, we can make an approximate calculation of the sample size required to detect the difference between the true and apparent means. The equation given in Sokal and Rohlf (1981) for finding the sample size needed to detect a given true difference between means[1] requires $\left(\frac{\sigma}{\delta}\right)$, where σ is the estimated true standard deviation and δ is the difference in the mean that must be detected. Here, $\delta = \mu - \mu_1 = c\sigma$ [equation 1] and therefore

$$\frac{\sigma}{\delta} = \frac{1}{c} \tag{2}$$

and is independent of σ or μ.

The sample size required in order to be 80% certain of detecting the difference at the 5% level of significance is shown in Table 1. At sample sizes of less than 300 for each sex, using a discriminant function that successfully determines the sex of more than 80% of birds is unlikely to yield an apparent mean for one sex which is significantly different from the true mean for that sex. Thus if we are restricted to small sample sizes discriminant functions with success rates of 80% and over are probably acceptable for all practical purposes. This means that the insistence on completely accurate sexing is not necessary.

True and apparent means of selected Adélie penguin characteristics are shown in Table 2. Bill length and depth behave approximately in conformity with the theoretical values given in Table 1. For example, apparent mean bill length for females is 0.378 mm smaller than the mean of females sexed by cloacal examination. Body weight does not behave in a similar way, presumably because it is not directly related to the discriminant function whereas bill length and depth are. We are therefore even less likely to be able to detect a difference between mean weight of the true and apparent populations if we use a discriminant function based on bill dimensions for sex determination.

4. EFFECT OF COMBINING MALES AND FEMALES

I now turn to the case where we want to be able to detect a change in a parameter. Is it better to ignore the sex of birds when trying to detect this change, or to sex birds with an understood error due to the success rate *p*. Consider first the special case of Figure 1, where the number of males and females in the sample are the same and σ and σ' are equal. In this case the point *v* corresponds to the mean of the combined sample, μ_2, and μ and μ' and σ and σ' are the means and standard deviations of the females and males respectively.

We can calculate μ_2 and σ_2 in terms of units of σ:

$$\begin{aligned} \mu_2 &= v = \mu + a\sigma \\ \sigma_2 &= b\sigma \end{aligned} \tag{3}$$

using the same methodology as described in the foregoing section, integrating instead from $-\infty$ to $+\infty$. Values of *a* and *b* are given in Table 3.

Turning once more to the Adélie penguin data (Table 2), μ_2 is taken to be the midpoint *v* between male and female distributions (very close to the calculated combined means), the mean of the standard deviations of males and females is taken as an estimate of σ, and μ is known.

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[1] $n \geq 2(\sigma / \delta)^2 \{t_{\alpha[v]} + t_{2(1-P)[v]}\}^2$: see Sokal and Rohlf (1981) for explanation

We can now estimate a and b:

bill length	$a = 0.913$	$b = 1.206$
bill depth	$a = 0.756$	$b = 0.931$
weight	$a = 0.949$	$b = 1.118$

Referring to Table 3 these estimates of a and b correspond to p of about 80%. This p derived for a single characteristic is lower than the success of the discriminant function for two characteristics described by Kerry *et al.* (1991) of 87%, as would be expected.

Now, the sample size required to detect a change k in the means μ and μ_2 can be calculated using the equation of Sokal and Rohlf (1981), which as previously stated requires $\left(\frac{\sigma}{\delta}\right)$. Firstly, for the mean of females, μ, set $\lambda = \frac{\sigma}{\delta}$ then

$$\lambda = \frac{\sigma}{\delta} = \frac{\sigma}{k\mu} \tag{4}$$

For the combined mean μ_2, $\frac{\sigma_2}{\delta_2}$ is required:

$$\frac{\sigma_2}{\delta_2} = \frac{\sigma_2}{k\mu_2} \quad \text{since we are looking for a combined change } k \text{ in males and females}$$

$$= \frac{b\sigma}{k(\mu + a\sigma)} \quad \text{substituting equation (3)}$$

$$= \frac{b\lambda}{1 + ka\lambda} \quad \text{substituting equation (4)} \tag{5}$$

We can now calculate the effective sample sizes, required to detect a change k in the means μ and μ_2 for different coefficients of variation of the female population, (r), since $\sigma = r\mu$ and $\frac{\sigma}{\delta}$ simplifies to $\frac{r}{k}$.

Table 3 shows values of a and b for different $\Delta\mu = \mu_1 - \mu$ in units of standard deviation, and the corresponding percentage success of a discriminant function acting through v. Sample size required to detect a change k is also given, for $k = 0.1$ and coefficient of variation $r = 0.05$, 0.1, 0.2, 0.4.

If a sample size n is required for a single sex, then $2n$ would be required to achieve adequate sampling of both males and females. Therefore only those cases where the combined sample size is greater than twice the single sex sample size imply that a greater sampling effort would be required should the data be combined for males and females.

It is clear that when there is a large overlap between male and female distributions ($\Delta\mu$ and p are low) and the coefficient of variation is high then the sample size required to reliably detect a 10% change in the mean is greater if single sexes are considered than if the sexes are combined. In terms of the sample number required, there is an advantage in combining the sexes unless μ and μ' are widely separated or r is very small.

5. THE EFFECT OF SEX RATIO ON COMBINED MALE AND FEMALE SAMPLING

The conclusion of the previous paragraph is dependent on the assumptions of equal variance and equal numbers of males and females in the sample. The first condition was met in our sample (variance covariance matrices were similar; see Methods) as was the second (the number of females was 34, males was 37). However, it is obvious that if the numbers of males 'and females in a sample vary, then it is likely that false changes in the characteristic may be identified, or that real changes may be masked. For instance, if all females are sampled one year, and all males the next, then the characteristic will appear to have increased in size.

Consider the situation of pooled sexes as described in the previous section. If the sex ratio changes then a in equation (3) will change. Figure 2 shows the effect of a changing sex ratio on q, where

$$q = \frac{a^*}{a_2} \tag{6}$$

and a^* is the value of a for the a certain sex ratio, a_2 is the value of a for equal numbers of males and females (sex ratio = 0.5 = number of males/total numbers). If we expect to get variation in the means of the combined male and female population purely as a result of variation in the sex ratio, then what is the magnitude of this error?

Let γ = proportional difference in the mean μ_2 that is due to sex ratio variation. If we sample at the extreme of the sex ratio variation, with μ^* and a^*, then

$$\gamma = \frac{\mu_2 - \mu^*}{\mu_2}$$

$$\gamma = \frac{ra_2(1-q)}{1+ra_2} \qquad \text{substituting equations 3 and 6} \tag{7}$$

where r = coefficient of variation for females γ will have its own distribution dependent on the distribution of sex ratios. However, if we assume that within a time period we know the maximum and minimum sex ratio, we can make a 'worst case' estimate of the amount of difference between two means that could be due to sex ratio 'sampling' alone.

For example, take the case of body weight in Table 2. Taking the expected combined mean to be halfway between the male and female mean weights, and the estimated σ to be the mean of the sample standard deviations, we get

combined population mean = 4.386
combined population SD = 0.385
a_2 from equation 3 = 0.949
coefficient of variation r = 0.344/4.021 = 0.09

Now let us suppose that we sample over a time when we can expect sex ratio to vary from 0.3 to 0.5 (ratio of males/total). Then q from Figure 2 is 0.74 and thus γ = 0.021 from equation 6. Therefore, if we observe a change in the mean of 10%, 2.1% of this may be due to changes in sex ratio, and only 7.7% can be said not to be attributable to possible changes in sex ratio.

An additional example: if the sex ratio is expected to vary from 0.1 to 0.9 then $q = 0.33$ and $2\gamma = 0.105$ (we require 2γ because Figure 2 only deals with sex ratios from 0.1 to 0.5). In this latter case, the usual criterion for changes in an index within CEMP (10% change) could not be used to indicate that there was a change in the combined mean of the characteristic, as it may have been due to a change in sex ratio (Type I error). Conversely, it is possible that a change in characteristic has been masked by an opposite change in sex ratio (e.g., males and females got smaller, but the proportion of males in the second sample was greater); thus a change of 10% could in fact be a masked change of up to 20%, a very serious situation (Type II error).

6. DISCUSSION

It is apparent that it would be dangerous to establish a monitoring program using data from two sexes combined without knowing the sex ratios at the time of sampling. This could be done for a small sample by cloacal examination, or for example by discriminant analysis. However, Brennan *et al.* (1991) have shown that estimating sex ratios by discriminant analysis requires considerable sample sizes. They estimated that for dunlins (*Calidris alpina*), using a discriminant analysis with $p = 89\%$ on a population of size 2 000, 300 birds would have to be sampled to be 95% confident of obtaining a proportion of females within 0.05 of the real ratio.

Sex can also be determined by behavioural means, and Kerry *et al.* (1991) have shown that for Adélies, sex ratio of birds on shore is highly sensitive to breeding behaviour and changes almost daily. Any sampling regime that utilises sex ratio information must be highly specific in relation to the breeding cycle of these birds, and without sub-sampling for sex it would appear that combining data from both sexes into one index would be unsuitable for Adélies.

It is shown in the first part of this paper that using a discriminant function that correctly identifies the sex of >80% of birds, the estimated mean of a characteristic for males and females is not likely to be significantly different from the actual mean unless the sample size is very large. Moreover, the error will be consistent and independent of the sex ratio of the birds so long as the discriminant function does not change Kerry *et al.* (1992) note that the discriminant function may change between populations, but will probably not change significantly between years within the same population.

The implications of this paper can be summarised as:

If the discriminant function is greater than about 80% successful:

- sexes should be separated; and
- sex determination by discriminant analysis will usually give acceptable indices.

If the discriminant function is less than 80% successful:

- sexes should probably not be separated;
- pooling sexes will require a smaller sample size; and
- sex ratio should be known and have low variance.

REFERENCES

BRENNAN, L.A., J.B. BUCHANAN, C.T. SCHICK and S.G. HERMAN. 1991. Estimating sex ratios with discriminant function analysis: the influence of probability cutpoints and sample size. *J. Field Ornithol.*, 62 (3): 357-366.

KERRY, K.R., D.J. AGNEW, J.R. CLARKE and G.ELSE. 1992. The use of morphometric characters for the determination of sex of Adélie penguins. *Wildl. Res.*, 19: 657-64.

KERRY, K.R., J.R. CLARKE and G. ELSE. 1991. Identification of sex of Adélie penguins from observation of incubating birds. Document *WG-CEMP-91/31*. CCAMLR, Hobart, Australia.

KLECKA, W.R. 1980. *Discriminant Analysis*. Sage Publication, Beverly Hills London: 71 pp.

PEARSON, E.S. and H.O. HARTLEY. 1976. *Biometrika Tables for Statisticians*, Vol. 2. Biometrika Trust: 385 pp.

SC-CAMLR. 1991. Report of the Working Group for the CCAMLR Ecosystem Monitoring Program. In: *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X)*, Annex 7. CCAMLR, Hobart, Australia: 347-418.

SCOLARO, J.A., Z.B. STANGANELLI, H. GALLELLI and D.F. VERGANI. 1990. Sexing of adult Adélie penguins by discriminant analysis of morphometric measurements. *Selected Scientific Papers, 1990 (SC-CAMLR-SSP/7)*. CCAMLR, Hobart, Australia: 543-550.

SOKAL, R.R. and F.J. ROHLF. 1982. *Biometry*. 2nd Edition.

Table 1: Apparent mean and standard deviation of a single sex (e.g., females) sexed by discriminant analyses of varying success. Values of c and d in equation (1) together with the sample size required to be 80% certain of detecting the difference between true and apparent means at 5% significance level (replicates = 2).

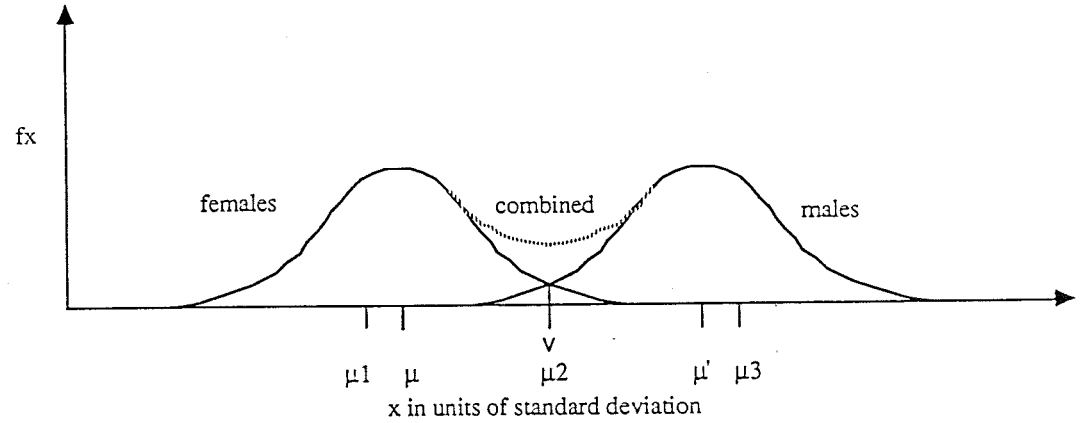
% Success of Discriminant Function	Apparent Mean in Units of Standard Deviation σ (constant c in $\mu_1=\mu\pm c\sigma$)	Apparent Standard Deviation in Units of σ (constant d in $\sigma_1=d\sigma$)	Sample Size (for single sex)
70.000	0.381	0.675	109
75.000	0.299	0.713	177
80.000	0.224	0.758	314
85.000	0.156	0.808	646
90.000	0.095	0.865	1740
91.000	0.084	0.877	>2000
95.000	0.042	0.928	.
99.000	0.007	0.984	.

Table 2: True and apparent mean and standard deviation of male and female Adélie penguins at Béchervaise Island. True was derived from cloacally sexed birds: 34 females, 37 males. Apparent was derived from birds sexed with the discriminant function D = 0.601 (bill length) + 1.154 (bill depth), mean discriminant score = 44.96 (Kerry *et al.*, 1992): 32 'females', 39 'males'.

	True Mean	True SD	Apparent Mean	Apparent SD
Females:				
Bill length (mm)	36.953	1.557	36.575	1.227
Bill depth (mm)	18.244	0.984	18.066	0.830
Weight (g)	4.021	0.344	4.025	0.299
Males:				
Bill length (mm)	40.381	2.197	40.515	1.936
Bill depth (mm)	19.630	0.849	19.705	0.785
Weight (g)	4.751	0.425	4.710	0.483

Table 3: The effect of the amount of overlap between two distributions on the mean and standard deviation of the combined populations. *a* and *b* are taken from equation (3). σ/δ and σ_2/δ_2 are calculated from equations (4) and (5), and the corresponding sample size necessary to detect a 10% change in the mean with 80% certainty and at a significance level of 1% is shown.

				coefficient of variation = 0.40		0.10		0.05	
v in units of standard deviation	% success of discriminant function	*a*, in $\mu_2=\mu+a\sigma$	*b*, in $\sigma_2=b\sigma$	σ/δ or σ_2/δ_2	sample size	σ/δ or σ_2/δ_2	sample size	σ/δ or σ_2/δ_2	sample size
calculation of	σ_2/δ_2			$\sigma_2/\delta_2=$		$\sigma_2/\delta_2=$		$\sigma_2/\delta_2=$	
0.52	70.00	0.52	1.13	3.73	326	1.07	28	0.55	9
0.67	75.00	0.67	1.21	3.80	338	1.13	31	0.58	10
0.84	80.00	0.84	1.31	3.91	359	1.21	35	0.63	11
1.04	85.00	1.04	1.44	4.07	388	1.30	41	0.68	13
1.28	90.00	1.28	1.63	4.30	433	1.44	50	0.76	15
1.65	95.00	1.65	1.93	4.64	505	1.65	66	0.89	20
2.33	99.00	2.33	2.53	5.25	645	2.05	100	1.13	31
calculation of	σ/δ								
				σ/δ=4	375	σ/δ=1	24	σ/δ=0.5	7



μ	true mean of females
μ'	true mean of males
μ1	apparent mean of females after sexing using discriminant analysis
μ2	mean of combined distribution = v when sample size is equal
μ3	.....males.....

Figure 1: Explanation of symbols used in the text. The distribution of a parameter of x for males and females, and the combined distribution is shown. The point v is the midpoint between the distributions.

Note: This figure shows overlapping normal distributions with the following symbols:

females	distribution f	mean μ	standard deviation (SD) σ	coef. var. (CV) r
males	distribution f'	mean μ'	standard deviation σ'	

point of contact between distributions = midpoint v
a discriminant function is presumed to separate these two distributions at the midpoint v
females identified with discriminant analysis have mean μ_1 SD σ_1
the combined distribution (equal males and females) has mean μ_2, SD, σ_2, CV, r_2.

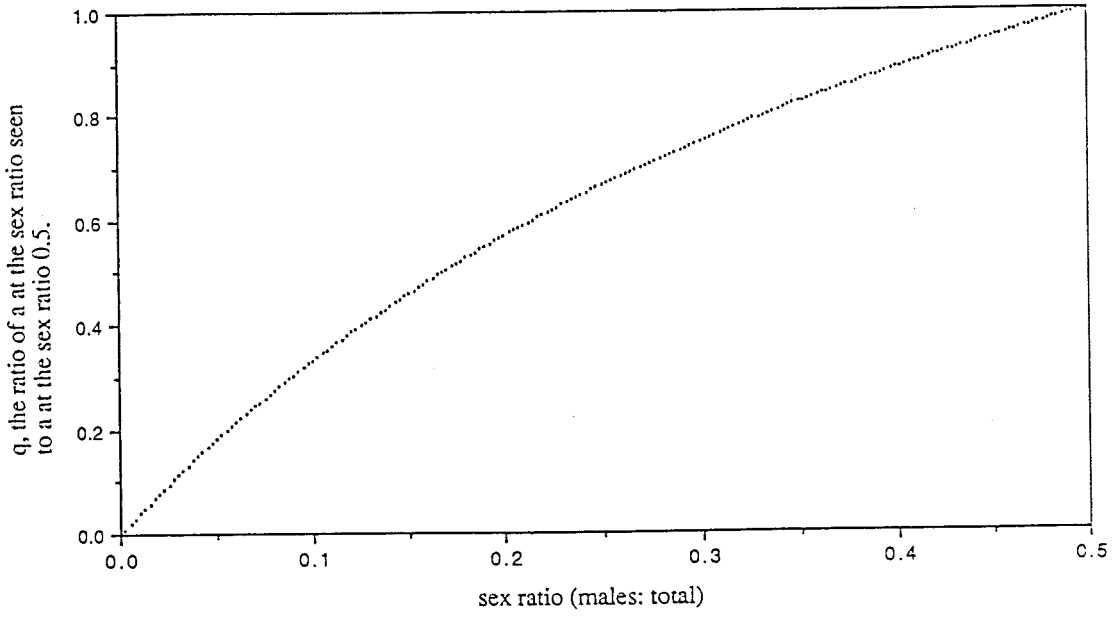


Figure 2: The effect of sex ratio on the mean of a combined population of males and females. See text for explanation of q and a.

Légende des tableaux

Tableau 1: Moyenne et écart-type apparents d'un seul sexe (par ex., femelles) qui a été déterminé avec plus ou moins de succès par des analyses discriminantes. Les valeurs de *c* et *d* de l'équation 1) considérées conjointement avec la taille de l'échantillon requise pour garantir à 80% que la différence entre les moyennes réelle et apparente sera décelée à un seuil de signification de 5% (répliques = 2).

Tableau 2: Moyennes réelle et apparente et écart-type des manchots Adélie mâles et femelles de l'île Béchervaise. La moyenne réelle a été dérivée d'oiseaux dont le sexe a été déterminé par examen du cloaque : 34 femelles et 37 mâles. La moyenne apparente a été dérivée d'oiseaux dont le sexe a été déterminé par la fonction discriminante D = 0,601 (longueur du bec) + 1,154 (hauteur du bec), moyenne discriminante = 44,96 (Kerry *et al.*, 1992): 32 "femelles" et 39 "mâles".

Tableau 3: Effet de l'ampleur du chevauchement de deux distributions sur la moyenne et l'écart-type des populations combinées. *a* et *b* proviennent de l'équation (3). σ/δ et σ_2/δ_2 sont calculés à partir des équations (4) et (5) et la taille correspondante de l'échantillon nécessaire pour déceler un changement de 10% dans la moyenne avec 80% de certitude et à un seuil de signification de 1% est indiquée.

Légende des figures

Figure 1: Explication des symboles utilisés dans le texte. La distribution d'un paramètre de *x* pour les mâles et les femelles et la distribution combinée sont indiquées. Le point *v* est le point central entre les distributions.

Figure 2: Effet du sex ratio sur la moyenne d'une population combinée de mâles et de femelles. Voir explications sur *q* et *a* dans le texte.

Список таблиц

Таблица 1: Видимое среднее и стандартное отклонение популяции одного пола (напр. самки), половая принадлежность которого определялась дискриминантными анализами с переменным успехом. Величины *c* и *d* в уравнении (1), а также размер проб, необходимый для того, чтобы иметь 80-процентный уровень достоверности выявления разницы между истинной и наблюдаемой средней величиной при уровне значимости 5% (повторения = 2).

Таблица 2: Истинная и наблюдаемая средние величины и стандартные отклонения для самцов и самок на о-ве Бешервез. Истинная средняя была получена путем клоакального осмотра птиц: 34 самки, 37 самцов. Наблюдаемая средняя была получена путем определения половой принадлежности с использованием дискриминантной функции D = 0,601 (длина клюва) + 1,154 (высота клюва), средний показатель дискриминанта = 44,96 (Kerry *et al.*, 1993): 32 "самки", 39 "самцов".

Таблица 3: Влияние степени частичного совпадения между двумя распределениями на среднее и стандартное отклонение объединенных популяций. *a* и *b* взяты из уравнения (3). σ/δ и σ_2/δ_2 вычислены по уравнениям (4) и (5), а также показан соответствующий размер проб, необходимый для того, чтобы выявить 10-процентное изменение средней при уровне удостоверности 80% и уровне значимости 1%.

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Tabla 2: Media real y aparente, y desviación típica del macho y la hembra de los pingüinos adelia de la isla Béchervaise. La media real se obtuvo de aves sexadas mediante examen cloacal: 34 hembras, 37 machos. La media aparente se derivó de las aves sexadas mediante la función discriminante D = 0.601 (largo del pico) + 1.154 (grosor del pico), resultado discriminante medio = 44.96 (Kerry *et al.*, 1992): 32 'hembras', 39 'machos'.

Tabla 3: El efecto del grado de superposición entre dos distribuciones sobre la media y la desviación típica de las poblaciones combinadas. *a* y *b* se obtienen de la ecuación (3). σ/δ y σ_2/δ_2 se deducen de las ecuaciones (4) y (5), y se presenta el tamaño de la muestra necesario para detectar un cambio del 10% en la media con un nivel de confianza del 80% y un nivel de importancia del 1%.

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Figura 1: Explicación de los símbolos utilizados en el texto. Se presenta la distribución de los parámetros de *x* para los machos y las hembras, y la distribución combinada; *v* es el punto medio entre las distribuciones.

Figura 2: Efecto de la proporción de cada sexo en la media de una población de machos y hembras. Véase el texto para una explicación de *q* y *a*.

DIFFERENCES IN DISTRIBUTION AND POPULATION STRUCTURE OF KRILL (*EUPHAUSIA SUPERBA*) BETWEEN PENGUIN AND FUR SEAL FORAGING AREAS NEAR SEAL ISLAND

T. Ichii[1], H. Ishii[1], J.L. Bengtson[2], P. Boveng[2], J.K. Jansen[2] and M. Naganobu[1]

Abstract

Shipboard tracking studies of krill-eating predators (penguins and female fur seals) near Seal Island were conducted to identify and evaluate their foraging areas during early January 1990/91. Penguin foraging areas were found in inshore regions where krill frequently occurred but higher density areas of krill (≥250 g/m^2) were rather limited. In contrast, fur seal foraging areas were found in offshore regions where krill occurred only occasionally but in large aggregations (surface length about 2 to 3 km) of higher densities (≥250 g/m^2). In the inshore foraging areas krill undertake diurnal vertical migrations, tending to be at a deeper range from 50 to 100 m in the day while at a shallower range from 20 to 50 m at night. In the offshore foraging areas krill do not undertake any diurnal vertical migrations, staying close to the surface throughout the day. With regard to body size and maturity of krill in the inshore foraging areas, middle-sized krill (modal length 43 mm), which consisted mainly of non-gravid krill, were dominant with occasional occurrences of juveniles (modal length 21 mm). In contrast, in the offshore foraging areas large krill (modal length 47 mm) were dominant, the majority of which were gravid females. Thus, horizontal and vertical distributions and population structure of krill were totally different in the foraging areas of penguins and fur seals. The reasons why fur seals chose offshore foraging areas instead of inshore foraging areas are discussed.

Résumé

Afin d'identifier et d'évaluer les secteurs d'alimentation de certains prédateurs de krill (manchots et femelles d'otaries) à proximité de l''île Seal, des suivis ont été effectués à bord de navires début janvier 1991. Les secteurs d'alimentation des manchots ont été découverts dans les régions côtières souvent fréquentées par le krill mais rarement en densité élevée (≥250 g/m^2). Par contre, les secteurs d'alimentation des otaries ont été découverts dans des secteurs du large où le krill n'est que rarement présent mais en concentrations étendues (d'environ 2 à 3 km de long) et de densités élevées (≥250 g/m^2). Dans les secteurs d'alimentation côtiers, le krill effectue des migrations verticales nycthémérales, se concentrant plutôt à une profondeur de 50 à 100 m de jour alors qu'il fréquente une couche moins profonde, de 20 à 50 m de nuit. Au large, dans les secteurs d'alimentation, le krill ne migre pas dans la colonne d'eau pendant la journée: il reste jour et nuit proche de la surface. En ce qui concerne la taille du corps et la maturité du krill dans les secteurs d'alimentation côtiers, le krill de taille moyenne (d'une

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longueur modale de 43 mm) consistant principalement en krill non gravide, dominait avec quelques cas de juvéniles (longueur modale, 21 mm). Par contre, dans les secteurs d'alimentation se trouvant au large, dominait le krill de grande taille (longueur modale, 47 mm) composé principalement de femelles gravides. Il en ressort que les distributions horizontales et verticales et la structure démographique du krill différaient entièrement dans les secteurs d'alimentation des manchots et des otaries. Les raisons pour lesquelles les otaries choisissent les secteurs d'alimentation éloignés de la côte, plutôt que côtiers, sont examinées.

Резюме

В начале января 1990/91 г.С борта судна велось слежение за хищниками, питающимися крилем (пингвинами и самками морского котика) около острова Сил с целью определения и оценки их нагульных ареалов. Нагульные ареалы пингвинов были обнаружены в прибрежных районах, где криль часто скапливается, но не образует плотных скоплений (≥250 г/м^2). По сравнению с этим, нагульные ареалы морских котиков наблюдались в открытом море, где криль встречался лишь время от времени но в больших агрегациях (около 2-3 км длиной на поверхности) бо̀льших плотностей (≥250 г/м^2). В прибрежных нагульных ареалах криль предпринимает суточные вертикальные миграции - днем обычно находясь на глубине 50-100 м, а ночью ближе к поверхности в диапазоне 20-50 м. В нагульных ареалах в открытом море криль вообще не предпринимает суточных вертикальных миграций, придерживаясь днем близко к поверхности. Что касается длины тела и половозрелости криля в прибрежных нагульных ареалах, доминировал криль средних размеров (модальная длина - 43 мм), в основном неикряные особи - молодь встречалась только иногда (модальная длина - 21 мм). По сравнению с этим, в нагульных ареалах в открытом море доминировал криль больших размеров (модальная длина - 47 мм), в основном икряные самки. Итак, горизонтальное и вертикальное распределение и структура популяции криля в нагульных ареалах пингвинов и морских котиков полностью различны. Обсуждаются причины выбора морскими котиками нагульных ареалов в открытом море, а не в прибрежных водах.

Resumen

A principios de enero 1990/91 se llevaron a cabo estudios de seguimiento de especies krilófagas (pingüinos y hembras de lobo fino) en el mar a la altura de la la isla Foca, para determinar sus áreas de alimentación. Se encontraron zonas de alimentación de pingüinos cercanas a la costa en donde generalmente hay kril, aunque las áreas en las que el kril se encuentra en gran densidad (≥250 g/m^2) son muy limitadas. Por otra parte, las zonas de alimentación de lobos finos se encontraron en las zonas de alta mar en donde rara vez se encuentra kril pero cuando hay, se da en grandes concentraciones (extensión aproximada de 2 a 3 km) de gran densidad (≥250 g/m^2). En la zona de

alimentación cerca de la costa se observaron migraciones diurnas del kril con una tendencia a permanecer a profundidades mayores (50 a 100 m) durante el día y en capas más superficiales (20 a 50 m) durante la noche. En alta mar no se da este fenómeno y el kril permanece cerca de la superficie durante todo el día. Con respecto a los estados de madurez y longitud del kril en las zonas de alimentación cercana a la costa, predominó el kril de tamaño medio (longitud modal de 43 mm) formado en su mayoría por kril sin ovas con alguno que otro juvenil (longitud modal de 21 mm). Por su parte, en las zonas de alimentación de alta mar hubo predominancia de kril de gran tamaño (longitud modal 47 mm), la mayoría del cual correspondía a hembras grávidas. Así se desprende que tanto las distribuciones horizontales como verticales y la estructura de la población del kril diferían totalmente en las zonas de alimentación de pingüinos y lobos finos. Se presentan las posibles razones de por qué los lobos finos eligen aquellas zonas de alimentación de alta mar en lugar de aquellas cercanas a la costa.

