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ON THE APPLICATION OF THE ECHO INTEGRATION METHOD

by

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ABSTRACT

The echo integration method used by the Institute of Marine Research is described. The model which are used to convert acoustic abundance indices into fish densities using length and species dependant conversion factors, are established and a computational example for a mixed cod and haddock recording is given. The data sampling and processing procedures onboard the survey vessel are described and discussed.

1. INTRODUCTION

During the last 10–15 years acoustic surveys have been extensively used to obtain information of the abundance of fish resources. Several methods are in use; echo counting, echo integration and school counting by horizontal ranging sonars, depending on the behaviour patterns of the species under observation. The method most widely used is the echo integration method which has been applied both on unexploited and exploited fish populations and provided information which has contributed largely to our knowledge of stock sizes and stock size fluctuations.

The Institute of Marine Research initiated annual acoustic surveys on capelin and blue whiting in 1970–1971 (Midttun and Nakken 1977), using the echo integration technique. Some years later, in 1975–1976, regular surveys on young cod and haddock were also commenced applying a similar technique (Dalen, Hylen and Smedstad 1977). The results from these surveys have been reported in several previous papers to symposias and annual meetings of the International Council for the Exploration of the Sea (Nakken and Dommasnes 1975 and 1977, Dalen and Smedstad 1979 and 1982, Dommasnes 1982, Hamre and Tjelmeland 1982, Dalen et al. 1982, Godø et al. 1982, Hylen and Nakken 1982). Some of these reports include also descriptions of the technique and methodology which are being applied.

In the present paper a more detailed description of the acoustic survey methodology developed by – and in regular use at – the Institute of Marine Research is attempted. In particular, the sampling and processing procedures involved are discussed with respect to the errors which may be introduced at the different steps in this procedure.

2. FISH DENSITY ESTIMATION

Briefly, the process of acoustic abundance estimation can be divided into two main steps. The first step is to determine the densities of fish along the track of the survey vessel. In principle, this is undertaken by using an echo integration system to obtain density indicies over fixed distances and thereafter convert the indicies to densities. The density estimates arrived at are averaged values for the fixed distances and the depth intervals sampled by the system. The conversion of the indicies or system outputs into fish densities requires knowledge of the system performance, the scattering properties of the recorded specimens and of their behaviour.

The second main step in the abundance estimation procedure is to integrate the computed densities over the investigation area in order to obtain estimates of the total amount of fish (in numbers or biomass) within that area. In the proceeding we will deal exclusively with the first of these two steps; the fish density estimation.

2.1 Single species recording; all specimens of equal length.

The basis of the echo integration method is the proportionality between the density of scatterers, ρ, and the echo intensity, I:

$$I \sim \rho \qquad (1)$$

The proportionality factor depends on the backscattering properties of the individual scatterers and the instrument characteristics of the measuring system. For a specific integration system the proportionality factor is constant as long as all the individual fish contributing to the echo intensity have equal effective back scattering cross sections and the performance of the system remains unchanged.

A convenient form of Eq. 1 in practical survey work is:

$$M \cdot C_I = s_a = \langle\sigma_{bs}\rangle \cdot \rho_a \qquad (2)$$

Where M is the output values of the integration system,

s_a is the area backscattering coefficient,

C_I is a system calibration constant which converts the output values to the units of s_a,

$\langle\sigma_{bs}\rangle$ is the effective back scattering cross section per fish including the effect of the behaviour of the fish and the beam pattern of the applied transducer,

ρ_a is the density of fish per unit area within the depth interval for which M is recorded.

When we rearrange Eq. 2 in order to have the density expressed explicitly as a function of the other quantities, we have

$$\rho_a = \frac{s_a}{\langle\sigma_{bs}\rangle} = \frac{C_I \cdot M}{\langle\sigma_{bs}\rangle} \qquad (3)$$

by which the fish densities, ρ_a, corresponding to the output values, M, from the integration system can be computed, provided that the calibration constant, C_I, and the effective back scattering cross section of the fish, $\langle\sigma_{bs}\rangle$, are known.

2.2 The system calibration constant, C_I.

As already mentioned the purpose of this quantity is to convert the system outputs to units of back scattering, per unit surface, s_a. Then, the density can be calculated from Eq. 3 by simple division when values of the back scattering cross section of the individual fishes are at hand.

The value of C_I is determined through calibration by having the integration system working on a standard target as described by Foote et. al. (1983). C_I is computed from the formula:

$$C_I = \frac{\sigma_{ST}}{M_{ST} \cdot D_{ST}^2 \cdot \psi} \cdot 3.43 \cdot 10^6 \qquad (4)$$

where σ_{ST} is the back scattering cross section of the standard target (m^2).

M_{ST} is the integration output from the standard target (mm/nautical mile).

D_{ST} is the depth of the standard target (m).

ψ is the equivalent solid angle of the beam of the transducer (sterad).

$3.43 \cdot 10^6$ is the number of square meters in a squared nautical mile (used in order to have the density expressed as number of fish per square nautical mile).

The mentioned method of calibration has been in use by the Institute for the past 2-3 years. Previously, the integration systems were calibrated by doing separate measurements of source level, voltage response and pulse length by a calibration hydrophone and integration of a standard input signal from a signal generator.

2.3 The output of the integration system, M.

The system in use onboard the research vessels of the Institute of Marine Research is described by Blindheim, Eide, Knudsen and Vestnes (1982). It is designed to give the integrated echo deflection for defined depth intervals (channels) over a given distance along the survey track. The system outputs are given as mm deflection per nautical mile referred to a calibrated recorder. When knowing the numerical size of C_I, the system outputs may also be presented as total integrated scattering cross section per squared nautical mile, $C_I M$, which is a system-independent value. A typical printout of values, M, for a part of a cruise track is given in Fig. 1. The corresponding echogram is shown in Fig. 2, where also the actual output values from Fig. 1 are inserted.

