NUSC Technical Report 5619

12

SC

Ocean Acre Final Report: A Comparison of Volume Scattering Prediction Models

Albert L. Brooks
Charles L. Brown
Special Projects Department

23 December 1977

NUSC
NAVAL UNDERWATER SYSTEMS CENTER
Newport, Rhode Island • New London, Connecticut

PREFACE

This study was partially supported by NUSC Project No. A-626-02, "Biological Reverberation as It Affects ASW Operations," Principal Investigator, C. L. Brown (Code 311), and Navy Subproject and Task No. SF-52-552-701-TU0203, Program Manager, A. Franceschetti (NAVSEA-06H1-4); and NUSC Overhead No. 631X11.

The Technical Reviewer for this report was L. C. Maples (Code 101).

REVIEWED AND APPROVED: 23 December 1977

R. W. Hasse
Head: Special Projects Department

The authors of this report are located at the New London Laboratory, Naval Underwater Systems Center, New London, Connecticut 06320.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR 5619	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) OCEAN ACRE FINAL REPORT: A COMPARISON OF VOLUME SCATTERING PREDICTION MODELS		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Albert L. Brooks Charles L. Brown		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Underwater Systems Center New London Laboratory New London, CT 06320		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS A-626-02, SF-52-552-701-TU0203 ~~63XX11~~ 62759N
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command (SEA-06H1-4) Washington, DC 20362		(11) 12. REPORT DATE 23 December 1977
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) NUSC-TR-5619 (12) 44p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. (16) F52552 (17) SF52552701		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Acoustical Data Acquisition; Airbladder, Midwater Fish; Biological Acoustical Profile; Biological Data Acquisition; Deep Scattering Layer (DSL); Measured Acoustical Profile; Net Trawl Data; Potential Scatterers; Reverberation Prediction Model; Scattering Strength Profile		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Vertical profiles of scattering strength were successfully predicted for an ocean area off Bermuda from net trawl data on the vertical population density of 55 species of airbladdered, midwater fish collected during different years and seasons. The final predicted profiles compare favorably in shape and magnitude with measured profiles of scattering strength at 3.85, 5.0, 7.0, 9.0, and 15.5 kHz. At 3.85 kHz, only one of the predicted scattering strength values exceeds the measured scattering strength by more than 5 dB. For the predictions at 15.5 kHz, most values → Next page		

DD FORM 1 JAN 73 1473

405 918 — LB

20. (Cont'd)

lie within 2 dB of the measured data. The surprisingly simple prediction model, using fish abundance as a function of depth correlated with measured profile data, achieves a notably superior attainment in its predictive capabilities over an earlier, more complicated model that required inputs on difficult-to-obtain swimbladder volume information. The success of the final prediction model is attributed largely to the fact that the vertical distribution density of the 55 species used serves as a reliable index to the total population of potential scatterers within the insonified volume measured. Failure of the earlier model, based essentially on swimbladder volumes, was caused primarily by the inability of sampling methods to furnish sufficiently precise input information.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

OCEAN ACRE FINAL REPORT: A COMPARISON OF VOLUME SCATTERING PREDICTION MODELS

INTRODUCTION

Early studies of the deep scattering layers (DSL's) concentrated primarily on descriptions of either the acoustical or biological aspects of the layers. Subsequent indications that fish possessing gas-filled swimbladders were a major cause of resonance scattering led to joint acoustical and biological investigations that endeavored to characterize the bioacoustic nature of the DSL's.[1] However, few of these studies quantitatively linked biological trawl data with acoustically measured volume reverberation. Chindonova and Kashkin[2] compared scattering strengths derived mathematically from collections of midwater swim-bladdered fish with earlier measurements of acoustically determined column scattering strengths over a wide frequency band (2 to 15 kHz). Satisfactory agreement between the biological and acoustical methods was shown between 5 and 15 kHz for adjacent layers of water several hundred meters thick. It was postulated that poorer agreement near the surface was attributable to poor trapping efficiency of the trawl with respect to both very large and very small scatterers.

From a deep submergence research vehicle, biological net samples were taken below, in, and above the DSL. Column scattering strength values from these samples were calculated for single frequencies of 4 and 12 kHz, as well as for several frequency bands.[3] The results at 12 kHz agree reasonably well with acoustic column scattering strength data for similar areas. At 4 kHz the biologically derived scattering strength is lower than those of other investigations.

Batzler et al.,[4] using a hypothetical assemblage of swimbladdered fish, determined reverberation patterns similar to those measured acoustically. On the other hand, only fair agreement was found between actual trawl data and acoustic measurements.

Over broad oceanic provinces, Seligman and Friedl[5] found a positive correlation between total fish concentration, as determined from trawl data, and column scattering strength measured at 12 kHz. On the other hand, Brown and Fessenden[3] found no significant relationship between numbers of fish and 12 kHz column strength.

The use of discrete-depth sampling trawls has allowed construction of detailed profiles of the vertical distribution of potential scatterers that can be compared with profiles of volume reverberation measured acoustically. Brown and Brooks[6] found reasonable agreement in overall shape between scattering strength profiles at 13.5 and 15.5 kHz calculated from midwater fish population density and swimbladder data and those based on acoustic measurements, but only fair to poor agreement in magnitude. More recently, Love[7] used biological trawl data on 21 species of swimbladdered fish collected from the Mediterranean Sea in a volume reverberation model essentially identical to that applied by Brown and Brooks[6] to 55 species of swimbladdered fish collected from the Sargasso Sea. He reported good agreement between model predictions and measured scattering strength profiles between 6.3 and 20 kHz, but with agreement less satisfactory at frequencies below 6.3 kHz.

In this report the final results of efforts to develop a model for predicting reverberation data from biological trawl samples collected in a one-degree quadrangle (Ocean Acre) of open ocean water located near Bermuda are discussed. A detailed progress report describing this research program has been presented by Brown and Brooks.[6]

DATA ACQUISITION METHODS

BIOLOGICAL DATA ACQUISITION

A 3 m Isaacs-Kidd Midwater Trawl (IKMT) fully lined with a 3/8 in. (0.95 cm) stretch-mesh knotless nylon liner and fitted with a four-chambered discrete-depth cod-end sampler was used for specimen collection. The discrete-depth sampling capability of the cod-end unit was controlled by signals transmitted through an electromechanical tow cable that also allowed signals from temperature and depth sensors on the net to be monitored on deck readouts. At an average ship speed of 3 knots, 3 horizontal samples, usually of 1 hour duration each, were taken at a preselected sampling depth. This method allowed collection of three repetitive samples at depth. Analyses of the three repetitive samples furnished information on the horizontal distribution of ichthyofauna within a given layer. A fourth sample was obtained as the net was towed obliquely to the surface. In this report only discrete-depth samples collected during nighttime are used. Nighttime is defined here as 1-1/2 hours after sunset to 1-1/2 hours before sunrise.

Aboard ship, samples were preserved, sorted into various toxonomic groups, and measured for wet-displacement volume. In the laboratory, the total number of fish was counted, and each fish was identified, its standard length measured, and its sex and stage of development determined. Swimbladder dimensions were also determined for representative size ranges of a variety of species of mesopelagic fish. Additional nondiscrete-depth samples were collected with an Engel Midwater Trawl (EMT). The biological methodology is more comprehensively reviewed by Gibbs et al.[8] and Brown and Brooks.[6]

ACOUSTICAL DATA ACQUISITION

A variety of specialized transducers was employed to obtain profiles of volume scattering strength versus depth at selected frequencies. For reverberation measurements at 3.85 kHz, a special hull-mounted array was used. Data at 5.0, 7.0, and 9.0 kHz were taken with a wideband transducer suspended from the ship. A modified hull-mounted AN/UQN echo sounder was used for 13.5 and 15.5 kHz data.

Reverberation data recorded on analog tape were processed with shipboard or laboratory-based computers. The reverberation signals were envelope-detected, ensemble-averaged over eight consecutive pings, and converted to scattering strengths as functions of depth. These scattering strength data were corrected for noise by subtraction of the mean square of the ambient-noise voltage from the mean square reverberation-plus-noise voltage. Scattering strength-versus-depth curves were produced on a high-speed printer. A finite data point was obtained for every 25 ft (8 m) of depth, each representing a 5 msec time-average value.

The resulting scattering strength profiles also were integrated over depth to yield scattering strength of the water column (column strength) for comparison with the data from other investigations. Profiles of volume scattering strength and integrated scattering strength have been presented for Ocean Acre cruises by Dullea,[9] Fisch and Dullea,[10] and Fisch.[11] Fisch and Dullea[9] present a detailed account of the acoustical data acquisition and reduction methodology. They also discuss volume scattering strength theory as applied to acoustic results of Ocean Acre studies.

RESULTS AND DISCUSSION

Measurements of scattering strength were obtained for every 25 ft (8 m) interval of depth. However, it was not possible to obtain information on the biological population inhabiting the sampling area to this fine degree of depth resolution. This introduced the first in a series of complications in our attempt to compare acoustical measurements of scattering strength with results of concomitant biological sampling.

By way of compromise, a mean value for scattering strength was calculated by averaging all measured scattering strength values within plus and minus 75 ft (25 m) of the median depth from which each biological trawl sample was collected. This 150 ft (50 m) depth interval represents what is believed to be the maximum error in the estimate of median trawl sampling depth. An error would be due to a combination of net porpoising and depth-readout instrument error.

Comparison of measured scattering strength profiles with biological sample data has been complicated further by the differences in the time-space relationships between the acoustical and biological data. Each measured scattering strength profile was obtained ordinarily in a matter of a few minutes of data collection at essentially one point in space on each of several days. The biologically generated scattering strength profile, on the other hand, was based on net collections of specimens captured over a considerable towing distance (about 3 nmi) at each nighttime discrete depth at one or more periods extending over the duration of the cruise. Variability between measured acoustical data sets of nighttime scattering strength profiles obtained over 5 separate days was shown by Fisch[11] to be as large as 10 dB over a frequency range from 3.85 to 15.5 kHz. This result further complicates the potential for comparison of acoustical and biological data. In order for such a comparison to be valid one must assume that (1) the order of biological events does not change significantly over the duration of the sampling period, and (2) at a given point in time the distribution of elements within the population that contributes to the observed scattering is representative of the entire 3600 nmi^2 of the sampling area.

The results of an analysis of variance suggest that this latter assumption may not be strictly valid, though it is difficult to determine to what degree it may be violated. The analysis was performed on the original scattering strength measurements taken during cruise 14 at 3.85 and 15.5 kHz, where the criteria of classification were days and depths, and indicates highly significant differences between mean scattering strengths from one day to the next over a 5 day period. It is difficult to reconcile such differences over this short time span with an actual species change in the scattering population, and it is concluded that the distribution of the existing population may undergo strong to moderate changes from one day to the next in response to changes in the environment. As will become evident later, failure of this assumption is of small consequence to the final conclusions reached in this research.

For this comparison of acoustical and biological data, we have chosen nighttime measurements collected during Ocean Acre cruises 10 (June 1970), 12 (August-September 1971), and 14 (June 1972)

MEASURED ACOUSTICAL PROFILE

Figures 1 through 10 show mean nighttime measured scattering strengths in decibels (shown as solid circles), ±1 standard deviation, at depths corresponding with biological sample collections for cruises 10 and 12 at 3.85 and 15.5 kHz and for cruise 14 at 3.85, 5.0, 7.0, 9.0, 13.5, and 15.5 kHz.