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1. INTRODUCTION

The Seal Island area is one of the active sites in the Antarctic Peninsula Integrated Study Region of CEMP (CCAMLR Ecosystem Monitoring Program). In accordance with CEMP protocols, studies have been carried out since 1986/87 by NOAA (National Oceanic and Atmospheric Administration of the USA) to assess and monitor reproductive and foraging behaviour of krill predators breeding at the island. As part of CEMP-related activities, in the early summer of 1990/91, a predator tracking study was conducted on board the Japanese research vessel *Kaiyo Maru* in cooperation with NOAA (AMLR, 1991). The objectives of this study were:

(i) to locate foraging areas of predators (penguins and fur seals) and describe characteristics of prey (krill) distribution and environment in these areas; and

(ii) to monitor foraging behaviour of predators using time-depth recorders and evaluate how prey availability and environmental conditions may influence predators' foraging behaviour.

This paper presents preliminary results of those objectives described in subparagraph (i) above.

2. MATERIALS AND METHODS

2.1 Radio Tracking

Tracking studies were conducted aboard the *Kaiyo Maru* from 1 to 8 January 1991. Four Yagi directional antennae were mounted on the upper bridge of the *Kaiyo Maru* to assist in locating fur seals and penguins at sea. These antennae were connected to an automatic direction finding system which guided the ship while it followed the target individuals. The automatic direction finding system was operated around the clock during tracking. Information on instrumentation of predators will be described by NOAA in the near future. Tracking operations proceeded as follows: the ship waited off Seal Island (approximately 1 to 2 n miles) until a fur seal or penguin departed to sea on a feeding trip; at that time, the ship followed the individuals as long as possible or until the fur seal or penguin returned to shore at the end of its feeding trip. Location of the ship was monitored every 15 minutes by radar and a satellite navigation system.

Tracks to foraging areas were recorded for four chinstrap penguins (*Pygoscelis antarctica*) (six trips), one macaroni penguin (*Eudyptes chrysolophus*) and one female fur seal (*Arctocephalus gazella*). Most penguins were tracked for the majority of one entire feeding trip. The trip of the female fur seal was tracked only on its outbound leg to the apparent outer limit of her foraging range.

2.2 Hydroacoustic Survey

While the ship was tracking fur seals or penguins at sea, the presence and depth of krill in the water column were monitored using an echo sounder (Furuno Electric FQ-50) at a frequency of 200 kHz. Echoes were continuously integrated at intervals of 0.5 n mile for the depth range of 10 to 150 m or 10 m to the bottom if shallower. Detailed operating parameters of the acoustic system are described in Ichii *et al.* (1992).

2.3 Net Sampling

Prey (krill) samples in foraging areas were collected by towing an ORI-200 net (diameter 1.6 m and mesh size 2.0 mm). When a swarm was detected acoustically, the net was towed horizontally at a speed of about 3 knots at swarm depth. Oblique tows were conducted from about 100 m to the surface in cases when no swarms were detected.

A sample from each haul was preserved in a 10% buffered formalin-seawater solution for later examination in the laboratory ashore. 150 individuals of krill were randomly selected from each sample for measurement of body length and determination of maturity stage; all individuals were analysed for small catches of $\leq$150 krill. Body length was measured to the nearest millimetres from the tip of the rostrum to the end of the telson. All measurements were carried out by a single observer to avoid methodologically biased differences in length frequency data (Watkins *et al.*, 1985). Maturity stages were identified according to the classification of Makarov and Denys (1981).

2.4 Hydrographic Observation

The temperature profile of the water column in foraging areas was determined using expendable bathythermographs (XBTs). During the study period surface salinity was continuously measured with a thermo-salinograph (NEIL BROWN Inc., Smart CTD A) to identify the slope front. Subsurface current patterns (30 to 35 m depth) in the foraging areas were assessed by tracking drifting buoys which were deployed off northern Livingston Island (see Ichii *et al.*, 1992).

3. RESULTS

3.1 Foraging Areas

Foraging areas were located mainly to the north of Seal Island (Figure 1). Penguin foraging areas were located within inshore regions; maximum foraging range was 25 km from the island. By contrast, the fur seal went beyond the continental slope and foraged in offshore regions. The outer limit of her foraging range was, surprisingly, as far as 240 km from the island.

3.2 Hydrographic Features

The continental slope water front was identified by a relative sharp northward decrease in salinity (from 34.1 to 33.8‰) over the area from 1 000 m to 3 000 m deep (Figure 1).

Subsurface currents in inshore and offshore region were determined from the tracks of the two buoys (Figure 2). In the offshore region a complex eddying current was observed along the shelf break (approximately 200 to 500 m deep), encircling Elephant Island in a counterclockwise direction. The inshore region may be described as an area of hydrodynamic accumulation and retention, considering that the buoy deployed off northern Livingston Island (170 km southeast of Seal Island) became trapped in this region. In the offshore region, however, the buoy moved smoothly eastward along the depth contour of about 3 000 m. Finally, it reached as far as South Georgia and became entrained in its shelf break area.

Vertical profiles of temperature indicated that the inshore region had a low degree of stratification, with indications of vigorous vertical exchange processes. Conversely, in the offshore region warm surface water with a subsurface temperature minimum ("Winter Water") a strong thermocline forms in the subsurface (40 to 70 m).

3.3 Horizontal Distribution of Krill

In the inshore foraging areas krill frequently occurred in various forms of aggregations, but higher density areas of krill ($\geq$250 g/m^2) were quite limited. It seemed that penguins did not necessarily forage in the higher krill density areas. In contrast, in the offshore foraging areas krill occurred only occasionally, but tended to form extensive aggregations (approximately 2 to 3 km across) of high densities ($\geq$250 g/m^2) (Figure 3). The fur seal clearly fed on these aggregations.

3.4 Vertical Distribution of Krill

In the inshore foraging areas krill undertook diurnal vertical migrations, tending to be at a deeper depth range (50 to 100 m) in the daytime, while at a shallower layer (20 to 50 m) at night (Figure 4). In the offshore foraging areas, however, krill undertook no diurnal vertical migrations, staying close to the surface throughout the day, which is probably caused by the shallow thermocline in the region.

3.5 Size and Maturity of Krill

As shown by accumulated size composition data for each foraging area (Figure 5), middle-sized krill (modal length 43 mm) were dominant with occasional occurrences of small specimens (modal length 21 mm) in the inshore foraging areas, whereas large krill (modal length 47 mm) were dominant in the offshore foraging areas. As for maturity, the majority of female krill were still undergoing maturation (IIIBC) in the inshore foraging areas, whereas almost all females were gravid (IIID) in the offshore foraging areas. Juveniles (I) were restricted to the inshore foraging areas.

4. DISCUSSION

Contrary to what might be expected, feeding locations of the fur seal were well offshore during the study period (early January). Later in the season (mid-February) NOAA conducted another tracking study of fur seals on board the Chilean research vessel in order to compare fur seal foraging areas early and late in their reproductive season (AMLR, 1991). Foraging locations of fur seals in mid-February were quite different from those in early January; they were mostly within inshore regions in mid-February. Moreover, foraging trip duration was shorter in February (1 to 3 days) than in January (5 to 9 days) (AMLR, 1991). Since krill was less abundant than usual in January, NOAA suggested that this lower krill abundance during January may be responsible for the offshore feeding of fur seals at that time. Offshore feeding trips,

however, may not be specifically linked with seasons of low krill abundance, but a rather usual event early in summer. The reason for such a conclusion is that tracking studies in 1988/89 and 1989/90 indicated that in January fur seals might utilise inshore as well as offshore areas (Bengtson and Eberhardt, unpublished data; AMLR, 1990).

The reasons why fur seals often choose offshore foraging areas over inshore ones, despite the former areas being far more remote from the island, are as follows.

In the case of fur seals, krill consumed during foraging trips is being digested and processed into milk, high energy concentrated food for pups. This enables fur seals to undertake long-distance foraging trips and to accumulate a large amount of food in the form of milk. In contrast, penguins are not capable of producing milk and can only accumulate krill in their stomachs. This means that for penguins, the amount of energy delivered to the chick per trip is limited, i.e., a stomach full of krill at most. Hence, long-distance feeding trips by penguins do not increase the amount of energy delivered per trip and may lead to chick starvation.

Secondly, the present study revealed that extensive and dense aggregations occasionally occurred in the offshore region. This may be a typical feature of early summer (Ichii, unpublished data), and toward the end of summer fewer and fewer krill may be distributed in the offshore region (Siegel, 1988). The occurrence of these exploitable aggregations is evidently another important reason why fur seals are attracted to offshore regions in early summer.

Finally, krill aggregations in the offshore region are favoured by predators because:

(i) krill are present in a shallower depth throughout the day and easily detected; only shallow diving is required to catch krill, even in the daytime; and

(ii) krill tend to be larger in size and gravid, i.e., of high nutritional value.

Expanding on (ii) above, in terms of energetic value gravid females have as much as 5.45 kJ/g wet weight as compared to 3.84 kJ/g wet weight for males (Clark, 1980). Costa (1991) suggests that due to the small size and low energy content of krill compared to fish, hunting krill is only viable for fur seals when only shallow diving is required. In fact, at South Georgia, fur seals made most dives at night when krill appeared near the surface (Croxall, 1985).

It may be suggested, therefore, that offshore foraging can be energetically advantageous for fur seals during early summer.

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REFERENCES

AMLR (Antarctic Ecosystem Research Group Staff, Eds). 1990. AMLR 1989/90 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-90-11. Document *WG-Krill-90/7*. CCAMLR, Hobart, Australia: 104 pp.

AMLR (ROSENBERG, J. and R. HEWITT, Eds). 1991. AMLR 1990/91 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-91-18. Document *WG-CEMP-91/11*. CCAMLR, Hobart, Australia: 97 pp.

CLARKE, A. 1980. The biochemical composition of krill, *Euphausia superba* from South Georgia. *J. Exper. Mar. Biol. Ecol.*, 43: 221-236.

COSTA, D.P. 1991. Reproductive and foraging energetics of high latitude penguins, albatrosses and pinnipeds: implications for life history patterns. *Amer. Zool.*, 31: 111-130.

CROXALL, J.P., I. EVERSON, G.L. KOOYMAN, C. RICKETTS and R.W. DAVIS. 1985. Fur seal diving behaviour in relation to vertical distribution of krill. *J. Animal Ecol.*, 54: 1-8.

ICHII, T., H. ISHII and M. NAGANOBU. 1992. Abundance, size and maturity of krill (*Euphausia superba*) in the krill fishing ground of Subarea 48.1 during 1990/91 austral season. In: *Selected Scientific Papers, 1992 (SC-CAMLR-SSP/9)*. CCAMLR, Hobart, Australia. (See this volume).

MAKAROV, R.R. and C.J. DENYS. 1981. Stages of sexual maturity of *Euphausia superba* Dana. *BIOMASS Handbook*, 11: 1-13.

SIEGEL, V. 1988. A concept of seasonal variation of krill (*Euphausia superba*) distribution and abundance west of the Antarctic Peninsula. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin Heidelberg: 219-230.

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

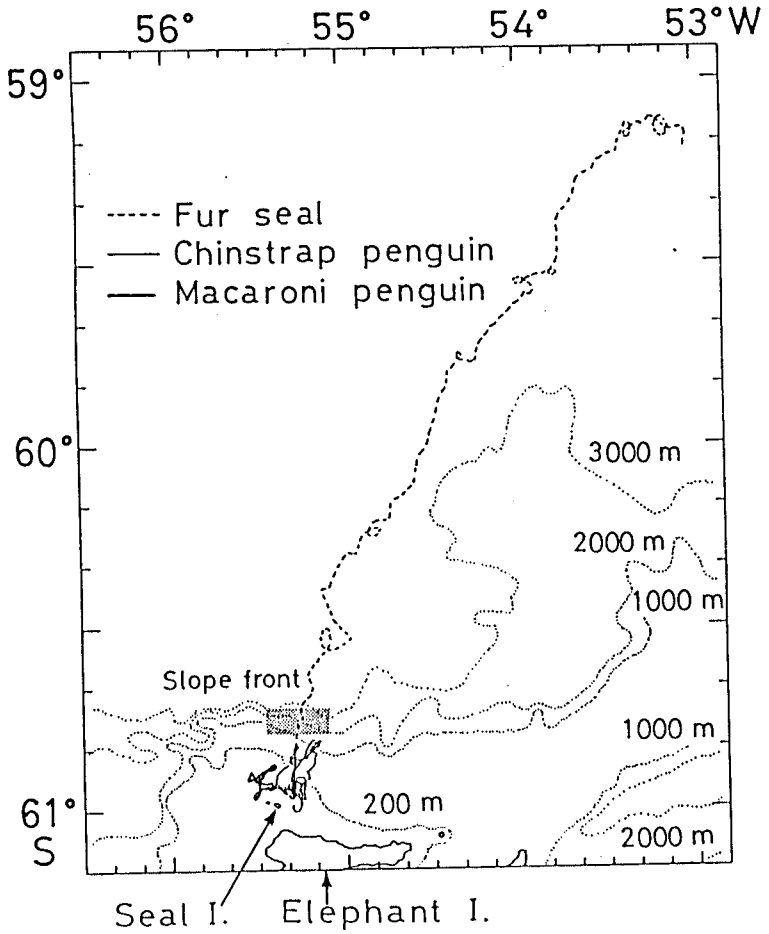


Figure 1: Fur seal and penguin foraging areas near Seal Island, 1 to 8 January 1991. Tracklines indicate the path of the ship during the tracking operations. Shaded area indicates slope front.

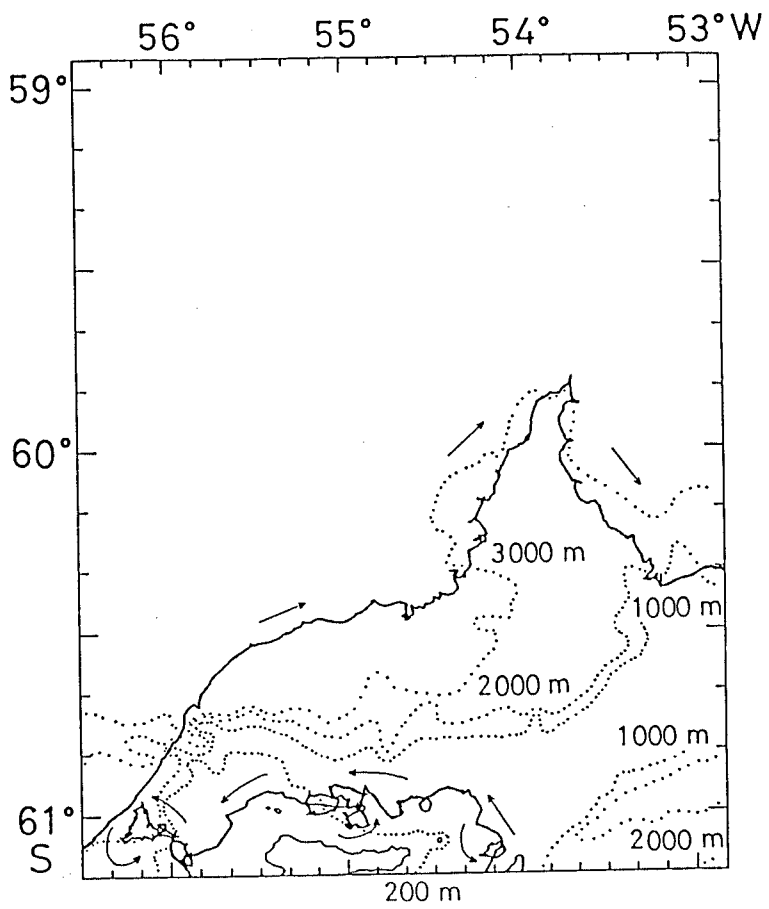


Figure 2: Subsurface (30 to 35 m depth) currents derived from the paths of two satellite-tracked buoys.

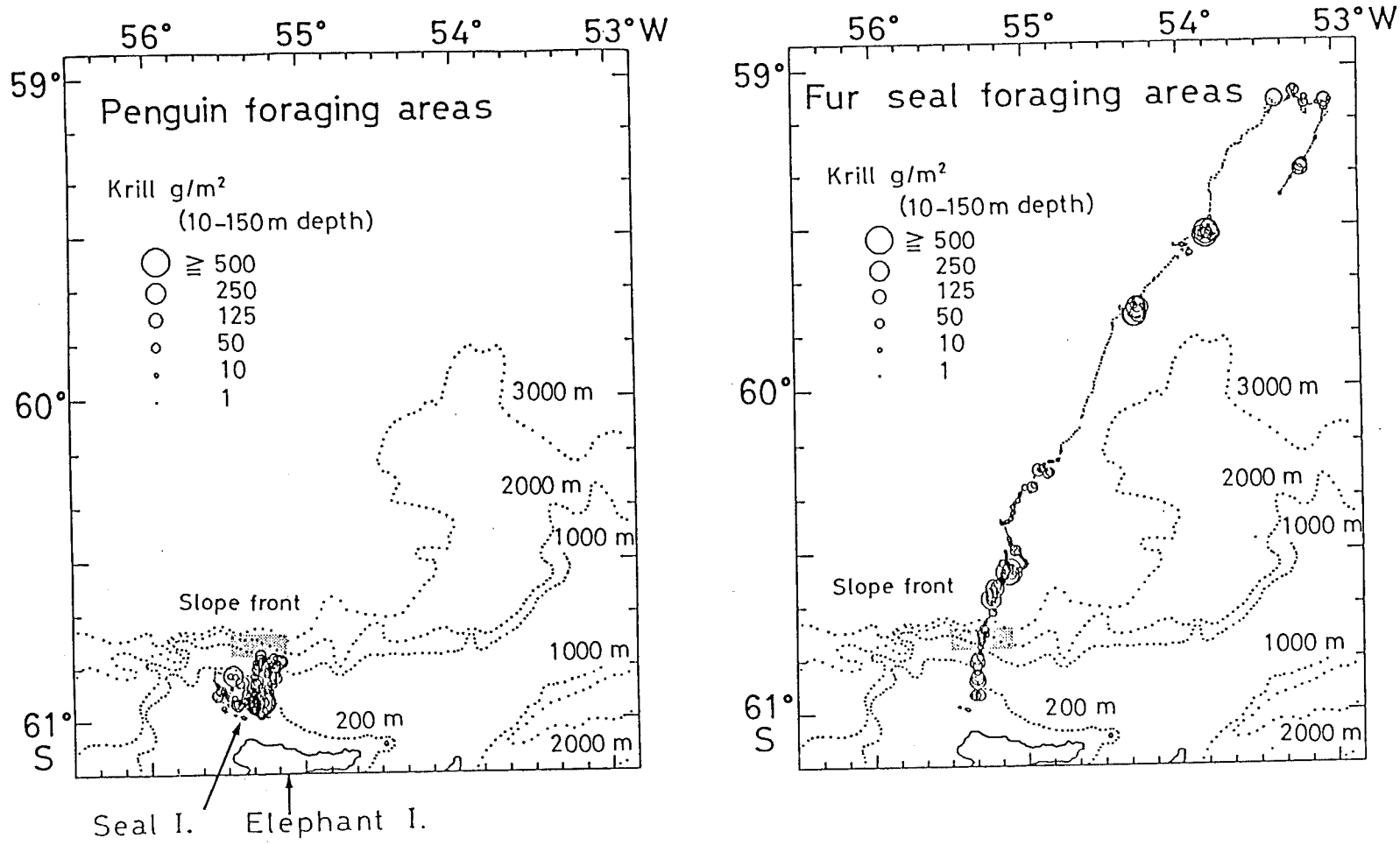


Figure 3: Horizontal distributions of krill detected during penguin (left) and fur seal (right) tracking. Shaded area indicates slope front.

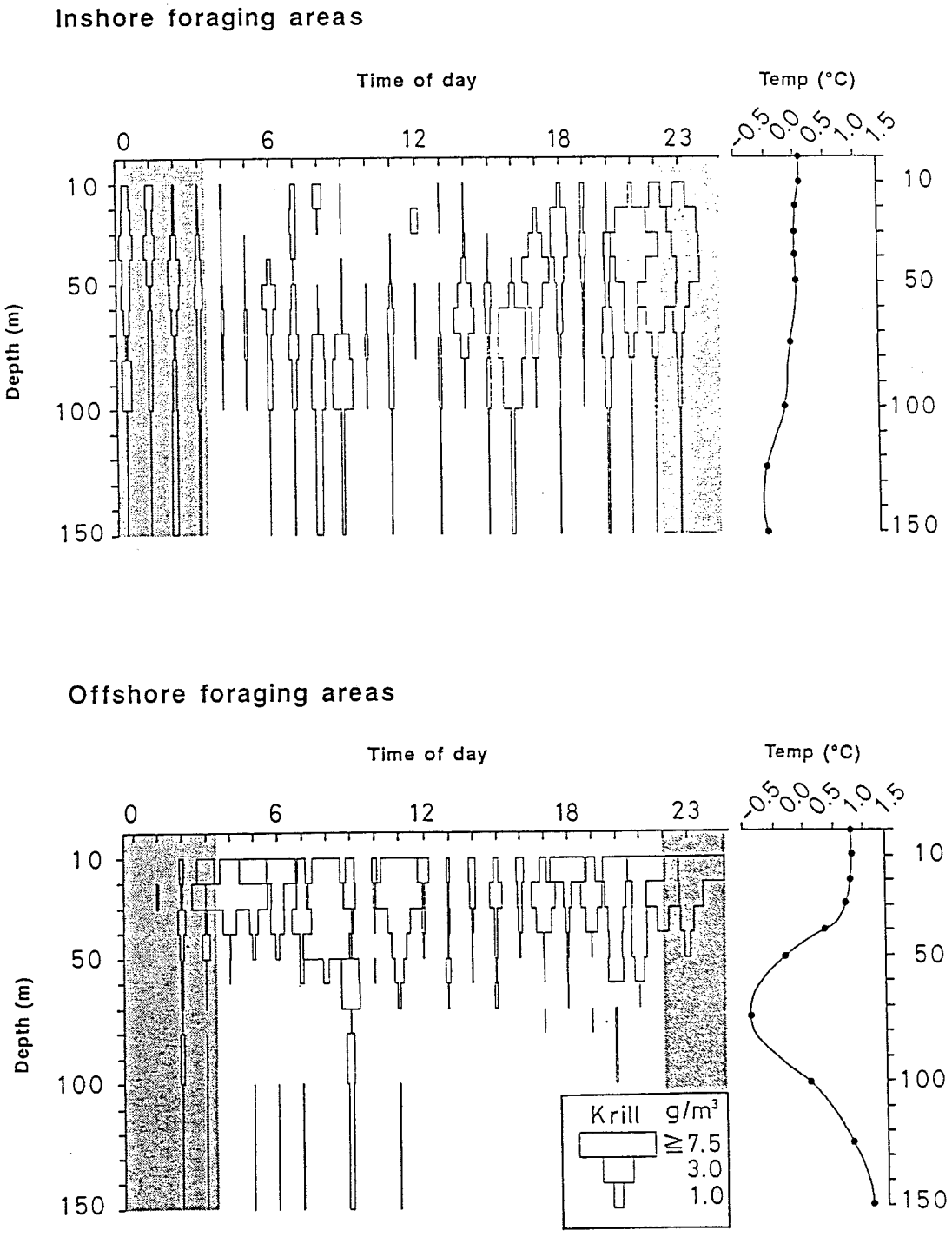
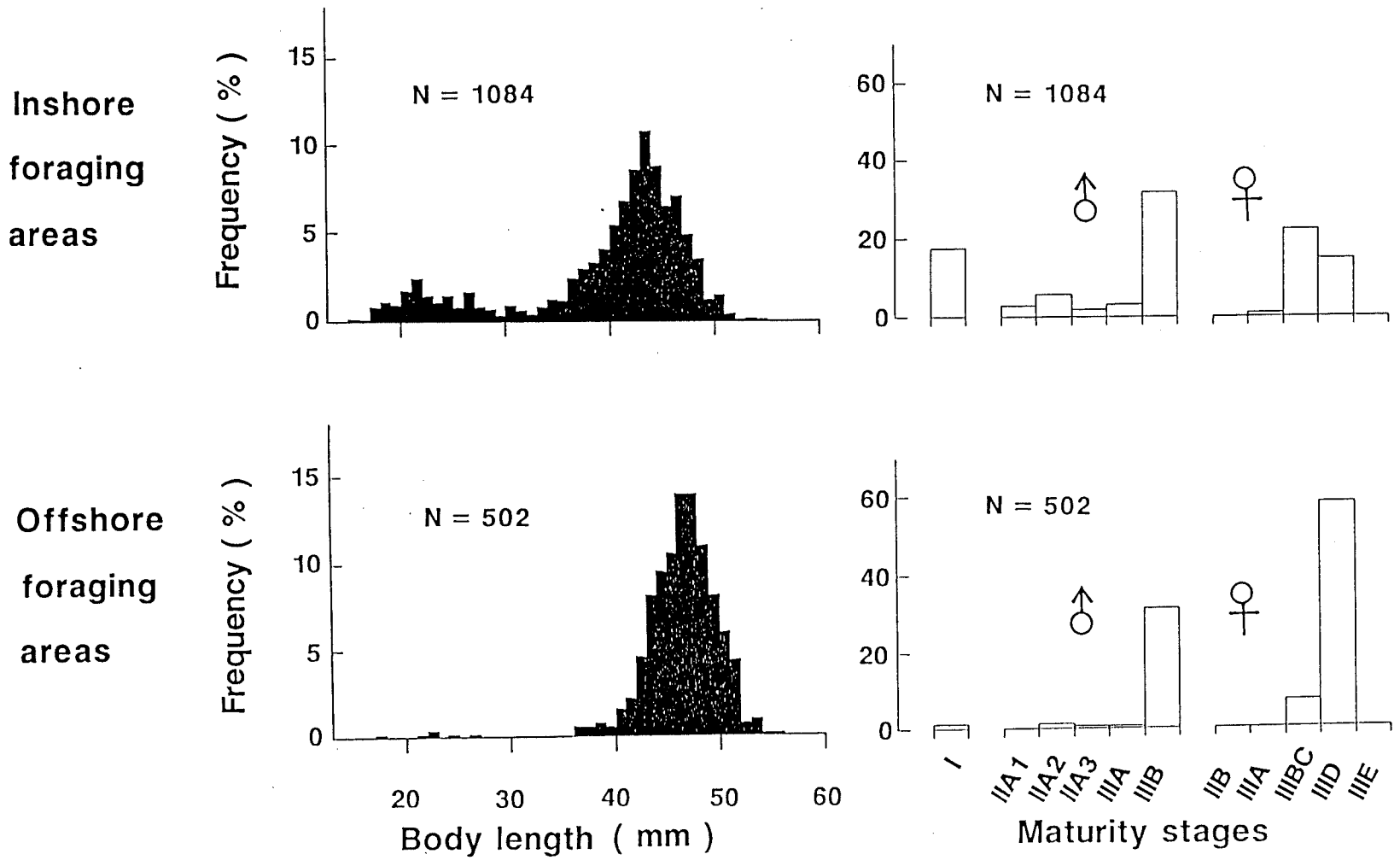


Figure 4: Diurnal vertical distributions of krill with vertical profiles of temperature in penguin (top) and fur seal (bottom) foraging areas. Shaded areas indicate night-time.



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DISTRIBUTION OF KRILL (*EUPHAUSIA SUPERBA* DANA) CATCHES IN THE SOUTH SHETLANDS AND SOUTH ORKNEYS

D.J. Agnew*

Abstract

A set of concentric zones of 20 km width was defined around selected colonies of penguins distributed around the coasts of the South Shetland and South Orkney Islands. Krill catches in these zones are shown to have a consistent pattern in Subarea 48.1 but an unpredictable distribution in Subarea 48.2, probably as a result of more variable hydrographic conditions. About 50% of the catch in Subarea 48.1 from December to March was taken within 40 km of the coast, and 90% within 80 km in all years 1988 to 1991. In 1987, 1988 and 1991, 75% of the catch in Subarea 48.2 between December and March was taken within 80 km of colonies in the South Orkneys. Estimates of consumption rates, foraging ranges and population sizes from the literature are used to show that for some years catches within 100 km of predator colonies between December and March may be up to 45% of the land-based predator consumption. Whilst the normal ratio of catch to consumption is relatively low (less than 27%), and the fishery may have to increase by a factor of 2 or 3 before ratios of catch to consumption approach maximum sustainable levels, any competition between the fishery and predators as a result of large increases in catch is likely to emerge in areas of high overlap between predators and the fishery earlier than would be expected considering the fishery as a whole.

Résumé

Un ensemble de zones concentriques de 20 km de large a été défini autour de colonies de manchots sélectionnées sur les côtes des îles Shetland du Sud et des Orcades du Sud. Dans ces zones, les captures de krill présentent une tendance régulière dans la sous-zone 48.1 mais une distribution imprévisible dans la sous-zone 48.2, vraisemblablement en raison des conditions hydrographiques plus variables. 50% environ de la capture de la sous-zone 48.1 de décembre à mars avait été effectuée à moins de 40 km de la côte, et 90% à moins de 80 km de 1988 à 1990. En 1987 et 1988, de décembre à mars, 75% de la capture de la sous-zone 48.2 provenait d'un rayon de 80 km autour des colonies des îles Orcades du Sud. Des estimations des taux de consommation, des secteurs d'alimentation et de la taille des populations extraites de la littérature sont utilisées pour indiquer qu'en certaines années, à des distances variant entre 20 et 60 km des colonies de prédateurs, les captures peuvent atteindre 48% de la consommation par les prédateurs terrestres en janvier et février. Bien qu'au total, la proportion capture-consommation soit relativement faible (27%), toute compétition entre la pêcherie et les prédateurs, à la suite d'une augmentation substantielle des captures, risque de se manifester dans ces zones plus tôt que ne le porterait à croire un examen global de la pêcherie.