2.4 The back scattering cross section, σ_{bs}, of fish.

The back scattering cross section of an individual fish varies with fish species, length and aspect. It has been determined empirically for a number of species and sizes. Midttun (1982) has summarized the results. Usually, the back scattering cross section for a given species is expressed as a function of fish length, l:

$$\sigma_{bs} = a \cdot l^{b} \tag{5}$$

where a and b are determined by undertaking a regression analysis on observed values of σ_{bs} and l. Most of the results are presented in logaritmic form using the target strength, TS, instead of the back scattering cross section:

$$TS = 10 \log \sigma_{bs} = 10\ b \log l + 10 \log a \tag{6}$$

where 10 b and 10 log a are determined through linear or functional regressions.

Since the back scattering cross section for a particular species and size varies with the aspect angle, and the distribution of aspect angles for the fishes contributing to the integration value is not observed and thereby unknown, the values of the effective backscattering cross sections, $\langle\sigma_{bs}\rangle$, to be used for the computation of fish density (Eq. 3) are not directly known. The estimation of values of the effective backscattering cross sections to be applied in Eq. 3 must therefore be based on the known beam width of the transducer and on certain assumptions of the distribution of aspect angles of the recorded fish. Observations on the distributions of aspect angles for wild fish are scarce. Olsen (1971) observed the spawning cod to have aspect angles which were approximately normal in distribution. Nakken and Olsen (1977) and Foote (1980) have estimated values of the effective backscattering cross section for fish in the wild for given distributions of aspect angles. Representative <u>in situ</u> measurements of back scattering cross sections would of course solve this problem, but the quality of such measurements have been rather poor until lately. A method to estimate $\langle\sigma_{bs}\rangle$ described by Foote (1980), has been applied at our institute since 1979. For both cod and haddock the normal aspect angle distributions are assumed to have a mean of 0° and a standard deviation of 20°.

2.5 The conversion factor, C, for the integration system.

In order to use Eq. 3 directly to compute fish density, figures of both the effective backscattering cross section of the recorded fish and the system calibration constant must be at hand. Due to the difficulties involved in the past to achieved such figures, Eq. 3 was written in a sligthly different way (Midttun and Nakken 1971).

$$\rho_a = C \cdot M \tag{7}$$

where $C = \frac{C_I}{\langle\sigma_{bs}\rangle}$.

This enabled us to establish a conversion factor, C, directly without knowing the exact values of $\langle\sigma_{bs}\rangle$ and C_I. The quantity, C, is termed the conversion factor for the integration system, and it expresses the density of fish corresponding to one unit of the output value of the integration system.

Several methods for a direct estimation of this conversion factor, C, are described in the literature. The methods have in common that series of corresponding measurements of density, ρ_a, and integration outputs, M, are used to estimate C, by linear or functional regressions. Basicly, the methods can be divided into three groups:

1) The counting method (Midttun and Nakken, 1977) by which parallell counting and integration of single fish recordings are utilized to obtain figures for ρ_a and M.

2) The catching method (Thorne et al. 1971, Hagstrøm and Røttingen 1982) by which parallell trawling/purse seining and integration of fish concentrations is used.

3) The cage method (Johannesson and Losse 1977) where the integration system is run on known quantities of fish kept in a cage within the acoustic beam.

The advantages of the two first mentioned methods are twofold: Firstly, the fish is exposed to nearly the same external stimuli during the experiment as it is during surveying. Its behaviour (aspect angle distribution) should thus also be expected nearly the same. Secondly, the determination of C is carried out with the integration system actually used during the survey so that an accurate instrument calibration in absolute terms is not a crucial point. When the conversion factor is determined for a given species of limited length range and for a given system, and we are able to determine the relative system performance rather than the absolute which to a large extent has been the case until lately, then the conversion factor can be adjusted according to the changes in performance. If the flexibility of the integration system is large enough it is a matter of convenience whether one choose to adjust the system output values or the conversion factor.

From Eqs. 5 and 7 it is evident that the conversion factor is dependent on fish length and that it can be expressed as (Nakken 1975):

$$C = \frac{C_I}{\langle\sigma_{bs}\rangle} = \frac{C_I}{a \cdot l^b} = \frac{C_I}{a} \cdot l^{-b} \qquad (8)$$

where $\frac{C_I}{a}$ and b are expected to be constants for a particular species having a certain behaviour mode. In order to have values of the conversion factors, C, for all lengths of that species the two constants have to be determined. Concerning the exponent, b, in Eq. 5, we have adopted the values arrived at by analysis of target strength measurements of individual fishes. Dalen et al. (1976) gave a figure of b = 1.91 for capelin, while for cod and haddock we are applying b = 2.18 (Foote 1979) and b = 1.69 (Foote, personal com.) respectively. Fig. 3 shows a sketch of the conversion factors for cod and haddock as applied for the integration system of RV "G.O. Sars".

The numerical size of $\frac{C_I}{a}$ was established by combining the results from the counting method and the target strength measurements. The counting method resulted in an estimate of the conversion factor for a particular length group of the species in question, and the constant C_I/a was thereafter determined using the expression:

$$\frac{C_I}{a} = C_c \cdot l_c^{\,b} \qquad \text{(Nakken 1975)} \qquad (9)$$

where C_c is the value of the conversion factor arrived at by the counting method.

l_c is the average length of the fish during the counting run(s).

b is from the results of the target strength experiments (as mentioned previously).

