SURVEY DESIGN TO ESTIMATE KRILL ABUNDANCE DURING FIBEX

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Abstract

One of the primary aims of FIBEX (First International BIOMASS Experiment), 1981 was to study the methodology for assessing the abundance of krill. The survey design used in the southwest Atlantic study area of the FIBEX is described in this papers. Sampling involved the use of echosounders for estimating krill abundance as well as collection of data on the size, density and distribution of krill swarms. In addition, information on surface water temperature, salinity and fluorescence as well as on seabirds was also collected. The study area was subdivided into several geographically distinct subareas in each of which randomly spaced transects were located. Subarea were treated as strata and a stratified random sampling method was used. The survey was done in two phases. In the first phase a fairly evenly dispersed subsample of transects was surveyed and these were also used to fix stratum boundaries. In the second phase the remaining transects were surveyed, using the stratum boundaries defined from the first phase. The design of the survey was directly related to the subsequent method of data analyses, some main aspects of which are discussed. The analytical formulae for the analyses are also presented.

Résumé

L'un des objectifs principaux de la FIBEX (Première expérience internationale BIOMASS), 1981 était d'étudier la méthodologie de l'évaluation de l'abondance du krill. Le modèle de prospection utilisé dans la zone d'étude de l'Atlantique sud-ouest est décrite dans ce document. L'échantillonnage a nécessité l'utilisation d'échosondeurs pour estimer l'abondance du krill ainsi que la collecte des données sur la taille, la densité et la distribution des essaims de krill. En sus, des informations ont été recueillies sur la température de l'eau de surface, la salinité et la fluorescence ainsi que sur les oiseaux de mer. La zone d'étude a été subdivisée en plusieurs sous-zones géographiques distinctes, dans chacune desquelles des transects ont été disposés au hasard. Ces sous-zones ont été considérées comme des strates et une méthode d'échantillonnage au hasard par couche a été utilisée. L'étude a été effectuée en deux phases. Dans la première phase, un sous-échantillon de transects, éparpillés de façon assez uniforme, a été étudié et ceux-ci ont aussi été utilisés pour établir les limites des strates. Dans la deuxième phase, le reste des transects a été étudié en utilisant les limites des strates établies au cours de la première phase. Le modèle de l'étude a un rapport direct avec la méthode subséquente des analyses de données, dont quelques aspects importants sont discutés. Les formules analytiques utilisées dans le traitement des données ont aussi été présentées.

Резюме

Одной из первейших задач программы FIBEX (Первый международный эксперемент BIOMASS), 1981 г., было изучение методологии при оценке численности криля. В этой работе описывается планирование съемки, использованное в юго-восточном атлантическом районе исследования FIBEX. Выборка включала в себя использование гидроакустических приборов для оценки численности криля, а так же для сбора данных о размере, плотности и распространении скоплений криля. Кроме того, была собрана информация о температуре поверхностного слоя воды, солености и флуоресценции, а также о морских птицах. Исследуемый район был разделен на несколько географически обособленных подрайонов, в каждом из которых были произведены гидрологические разрезы на произвольно выбранном расстоянии друг от друга. Подрайоны рассматривались как стратум, и использовался стратифицированный метод произвольной выборки. Съемка производилась по двум этапам. На первом этапе под наблюдением находилась равномерно рассредоточенная часть пробы разрезов, использованных также для определения границ стратума. На втором этапе обследовались оставшиеся разрезы при использовании границ стратума, определенных на первом этапе. Планирование съемки было непосредственно связано с последующим методом анализа данных, некоторые основные аспекты которых здесь обсуждаются. Также представляется аналитическая формула для этого анализа.

Resumen

Uno de los objetivos principales del FIBEX (Primer Experimento Internacional de la BIOMASA), en 1981 fue el estudio de la metodología para evaluar la abundancia del krill. Se describe en este documento el diseño de la prospección utilizado en el área de estudio del FIBEX en el suroeste Atlántico. El muestreo requirió el uso de ecosondas para estimar la abundancia del krill, así como la recopilación de datos sobre la talla, densidad y distribución de los cardúmenes de krill. Asimismo, se recogió información sobre la temperatura, salinidad y fluorescencia de las aguas superficiales así como sobre las aves marinas. El área de estudio fue subdivida en varias subáreas geográficamente distintas, colocándose en cada una de ellas transectos espaciados aleatoriamente. Se trató a las subáreas como estratos y se utilizó un método de muestreo aleatorio estratificado. Se realizó la prospección en dos fases. En la primera fase se prospeccionó una submuestra de transectos dispersados de modo uniforme, los cuales se utilizaron también para determinar los límites del estrato. En la segunda fase se prospeccionaron los transectos restantes, utilizando los límites del estrato definidos en la primera fase. El diseño de la prospección estuvo directamente relacionado con el método subsiguiente de análisis de datos. Se discuten algunos aspectos principales del mismo. Asimismo se plantean las formulas analíticas para el análisis.

