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A short note on hydroacoustical echo signal components and their effect on fish target density estimations

by

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Introduction

The fundamental concept embodied in the measurement of the density of an aggregation of unresolved* targets is that the received hydroacoustical echo signal is from an array of elements which scatter energy in a known manner.

This concept is almost universally accepted, within the fisheries scientific community, as the model of the environment encountered during fish abundance surveys employing hydroacoustical methods.

It is appropriate to note that the specification of an array of elements which scatter energy in a particular manner merely provides a mathematically tractable form for the analysis of probable effects and it must be recognized that the actual connection between a received hydroacoustical echo signal and the density of insonified fish, in a wild environment, is not clearly understood.

The purpose of this note is to briefly discuss the components of the received echo signal which are believed to be the result of postulated distribtuions of insonified targets and their effect on fish target density estimations.

Incoherent Component

If the average target distribution is uniform**, at any given time, serial estimations of the target density will exhibit significant variations. The arithmetic average of the serial estimations can be shown to be proportional to the number of insonified targets. This proportionality is consistent if the average distance between the targets is greater than the wavelength of the transmitted hydroacoustical carrier signal.

*For a definition of target resolution see Reference 1.

**The targets are uniformly and independently dispersed throughout a volume such that the density may be interpreted as the mean rate at which the targets occur per unit volume. It is assumed that these occurrences are a form of random phenomena which can be described by a three dimensional Poisson process.

Subject to these conditions this form of scattering is defined as incoherent and will predominate in the received echo signal.

For detailed discussions on this form of scattering and the relationship to fish abundance estimations see References 2 and 3.

Coherent Component

If the average target distribution is uniform and the average distance between the targets is less than the wavelength of the transmitted carrier signal, or if the number of targets, in regions determined by one quarter of this wavelength is large, it can be shown that a single estimation of target density is proportional to the square of the number of insonified targets***.

Subject to these conditions this form of scattering is defined as coherent and will predominate, at specific time intervals, in the received echo signal.

A number of investigators have addressed this phenomena. For detailed discussions of this work see References 4,5,6,7, 8, and 9. It should be noted that all investigations are not in complete agreement, however, Reference 5 presents a useful approach for an initial examination of the coherent component of an echo signal received from an aggregation of insonified fish targets.

Relationship Between the Incoherent and Coherent Component

In order to illustrate the relationship between the incoherent and coherent component of an echo signal received from an aggregation of insonified targets the following physical model is postulated.

A transducer is positioned over an aggregation of fish which are in the form of a thick layer. The fish targets are uniformly distributed and have known hydroacoustical characteristics. At a given time a rectangularly shaped pulse of hydroacoustical energy is projected from the transducer to the aggregation. At a later time the front, or leading edge, of this pulse will have propagated a distance equal to its length into the aggregation. At this time the average hydroacoustical intensity, referenced to the transducer, can be shown, from Reference 5, to be:

$$\overline{I} = \frac{\overline{\rho^2}\pi^2 \ (c\tau)^2\overline{A^2}}{4\left(\frac{4\pi^2}{\lambda^2}\right)R} + \frac{\overline{\rho}\pi \ (c\tau)^2\overline{A^2}}{4R^3} \qquad (1)$$

where

- ρ - target density
- c - velocity of sound
- τ - time interval of insonifying pulse
- R - range to target aggregation
- λ - wavelength of carrier signal
- A - amplitude of signal

***This definition is not strictly complete since it is beyond the scope of this note to discuss the physical wave concepts involved.

The first term in the expression above describes the coherent component of the received echo signal, the second term describes the incoherent component. It should be noted that the target strength, transducer directivity function and other hydroacoustical equipment characteristics are included in A and the attenuation of the sound path due to scattering and absorption are not included.

Effect of the Coherent Component on Target Density Estimations

All of the current operational fish abundance surveys employing hydroacoustical methods assume that, at all times, the incoherent component predominates in the received hydroacoustical echo signal from an insonified aggregation of unresolved fish targets.

It is instructive to examine the effects, on an estimation of fish target density, of a coherent component in the received echo signal which is assumed to contain only the incoherent component.

By the appropriate manipulations of expression (1) above the following can be derived

$$\bar{\beta} = \bar{\rho} \left(\bar{\rho} \frac{R\lambda^2}{4\pi} + 1\right) \qquad (2)$$

Define

$$\frac{R\lambda^2}{4\pi} \equiv \frac{1}{\alpha} \qquad (2a)$$

Then

$$\bar{\beta} = \bar{\rho}\left(\frac{\bar{\rho}}{\alpha} + 1\right) \qquad (3)$$

Where

$\bar{\beta}$ - Estimated average target density

$\bar{\rho}$ - Actual or true average target density

Figure 1 depicts a graphical representation of expression (3). This figure may be used to illustrate the possible error introduced in a measurement of the density of an insonified aggregation of targets when the received hydroacoustical echo is assumed to contain only an incoherent component.