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Резюме

На карте были нанесены серии концентрических зон, каждая шириной 20 км. Вокруг нескольких колоний пингвинов, расположенных вдоль побережья Южных Шетландских и Южных Оркнейских о-вов, показано, что распределение уловов криля в этих зонах Подрайона 48.1 имеет закономерный характер. В Подрайоне 48.2 такой закономерности не наблюдатеся, вероятно в результате более изменчивых гидрографических условий. Ежегодно в период 1988-1990 гг. приблизительно 50% вылова в Подрайоне 48.1 с декабря по март было получено в радиусе 40 км от берега и 90% в радиусе 80 км от берега. В 1987 и 1988 гг. 75% вылова в Подрайоне 48.2 за период декабрь-март было получено в радиусе 80 км от колоний на Южных Шетландских о-вах. Из литературы взяты оценки уровней потребления криля, нагульных ареалов и размеров популяции хищников чтобы показать, что для некоторых лет на расстоянии 20-60 км от колоний хищников, в январе-феврале уловы могут составлять до 48% криля, потребляемого обитающими на суше хищниками. Хотя общее отношение вылова к потреблению относительно низко (27%), конкуренция между промыслом и хищниками в результате больших увеличений в вылове вероятно возникнет в этих районах раньше, чем следует ожидать при рассмотрении промысла в целом.

Resumen

Se ha definido un grupo de zonas concéntricas de 20 km de ancho alrededor de colonias seleccionadas de pingüinos que están distribuidas a lo largo de las costas de las islas Shetland del Sur y Orcadas del Sur. Las capturas de kril en estas zonas han mostrado una distribución regular en la Subárea 48.1 pero no en la Subárea 48.2, probablemente debido a las condiciones hidrográficas más variables en esta última. Desde 1988 a 1991, alrededor del 50% de las capturas de diciembre a marzo en la Subárea 48.1 se realizaron en un radio de 40 km de la costa; y un 90% a 80 km de la costa. En 1987, 1988 y 1991, el 75% de la captura de la Subárea 48.2 fue extraída en un radio de 80 km de las colonias de Orcadas del Sur en el período entre diciembre y marzo. Se han utilizado las estimaciones publicadas de los niveles de consumo, de las áreas de alimentación y del tamaño de las poblaciones, para demostrar que por varios años las capturas realizadas entre diciembre y marzo - a 100 km de distancia de las colonias de depredadores - pueden representar hasta un 45% del consumo de los depredadores terrestres. Mientras la proporción normal de la captura en relación al consumo es relativamente baja (menos del 27%), y la pesquería tendría que aumentar por un factor de 2 o 3 antes de que la proporción de captura/consumo se aproxime a los niveles máximos sustentables, cualquier competencia entre la pesquería y los depredadores que se da como resultado de los aumentos considerables de las capturas es muy probable que ocurra antes de lo que se podría esperar en estas áreas, si se considera la pesquería en un contexto global.

1. INTRODUCTION

Since 1974 when fishing for Antarctic krill first started in the Southern Ocean a fundamental concern has been to ensure that harvesting did not proceed like that of seals, whales and fin-fish, whereby substantial over-exploitation brought at least some stocks to the verge of extinction. A further concern was that harvesting should not have detrimental effects on species that depend on krill for their primary food source (Edwards and Heap, 1981). In this light the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was negotiated, coming into effect in 1982, the first 'fisheries' convention to have a so-called 'ecosystem perspective' and to require the well-being of dependant species to be considered in the management of commercial harvesting.

After an initially rapid expansion to 500 000 tonnes in 1981/82, the krill harvest has remained stable since 1985/86 at around 300 000 tonnes (Miller, 1989). This is small in comparison to the tens to thousands of millions of tonnes estimated for the total biomass of krill in the Southern Ocean (see review of Miller and Hampton, 1989) and in comparison to the total consumption of krill by birds and seals (estimated by Miller and Hampton, 1989 to be about 144 million tonnes).

CCAMLR divides the Southern Ocean into three major areas, each of which is divided further into subareas. Everson and Goss (1991) have shown that there is a consistent pattern to the fishery within the Atlantic Sector of the Southern Ocean, Statistical Area 48, where over 90% of the total world catch is currently taken. Fishing around South Georgia in the winter months is followed by a shift to fishing to around the South Orkneys and South Shetlands in the summer, as the retreating ice allows. Between 24 and 70% of the total world catch of Antarctic krill is from the Southern part of the Scotia Sea around these two archipelagos, in Subareas 48.1 and 48.2. Moreover, examination of the CCAMLR *Statistical Bulletin* (CCAMLR, 1992) reveals that the patterns of catches around these islands is fairly consistent from year to year, and is located over the shelf break to the north and west of and close to the islands. The study of Everson and Goss (1991) and data published in the *Statistical Bulletin* were the first clear suggestions that the fishery might be regularly located in quite restricted geographical areas in proximity to substantial concentrations of breeding sea-birds and seals.

This observation gives rise to the concern that although the total catch of krill in the Southern Ocean is low relative to estimates of total stock, high localised catches may be having a detrimental effect on some predators, especially during the months in which they are breeding and having to forage for food in the vicinity of their breeding sites where these are situated on land.

The aim of this paper is to make a preliminary assessment of the magnitude of the overlap between the fishery for krill in Subareas 48.1 and 48.2 and the requirements of predators. Croxall *et al.* (1985) have calculated that in the southern Scotia Sea crabeater seals and penguins are the main consumers of krill, accounting for 45% of the total krill consumed each year. Crabeater seals (*Lobodon carcinophagus*), which are not restricted to land-based sites, and fur seals (*Arctocephalus gazella*) whose estimated consumption of krill in the southern Scotia Sea is less than 1%, are not considered here.

2. METHODS

2.1 Predator Consumption

Identification of the times and areas of coincidence between the fishery and predator foraging areas required identification of the relevant times of overlap, the distances that penguins are likely to forage over, their population numbers and estimated consumption of krill.

The three major species of penguin in the southern Scotia Sea are chinstrap, Adélie and gentoo penguins (*Pygoscelis antarctica*, *P. adeliae* and *P. papua*). These penguins arrive at their breeding colonies from October to November and the chicks complete fledging in mid to late February (SC-CAMLR, 1991). Chicks and adults probably continue to be restricted to areas close to the breeding sites into March (J. Croxall, pers. comm.). Conversely, Croxall *et al.* (1985) estimate that total prey consumption declines in November before egg laying. Thus to cover all periods when predators may be restricted in their foraging range the present analysis used the four months December to March.

The extent of foraging of these species is estimated as within a 10 to 90 km radius of breeding sites at these times of year: Adélie penguin, 50 to 80 km (Everson, 1987), 80 to 120 km (Lishman, 1985), 50 km (Sadleir and Lay, 1990; Trivelpiece *et al.*, 1987); chinstrap penguin 40 to 60 km (Everson, 1987), 66 to 92 km (Lishman, 1985), 27 km (Trivelpiece *et al.* (1986), 25 to 50 km (CCAMLR, 1990); gentoos 10 km (Croxall *et al.*, 1984), 17 km (Trivelpiece *et al.*, 1986). For the purpose of estimating food requirements of penguins with dependent offspring they were assumed to be foraging equally over ranges of 80, 60 and 20 km (Adélie, chinstrap and gentoo) from their colonies.

Although there are penguin colonies throughout the Antarctic Peninsula and on all the Subantarctic island groups in Statistical Area 48, the selection of colonies for the study was restricted to the South Shetland and South Orkney Islands (Figure 1). Elimination of the Antarctic Peninsula colonies was done because the krill fishery in Subarea 48.1 is restricted to the western side of the South Shetland Islands north of 63°30'S only, and has not so far exploited the Bransfield Strait (CCAMLR, 1992). This is too far (greater than 80 km) for penguins from colonies on the Peninsula, Anvers and Brabant Islands to swim to during the period when they have dependent offspring, and these colonies are therefore unlikely to be directly affected by fishing activity.

The total number of pairs of penguins in the South Shetlands was calculated from Woehler (1991) as:

South Shetlands:	Adélie	60 000
	chinstrap	1 457 000
	gentoo	34 000
South Orkneys:	Adélie	215 000
	chinstrap	600 000
	gentoo	11 000

Croxall *et al.*, (1985) have described detailed calculations of total food consumption by birds and seals in the Scotia Sea. Using their Table 1 it is possible to calculate mean monthly consumption rates of krill by selected predators: Adélie (51.6 kg/pair/month), chinstrap (50 kg) and gentoos (50 kg). More recent calculations have been performed by Croll (1990) for the South Shetlands, yielding mean consumption over the period December to March of 80, 64 and 68 kg krill/pair/month for Adélies, chinstraps and gentoos respectively. Both models indicate that for gentoos and chinstraps consumption is depressed by about 15% in December and increased by 15% in January and February. For Adélies, Croll (1990) estimated that this increase occurs in December and January. For the present study, intermediate consumption figures of 65, 57 and 59 are used, and these monthly figures are adjusted by -15% (December), +15% (January, February) for gentoos and chinstraps, and +15% (December, January) for Adélies.

2.2 Krill Catches

The distribution of krill catches in Statistical Area 48 is published by CCAMLR in its *Statistical Bulletin* (CCAMLR, 1992 - Figure 25). Krill catches are displayed in map form, with

data given for each CCAMLR fine-scale square (1° longitude by 30' latitude) for each quarter (three months) of the year. Total catches are shown by a series of ranges, distinguished by shading on the map corresponding to the ranges 1 to 4, 5 to 24, 25 to 124, 125 to 624, 625 to 2 999 and ≥3 000 tonnes. Data are available from 1988 for Subarea 48.1 and 1987 for Subarea 48.2.

Because only ranges of catches are available from CCAMLR (1992) the total catch in each fine-scale square was estimated by first taking the initial estimate of the catch to be equal to the lower catch bound for that square, and they applying the calculation.

Estimated catch in a quarter for square =

$$\text{Initial estimate for square} \times \frac{\text{total catch in the subarea in that quarter}}{\text{sum of initial estimates for all squares in that quarter}}$$

The total catch in the subarea in a quarter was taken from the STATLANT column of Table 15 of CCAMLR (1992).

In order to compare catches with predator data, a critical period for predators of December to March was defined. Total catches in the period January to March were easily obtained from data for quarter 3, using the calculation above. Catches for December were obtained similarly using data for quarter 2 (October to December) but a correction factor was applied which corrected for the proportion of quarter 2 catches which were taken in December. For Subarea 48.1 this correction is unnecessary because all catches in quarter 2 were taken in December. For Subarea 48.2 the correction is small because most catches were taken in December (CCAMLR, 1992 - Tables 9.2 and 9.3).

Having obtained estimated total catches of krill in each fine-scale square for December to March, the pattern of krill catches in relation to predator colonies was investigated by dividing the sea into concentric zones around the major colonies with radii in 20 km increments. Major colonies (greater than 20 000 pairs) of the most abundant penguin species, chinstraps, were used for this purpose and were identified from Woehler (1991) (Figure 1). For each fine-scale square, the catches were assigned to different zones in the proportion that each zone covered water estimated deeper than 50 m (and therefore available to the fishery) within the square.

3. RESULTS

Total catches and estimated penguin consumption by month and zone are shown in Tables 1 and 2, and Table 3 shows the proportion of the total catch for the split year that was taken in the four months December to March within 100 km of predator colonies. The total consumption of krill by penguins from December to March was calculated as 370 000 tonnes in Subarea 48.1, and 195 000 tonnes in Subarea 48.2, and by far the largest component of this was due to chinstrap penguins. The former figure is similar to that calculated by Croll (1990) for the South Shetlands (345 000 tonnes). The total consumption, however, (565 000 tonnes) is only about a third of the 1 445 000 tonnes estimated by Croxall *et al.* (1985) for the whole of the southern Scotia Sea over four months. The difference is explained by the greater population estimates used by Croxall *et al.* which apply not only to the South Shetlands and South Orkneys, but to the Antarctic Peninsula as well.

The pattern of catches for Subareas 48.1 and 48.2 over the period 1988 to 1992 is shown in Figure 2. Three areas of high concentration are apparent, north of Livingston Island, northwest of Elephant Island and northwest of Coronation Island, South Orkneys. The pattern of catches for Subarea 48.1 was similar for each of the years examined whereas that for Subarea 48.2 changed each year (Figures 3 and 4). In only three years (1987, 1988 and 1991) were the majority of catches in Subarea 48.2 taken within 100 km of colonies during these months.

The years with the greatest fishery impact were 1989 in Subarea 48.1 and 1988 in Subarea 48.2 (Table 3). In these years, the catch within the 21 to 40 km zone was 23 to 27% of the calculated consumption in this zone for the months December to February. The ratio of the total catch in theSubarea in December to March to total consumption for these years was 0.26 for Subarea 48.1 and 0.27 for Subarea 48.2. The greatest impact of the fishery was in Subarea 48.2 in 1991, however, when the catch was equivalent to 45% of the predator consumption (Table 3). In other years and zones the proportionate impact of the fishery was much lower.

4. DISCUSSION

The consistency in the distribution of catches appears to be a feature of the fishery around the South Shetlands, with its pattern of increased fishing intensity to the north of Livingston Island and to the north and west of Elephant Island (Figure 2; see also Everson and Goss, 1991; CCAMLR, 1992). Everson and Goss (1991) have shown that the gross pattern of krill catches in the Scotia Sea is determined by the extent of ice cover; the major fishing effort switches from South Georgia in the winter to the South Orkneys and South Shetlands in the Antarctic summer, following the ice edge as it moves south. Data from Jacka (1983 and pers. comm.) on mean monthly sea ice edge position along longitudes 60°, 50° and 40°W shows that for most of these months and years the South Shetlands and South Orkneys were ice-free, and it is therefore difficult to explain the detailed location of catches with reference to sea-ice distribution. The only time when the ice edge was close to the South Orkneys (50°W to 40°W) was January 1989, and the fishery in this year moved further north, taking place over a bank to the north of the South Orkney Islands around 59°S 44°W. This could explain the major shift in catch positions and the very low catch within 80 km of predator colonies in 1989 (Table 3). However, in general the localised distribution of krill catches cannot be explained by ice distribution.

In Subarea 48.1, krill is known to be generally concentrated to the north of Livingston and Elephant Islands (Nast *et al.*, 1988; Ichii *et al.*, 1991). The main hydrographic phenomenon in the area, the Weddell-Scotia confluence, was implicated by Nast *et al.*, (1988) in producing the hydrographic conditions that brought about persistent concentrations of krill around Elephant Island, although it is not clear how it could influence concentrations further west. Ichii *et al.* (1991) attribute the concentration of krill to the north of Livingston Island to retention in topographic eddies or to active swarming around concentrations of phytoplankton. Hydrographic conditions are much more unstable around the South Orkneys (Sievers and Nowlin, 1987), and the Weddell-Scotia confluence much more variable from year to year and this may account for the high variability in fishing pattern in Subarea 48.2. Reference to Figures 1 and 2 also suggests that the major catches are located over areas of the shelf break and in very steep shelf slopes, at positions where the bottom topography is considerably disturbed; this applies to all three major areas of krill catches, north of Livingston and Elephant Islands and to the west of the South Orkney Islands.

The ratio of catch to natural mortality is important. The assumption that fish (and krill) populations may show their maximum sustainable yield at the point where fishing mortality (catch) equals natural mortality (natural predation) (Gulland, 1971) have been challenged by Beddington and Cooke (1983) who showed through simulations that a 'safe' maximum sustainable yield usually occurs at levels of fishing mortality that are lower than natural mortality. The assumption here is that predator populations are utilising the food resource (krill) at levels of natural mortality that allow the same sorts of ratios of catch to be withstood by the prey stock as in other ecosystems, and that ratios of catch/consumption (ρ in Table 3) that approach 1 indicate a stock that is close to the maximum sustainable exploitation rate, with the implication that these levels will not impact adversely on predator populations.

When calculating the ratio ρ, it is necessary to take into account all potential predators of krill. Inclusion of non-breeding penguins, and crabeater seals (calculated by Croxall *et al.*,

1985 to consume 45% of all krill in the southern Scotia Sea) if they are in the vicinity of predator colonies will decrease the ratio of catch to consumption. Other predators important in the Antarctic as a whole, such as whales, fish and squid (Everson, 1977; Miller and Hampton, 1989) may also be expected to consume krill around the study sites. Details of the consumption by squid and whales is unknown in the area. Commercial fish stocks in Subareas 48.1 and 48.2 have been at low levels for several years, the last significant catches being in the early 1980s (Kock and Köster, 1990; CCAMLR, 1991), and despite their known concentrations in areas of persistent krill occurrence (Nast *et al.*, 1988) are unlikely to be major consumers of krill.

The accuracy of the present estimates of predator consumption may be examined by application of various estimates of natural mortality rates derived from investigations of the demographic parameters of krill to current estimates of total krill biomass. The definition of krill stocks in the Scotia Sea is not yet clear (Miller and Hampton, 1989). However, restricting the calculations to January to March in Subarea 48.1, Siegel (1991) has calculated that the exchange rate of water masses within the subarea means that the population of krill around the South Shetlands will be changed every three months. Based on four years of survey data Siegel calculated that total biomass around the South Shetlands, including productivity during this period, would be about 2 million tonnes each year, and this result is similar to that obtained by Ichii (1991). Siegel and Kalinowski (1991) have reviewed natural mortality estimates for krill, and if it is assumed that $^1/_4$ of the yearly natural mortality of about 0.9 occurs by predator consumption in January to March, then about 400 000 tonnes of the 2 million estimated above should be consumed in this period. The predator consumption calculated in Table 1 of 293 000 tonnes in January to March is only 73% of this estimated total, and therefore ρ may be overestimated.

Whilst the results in Table 3 indicate that for some months and years the catches within the foraging ranges of penguins approached 50% of the estimated consumption, for most years the fishery was much lower than this, even within the critical periods and zones. For the South Shetlands and South Orkneys, an historical upper limit for ρ was calculated as about 0.25 and 0.45. Thus the fishery would have to increase at least three-fold from its current maxima in Subarea 48.1 and twofold in Subarea 48.2 before it approached a theoretical limit of sustainability, and more if other predators were taken into account.

However, the overlap between fisheries and predators would be likely to become critical well before this on local scales, and in particular 20 to 60 km from predator colonies. In addition, it is possible that predators could respond adversely to temporary decreases in krill density, the availability of certain swarm sizes or other factors influenced by fishing operations even though assessments indicate the overall catch of krill to be relatively low. These effects may be offset by the concentration of krill stocks in the areas of highest consumption as observed, for example, by Ichii *et al.* (1991). Whilst there is as yet no evidence that predators are being adversely affected by fishing operations in these areas monitoring for the effects of the fishery on predators should concentrate on this zone.

CCAMLR currently has imposed a precautionary limit of 1.5 million tonnes on the krill catch from Statistical Area 48. Should further regulation be necessary, the consistency of pattern of the Subarea 48.1 fishery (Figure 3) would make definition of time and space for the operation of a management plan that utilised closed areas and seasons, and assessment of the impacts of such a plan on the returns from the fishery, relatively easy to determine. For instance, a closure of a 40 km zone off the coastline of the South Shetlands from December to March would exclude the fishery from about 45% of its traditional catch in Subarea 48.1 (50% [from Figure 3] x 90% [percentage of the catch in Subarea 48.1 taken between December and March from Table 3]). Determination of the impacts of such plans on the fishery around the South Orkneys is less easy because of the unpredictability of this fishery.

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REFERENCES

BEDDINGTON, J.R. and J.G. COOKE. 1983. The potential yield of fish stocks. *FAO Fish. Tech. Pap.*, 242: 47 pp.

CCAMLR. 1990. *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX).* CCAMLR, Hobart, Australia: 345 pp.

CCAMLR. 1991. *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X).* CCAMLR, Hobart, Australia: 427 pp.

CCAMLR. 1992. *Statistical Bulletin*, Vol. 4 (1982-1991). CCAMLR, Hobart, Australia: 133 pp.

CROLL. D.A. 1992. Estimation of the energy and prey requirements of predators breeding on the South Shetland Islands. (In prep.)

CROXALL, J.P., C. RICKETTS and P.A. PRINCE. 1984. The impact of seabirds on marine resources, especially krill, at South Georgia. In: WHITTOW, C.G. and H. RAHN (Eds). *Seabird Energetics.* Plenum: 285-318.

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.* Springer-Verlag, Berlin: 516-533.

EDWARDS, D.M. and J.A. HEAP. 1981. Convention on the Conservation of Antarctic Marine Living Resources: a commentary. *Polar Record*, 20 (127): 353-362.

EVERSON, I. 1987. Prey monitoring surveys. A discussion of the characteristics necessary in prey surveys. In: *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4).* CCAMLR, Hobart, Australia: 375-391.

EVERSON, I. and C. GOSS. 1989. Krill fishing activity in the southwest atlantic. *Antarctic Science*, 3 (4): 351-358.

EVERSON, I. 1977. The living resources of the Southern Ocean. Southern Ocearn Fisheries Programme. FAO Document GLO/SO/77/1: 156 pp.

GULLAND, J.A. 1971. The fish resources of the ocean. *FAO Fish. Tech. Pap.*, 97: 425 pp.

ICHII, T., H. ISHII and M. NAGANOBU. 1991. Krill (*Euphausia superba*) distribution in relation to water movement and phytoplankton distribution off the northern South Shetland Islands. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 123-140.

JACKA, T.H. 1983. A computer data base for Antarctic sea ice extent. *Anare Research Notes*, 13.

KOCK, K.-H. and F.W. KÖSTER. 1990. The state of exploited fish stocks in the Atlantic Sector of the Southern Ocean. In: KERRY, K.R. and G. HEMPEL (Eds). *Antarctic Ecosystems. Ecological Change and Conservation.* Springer-Verlag, Berlin Heidelberg: 308-322.

LISHMAN, G.S. 1985. The food and feeding ecology of Adélie and chinstrap penguins at Signy Island, South Orkney Islands. *J. Zool. Lond.*, 205: 245-263

MILLER, D.G.M. and I. HAMPTON. 1989. Biology and ecology of the Antarctic krill (*Euphausia superba* Dana): a review. *BIOMASS Scientific Series*, 9.

MILLER, D.G.M. 1989. Commercial krill fisheries in the Antarctic 1973 to 1988. In: *Selected Scientific Papers, 1989 (SC-CAMLR-SSP/6).* CCAMLR, Hobart, Australia: 229-282.

NAST, F., K.-H. KOCK, D. SAHRHAGE, M. STEIN and J.E. TIEDTKE. 1988. Hydrography, Krill and Fish and their possible relationships around Elephant Island. In: SEIGFRIED, W.R., P.R. CONDY and R.M. LAWS (Eds). *Antarctic Nutrient Cycles and Food Webs.* Springer-Verlag, Berlin: 183-198.

SADLEIR, R.M. and K.M. LAY. 1990. Foraging movements of Adélie penguins (*Pygoscelis adeliae*) in McMurdo sound. In: DAVIS, L.S. and J.T. DARBY (Eds). *Penguin Biology.* Academic Press: 157-180.

SC-CAMLR. 1991. *CCAMLR Ecosystem Monitoring Program: Standard Methods for Monitoring Studies.* CCAMLR, Hobart, Australia.

SIEGEL, V. 1991. Estimation of krill (*Euphausia superba*) mortality and production rate in the Antarctic Peninsula region. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 159-176.

SIEGEL, V. and J. KALINOWSKI. 1991. Krill demography and small scale processes - a review. *Polar Biology* (in press).

SIEVERS, W.D. and W.D. NOWLIN, JR. 1988. Upper ocean characteristics in Drake Passage and adjoining areas of the Southern Ocean, 39°W to 95°W. In: SAHRHAGE D. (Ed.). *Antarctic Ocean and Resources Variability.* Springer-Verlag, Berlin: 57-80.

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 radiotelemetry 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.

WOEHLER, E.J. (Ed.). In press. *The Distribution and Abundance of Antarctic and Sub-Antarctic Penguins.* SCAR, Cambridge.

Table 1: Subarea 48.1. Krill catch and predator consumption from December to March at various distances from penguin colonies. Catches are estimated from CCAMLR (1992).

Distance from colonies	Catches by Year, December to March				Predator Consumption				
	1988	1989	1990	1991	DEC	JAN	FEB	MAR	Total
0-20	8206	10890	4318	10551	26357	35263	32117	30664	124401
21-40	21415	32819	13031	17613	24652	32956	32810	28658	119076
41-60	23070	30383	9744	14526	24652	32956	32810	28658	119076
61-80	8594	14477	6559	4117	1121	1121	975	975	4192
81-100	5008	6311	3989	1632					
101-120	23	1410	266	158					
121-140	549	291	25	128					
141-160	667	113	4	29					
161-180	949	47	4	10					
181-200	117	9	0	1					
Total	68598	96750	37940	48765	76782	102296	98712	88955	366745
Total in Subarea	68848	96798	37941	49159					

Table 2: Subarea 48.2. Krill catch and predator consumption from December to March at various distances from penguin colonies. Catches are estimated from CCAMLR (1992).

Distance from colonies	Catches by Year, December to March					Predator Consumption				
	1987	1988	1989	1990	1991	DEC	JAN	FEB	MAR	Total
0-20	696	13636	83	347	7219	14430	17563	16655	13522	62170
21-40	3449	14063	744	3125	28970	13866	16830	15921	12957	59574
41-60	5146	10441	1715	6666	33031	13866	16830	15921	12957	59574
61-80	4509	2019	3833	12292	18020	3948	3948	3040	3040	13976
81-100	1965	11482	6414	18125	917					
101-120	1632	1282	6005	28890	33					
121-140	203	34	1919	14862	11					
141-160	328	27	1497	4584	4					
161-180	120	12	1918	0	2					
181-200	23	4	11963	0	1					
Total	18071	53000	36091	88891	88208	46110	55171	51537	42476	195294
Total in Subarea	18103	53004	78254	88890	88211					

Table 3: Catch of krill in the subarea and in the critical period-distance (CPD, defined as 100 km from colonies from December to March inclusive). The percentage of the total catch in the subarea for the year which is caught in the CPD is given, together with the catch as a percentage of total krill demand for December to March (predators + the fishery) which is caught in the CPD. Data from CCAMLR (1992).

Year	Total Catch in Subarea for the Year	Catch in Subarea from December to March	Catch within the CPD	Percentage of Yearly Catch Within the CPD	CPD Catch as % of Estimated Predator Consumption (ρ-see text)	CPD Catch as % of Estimated Total Demand (predators and fishery)
Subarea 48.1						
1988	78918	68848	66292	84.0	17.9	15.2
1989	105554	96798	94880	89.9	25.7	20.4
1990	42477	37941	37642	88.6	10.2	9.2
1991	64641	47948	48440	74.9	13.1	11.6
Subarea 48.2						
1987	19902	18102	15765	79.2	8.1	7.5
1988	94659	53003	51641	54.6	26.4	20.9
1989	82406	78253	12789	15.5	6.5	6.1
1990	220518	88890	40555	18.4	20.8	17.2
1991	167257	88211	88158	52.7	45.1	31.1

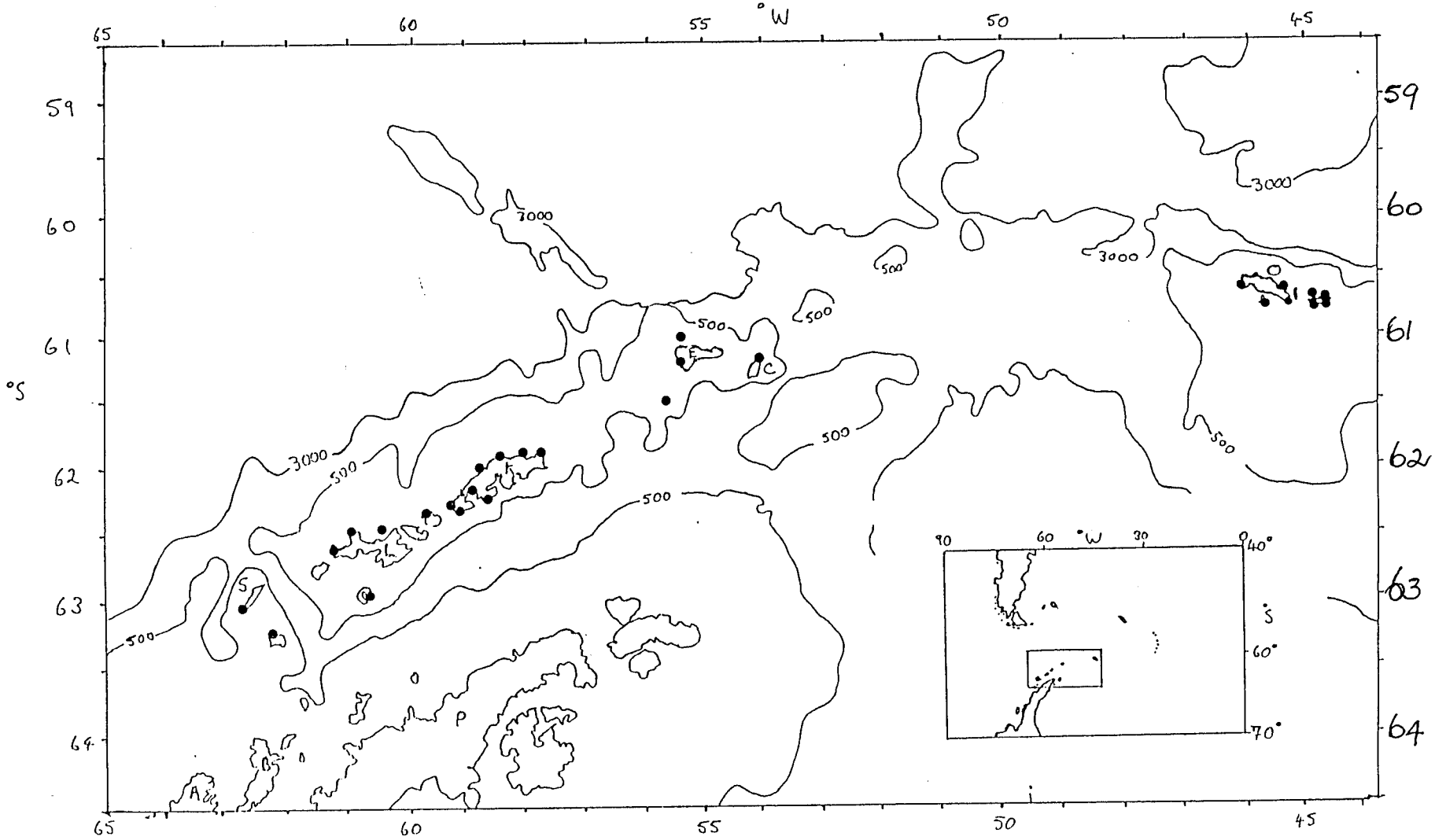


Figure 1: Map showing the study area in the south Scotia Sea. Colonies selected for determination of zones (see text) (o) and 500 and 3 000 m depth contours (start and end of the continental slope are shown. A = Anvers Island, B = Brabant Island, L = Livingston Island, K = King George Island, E = Elephant Island, C = Clarence Island, S = Smith Island, O = South Orkney Islands group, P = Antarctic Peninsula. The islands from S to C form the South Shetland Islands group.

