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HOW TO CORRECT FISH DENSITY ESTIMATES FOR EXTINCTION

by

Kenneth G. Foote
Institute of Marine Research
5024 Bergen, Norway

ABSTRACT

There have been many experimental studies on acoustic shadowing, but once the effect is quantified, how is the compensation to be effected? This work shows how, through postprocessing of stored time series, containing the depth dependence of the volume backscattering strength for each ping, by a simple formula. The *a priori* components of this are the mean backscattering cross section and the mean extinction cross section.

RESUME: COMMENT CORRIGER UNE EVALUATION DE DENSITE DE POISSONS EN PRESENCE DU PHENOMENE D'EXTINCTION

Plusieurs études expérimentales sur l'ombre acoustique ont été réalisées mais, une fois le phénomene quantifié, comment doit-on effectuer la compensation? Ce travail montre comment le faire en utilisant une simple formule sur un traitement différé des données avec, pour chaque coup de sonde, la variation de la réverbération de volume en fonction de la profondeur. Pour cela, les données à connaître à priori sont les surfaces équivalentes moyennes de réverbération et d'extinction.

INTRODUCTION

A favorite strategy used in the abundance estimation of fish stocks by acoustics (MacLennan 1990) is to survey the stock when it is gathered together, as on spawning grounds or when hibernating. The physical extent of the stock may then be quite limited. Recognized topographic peculiarities of the local sea area may mark the geographical extent.

While the problem of knowing where the fish is is thus addressed, another intrinsic to the concentration itself is introduced. This is the effect of extinction. It has earlier been studied experimentally under quite controlled conditions, as by Davies (1973), Røttingen (1976), Ishii et al. (1983), Furusawa et al. (1984), Armstrong et al. (1989), and MacLennan et al. (1990), and in the field, as by Olsen (1986) and MacLennan et al. (1990). The effect has also been studied theoretically, for example, by Weston (1967), Foote (1978), and Lytle and Maxwell (1983).

Interest in the subject of acoustic extinction by fish aggregations continues, with potentially important applications to the resurgent stock of Norwegian spring-spawning herring (Clupea harengus) (Røttingen 1989).

Curiously, few studies show how knowledge of the extinction effect is to be applied, and some of the ones that do are unclear in their methods. It is the aim here to show how to correct acoustic measurements of fish density for extinction. Reference is made to a recent publication on this topic (Foote 1990) to justify the present brevity.

METHOD

An aggregation of similar fish is assumed to be distributed over the depth range from 0 to z, relative to the transducer. The characteristic mean backscattering and extinction cross sections, σ_b and σ_e, respectively, are each assumed at the outset to be constants independent of depth. The mean volume backscattering coefficient s_v over the depth interval $[z_1,z_2]$ within $[0,z]$ is, in the neglect of beam spreading,

$$s_v(z_1,z_2) = \exp[-2\int_0^{z_1}\rho(z)\,\sigma_e\,dz]\int_{z_1}^{z_2}\rho(z)\frac{\sigma_b}{4\pi}\exp[-2\rho(\zeta)\sigma_e(\zeta-z_1)]d\zeta/(z_2-z_1) \quad , \qquad (1)$$

where the depth dependence of the density ρ is explicitly shown.

Given measurements of s_v through the water column, it is desired to determine the form of $\rho(z)$. This can be done in the following way. The depth range of interest or influence is divided up into N horizontal layers, with bounding depths of $z_1,z_2,\ldots,z_{N+1}$, within each of which the density is constant. The j-th layer thus lies between z_j and $z_{j+1}=z_j+\Delta z_j$, and its density is denoted by ρ_j. The first integral factor in equation (1) is rewritten thus:

$$\exp(-2\sum_{j=1}^{n-1}\rho_j\sigma_e\Delta z_j) \quad ,$$

assuming interest in the interval $[z_n,z_{n+1}]$. For the case n=1, the summation in the integral is assumed to vanish, hence the factor is unity. The second integral term is also rewritten:

$$\rho_n\frac{\sigma_b}{4\pi}\int_{z_n}^{z_{n+1}}\exp[-2\rho_n\sigma_e(\zeta-z_n)]\,d\zeta = \frac{\sigma_b}{8\pi\sigma_e}[1-\exp(-2\rho_n\sigma_e\Delta z_n)] \quad .$$

Combining the several parts, while expressing the volume backscattering coefficient in the same abbreviated terms,

$$s_{v,n} = \exp(-2\sum_{j=1}^{n-1}\rho_j\sigma_e\Delta z_j)\frac{\sigma_b}{8\pi\Delta z_n\sigma_e}[1-\exp(-2\rho_n\sigma_e\Delta z_n)] \quad . \qquad (2)$$

Solution for ρ_n is immediate. Defining

$$\hat{s}_{v,n} = s_{v,n} \exp(2 \sum_{j=1}^{n-1} \rho_j \sigma_e \Delta z_j) \quad , \qquad (3a)$$

$$\rho_n = - \frac{1}{2\sigma_e \Delta z_n} \ln(1 - 8\pi \hat{s}_{v,n} \Delta z_n \sigma_e / \sigma_b) \quad . \qquad (3b)$$

To evaluate this, $\hat{s}_{v,n}$ and ρ_n are computed in order from n=1 to n=N. At the beginning of this process, in accordance with the above interpretation of the summation in the exponential argument of equation (3a), $\hat{s}_{v,1}=s_{v,1}$.

