International Council for
the Exploration of the Sea

C.M. 1980/B:23
Fish Capture Committee

ACOUSTIC DATA IN LARGE-SCALE SURVEYS

by

J. B. Suomala, Jr.
The Charles Stark Draper Laboratory, Inc.
555 Technology Square
Cambridge, Mass. 02139 U.S.A.

ABSTRACT

An examination of the current processes, methods, and assumptions used to calculate the weight or number of fish in a given survey area suggests that the results of current large-scale acoustic fish abundance surveys may be subject to considerable uncertainty. To demonstrate this uncertainty, this paper outlines the method of arriving at a numerical or biomass estimate by using the averaged echo-signal integration from a vessel track. Comments concerning the process, method, and assumptions invoked are given.

1. INTRODUCTION

Theoretically, the acoustic echo signal from an insonified layer of unresolved fish targets is the product of the average density and the average backscattering characteristics of the individual fish (Urick, 1975). This product, called volume reverberation or volume backscatter, is the fundamental acoustic quantity of the echo-integration process, the most common acoustic method used to estimate fish abundance. The average volume backscatter from a single acoustic transmission may be calculated from:

$$\overline{\rho \cdot \frac{\sigma}{4\pi}} = \frac{\overline{R}^2 10^{-0.2\alpha\overline{R}}}{P_o^2 K^2 \Delta R \psi_\phi} \sum_{n=1}^{M} \left(V^2{}_{rms}\right)_n \qquad (1)$$

where

- ρ = density of targets (1/m^3)
- σ = acoustic scattering cross section of target (m^2)
- ΔR = range (depth) interval (m)
- R = range to depth interval (m)
- α = attenuation coefficient of water (dB/m)
- K = voltage response (V/μPa)
- P_o = source level (μPa/m)
- ψ_ϕ = integrated transducer directivity function
- M = $\Delta R/(c\tau/2)$ = number of pulse-length intervals in ΔR
- c = acoustic wave propagation velocity (m/s)
- τ = transmitted pulse-time interval (s)
- $\left(V_{rms}\right)_n$ = received voltage (V) at the nth pulse-length interval

2. NUMERICAL OR BIOMASS DENSITY ESTIMATION

Combining the fundamental equation (Eq. 1) with certain assumptions, data gathered during acoustic fish abundance surveys are used to derive either a numerical or biomass estimate of a particular species in the following manner.

2.1 Single Track Interval

The single transmission volume backscatter values are summed and averaged over a given vessel survey track interval:

$$\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}} = \frac{1}{m} \sum_{n=1}^{m} \overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}_n \qquad (2)$$

where

- $\left(\rho \cdot \frac{\sigma}{4\pi}\right)_n$ = volume backscatter from nth transmission
- m = number of acoustic samples from a given track interval

The volume backscatter is now doubly averaged.

For a track interval of 1 nautical mile, the volume backscatter averaged to a 1-meter range interval ($\Delta R = 1$) is interpreted to represent the distribution over 1 square nautical mile (Midttun and Nakken, 1977; Johannesson and Losse, 1977; Burczynski, 1979). This assumes that the distribution of insonified fish ±0.5 nautical mile cross track is the same as the distribution of those insonified on track.

Given the validity of this assumption, a numerical or biomass density per nautical square mile can be calculated:

(1) Numerical density (no./mi^2)

$$\rho_{N_{\Delta R=1}} = \frac{\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}_{\Delta R} \cdot 3.43 \times 10^{6}}{\frac{\bar{\sigma}}{4\pi}} \qquad (3)$$

(2) Biomass density (tons/mi^2)

$$\rho_{B_{\Delta R=1}} = \frac{\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}_{\Delta R} \cdot w \cdot 3.43 \times 10^{3}}{\frac{\bar{\sigma}}{4\pi}} \qquad (4)$$

where

w = weight of individual fish in insonified volume (kg)

2.2 Multiple Track Intervals

In practice, the doubly averaged volume backscatter (Eq. (2)) is further summed and averaged over all track intervals in a particular survey region

$$\overline{\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}} = \frac{1}{M} \sum_{n=1}^{M} \overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}_{n} \qquad (5)$$

where

M = number of track intervals

A numerical or biomass density for all survey track intervals can now be calculated:

(1) Numerical density (no./mi^2)

$$\bar{\rho}_{N_{\Delta R=1}} = \frac{\overline{\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}}_{\Delta R} \cdot 3.43 \times 10^{6}}{\frac{\bar{\sigma}}{4\pi}} \qquad (6)$$

(2) Biomass density (tons/mi^2)

$$\bar{\rho}_{B_{\Delta R=1}} = \frac{\overline{\overline{\overline{\left(\rho \cdot \frac{\sigma}{4\pi}\right)}}}_{\Delta R} \cdot w \cdot 3.43 \times 10^{3}}{\frac{\bar{\sigma}}{4\pi}} \qquad (7)$$

3. AREA FISH NUMBER OR WEIGHT

Finally, the numerical or biomass densities, Eq. (6) or (7), may be multiplied by the area, A, of the survey region included in the range interval, ΔR, specified in Eq. (1):

