Canadian Atlantic Fisheries
Scientific Advisory Committee

CAFSAC Research Document 89/ 72

Comité scientifique consultatif des
pêches canadiennes dans l'Atlantique

CSCPCA Document de recherche 89/ 72

Hydroacoustic Survey Methodologies for Pelagic Fish as Recommended by CAFSAC

edited by

R.N. O'Boyle

Marine Fish Division
Bedford Institute of Oceanography
Dartmouth, Nova Scotia B2Y 4A2

and

D.B. Atkinson

Science Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

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Abstract

Acoustic surveys for pelagic fish have been on-going in Atlantic Canada by the Department of Fisheries and Oceans, Government of Canada, since the mid-1970's. Generally, these surveys were conducted following a variety of designs, selection being based upon considerations of the particular stock by the primary investigator. The Pelagic Subcommittee of CAFSAC recognized the inconsistencies in design and the lack, in many instances, of statistical information associated with survey results. The subcommittee therefore met in the summer of 1988 to discuss the issue and to derive a standardized procedure. The subcommittee selected, as most appropriate, a random parallel transect survey design. Formulations to derive associated statistics were made available and subsequently the method of data presentation (table format) was standardized.

Résumé

Le ministère des Pêches et des Océans du gouvernement du Canada effectue des relevés acoustiques des stocks de poissons pélagiques dans la région canadienne de l'Atlantique depuis le milieu des années 1970. Généralement, ces relevés sont réalisées de manières diverses, la méthode choisie par les principaux intéressés dépendant de considérations relatives au stock étudié. Le sous-comité des poissons pélagiques du CSCPCA a pris conscience de l'absence d'uniformité dans la manière de procéder et également du manque fréquent de données statistiques sur les résultats obtenus. Réuni en été 1988 pour discuter de la question et établir une manière uniforme de procéder, le sous-comité a jugé que la méthode d'étude de bandes parallèles choisies au hasard était celle qui convenait le mieux. Il a aussi fourni des formules permettant d'obtenir des statistiques à partir des résultats des études et a subséquemment normalisé la présentation des données (sous forme de tableaux).

Introduction

Acoustic surveys for pelagic fish have been carried out in Atlantic Canada by the Department of Fisheries and Oceans, Government of Canada, since the mid-1970's. Most of these surveys have been typically for capelin and herring. A variety of survey designs have been routinely employed. For capelin, the offshore surveys have employed a block design and the transects within each block followed a zig-zag pattern (cf. Miller *et al.,* 1982). The designs used for herring have varied. Wheeler *et al.* (1986) established transects parallel to, and a fixed distance from the coastline. In Chaleur Bay, Shotton (1986) used zig-zag transects. Buerkle (1985) employed a two-stage type of sampling in that a large area was surveyed until schools were located and the schools were then surveyed with a high density zig-zag transect design. Buerkle surveyed a particular school repeatedly and then selected his highest estimate as being indicative of the stock biomass.

All of the above procedures were 'justified' by the researchers based on particular criteria. As hydroacoustic estimates became more integrated into the assessments of herring and capelin, it became increasingly important that unbiased estimates of not only mean biomass, but also variance due to survey design, be available.

In August 1988, the Pelagic Subcommittee of CAFSAC met to discuss survey design as it applies to acoustic surveys for capelin and herring. Subsequently (May 1989) the same subcommittee discussed other acoustic related matters pertaining to the reporting of the results of acoustic surveys. The purpose of this document is to summarize the discussions of acoustics survey design and reporting procedures. All recommendations of the subcommittee have been put in place by those responsible for acoustic surveys of pelagic stocks falling under the jurisdiction of CAFSAC. In some instances, these have also been incorporated in work on groundfish species, particularly cod and redfish.

Discussion

Acoustic Survey Considerations

(a) Design Theory and Practice

The basic concepts of sampling finite populations (Jolly and Hampton, 1988) were presented. The finite aspect refers to the finite number of identifiable and mutually exclusive sample units of all possible sample units in the target population. The recommended sample frame of sample units for marine acoustic surveys consists of contiguous parallel transects with the measurement of concern being the density of fish along the transect. The objective of sampling this population is to estimate the total number of fish over all population sample units. In general, the essence of a valid sample is the independent selection of a random sample of these sample units. The simple arithmetic mean of the observations is an unbiased estimator of the population mean and the usual formula for a sample mean square divided by the number of units minus one in the sample provides an unbiased estimate of the variance of the sample mean. No assumptions are required with respect to the distribution over the population of any measurement made on the sample unit (transect) (eg., number of fish). It was noted that for purposes of estimating the variance of the sample mean, only the between transect differences, and not the within transect variation, were required.

