CHOOSING DISTANCE BETWEEN ACOUSTIC SURVEY TACKS

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Abstract

A mathematical model was used to show that the distance between acoustic survey tacks can reasonably be selected on the basis of typical size of the surveyed region, allowable relative error in the biomass estimate, and the variation coefficient of the density values of the krill concentrations. It is recommended that the suggested criterion be applied in real hyroacoustic surveys.

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CHOISIR LA DISTANCE ENTRE LES BORDEES D'ETUDE ACOUSTIQUE

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Résumé

Un modèle mathématique a été utilisé pour démontrer que la distance entre les bordées d'étude acoustique peut être raisonnablement sélectionnée en se basant sur l'étendue type de la région à l'étude, sur l'erreur relative permissible dans l'estimation de la biomasse et sur le coefficient de variation des valeurs de densité des concentrations de krill. Il est recommandé que le critère suggéré soit appliqué dans les études hydroacoustiques réelles.

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SELECCION DE DISTANCIA ENTRE LOS CAMBIOS DE RUMBO DE LAS PROSPECCIONES ACUSTICAS

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Resumen

Se utilizó un modelo matemático para demostrar que la distancia entre los cambios de rumbo de las prospecciones acústicas se pueden seleccionar razonablemente basándose en el tamaño típico en la región que se inspecciona, en el error relativo admisible en el cálculo de la biomasa, y en el coeficiente de variación de los valores de densidad de las concentraciones de krill. Se recomienda que el criterio sugerido se aplique en las prospecciones hidroacústicas reales.

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ВЫБОР РАССТОЯНИЯ МЕЖДУ ГАЛСАМИ ПРИ АКУСТИЧЕСКОЙ СЪЕМКЕ

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Резюме

Используется математическая модель, демонстрирующая, что расстояние между галсами при акустической съемке целесообразно выбирать, основываясь на типичном размере обследуемого района, допустимой относительной погрешности в оценке биомассы и коэффициенте вариации величин плотности концентраций криля. Рекомендуется применение предлагаемых критериев при проведении настоящих гидроакустических съемок.

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CHOOSING DISTANCE BETWEEN ACOUSTIC SURVEY TACKS

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Choosing the frequency of survey tacks is an important aspect of acoustic surveying tactics. The allowable time for the study of a given area usually determines the choice of distance between tacks. However, it is not only the economic aspect but also the overall value of the survey which is determined by the tack frequency. The distance between tacks should therefore be selected so as to provide the desired accuracy of the biomass assessment in the area, in the least time and with the lowest expenditure.

Since the error in biomass assessment depends on the variability of the random concentration density field, the choice of tack frequency should be based on statistical characteristics of the field. It was recently recommended to fix tacks at a distance somewhat exceeding the correlation radius, which is the minimal distance at which the density values are not related statistically (Yudanov et al, 1984).

However, the biomass assessment error corresponding to such a tack frequency has not been found. Moreover, determination of the correlation radius prior to a detailed survey is complicated. It is easier to evaluate the other statistical index of the extent of variability - the coefficient of variation of density values in the given area*.

Developing criteria for choosing the distance between tacks requires a knowledge of the relationship between the biomass assessment error and the tack frequency when surveying density fields with different

* The variation coefficient is the ratio of the standard deviation to the average value. All values (zero inclusive) should be taken into account when calculating the variation coefficient.

variation coefficients. Since the actual biomass under real conditions is unknown, the problem was solved using computerized mathematical simulation techniques. The mathematical model used is based on the results of analysis of data from actual hydroacoustic surveys. The model consists of two parts, one imitating density field and the other the echo-sounder survey (Kizner et al, 1982; Kizner, 1984).

The density field model is an array of 2500 figures making up a matrix of 50 lines by 50 columns. Concentrations of fishing species are imitated by patches of irregular shape; density outside the patches is zero while it grows from the outer edge towards the inside according to a certain law obscured by random fluctuations. The patches may be separate, adjoin or overlap, so forming bigger concentrations which we call aggregations. Concentrations may be static (example in Figure 1), or dynamic in which case motion may alter the shape of the patches. True statistical characteristics of the field, and the biomass of the fishing species are calculated.

This is followed by simulating hydroacoustic surveys having parallel tacks i.e. the distance between tacks in each survey is constant. All density values at points crossed by tacklines are considered measured. The results of surveying the entire area or a part are processed by the methods of mean weighted assessment, global and local averaging. The statistical characteristics of field density, and of fishing species biomass are estimated. The average value of biomass estimates obtained by various methods is calculated.

The following parameters may vary in the model : the number, size and location of concentrations, the trajectory and speed of their movement, the vessel speed during the survey, the density distribution in the patch, the distance between tacks, the position of the starting point, the extension of tacks, the form and size of the surveyed area, and the number of strata in local averaging.