(1) Area fish number

$$N_{\Delta R} = \bar{\rho}_{N_{\Delta R}} \cdot A_{\Delta R} \qquad (8)$$

(2) Area fish weight (tons)

$$B_{\Delta R} = \bar{\rho}_{B_{\Delta R}} \cdot A_{\Delta R} \qquad (9)$$

4. COMMENTS CONCERNING CURRENT PRACTICE

Assuming the accuracy of the acoustic fish enumeration method (Suomala and Yudanov, 1980), the validity of fish density or biomass derived by the procedure described is critically dependent on the distribution of the animals in the survey region. In practice, the fish of interest are rarely uniformly distributed over large regions. Thus, it is to be expected that there will be widely varying density distributions in range (depth), track, and cross track. Assuming that the average acoustic properties of the insonified fish are known and constant, density variations in both range and track can be detected and quantified.

4.1 Spatial Correlation and Statistical Independence of Acoustic Samples

Present practice maximizes the integrated echo range interval, ΔR (see Eq. (1)), and the number of insonifications, m, in a given track interval (see Eq. (2)). This produces a large amount of data which is expected to increase the statistical precision of the doubly averaged volume backscatter estimate.

Invariably, the insonification sample volumes, m, overlap, and because of this, some degree of spatial correlation is expected. The correlation between samples due to this "shared" sampling volume may be significant; factual investigations and the results of analyses of the effects of spatial coincidence versus the statistical independence of acoustic samples are lacking.

4.2 Range, Track, and Track-Interval Averaging

Present large-scale survey practice includes the averaging of volume backscatter data over fixed track intervals. (In Eq. (5), the number of track intervals, M, in a given track is arbitrary; a track may typically be divided into intervals of 1, 2, 5, and up to 25 nautical miles.)

These data are sometimes classified according to range (depth) intervals, with the expectation of enhancing the statistical precision of the results.

Investigations of the effects of fixed-interval echo-signal averaging versus the frequency and rate of change of fish-density variations are not, at present, reported. Present practice, which is expected to minimize errors of this kind, relies on the interpretation of acoustic data displays, principally echograms. However, this method is extremely sensitive to observer subjectivity and bias.

The indiscriminant averaging of echo signals in range, track, and track intervals may seriously distort the resulting fish density or biomass calculation. To date, this has not been examined.

4.3 Acoustic Sample Volume and Cross-Track Density or Biomass

It was noted in Section 2.1 that the track-interval volume backscatter is assumed to extend a cross-track distance of 1 nautical mile. Clearly, this assumption depends upon the spatial and temporal distribution of the fish. Without this information, the extrapolation of small on-track acoustic samples to include a large off-track area is, at best, tenuous.

4.4 Survey Track Spacing and Cross-Track Density or Biomass

The spacing between tracks in current large-scale surveys can range from 5 to 60 nautical miles. The reasons for this are related to the apparent time, costs, and objectives of a given acoustic fish abundance survey. Again, the uniformity of the fish distribution is crucial in this situation. Large distances between adjacent survey tracks may introduce considerable uncertainty into the extrapolation of cross-track density or biomass.

Investigations into the level of uncertainty in a fish-abundance estimation caused by widely spaced acoustic survey tracks are lacking. Cross-track values are derived subjectively, based upon the preferences of the investigator(s) involved. Because of this subjectivity, and without standardized procedures and supporting data, cross-track density or biomass calculations may be considered speculative.

5. CONCLUSION

In light of the preceding discussion, it appears that it is virtually impossible to objectively and quantitatively evaluate large-scale acoustic survey results.

REFERENCES

1. Urick, R. 1975. *Principles of Underwater Sound for Engineers*. McGraw Hill Book Co., New York, U.S.A., 284 pp.
2. Midttun, L. and Nakken, O. 1977. Some results of abundance estimation studies with echo integrators. *Rapp. P.-v. Rēun. Cons. int. Explor. Mer, 170*: 253-258. 1977.
3. Johannesson, K.A. and Losse, G.F., 1977. Some results of observed abundance estimation in several UNDP/FAO resource survey projects. *Rapp. P-v. Rēun, Cons. int. Explor. Mer, 170*: 296-318. 1977.
4. Burczynski, J. 1979. *Introduction to the Use of Sonar Systems for Estimating Fish Biomass*. FAO Fisheries Technical Paper No. 191, Food and Agriculture Organization of the United Nations, Rome, 89 pp.
5. Suomala, J.B. and Yudanov, K.I., eds. 1980. *Meeting on Hydroacoustical Methods for the Estimation of Marine Fish Populations, 25-29 June 1979.* I: Findings of the scientific and technical specialists: a critical review. The Charles Stark Draper Laboratory, Inc., Cambridge, Mass., U.S.A., 71 pp.

ACKNOWLEDGMENT

The preparation of this paper was sponsored by the U.S. National Marine Fisheries Service Contract No. NA-80-FAC-0007 (CSDL Project 92600). The publication of this paper is only for the exchange and stimulation of ideas.