International Council for the Exploration of the Sea

C.M. 1991/B:33
Ref. Sess. U
Fish Capture Committee

ABUNDANCE ESTIMATION OF PELAGIC FISH STOCKS BY ACOUSTIC SURVEYING

by

Kenneth G. Foote

Institute of Marine Research

5024 Bergen, Norway

ABSTRACT

The echo integration technique is outlined. Weaknesses are identified and remedies described. While the technique is adequate for surveying some stocks, improvements are necessary for its proper application to others. An ongoing programme of research is attempting to address the several shortcomings.

RESUME: EVALUATION D'ABONDANCE DE STOCKS DE POISSONS PELAGIQUES PAR PROSPECTION ACOUSTIQUE

Dans cette note, la technique de l'écho-intégration est décrite. Ses faiblesses sont identifiées et les remèdes décrits. Alors que cette technique est adaptée pour l'évaluation de certains stocks, des améliorations s'avèrent nécessaires pour une application correcte sur d'autres. Un programme de recherche est entrepris pour prendre en charge ces imperfections.

INTRODUCTION

Echo integration has several usages. In its narrowest sense, it refers to the signal processing operation whereby the received echo signal amplitude is squared and integrated over a definite time or range interval. More broadly, echo integration refers both to this operation and to its application in fisheries research as a surveying tool for assessing fish stock abundance.

As an established tool, echo integration is routinely applied to a number of pelagic fish stocks. These include, among other species, blue whiting (Micromesistius poutassou) west of the British Isles (Monstad 1988), Icelandic summer-spawning herring (Clupea harengus) (Jakobsson 1983), and Norwegian spring-spawning herring (Røttingen 1988).

Notwithstanding these and other important examples of commercial pelagic stocks that are acoustically surveyed, the technique cannot be used in uncritical fashion. In so-called routine applications, vigilance is required to ensure that essential conditions are fulfilled. In other, potential applications, the technique requires improvement.

The purpose of this paper, which is a contribution to a special ICES C.M. theme session, is to describe the method, criticize it by listing weaknesses, and describe remedies. These are part of an ongoing programme of research at the Institute of Marine Research, Bergen, but may, of course, benefit from new work being conducted at other institutes.

ECHO INTEGRATION TECHNIQUE

The echo integration technique, first described by Dragesund and Olsen (1965), has been described in detail by Forbes and Nakken (1972) and MacLennan (1990), among others. According to the author (Foote 1989a), it may be modeled as a process consisting of a number of distinct elements.

Equipment The minimum includes a directional transducer, some electronics to control transmission and reception, a display, an echo integrator, and a platform to bear the transducer. Typical platforms are research vessels, including towed vehicles. Other electronic equipment may facilitate the gathering and processing of data. Examples are a programmable digital echo integrator and dedicated computer, with database, for other data processing. Physical sampling gear, such as a pelagic trawl, is required for both species identification and sizing.

Equipment use The transducer is moved along tracks or transects crossing the geographical region to be surveyed. The echo signal is registered from repeated, regular transmissions, about 50 per minute. It is detected and displayed on a so-called echogram and is further processed. Calibration of the acoustic instruments is essential both to ensure the absoluteness of measurements and to monitor performance. Special attention may need to be paid to the phenomenon of avoidance reaction, as this may affect the accessibility of fish to acoustic observation and the interpretation of catch data.

Signal processing Since it is desirable to be able to survey a stock without regard to its depth, at least within wide limits, some kind of equalization or signal conditioning is necessary. For usual echo integration applications, which assume layer-like scattering, range and absorption compensation is applied in the logarithmic domain according to the function $20 \log r + 2\alpha r$, where r is the range, and α is the absorption coefficient. Ideally, the range r may be expressed in terms of the elapsed time t from the start of signal transmission: $r=ct/2$, where c is the sound speed. Integration of the resulting range-compensated echo intensity over a defined range, and expression of the result in absolute physical units, determines the area backscattering coefficient s_A. This quantity is most useful for characterizing a population of scatterers by its cumulative backscattering cross section per unit surveyed area. In the case of dense concentrations, it may be necessary to compensate for extinction, which is possible by means of a simple postprocessing algorithm (Foote 1990a).

Medium The quality of acoustic measurements is affected, and sometimes determined, by the medium, or acoustic environment. At the least, it is necessary to account for acoustic absorption in the range compensation operation. It may also be necessary to compensate for additional sources of medium absorption, such as an air-bubble layer in the upper water column, if present and impossible to avoid, as by towing a transducer beneath it.