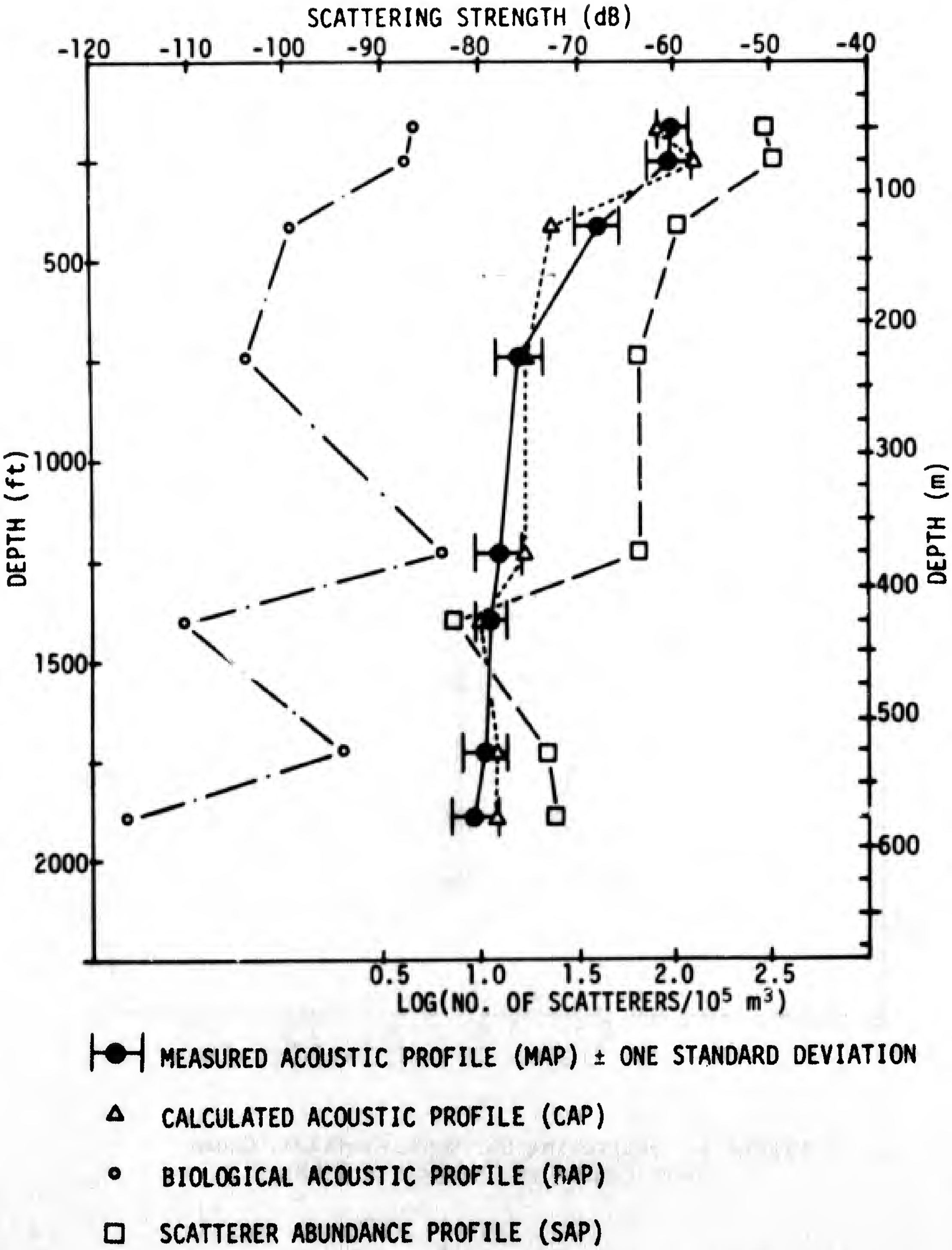


Figure 1. Scattering Strength Profiles, Ocean Acre Cruise 10, Night, 3.85 kHz

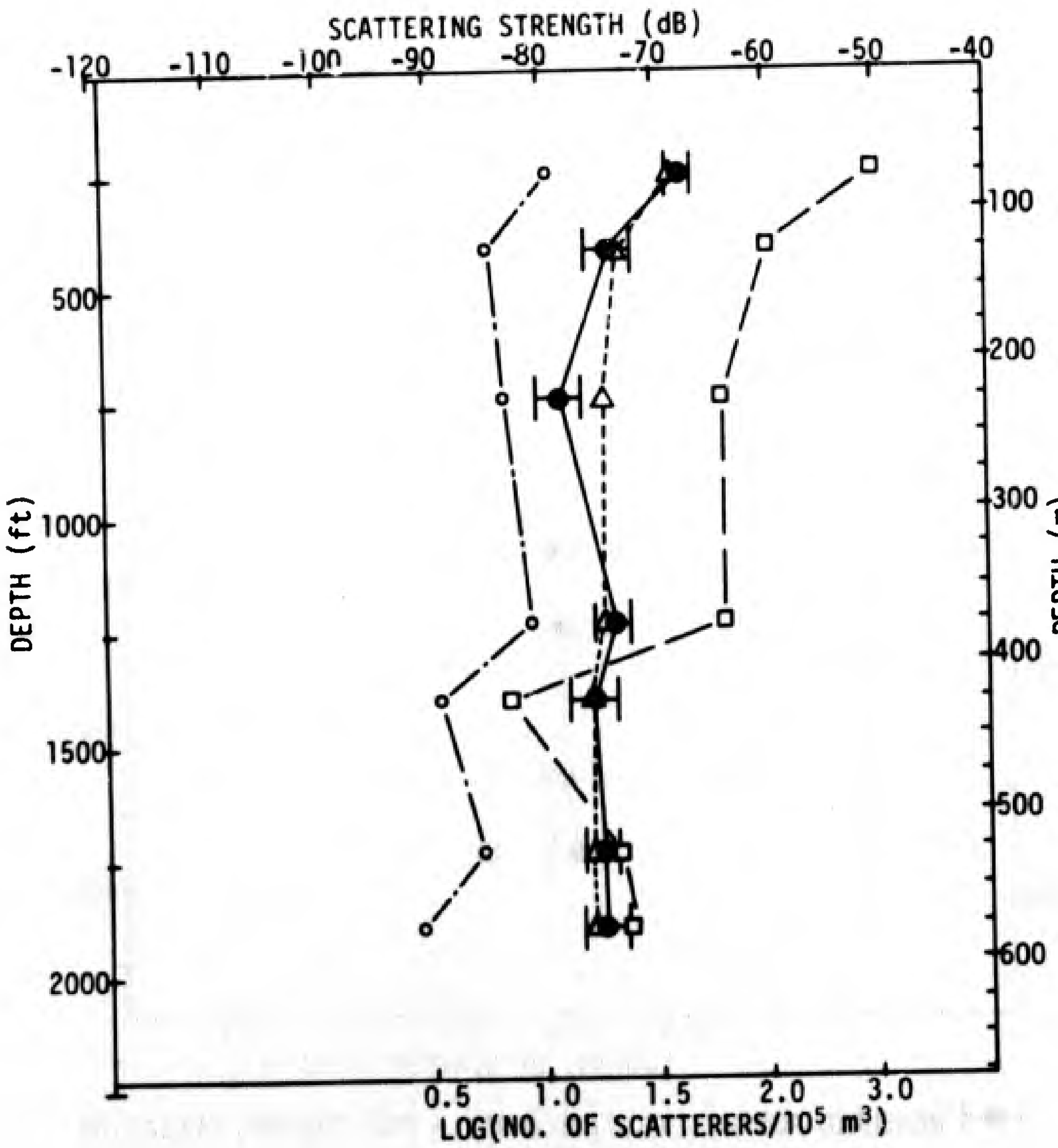


Figure 2. Scattering Strength Profiles, Ocean Acre Cruise 10, Night, 15.5 kHz

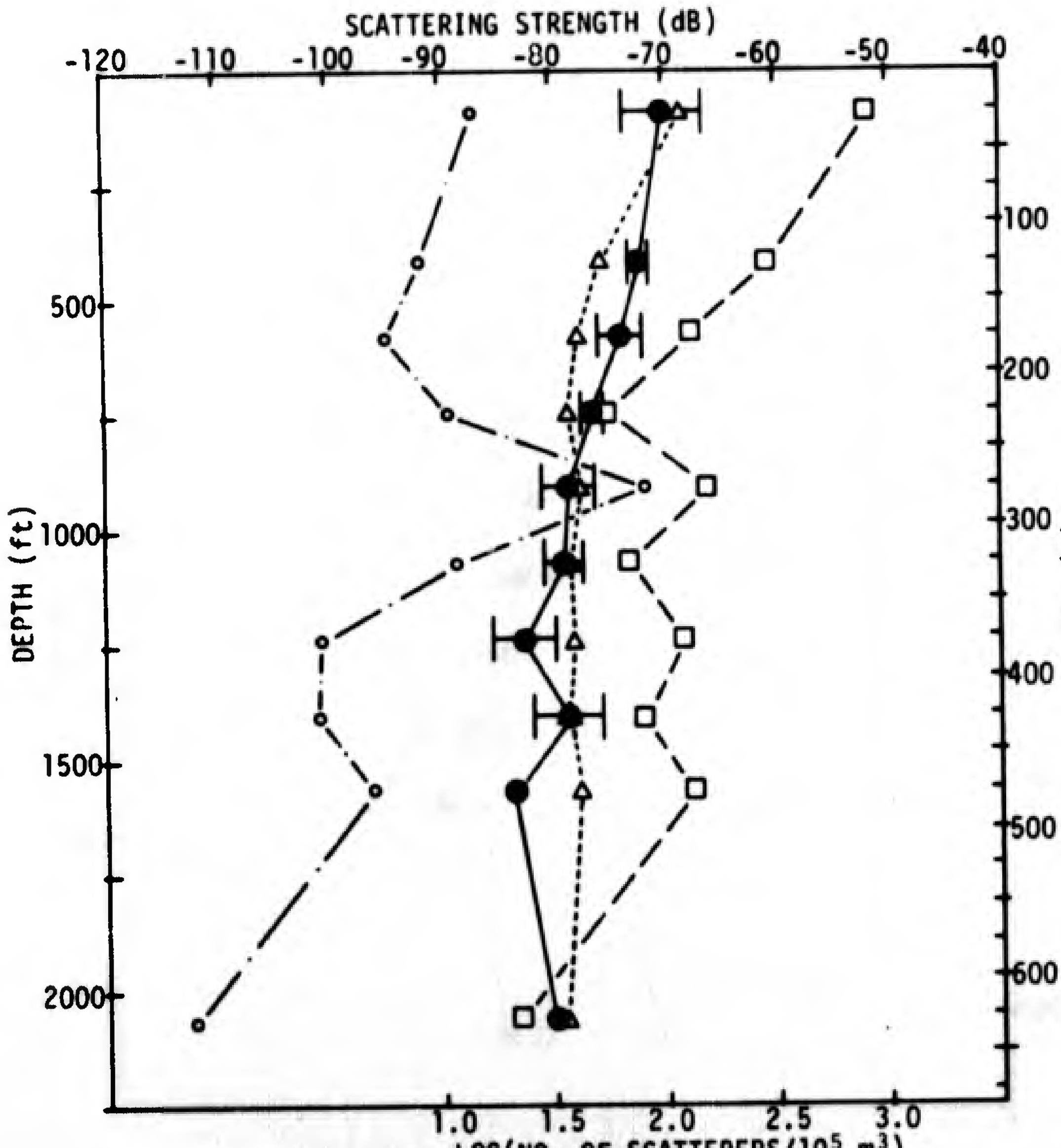


Figure 3. Scattering Strength Profiles, Ocean Acre Cruise 12, Night, 3.85 kHz

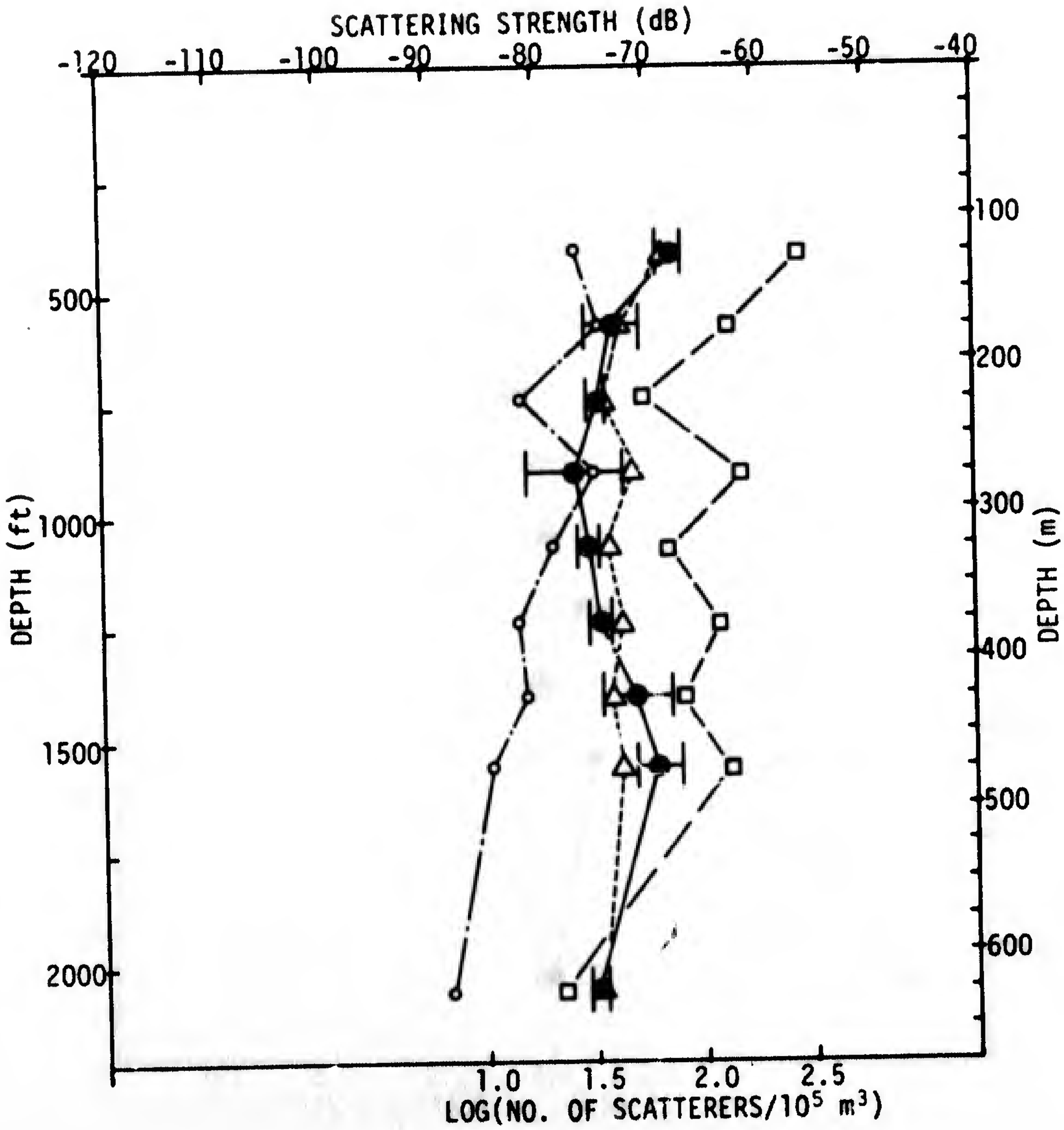


Figure 4. Scattering Strength Profiles, Ocean Acre Cruise 12, Night, 15.5 kHz

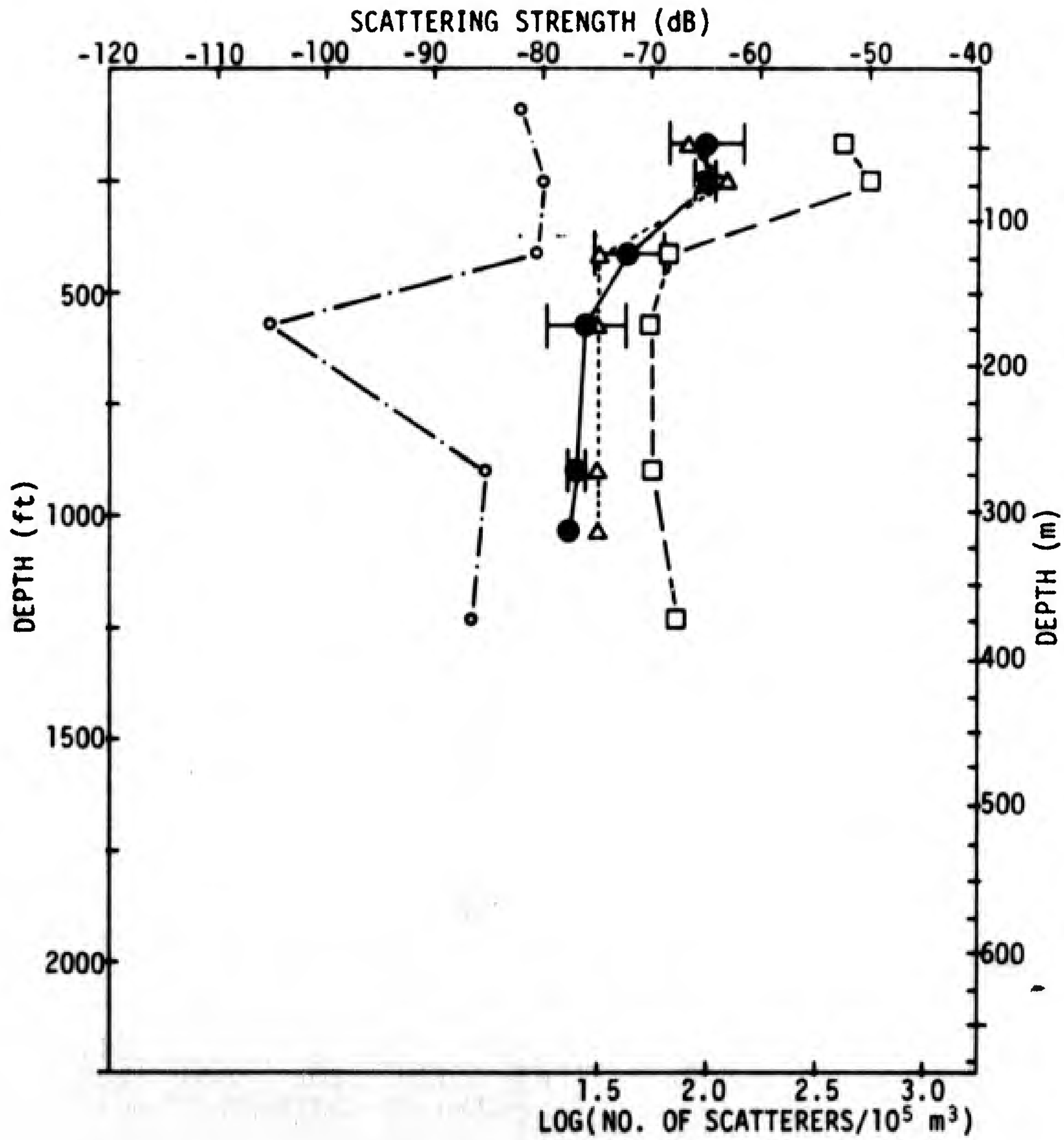


Figure 5. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 3.85 kHz

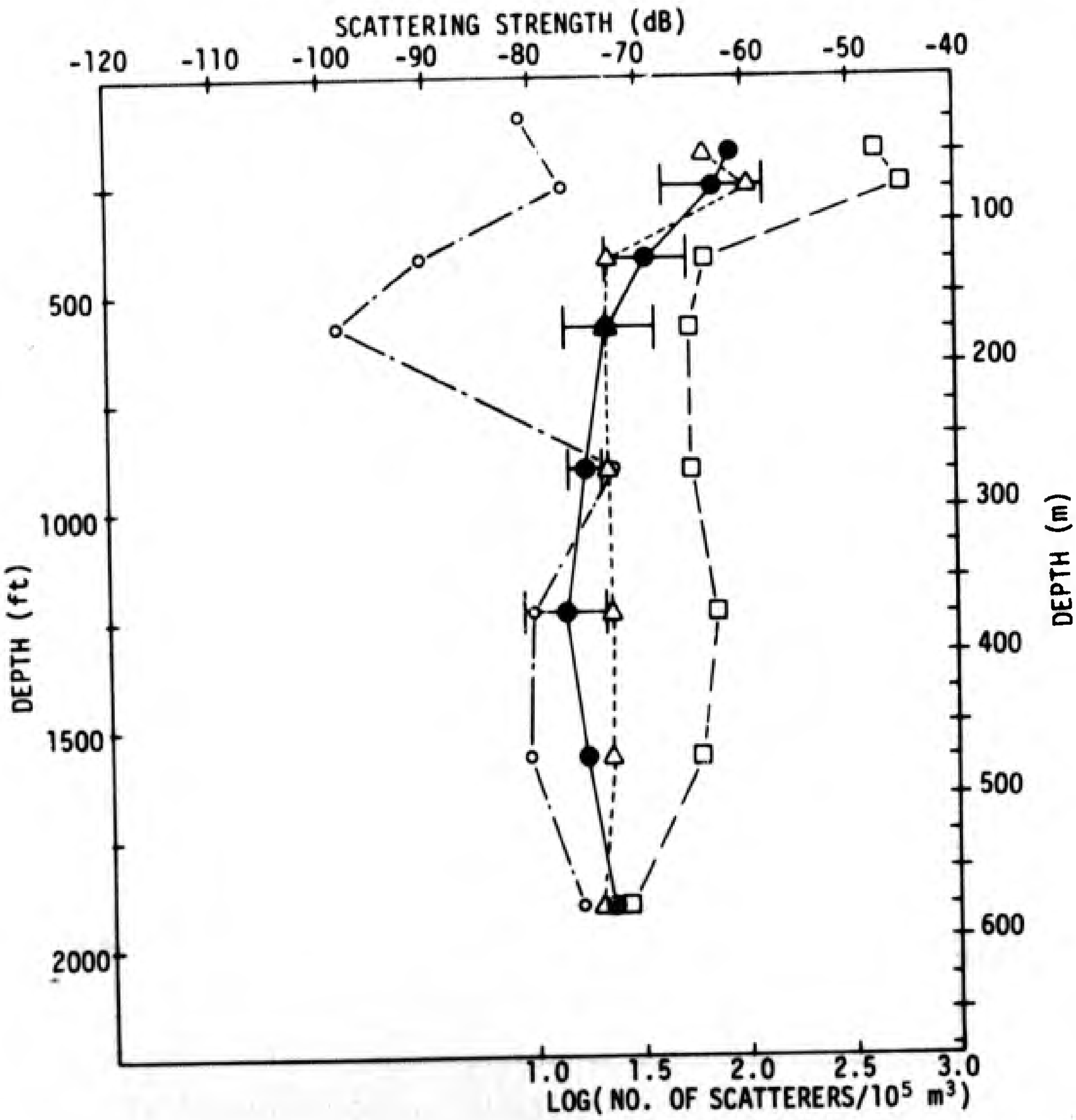


Figure 6. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 5.0 kHz

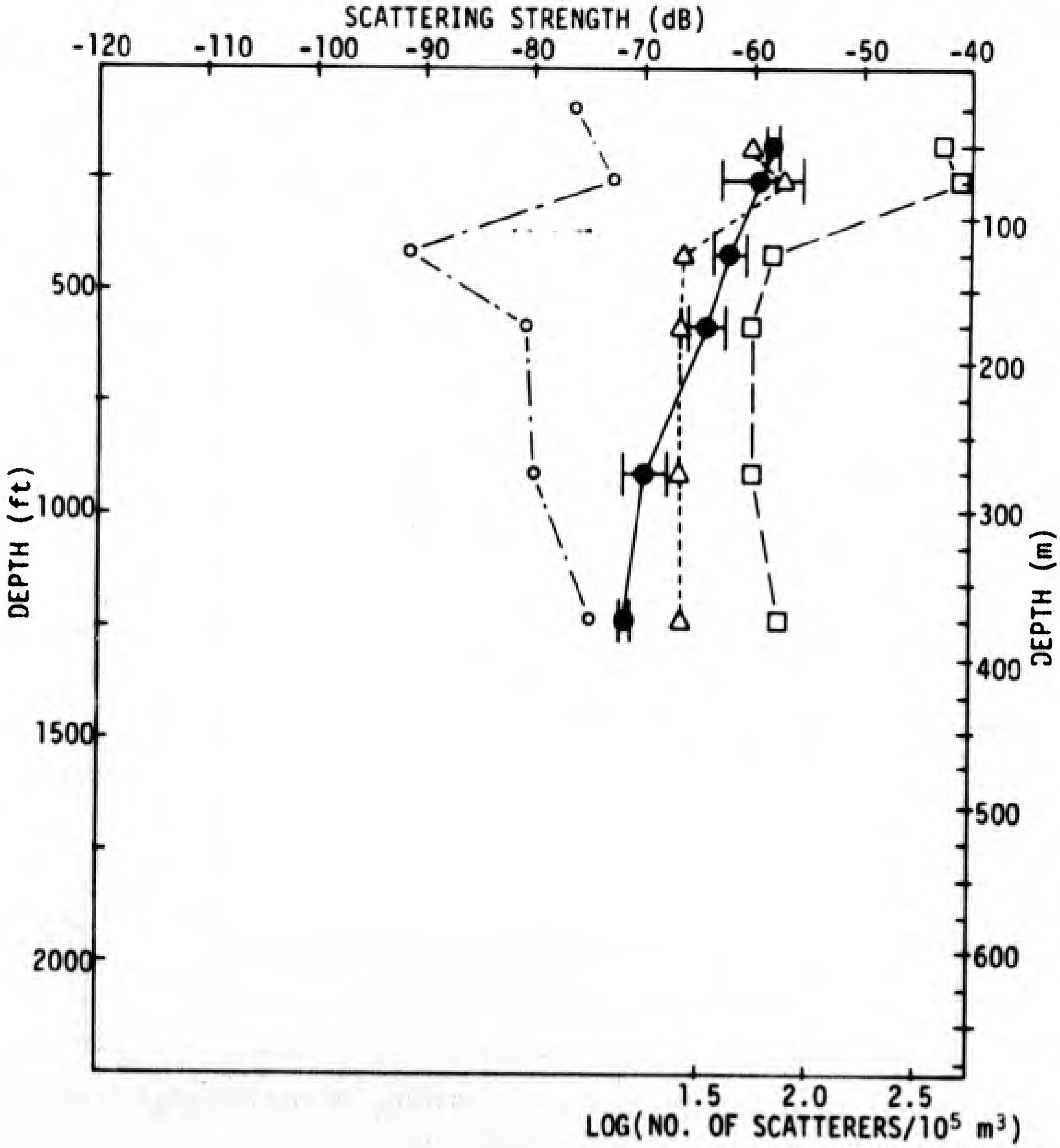


Figure 7. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 7.0 kHz

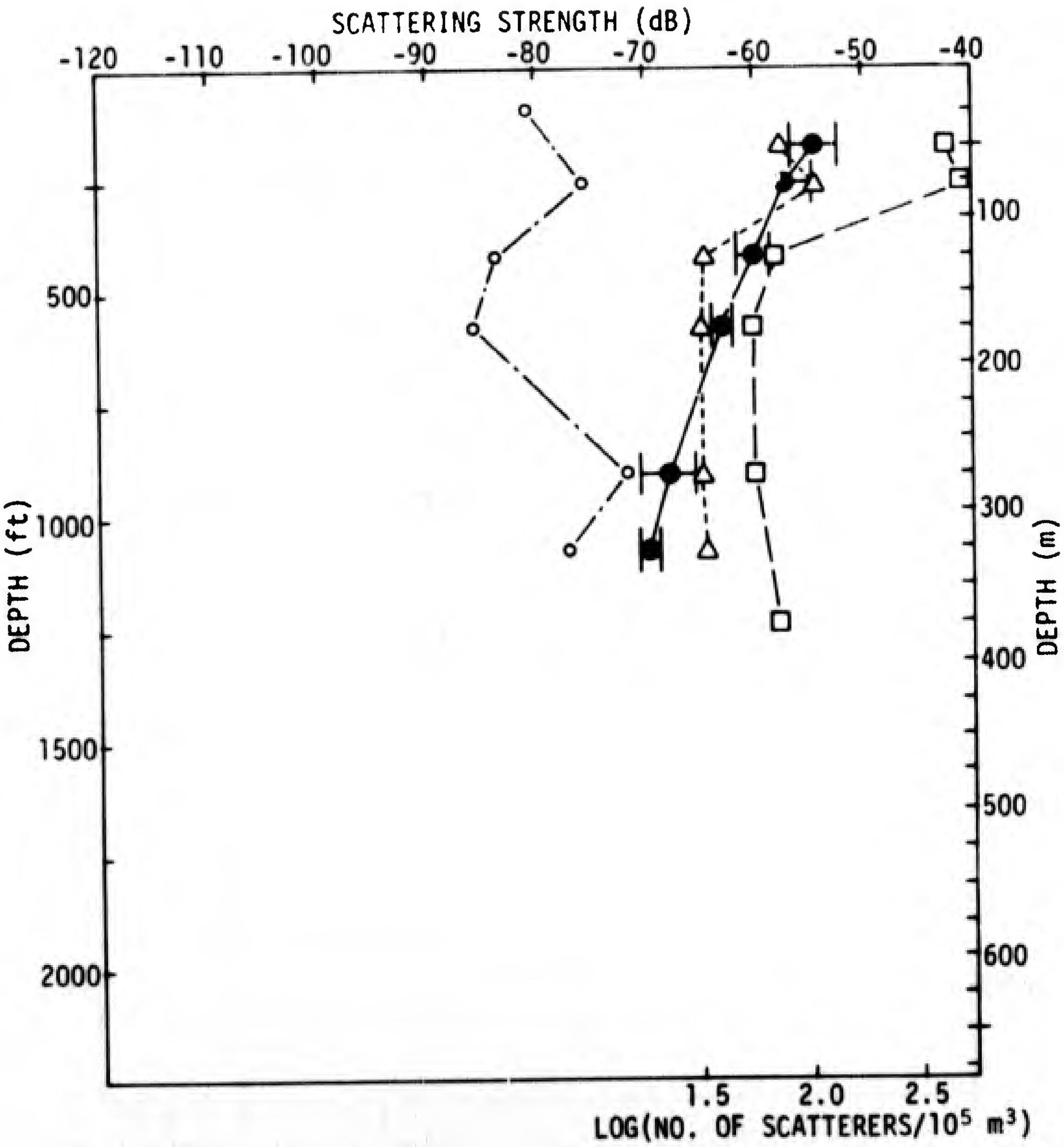


Figure 8. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 9.0 kHz

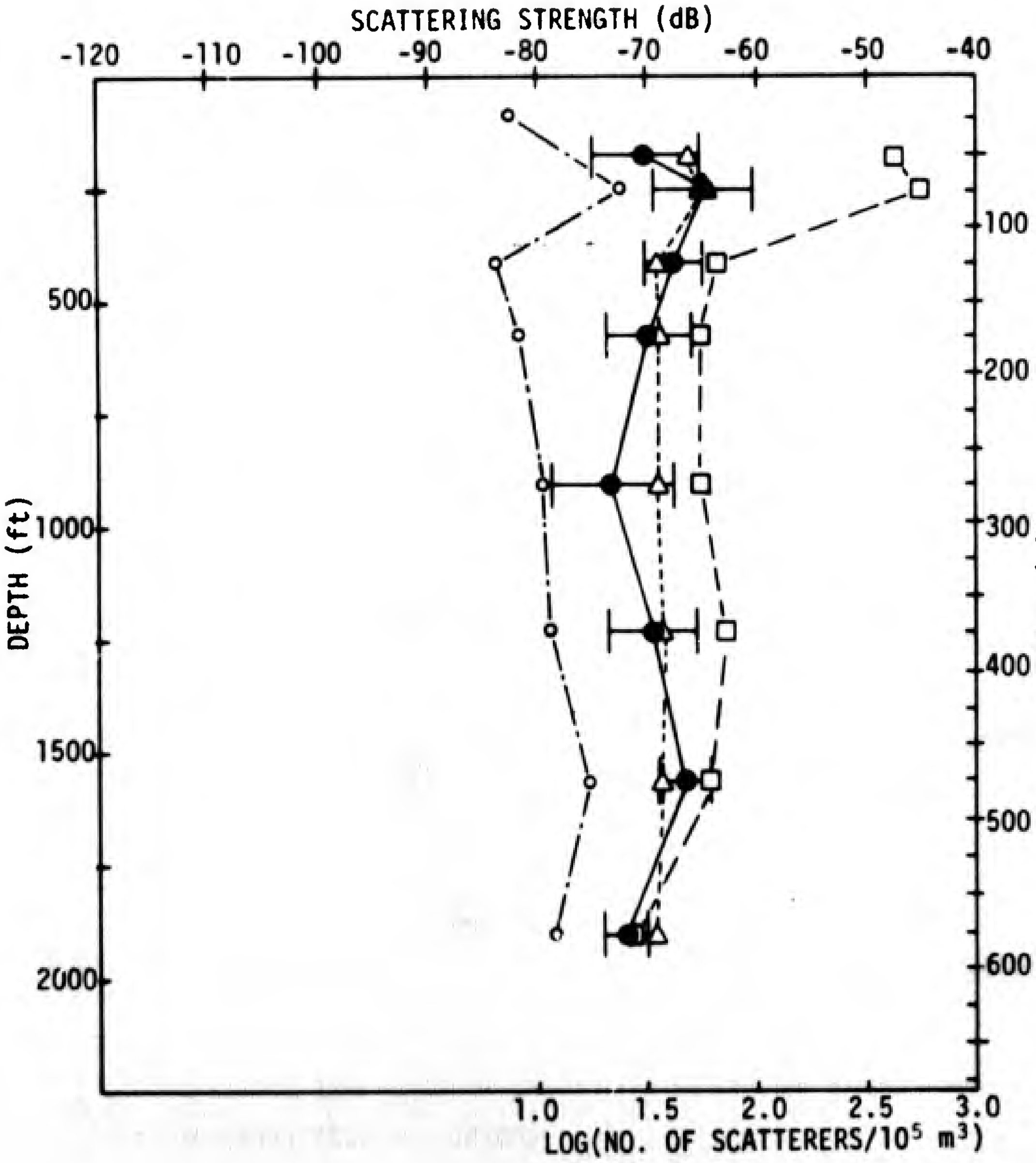


Figure 9. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 13.5 kHz

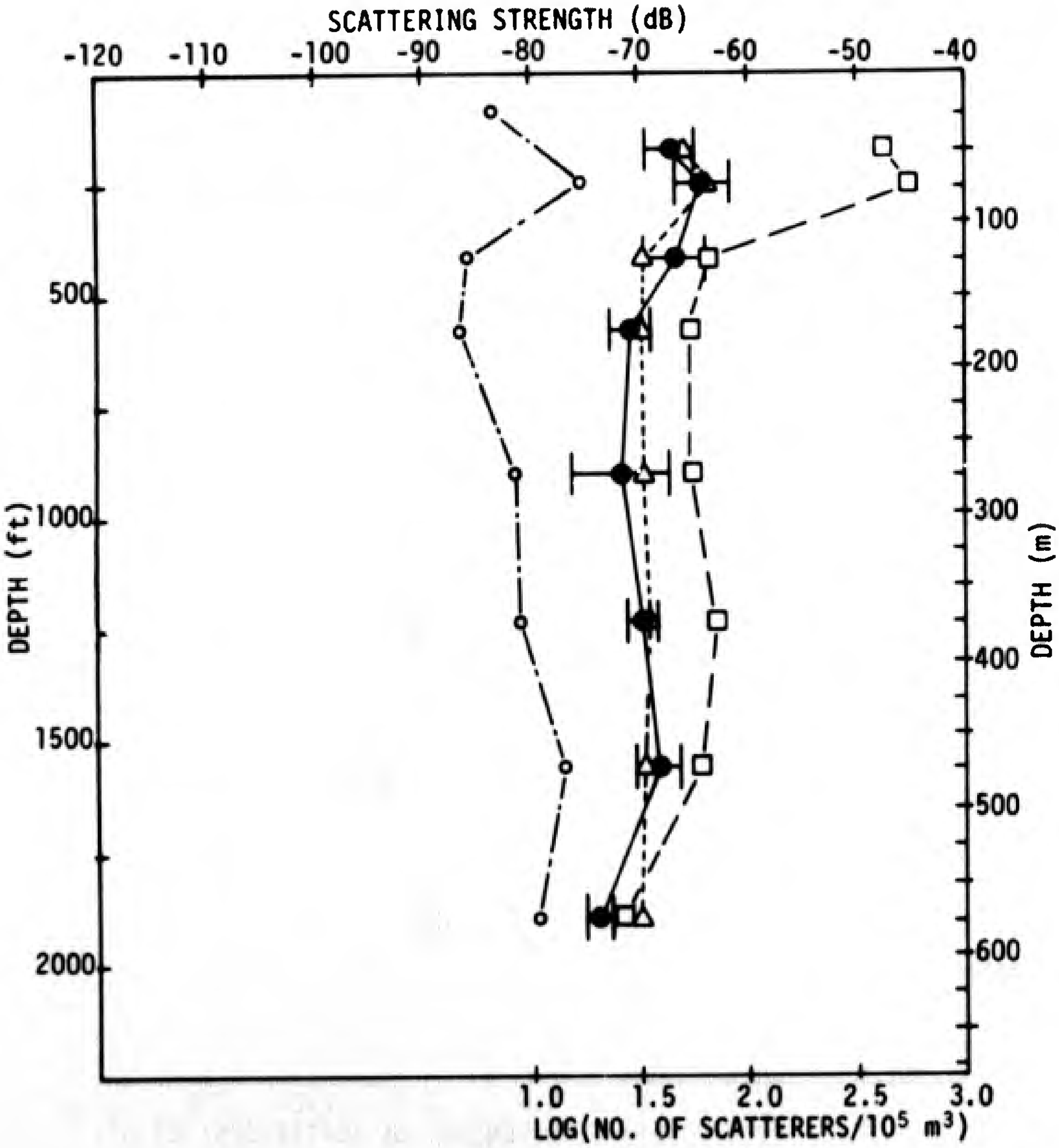


Figure 10. Scattering Strength Profiles, Ocean Acre Cruise 14, Night, 15.5 kHz

These scattering strength means were derived from quantities expressed in logarithmic space (dB) and are, thus, the logarithms of the geometric means of the datum points in each series. In most cases each mean is based on a sample size of five, representing data collected on each of 5 separate days. As a quantitative measure of the variability within data sets, 1 standard deviation is shown on either side of each mean. Where no standard deviation is indicated (e.g., figure 3, 475 and 625 m and figure 6, 475 and 575 m), only one value for measured scattering strength was available.

We consider these measured scattering strength means plus and minus their standard deviations as the basic measured acoustic profile (MAP) to which subsequently derived profiles will be referred for comparison.

Comparison of daytime biological and acoustical data is not included in this report because daytime net trawls in the upper waters captured an insufficient quantity of biological material for a meaningful analysis.

BIOLOGICAL ACOUSTICAL PROFILE

It is generally believed that airbladdered fish cause most of the biological reverberation in the open ocean, and a considerable effort during Ocean Acre research has been directed toward the study of these fish and their swimbladders (Kleckner,[12] and Brooks[13]). Theoretically, it should be possible, given information on airbladdered fish population density, vertical distribution, individual bladder volume, and insonifying frequency, to calculate the scattering strength profile for a given column of water.

A first attempt to develop a mathematical model that would provide the volume reverberation expected from a given population of airbladdered fish from Ocean Acre was presented by MacDonald.[14] In this model the scattering population was considered to be represented by 19 of the most common airbladdered fish species found in the Ocean Acre area. As additional information became available during the course of the investigation, MacDonald's initial model was enlarged, refined, and developed into a computer program. Typical examples of the program printouts giving bioacoustic scattering strengths for pertinent assemblages of Ocean Acre bladdered fishes have been given by Brown and Brooks.[6] The results of early attempts to compare biologically generated scattering strength profiles with profiles generated from acoustic measurements are also discussed. Since that publication, the model has been refined further and updated in response to the accumulation of information as the analyses of biological samples neared completion. The final version of the mathematical model includes 55 species of airbladdered scatterers and it has been used to generate the biological-acoustical profiles (BAP) shown as open circles in figures 1 through 10.