The statistical relationship between the frequency of tacks, and the biomass assessment error was found by simulating 11 density fields and 108 hydroacoustic surveys. All concentrations were static, but varied in character and size. We used the laws of density distribution in the patch obtained by analysing data from actual hydroacoustic microsurveys. A series of surveys with different distances between tacks was simulated for each field of density.

Comparison of biomass estimates obtained by different methods at different tack frequencies indicated that the error mostly depends on the surveying tactics, rather than on the method of calculating the biomass estimate. The data from the numerical simulations, and results of their mathematical processing are given in Figure 2. Errors were random so their absolute values are given. The empirical relationship of the relative biomass assessment error δ (in fractions of one) to the density values variation coefficient ν, and of the ratio of the distance between tacks r to the typical area size l is well approximated by the following function :

$$\frac{r}{l} = \frac{\sqrt{\delta}}{\nu} \qquad (1)$$

The presence of a simple and statistically significant dependence (1) supports the hypothesis of the possibilty of using the variation coefficient as a field characteristic in choosing tack frequency. Hence, if two fields having different distributions of concentrations have similar variation coefficients (Figure 1), and the biomass assessment error does not exceed the given values, the average distance between tacks will be equal.

Figure 2 indicates that in 56 of 108 model surveys, the distance between tacks was less than the values determined by the expression (1). In 53 of those 56 surveys, the level of biomass assessment error did not exceed the given values. Consequently, if the distance between tacks is equal to or less than the value r calculated by formula (1), the biomass assessment error does not, with 95% probability, exceed the level of δ used in this formula. Since shorter distances between tacks raise the expense of a survey, it is reasonable to choose a distance equal to r.

There are special considerations in determining parameters δ, ν and in real conditions. Biomass assessment error δ_B includes two independent components : hydroacoustical δ_H and tactical δ. The tactical error can therefore be found from the relationship

$$\delta = \sqrt{\delta^2_B - \delta^2_H} \qquad (2)$$

The density values variation coefficient ν can be estimated by the data from the preliminary studies; numerical simulations have shown that this parameter remains relatively stable under decreasing tack frequency. The distance sampling unit in the preliminary study should be sufficiently small not to allow loss of information on the field of concentration density.

Typical size l studies were made theoretically. It was found that this parameter is not dependent on the shape of surveyed region but is rather determined by the region area S, and by the typical relationship between the sizes of concentrations in the reciprocally perpendicular directions k. If one can detect the direction of elongation of concentrations, then the typical ratio of the longitudinal size to the transverse size k>1. Such configuration is typical for concentrations on shelves. In this case, the tacks have to be made across the concentrations (the angle between tacks and the longitudinal direction $\alpha=90^{\circ}$). In the case where the longitudinal and transversal directions cannot be identified (concentrations are directed chaotically or are approximately round in shape), k=1. This situation can be exemplified by krill or other slowly moving concentrations distributed over large oceanic areas. Mathematically, it can be strictly proved that the typical size is determined by the relationship

$$l = \sqrt{kS} \qquad (3)$$

In the event that survey planners do not know the k-parameter, they should assume k=1. If the results of a completed survey indicate that the used biomass values of parameters S, ν, k and α are not accurate, the actual biomass assessment error may differ from the given one, and is estimated by the formula

$$\delta'_B \le \sqrt{\delta_H^2 + \left[\frac{(r\nu')^2}{S'(\frac{1}{k'}\cos^2\alpha' + k'\sin^2\alpha')}\right]^2} \qquad (4)$$

where S', ν', k' and α' are corrected values.

Let us consider an example of finding the distance between tacks of an echo-sounder survey. We assume that in view of the stock exploitation rate and other factors, we have to estimate the biomass with an error $\delta_B \leqslant 30\%$, while the error of the hydroacoustic method applied to the survey conditions $\delta_H \leqslant 20\%$ (Kalikhman, 1982). The area of the surveyed region $S=10^4$ square miles. The results of the preliminary survey indicate that the density values variation coefficient $\nu=3.0$*; the configuration of concentrations is unkown.

In order to choose the distance between tacks we find by formula (2) the allowable tactical error $\delta=\sqrt{30^2-20^2}\approx 20\%=0.2$. Assuming k=1, we use expression (3) to find a typical size $l=\sqrt{10^4}=100$ miles. Substituting values δ, ν and l into formula (1) we find the distance between tacks $r=\frac{100\sqrt{0.2}}{3.0}=15$ miles.

