NOTE ON ESTIMATING KRILL ABUNDANCE FROM ACOUSTIC DATA ON INDIVIDUAL AGGREGATIONS

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Abstract

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

Résumé

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

Резюме

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

Resumen

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

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1. INTRODUCTION

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

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

2. ABUNDANCE ESTIMATION BY ECHO-INTEGRATION

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

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

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

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

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

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

C = system constant, incorporating equipment parameters and mean target strength.

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

3. ABUNDANCE ESTIMATION FROM AGGREGATION DENSITY

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

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

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

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

and

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

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

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

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

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

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

where $\left(\bar{\mathbf{I}}'_k\right)_1$ is the average intensity for ping i from aggregation k, averaged over $(\mathbf{h}_k)_i$, the vertical limits of the aggregation at that point, and n_k is the number of pings received from aggregation k. Substitution of $\bar{\mathbf{I}}_k$ in Equation 2 gives $\left(\bar{\mathbf{I}}\right)_j$, and hence $\bar{\rho}_j$ from Equation 1.

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

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

4. ABUNDANCE ESTIMATION FROM AGGREGATION BIOMASS

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

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

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

5. CONCLUSION

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

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

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