Scatterer identification Acoustic surveying by one or even several conventional resonant transducers cannot generally provide sufficient data for classifying and sizing the registered scatterers. This is accomplished by a separate catching operation. Given that this process is fraught with error sources itself, due to fish reactions such as net avoidance (Ona and Toresen 1988a,b), it behooves the user to be cautious in the collection or interpretation of catch data.

Survey planning Determination of the time and place of an acoustic survey, like other elements listed here, is crucial to the success of a survey. Some considerations involved in deciding when and where to perform an acoustic survey are the following: fish biology, anticipated surveying conditions, and availability of vessel. Given the availability of a vessel at any arbitrary time, if limited in duration, the biology and anticipated conditions should be the deciding factors. In some cases, it may be advantageous to perform the survey when the fish is relatively concentrated, as blue whiting is when spawning. In other cases, such as capelin (*Mallotus villosus*) in the Barents Sea (Dommasnes and Røttingen 1984), it may be easier to perform a synoptic survey when the fish is relatively dispersed over a wide area. While the biological state may be excellent for conducting a survey in the autumn or winter, the likelihood of poor sea conditions in some areas might argue for choosing another season for the survey. As a further example, the summer may be a poor time for surveying certain northern-latitudes fish stocks because of the effect of light on behaviour, hence possible changes in aggregation density or position in the water column.

Interpretation Association of measurements of s_A with specific species and size or age classes is called interpretation. This is done on the basis of the appearance of the echogram and the user's experience, knowledge of local biology, results of catching operations, and availability of other data, such as salinity-temperature-depth (STD) profiles.

Density measurement Following interpretation, the data consist of sequences of values of the acoustic density, for particular species, along the survey track. To convert these to values of absolute number density of fish, the acoustic density must be divided by the average backscattering cross section per individual.

Interpolation For fish stocks distributed over large areas, only a small fraction of the fish can actually be acoustically observed. In order to map the distribution of fish, if desired, or to estimate the abundance in a region, it is generally necessary to describe the fish distribution from the line-transect measurements of fish density. This process is called interpolation. It involves assumptions about the aggregation properties of the fish, explicitly if recognized, implicitly if not.

Abundance estimation To estimate the abundance of a fish stock over the entire survey region, it is necessary to integrate the line-transect measurements and interpolated estimates of fish density. It may also be possible to estimate the uncertainty, or confidence interval, of the so-called global estimate of abundance, at least within the context of a statistical model for the aggregation characteristics of the stock.

TECHNICAL WEAKNESSES AND REMEDIES

There are problems with the application of the echo integration technique to the acoustic surveying of pelagic fish stocks. These and some remedies are treated in the same order as above.

Equipment Several years ago, the state of echo sounders, the heart of an echo integration system, would have required much comment. Now it is sufficient to cite the SIMRAD EK500 echo sounding system (Bodholt et al. 1989). The dynamic range of this permits the capture of both very weak and very strong echoes, for example, from individual macrozooplankton and the bottom, respectively, with a single set of receiver settings. Indeed, there are no choices, for the receiver is essentially wide open. The heart of an echo sounder, the transducer, may, however, be improved. Motivating factors include, for example, the desire for special beam pattern characteristics, the need to conform transducers or transducer arrays to particular geometries, or the convenience of being able to operate a transducer with several modes. Research on each of these has been documented in recent contributions to Statutory Meetings of ICES (Foote 1989b, 1988, 1990b). Problems with non-acoustic equipment, namely trawls, are described below in the section on scatterer identification

Signal processing Echo sounders, including the mentioned EK500, quite often assume a constant sound speed throughout the water column. To avoid errors caused by this approximation, it is possible to correct for errors in the range compensation algorithm by postprocessing (Foote et al. 1991). This could be done with respect to the volume backscattering strength S_V as a function of depth, or with respect to values of s_A, based on the measured or assumed STD profile. Compensation for extinction in dense or extended fish aggregations is seldom effected. This can be automated in a postprocessing system through the algorithm already mentioned.

Equipment use The greatest weakness here must be due to fish reactions, as induced, for example, by the passage of the survey vessel or trawl. The effects are potentially severe, but can be quantified. Both the acoustic and trawl sampling processes can be examined by acoustic methods, as has been demonstrated by Ona and Toresen (1988a,b), among others. These are vessel- and gear-specific, hence costly. An acoustic method for investigating the effect of vessel passage on fish behaviour, apropos of use of the echo integration technique, has been developed by Olsen et al. (1983). Other methods that might be used, and perhaps should be, are those of echo trace analysis (Aksland 1985) and statistical analysis of fish position data (Foote 1987). At least under some circumstances this may reveal the presence of avoidance effects. Whether correction or compensation should be performed or whether remedial action must be taken, as through use of a wider transducer beam or multiple transducer beams, remains to be determined.