The values of $\frac{C_I}{a}$ arrived at by the described procedure have been adjusted according to the changes in performance of the integration system, while the values of b have been unchanged. The values of the conversion factors for the integration system onboard the research vessel "G.O. Sars" during winter 1983 (January–March) were:

$$C_{capelin} = 1.5 \cdot 10^6 \cdot l^{-1.91}$$

$$C_{cod} = 1.87 \cdot 10^6 \cdot l^{-2.18}$$

$$C_{haddock} = 6.11 \cdot 10^5 \cdot l^{-1.69}$$

(The differences between these figures and those which were applied in previous years are caused by changes in system performance mainly due to replacement of the Simrad EK 38 S echosounder by a Simrad EK 400).

2.6 Multispecies recording, specimens of varying size.

Eqs. 3 and 7 enable us to calculate fish densities only when all the fish contributing to an integration output value have the same effective backscattering cross section. Since the back scattering cross section is a function of species and size this means that in order to use either of the two equations we should split each of the integration outputs into components belonging to the species and size groups recorded. Since this cannot be done in a direct way we have tried an indirect approach.

Let us consider the case when fish with various back scattering cross sections, i.e. more than one species and each species varying in length, have contributed to the integration value. Then the sum of all individual contributions equals the output, M, and Eq. 3 will take the form (Forbes and Nakken 1972, Clay and Medwin 1977):

$$M \cdot C_I = s_a = \langle\sigma_{bs_1}\rangle \cdot \rho_{a_1} + \langle\sigma_{bs_2}\rangle \cdot \rho_{a_2} + \ldots = \sum_i^n \langle\sigma_{bs_i}\rangle \cdot \rho_{a_i} \qquad (10)$$

where we have grouped the fish in categories of equal scattering cross sections, 1, 2, 3 ....n. When the fish distribution includes a number of species, p, and a number of length groups, n, Eq. 10 takes the form:

$$M \cdot C_I = \sum_{i=1}^{n} \sum_{k=1}^{p} \langle\sigma_{bs_{ik}}\rangle \cdot \rho_{a_{ik}} \qquad (11)$$

Forbes and Nakken (1972) points out that if the density ratios between the different categories are known then Eq. 10 (or 11) enable us to calculate the densities of each category provided that the effective back scattering cross sections of the categories are known.

Let us assume that trawlcatches provide reliable estimates of the density ratios. Then we write:

$$\frac{m_{j,h}}{\sum_{i=1}^{n} \sum_{k=1}^{p} m_{i,k}} = \frac{\rho_{a_{j,h}}}{\sum_{i=1}^{n} \sum_{k=1}^{p} \rho_{a_{i,k}}} \tag{12}$$

where $m_{j,h}$ is the number of fish of category j,h (length group j and species h) and $\sum_{i=1}^{n} \sum_{k=1}^{p} m_{i,k}$ is the total number of fish in the catch.

Multiplication of Eq. 11 by Eq. 12 gives:

$$\rho_{a_{j,h}} = \frac{m_{j,h}}{\sum_{i=1}^{n} \sum_{k=1}^{p} <\sigma_{bs_{i,k}}> \cdot m_{i,k}} \cdot C_I \cdot M \tag{13}$$

For computer-aided estimation this model is more convenient to use on matrix form:

$$[\rho_a] = [m] \frac{C_I M}{\sum_{i=1}^{n} \sum_{k=1}^{p} <\sigma_{bs_{i,k}}> \cdot m_{i,k}} \tag{14}$$

where the square brackets indicate a matrix.

Here, the density, $\rho_{a_{j,h}}$, of each length and species is expressed by known and observable quantities only, and it can thus be computed.

When the effective back scattering cross sections $<\sigma_{bsj,k}>$ and the system calibration constant, C_I, are not known separately, but values of the conversion factors $C_{j,k} = C_I/<\sigma_{bs_{j,k}}>$ are available, the equation to be used for the computation of density is [Nakken and Dommasnes (1975), Dalen et al. (1976)]:

$$\rho_{a_{j,h}} = \frac{m_{j,h}}{\sum_{i=1}^{n} \sum_{k=1}^{p} \frac{m_{i,k}}{C_{i,k}}} \cdot M \tag{15}$$

In matrix form:

$$[\rho_a] = [m] \frac{M}{\sum_{i=1}^{n} \sum_{k=1}^{p} \frac{m_{i,k}}{C_{i,k}}} \tag{16}$$

3. COMPUTATIONS OF FISH DENSITY. AN EXAMPLE.

The total surveyed area is divided into subareas or statistical squares and fish densities, ρ_{a_j}, are computed for each subarea. We have found it convenient to use subareas which have the dimensions half a degree latitude (30 nautical miles) by one degree longitude (Dalen and Smedstad 1982). For each subarea we first calculate the average value of the integration output, $\overline{M}$, and the average or total species and size distribution the trawl catches within the area. These average values together with the conversion factor C are next used as input values to Eqs. 14 or 16.

Fig. 4 shows a typical cruisetrack through a subarea on a cod/-haddock survey. The integration outputs M for the mixed recording of the two species are given along the cruisetrack and the trawl stations (A, B and C) are indicated.

The average integration output for the two species over the subarea is:

$$\overline{M} = \frac{30 + 75 + 204 + 118 + 90 + 57}{6} = 95.7 \tag{17}$$

The species and length composition of the three trawlcatches are given in Table 1. It is the total figures (right hand side) which are being used in the computations.

Eq. 15 for the present example using five length groups and two species, is reduced to:

$$\rho_{aj,cod} = \frac{m_{j,cod}}{\sum\limits_{i=1}^{5} \left(\frac{m_{cod}}{C_{cod}} + \frac{m_{haddock}}{C_{haddock}}\right)_i} \cdot \overline{M} \qquad (18)$$

and similarly

$$\rho_{aj,haddock} = \frac{m_{j,haddock}}{\sum\limits_{i=1}^{5} \left(\frac{m_{cod}}{C_{cod}} + \frac{m_{haddock}}{C_{haddock}}\right)_i} \cdot \overline{M} \qquad (19)$$

where we have used the species names instead of a subscript.