The survey results indicate that concentrations are of elongated shape, and are about similarly directed. Now we shall specify the values of parameters used : area of the surveyed region $S'=1.2\times10^4$ miles^2; variation coefficient $\nu'=3.5$; typical ratio of the concentration longitudinal size to the transverse size $k'=2$; angle between the tacks and the longitudinal direction $\alpha'=45^\circ$. Substituting these values, as well as the value of error of the hyrdoacoustic method into formula (4) we shall estimate the actual biomass assessment error

$$\delta_B' \leq \sqrt{0.2^2+\left[\frac{(15\cdot3.5)^2}{1.2\cdot10^4\left(\frac{1}{2}\cos^2 45^\circ+2\sin^2 45^\circ\right)^2}\right]^2} = 0.35=35\%$$

This criterion for choosing distance between tacks, supported by the mathematical model, is recommended for hydroacoustic surveys of commercial fishing concentrations, but we want to stress that the basic formula (1) was obtained empirically only for the given interval of the δ values.

* Data from several actual hydroacoustic surveys were statistically processed. Estimates of variation coefficient of concentration density values were obtained. Applied to the field studies the variation coefficient changes from 1.0 up to 4.0.

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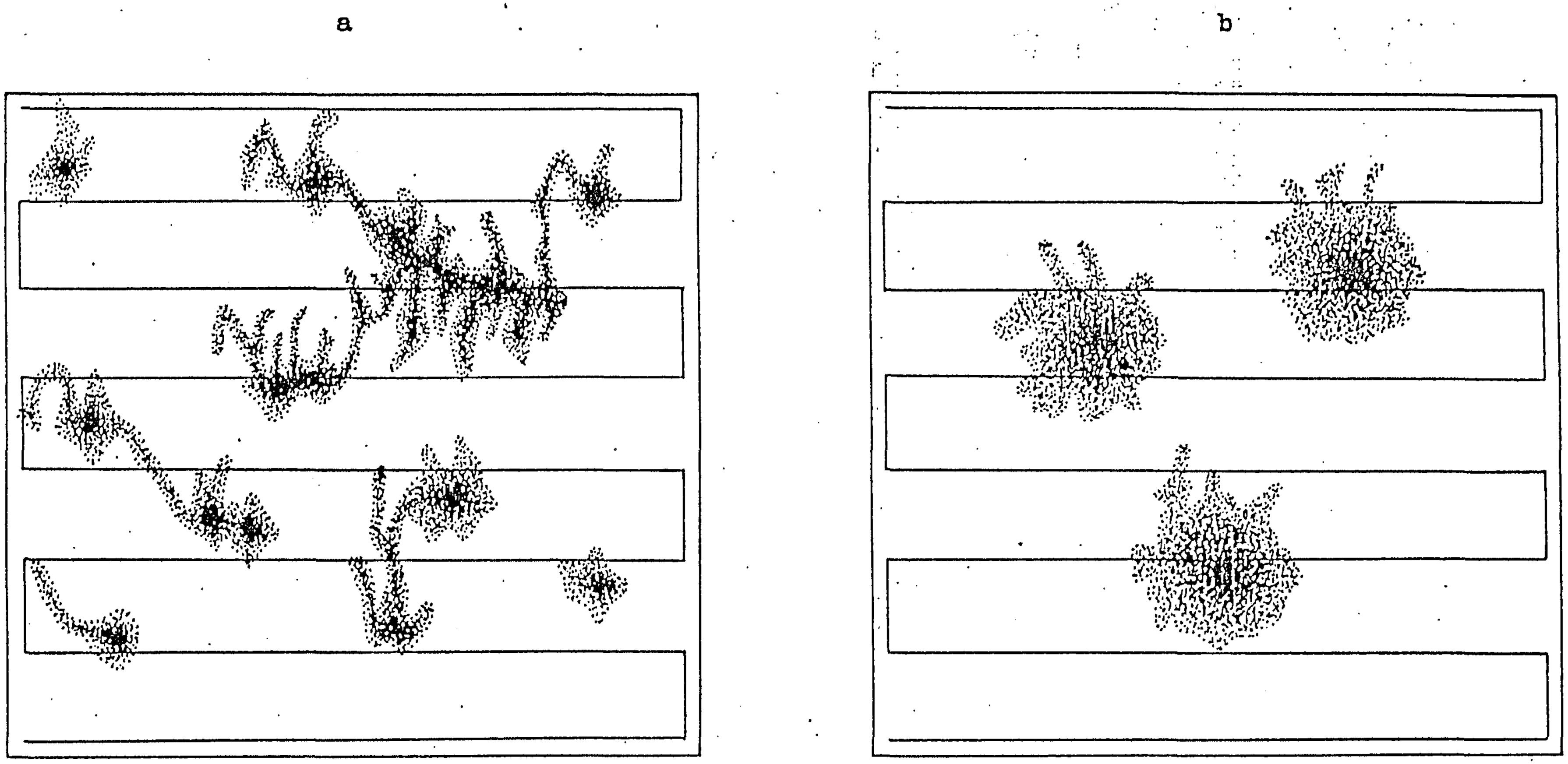

Figure 1 Mathematical models of concentration density fields, and the trajectories of hydroacoustical surveys. Darker range proportional to density. Variation coefficient values : a - 3.1; b - 3.2.