COMPUTATIONAL EXAMPLE

This is taken from a repeated survey of part of the 1983-year class of herring in Gratangen, a fjord in northern Norway. The particular survey was performed by R/V MICHAEL SARS on 10 December 1989, using the SIMRAD EK500 echo sounding system (Bodholt et al. 1988, 1989) with the 38-kHz ES38B transducer. The herring were distributed in a rather dense layer in the fjord. This was mostly stationary in about the upper 50 m of the water column, but descended towards the bottom during the several hours of midday twilight. The atmospheric weather was very fine, hence the object registration, made at 1400 hours GMT and represented by the echogram in Fig. 1, shows the herring at the beginning of their return to the near-surface layer.

Corresponding to the echogram are values of the volume backscattering strength S_v, stored by means of the Bergen Echo Integrator (Knudsen 1989). In the analyzed data file the S_v-values are recorded for each ping at 0.5-m increments from the transducer depth to 250-m range. The data were gathered at a nominal pulse repetition frequency (PRF) of 50/minute at a vessel speed of 6 knots. Since the log-based representation mode is used here, with evenly interpolated subdivision of each nautical mile into 200 intervals, the distance between each sounding is nominally 9.26 m.

In the present example the herring were surveyed along a zigzag grid, thus a cross section of the fjord is represented in Fig. 1. The bottom echo signal in the echo sounder was triggered by the upper surface of the layer over much of the sailed interval, however, it is easy to ignore this when processing the data.

The mean area backscattering coefficient s_A was computed in each of two ways for the log interval 5511.355-5512.160 for the constant depth range 0-135 m relative to the transducer. The coefficient was computed both in the neglect of extinction and assuming its presence. A sample of herring acquired from a local seiner indicated that the mean length was 33.1 cm. The backscattering cross section σ_b was determined by MacLennan et al. (1990) to be 8.70 cm^2, which is consistent with the target strength relation TS=20 log ℓ - 72.0, where ℓ is the mean length in centimeters, and TS is the target strength in decibels. This relation resembles that recommended by ICES (Anon. 1983), TS=20 log ℓ - 71.2, as later refined to TS=20 log ℓ - 71.9 (Foote 1987). The mean extinction cross section of the same fish was measured by D. N. MacLennan, with the result $\sigma_e=(1.4\pm0.3)\sigma_b$ (MacLennan et al. 1990). Here the central value σ_e=12.2 cm^2 is used.