Table 2 shows the different steps in the computations and the results.

4. SAMPLING AND PROCESSING OF DATA AT SEA.

During a survey the information which can be extracted exclusively from the system outputs, s_a or M, is limited. The outputs are just indicies of the total amount of back scattered energy from the watermasses which are being sampled by the echosounder, and give no information about the species composition or the size distribution of the scatterers. Such information are obtained from the paper record of the sounder – the echogram – and from the trawlcatches.

4.1 The acoustic data.

On a regular survey the acoustic data include:

1) Output values from the echointegration system at 1 or 5 nautical mile intervals in 8 depth channels.

2) Continuous paper recordings – echograms – along the cruise track.

3) Continuous observations with horizontal ranging sonar along the track.

4) Net sonde recordings from the trawl stations.

Since we make extensive use of the echograms, it is essential that the integrator and the echosounder paper recorder are matched carefully to have the same minimum recordable echo on both instruments.

All these data are daily examined minutely during the survey. The purpose of the examination is to sort out false contributions to the recorded echo abundance and to determine the types of scatterers in terms of species or groups of species which have contributed to the recordings.

Fig. 1 showed a page of the echointegrator journal. A corresponding echogram from log 820 to 825 was shown in Fig. 2. The inserted integrator values which not yet are discussed, may contain contributions from noise sources (see section below) in addition to contribution from plankton and fish. On the logsheet are given the system outputs before and after being corrected for non-biological contributions and for the weather conditions.

Firstly, the integration outputs have to be corrected for contributions from erroneous sources like ghost-bottoms, wakes and noise. Contributions from the bottom when having bottom-breakthroughs are observed and excluded automatically in the integrator itself. The corrected integration values M_{corr} are thereafter written on the echogram as demonstrated in Fig. 5, where both the values for each nautical mile and the averaged value over 5 nautical miles (log 821-825) are given. The figures below the echogram represent the depth interval between 200 and 250 m. Since we here applied a hull-mounted transducer we have to correct the integrator values for excess attenuation due to the weather conditions (airbubbles) (Dalen and Løvik 1981). At the present example the wind force was 5 Beaufort (wind velocity 18–20 knots) which for RV "G.O. Sars" means a correction factor of 1.7. When using a towed transducer below the aerated water masses such a correction is not neccessary. Finally we decide which species or groups of species that have contributed to the corrected integration value by comparing the various types of recordings on the echogram with the occurring fish that have been sampled by trawling.

On the basis of the appearance of the recordings on the echogram and two trawlcatches, one at log 812 the other at log 829, we have distributed the corrected integration values into different categories. In the uppermost channel (10–50 m) noise (airbubbles) and planctonic organisms were recorded. The second channel had virtually no recordings - just a few scattered fishes, while a scattering layer and small schools of fish were observed below 100 m. According to the catches on the two trawlstations the layer and the scattered fish recordings to the left hand side of the figure, log 820-825, was young cod while the schools to the right of the figure, log 823-826, consisted of young haddock. Judged from the outlook of the echogram and the composition of the catches we found that the recordings to the right were exclusively haddock, those to the left were exclusively cod while the two species were mixed over the log interval 823 to 825. For the three nautical miles where the species were mixed, we have estimated the integration outputs for the two species separately according to the appearance of the echogram. [It should be noted that the dynamics, and thus the details, of the original echogram was far better than the reproduction in Fig. 5].

In order to explain the described procedure in more detail we shall consider one integration sampling unit (Fig. 6). The upper legend, M_{corr}, represents the integrator value after being corrected for noise, while the successive legends $\underline{M_{sp.j}}$ represent the integrator values attributed to species or groups of species and corrected for weather-dependant attenuation. We consider now the integration sampling unit from log 822 to 823 between 100 and 150 m depth (Fig. 5). The recorded integrator value was 18. There were no contributions from ghost-bottoms or other noise sources. The echogram indicated that two species were present which on the basis of the two trawl catches and the details of the echogram were determined to be cod and haddock. The school of haddock to the right in the unit was rather dense and denser than the consentration of cod to the left and we concluded therefore that there were slightly more haddock than cod. A correction factor of 1.7, resulted in an integration value for total fish (cod + haddock) of 32, out of which 15 was given to cod and 17 to haddock.

Usually young cod and haddock are not separated to the extent as shown in Fig. 5, the two species will as a rule be mixed in the catches and not separable on the echogram and thus treated as shown in the example given previously.

The personal experience is of great importance for the described type of work. A person with knowledge of the distributional and behavioural aspects of the predominating fish species of the area will in general carry out the work more satisfactorily than an unexperienced man. Extensive fishing of the different types of fish distributions, especially during the first part of a survey will to a large extent compensate for this shortcoming if and when it exists.

When a single species recording predominates during the whole cruise which is the case for most of the capelin and blue whiting cruises (Nakken and Dommasnes 1975, Midttun 1983) the work is much easier. However, also in such a case careful examination of the recording paper is needed in order to achieve optimal results. In large parts of its distribution area 1-group capelin has frequently been recorded in shallow layers which are well separated from the deeper layers of older fish over large distances. Then, the integration outputs from the two layers are kept separately throughout the computation, resulting in more presice estimates than when the integration outputs and trawl catches from the two layers are merged before computation.

Since fishes of different sizes or species often are distributed at different depths small integration sampling units might easy the work described in the preceeding. There are, however, practical limitations to the number of integration values which can be examined thoroughly and the selection of sampling units should thus be carefully considered for each particular type of survey situation.

The main purpose of the trawling is to obtain representative samples of the scatterers which have contributed to the recordings. To ensure this the netsonde is always used when pelagic trawl hauls are made and also at times during bottom trawl hauls. Bottom trawl hauls also give information about the abundance of fish in the near bottom layer – the deadzone of the echo sounder.