Comparison of these profiles (BAP's) with their respective MAP's shows fair agreement in shape, especially at the higher frequencies, but only fair-to-poor agreement in magnitude at any frequency.

Some of the factors that contribute to the inability of the BAP model to match more nearly the MAP have already been discussed. Additional contributing factors are summarized in the following paragraphs.

Sampling

The difficulties inherent in obtaining a representative quantitative sample of a relatively fast-moving open-ocean mesopelagic population are widely appreciated (Pearcy[15]). These difficulties have contributed to the inadequacy of the biological sample collections to furnish our program with sufficiently precise information on the population density and size distribution of the existing scattering population. To more nearly represent the true population density and size relationships of the swimbladdered fish, various adjustments have been applied to the data.

Factors common to all net trawl collections, such as avoidance and mesh losses as well as diurnal catch differentials, introduce an unknown bias into the samples. A limited insight into the degree of bias in IKMT collections was obtained by analysis of samples collected during cruise 12. It was found that although the overall range in fish length was similar for both nets, the mean fish standard length (SL) of specimens captured by the much larger EMT (476 m^2 mouth opening) commonly was twice that of individuals collected by the IKMT (7 m^2 mouth opening), although the percentage increase in size varied according to the fish species. In an attempt to reduce the effect of this bias, the appropriate percentage increase was applied to the SL of each fish species captured by the IKMT before use in the computer model. Another factor influencing fish density estimates is the filtering efficiency of the net. Based on a study by Brooks, Brown, and Scully-Power[16] in which the IKMT was shown to have a filtering efficiency of 92 percent, the original IKMT estimates of fish concentration were increased by 8 percent before use in the computer model.

The catch capacity (i.e., the ability of a net to capture the organisms present in the volume of water presented to the net mouth) bears directly on final estimates of population density. It would have been instructive to compare estimates of this variable derived for each net. Unfortunately, because of wide differences in net construction and nature of samples collected (i.e., nondiscrete oblique samples in the EMT and discrete-depth samples in the IKMT), estimates of fish concentration derived from samples collected by these two nets were not comparable. The inability to establish satisfactory criteria for assessing catch capacity of the IKMT and the resultant lack of any quantitative basis for adjusting catch data have forced acceptance of the population density estimates derived from samples collected by this net.

Data Acquisition, Reduction, and Handling

Measurements of fish SL were obtained for all specimens collected (Gibbs et al.[8]). It was not practical, however, to obtain swimbladder volume measurements for every individual. Instead, for each species used in the model, swimbladder volumes were calculated using regression equations relating this variable to fish SL (Brooks[13]). Since swimbladder volume can vary considerably among individuals of the same species with identical SL's (Brooks[13]), this method of bladder volume calculation introduces another potential for error in the estimated scattering strength of an assemblage of swimbladdered fish. In the final calculations of scattering strength, a mean SL based on the adjusted measurements of all specimens was determined for each species collected within a given discrete-depth interval. A bladder volume for each of these mean specimens was then provided for use in the calculation of scattering strength by application of the appropriate regression equation relating fish SL and swimbladder volume. The adjusted estimates of population density were then applied in the Andreeva equations (Andreeva and Chindonova[17]) to total scattering strength of each species for the depth interval examined.