Medium It is unlikely that the values being used for the absorption coefficient at present are as good as they could be, especially at higher survey frequencies, say over 100 kHz. However, the empirical basis for such numbers is slender. Improvements may be expected in the future. The problem of air bubbles is of greater moment. While standard advice, in Norwegian surveys at least, is to use a towed vehicle to lower the transducer beneath the surface zone, it is well known that this is not always feasible or even desirable, as because of operational constraints. Because of the spatial inhomogeneity of air-bubble clouds and the generally unknown effect of the vessel on the bubble distribution (Hall 1989), an in situ bubble-measuring technique that can specify the absorptive effect of the layer from ping to ping is needed. Use of auxiliary transducers operating at different frequencies than for surveying may be necessary. If successful, S_V or s_A values might be corrected through postprocessing.

Scatterer identification Catching is the traditional way of determining what is being acoustically observed. Pelagic trawls may be non-representative with respect to species content and size distribution, at least for mixed species and sizes for which the trawl is not optimal. For specific target pelagic fish stocks, choice of an alternate trawl may be an effective remedy. Acoustic classification, as by discriminant analysis of echogram data (Rose and Leggett 1988, Vray et al. 1990), may also provide an effective remedy in some situations.

Survey planning Since two of the major ingredients for planning a survey are biology and surveying conditions, improved knowledge of these must aid the planning process. Knowing the target species biology is, in fact, a precondition for performing a reasonable acoustic survey. It is sometimes easy to forget that repetition of traditional acoustic surveying patterns may be detrimental to the overall aim of producing the best estimate possible: there may indeed be better times and places to survey the same stock. As always, there is no substitute for a critical attitude, an antidote to complacency, in such matters.

Interpretation Association of s_A values with fish species and size or age groups is yet another crucial and generally subjective process, especially when several fish species are mixed. Advances in scatterer identification should aid interpretation. A higher degree of consistency in interpretation from user to user may be achieved by assembling a catalogue of echograms that are representative of the varying situations that may be encountered while surveying specific pelagic stocks.

Density measurement The key element in the conversion of so-called acoustic density measurements to measurements of fish density is the mean backscattering cross section or, in the logarithmic domain, target strength. This subject has been repeatedly reviewed, as research on it continues. Several dependences of target strength that are in need of elucidation are those of depth, behaviour, biological condition, and frequency. A particularly germane approach is illustrated by that in which the inverse relation between fat content and swimbladder size in herring was discovered (Ona 1990).

Interpolation To improve the operation of mapping fish distributions over an area from estimates of fish density along line transects, the statistical characteristics of fish aggregations must be quantified. The complexity of required analysis has earlier militated against this, but new statistical techniques being introduced to the fisheries research community, such as geostatistics (Gohin 1985, Conan et al. 1988, Petitgas and Poulard 1989), may change this situation for the better.

Abundance estimation Present techniques may be adequate for producing unbiassed estimates of stock size over a surveyed region, but few can claim to give a realistic confidence estimate. One exception, namely geostatistics, can specify a realistic confidence level along with the global estimate (Petitgas 1990). Other spatial statistical techniques (Foote and Stefánsson 1990) may do the same, with expected very significant benefits to fisheries managers.

ADDITIONAL DISCUSSION

This discussion paper has attempted to review the echo integration technique for surveying pelagic fish stocks. It has particularly criticized present shortcomings, but also has indicated what is being done or could be done to remedy these.

Implicit in all of this are the strengths of the technique. It is a simple fact, mentioned above, that a number of major commercial fish stocks are being managed on the basis of acoustic survey data. This speaks most eloquently for the power of the technique.

Clearly, however, some of the present fish stocks being managed on the basis of acoustic data could be managed better, as through an improved or more critical application of the echo integration technique. Other important pelagic fish stocks, which are not presently being survey acoustically, could be, especially were the technique to be improved. The main attraction of the technique is invariably that it enables timely, synoptic, quantitative, fisheries-independent information to be gathered about the state of a stock.

ACKNOWLEDGEMENT

N. Diner is thanked for rendering the abstract.

REFERENCES

Aksland, M. 1985. Basic echo-trace-length statistics. ICES C.M. 1985/B:32. 12 pp. [mimeo]

Bodholt, H., Nes, H., and Solli, H. 1989. A new echo-sounder system. Proc. IOA, 11(3): 123-130.