1. INTRODUCTION

Increasing interest in the marine living resources of the Southern Ocean has highlighted significant gaps in our knowledge of their basic ecology. This is particularly true of Antarctic krill (*Euphausia superba*). Against this background and in view of the developing fishery for krill it is necessary to provide a sound framework for future research. This has resulted in the formation of BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks). The principal objective of BIOMASS is to gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for future management of potential living resources (SCAR 1977).

Estimation of krill abundance was identified as being one of the key topics for study and this became one of the major investigations for FIBEX (First International BIOMASS Experiment). The primary aims of FIBEX (BIOMASS 1980a) were:

1. To study the methodology for assessing the abundance of the total krill population.

2. To map the distribution of krill in parts of the southwest Atlantic, southern Indian and western Pacific sectors of the Southern Ocean and if possible relate the distribution of krill to the distribution of water masses.

3. To obtain a synoptic assessment of the abundance of krill in the south-west Atlantic sector of the Southern Ocean.

It was anticipated that about 12 vessels from 11 nations might participate in the experiment. The coordinated multiship part of the study was scheduled to take 30 days. Two main areas were identified for study, in the southwest Atlantic and the southeast Indian Ocean. A greater level of sampling activity per unit area was expected in the former area and this allowed a more sophisticated survey design, described here, to be used.

2. SAMPLING PROGRAMME

Underway sampling centred on the use of echosounders for estimating krill abundance and also providing information on the size, density and distribution of krill swarms. The requirements in this field were as follows:

1. Data should be integrated along the shortest track interval that practical limitations allow (generally this interval would be one nautical mile).

2. Data should be reported as mean volume back-scattering strength.

3. The depth, size and density of swarms should be estimated either by processing of digitised echosignals or from examination of echocharts with respect to integrator output.

4. The operating frequency of echosounders should be between 50 and 200 kHz. The standard frequency would be 120 kHz.

In addition, underway observations were requested for surface temperature, salinity, fluorescence and observations on seabirds.

3. SURVEY DESIGN

3.1 Anticipated Distribution of Krill

Published information indicated that krill would be distributed northwards from the pack ice zone (Marr 1962; Mackintosh 1973) with the abundance decreasing rapidly some distance from the ice edge.

3.2 Selection of Transects

The design used in the Atlantic Sector of the FIBEX survey was that recommended in BIOMASS (1980b). The Sector was subdivided into several geographically distinct subareas (Figure 1) in each of which parallel, randomly spaced sample transects were located. Subareas were treated as strata, the result being a stratified random sample of transects analysable by standard statistical methods as recommended, for example, by Cochran (1977).

For a given subarea (stratum) the direction of transects was chosen to run across the direction of ocean currents and thus across the probable contour lines of krill abundance. Generally, therefore, transects tended to run north/south, the northern boundary of a stratum being determined by the limit of the krill population. Since this limit had to be defined during the survey, the pre-determined sample of transects was surveyed in two phases.

In the first phase a fairly evenly dispersed subsample of transects was surveyed and these were also used to fix stratum boundaries. The second-phase transects, that is, selected transects not surveyed in the first phase, were surveyed on the return journey to base, using the stratum boundaries defined from the first phase. This meant that second-phase transects tended to be shorter than first-phase transects, which gave strata of the shape seen in Figure 2, the procedure being unbiassed as far as estimation of krill population was concerned and efficient inasmuch as no transect data had to be discarded. In practice, in order to achieve the maximum of survey time in the total available time (about 30 days) each Chief Scientist made calculations throughout the survey as to how many transects could be included in the time remaining, deleting transects as necessary from the list according to pre-assigned random numbers.

A further advantage of the two-phase system was that it allowed a larger number of transects to be sampled in strata of apparently higher density, thus further increasing sampling efficiency (see Cochran 1977).