Special Nature of Resonance Scattering

It was shown by Brown and Brooks[6] that a single specimen whose bladder volume is at or near the resonance frequency of the insonifying wavelength can account for virtually 100 percent of the total biologically derived scattering strength at a given depth. Thus, the use of a mean fish SL for all specimens of a given species collected within a given depth interval (necessitated by the large sample sizes) may introduce yet another potential error in the calculations of scattering strength. The bladder volume of a fish of mean SL may be nonresonant, whereas the potential exists that one or more resonant bladders could be present in the individuals used to calculate the mean SL.

A limited number of program runs was conducted from which scattering strengths were derived using SL of all specimens versus mean SL for each species at a given depth. A comparison of these runs, however, showed only slight differences in the totally biologically derived scattering strengths and suggested that the small error introduced was outweighed by the advantage of using a single mean fish SL in the calculations. As mentioned previously, airbladdered fish generally are believed to account for most of the biological reverberation in the open sea. All the common airbladdered fish present in the Ocean Acre area are included within the 55 species used in the scattering strength model. However, of the remaining 250 or more fish species collected from the area, it is probable that the occurrence of a rarely encountered scatterer not included in the model contributes to the measured scattering strength. Other organisms, too, such as siphonophores (Barham[18]) and squid (FAO[19]), have, in certain circumstances, been shown to cause acoustical scattering. The omission in this model of the potential contribution of these organisms to total scattering strength may account, at least in part, for the difference in magnitude observed between the BAP and the MAP.

When one considers all the previously discussed factors contributing to the potential for error, it is not surprising that the profile of scattering strength determined from swimbladdered fish (BAP) achieves only a fair-to-poor match with the MAP.

NUMBER OF SCATTERERS VERSUS DEPTH

During the course of the research it was noted that the profile generated from a plot of the logarithm of the number of scatterers per 10^5 m^3 against depth at capture (dubbed the scatterer abundance profile, or SAP), though often similar in shape to the BAP, especially at the higher frequencies, in many cases more nearly resembled the shape of the MAP than did the BAP. In figures 1 through 10, plots of the log of the number of scatterers per 10^5 m^3 versus depth are shown as open squares. These plots are shown with logarithmic ordinate scale in order to be consistent with the plots for measured scattering strength and also as a means of handling more conveniently the spread of the data. In the original arithmetic scale, they may extend over two orders of magnitude. It should be pointed out that the scattering strength scale (in dB) and the scale against which scatterers are plotted (i.e., log of number of scatterers per 10^5 m^3) bear no direct quantitative relationship to one another, and the two plots are compared only to illustrate their similarity in shape.