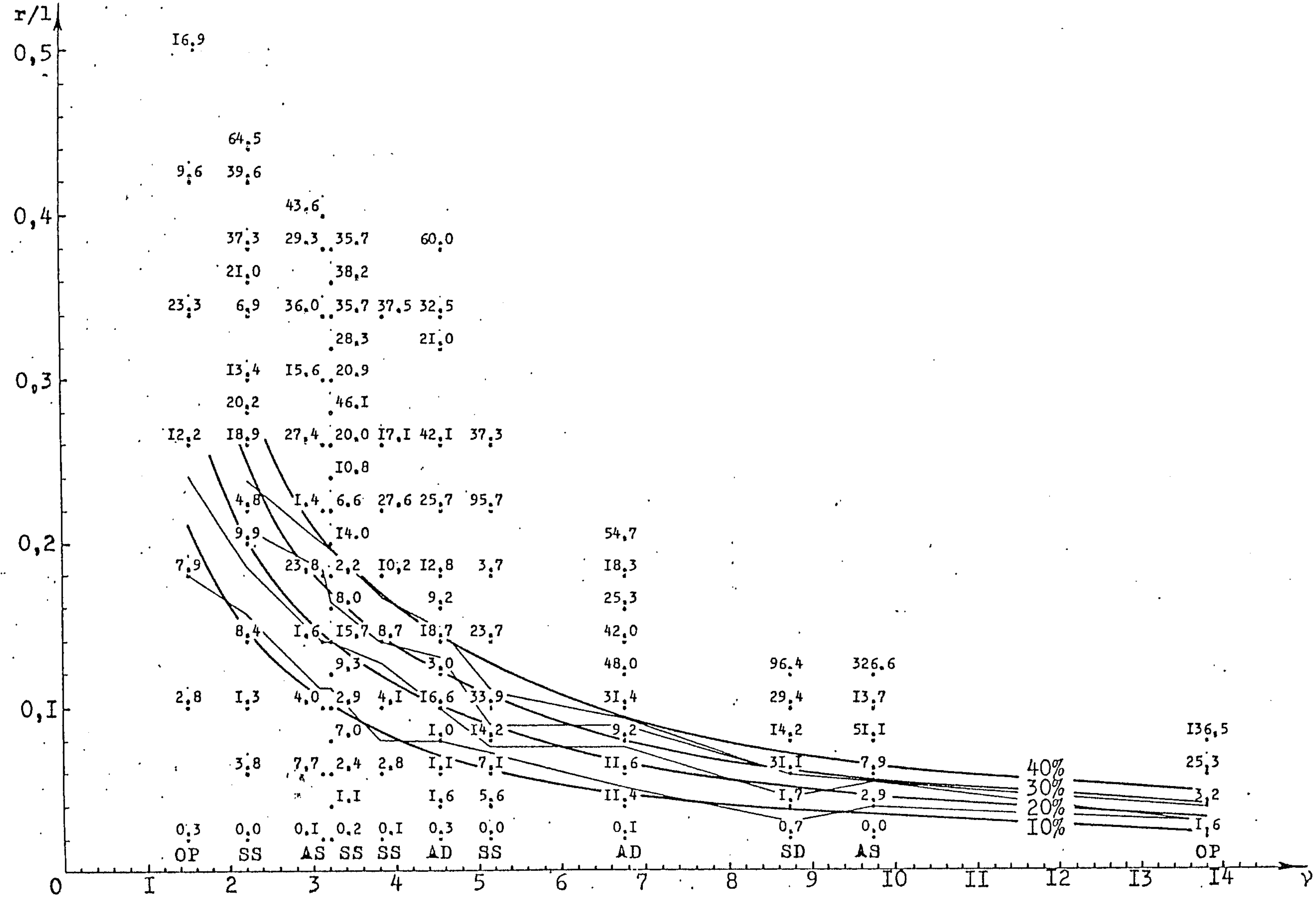

Figure 2. Dependence of distance between tacks r/size area l ratio upon variation coefficient ν under different biomass assessment error δ (empirical regression lines, and diagrams of approximating function). The marks over values of ν are field character (OP is one parch, SS are separate patches of the same size, SD are separate patches of different sizes, AS are aggregations of patches of the same size, AD are aggregations of patches of different sizes). Values of δ (in percent) correspond to the ration r/l used.

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