3.3 Associated Analysis

Since the design of a survey has a direct bearing on the subsequent method of data analyses, some comment on this is desirable here. The main considerations are:

1. Assuming that an unbiassed estimate of mean krill density can be obtained for each sampled transect, the design is capable of providing an unbiassed estimate of density for each stratum.

2. Stratification ensures that major sources of variation are eliminated from the overall estimate of mean density for the region.

3. Randomisation ensures that (a) an unbiassed estimate of the variance of mean density is obtainable, and (b) the possibility of bias, such as might arise if

equally spaced transects were to coincide with a periodicity in the krill distribution, is eliminated.

4. By taking account of the different lengths of the sampled transects, the variance can be further reduced. The appropriate method for the present circumstances is a ratio-to-size estimate in which transect means are weighted by their length in calculating the stratum mean. Although, in general, ratio estimates are subject to small-sample bias, it can be shown that this bias is zero when the ratio of the observed variate (biomass) to the supplementary variate (transect length) for a particular sampling unit (transect) is uncorrelated with the supplementary variate; these conditions can be assumed to apply here as density is unlikely to be related to transect length. This source of bias was considered negligible in the present survey. For a detailed discussion of ratio estimation the reader is referred to Cochran (1977) or other standard texts on sampling methods.

5. Confusion sometimes arises when a variance is estimated from a sum of squares of deviations of transect means from the stratum mean, the procedure is so simple that it is thought not to take account of serial correlations between or within transects or of other features of the distribution pattern (for example, aggregations). Such a belief, of course, is wholly incorrect. These methods make no assumptions whatever as to distribution patterns and are entirely valid for any population, provided of course, that selection of transects is at random within a stratum. A full account of the analytical methods used is given in BIOMASS (1985).

4. ANALYTICAL FORMULAE

The surveyed area contains J strata whose individual areas are denoted by A_j. Each stratum is composed of K transects and each transect contains M distance intervals. The useable length of one of the transects is therefore given by the formula:

$$L_k = \sum_{m=1}^{M_k} (D_k)_m$$

The mean weight density for each transect is given by the formula:

$$\overline{W}_k = \frac{1}{L_k} \sum_{m=1}^{M_k} (\overline{W}_k)_m \cdot (D_k)_m$$

The mean weight density within a stratum is given by the formula:

$$\overline{W}_k = \frac{\sum_{k=1}^{K} \overline{W}_k \cdot L_k}{\sum_{k=1}^{K} L_k}$$

and the mean weight density for J non overlapping strata is given by the formula:

$$\overline{W} = \frac{\sum_{j=1}^{J} (\overline{W_k})_j A_j}{\sum_{j=1}^{J} A_j}$$

The variance of the within stratum mean weight density (W_k) is given by the formula:

$$\text{Var}(W_k) = \frac{K \bullet \sum_{k=1}^{K} (\overline{W_k} - \overline{W_K})^2 L_k^2}{(K-1) \bullet (\sum_{k=1}^{K} L_k)^2}$$

The deviation of these formulae is given fully in BIOMASS (1986).

5. FIELDWORK

A total of 10 ships from Argentina, Australia, Chile, France, Federal Republic of Germany, Japan, Poland, South Africa, the USA and the USSR participated in the FIBEX acoustic survey. This allowed full coverage of virtually the whole area initially planned with the exception of the South Georgia subarea, allotted to the UK who withdrew due to mechanical breakdown of RRS *John Biscoe*. A part of the South Georgia subarea was covered by scientists from the USSR on the research vessel *Odyssee*.

Inevitably the FIBEX survey generated large datasets which are being analysed by several groups. A resume of the datasets has been published (Hempel 1983) while a detailed analysis on abundance estimation has been prepared (BIOMASS 1986).