The same species and abundance of scatterers are included in the SAP as in the model used to generate the BAP, a fact that probably accounts in large part for the resemblance in overall shape. The comparatively greater excursions seen in the BAP are undoubtedly related to the special nature of resonance scattering, wherein the presence or absence of a single individual with a swimbladder at or near resonance may have a disproportionate effect on total scattering. Additional factors already cited as potential causes of error in the generation of the BAP may also be contributing to these seemingly spurious points. A probable explanation to account for the observed similarity between the shape of the SAP and the MAP is suggested by figures 11 and 12.

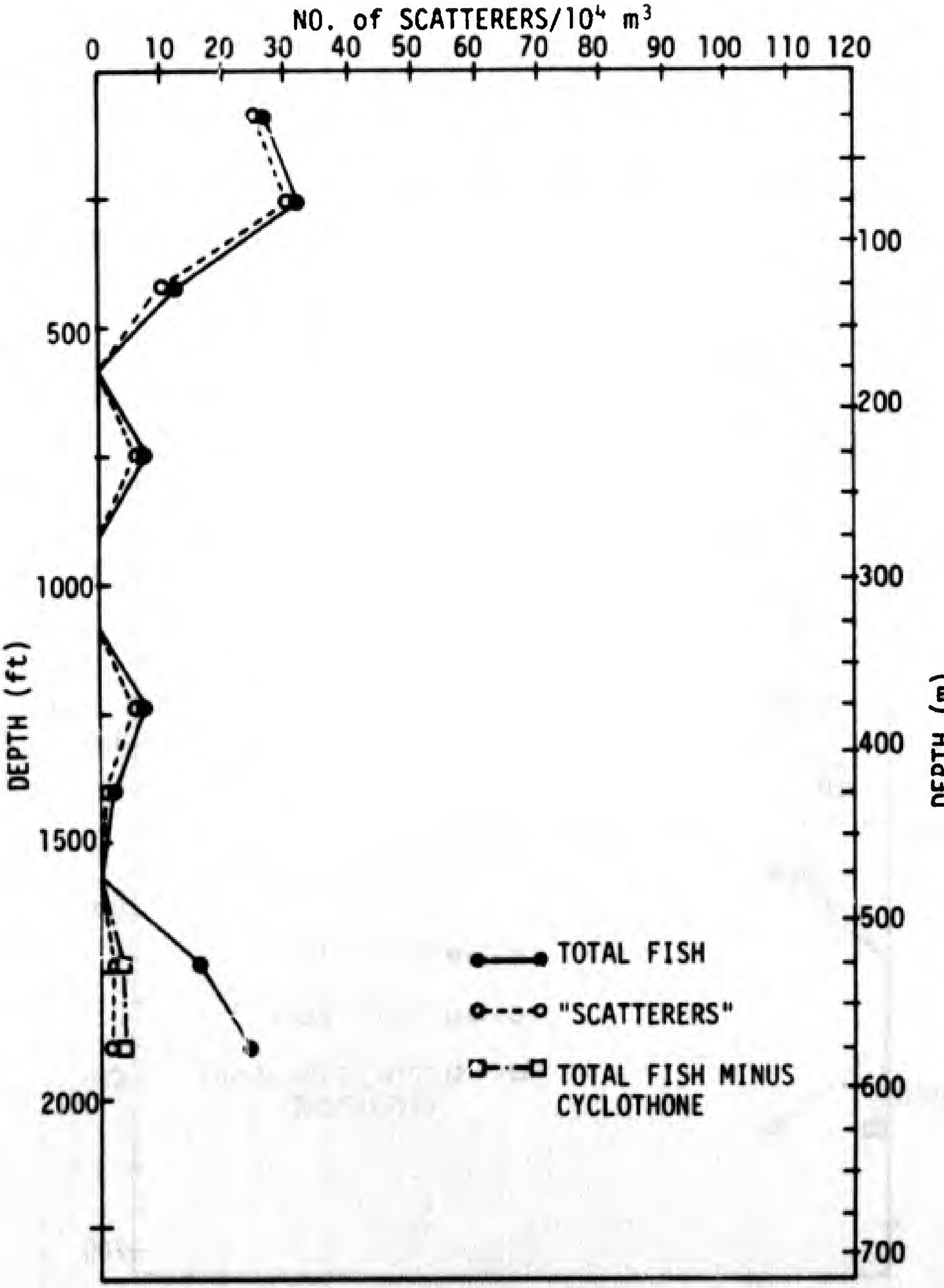


Figure 11. Midwater Fish Population Density Versus Depth, Ocean Acre Cruise 10, Night

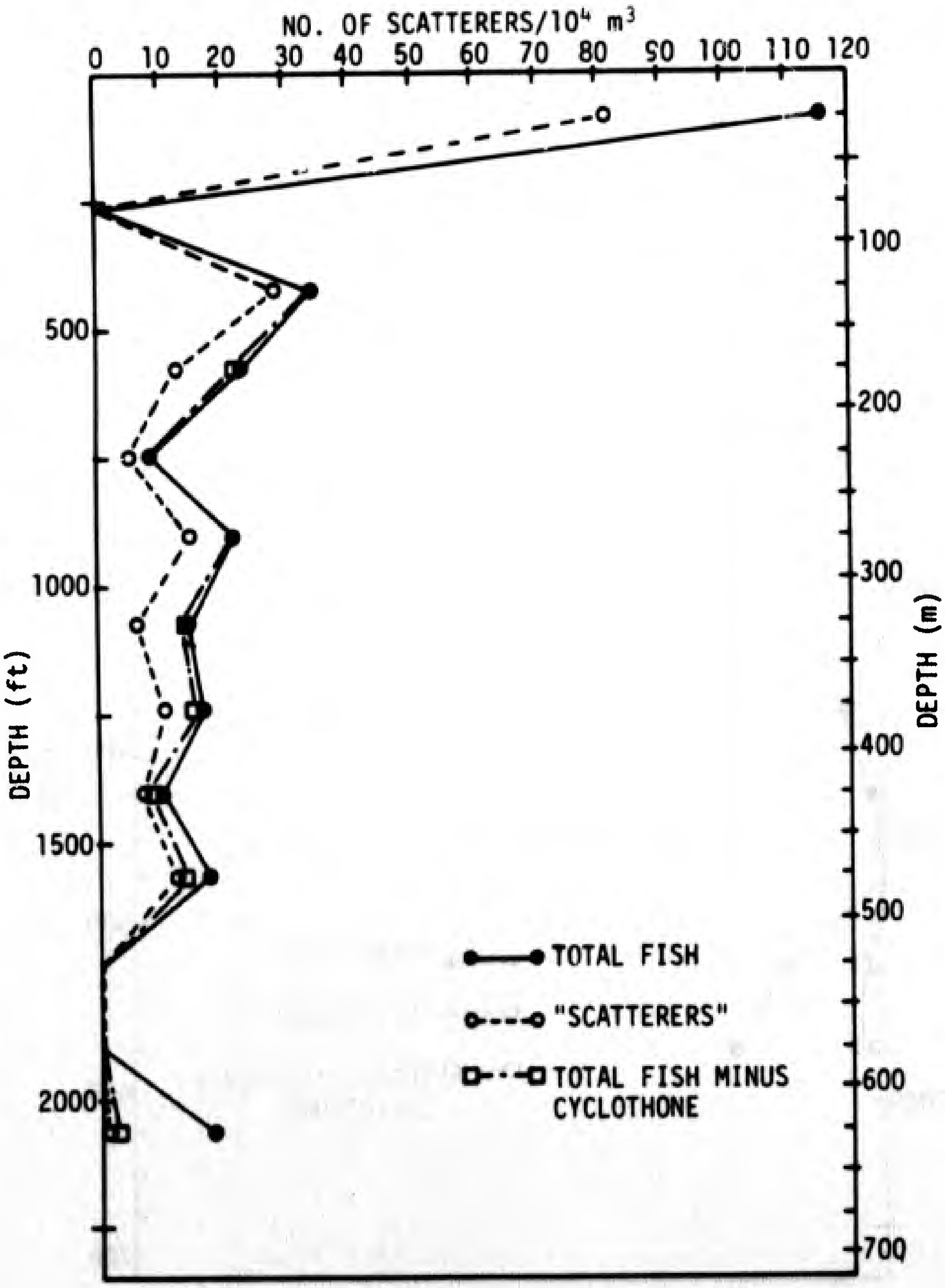


Figure 12. Midwater Fish Population Density Versus Depth, Ocean Acre Cruise 12, Night

The solid lines in these figures show the number of fish captured (all species) per 10^4 m^3 within each depth interval at night during cruises 10 and 12 and are based on sample sizes (i.e., total number of all specimens captured) of 1089 and 4290, respectively. The dashed lines also give the number of fish captured per 10^4 m^3 within each depth interval at night, but are based solely on the species present in the collections that are included in the list of 55 airbladdered scatterers referred to previously. In both figures, it is at once apparent that the curves for numbers of scatterers per 10^4 m^3 provide an accurate index to the relative concentrations of all fish specimens (and perhaps other potential contributors to resonance and nonresonance scattering) present within each depth interval.

The only regions where the shapes of these two curves diverge to any great degree are at the deepest levels. This is because of the presence, in the curve for total number of fish, of a large number of specimens of the genus Cyclothone. Because of their small size, depth of concentration, and the fact that the swimbladders of many specimens, especially the larger ones (whose potential contribution at their depths of concentration might ordinarily be expected to be important to resonance scattering), are fat-invested, it is unlikely that members of this genus are important contributors to volume scattering at the frequencies used in this study. When these specimens are excluded, the shape of the curves showing total number of fish and total number of scatterers are very similar. Since the relative concentrations of resonant and nonresonant organisms within the insonified volume determine the shape of the MAP, any index to these concentrations also might be expected to provide a profile similar in shape to the MAP.

The encouraging degree of similarity between the shape of the SAP and the MAP prompted the development of the fourth profile, shown in figures 1 through 10, which we have labeled the calculated acoustic profile, or CAP. To relate the SAP to the decibel scale of the MAP, the numbers of scatterers per 10^4 m^3 within each depth interval were plotted against the calculated means of the acoustic measurements at corresponding depths and fitted to straight lines by the method of least squares. These analyses yielded the regression equations shown in table 1 relating the two parameters for each cruise at each frequency. The appropriate regression equation was then used to calculate the mean scattering strength at the depths of all biological sample collections for their respective scatterer population densities, acoustic frequencies, and cruise numbers. These calculated values for mean scattering strength are shown in figures 1 through 10 as open triangles. The standard deviation rarely exceeded 2 dB. To simplify the graphic display and reduce any possible confusion, these standard deviations are not shown in the figures.

Table 1. Results of Regression Analyses of Number of Scatterers Versus Measured Scattering Strengths

Cruise Number	Frequency (kHz)	Correlation Coefficient (r)	Regression Equation
10 Night	3.85	0.96	Y = -79.8 + 0.72X
	15.50	0.87	Y = -75.9 + 0.26X
12 Night	3.85	0.72	Y = -79.6 + 0.14X
	15.50	0.64	Y = -75.4 + 0.25X
14 Night	3.85	0.90	Y = -76.5 + 0.22X
	5.00	0.88	Y = -74.2 + 0.24X
	7.00	0.75	Y = -67.8 + 0.18X
	9.00	0.76	Y = -65.8 + 0.19X
	13.50	0.64	Y = -69.3 + 0.08X
	15.50	0.73	Y = -70.3 + 0.11X

Of the 76 calculated means, 55 percent (or 42) fall within 2 dB or less of their corresponding measured mean scattering strength values. The maximum difference among all means is 5.5 dB.

Since a 5 dB spread in measured scattering strengths is not unusual, these results successfully demonstrate the ability of this regression technique to fit the measured acoustic data.

PREDICTED ACOUSTICAL PROFILE

One of the primary objectives of the Ocean Acre research was to develop a model to predict scattering strength from net trawl collections. In the following discussion, the regression technique described earlier is expanded to satisfy this objective. The regression lines relating number of scatterers per 10^4 m^3 to scattering strength are shown in figure 13 for cruises 10, 12, and 14 at 3.85 and 15.5 kHz. With the striking exception of the line for cruise 10 and 3.85 kHz, the relationship between the two parameters is similar for all three cruises, differing primarily in the elevation of the lines. It has already been shown that the mean scattering strengths calculated from the equations match their respective measured scattering strengths satisfactorily.