The direction of the transects can often be chosen to maximize variation along a transect and, hence, minimize variation between transects. This, in turn, will minimize the estimated variance of the sample mean. Stratification of the sample units coupled with optimum allocation of sampling effort with respect to the variance within strata are also effective tools for increasing the precision of the sample mean. Stratification is also useful as a means of spreading out sampling effort over the population area. However, there will be a tradeoff between the number of strata being defined and the number of transects available within strata to estimate the variance. The weighting of the within strata transect mean by the transect length can further reduce the variability of the estimate without introducing bias.

A two-phase scheme for the allocation of effort to strata was described whereby an initial proportion of the selected transects are surveyed as the survey proceeds from one end of the survey region to the other. The remaining transects are then allocated on the return. This procedure requires the assumption that the fish do not move out of the stratum between the first and second pass. If it is suspected or known that such movements occur, the current strata definition need to be reconsidered.

Discussion took place on the validity of alternative sampling procedures with particular attention being directed to the zigzag transect. Whether a single leg or the complete traverse of the zigzag is treated as the sampling unit, the basic requirements of mutual exclusivity and independence cannot be met and, therefore, zigzag transects are not valid as sample units. Serious bias could occur in the estimated mean for irregularly shaped strata and the variance would tend to be underestimated if individual legs were used as sample units. A paper by Kimura and Lemberg (1981) compared the relative precision of zigzag and parallel transects and had been used for guidance in the incorporation of zigzag transects in the past. This paper, however, was not considered to be relevant to the discussion because there was no variance estimator for the zigzag transect type of sample unit and, therefore, there was no quantitative advantage in using this approach.

The alternative method of locating and mapping out discrete schools of fish for the estimation of abundance by school was discussed. The methods currently used to define the boundaries of the schools were *ad hoc* and subjective with the result that the properties of this kind of estimator are poorly understood at present.

The question of continuity between past surveys and future surveys which will be designed according to the principle of random parallel transects was also discussed. It was concluded that as long as the same area is being surveyed and the strata are regularly shaped, the results should be comparable over time. It may be possible to adjust for the bias incurred by irregularly shaped strata but this will have to be investigated on a case-by-case basis.

The subcommittee recommended that randomly selected parallel transects form the basis of future acoustic surveys which are directed towards the estimation of total or relative abundance of fish populations. Estimates should include the survey variance and calculations carried out following the general guidelines shown in Annex I.

(b) The Estimation and Use of Target Strength Information

Acoustically-derived abundance estimates are a function of the backscattering cross-section/fish length relationship that is used in the fish density/echo integration model. Thus, any error in this relation will result in a corresponding error in abundance estimates.

The backscattering cross-section measures the ratio of the incident sound on a fish that is reflected back towards the transducer. It is a function of the coefficient of reflectivity of the components of the fish's body - a swimbladder, filled with air, has a high reflectivity; bone and flesh have a lower reflectivity. About 90% of the echo intensity is derived from the swimbladder; hence, changes in the degree of inflation of a swimbladder, which may be depth related, will markedly change the backscattering cross-section of a fish.

Because of diffraction, the sound intensity reflected by a fish will not be uniform in all directions; thus, the backscattering cross-section will also depend on the aspect (pitch and roll) of the fish relative to the transducer. Small changes in aspect can cause the backscattering cross-section to vary from a maximum value to near zero. The rate of change of backscattering cross-section with change in aspect depends on the quotient of fish length and the wave length of sound used (L/λ). The larger the fish and the smaller the wave length, the greater the number of lobes in the directivity response of the fish; thus, the more variable will be measurements of its backscattering cross-section. Thus, it seems that individual measurements alone will provide little meaning and relations describing the dependence of backscattering cross-section on length, for a given species, must depend on a large number of observations. Recent work shows that changes in the body composition of the fish - i.e., relative size of gonads and stomach contents and their effect on swimbladder size and shape - and the fat content also produce measurable changes in the backscattering cross-section of fish.

Estimates of target strength/length relationships have been determined both experimentally and through *in situ* observation. Experimental methods involve cage experiments, and the sonification of individual fish fixed at known aspects. Alternatively, by capturing fish that have been sonified in actual survey situations, *in situ* estimates can be obtained. Experimental methods suffer from the unknown consequences of the experimental situation on the fish relative to the natural situation. The *in situ* method is best because fish behaviour, and the swimbladder size, are relatively unaffected by experimental procedures. This technique requires that individual fish can be isolated in the acoustic data. This is more difficult at present for herring sonified during the day; at night, individual fish can be identified, but they still comprise only a small percentage of the total number of fish sonified. Implicit in this method is that the identified single target fish are representative of the population. *In situ* measurements of backscattering cross-section will be biased upward if individual fish with sub-threshold echoes are not detected or if two fish have coincident echoes. The abundance will be correspondingly underestimated.