The uppermost watermasses, which are not covered satisfactorily by the echo sounder, are often being searched by horizontal searching sonar, Fig. 7. The sonar observations are not quantified in a similar manner as the echointegration information, but the observations might be of great help in assessing to which extent the integration values represent the total amount of fish within the surveyed area.

4.2 The biological data.

The biological data originate from hauls with pelagic trawl or bottom trawl, and there are two main reasons for which trawling is undertaken:

1. The trawlcatches should provide representative samples of the scatterers so that the density ratios, between species and length groups, in the catches can be used for the computation of densities (Eqs. 13/14 or 15/16).

2. Trawling should be conducted in order to enable the personnel to assess to which extent the integration outputs represent the total amount of fish in the water column.

A sketch of the general sampling situation is given in Fig. 7. The echo integrator provides data on fish density only in a layer between a certain depth below the transducer and the upper limit of the echosounder bottom deadzone. The blind-zone and the dead-zone, near surface and near bottom should therefore be sampled by other means; trawling and horizontal ranging sonar since such data might be of great help during the evaluation of the results of the abundance estimation.

Since 1976 the Institute has used a 1600 mesh (20 cm mesh size) capelin net and a 700 mesh (50 cm mesh size) cod net as the pelagic sampling trawls while a 1800 mesh (8 cm mesh size) shrimp trawl has been used as bottom trawl - all with fine meshed net in the cod-end (Godø et al. 1983). Trawling is carried out when the distribution pattern of the echosounder paper record changes or when large density changes are observed. Trawling is also done when biological data is needed in order to cover the horizontal and vertical distribution patterns of fish satisfactorily. Dense concentrations of fish are sampled more frequently than scattered recordings. The netsonde is used to secure sampling of the right recording(s). Standard towing procedures are established both for demersal and pelagic trawl stations.

The catches are treated according to standard sampling procedures; sorting into species, length-measurements and maturity determination of individuals, and sampling of scales and otholits for age determinations. On the capelin cruises the age reading is done onboard, otherwise the age determination is carried out at the laboratory after completion of the cruise.

Length- and species distributions for each subarea are calculated as shown in the computational example given previously. Catches which for various reasons are expected not to be representative for the recording are not used. In subareas where none or only one or two trawlstations have been carried out, catches from neighbouring areas with similar recordings are included in the mean distribution for the subarea.

DISCUSSION

Since acoustic density estimation includes sampling and processing which to a certain degree depends on personal ability and experience (aimed trawling and the evaluation of the echosounder paper record) it is difficult to assess quantitatively the overall accuracy of the density estimates.

To remove the contributions of ghost bottoms and noise from the integration outputs is quite a straight forward process and can also to a large extent be done by selecting suitable control-settings of the system. Layers of very small organisms like plankton and fish larvae are, as a rule, easily recognized on the paper record and can thus be accounted for, in particular when the integration sampling units are small. Yet, when scattered fish are recorded within dense layers of plankton as observed by Sætersdal et al. 1982 it is impossible to directly separate the integration values into fish and plankton, unless information from more than one frequency can be used. The reliability of the separation of the integration outputs into fish species or groups of species is highly dependent on the intensity of the fishing. As a rule all recordings where doubt exists as to the type of scatterers causing them should be fished. Careful selection of the survey period to a time of the year when the species and size groups of main interest are well separated from other fishes will make the work both easier and more precise.

The requirement that the trawl catches should provide estimates of the "true" density ratios between species and size groups is probably met only rarely. The problems of having representative catches by trawl hauls are well known, and the results from the acoustic surveys both on capelin and cod and haddock have indicated that gear selection (mesh selection and avoidance and hearding effects) have been one of the largest sources of error (Dalen and Smedstad, 1982, Nakken and Dommasnes 1975, Nakken and Ulltang, 1982).

The reliability of the conversion factors or scattering cross sections which are being used are also questionnable. Olsen et. al. (1982) have shown that the surveying vessel affected the behaviour of the recorded fish significantly. Hence, conversion factors or scattering cross sections observed <u>in situ</u> at various depths should be preferred for the calculation of fish densities. The values used by the Institute were determined <u>in situ</u>, but the depth dependency was not studied. The scattering cross sections and conversion factors which are being used differ considerably between species. The length dependency was assumed to be equal to that established from the analyses of controlled target strength observations (Dalen et al. 1976, Foote, 1979, Nakken and Olsen 1977). Love (1977) and Foote (1979) have discussed length- and species dependency of scattering cross sections of fish. Their findings indicated that the value of the exponent b (Eq. 5) should be in the range 1.5–2.5 and that its variation with aspect was small within reasonable aspect angles. In situ measurements of scattering cross sections of herring (Halldorsson and Reynisson 1982) resulted in a value of b equal to 2.17 for herring which is comparable to the value we have used for capelin, b = 1.91 (Dalen et al. 1976). The difference between our b-values of cod and haddock, respectively 2.18 and 1.69, seems large, in particular since cod and haddock both are gadoids and almost similar in shape. However, in lack of an appropriate model which describes the scattering cross section as a function of shape and dimensions of fish body and swim-bladder, we have chosen to use values of b actually arrived at by observations of each species.

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Table 1. Length frequencies (number) for cod (c) and haddock (h) at trawlstations A, B and C and the total distribution for the subarea (Fig. 3).

Length group		Numbers							
No.	Cm	Station A		Station B		Station C		Total	
		c	h	c	h	c	h	c	h
1	20-24	4	5	2	3	1	0	7	8
2	25-29	7	6	8	10	5	5	20	21
3	30-34	7	4	55	39	33	18	95	61
4	35-39	2	1	35	18	21	8	58	27
5	40-44	0	0	3	0	5	0	8	0

Table 2. The table shows the details of the computations and the resulting fish densities (see text) for the subarea (Fig. 4).