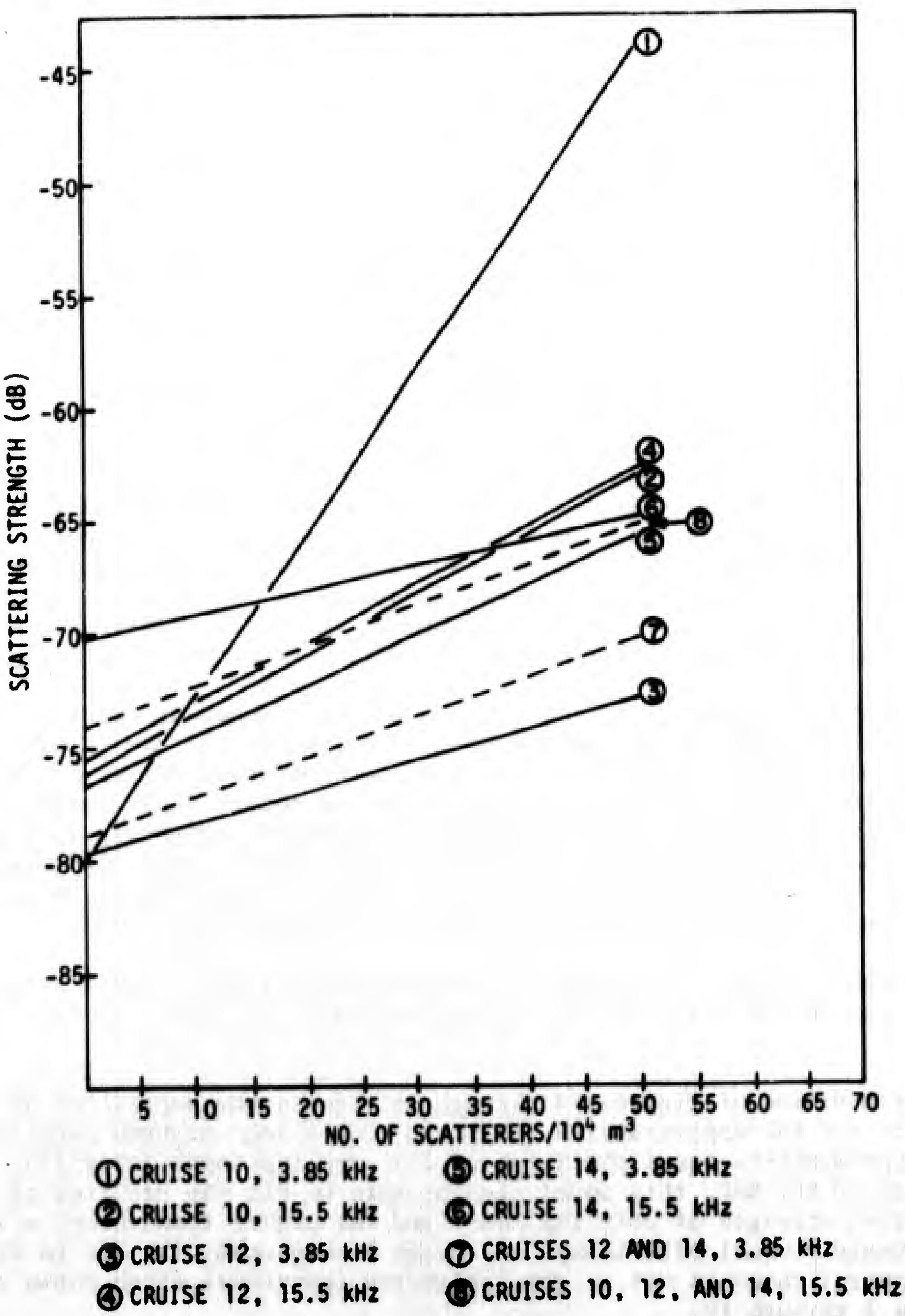


Figure 13. Regression Relationships Between Numbers of Scatterers per 10^4 m^3 and Measured Scattering Strength for Cruises 10, 12, and 14

In an effort to expand the capabilities of the model to satisfy more nearly the general case, two equations, one for 3.85 kHz and one for 15.5 kHz, were obtained from linear regression analyses of the combined data on number of scatterers per 10^4 m^3 and scattering strength measured during cruises 12 and 14 at 3.85 kHz and cruises 10, 12, and 14 at 15.5 kHz. The equations resulting from these analyses are

$$3.85 \text{ kHz}: Y = -78.9 + 0.17X \quad (1)$$

and

$$15.5 \text{ kHz}: Y = -74.1 + 0.17X, \quad (2)$$

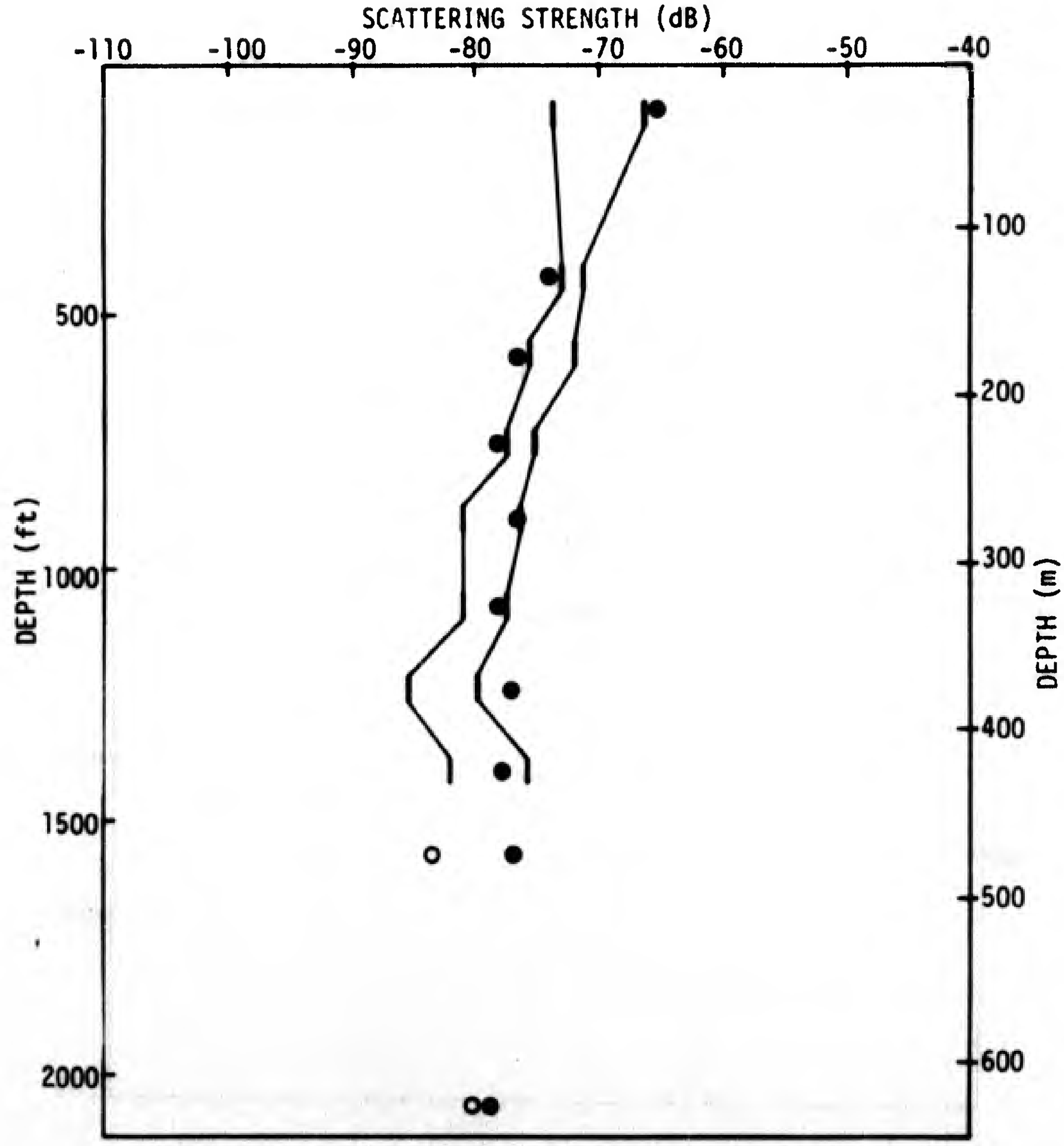
with correlation coefficients of 0.74 and 0.68, respectively. Additional analyses of the combined data revealed that a second-degree polynomial fit to the data raised the value of the correlation coefficient only slightly and provided no practical advantage over use of the linear equation. The solutions to the linear equations are shown in figure 13 as dashed lines and are considered to represent the average nighttime summer relationships between these two parameters, scattering strength and number of scatterers, at the two frequencies. Because the regression equation for cruise 10 at 3.85 kHz was so widely different from the remaining regressions, these data were omitted from the calculations.

Scattering strength values were calculated (shown as circles in figures 14 through 18) by substituting in equations (1) and (2) the numbers of scatterers collected at each depth interval during a cruise. To ascertain the fit of this second generation model, these values are compared with the profile of the combined measured scattering strengths (shown as a band of varying width) resulting when the upper and lower limit of one standard deviation on either side of the measured mean scattering strength value are plotted for each depth interval.

Roughly 50 percent of these calculated values fall within ±1 standard deviation and less than 20 percent exceed these limits by more than 2 dB.

Examination of figures 14 through 18 reveals the capability of the model to fit the empirically established scattering strength profiles with approximately equal precision at all sampling depth intervals. Contrary to the BAP, this model also appears to fit the profiles of scattering strength at both the lower and the higher frequencies with approximately equal efficiency. As might be expected, the fit in these more general cases is not as good as in the individual cases shown in figures 1 through 10.

The real test of this model arises when these equations are used to predict scattering strengths for other cruises. The ideal case, of



MEASURED MEAN SCATTERING STRENGTH ± ONE STANDARD DEVIATION CRUISE 12, 3.85 kHz

o MEASURED SCATTERING STRENGTH, SINGLE VALUE ONLY

● SCATTERING STRENGTH CALCULATED FROM REGRESSION EQUATION DERIVED FROM COMBINED DATA OF CRUISES 12 AND 14 AT 3.85 kHz

Figure 14. Comparison of Calculated Scattering Strengths With Measured Scattering Strengths, Cruise 12, 3.85 kHz

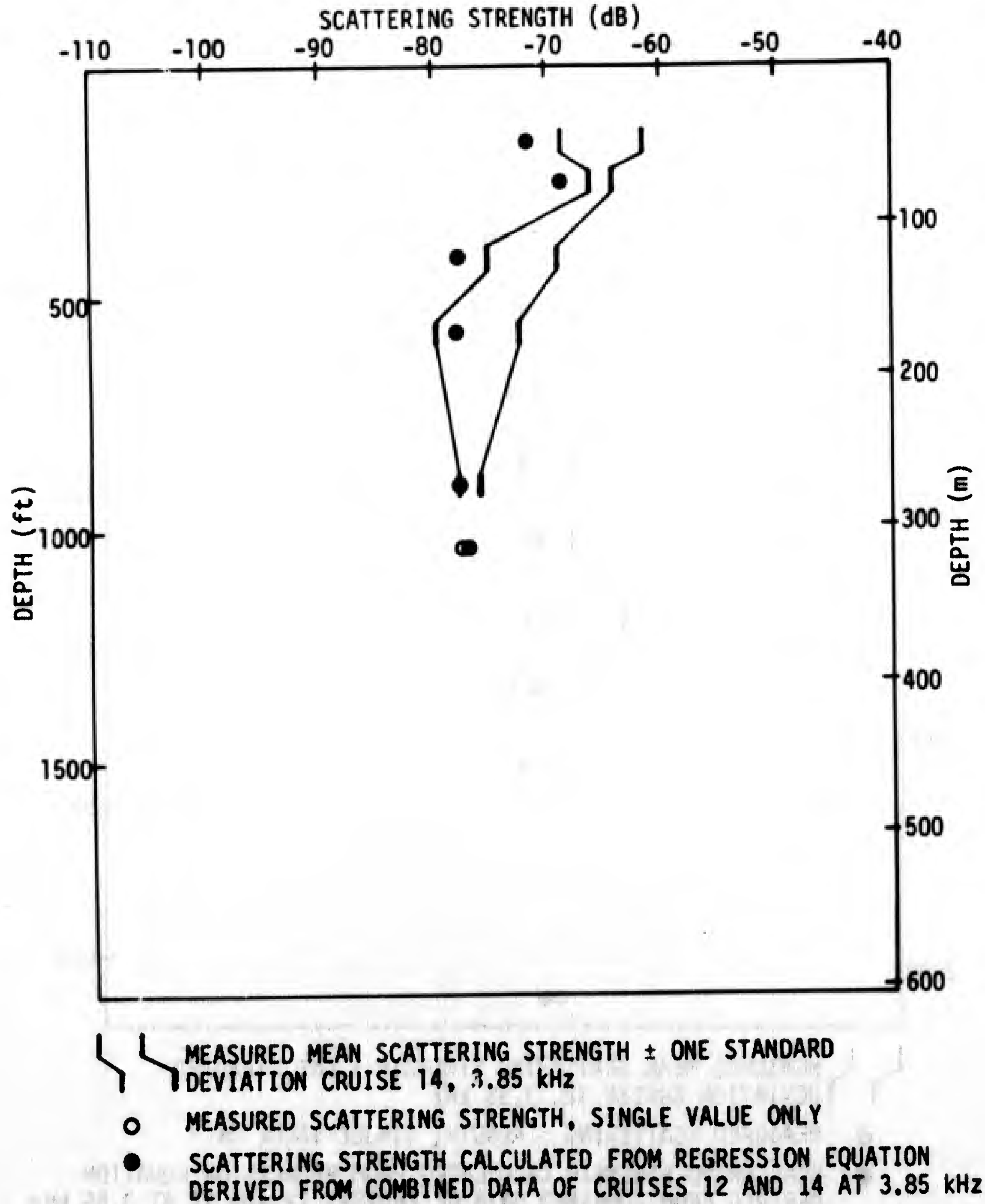
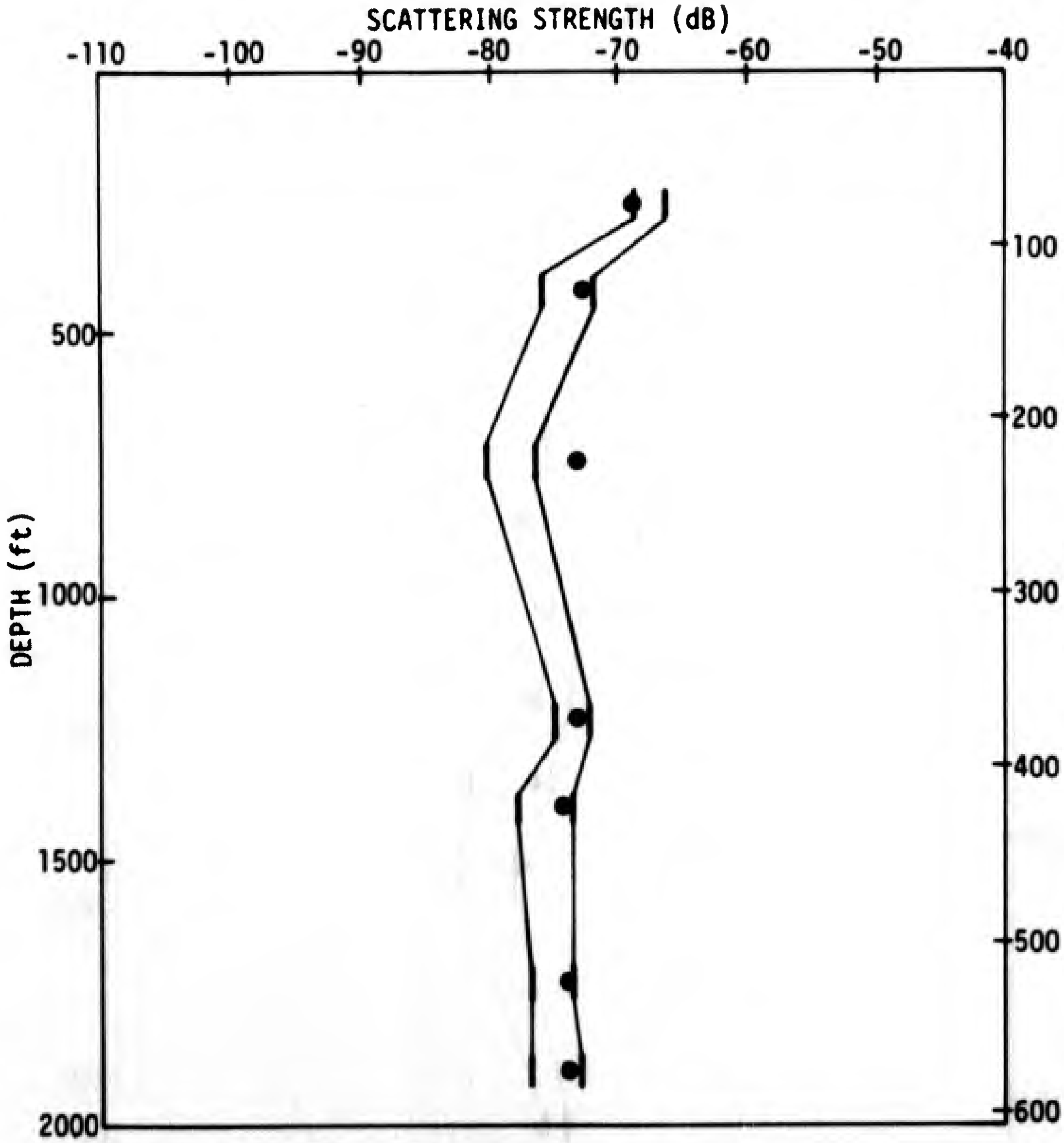