Acoustic methods are used extensively in Europe to provide management advice. ICES working groups recommend that *in situ* measurements be made when possible because the backscattering-length relation may vary from place to place, even for the same fish.

The subcommittee recommended that *in situ* estimates of backscattering cross-section of sonified fish should be obtained on a stratum basis when possible - i.e., suitable data are available. Further, the investigation of backscattering cross-section/length relationships should be encouraged. In the interim, a target strength of -64 dB/gram for capelin will continue to be used. Previously, different target strength-length relationships have been used for the surveys of the different herring stocks (different researchers). The subcommittee recognized that ICES had reviewed the available literature on the subject and settled upon a single relationship (Anon., 1983). Concern was expressed, however, since it was felt important that only data appropriate for comparison be used, and the ICES process was unclear. Foote (1987), on the other hand, did use appropriate data derived from *in situ* experiments only. It was therefore recommended that his relationship:

$$TS(dB) = 20 \log L(cm) - 71.9$$

be used for all future herring work until *in situ* measurements become available for the Northwest Atlantic stocks.

Data Presentation

At its meeting in May, 1989, the subcommittee noted differences in the formats used by the different researchers to present the results of acoustic surveys. Because this practise posed difficulties for those reviewing the work, it was decided to standardize the presentations as much as possible. The information to be provided in future documents is outlined in Annex II.

Conclusions

The subcommittee reviewed the design and operation of all the existing pelagic acoustic surveys on Canada's Atlantic coast. Through comparison to the theoretical framework for the stratified-random transect survey, all were shown to be deficient in greater or lesser degrees.

The greatest deficiency was in the lack of valid estimates of variance which could be used to guide further design modification and data analysis. As a consequence, new designs were proposed which will produce unbiased estimates of the mean and variance of the total backscatter volume.

Discussion of the translation of total backscatter to abundance, relative or total, was limited to the issue of target strength. The subcommittee recommended that, where possible, *in situ* estimates be generated which would be applied to the backscatter data at the most detailed level possible, which, under the adopted design, is the stratum. Interim target strengths for herring and capelin have been agreed upon. There is a need to undertake analyses of the long-term variability of target strength estimates.

It was noted that all surveys suffer from availability problems. Herring are more dispersed at night than during the day. As well, unquantifiable numbers remain in close proximity to the bottom. Until more sophisticated technology can be developed, this will contribute a large component of uncertainty to the estimates generated.

Equipment calibration including the software and hardware systems remains an issue. A number of different systems are being used by the various labs in the zone. It was not felt necessary to standardize to one supplier. Rather, it was considered sufficient to ensure that all systems generate the same results under a given set of conditions.

The subcommittee recommended that, when results of acoustic surveys are presented, comparisons of biologically sampled to non-sampled backscatter be included, preferably on a stratum by stratum basis. In this manner, the adequacy of the biological sampling should become evident.

Acknowledgements

We would like to thank all those who participated in, and contributed to, the discussions of the Pelagic Subcommittee pertaining to hydroacoustic survey design. A special thank you is extended to Mr. G.M. Jolly for his advice and assistance concerning this issue.

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Annex I: Formulae for the calculation of means, variances and biomass from acoustic survey results. (It should be noted that these are specific examples as used with offshore capelin surveys (fixed transect length) and inshore herring surveys (variable transect lengths). These formulations may be adapted, as necessary, to suit individual needs.)

a) When transects are all of equal length

L - the number of strata

N_h - total possible number of sampling units (or transects) in the h^{th} stratum

n_h - number of units actually sampled in the h^{th} stratum

$$N = \sum_{h=1}^{L} N_h$$ - total number of units for the survey if all were sampled

y_{hi} - biomass estimated for the i^{th} unit in the h^{th} stratum

$$W_h = \frac{N_h}{N}$$ - weighting factor for the h^{th} stratum

$$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$$ -mean biomass per unit for the h^{th} stratum

$$\sigma^2 \bar{y}_h = \frac{\sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2}{n_h - 1}$$ - variance of the mean biomass per unit for the h^{th} stratum

$$b_h = \bar{y}_h N_h$$ - biomass of the h^{th} stratum

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$$ - stratified mean biomass per unit (for the entire survey)

$$\sigma^2 \bar{y}_{st} = \frac{1}{N^2} \sum_{h=1}^{L} \frac{N_h (N_h - n_h) \sigma^2 \bar{y}_h}{n_h}$$ - variance of the stratified mean biomass per unit (for the entire survey)

$$\hat{y}_{st} = N \bar{y}_{st}$$ - estimate of the total biomass

$\sigma^2 \hat{y}_{st} = N^2 \sigma^2 \bar{y}_{st}$ - variance of the total biomass estimate for all strata

b) When transects are of unequal length

L	- the number of strata
l_{hi}	- length (nautical miles) of i^{th} transect in h^{th} stratum
n_h	- number of units sampled in the h^{th} stratum
A_h	- surface area (m^2) of the h^{th} stratum
y_{hi}	- numbers of fish estimated in i^{th} block of h^{th} stratum
W_h	- mean weight (g) of fish sampled in the h^{th} stratum