Conan, G. Y., Buerkle, U., Wade, E., Chadwick, M., and Cumeau, M. 1988. Geostatistical analyses of spatial distribution in a school of herring. ICES C.M. 1988/D:21. 8 pp. [mimeo]

Dommasnes, A., and Røttingen, I. 1984. Acoustic stock measurement of the Barents Sea capelin 1972-1984. A review. In Proceedings of the Soviet-Norwegian Symposium on Barents Sea Capelin. Bergen, Norway, 14-17 August 1984. Institute of Marine Research, Bergen. pp. 45-108.

Dragesund, O., and Olsen, S. 1965. On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish. FiskDir. Skr. Ser. HavUnders., 13(8): 48-75.

Foote, K. G. 1987. Scheme for displaying fish position data in real time. J. Cons. int. Explor. Mer, 45: 93-96.

Foote, K. G. 1988. Cylindrical sonar design for fish echo surveying. ICES C.M. 1988/B:3. 12 pp. [mimeo]

Foote, K. G. 1989a. Fisheries acoustics: diagnosis and prognosis. Proc. IOA, 11(3): 1-10.

Foote, K. G. 1989b. Three-in-one transducer design for a triple-frequency echo sounder. ICES C.M. 1989/B:8. 6 pp. [mimeo]

Foote, K. G. 1990a. Correcting acoustic measurements of scatterer density for extinction. J. acoust. Soc. Am., 88: 1543-1546.

Foote, K. G. 1990b. Designing an improved transducer array geometry. J. Cons. int. Explor. Mer, 46: 129-132.

Foote, K. G., and Stefánsson, G. 1990. Definition of the problem of estimating fish abundance over an area from acoustic line-transect measurements of density. ICES C.M. 1990/D:25. 17 pp. [mimeo]

Foote, K. G., Knudsen, H. P., Korneliussen, R. J., Nordbø, P. E., and Røang, K. 1991. Postprocessing system for echo sounder data. J. acoust. Soc. Am., 90: 37-47.

Forbes, S. T., and Nakken, O. (Eds.) 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man. Fish. Sci., 5: 1-138.

Gohin, F. 1985. Planification des expériences et interprétation par la théorie des variables régionalisées: application à l'estimation de la biomasse d'une plage. ICES C.M. 1985/D:3. 11 pp. [mimeo]

Hall, M. V. 1989. A comprehensive model of wind-generated bubbles in the ocean and predictions of the effects on sound propagation at frequencies up to 40 kHz. J. acoust. Soc. Am., 86: 1103-1117.

Jakobsson, J. 1983. Echo sourveying of the Icelandic summer spawning herring 1973-1982. FAO Fish. Rep., 300: 240-248.

MacLennan, D. N. 1990. Acoustical measurement of fish abundance. J. acoust. Soc. Am., 87: 1-15.

Monstad, T. 1988. Report on Norwegian blue whiting survey, spring 1988. ICES C.M. 1988/H:36. 10 pp. [mimeo]

Olsen, K, Angell, J., Pettersen, F., and Løvik, A. 1983. Observed fish reactions to a surveying vessel with special reference to herring, cod, capelin and polar cod. FAO Fish. Rep., 300: 131-138.

Ona, E. 1990. Physiological factors causing natural variations in acoustic target strength of fish. J. Mar. Biol. Assoc. U.K., 70: 107-127.

Ona, E., and Toresen, R. 1988a. Reactions of herring to trawling noise. ICES C.M. 1988/B:36. 8 pp. [mimeo]

Ona, E., and Toresen, R. 1988b. Avoidance reactions of herring to a survey vessel, studied by scanning sonar. ICES C.M. 1988/H:46. 8 pp. [mimeo]

Petitgas, P. 1990. A geostatistical variance of the total abundance estimate for a regular sampling grid. ICES C.M. 1990/D:12. 12 pp. [mimeo]

Petitgas, P., and Poulard, J. C. 1989. Applying stationary geostatistics to fisheries: a study on hake in the Bay of Biscay. ICES C.M. 1989/G:62. 21 pp. [mimeo]

Rose, G. A., and Leggett, W. C. 1988. Hydroacoustic signal classification of fish schools by species. Can. J. Fish. Aquat. Sci., 45: 597-604.

Røttingen, I. 1988. Distribution and migration of the 1983 year class of Norwegian spring spawning herring in the period July 1987 - August 1988. ICES C.M. 1988/H:41. 6 pp. [mimeo]

Vray, D., Gimenex, G., and Person, R. 1990. Attempt of classification of echo-sounder signals based on the linear discriminant function Fisher. Rapp. P.-v. Réun. Cons. int. Explor. Mer 189.