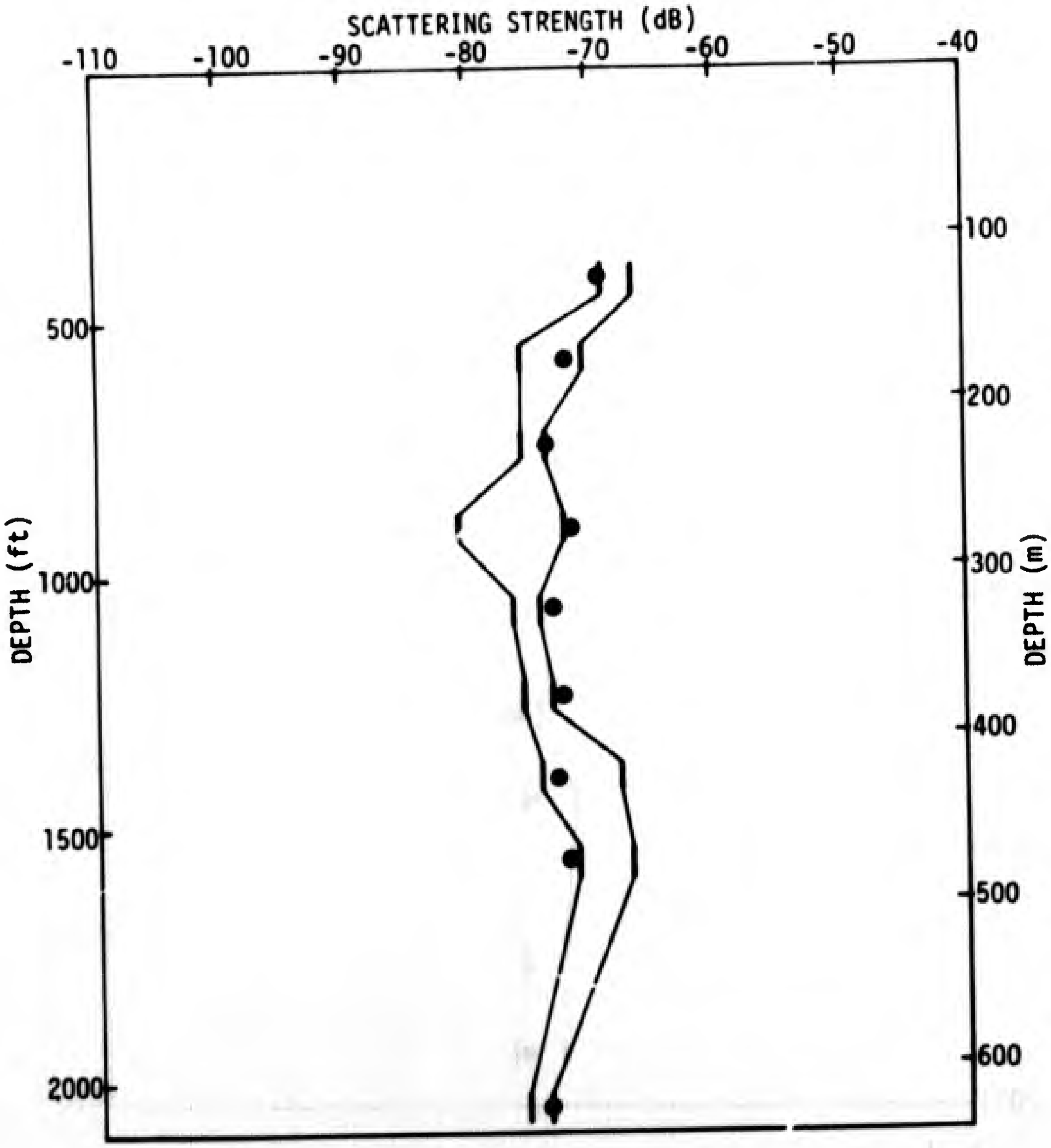
Figure 15. Comparison of Calculated Scattering Strengths With Measured Scattering Strengths, Cruise 14, 3.85 kHz



MEASURED MEAN SCATTERING STRENGTH ± ONE STANDARD DEVIATION CRUISE 10, 15.5 kHz

● SCATTERING STRENGTH CALCULATED FROM REGRESSION EQUATION DERIVED FROM COMBINED DATA OF CRUISES 10, 12, AND 14 AT 15.5 kHz

Figure 16. Comparison of Calculated Scattering Strengths With Measured Scattering Strengths, Cruise 10, 15.5 kHz



MEASURED MEAN SCATTERING STRENGTH ± ONE STANDARD DEVIATION CRUISE 12, 15.5 kHz

● SCATTERING STRENGTH CALCULATED FROM REGRESSION EQUATION DERIVED FROM COMBINED DATA OF CRUISES 10, 12, AND 14 AT 15.5 kHz.

Figure 17. Comparison of Calculated Scattering Strengths With Measured Scattering Strengths, Cruise 12, 15.5 kHz

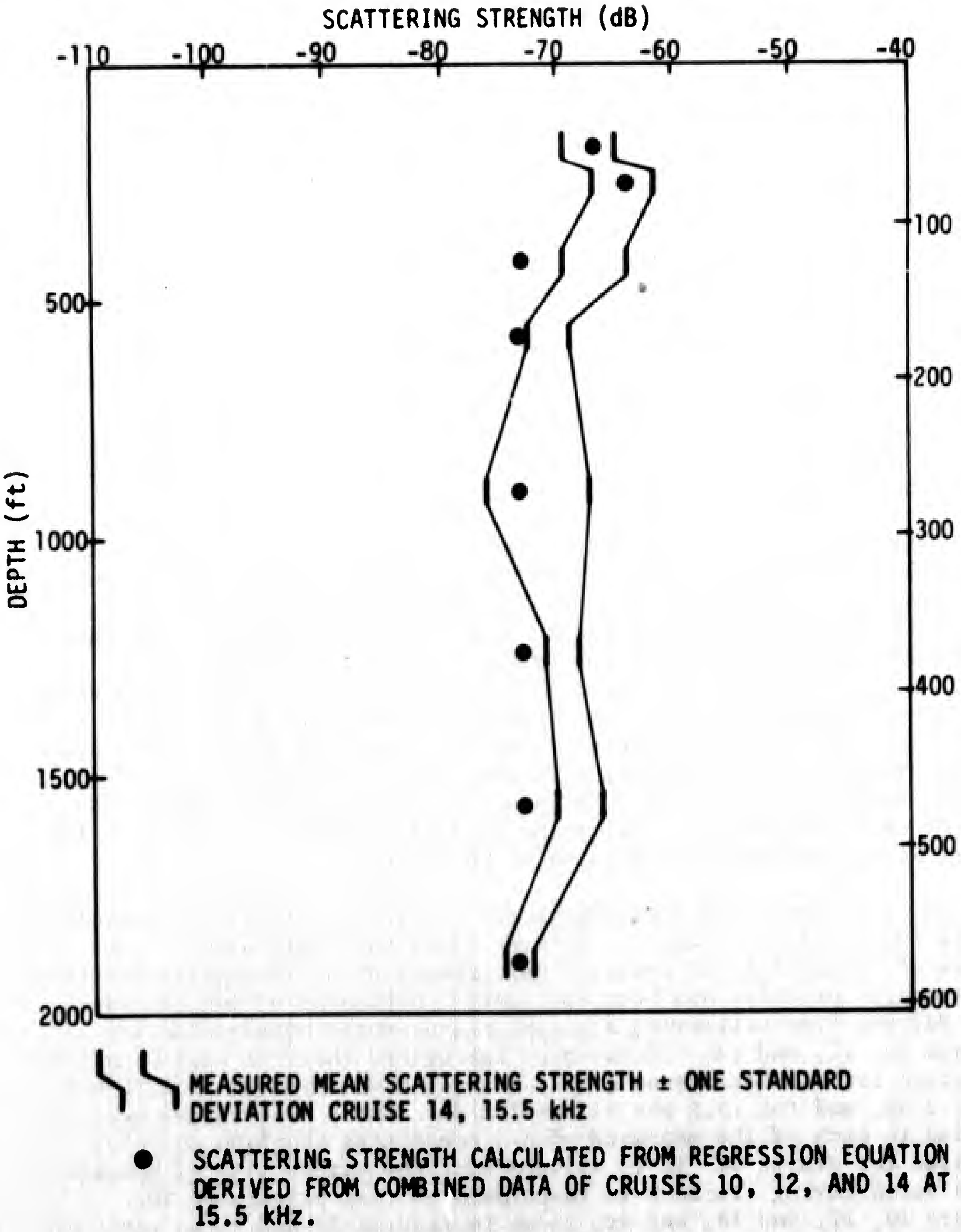


Figure 18. Comparison of Calculated Scattering Strengths With Measured Scattering Strengths, Cruise 14, 15.5 kHz

course, would be to test the model against data collected during the same season of the year as those from which the model was constructed. Unfortunately, no suitable summertime biological or acoustical data, other than those that were used to construct the model, are available for the Ocean Acre area. Consequently, acoustical data collected during cruise 9, in the spring of 1970 (for which no suitable biological data are available), and biological data collected during cruise 13, in the spring of 1972 (for which no suitable acoustical data are available), were combined and used to test the predictive capabilities of the model.

In the following discussion the assumption is made that the biological populations and the resultant volume reverberation levels were essentially similar during these two different years. At the same time, it is recognized that population density, species composition, and vertical distribution of potential scatterers may be somewhat different between spring and summer months and probably contribute to disparities between the predicted (summertime) scattering strength profiles and the measured springtime profiles represented by Ocean Acre cruise 9 acoustical data.

Predicted scattering strength profiles were calculated for 3.85 and 15.5 kHz by substituting for "X" in equations 1 and 2 the number of scatterers per 10^4 m^3 captured at each of the depths sampled during cruise 13. These predicted values, shown as open triangles in figures 19 and 20, are compared with scattering strengths measured during cruise 9 (closed circles). AT 3.85 kHz only one of the predicted values exceeds the measured scattering strength by more than 5 dB (at 575 m). At 15.5 kHz the maximum difference between predicted and measured scattering strengths is 3.9 dB, which occurs at 175 m depth. At most depths, however, the two 15.5 kHz profiles differ by less than 2 dB. Because only one measured scattering strength profile is available for cruise 9, no measure of dispersion is possible.

It is evident from measurements of scattering strengths obtained during cruises 10, 12, and 14, however, that one could expect some degree of variability in cruise 9 measurement data, if several scattering strength profiles had been available. Estimates of the variance were derived from scattering strength measurements obtained during cruises 10, 12, and 14. It has been calculated that the mean standard deviation for all measurements taken during these cruises at 3.85 kHz was 2.3 dB, and for 15.5 kHz it was 2.2 dB. These mean values were applied to each of the measured points comprising the 3.85 and 15.5 profiles for cruise 9. It is assumed that the variability of measurements taken during cruise 9 is comparable to that calculated for cruises 10, 12, and 14, and are shown in figures 19 and 20 as vertical bars on either side of each point.