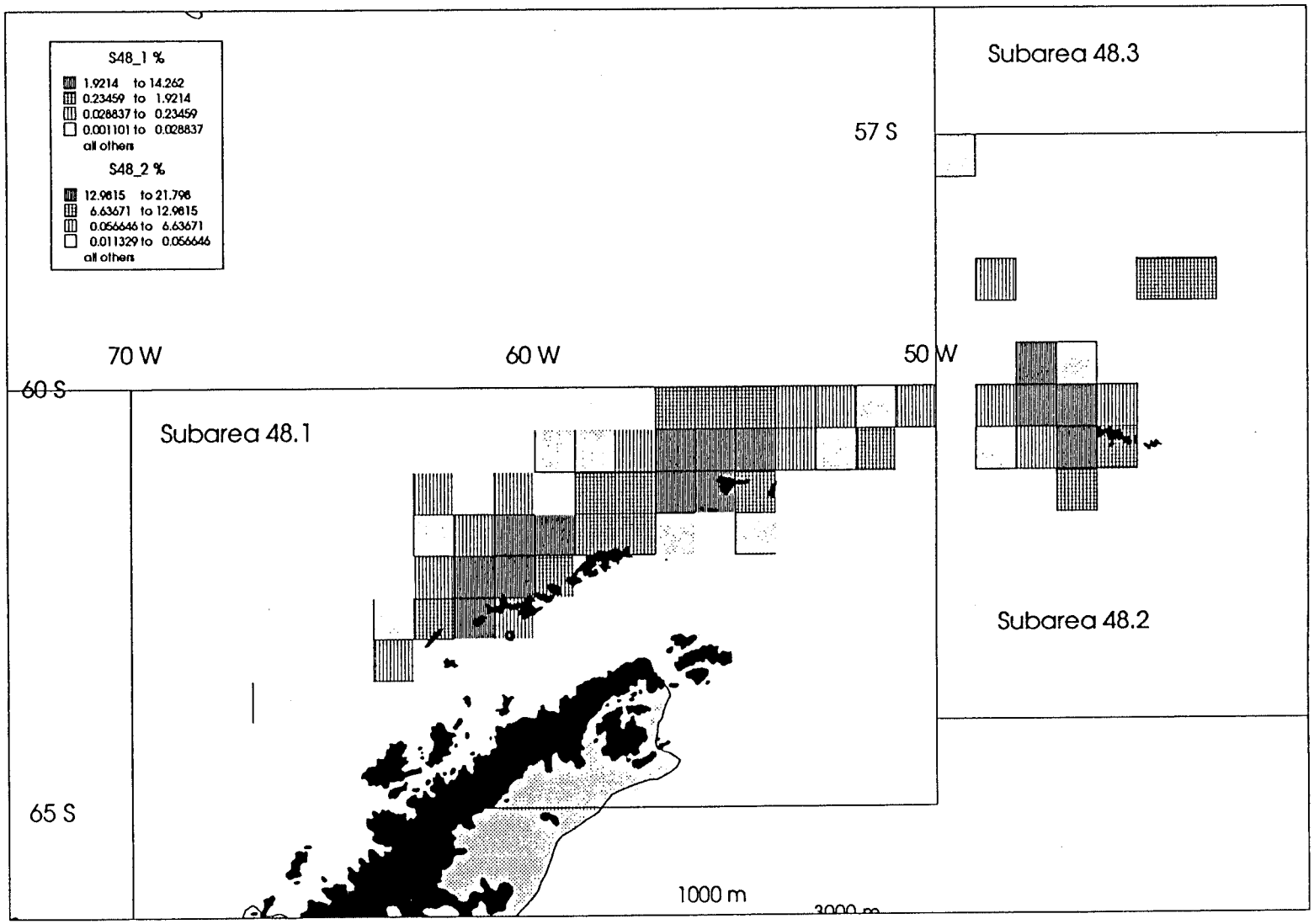


Figure 2: Estimated distribution of catches from January to March over the period 1988 to 1991. Catches are given as a percentage of total catch in January to March. The analysis is separated for Subareas 48.1 and 48.2.

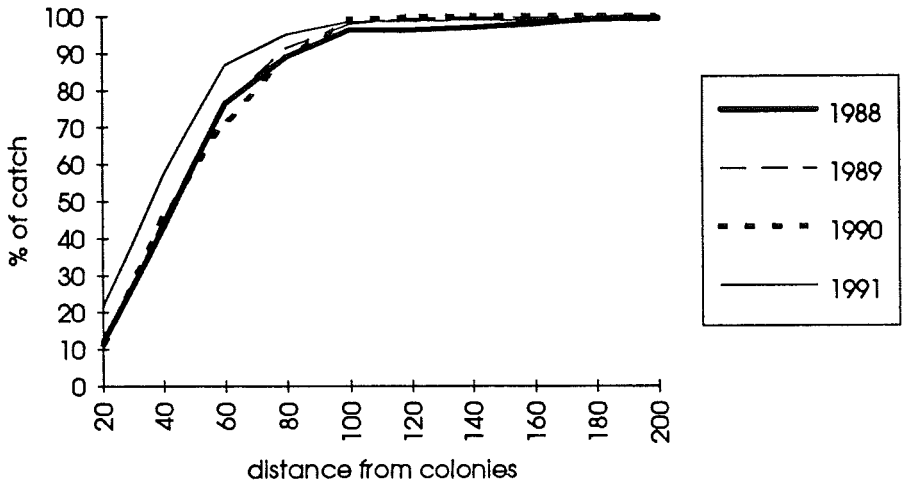
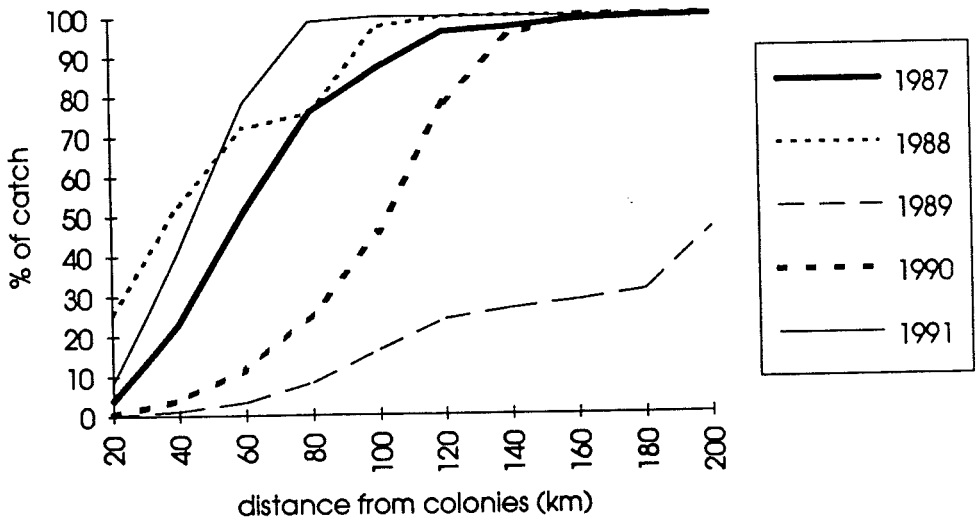


Figure 3: Catches of krill in relation to distance from penguin colonies in the South Shetland Islands, expressed as a percentage of the total krill catch in Subarea 48.1, over the months December to March.



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LOCATION AND INTENSITY OF THE SOVIET KRILL FISHERY IN THE ELEPHANT ISLAND AREA (SOUTH SHETLAND ISLANDS), 1988/89

V.A. Sushin and A.S. Myskov*

Abstract

This paper analyses fine-scale data from the Soviet krill fishery off Elephant Island (Subarea 48.1) between 59°-62°S and 53°-57°W during the period from 21 November 1988 to 25 March 1989. Although the total catch of the USSR in this season reached a maximum, for the last nine seasons the total fishing intensity by the USSR around Elephant Island has been low. In 1988/89 only one standard fishing vessel operated in the area over 40% of the time. The highest catch-per-unit-effort was observed in January 1989 (7.7 tonnes per hour of trawling on average), and the lowest in November 1988 (3.5 tonnes per hour of trawling on average). Fishing strategy in the Elephant Island area conforms to the following simple pattern: (i) vessels enter the island near-shore zone (north of Elephant Island) and start searching for krill concentrations; (ii) krill concentrations are fished and followed as they drift from the island with the current; and (iii) vessels return to position (i) when aggregations are dispersed or lost due to storms and other factors. The velocity of the northeast drift of krill concentrations, calculated on the basis of vessel relocation, was from 9.7 to 11.1 km/day (11 to 13 cm/sec). An analysis of the location of fishing grounds by five-day periods showed that the areas in which the fleet operated overlap a minor part of the foraging zones of krill predators. Based on this, and taking into account the low fishing intensity, it was concluded that the current krill fishery does not significantly affect krill-eating seals and birds.

Résumé

Analyse des données à une échelle très précise sur la pêche soviétique de krill effectuée au large de l'île Eléphant (sous-zone 48.1) entre 59-62°S et 53-57°W durant la période comprise entre le 21 novembre 1988 et le 25 mars 1989. Bien que la capture totale de l'URSS pendant cette saison ci-dessus ait atteint un maximum, l'intensité de pêche totale de l'URSS autour de l'île Eléphant a été faible ces neuf dernières saisons. En 1988/89, un seul navire standard de pêche menait des opérations de pêche dans le secteur pendant 40% de la période. La capture par unité d'effort la plus élevée était observée en janvier (en moyenne, 7,7 tonnes par heure de chalutage), et la plus faible en novembre (en moyenne, 3,5 tonnes par heure de chalutage). La stratégie de pêche dans le secteur de l'île Eléphant suit le simple schéma suivant: (i) les navires entrent dans la zone de l'île proche du littoral (au nord de l'île Eléphant) et commencent à rechercher les concentrations pêchables de krill; (ii) ils exploitent ces concentrations en les suivant alors qu'elles s'éloignent de l'île à la dérive du fil de l'eau; (iii) les navires retournent à la première zone de recherche lorsqu'ils ont perdu la trace des concentrations par suite d'orages et d'autres facteurs, ou lorsque les

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concentrations se sont dispersées. La vitesse de la dérive des concentrations de krill vers le nord-est, calculée à partir des déplacements des navires, variait de 9,7 à 11,1 km/jour (de 11 à 13 cm/sec). Une analyse de la répartition des lieux de pêche par période de cinq jours a révélé que les secteurs d'opération de la flotte empiétait sur une partie peu importante des secteurs d'alimentation des prédateurs de krill. A partir de ces résultats, et compte tenu de la faible intensité de la pêche, il a été déduit que la pêcherie actuelle de krill n'affecte pas de manière significative les phoques et les oiseaux qui s'alimentent de krill.

Резюме

В настоящей работе анализируются мелкомасштабные данные по советскому промыслу криля около о-ва Элефант (Подрайон 48.1) между 59°- 62°ш. и 53°-57°р.д. за период с 21ноября 1988 г. по 25 марта 1989 г. Несмотря на то, что общий вылов СССР за вышеупомянутый сезон достиг максимума, за последние девять сезонов общая промысловая интенсивность СССР в районе о-ва Элефант была низкой. В 1988/89 г. лишь одно стандартное промысловое судно работало в этом районе в течение 40% данного периода. Наивысшая величина СЗГУ наблюдалась в январе (7,7 тонны за час траления в среднем), а наименьшая - в ноябре (3,5 тонны за час траления в среднем). Промысловая тактика сводится к следующей простой схеме: (i) суда входят в прибрежную зону (к северу от о-ва Элефант) и начинают разыскивать концентрации криля; (ii) эти концентрации облавливаются по пути их дрейфа от острова; и (iii) суда возвращаются в район первоначального поиска когда концентрации теряются в результате штормов и прочих факторов. Скорость северовосточного дрейфа концентраций криля, вычисленная по перемещению судов, составила 9,7 - 11,1 км/день (11 - 13 см/секунду). Анализ местоположения промысловых участков по пятидневным периодам указал на частичное совпадение незначительной части нагульных ареалов питающихся крилем животных и районов ведения промысла. В связи с этим и приняв во внимание низкую интенсивность промысла, мы пришли к заключению, что промысел криля в настоящее время не оказывает значительного влияния на питающихся крилем тюленей и птиц.

Resumen

Este documento analiza los datos de microescala obtenidos durante el período del 21 de noviembre de 1988 al 25 de marzo de 1989 de la pesquería de kril soviética, realizada a la altura de la isla Elefante (Subárea 48.1) entre 59° a 62°S y 53° a 57°W. Aunque la captura total de la URSS alcanzó un máximo durante esta temporada, la intensidad de pesca total de este país alrededor de la isla Elefante en las últimas nueve temporadas ha sido baja. En 1988/89 sólo un buque pesquero estándar faenó en esta zona durante el 40% de este período. En enero se registró la captura por unidad de esfuerzo más alta (un promedio de 7.7 toneladas por hora de arrastre), y en noviembre la más baja (un promedio de 3.5 toneladas por hora de arrastre). Las tácticas pesqueras

en la zona de la isla Elefante se ciñen al siguiente régimen: (i) los buques entran a la zona costera de la isla (al norte de la isla Elefante) e inician la búsqueda de concentaciones de kril; (ii) comienzan la pesca de estas concentraciones, y se desplazan juntamente con éstas, alejándose de la isla ayudados por la corriente; y (iii) regresan a la posición (i) cuando las concentraciones se dispersan o se pierden debido a las tormentas u otros factores. La velocidad del desplazamiento noreste de las concentraciones, calculada según la nueva posición del buque, fluctuó entre 9.7 a 11.1 km/día (11 a 13 cm/seg). El análisis de la asignación de los caladeros de pesca por períodos de cinco días demostró que las zonas en que faena la flota coincide solo en una pequeña parte de las zonas de alimentación de los animales krilógrafos. Basado en esto, y tomando en cuenta la baja intensidad de pesca, se concluyó que la pesquería actual de kril no afecta significativamente a las aves y focas que se alimentan de éste.

1. INTRODUCTION

One of the tasks of the Working Group on Krill (WG-Krill) is to analyse the operation of the krill fishery, including catch size and fishing area locations. The results of such analyses are important in developing measures for managing the krill fishery within the framework of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). The information obtained may be useful for stock identification, studying krill drift in fishing areas, and assessing the potential effect of the krill fishery on other ecosystem components (Marín *et al.*, 1991). Such information also provides a better understanding of strategies employed in the krill fishery by various nations. This document presents the preliminary results of an analysis of Soviet fishing fleet's activities around Elephant Island (Subarea 48.1) in the 1988/89 season. An attempt was made to interpret available data in relation to fishing regimes, krill flux from Elephant Island to the South Orkney Islands, and the potential effect of the fishery on krill-dependent predators in the Elephant Island area.

2. MATERIAL AND METHODS

The source information was obtained from commercial vessels (Komarevtsev, 1989) and vessels' log books (where available).

The following data were extracted from this information and stored as a computer database:

- date, time and haul duration;
- coordinates at start of haul;
- vessel course and towing speed;
- haul depth; and
- catch per haul.

At present the database consists of information on 1 200 hauls. This constitutes some 70 to 90% of the total number of hauls made by the Soviet fleet in the area during the 1988/89 fishing season (Komarevtsev, pers. comm.).

Fishing activity was analysed using methods developed in AtlantNIRO (Kadylnikov, 1985). The BMRT vessel of the *Grumant* class with a 78/420 m trawl was taken to be the standard fishing unit. It yielded the highest total catch of all vessels engaged in the fishery.

Calculations and mapping of fishing areas were made with an EC-1046 computer, using the STARTOP and STARTK programs developed by AtlantNIRO.

The starting co-ordinates of each haul were shown on the maps attached (Figures 1 to 8).

3. RESULTS

Summary results of the Soviet krill fishery in the Elephant Island area (Subarea 48.1) in 1988/89 are given in Table 1.

The information in Table 7 demonstrates that the krill fishery was variable in terms of the number of vessels operating and their fishing efficiency. Over 40% of the time the average number of vessels fishing was one to two (standard fishing units) with a maximum of seven vessels during one five-day period.

Catch-per-day fished and catch-per-hour of fishing by a standard vessel by month were highest in January 1989. The number of fishing hours-per-day was about 12 hours, while in other months it was close to 15 hours. In February/March catch-per-day fished decreased from 85-90 tonnes to 50 tonnes. This may have been due to vessels moving to other areas where the fleet's catching efficiency increased considerably.

The locations of fishing grounds from November 1988 to March 1989 are shown in Figures 1 to 5.

In November 1988, the fishery was concentrated within one small area northeast of Elephant Island between 60°-60°30'S and 54°-55°W.

In December 1988, krill was targetted in a larger area within the broad zone from Elephant Island to 59°S.

In January 1989, vessels worked in three main areas. The first and most remote area to the northeast of Elephant Island between 59°45'-60°15'S and 53°-54°15'W, the second one to the north of Seal Island between 60°-60°30'S and 55°-56°00'W and the third one located to the west of Elephant Island in the area between 61°-61°30'S and 56°-57°W.

In February and March 1989 the fishery was carried out mainly in one area to the north of Seal Island, almost in the same area as in January 1989. Compared with February, in March the fishing area extended further east to 54°30'W.

Figures 6a to 6f show the locations of fishing grounds by five-day period in December 1988 and January and February 1989 (i.e., in months critical for the breeding populations of penguins and seals).

During the first five days of December 1988 (Figure 6a) the area 60° to 61°S was the main fishing ground, moreover most hauls were carried out in the small "patch" northeast of Elephant Island between 60°-60°15' and 54°10'-54°45'W.

After the second five-day period, the fleet gradually moved northeast (Figures 6b and 6c). In the fourth five-day period vessels operated at a considerable distance from Elephant Island in the northeast corner of the area (Figure 6d) and then moved south. In the last five-day period of December most vessels worked in two groups, and in the area far from Elephant Island, 59°30'-60°30'S and 53°-54°W (Figure 6f).

Early in January 1989 some vessels moved closer to Elephant Island and operated in two fishing grounds (Figures 7a to 7f). The first one, fished throughout the month, was located to the north of Seal Island between 60°30'-61°S and 55°-56°W. The second one was to the west

of Elephant Island between 61°-61°30'S and 56°-57°W, where vessels fished only during the second five-day period. The remote area northeast of Elephant Island (53°-54°30'S and 59°30'-60°30'W) was the main fishing ground in the first half of January 1989.

In the next five-day period vessels started to leave the study area one by one and in the last ten days of January 1989 fishing in the area had ceased (Figure 7f).

Early in February 1989, krill fishing in the study area resumed and was carried out at low fishing effort within the coastal zone between 60°45'-61°S and 55°10'-55°45'W. Fishing then ceased until early in the fifth five-day period (Figures 8a to 8c). When the fishery resumed in the fifth five-day period, this area became the major fishing ground until the end of February 1989 (Figures 8d and 8e).

4. DISCUSSION

The data presented reveal significant instability in the location of fishing grounds within the study area over the period concerned, particularly in December 1988 and January 1989. Some regularities were noted, however, such as the existence of two general directions of vessel movement relocation during the season: to the northeast of Elephant Island and from the east and northeast towards the island.

The first one was most apparent in December 1988 (Figures 6a to 6d) and was probably related to the direction of the krill flux. The direction of krill flux follows the current direction in the area.

Relocation of vessels in the opposite direction towards Elephant Island was most evident in the first five days of January and February 1989 (Figures 7a and 8a). It is unlikely that movement in this direction is related to krill migrations because krill, in this case, should move upstream. It is more probable that the relocation of fishing vessels had resulted from searching for previously known locations of krill concentrations.

Fishing strategy in the Elephant Island areas conforms to the following pattern:

(i) vessels enter the Elephant Island area and start searching for krill concentrations;

(ii) fishing is targetted on these concentrations and vessels follow these concentrations as they drift from the island; and

(iii) if the targetted concentrations are lost due to storm or other circumstances, vessels return to the area where krill concentrations were initially found.

This strategy has been commonly used by Soviet vessels operating in Statistical Area 48. As a rule, early in the season (November) one or two vessels enter the Elephant Island area and start searching for krill concentrations.

Assuming that the relocation of fishing vessels to the northeast of Elephant Island follows the drift of krill concentrations, it is possible to calculate the velocity of the latter. Krill aggregations drifted northeast for about 105 to 120 n miles (194 to 222 km) from 1 to 20 December 1988 (Figures 6a to 6d). Thus, the average krill drift velocity would be from 9.7 to 11.1 km/day or 11 to 13 cm/sec. The value obtained is within the range determined by WG-Krill in 1991 (SC-CAMLR, 1991 - Annex 5, Table 1).

Although the Soviet catch from Subarea 48.1 during the season discussed was the highest one for the last nine seasons and amounted to 20.9 thousand tonnes (CCAMLR, 1991 - Table 7.2; SC-CAMLR, 1991), fishery intensity was low. Data in Table 1 show that during the

period critical for the survival of krill-dependent predators from December to March (SC-CAMLR, 1990 - Annex 4, Table 3), fishing effort never exceeded 1.0 vessel/day, i.e. only one vessel had permanently worked in the area from 16 January to 20 February.

Comparison of the distribution of fishing grounds with the location of krill predator foraging zones (during the periods when fishing effort exceeds 1.0 vessel/day*) showed that they do overlap, although not always entirely. Thus, in the second half of December, the Soviet krill fishery moved out of the 50 km foraging zone. The vessels worked only in the northeastern part of the 100 km zone (Figure 6). During the first half of January the majority of vessels also operated in the northeastern part of the 100 km zone, while in the 50 km zone they were dispersed and only sometimes (the second five-day period of January) covered up to one-third of the area (Figure 7b). The highest density of vessels within the 50 km zone was observed from the end of February (Figures 8d and 8e). However, the fishing effort applied in the 50 km zone off Elephant Island was within the range of 13.7 to 25.1 vessel/days per five-day period at the end of February to March 1989. Such a level of fishing effort would hardly have any impact on predator populations.

According to the latest calculation the amount of krill caught in the nearshore zone of Subarea 48.1 at the current rate is comparable with the total amount of krill consumed by predators inhabiting the area. However, at present there is no evidence of the fishery having a negative impact on the populations of krill-eating birds and seals as krill biomass is sufficiently high in the area (Agnew, 1991).

The survey of fishing ground locations and fishing intensity supports the assumption that krill predators always have a sufficient amount of krill for feeding outside commercial fishing grounds.

REFERENCES

AGNEW, D. 1991. Krill catches and consumption by land-based predators in relation to distance from colonies of penguins and seals in the South Shetlands and South Orkneys. Document *WG-CEMP-91/25*. CCAMLR, Hobart, Australia.

CCAMLR. 1991. *Statistical Bulletin,* Vol. 3 (1981-1990). CCAMLR, Hobart, Australia.

KADILNIKOV, Yu.V. 1985. Catch intensity calculated from actual fishing effort data from trawler fleet. Methodical Recommendations. AtlantNIRO, Kaliningrad: 88 pp. (In Russian.)

KOMAREVTSEV, B.I. 1989. Experience in application of information system in the Western Basin. In: *Principles of fishery predicting system.* Trudy AtlantNIRO, Kaliningrad. (In Russian.)

MARIN, V.H., A. MUJICA and P. EBERHARD. 1991. Chilean krill fishery: analysis of the 1991 season. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 273-287.

SC-CAMLR. 1990. *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX).* CCAMLR, Hobart, Australia.

SC-CAMLR. 1991. *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X).* CCAMLR, Hobart, Australia.

* Foraging zones of krill predators are marked by circles in the figures; the centres of the two most densely populated predator colonies in the area (Seal Island and Point Lindsey at Elephant Island) were used to mark foraging zones (Agnew, 1991). The large circle (radius of 100 km) outlines the outer boundary of the seal foraging zone and the small one (radius of 50 km) outlines the outer boundary of the bird foraging zone (SC-CAMLR, 1990 - Annex 4, Table 3).

Table 1: Summary of Soviet commercial krill fishery in the Elephant Island area in 1988/89 (standard vessel - BMRT *Grumant*).

Period	Total Catch (tonnes)	Number of Days Fished	Catch-per-Day Fished (tonnes)	Catch-per-Hour Trawling (tonnes/hour)
1988:				
21 to 25 November	333	6.6	50.4	3.60
26 to 30 November	1 636	29.4	55.6	3.50
Total for November	1969	36.2	54.4	3.50
1 to 5 December	1 548	18.9	81.9	4.67
6 to 12 December	764	7.5	101.9	5.30
11 to 15 December	608	5.3	83.3	4.85
16 to 20 December	1 537	20.0	76.9	5.40
21 to 25 December	1 091	12.2	89.4	5.55
26 to 31 December	1 874	16.6	112.9	9.01
Total for December	7 422	90.1	82.4	5.70
1989:				
1 to 5 January	2 900	38.5	75.3	4.74
6 to 10 January	1 707	20.9	81.7	6.41
11 to 15 January	664	7.4	89.7	7.45
16 to 20 January	368	1.5	245.3	22.30
21 to 25 January	158	1.0	158.0	15.50
26 to 31 January	209	1.0	209.0	15.40
Total for January	6006	66.4	90.5	7.74
1 to 5 February	310	3.5	88.6	5.10
6 to 10 February	598	3.9	153.3	6.54
11 to 15 February	-	-	-	-
16 to 20 February	84	1.0	84.0	15.24
21 to 25 February	1 935	22.9	84.5	5.56
26 to 28 February	1 244	15.1	82.4	5.28
Total for February	4 171	48.2	86.5	5.63
1 to 5 March	1 658	25.1	66.1	3.91
6 to 10 March	2 346	24.6	95.4	6.14
11 to 15 March	1 726	19.0	90.8	5.28
16 to 20 March	965	13.7	70.4	5.40
21 to 25 March	706	14.0	50.4	3.95
Total for March	7 401	95.1	77.8	5.07

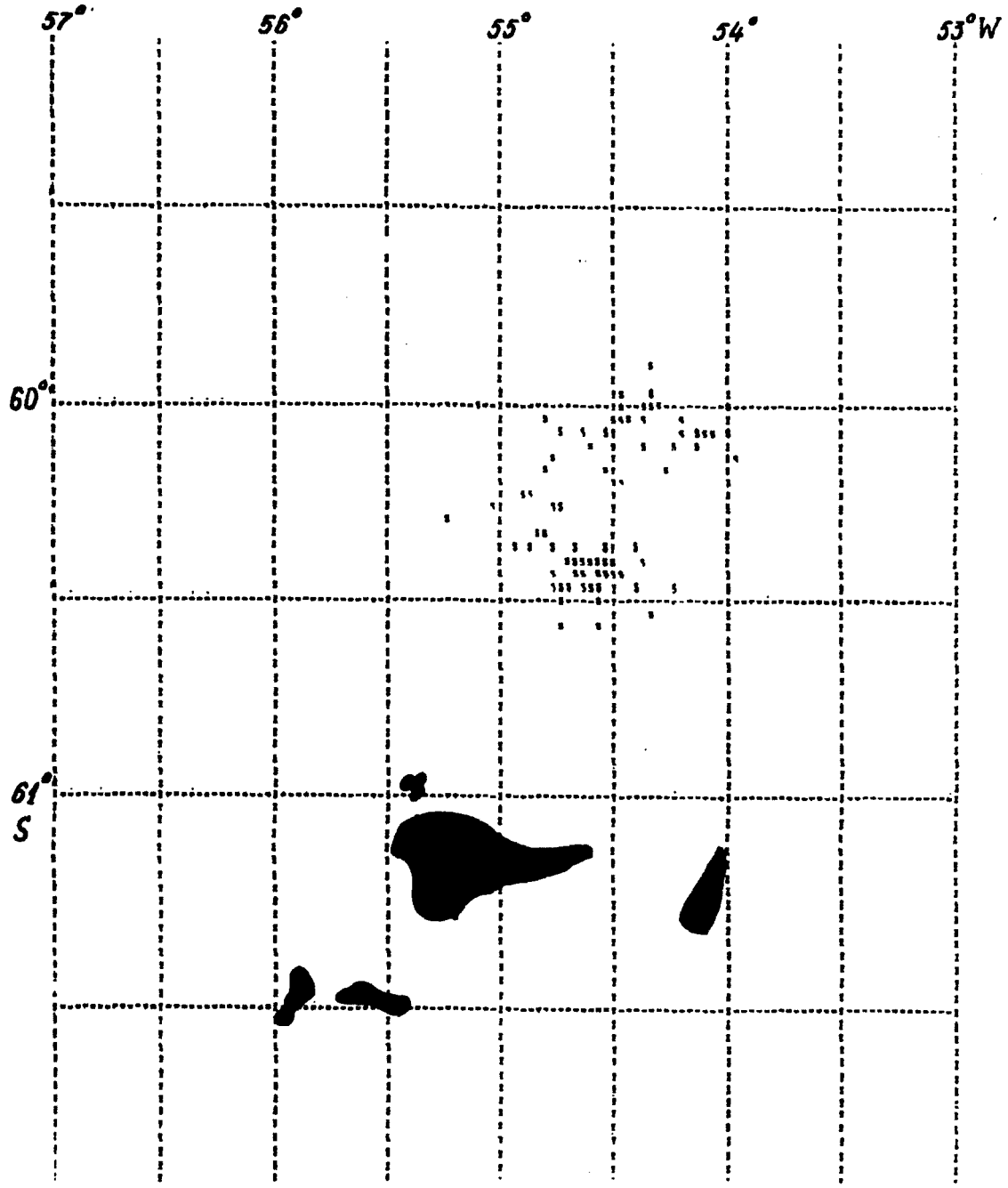

Figure 1: Krill fishery location from 21 to 30 November 1988 (here and elsewhere the haul locations are shown by the starting coordinates).