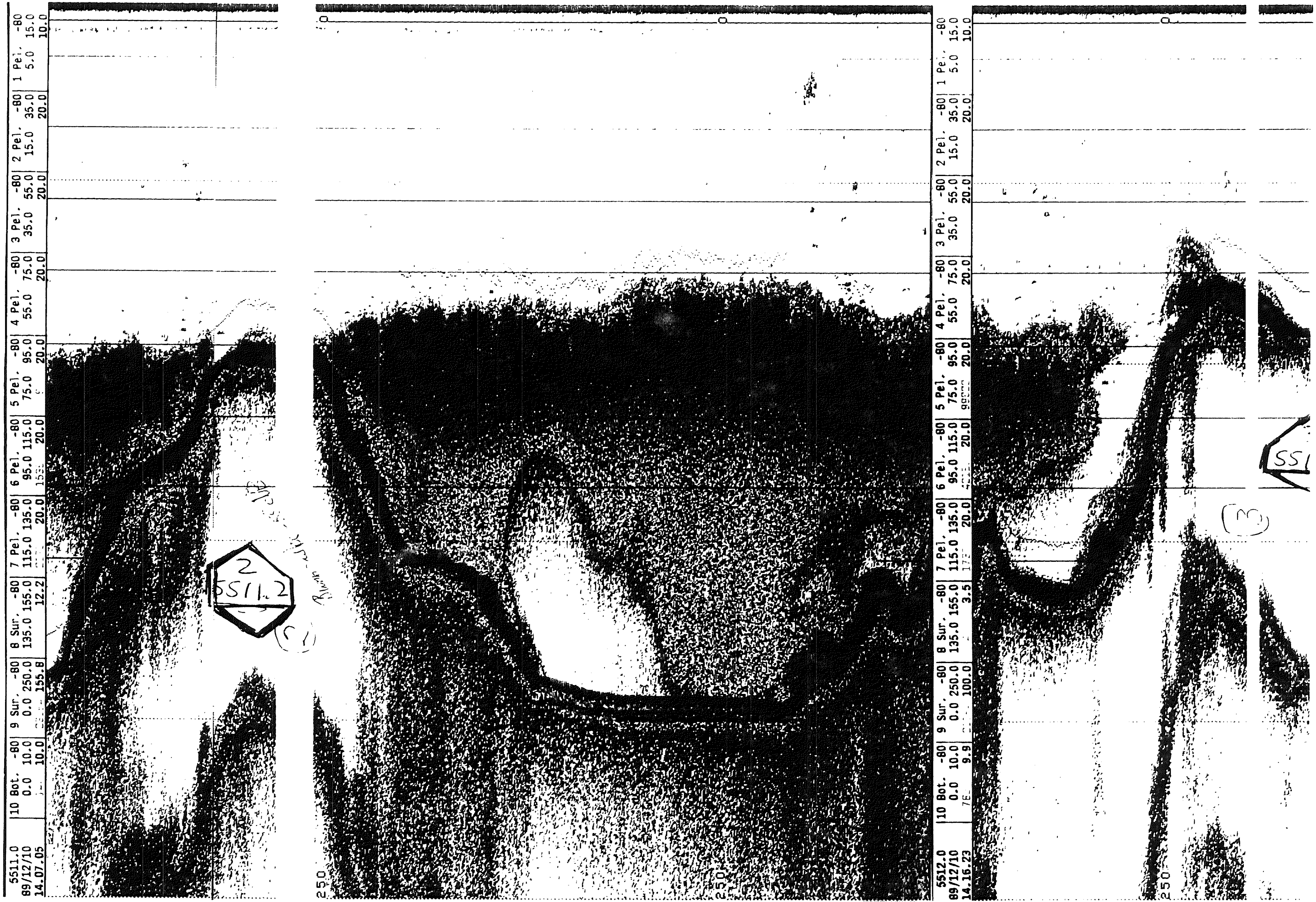

Fig. 1. Echogram of a herring aggregation in Gratangen, a northern Norwegian fjord at 68°44'N 17°20'E, on 10 December 1989 at 1400 hours GMT, as recorded by the SIMRAD EK500/38-kHz echo sounder. The horizontal lines and that following the bottom or upper side of the aggregation indicate integration channels. In the case of the bottom-tracking line, this is placed 10 m above the detected bottom, from whatever target, whether fjord bottom or dense fish aggregation.

The results are simply stated. The s_A-values are $3.92\ 10^5$ and $3.95\ 10^5$ m^2/NM^2, without and with assumption of extinction. That is, in the present example there is little difference apropos of s_A. Values of density in the layer do show significant differences as extinction is neglected or heeded. The maximum measured density, according to the extinction-corrected value of the volume backscattering strength, occurred at log 5511.710 at a range of 89 m. The values of density wihout and with allowance for extinction are 103.5 and 116.7 fish/m^3, respectively. The corresponding value of s_v are 0.00686 and 0.00723 m^{-1}.

DISCUSSION

The formula given in equation (3) is mathematically well-behaved and easy to execute by means of a digital computer. The assumption of constant density in each analyzed layer need not limit the use of this for ordinary computer processing, for the layer thickness can - with foresight - be chosen sufficiently small, e.g., 1 m, to avoid the possibility of significant variation. In the computational example the layer thickness is 0.5 m.

The solution does apply to the mean field, or echo intensity in the mean of a large number of observations or in the presence of a large number of scatterers. Since extinction is only significant in the presence of many scatterers, the implicit mean-field assumption is believed to be good. This may be examined by simulation, however, although involving considerable computations, at least according to one scheme (Foote 1989).

Another assumption underlying equation (3) is that effects of beam spreading are negligible. This is reasonable because of the high degree of directionality of typical transducers used in echo surveying. For the SIMRAD ES38B transducer, for example, the beamwidth between -3-dB levels is about 8 deg, while that for the ES5 transducer in its narrow-beam mode is about 5 deg. The assumption of one-dimensional propagation indicated in equation (1) is thus reasonable. This, like the mean-field assumption, can be investigated by simulation, thus touching on so-called second-order or multiple-scattering effects too (Stanton 1983).

In developing the present method for correcting measurements of scatterer density for extinction the mean backscattering and extinction cross sections are assumed to be constant, independent of depth. This assumption is unnecessary, and both cross sections may vary arbitrarily and independently with depth. In fact, this more general case can be incorporated into equation (3) by replacing all instances of σ_b and σ_e by the respective subscripted quantity, e.g., $\sigma_{b,n}$ and $\sigma_{e,n}$ in equation (3b), where the additional assumption is now made that the new quantities, like ρ_n, are constant within the applicable layer.

If the present scheme seems at all complicated - it is not - then it should be remembered that the requirements on interpretation are no different from those implicit in every quantitative analysis of echo data. The single new ingredient is the mean extinction cross section. This is known for some fish species under some circumstances (Foote 1978, Ishii et al. 1983, Furusawa et al. 1984, MacLennan et al. 1990), and will undoubtedly be specified better for these and other species in the future. The purely computational part of the analysis is not especially encumbered by the algorithm given in equation (3), or its mentioned generalization, for postprocessing by a workstation-level computer is entirely feasible (Knudsen 1989).

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