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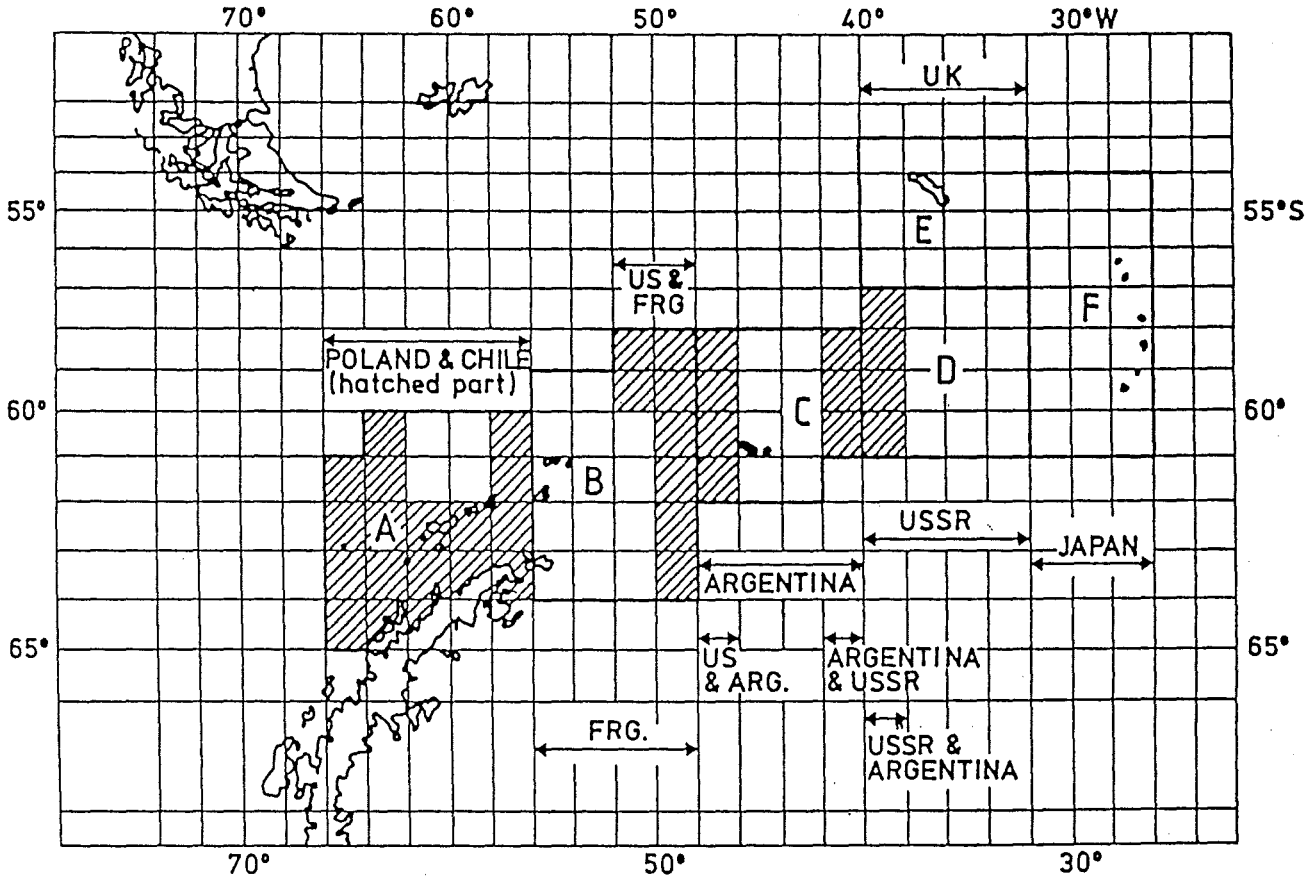

Figure 1: Proposed FIBEX survey areas in the Southwest Atlantic sector of the Southern Ocean (BIOMASS 1980a).