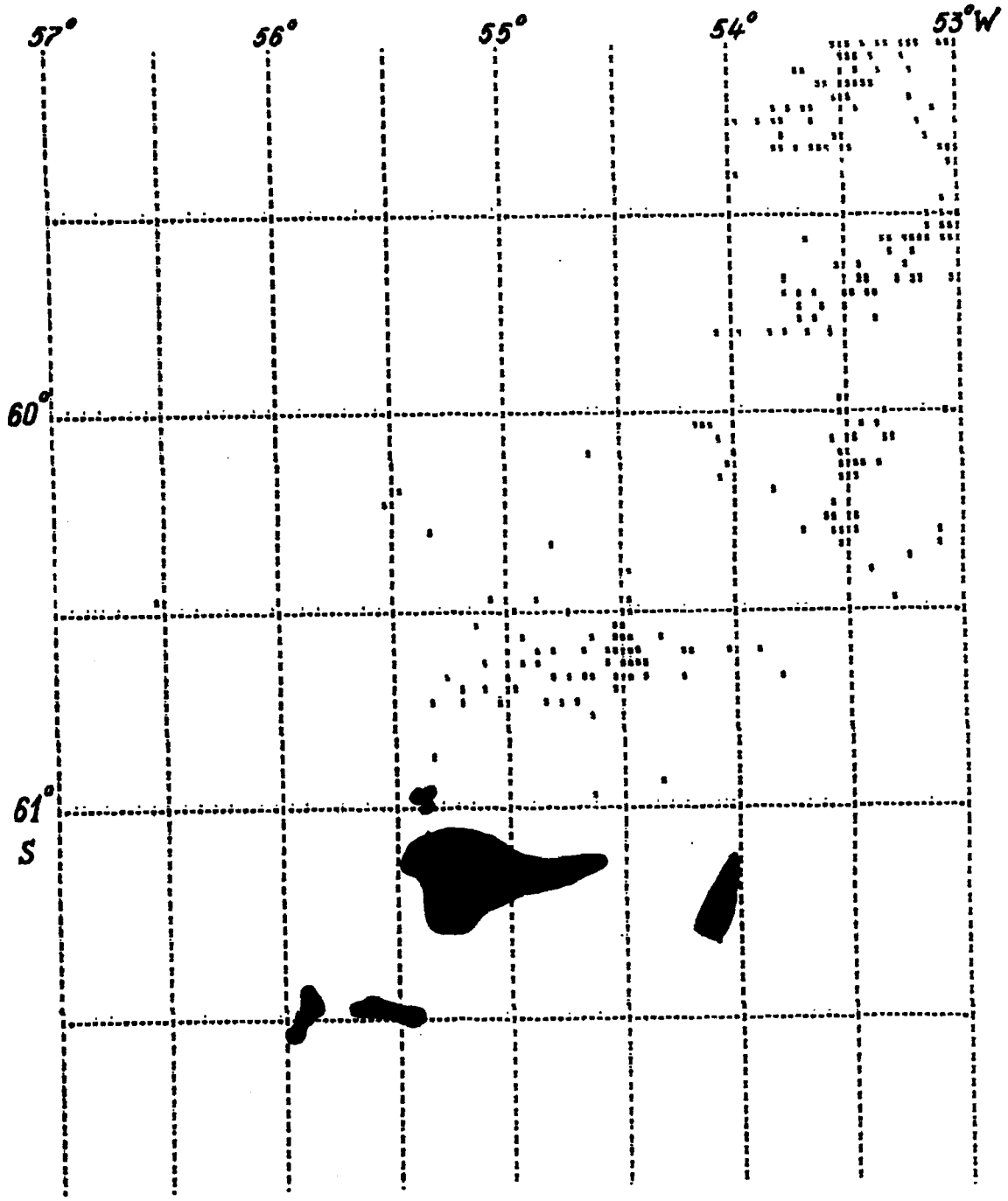

Figure 2: Krill fishery location from 1 to 31 December 1988.

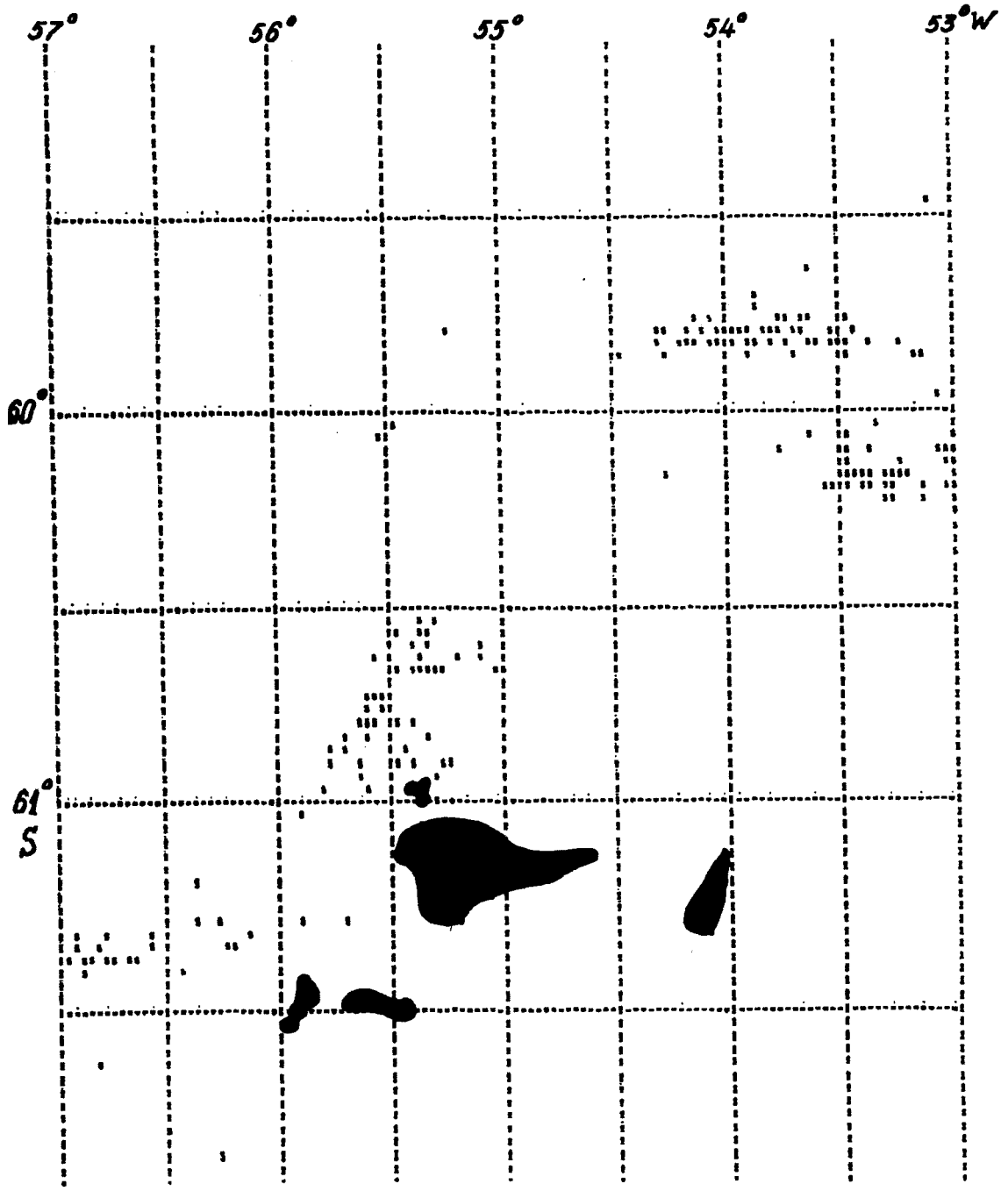

Figure 3: Krill fishery location from 1 to 31 January 1989.

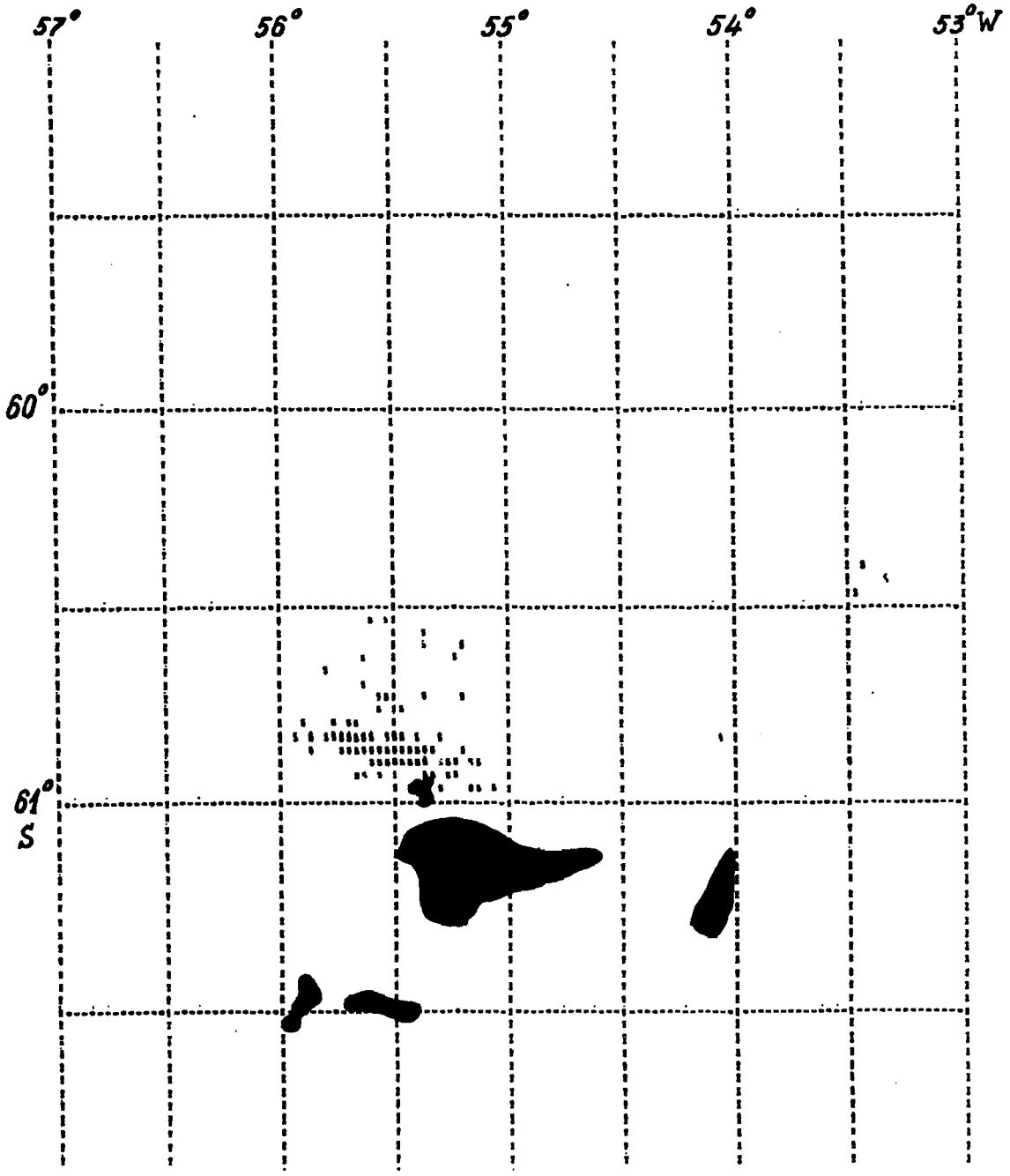

Figure 4: Krill fishery location from 1 to 28 February 1989.

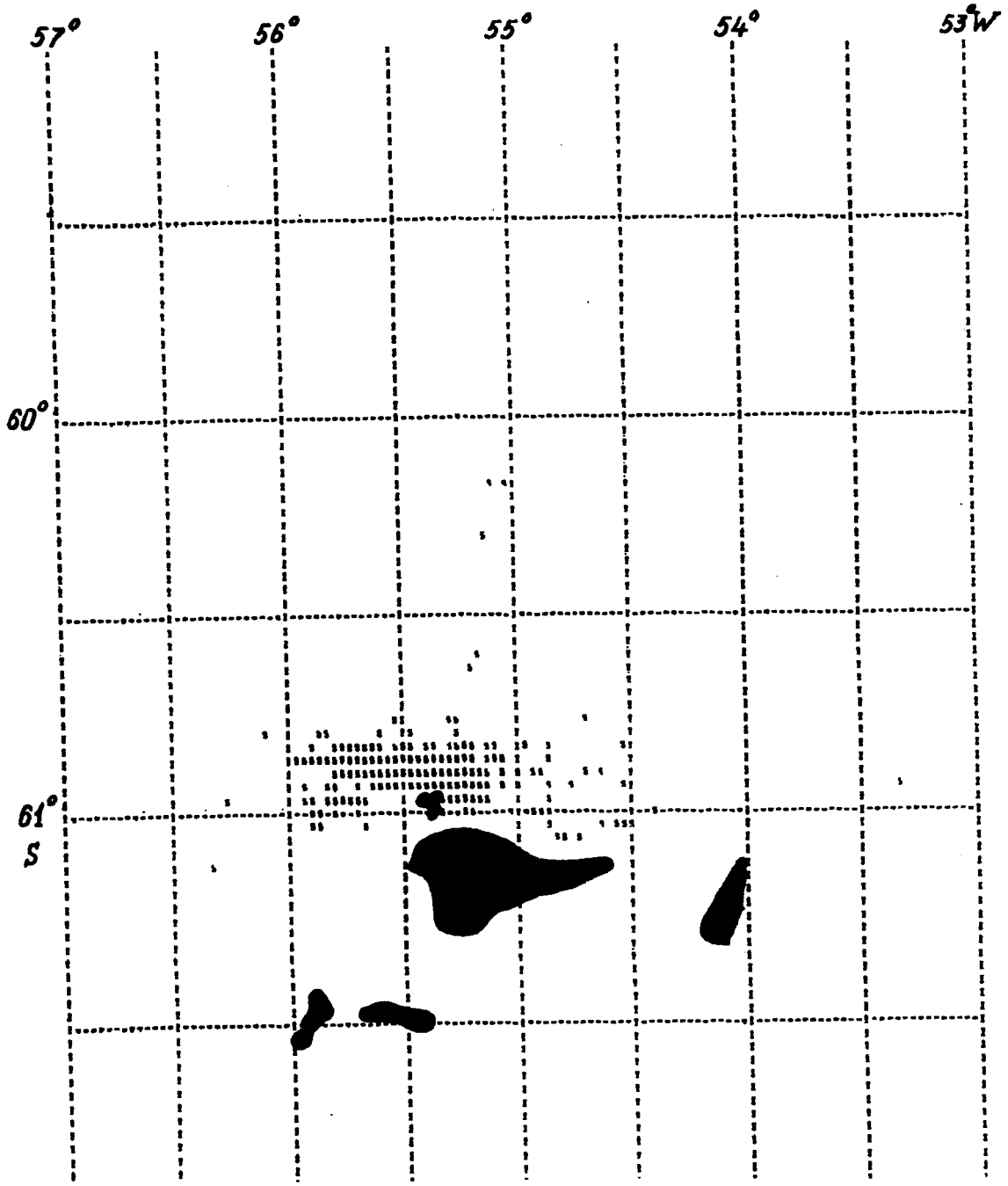

Figure 5: Krill fishery location from 1 to 25 March 1989.

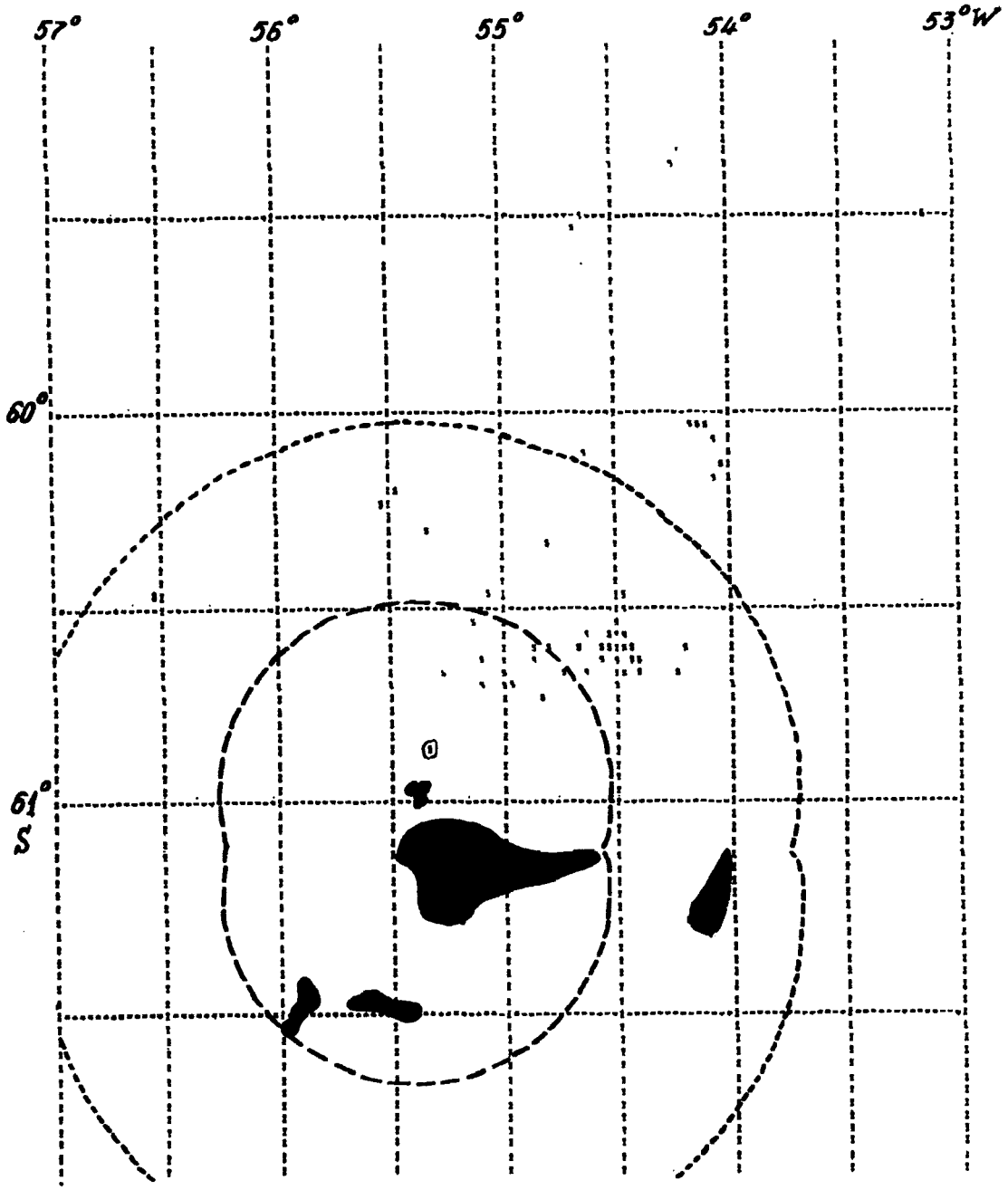

Figure 6a: Krill fishery location by five-day periods from 1 to 5 December 1988.

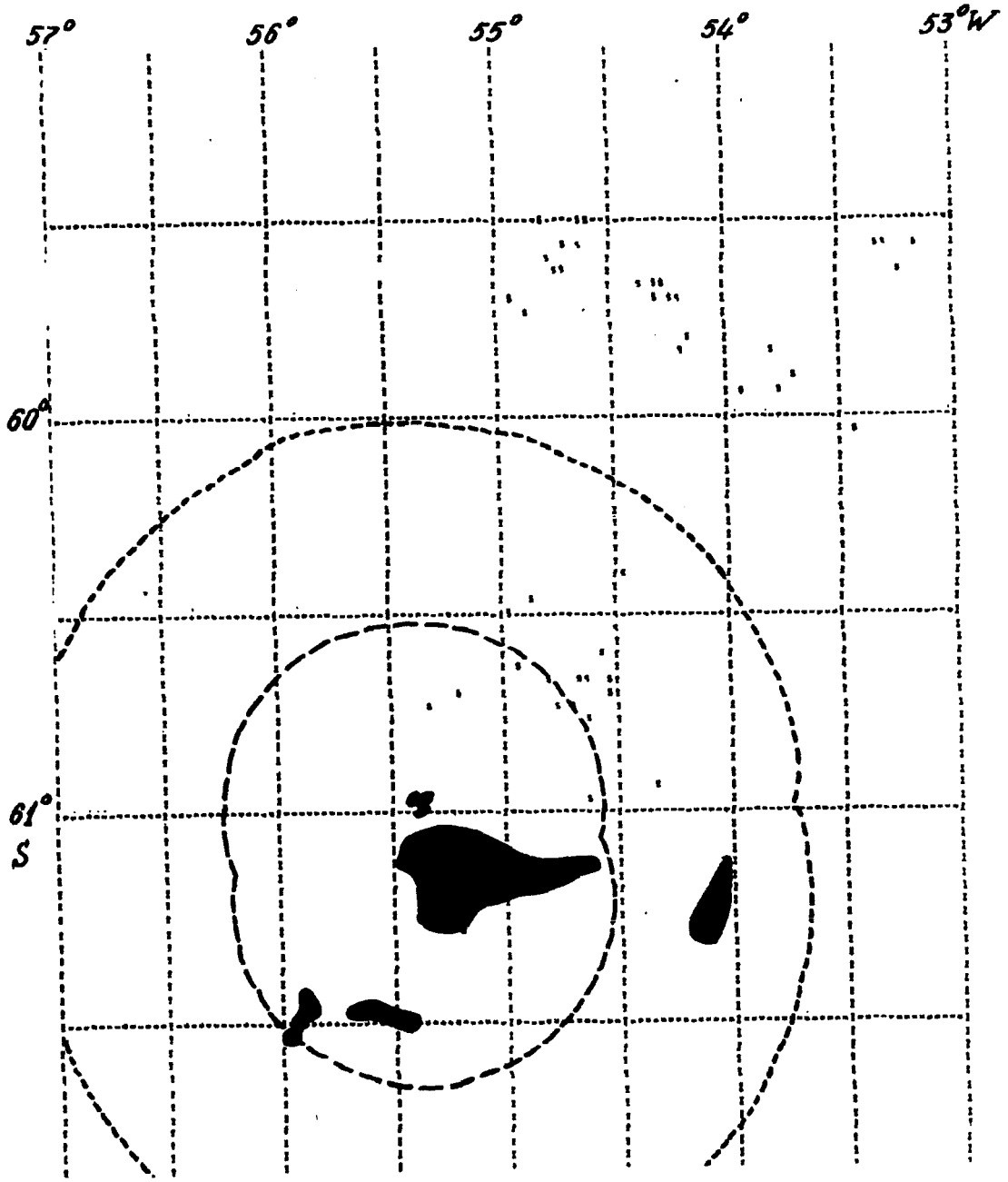

Figure 6b: Krill fishery location by five-day period from 6 to 10 December 1988.

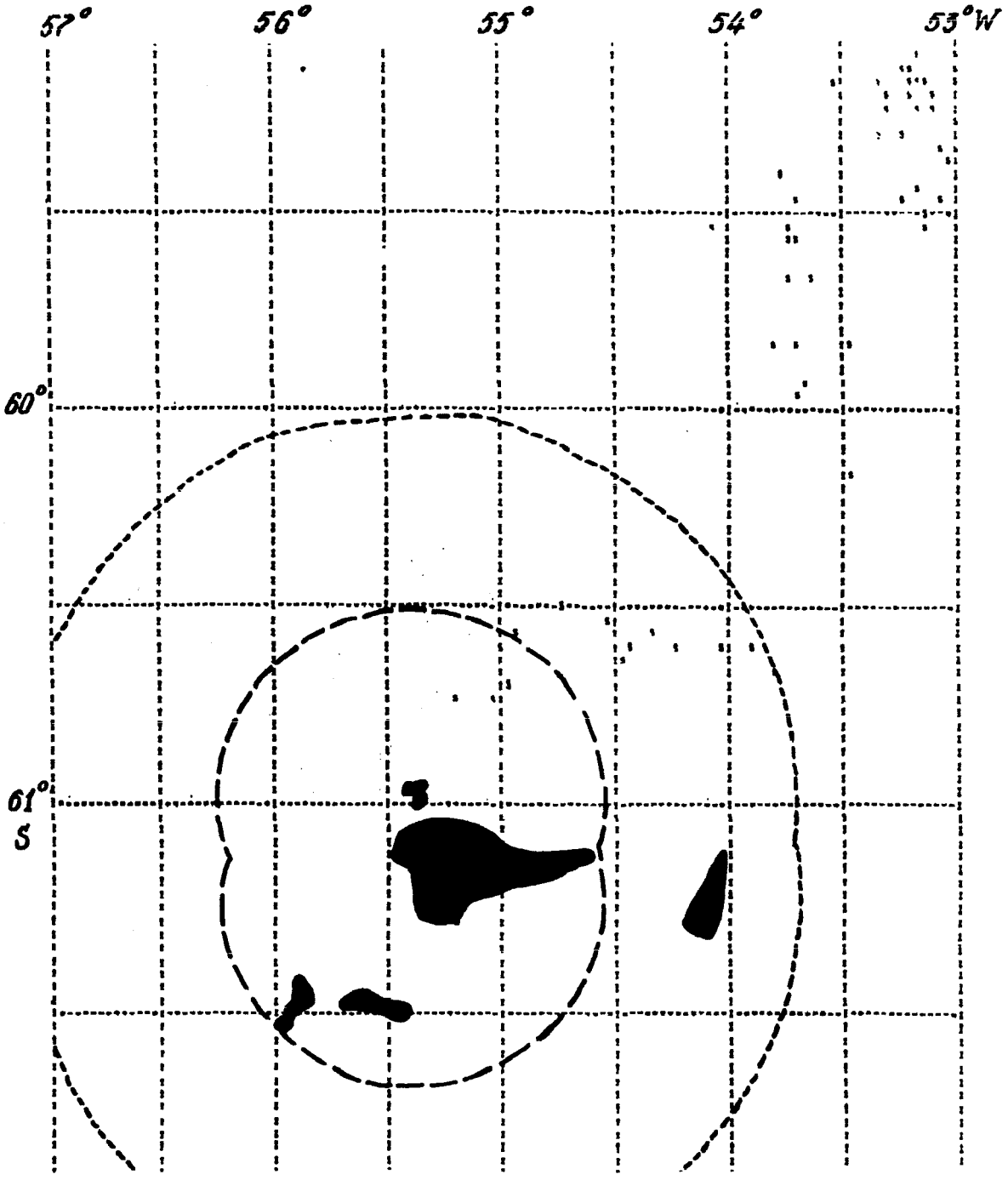

Figure 6c: Krill fishery location by five-day period from 11 to 15 December 1988.

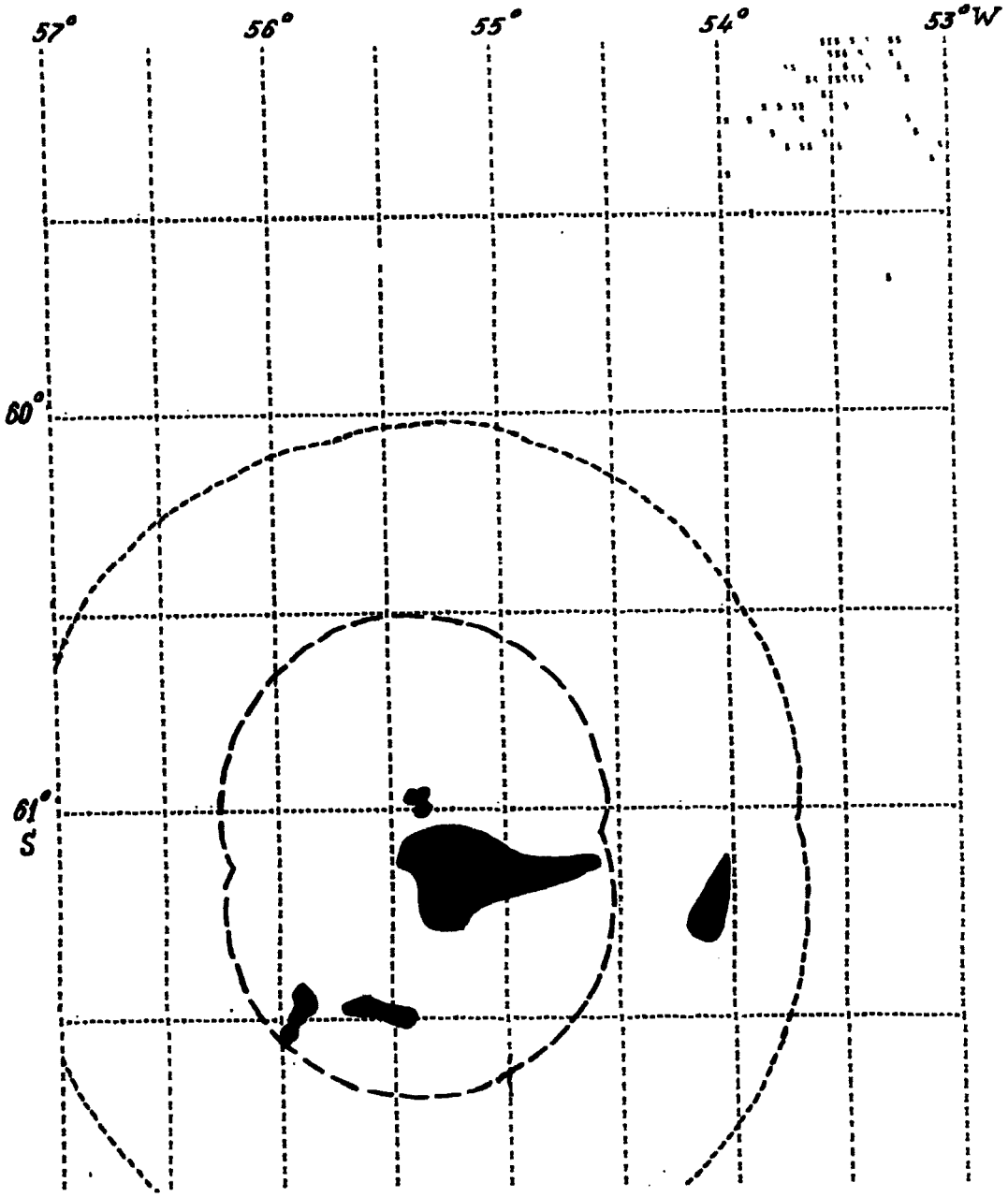

Figure 6d: Krill fishery location by five-day period from 16 to 20 December 1988.