Length group		Conversion factor		Number in catch		"Weighting factor"		Fish density in thousands number/(nm)^2	
No	Cm	$C_c \cdot 10^{-3}$	$C_h \cdot 10^{-3}$	m_c	m_h	$\frac{m_c}{C_c} \cdot 10^3$	$\frac{m_h}{C_h} \cdot 10^3$	ρ_{ac}	ρ_{ah}
1	20-24	2.22	3.29	7	8	3.2	2.4	2.45	2.80
2	25-29	1.42	2.33	20	21	14.1	9.0	7.00	7.35
3	30-34	0.98	1.75	95	61	96.9	34.9	33.25	21.35
4	35-39	0.71	1.37	58	27	81.7	19.7	20.30	9.45
5	40-44	0.54	1.11	8	0	14.8	0	2.80	0
						210.7	66.0	65.80	40.95

Conversion factor for cod, C_c $= 1.87 \cdot 10^6 \cdot l^{-2.18}$

Conversion factor for haddock, C_h $= 6.11 \cdot 10^5 \cdot l^{-1.69}$

Mean integration output, $\overline{M} = 95.7$

Denumerator of Eqs. 16, 17: $\Sigma\left(\frac{m_c}{C_c} + \frac{m_h}{C_h}\right) = 276.7 \cdot 10^{-3}$

Constant for the subarea: $\frac{\overline{M}}{\Sigma\left(\frac{m_c}{C_c} + \frac{m_h}{C_h}\right)} = \frac{95.7}{276.7 \cdot 10^{-3}} = 0.35 \cdot 10^3$

SHIP: "G.O. Sars"									DATE:						SHEET NO. 73		
hour-log		Sonar-contacts	INTEGRATORS I A	I B	II A	II B	III A	III B	SPECIES Plankt. org.	Cod	Haddock	Capelin		TOTAL	NOTES	CORR. FACT.	D
0535	800		30	20	3	34	8	3	10	78	–	4				1.7	
	805		25	18	4	45	11	8	9	102	–	3				"	
0645	810		15	11	15	109	19	5	12	240	–	–				"	
																	D46
	815		8	6	1	49	49	7	15	175	–	–				"	
0920	820		23	24	1	45	46	3	18	161	–	–				"	
	821		40	28	1	55	78	7	19	240	–	–				"	
	822		38	26	1	18	39	5	17	108	–	–				"	
	823		44	33	2	18	15	3	22	49	17	–				"	
	824		28	20	1	19	3	1	14	19	22	–				"	
	825		26	18	1	5	12	0	12	11	12	–				"	
1015	825		32	25	1	23	29	3	17	84	10	–				"	
																	D47
	830		14	10	0	30	65	18	7	15	177	–				"	
1245	835		14	11	1	15	12	5	8	5	51	–				"	
1320	840		17	12	9	2	1	2	8	3	5	–				"	

Sonar Setting	Echosounder Setting		No I Integrator	No II Integrator	No III Integrator
Range	Range	0-250 m	A from 10 m. to 50 m.	A from 50 m. to 100m.	A from 150 m. to 200m.
Frequency	Frequency	38 kHz	gain 30	gain 30	gain 30
Transducer	Transducer	5•5.5°	threshold 0	threshold 5	threshold 6
Output	Output	High	B from 10 m. to 50 m.	B from 100m. to 150m.	B from 200 m. to 250m.
Pulse L.	T. V. G. and GAIN	20 LR - 20 db	gain 30	gain 30	gain 30
Gain-bandw.	Recordergain	8	threshold 2	threshold 5	threshold 5
Tilt	Bandw. and pulse	3 kHz, 1.0 ms			

Reklametrykk A.s - Bergen

Fig. 1. A page of the echo integrator log-book (older version). The five nautical miles on the echogram in Fig. 2 are framed.

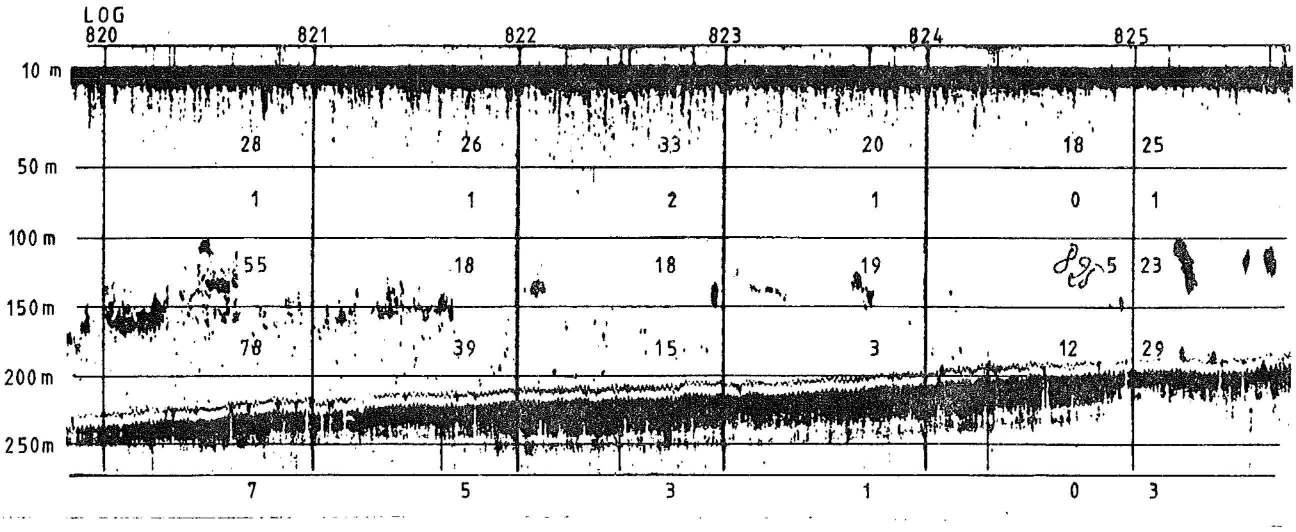

Fig. 2. An echogram from a cod and haddock survey, recorded by EK 38 (38 kHz). Distance markers are for each nautical mile, depth markers are for every 50 m.