$L_{hi} = (l_{hi} * 1852) * 926$ m - the area sampled (m^2) for i^{th} transect in h^{th} stratum (ie. the unit) (due to navigation precision, the minimum distance between transects was predetermined to be 0.5 nautical miles (926 m))

$$\bar{L}_h = \frac{\sum_{i=1}^{n_h} L_{hi}}{n_h}$$

- the mean area (m^2) for units sampled in the h^{th} stratum

$$K_{hi} = \frac{L_{hi}}{\bar{L}_h}$$

- the weighting factor for i^{th} unit in the h^{th} stratum (to account for different unit areas due to different transect lengths)

$$D_{hi} = \frac{y_{hi}}{L_{hi}}$$

- density (fish/m^2) for i^{th} unit in the h^{th} stratum

$$\bar{D}_h = \frac{\sum_{L=1}^{n_h} (K_{hi} * D_{hi})}{n_h}$$

- mean density (fish/m^2) per unit area in the h^{th} stratum

$$\hat{y}_h = A_h * \bar{D}_h$$

- total numbers of fish in the h^{th} stratum

$$\sigma^2 \hat{y}_h = \frac{\sum_{L=1}^{n_h} K_{hi}^2 (D_{hi} - \bar{D}_h)^2}{n_h (n_h - 1)}$$

- variance of the total numbers in the h^{th} stratum

$$\hat{y}_{st} = \sum_{h=1}^{L} \hat{y}_h$$

- total numbers of fish in all strata

b) When transects are of unequal length (continued)

$$\sigma^2 \hat{y}_{st} = \sum_{h=1}^{L} A_h^2 * \sigma^2 \hat{y}_h$$ - variance of the total fish numbers in all strata

$$B_h = (\hat{y}_h * W_h) * 1000$$ - the biomass (t) for the h^{th} stratum

$$B = \sum_{h=1}^{L} B_h$$ - the total biomass for all strata surveyed

Annex II: Items to be included when reporting the results of acoustic surveys on pelagic fish to CAFSAC.

Calibration parameters to be reported

1. Source level (dB re µbar at 1 metre).
2. Receive sensitivity (dB re 1 volt per µbar). [If calibration is by standard target, source level and receive sensitivity are combined as one parameter].
3. Receiver gain (dB); also fixed and TVG gain where applicable - 20 or 40 log R and attenuation coefficient alpha.
4. Equivalent ideal beam angle (average beam pattern factor - dB).
5. Pulse length (milliseconds) and bandwidth (kHz).
6. Sampling threshold.
7. Target strength/length relationship (from Foote, 1987 for herring unless reason for alternate relationship documented); and length/weight relationship used for conversion to biomass.

Other information to be reported

1. A brief description of any procedure used to edit and selectively delete raw acoustic data before integration should be provided.
2. A figure(s) should be included showing strata surveyed, transects completed and the location of fishing sets.

Tables to be included

Table 1:

Backscatter and biomass for individual transects:

Stratum	Transect Number	Transect Length (km)	Transect Area (m^2)	Target Strength (dB/kg)	Sa-Area Scattering (sr^{-1})	Total Back-Scattering (m^2/sr)	Biomass Density (kg/m^2)	Total Biomass (t/trans.)	Set Number	Number of fish sampled

Table 2: (fixed length transects)

Backscatter and biomass for individual strata

Stratum	Target Strength (dB/kg)	Number of Possible Transects	Transect Area (km^2)	Transect Area Scattering Coefficient (sr^{-1})		Stratum Total Back-scatter (m^2/sr)	Biomass per Transect (t/transect)		Total Biomass (t) per Stratum (t/stratum)	
				mean	S.E.		mean	S.E.	mean	S.E.

Table 2: (variable length transects)

Backscatter and biomass for individual strata

Stratum	Target Strength (dB/kg)	Stratum Area (m^2)	Stratum Area Scattering Coefficient (sr^{-1})	Total Backscattering (m^2/sr)		Stratum Biomass Density (kg/m^2)	Total Biomass per Stratum (t/stratum)	
				mean	S.E.		mean	S.E.

The final estimate of total biomass should include coefficients of variation related to survey design.