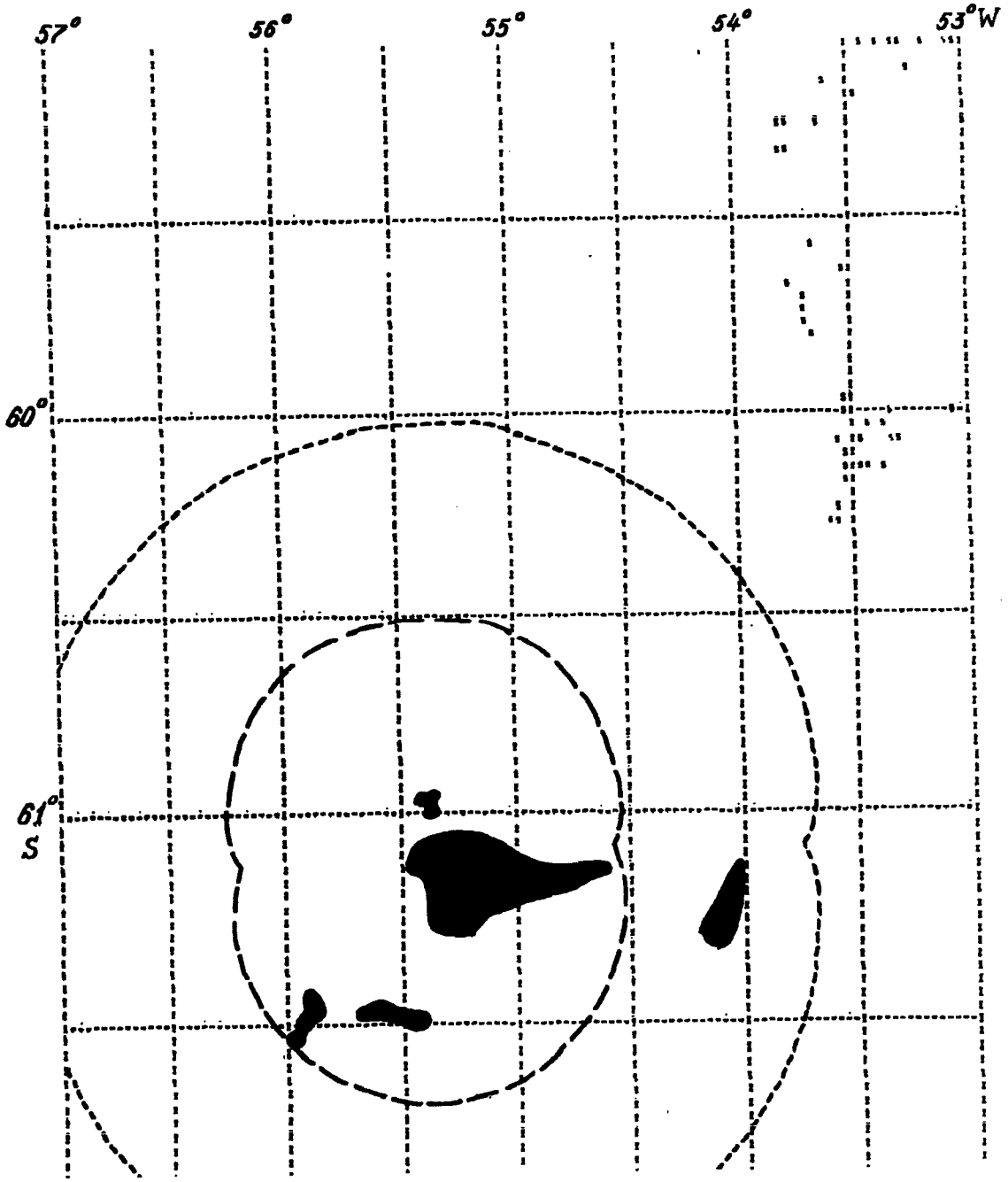

Figure 6e: Krill fishery location by five-day period from 21 to 25 December 1988.

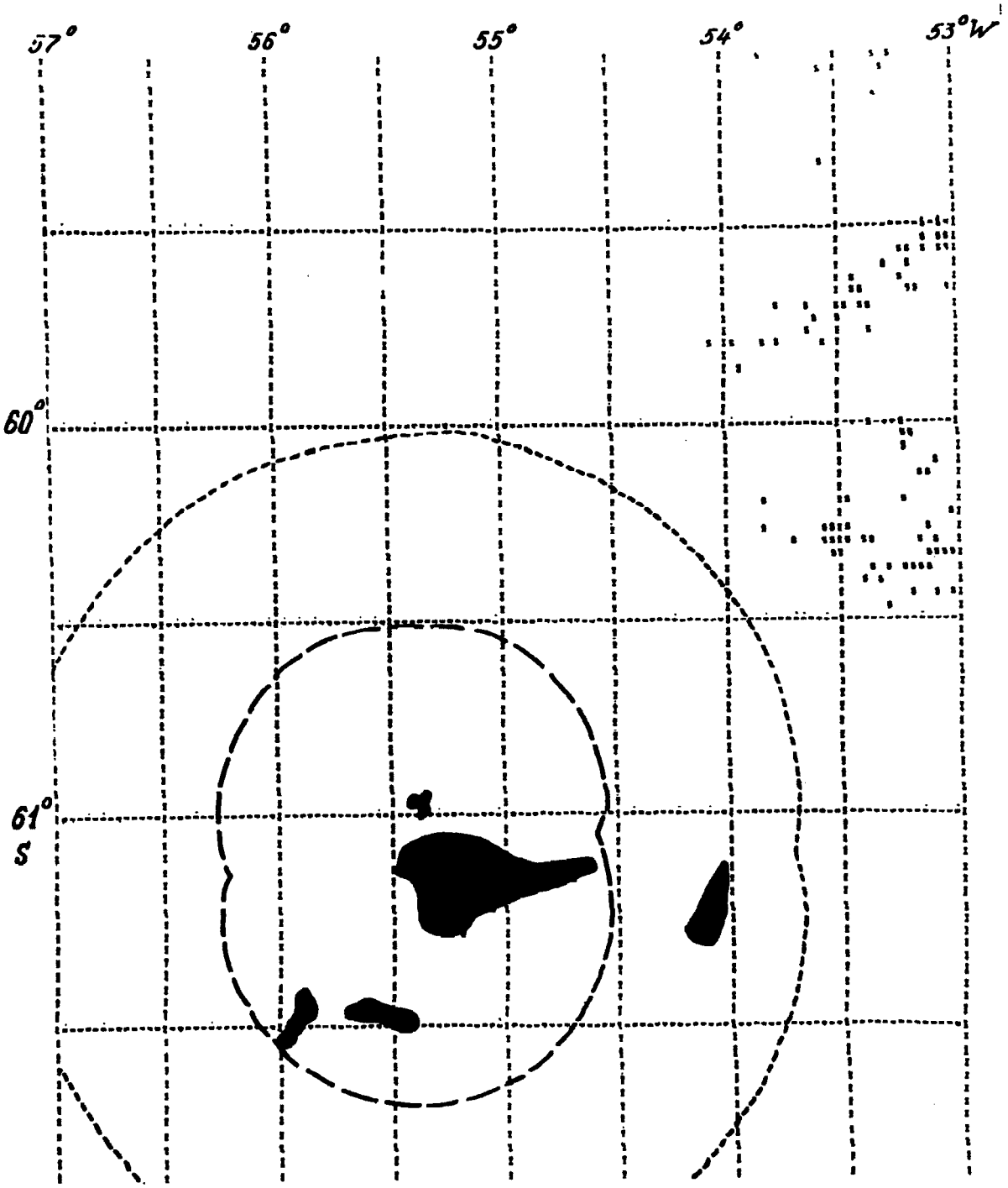

Figure 6f: Krill fishery location by five-day period from 26 to 31 December 1988.

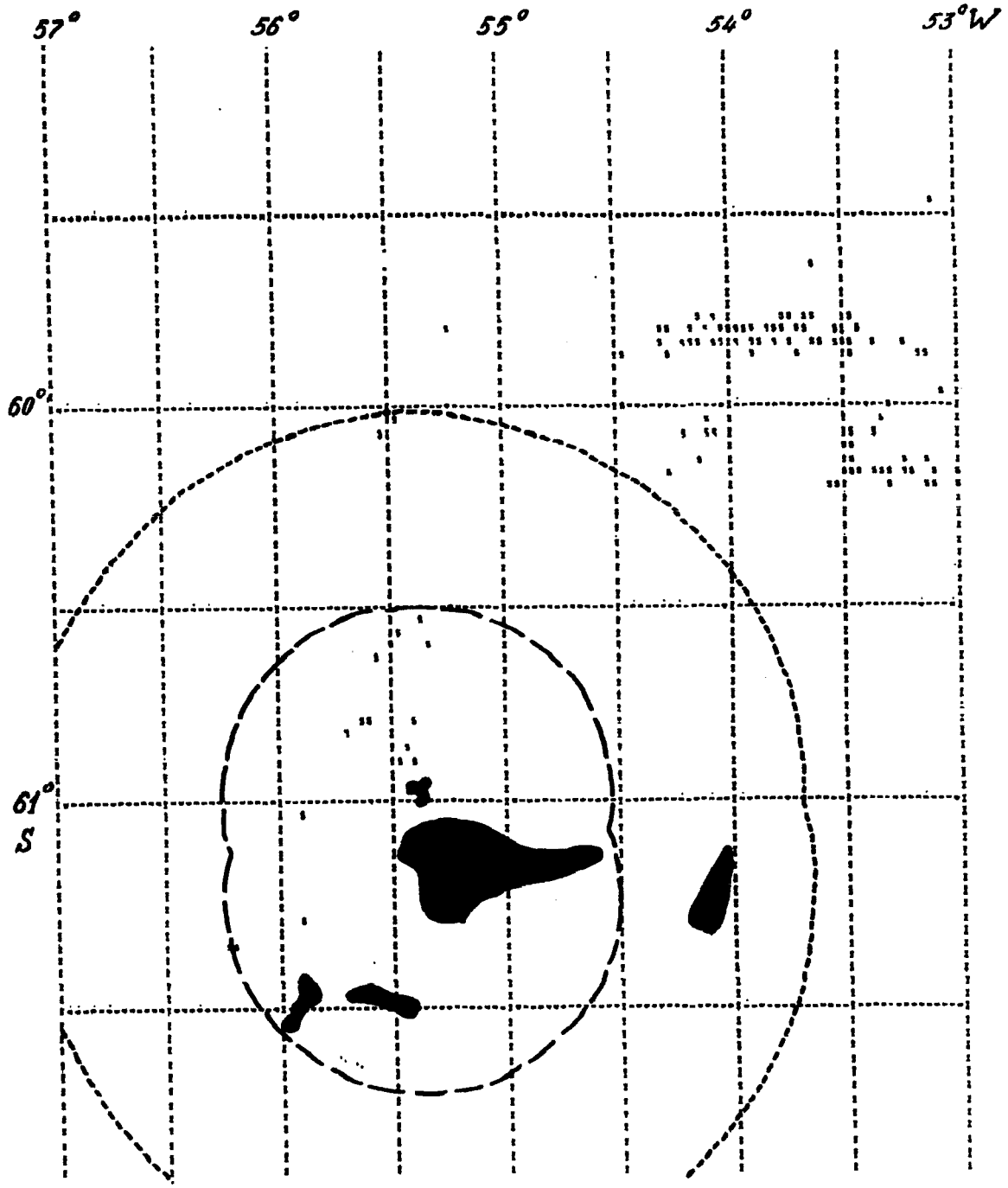

Figure 7a: Krill fishery location by five-day period from 1 to 5 January 1989.

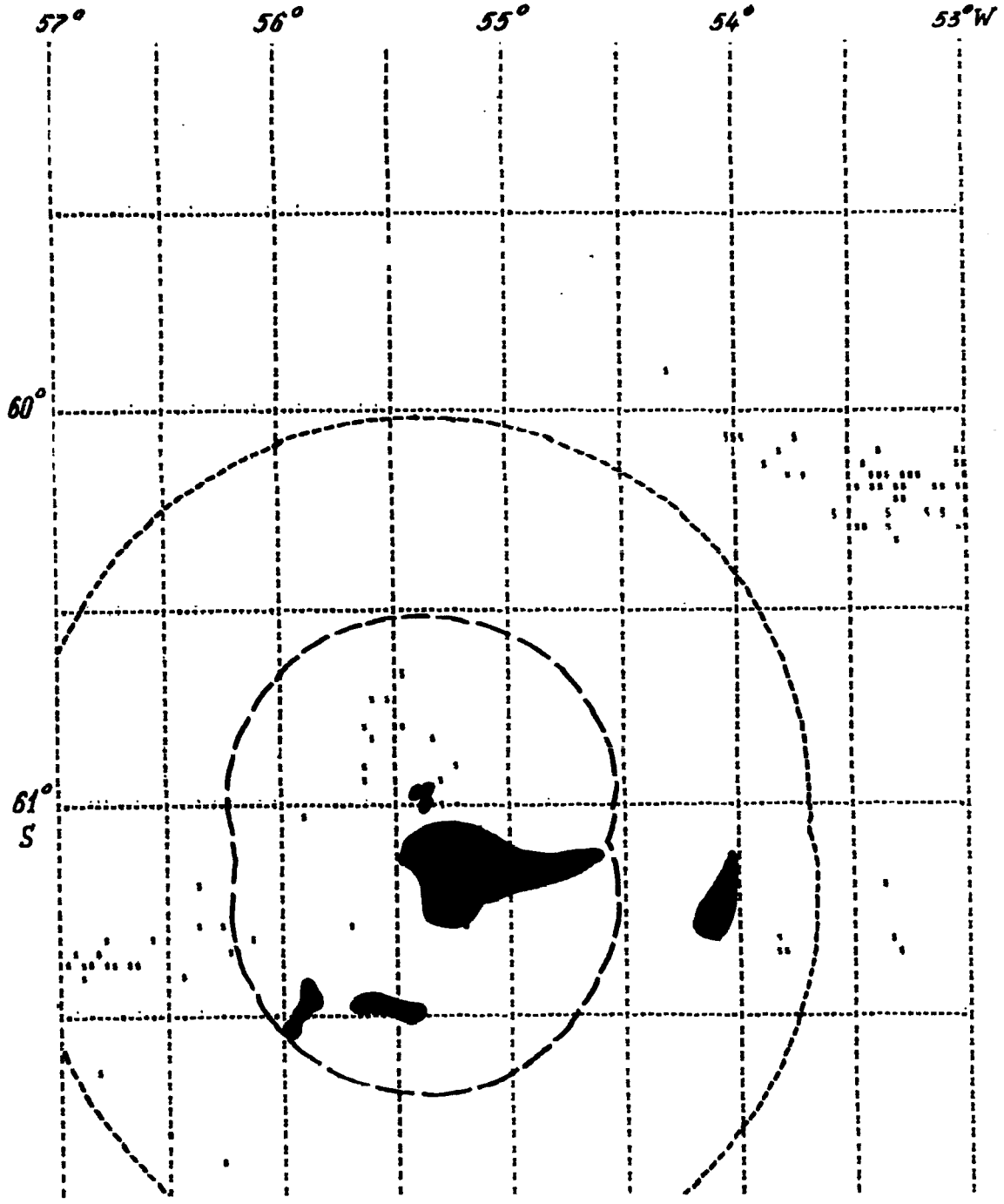

Figure 7b: Krill fishery location by five-day period from 6 to 10 January 1989.

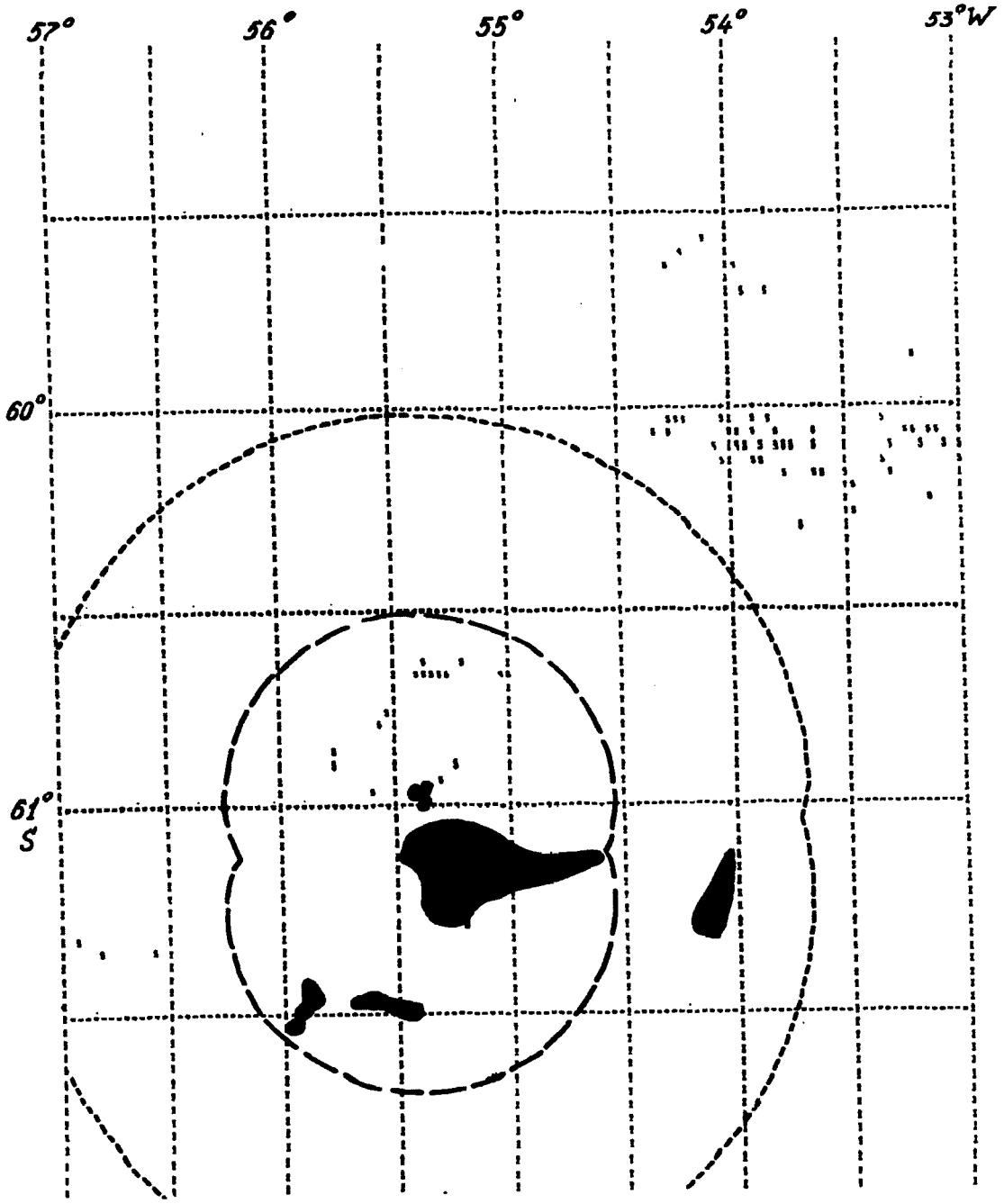

Figure 7c: Krill fishery location by five-day period from 11 to 15 January 1989.

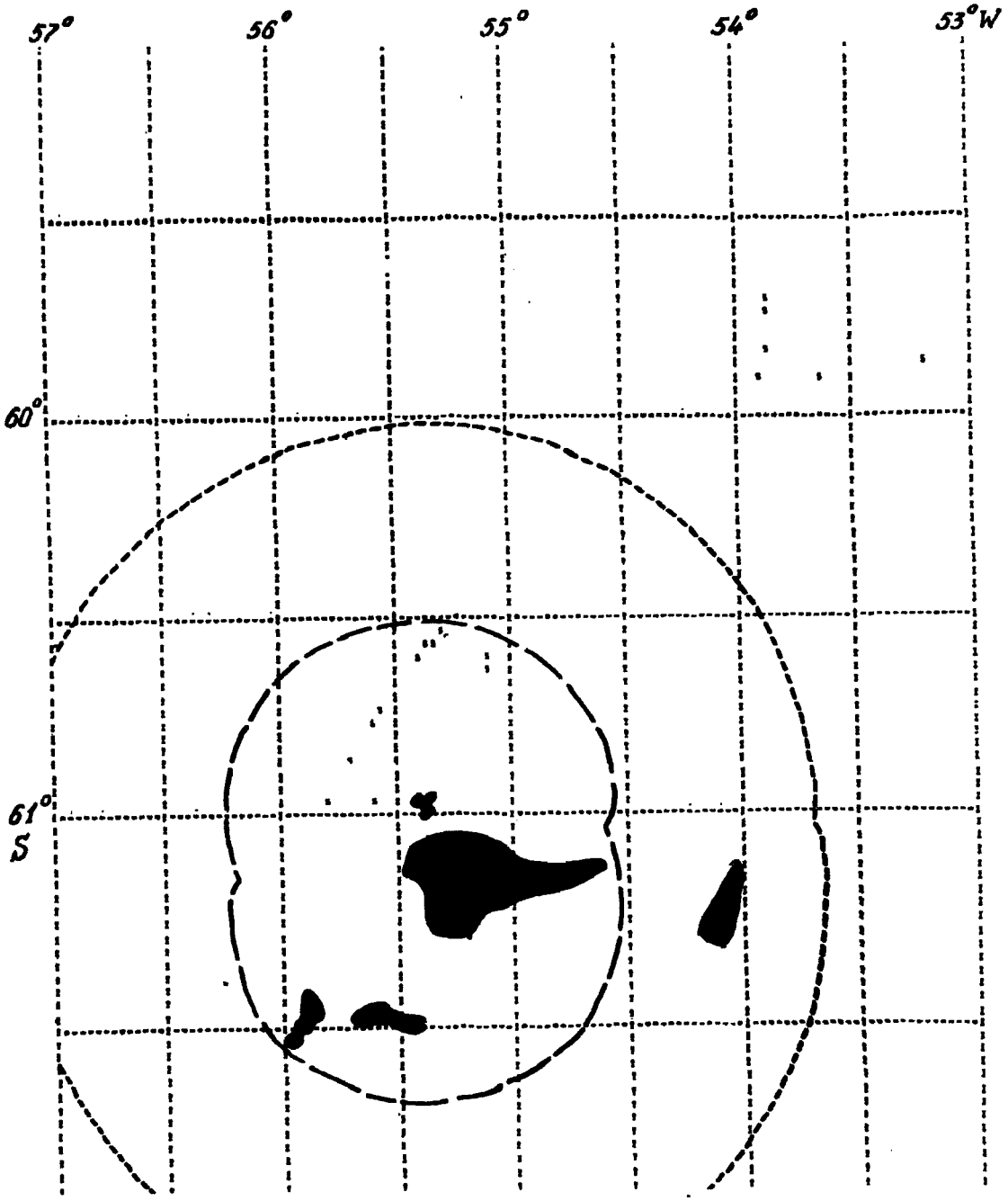

Figure 7d: Krill fishery location by five-day period from 16 to 20 January 1989.

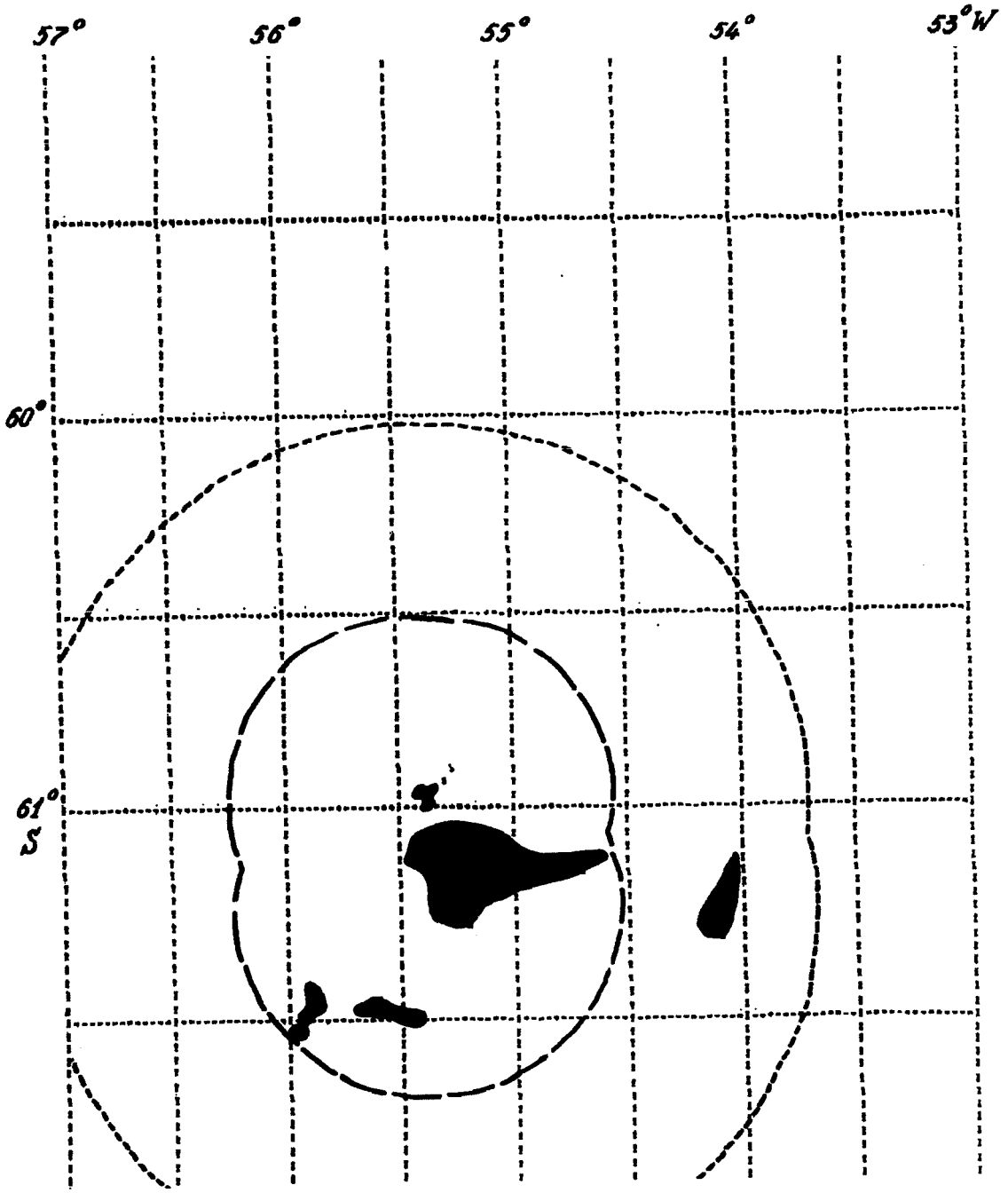

Figure 7e: Krill fishery location by five-day period from 21 to 25 January 1989.

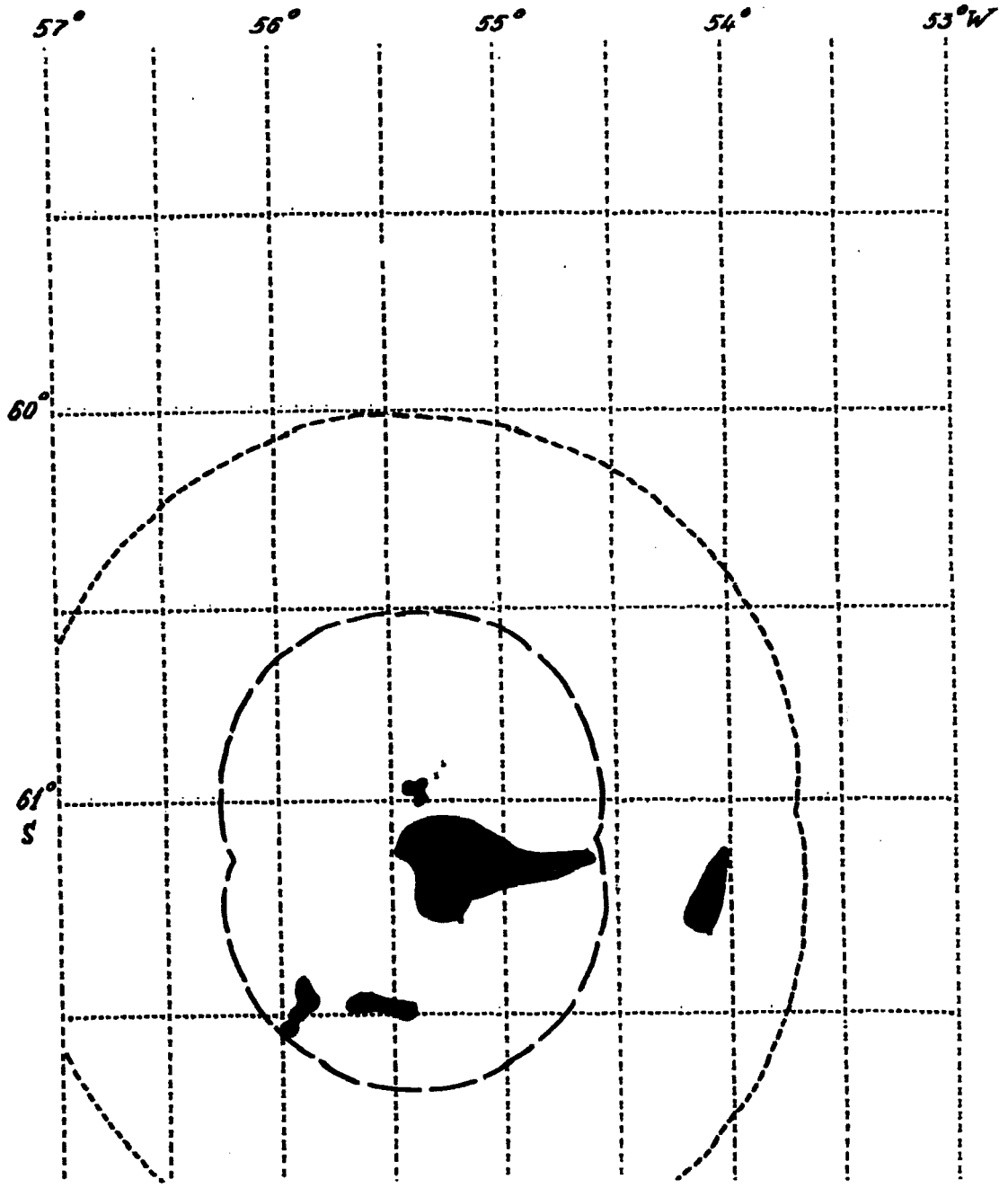

Figure 7f: Krill fishery location by five-day period from 26 to 31 January 1989.