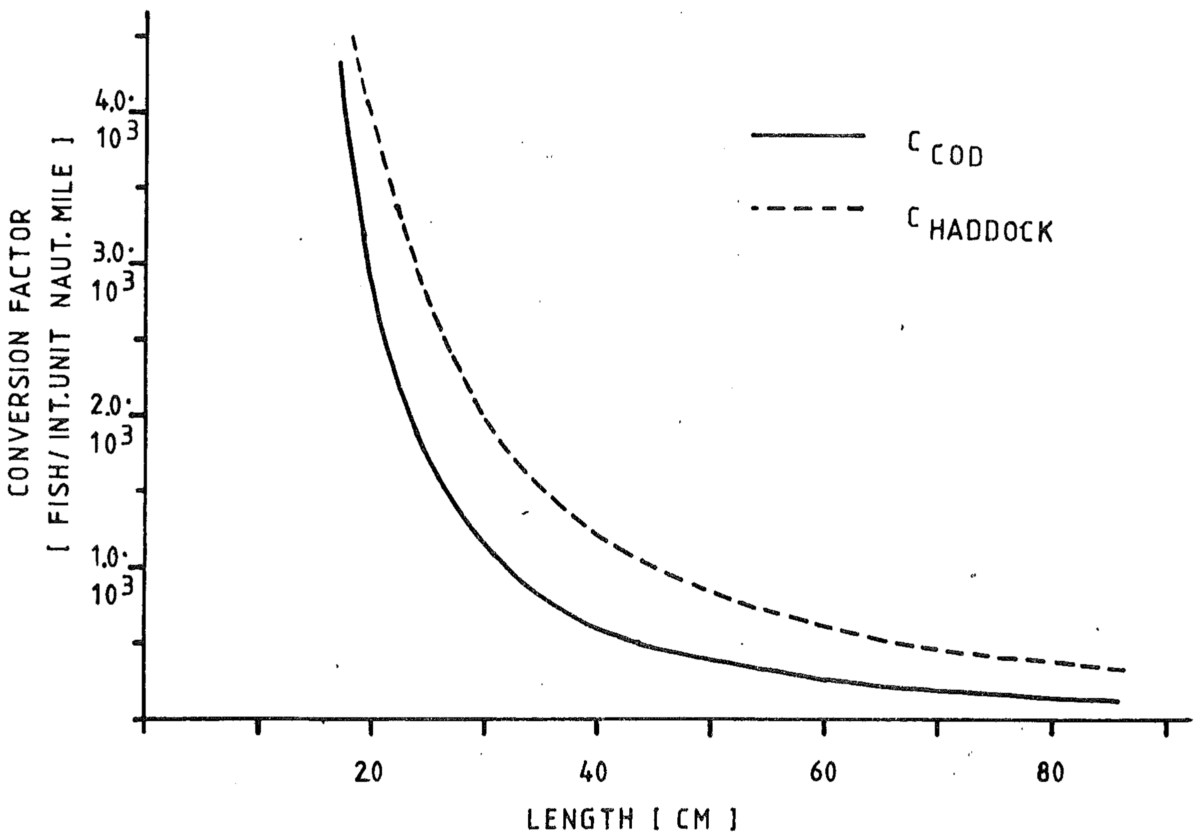

Fig. 3. The conversion factors, C, for the integration system of RV "G.O. Sars" as functions of fish length for cod and haddock.

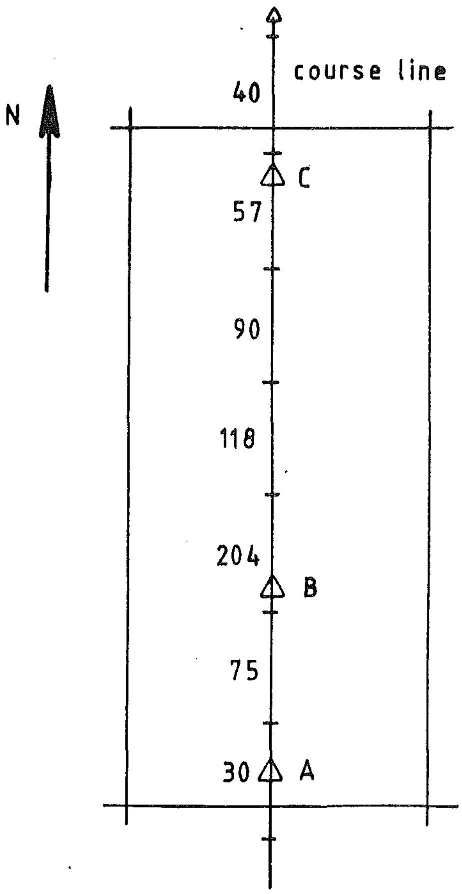

Fig. 4. A statistical square (subarea) with a transecting course line, integration values for each five nautical mile and three trawl stations, A-C.