In order to use Figure 1 the actual or true target density must be known. The actual average density of an aggregation of fish is a function of the behavioral characteristics of the animal at the time of observation, therefore, it is to be expected that the specification of a value of the average density of, a particular fish species, will exhibit wide variations. In the absence of definitive values of density and for purposes of illustration the following situations are postulated.

An aggregation of pelagic fish at a range of 40 meters is insonified by a pulse with a carrier frequency of 38KHz. From expression (2) α can be calculated to be approximately equal to 200. If the true density of the insonified aggregation could be from 25 to 75 fish/m^3, in Figure 1 it is shown that the estimated average target density is 28 to 103/m^3, representing a 12 to 38% overestimation of the density.

However, if the true average density of an aggregation of fish were say $500/m^3$ and at a range of 40 meters and insonified at 38 KHz, the estimated density would be approximately $1700/m^3$, an overestimation by a factor of 3.5.

Summary

It is shown, theoretically, that the coherent component of the hydroacoustical echo signal received from an array of insonified fish targets can introduce a positive error, or overestimation in an estimate of density.

An expression which may be used to estimate the probable effect of the coherent component in a density estimation is given.

By increasing the transmitted hydroacoustical frequency, decreasing the range to the insonified target aggregation, or both, the effect of the coherent component can be minimized.

Conclusions

This note has only addressed, in a very limited manner, the uncertainties in an estimate of fish density that may be the result of an unknown or ignored coherent component in a received echo signal and, at this time, a practical evaluation of this situation has not been performed.

It must be recognized that unless the distribution and scattering characteristics of pelagic fishes in an insonified aggregation are clearly understood and defined it is realistic to regard hydroacoustically derived estimations of the density of these animals the result of a flimsy artifice. Accordingly, representations of the precision and the accuracy of the biomass of a particular pelagic species may be merely the final result of a series of meaningless mathematical abstractions.

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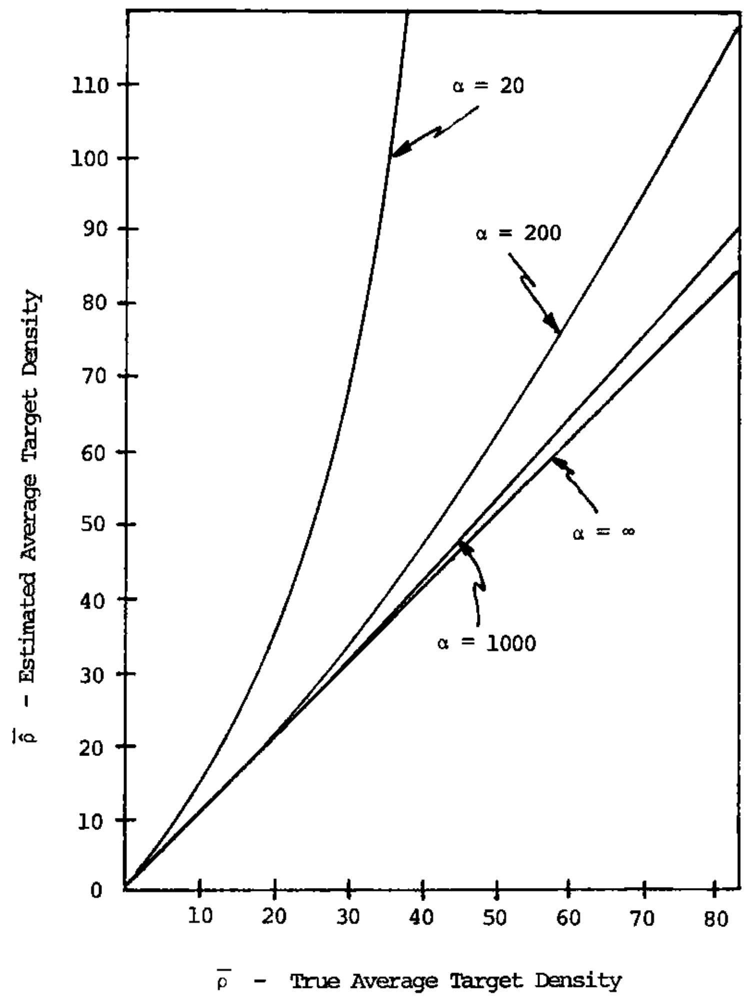

Fig. 1. True average target density *vs* estimated average target density as a function of α.