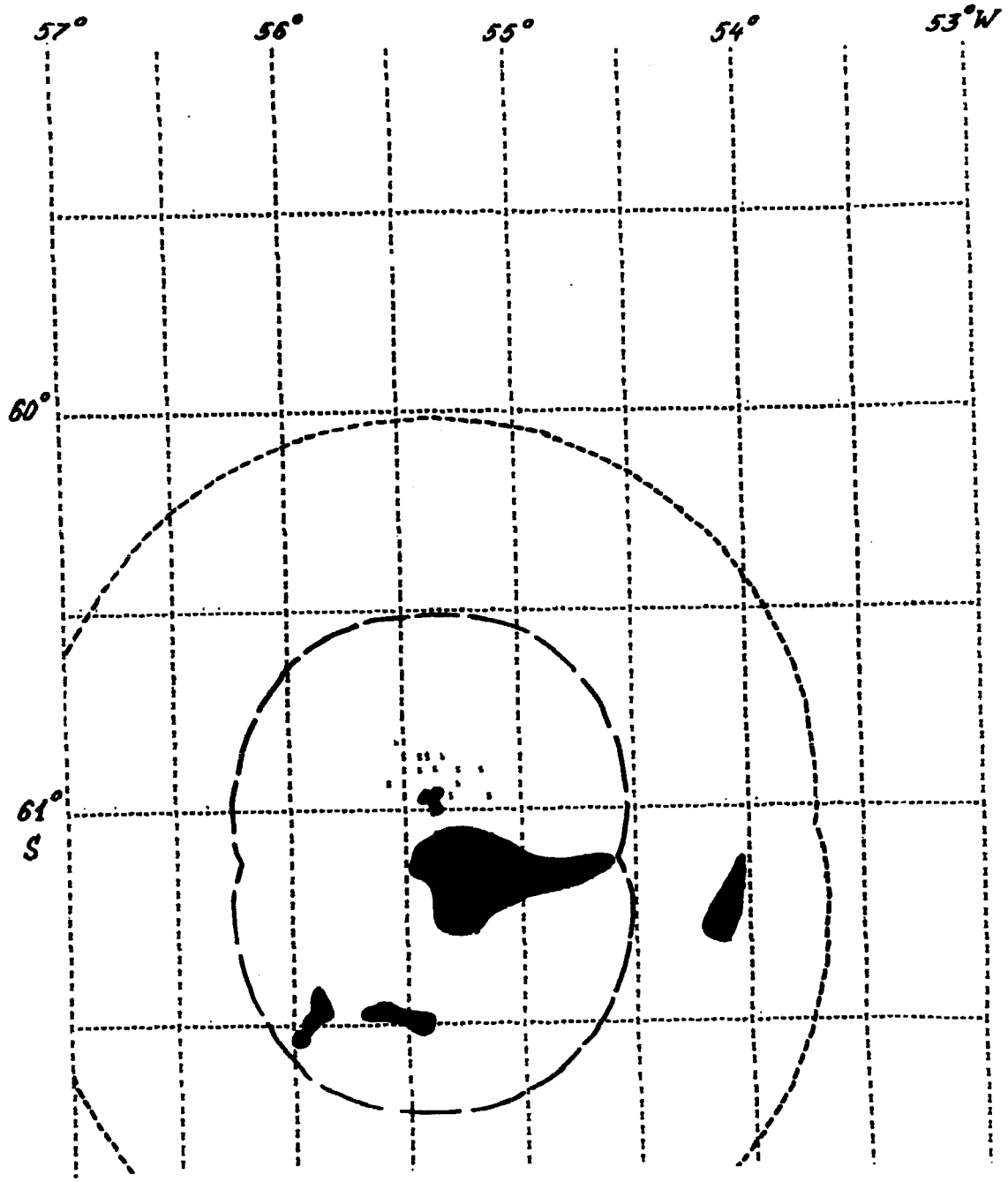

Figure 8a: Krill fishery location by five-day period from 1 to 5 February 1989.

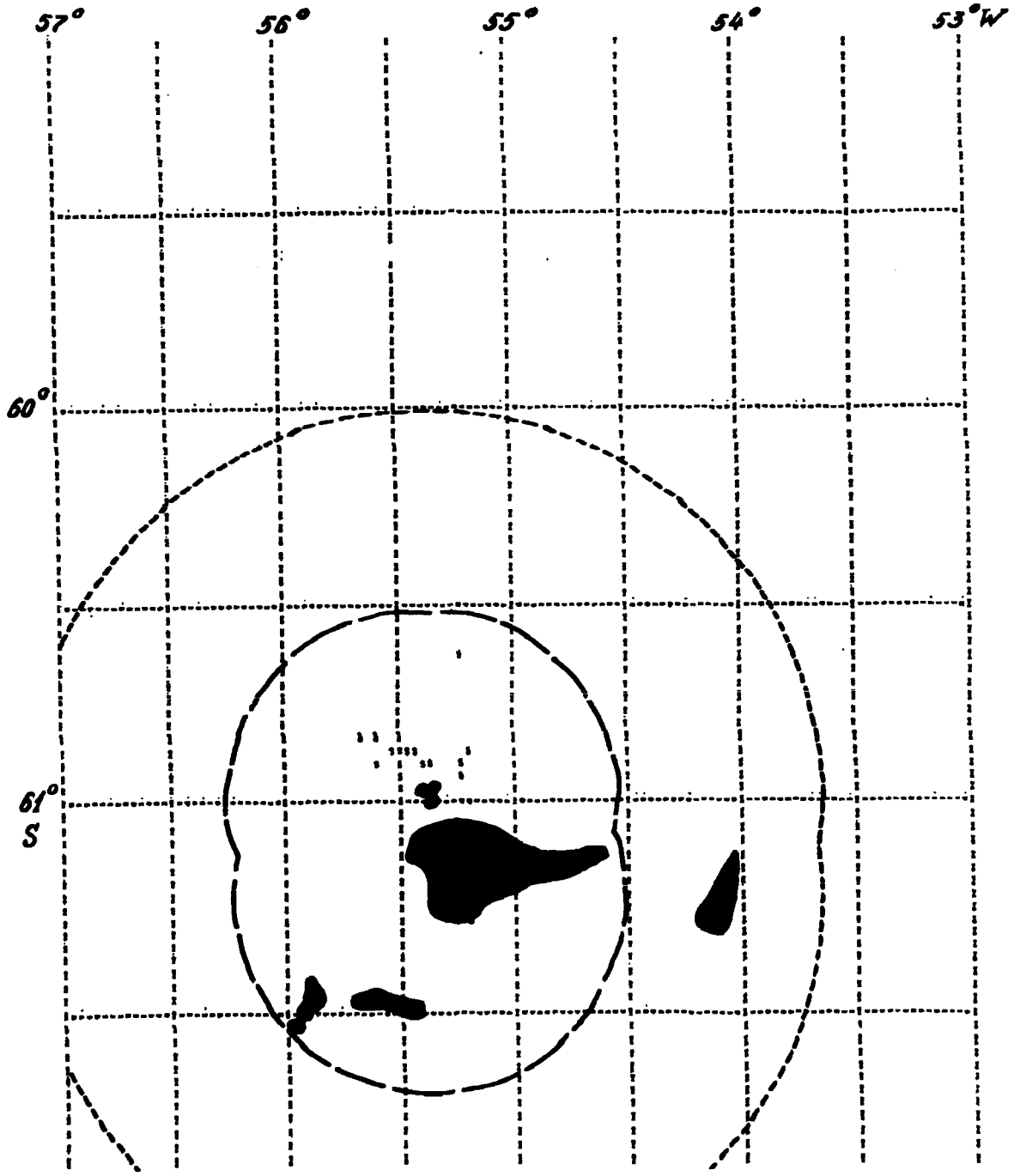

Figure 8b: Krill fishery location by five-day period from 6 to 10 February 1989.

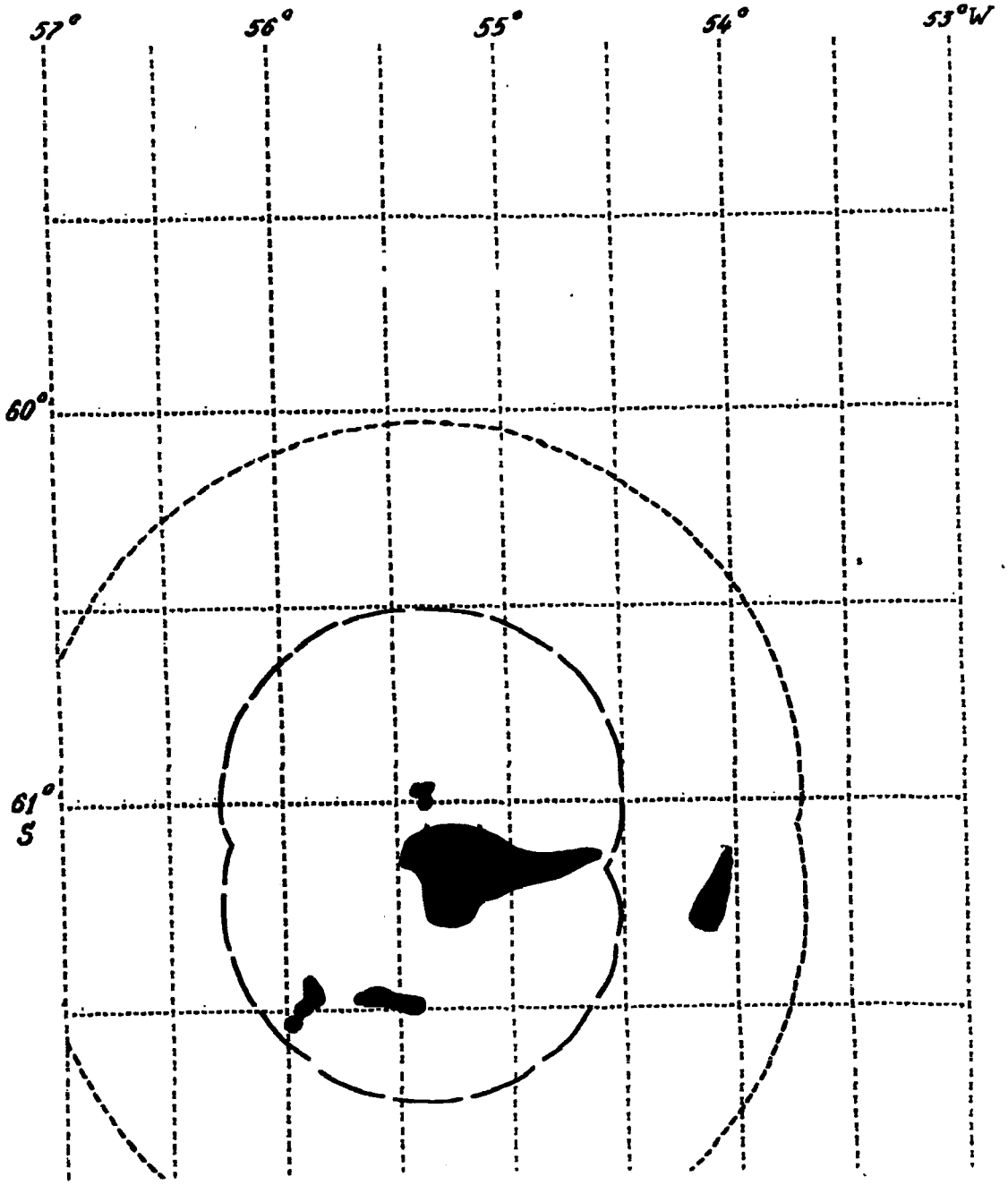

Figure 8c: Krill fishery location by five-day period from 16 to 20 February 1989.

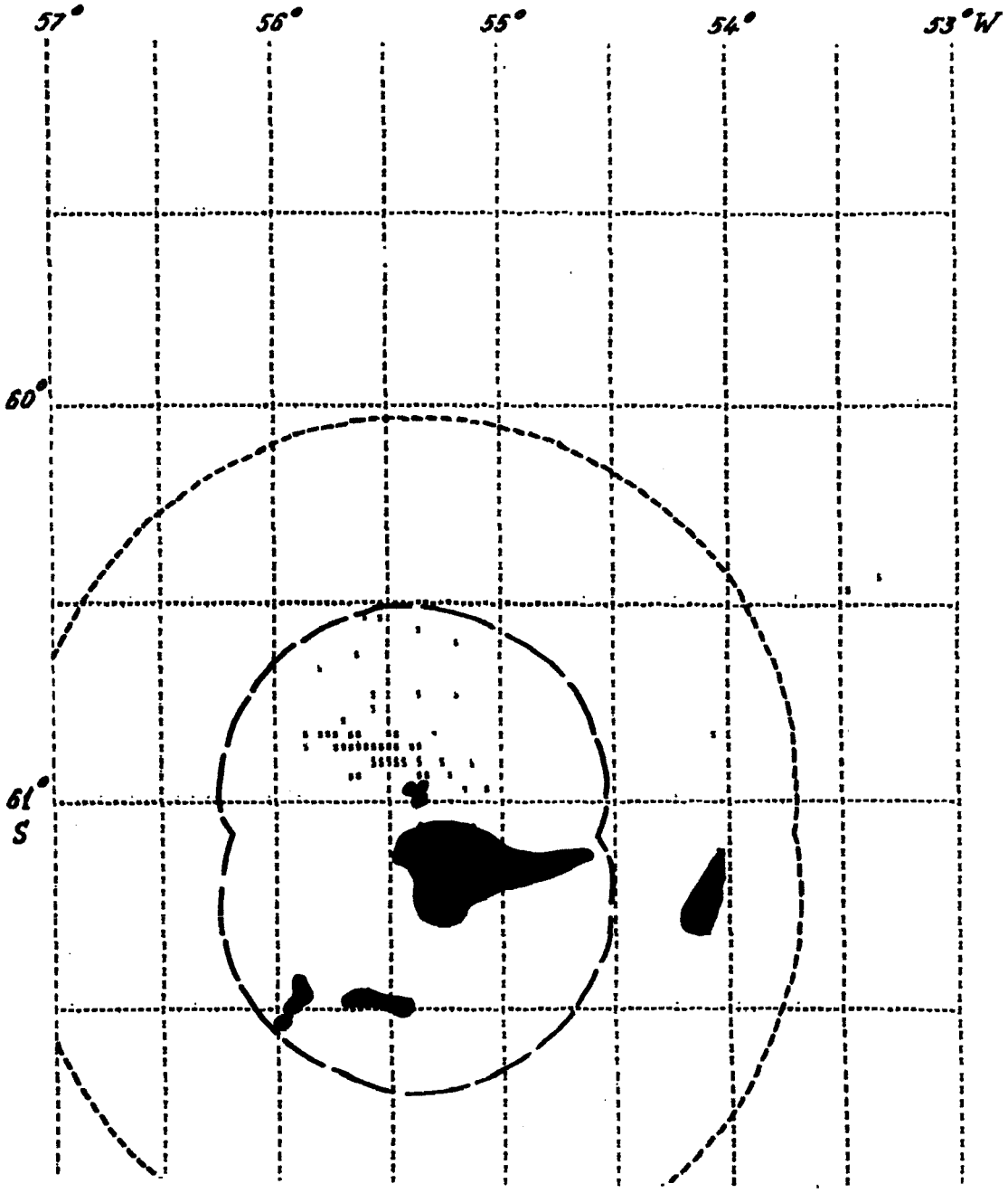

Figure 8d: Krill fishery location by five-day period from 21 to 25 February 1989.

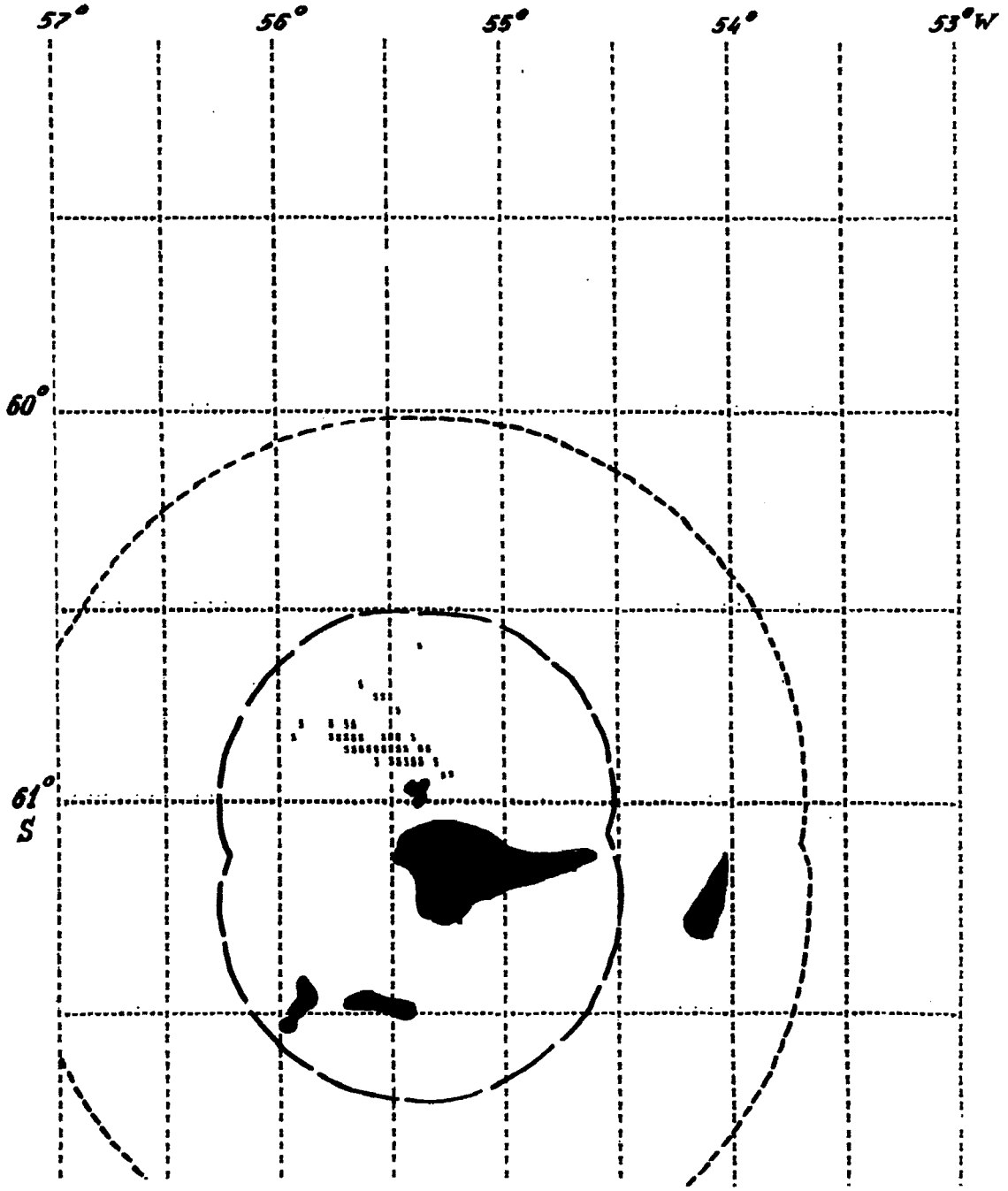

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Figure 3: Position géographique de la pêcherie de krill du 1er au 31 janvier 1989.

Figure 4: Position géographique de la pêcherie de krill du 1er au 28 février 1989.

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Figure 6: Position géographique de la pêcherie de krill par période de cinq jours en décembre 1988:

(a) 1er-5 décembre 1988 (c) 11-15 décembre 1988 (e) 21-25 décembre 1988
(b) 6-10 décembre 1988 (d) 16-20 décembre 1988 (f) 26-31 décembre 1988

Figure 7: Position géographique de la pêcherie de krill par période de cinq jours en janvier 1989:

(a) 1er-5 janvier 1989 (c) 11-15 janvier 1989 (e) 21-25 janvier 1989
(b) 6-10 janvier 1989 (d) 16-20 janvier 1989 (f) 26-31 janvier 1989

Figure 8: Position géographique de la pêcherie de krill par période de cinq jours en février 1989:

(a) 1er-5 février 1989 (c) 11-15 février 1989 (e) 21-25 février 1989
(b) 6-10 février 1989 (d) 16-20 février 1989 (f) 26-28 février 1989

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(a) 1-5 декабря 1988 г.
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(a) 1-5 января 1989 г.
(b) 6-10 января 1989 г.
(c) 11-15 января 1989 г.
(d) 16-20 января 1989 г.
(e) 21-25 января 1989 г.
(f) 26-31 января 1989 г.

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(a) 1-5 февраля 1989 г.
(b) 6-10 февраля 1989 г.
(c) 11-15 февраля 1989 г.
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THE FORAGING RANGE OF ADELIE PENGUINS AT BECHERVAISE ISLAND, MAC. ROBERTSON LAND, ANTARCTICA, AND ITS OVERLAP WITH THE KRILL FISHERY

K.R. Kerry, J.R. Clarke and G.D. Else*

Abstract

The foraging ranges of six female and four male Adélie penguins breeding at Béchervaise Island near Mawson Station (Mac. Robertson Land) were determined by satellite tracking using the ARGOS system. Birds were tracked over four foraging trips (two females and four males) during the incubation period (November to December 1991) and 17 trips (four females and two males) throughout January 1992 when birds were feeding chicks. Most birds made foraging trips to the continental shelf break (1 000 m isobath) approximately 110 km distant at its closest point. Birds feeding chicks also made journeys of one to two days ranging up to 12 km after 17 January when the sea became ice free to the coast. Concentrations of krill, *Euphausia superba*, which have in the past been the subject of a fishery, occur along the shelf break zone where the birds were foraging. There is potential for overlap between the foraging range of Adélie penguins breeding along the Mac. Robertson Land Coast (approximately 150 000 pairs) and any future harvest of krill in the region. The foraging range of the birds at Béchervaise Island considerably exceeds the 15 to 50 km determined for birds in the South Shetland and South Orkney Islands and reflects the distance offshore of krill, one of their major food sources.

Résumé

Les secteurs d'alimentation de six femelles et quatre mâles de manchots Adélie se reproduisant à l'île Béchervaise, près de la base Mawson (Terre Mac. Robertson) ont été déterminés par suivi par satellite grâce au système ARGOS. Les oiseaux ont été suivis lors de quatre sorties alimentaires (deux femelles et quatre mâles) pendant la période d'incubation (de novembre à décembre 1991) et 17 sorties (quatre femelles et deux mâles) pendant tout le mois de janvier 1992 alors que les oiseaux élevaient des poussins. Les sorties alimentaires de la plupart des oiseaux les ont menés jusqu'à la rupture de pente du plateau continental (isobathe 1 000 m) distante d'environ 110 km en son point le plus proche. Les oiseaux élevant des poussins ont également effectué des sorties d'un ou deux jours et d'un maximum de 12 km après le 17 janvier quand la mer s'est libérée des glaces jusqu'à la côte. Des concentrations de krill, *Euphausia superba*, qui par le passé ont fait l'objet d'une pêcherie, sont présentes le long de la zone de la rupture de pente, là où les oiseaux se sont alimentés. Il est possible qu'à l'avenir le secteur d'alimentation des manchots Adélie se reproduisant le long de la côte de la terre Mac. Robertson (environ 150 000 couples) et une exploitation de krill dans la région se chevauchent. A l'île Béchervaise,

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le secteur d'alimentation des oiseaux, dépassant considérablement l'intervalle de 15 à 50 km déterminé pour les oiseaux des îles Shetland du Sud et des Orcades du Sud, reflète la distance du krill, l'une de leurs principales sources d'alimentation, par rapport à la côte.

Резюме

Нагульные ареалы шести самок и четырех самцов пингвина Адели, размножающихся на о-ве Бешервез около станции Моусон (Земля Мак-Робертсон), были установлены с помощью спутникового слежения, используя систему "Аргос". Слежение за птицами велось в ходе четырех походов за пищей (две самки и четыре самца) в течение периода насиживания яиц (ноябрь-декабрь 1991 г.) и 17 походов (четыре самки и два самца) в течение января 1992 г., когда птицы вскармливали своих птенцов. Большинство птиц совершило походы за пищей на границу континентального шельфа (изобата 1 000 м), ближайшая точка которой расположена приблизительно 110 км от берега. После 17 января, когда море стало свободным ото льда до берега, птицы, вскармливающие своих птенцов, совершали одно- двухдневные походы на расстояние до 12км. Концентрации криля (*Euphausia superba*), которые в прошлом являлись объектом промысла, встречаются вдоль границы шельфа, где птицы искали корм. Существует возможность частичного совпадения между нагульным ареалом пингвина Адели, размножающегося вдоль побережья Земли Мак-Робертсон (приблизительно 150 000 пар), и будущим промыслом криля в данном районе. Нагульный ареал птиц на о-ве Бешервез намного превышает 15-50 км, установленных для птиц на Южных Шетландских и Южных Оркнейских о-вах, и отражает расстояние от берега местонахождений криля, который является одним из основных компонентов рациона пингвинов.

Resumen

Se determinó la zona de alimentación de seis hembras y cuatro machos adelia durante la reproducción en isla Béchervaise cerca de la base Mawson (Territorio de Mac. Robertson) mediante el seguimiento por satélite con el sistema ARGOS. Se siguió el curso de cuatro viajes de alimentación (dos aves hembras y cuatro machos) durante el período de incubación (noviembre y diciembre 1991); y 17 viajes (cuatro hembras y dos machos) realizados durante el mes de enero de 1992, cuando las aves estaban alimentando a sus polluelos. La mayoría de las aves se desplazaron al borde continental (isóbata 1 000 m) el cual queda a unos 110 km de distancia en su punto más cercano. Aquellas aves que estaban alimentando a sus polluelos realizaron viajes de uno a dos días de duración hasta una distancia máxima de 12 km después del 17 de enero, fecha en la cual el mar está libre de hielo hacia la costa. Los cardúmenes de kril, *Euphausia superba*, que en el pasado han sido el objetivo de la pesquería, se encuentran a lo largo del borde continental que es donde las aves se estaban alimentando. Por lo tanto, existe la posibilidad de que se produzca una superposición entre la zona de alimentación de los pingüinos adelia, cuyas colonias se encuentran a lo

largo de la costa del Territorio de Mac. Robertson (alrededor de unas 150 000 parejas), y cualquier recolección de kril que se pudiera realizar en el futuro en la zona. La extensión de la zona de alimentación de las aves de isla Béchervaise excede en gran medida los 15 a 50 km determinados para las aves de los archipiélagos de las Shetland del Sur y Orcadas del Sur y refleja la distancia costa afuera a la que se encuentra el kril, una de sus fuentes de alimento más importante.

1. INTRODUCTION

The foraging range of Adélie penguins is limited during the breeding season by the time they must remain in the colony to brood, guard and feed their chicks and the frequency of feeding visits required. During the incubation period birds make foraging trips of between two and three weeks. Later in January/February both parents are required to forage to feed the chick and each bird must provide food every one to three days. It is during this time that the greatest pressure is placed upon the birds to nourish themselves and their chicks and thus when they are most vulnerable to the impacts of a fishery on their food source.

The probable overlap of the foraging range of 50 to 100 km of Adélie (and chinstrap and gentoo) penguins with the krill fishery in the South Shetland and South Orkney Islands was highlighted by Agnew (1991). He pointed out the theoretical possibility of the existing krill fishery taking an amount of krill up to 50% of that required by these krill predators to successfully raise their chicks.

The krill catch in the Indian Ocean sector of the Southern Ocean (Statistical Area 58) has in the past been significant, with fishing being undertaken by a number of nations, particularly the Soviet Union, Korea and Japan. The Soviet Union was most active in the region during the early 1980s, taking a maximum annual krill catch of 119 381 tonnes in 1982 (CCAMLR, 1992). The location of these catches has not been reported. Fishing by Japan has taken place intermittently and at a lower level since 1973 (Ichii, 1990); Korea has also been fishing for krill since 1982 (Anon., 1982). Reports of these fisheries show that much of their catch occurred in the Prydz Bay region (Division 58.4.2). The Soviet Union has also conducted limited fishing in this subarea since 1988 and it is likely that a large proportion of their earlier catches also took place here.