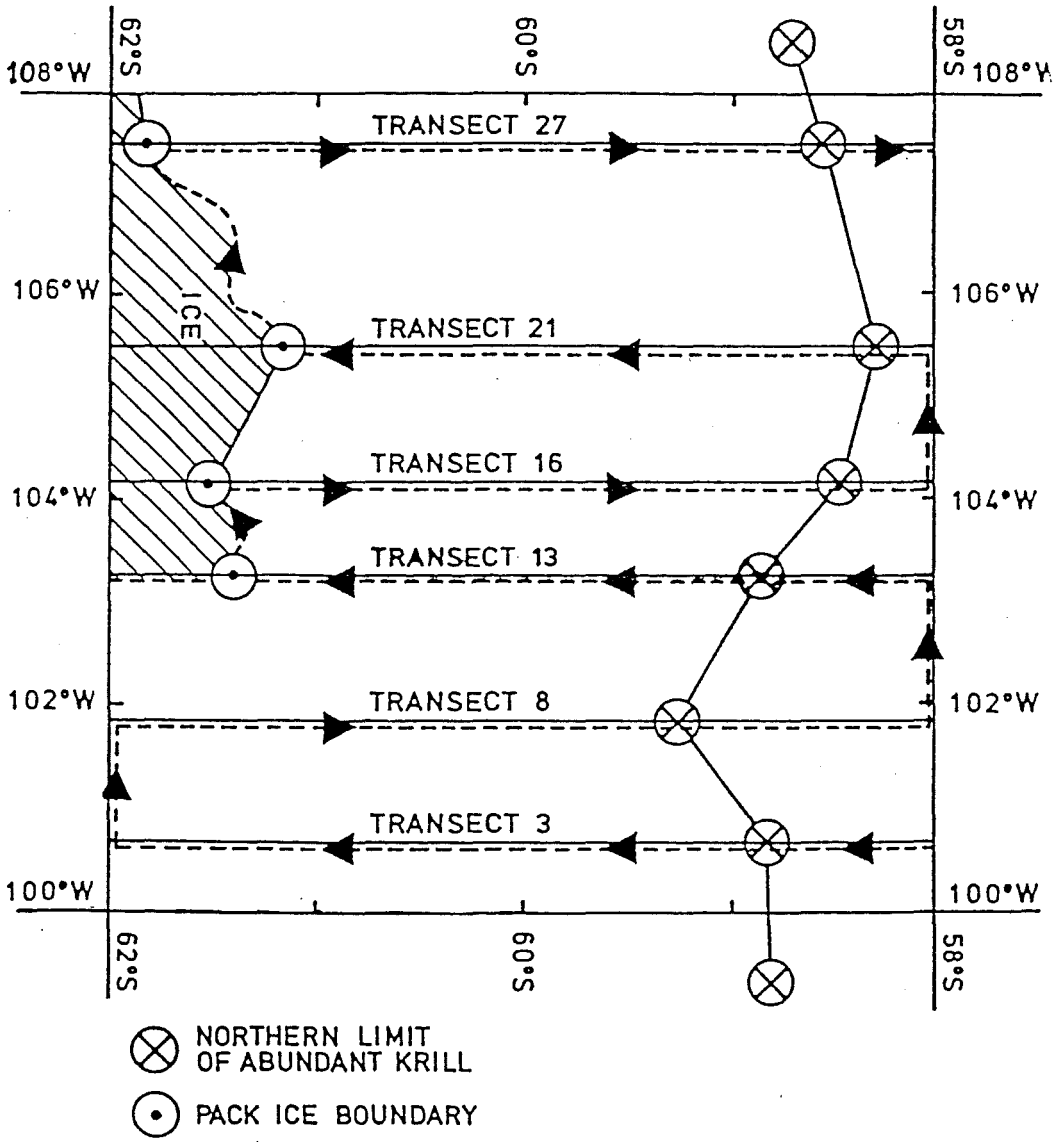

Figure 2: Example of a survey subarea at the end of the primary phase (after BIOMASS 1980b). Phase 2 transects would be run only in the anticipated high density stratum between the pack ice boundary and the northern limit of abundant krill.

Légende de la figure

Figure 1 Zones d'étude proposées de la FIBEX dans le secteur sud-ouest Atlantique de l'océan Austral (BIOMASS 1980a).

Figure 2 Exemple d'une sous-zone d'étude à la fin de la phase primaire (après BIOMASS 1980b). Les transects de la Phase 2 ne seraient effectués que dans la strate de haute densité anticipée entre la limite de la banquise et la limite nord du krill abondant.

Подписи к рисункам

Рисунок 1 Предлагаемые районы съемки (FIBEX) в юго-западном секторе Южного океана (BIOMASS 1980a).

Рисунок 2 Пример съемки подрайона в конце первичной стадии (после BIOMASS 1980b). Поперечные разрезы будут осуществлены только в предполагаемом слое высокой плотности между границей пакового льда и северным лимитом обильного криля.

Leyenda de la Figura

Figura 1 Areas de prospección FIBEX propuestas en el sector del Sudoeste Atlántico del Océano Austral (BIOMASS 1980a).

Figura 2 Ejemplo de una subárea de prospección al final de la primera fase (después de BIOMASS 1980b). Los transectops de la fase 2 se llevarían a cabo únicamente en el estrato de alta densidad anticipado entre el límite del hielo a la deriva y el límite norte de abundancia del krill.