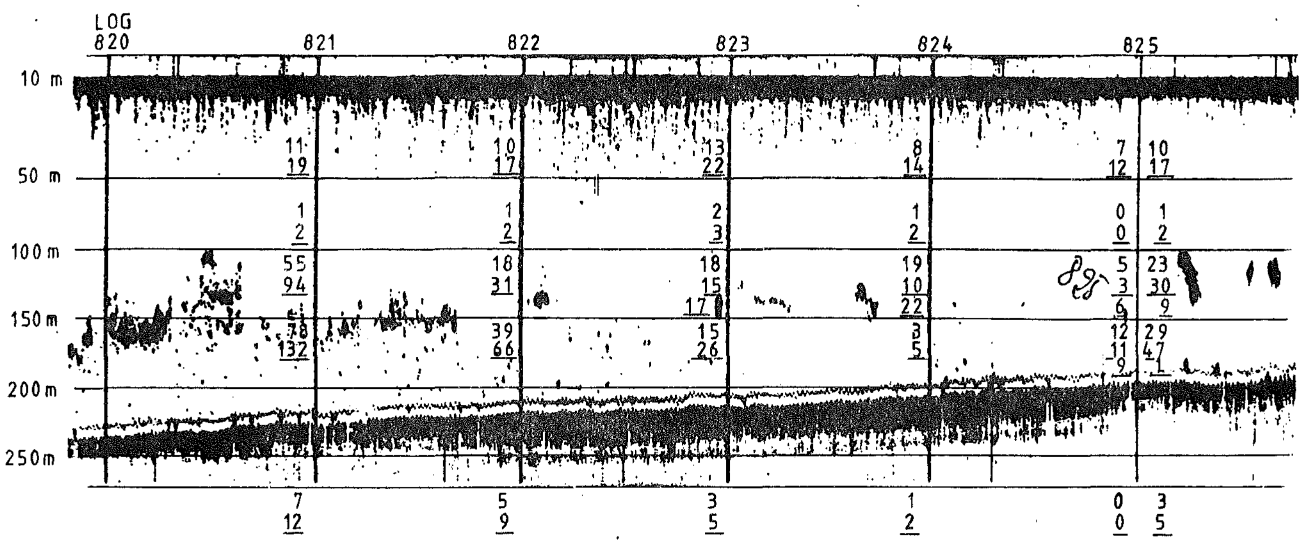

Fig. 5. The echogram after the correction and the allocation of integration values to species.

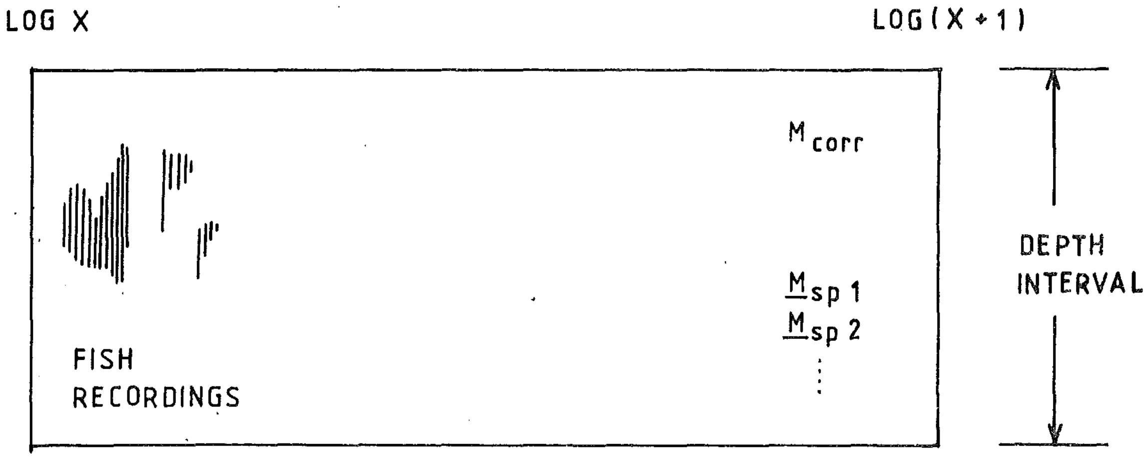

Fig. 6. The integration sampling unit defined by the distance logx to log(x+1) and a specific depth interval. Integration values are shown.

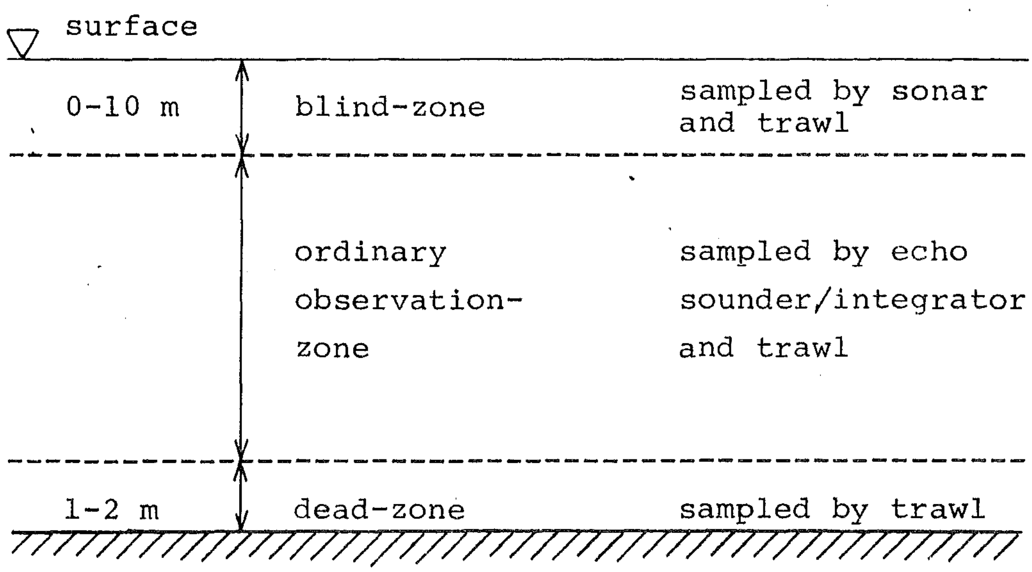

Fig. 7. Schematic representation of the layers sampled effectively by the various instruments and gears during an acoustic survey.