Although there has been no significant harvest of krill in Division 58.4.2 since 1988 it is likely that further harvests will take place. A CCAMLR Ecosystem Monitoring Program (CEMP) site has been established at Béchervaise Island (67°35'S, 62°48'E), offshore from the coast of Mac. Robertson Land near Mawson Station, in order to monitor krill predators in this subarea. As part of the program the foraging range of Adélie penguins during all stages of the 1991/92 breeding season was determined by satellite tracking. We report here data that show for the first time an overlap occurring in the Prydz Bay region between the foraging range of Adélie penguins and the locations of previous krill fisheries.

2. METHODS

The study was commenced in November 1991. Birds in good condition were selected from breeding birds with eggs or chicks and were marked at the nest. They were caught as they departed the breeding colony and a Platform Transmitter Terminal (PTT) attached; they were then sexed by cloacal examination and given an implanted electronic tag (Tiris, Texas Instruments).

The birds were tracked by the ARGOS satellite system using either Telonics ST-6 or Toyocom 2038 PTT set on a 50s repeat transmission cycle. These were packaged together with their batteries in epoxy resin. The packages weighed approximately 160 g and were slightly negatively buoyant in sea water. They were virtually identical to those used in the study by Davis and Miller (1992), both being packaged by Sirtrak in New Zealand. The number of satellite passes capable of detecting the PTTs averaged 22 per day. Few passes occurred between 0900 to 1300 hours solar time.

Each PTT was attached to the bird using a Velcro™ patch and cable ties which were glued to the middle of the bird's back; the corresponding half of the Velcro™ was glued to the PTT. The PTT was then placed on the bird's back and the cable ties tightened over the package. When required the PTT could be removed after cutting the ties. The Velcro™ patch remained on the bird to be moulted off later. This system of attachment allowed the bird some flexing of its back. Birds were logged in and out of their colony by an automated monitoring system (Kerry *et al.*, 1992).

The location of the fast ice was determined from AVHRR images obtained from NOAA 11 and NOAA 12 satellites and relayed to Hobart from the receiver at Casey Station. The ice front was determined for each 0.2° longitude at various dates throughout the summer.

3. RESULTS AND DISCUSSION

Ten birds were instrumented utilising seven PTTs. Twenty-one foraging trips were recorded ranging in duration from 1 to 34 days between 25 November 1991 and 1 February 1992 thus covering the period from early laying to early fledging. The periods over which each bird was tracked, the stage of the breeding cycle and the distance and the direction of travel are given in Table 1. The tracks, together with the position of the continental shelf break and the locations of previous krill fisheries, are shown in Figure 1.

During the incubation period the off-duty birds travelled in a northwesterly direction; the two females reached distances of 341 and 243 km and the two males 161 km and 164 km from the colony. All four birds travelled in a generally northwesterly direction until the edge of the fast ice was reached and then two (a male and a female) travelled in westerly direction along the edge of the continental shelf at approximately the same speed (1 km/hr) as the prevailing currents. All four birds appeared to forage at leisure as they travelled away from the colony. Once the birds started to return they did so directly and quickly following along the edge of the fast ice to a point north-northwest from the colony and then walking.

The pattern of foraging changed after hatching (24 December onward). The journeys were less than seven days duration and appeared more purposeful than those made during the incubation period. Birds travelled directly to points between north-northeast and north-northwest from the colony and usually spent less than two days at the northern most point before returning again directly. Journeys were made to the edge of the fast ice, up to 80 km distant, with some reaching the edge of the continental shelf approximately 110 km from the colony. Once the sea-ice had blown out from the coast (17 January) penguins spent time within a few kilometres of the colony before suddenly departing out to the edge of the continental shelf. Others made short journeys of up to 12 km range and then returned briefly to land before making the longer journeys just described.

Numerous research cruises and fishing operations have shown the occurrence of krill *Euphausia superba* in considerable concentrations at the shelf break along the coast of Mac. Robertson Land (Higginbottom *et al.*, 1988; Ichii, 1990). This study suggests that the penguins specifically travel to this region to forage throughout the breeding season. The long distances of up to 135 km travelled to forage even when feeding chicks are thus in marked contrast to the suggested foraging range for Adélie penguins in the Antarctic Peninsula region of 50 km (Trivelpiece *et al.*, 1987) and 15 km (Wilson *et al.*, 1989) although similar to 83 to

119 km determined by Lishman (1985). The shorter foraging range for birds in the Antarctic Peninsula region (Trivelpiece *et al.*, 1987; Wilson *et al.*, 1989) reflect the closer proximity of *E. superba* to shore and hence to the breeding colony. Since all birds in the present study carried an instrument package causing considerable drag in water it is expected that unencumbered penguins would be able to decrease the time necessary for foraging and probably extend the foraging range.

There is a clear overlap, as Figure 1 shows, between the foraging range of penguins from Béchervaise Island and the locations of areas where fishing has been undertaken by Korea (Anon., 1982), Japan (Ichii, 1990) and the Soviet Union (CCAMLR, unpublished data). Breeding colonies of Adélie penguins with an estimated breeding population of 150 000 pairs (Horne, 1983; Woehler *et al.*, 1989) including those on Béchervaise Island are found scattered along the coastline of Mac. Robertson Land between 56°E and 65°E. These birds forage in the same region and their range presumably also extends into the same fishing grounds.

The foraging range of the birds from Béchervaise Island extends only into the southern end of the fishing grounds. This may be due however to the fishing vessels staying to the north of the pack-ice. It would appear at present that the penguins are able to obtain sufficient food without having to extend their range much beyond the continental shelf break. Considerably more overlap could occur in those years where ice conditions allow the fishing fleet to operate further south or in poor krill seasons when the penguins are forced to forage further north.

REFERENCES

AGNEW, D.J. 1991. Krill catches and consumption by land-based predators in relation to distance from colonies of penguins and seals in the South Shetland and South Orkney Islands. Document *WG-CEMP-91/25*. CCAMLR, Hobart, Australia: 14 pp.

ANON. 1982. Summary Report of krill (*Euphausia superba*) Fishing Ground Exploitation in the Antarctic Ocean (1981/1982). National Fisheries Research and Development Agency. Republic of Korea.

CCAMLR. 1992. *Statistical Bulletin,* Vol. 4 (1982-1991). CCAMLR, Hobart, Australia: 133 pp.

DAVIS, L.S. and D.G. MILLER. 1992. Satellite tracking of Adélie penguins. *Polar Biology* (in press).

ICHII, T. 1990. Distribution of Antarctic krill concentrations exploited by Japanese krill trawlers and minke whales. *Proc. NIPR Symp. Polar Biol.*, 3: 36-56.

HIGGINBOTTOM, I.R., K.R. KERRY and S.E. WAYTE. 1988. Hydroacoustic surveys of the distribution and abundance of krill: Prydz Bay region- FIBEX, ADBEX II, and SIBEX II, MV *Nella Dan. ANARE Research Notes*, 62: 46 pp.

HORNE, R.S.C. 1983. The distribution of penguin breeding colonies on the Australian Antarctic Territory, Heard Island, the McDonald Islands and Macquarie Island. *ANARE Research Notes*, 9: 82 pp.

KERRY, K.R., J.R. CLARKE, and G.D. ELSE. 1992. The use of an automated weighing and recording system for the study of the biology of Adélie penguins(*Pygoscelis adeliae*). *Proc. NIPR Symp. Polar Biol.*, 6 (in press).

LISHMAN, G.S. 1985. The food and feeding ecology of Adélie and chinstrap penguins at Signey Island, South Orkney Islands. *J. Zool. Lond.*, 205: 245-263.

TRIVELPIECE, W.Z., S.G. TRIVELPIECE and W.J. VOLKMAN. 1987. Ecological segregation of Adélie, gentoo and chinstrap penguins at King George Island, Antarctica. *Ecology,* 68: 351-361

WOEHLER, E.J., G.W. JOHNSTONE and H.R. BURTON. 1989. *ANARE Research Notes*, 71: 36 pp.

Table 1: Details of each foraging trip by Adélie penguins as determined by satellite tracking. The bearing is given in degrees true from Béchervaise Island. Each PTT was used twice as designated by A or B after the PTT number. Where the PTT failed the point of failure is recorded as the furthest distance; in each case the PTT failed on a north bound track.

PTT No.	Sex	Date Departed	Days Away	Latitude	Longitude	Distance (km)	Bearing	Approx. Position of Fast Ice Front	Stage of Breeding Cycle	Notes
				S	E			S		
1396A	F	25 November 1991	34	65.7°	56.8°	341	307	66.8°	first foraging trip post laying	travelled along continental shelf
8402A	F	26 November 1991	21	65.9°	59.2°	243	319	66.8°	first foraging trip post laying	travelled along and to north of continental shelf
1397A	M	11 December 1991	23	66.2°	62.0°	164	347	67.0°	long foraging trip after first incubation shift	travelled north of continental shelf before PTT failed
1399A	M	18 December 1991	15	66.7°	59.8°	161	307	67.2°	long foraging trip after first incubation shift	travelled along ice edge south of continental shelf
8404A	F	3 January 1992	3	67.0°	63.0°	62	11	67.2°	feeding young chick	travelled to ice edge
		9 January 1992	6	66.5°	62.0°	128	344	67.4°	feeding young chick	travelled to continental shelf
		16 January 1992	5	66.5°	61.5°	135	335	67.5°	feeding young chick	travelled to continental shelf
1398A	M	4 January 1992	1			2		67.2°	feeding young chicks	only 1 to 2 km from colony
		7 January 1992	1			2		67.4°	feeding young chicks	only 1 to 2 km from colony
		11 January 1992	4	66.9°	63.3°	76	15	67.4°	feeding young chicks	travelled to ice edge before PTT failed
1396B	M	19 January 1992	1			5	275	none	feeding growing chick	only 1 to 5 km from colony
		20 January 1992	1			5	263	none	feeding growing chick	only 1 to 5 km from colony
		23 January 1992	1			5	263	none	feeding growing chick	only 1 to 5 km from colony
		26 January 1992	1			4	148	none	feeding growing chick	only 1 to 5 km from colony
		27 January 1992	4	67.2°	62.9°	43	5	none	feeding growing chick	travelling north when PTT failed
8402B	F	18 January 1992	7	66.5°	62.2°	125	348	none	feeding small chick	travelled to continental shelf
1399B	M	17 January 1992	1			3	357	none	feeding small chick	only 1 to 2 km from colony
		19 January 1992	45+	67.5°	62.5°	20	318	none	feeding small chick	travelling northwest when PTT failed
8404B	M	27 January 1992	1	67.5°	62.9°	12	11	none	feeding large chick	short foraging trip
		28 January 1992	3	66.7°	63.8°	114	23	none	feeding large chick	travelled to continental shelf
		1 February 1992	1	67.6°	62.3°	6	286	none	feeding large chick	short foraging trip

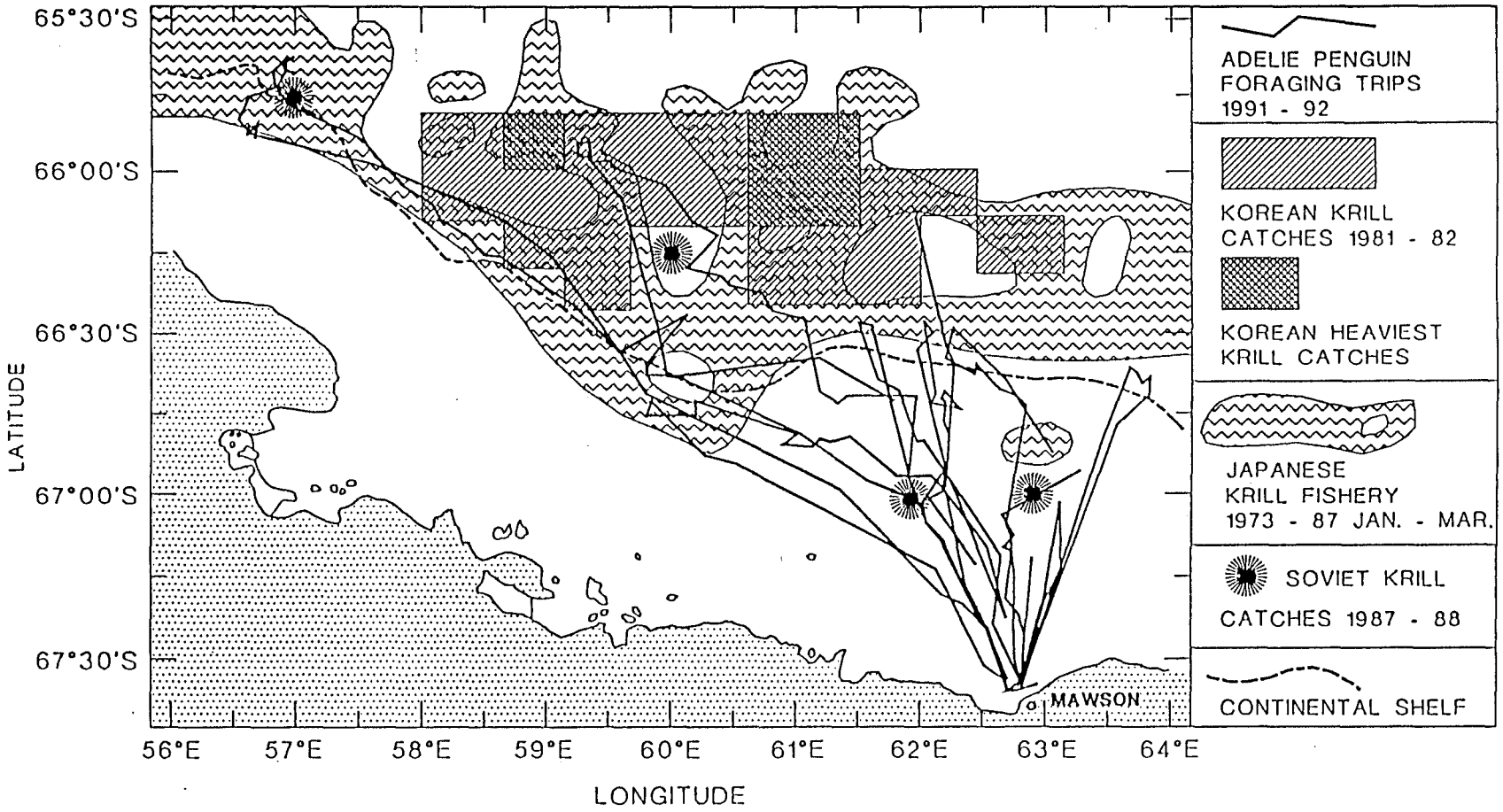

Figure 1: Tracks of all penguins and the position of the continental shelf break (1 000 m isobath). The locations of the Korean and Japanese fisheries and the positions of single commercial hauls made by the USSR in the 1987/88 season, (CCAMLR, unpublished data) are shown.

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Tableau 1: Détails de chaque sortie alimentaire des manchots Adélie, déterminés par suivi par satellite. L'orientation est donnée en degrés actuels à partir de l'île Béchervaise. Chaque plate-forme de terminal de transmission (PTT) a été utilisée deux fois comme l'indiquent les lettres A et B après le numéro de la PTT. Lorsque la PTT n'a pas fonctionné, le point d'échec est enregistré comme étant l'emplacement le plus distant; chaque fonctionnement défectueux de la PTT s'est produit sur une piste se dirigeant vers le nord.

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Figura 1: Trayectorias de todos los pingüinos y la posición del borde continental (isóbata de 1 000 m). Se muestra la ubicación de las pesquerías japonesa y coreana y las posiciones de lances comerciales individuales realizados por la URSS en la temporada 1987/88 (datos inéditos de la CCRVMA).

CCAMLR ECOSYSTEM MONITORING AND A FEEDBACK MANAGEMENT PROCEDURE FOR KRILL

A.J. Constable*

Abstract

The CCAMLR Ecosystem Monitoring Program has been developing a technique which might detect short-term declines in land-based predator performance (e.g., reproductive performance) that may be attributable to loss of prey through fishing activities. The principal fishery in the CCAMLR Convention Area is the krill fishery and this paper examines ways in which the information being obtained from the Ecosystem Monitoring Program might be incorporated into a feedback management strategy for this fishery.

Résumé

Le Programme de contrôle de l'écosystème de la CCAMLR met au point une technique pour déceler des baisses à court terme de performance des prédateurs terrestres (le taux de reproduction, par ex.) qui peuvent être imputées à une perte de proies résultant des activités de pêche. L'auteur examine des moyens d'incorporer les informations provenant du Programme de contrôle de l'écosystème dans une stratégie de gestion par rétroaction de la pêcherie de krill, pêcherie principale de la Zone de la Convention de la CCAMLR.

Резюме

Программа АНТКОМа по мониторингу экосистемы разрабатывает метод, который может выявить краткосрочные снижения в биологической эффективности (напр. эффективность воспроизводства) размножающихся на суше хищников, возможно вызванные потерями пищи в результате промысла. Главным промыслом в зоне действия Конвенции АНТКОМ является промысел криля. В настоящей работе рассматривается каким образом можно включить в стратегию управления этим промыслом с обратной связью информацию, получаемую в рамках Программы по мониторингу экосистемы.

Resumen

El Programa de Seguimiento del Ecosistema de la CCRVMA ha estado desarrollando una técnica que podría detectar la reducción, a corto plazo, en el rendimiento de los depredadores terrestres (por ejemplo, el rendimiento reproductor) y que podría atribuirse a la pérdida de especies presa causada por las actividades de pesca. La pesquería de kril es la

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pesquería de mayor importancia que se realiza en el Area de la Convención de la CCRVMA y este documento examina la manera en que la información obtenida por el Programa de Seguimiento del Ecosistema podría incorporarse en la estrategia de administración interactiva para esta pesquería.

1. INTRODUCTION

The need to establish conservation measures on the Antarctic krill fishery to protect both krill and predator populations has been the subject of many recent discussions (see Nicol, 1991 for review) and resulted in the establishment of a Precautionary Catch Limit of 1.5 million tonnes in the Atlantic Sector of the CCAMLR Convention Area at the Tenth Meeting of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR, 1991). The Commission has given a high priority to the establishment of additional precautionary catch limits in the other parts of the Convention Area as well as the establishment of conservation measures to ensure that sufficient krill remain available to meet the needs of predators. Also, the Commission agreed that feedback management should be developed for the krill fishery (CCAMLR, 1991 - paragraph 4.9).

The Working Group on the CCAMLR Ecosystem Monitoring Program (WG-CEMP) has the responsibility of providing advice to the CCAMLR Scientific Committee on the effects that fishing may have on species dependent on or related to the target species. It has been developing a program intended to detect short term declines in land-based predator performance (e.g., reproductive performance) that may be attributable to loss of prey through fishing activities (Anon., 1989; Croxall, 1989).

The development of a useful approach to the maintenance of predator populations, including the recovery of depleted whale populations, by the CCAMLR Convention requires an examination of the design of the CEMP so that advice arising from WG-CEMP will not inadvertently affect other predators and can be utilised in a feedback management procedure by the Commission. This paper examines some of the issues that need to be addressed by the Scientific Committee in evaluating how the CEMP can be utilised to protect predators from adverse effects arising from the krill fishery.

2. FEEDBACK MANAGEMENT

Feedback management uses information on the status of the ecosystem to alter the levels of harvesting in order to ensure that the desired state of the ecosystem is sustained (de la Mare, 1991). This process relies on a field program that monitors the status of important features of the ecosystem (such as the krill stocks and predators) as well as the conduct of the fishery (de la Mare, 1986 and 1991). The Scientific Committee uses this information to advise the Commission as to whether the ecosystem or some of its components (krill stocks and/or predators, etc.) are being affected or are likely to be affected by krill harvesting. The Commission then can formulate or alter conservation measures based on options in Article IX of the CCAMLR Convention and dictated by the management procedure (see de la Mare, 1991 for discussion).

The important aspect of feedback management is that the monitoring program can provide information that triggers action by the Commission in sufficient time to ensure that the objectives set out in Article II of the CCAMLR Convention are not contravened.

3. APPROACHES TO PREDATOR PROTECTION

Once fishing has begun in a particular area, Article II can be translated, in the case of the predators, to ask the general question "Will fishing for krill at the specified level cause the health of predator populations to decline below an acceptable level?".

There are two issues that arise from this general question. First, the degree of change (decline) in the predator parameters that is considered acceptable (i.e., for which no management action is required) needs to be specified. Second, the approach taken to monitor and assess the status of the ecosystem needs to be one that minimises errors in interpretation and action by the Commission. The above question can be addressed by using either mensurative or experimental approaches.

3.1 Specification of Acceptable Changes in Predator Populations

The provision of advice by the Scientific Committee to the Commission on the status of the Antarctic marine ecosystem is contingent on a view established by the Commission as to what is an unacceptable state of either individual predator populations or of the community at large. While some attempts have been made to describe positive and negative aspects of change in predator populations and communities (e.g., Croxall *et al.*, 1988) and the scale at which interactions between different species needs to be considered (e.g., Murphy *et al.*, 1988) there has been no systematic evaluation of the status of predators required to maintain ecological relationships as described in Article II. As a result, the goals in predator protection for the krill fishery are difficult to define.

3.2 The Mensurative Approach to Ecosystem Monitoring

The current approach used by WG-CEMP to determine the effects of fishing is to construct models of the predator-prey system in the area in which harvesting occurs and examine the possible effect that a reduction in prey availability may have on predator performance. These models are based on knowledge of the diets of predators and estimates of predator and prey abundances and life history parameters. Although a study of penguins off the Antarctic Peninsula has indicated that the recent decline of their populations may be attributed to a shortage of krill (Anon., 1991), the interpretation of short-term changes in predator parameters are still uncertain due to the inability to relate these directly to changes in krill abundance (Croxall, 1989) or environmental features, such as ice conditions (e.g., Trivelpiece *et al.*, 1990).

Additional to the problems of understanding how environmental and biological factors may influence predators is the lack of knowledge on what may have happened to these predator populations had there been no fishing. Consequently, predictions of future changes in predator performance in response to fishing pressure are difficult to make.

The uncertainty in these models highlighted by Croxall (1989) has led WG-CEMP and the Scientific Committee to agree that "analysis and evaluation of submitted CEMP data and developments of recommendations based thereon did not require, and should not await, the determination of the precise quantitative nature of predator/prey/environmental relationships." (SC-CAMLR, 1990 - paragraph 5.4). While this provides an important opportunity to give advice on predator status there has been no indication by the Commission of the required precision of such advice before it will be used to formulate conservation measures for the krill fishery.

3.3 The Experimental Approach to Ecosystem Monitoring

Monitoring of the impact of krill harvesting on predators using a controlled fishing regime may avoid many of the problems associated with the elaboration of ecosystem models

fundamental to the current approach in the CEMP (Nicol and Constable, 1991). The development of experimental fishing regimes to clarify the effects of fishing on the Antarctic marine ecosystem has been advocated for many years (e.g., Beddington and de la Mare, 1985; de la Mare, 1986 and 1991; SC-CAMLR, 1991 - paragraph 11.13). The principle approach that has been proposed is to identify management areas based on biological characteristics (e.g., Chittleborough, 1987; de la Mare, 1991) and to monitor the performance of predators in selected areas that are within the proximity of fishing (such as the current CEMP areas) and compare this to predator performance in control areas that are far from the effects of fishing.

The rationale for spatial and temporal replication of monitoring programs has been developed mostly for non-fishing human impacts on marine systems (see Green, 1979; Stewart-Oaten *et al.*, 1986; Underwood, 1990 and 1991, for background and discussion). However, the principles are easily transferred to fisheries. In the context of the krill fishery, these designs focus on the question of whether changes in predator performance in areas being fished are likely to be different from changes that may have occurred in the absence of fishing. To do this, these authors specify that a number of replicate control areas are required in addition to the experimental areas (even if only one experimental area is being used). They also recommend that unambiguous interpretation of changes in predator performance in the experimental areas is facilitated by having the monitoring program proceed in all experimental and control areas before fishing begins as well as after it has begun. This is known as the 'Before-After-Control Impact' (BACI) design. Here, the prediction is that, if fishing affects the predators, the naturally occurring differences between experimental and control areas in the absence of fishing will alter (become smaller or larger) after fishing begins.

Further, the ability to determine the effects of fishing could be facilitated by attempting to control for environmental parameters, such as ice conditions, and prey abundances.

An elaboration of this approach was discussed briefly at the 1991 Meeting of the Scientific Committee (SC-CAMLR, 1991 - paragraph 11.13) indicating that control and experimental sites may be able to be established in the near future.

4. DISCUSSION

There are considerable differences of opinion in the ecological literature as to which method (mensurative or experimental) is more appropriate. However, the method that is chosen and the resulting design in the monitoring program should meet the following criteria:

(i) the program has sufficient power to signal that action needs to be taken by the Commission to prevent the fishery from negatively affecting the predators (or, in the case of testing the effectiveness of conservation measures, that the predators are no longer being affected by the fishery) (Peterman, 1990);

(ii) its cost is commensurate with the value of the fishery (de la Mare, 1991); and

(iii) it is feasible.

WG-CEMP now has the data available to begin examining, using analytical and simulation techniques, the potential designs and analyses of monitoring programs that meet these criteria. While the mensurative approach has been the focus of WG-CEMP so far this should not preclude an examination of the experimental approach, despite the existing CEMP sites being concentrated mostly within only a few areas from which most of the krill catch is taken.

Further, the WG-CEMP needs to examine the long-term implications of recommendations it gives to the Scientific Committee. For example, its suggestion that it may be desirable to prohibit fishing from the foraging range of land-based predators during their reproductive

season in the Atlantic sector, where a high proportion of the krill catch is taken currently (SC-CAMLR, 1991 - paragraph 6.34), may impact on the capacity for the WG-CEMP to provide management advice derived from predator performance in these areas. Similarly, the potential impact of a shift in fishing effort to unmonitored areas, such as whale feeding grounds, would need to be addressed.

In summary, two important issues need to be addressed by WG-CEMP and WG-Krill:

(i) the status of predators required to maintain ecological relationships as described in Article II of the CCAMLR Convention; and

(ii) the design of CEMP that ensures a low probability of errors in interpretation on the status of the ecosystem and consequent action by the Commission.

In the event that no design of the CCAMLR Ecosystem Monitoring Program is able to meet the above criteria, the Scientific Committee and Commission will need to examine other methods for protecting land- and sea-based predators from adverse effects that may arise from the krill fishery.

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BIBLIOGRAPHY

ANON. 1991. Penguins losing the struggle. *Nature*, 350: 294.

BEDDINGTON, J.R. and W.K. DE LA MARE. 1985. Marine mammal-fishery interactions: modelling and the Southern Ocean. In: BEDDINGTON, J.R., R.J.H. BEVERTON and D.M. LAVIGNE (Eds). *Marine Mammals and Fisheries*. Allen and Unwin, Boston: 94-105.

CCAMLR. 1991. *Report of the Tenth Meeting of the Commission (CCAMLR-X)*. CCAMLR, Hobart, Australia: 427 pp.

CHITTLEBOROUGH, R.G. 1987. A rationale for conservation areas within Antarctic waters. In: *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4)*. CCAMLR, Hobart, Australia: 513-535.

CROXALL, J. P. 1989. Use of indices of predator status and performance in CCAMLR management strategies. In: *Selected Scientific Papers, 1989 (SC-CAMLR-SSP/6)*. CCAMLR, Hobart, Australia: 353-365.

CROXALL, J.P., T.S. MCCANN, P.A. PRINCE, and P. ROTHERY. 1988. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: Implications for Southern Ocean monitoring studies. In: SAHRHAGE, D. (Ed.) *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin: 261-285.

DE LA MARE, W. K. 1986. Some principles for fisheries regulation from an ecosystem perspective. In: *Selected Scientific Papers, 1986 (SC-CAMLR-SSP/3)*. CCAMLR, Hobart, Australia: 323-339.

DE LA MARE, W. K. 1990. Factors to consider in developing management measures for krill. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/7).* CCAMLR, Hobart, Australia: 175-188.

GREEN, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists.* Wiley, New York.

MURPHY, E.J., D.J. MORRIS, J.L. WATKINS and J. PRIDDLE. 1988. Scales of interaction between Antarctic krill and the environment. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability.* Springer-Verlag, Berlin: 120-130.

NICOL, S. 1991. CCAMLR and its approaches to management of the krill fishery. *Polar Record,* 27 (162): 229-236.

NICOL, S. and A.J. CONSTABLE. 1991. When will the information required for rational management of the krill fishery become available and what should CCAMLR do in the meantime? Document *WG-Krill-91/26.* CCAMLR, Hobart, Australia: 21 pp.

PETERMAN, R.M. 1990. Statistical power analysis can improve fisheries research and management. *Can. J. Fish. Aquat. Sci.,* 47: 2-15.

SC-CAMLR. 1990. *Report of the Ninth Meeting of the Scientific Committee (SC-CAMLR-IX).* CCAMLR, Hobart, Australia: 354 pp.

SC-CAMLR. 1991. *Report of the Tenth Meeting of the Scientific Committee (SC-CAMLR-X).* CCAMLR, Hobart, Australia: 427 pp.

STEWART-OATEN, A., W. MURDOCH and K. PARKER. 1986. Environmental impact assessment: 'Pseudoreplication' in time. *Ecology,* 67: 929-940.

TRIVELPIECE, W.Z., S.G. TRIVELPIECE, G.R. GEUPEL, J. KJELMYR and N.J. VOLKMAN. 1990. Adélie and chinstrap penguins: their potential as monitors of the Southern ocean marine ecosystem. In: KERRY, K.R. and G. HEMPEL (Eds). *Antarctic Ecosystems. Ecological Change and Conservation.* Springer-Verlag Berlin Heidelberg: 191-202.

UNDERWOOD, A.J. 1990. Experiments in ecology and management: their logics, functions and interpretations. *Aust. J. Ecol.,* 15: 365-389.

UNDERWOOD, A.J. 1991. Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Aust. J. Mar. Freshw. Res.,* 42: 569-587.