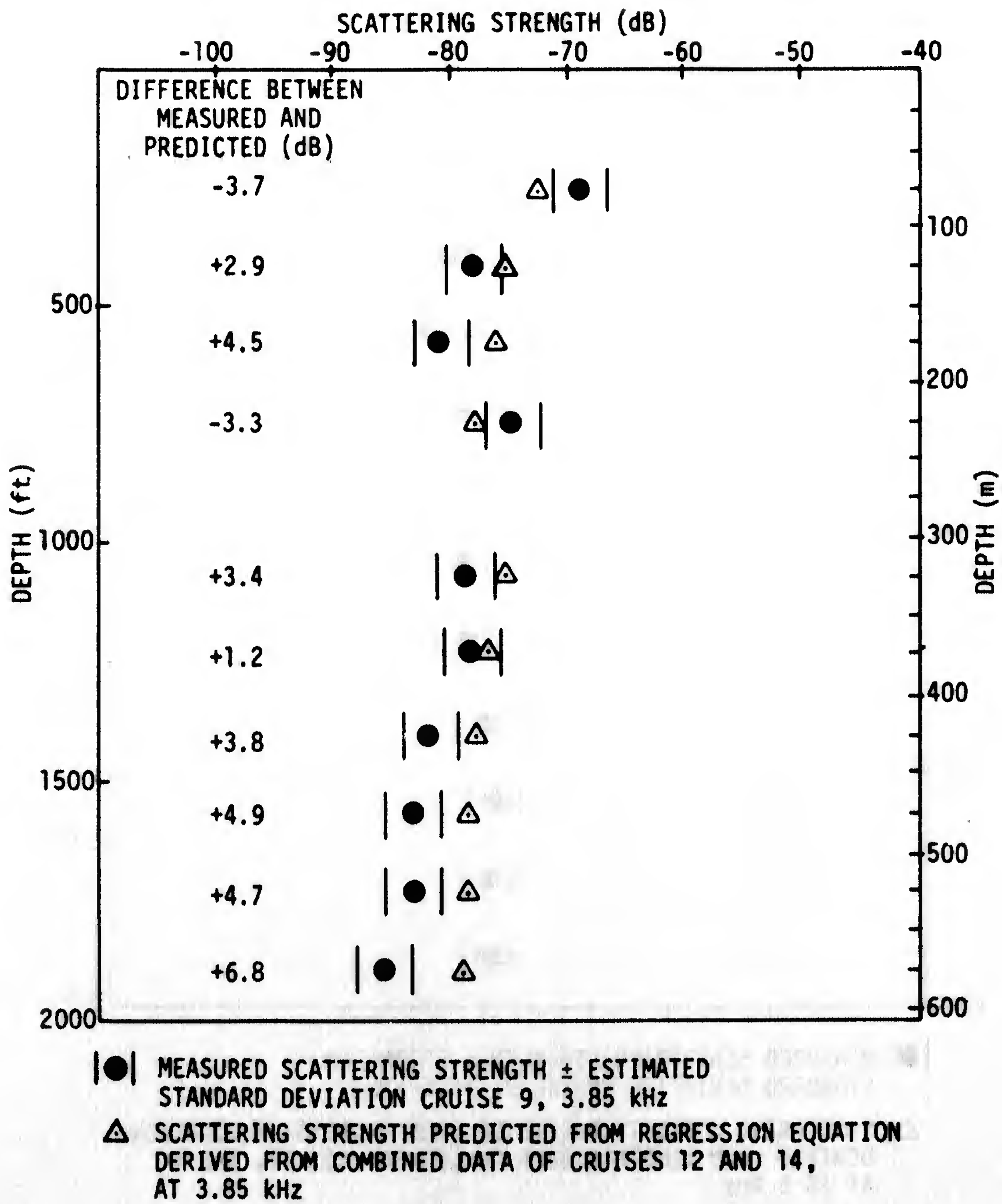


Figure 19. Comparison of Predicted Scattering Strengths With Scattering Strengths Measured at 3.85 kHz

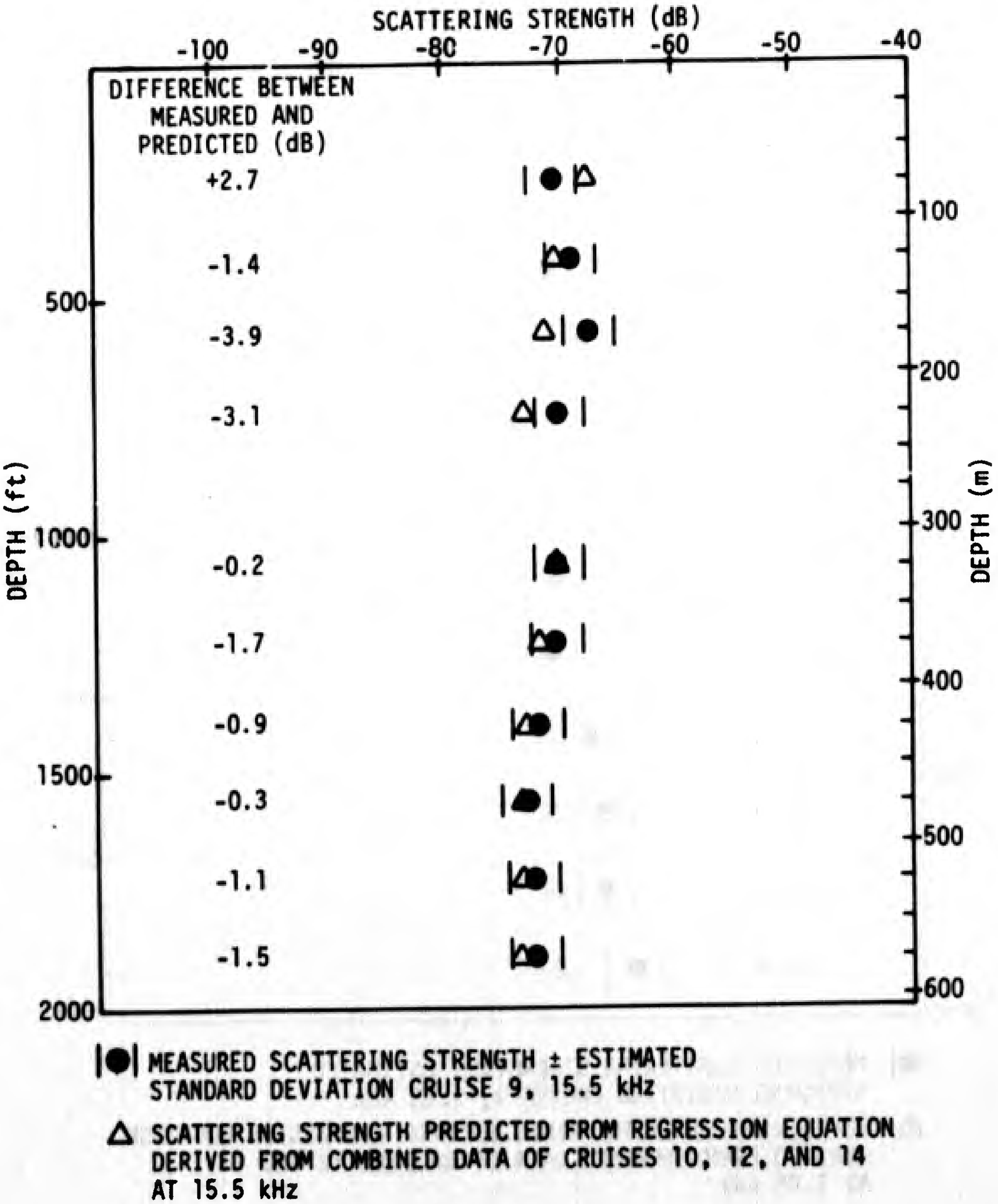


Figure 20. Comparison of Predicted Scattering Strengths With Scattering Strengths Measured at 15.5 kHz

In the 3.85 kHz profile all but one of the predicted scattering strength values fall outside these limits. However, the maximum difference between predicted value and the point marking one standard deviation from the measured value is only 4.5 dB, which occurs at a depth of 575 m.

In the case of the 15.5 kHz profile, only three of the predicted values exceed the limits described by ±1 standard deviation on either side of the measured scattering strength.

For the most part, the degree of agreement between the model predictions and the measured scattering strengths, especially at 15.5 kHz, is very good and is decidedly superior to the values predicted by the BAP model.

CONCLUSIONS

The results of this study have shown that vertical profiles of scattering strength can be predicted successfully for the Ocean Acre study area from net trawl data on the vertical population density of 55 species of airbladdered midwater fish. The final predicted profiles compare favorably in shape and magnitude with measured profiles of scattering strength. The surprisingly simple prediction model achieves a notably superior success in its predictive capabilities over an earlier, more complicated model that required inputs on difficult-to-obtain swimbladder volume information.

It appears that the success of the prediction model is probably due to the fact that the vertical population density of the 55 species of swimbladdered fish used in the final model furnishes an accurate index to the total population of potential scatterers within the insonified volume of the measuring system transducer.

Failure of the earlier, more complicated, prediction model (biological-acoustical profile, BAP) is attributed primarily to the inability of sampling methods to furnish the model with sufficiently precise input information.

It is hoped that this report will provide the stimulus for the future application of the prediction model to archival open ocean fish and acoustical data to determine its applicability to scattering populations of other zoogeographic provinces.

RECOMMENDATIONS

It is recommended that additional research be performed to determine the applicability of the final model developed here to ocean areas other than the Sargasso Sea. This research would be designed to satisfy specific objectives in the following fashion:

1. Validation. The validity of the model can be tested using data on the vertical distribution of midwater fish abundance and concomitant acoustically measured scattering strength profiles collected in the Mediterranean.[7,20] Model-generated scattering strength profiles using the Mediterranean data could be compared with acoustically measured profiles to test the model's applicability to this deep-sea area and provide an insight into the model's potential for use in other areas of the world's oceans. Assuming satisfactory validation of the model, the investigation would proceed to satisfy the objective set forth in the next step.

2. Development of Equations Defining Scattering Strength for Any Desired Frequency Over the Range of 2.0 to 20.0 kHz. The model developed during Ocean Acre research has related vertical fish population density to scattering strength at a number of discrete frequencies for an area of the Sargasso Sea. In its present form the model generates data that are of limited use in performance prediction models. These models may require inputs at several frequencies, not necessarily those of Ocean Acre, and for numerous different regions of the world's oceans. Application of appropriate multiple regression techniques to the fish abundance data should furnish equations that relate scattering strength to vertical population density at any desired frequency over the range of 2.0 to 20 kHz. Performance prediction models may require inputs on the scattering strengths in different regions of the world's oceans. The final step in this investigation would be designed to satisfy this added dimension.

3. Use of Archival Fish Abundance Data. Archival data are available that provide information on the vertical density distributions of mesopelagic fish for several oceanic areas.[21-25] At this time, not all the literature or sources of data have been searched to determine the extent of geographical coverage on the vertical distribution of midwater fish abundance. However, it is expected that most of the data relate to the North Atlantic, with lesser amounts referring to the Pacific. In order to obtain other data for model use, literature searches for published data and communication with numerous researchers and institutions would have to be conducted with the specific goal of obtaining additional unpublished data. With this collection of data in

hand it should be possible to construct a table giving vertical profiles for fish abundance for various specific oceanic provinces. These tables, when used in conjunction with the equations derived from step 2, should provide systems engineers with input data on scattering strength suitable for use in performance prediction models. Representative scattering strength profiles would, therefore, be obtained for areas where acoustical data are lacking without recourse to expensive measurements at sea on a global scope.

REFERENCES

1. G. B. Farquhar, (Ed.), Proceedings of an International Symposium on Biological Sound Scattering in the Ocean, Maury Center, Washington, D. C., Report 005, 1970.

2. Yu G. Chindonova and N. I. Kashkin, "Comparison of the Biological and Accoustic Methods of Assessing Sound: Scattering Layers," Oceanology 9 (3), 1969, pp. 430-439.

3. C. L. Brown and F. P. Fessenden, Acoustical and Biological Results of Sampling in the Deep Scattering Layers, NUSC Technical Report 1048, 30 October 1969.

4. W. E. Batzler, J. W. Reese, and W. A. Friedl, Acoustic Volume Scattering: Its Dependence on Frequency and Biological Scatterers, NUC TP442, Naval Undersea Center, San Diego, CA, 1975.

5. P. F. Seligman and W. A. Friedl, FASOR II: Correlative Biological and Acoustical Studies in the North Pacific Ocean, NUC TP448, Naval Undersea Center, San Diego, CA, 1975.

6. C. L. Brown and A. L. Brooks, A Summary Report of Progress in the Ocean Acre Program, NUSC Technical Report 4643, 30 January 1974, pp. 1-44.

7. R. H. Love, "Predictions of Volume Scattering Strengths from Biological Trawl Data," Journal of the Acoustical Society of America, vol. 57 (2), 1975, pp. 300-306.

8. R. H. Gibbs, Jr., C. F. E. Roper, D. W. Brown, and R. H. Goodyear, Biological Studies of the Bermuda Ocean Acre, I, Station Data, Methods, and Equipment for Cruises 1 - 11, October 1967 - January 1971, Report to NUSC, Smithsonian Inst., Washington, DC, 1971.

9. R. K. Dullea, Acoustical Investigation of the Deep Scattering Layer at the Bermuda Ocean Acre Site in April and November 1969, NUSC Technical Report 3038, 10 December 1970, pp. 1-10.

10. N. P. Fisch and R. K. Dullea, Acoustic Volume Scattering at the Bermuda Ocean Acre Site During Spring and Summer 1970 and Summer 1971 (Cruises 1, 10, and 12), NUSC Technical Report 4469, 30 April 1973, pp. 1-24.

REFERENCES (Cont'd)

11. N. P. Fisch, Acoustic Volume Scattering at the Bermuda Ocean Acre Site (Cruise 14 and Related Earlier Studies), NUSC Technical Report 5365, 3 January 1977, pp. 1-12.

12. R. C. Kleckner, Swimbladder Morphology of Mediterranean Sea Mesopelagic Fishes, M. S. Dissertation, University of Rhode Island, 1974, pp. 1-66.

13. A. L. Brooks, Swimbladder Allometry of Selected Midwater Fish Species, NUSC Technical Report 4983, 5 January 1976, pp. 1-43.

14. R. B. MacDonald, "A Comparison of Acoustical and Biological Backscattering Strengths at Discrete Depths for Ocean Acre Cruises 6 (April, 1969) and 10 (June, 1970)," NUSC Technical Memorandum TA131-225-72, 20 September 1972, pp. 1-49.

15. W. G. Pearcy, (Ed.), Workshop on Problems of Assessing Nekton, ONR/NSF, Santa Barbara, CA, 1975.

16. A. L. Brooks, C. L. Brown, and P. Scully-Power, "Net Filtering Efficiency of a 3-Meter Isaacs-Kidd Midwater Trawl," Fish. Bull. 72 (2): 1973, pp. 618-621.

17. O. B. Andreeva and Yu G. Chindonova, "On the Nature of Sound-Scattering Layers," Okeanologiya, 4 (1), 1964, pp. 112-124.

18. E. G. Barham, "Siphonophores and the Deep Scattering Layer," Science 140, 1963, pp. 826-828.

19. FAO Fisheries Circular No. 142, Food and Agriculture Organization (FAO) of the United Nations, 1972, 4 papers.

20. R. H. Gibbs, Jr., et al., Mediterranean Biological Studies, Final Report, Vols. I, II. Smithsonian Inst., Washington, DC, 1972.

21. W. I. Aron, F. I. Bourbeau, and R. E. Pieper, Acoustical and Biological Studies of the Deep Scattering Layer in the Eastern North Pacific, TR 67-13, AC Defense Research Laboratories, General Motors Corp., Santa Barbara, CA, April 1967.

22. R. H. Backus, J. E. Craddock, R. L. Haedrich, and D. L. Shores, "Mesopelagic Fishes and Thermal Fronts in the Western Sargasso Sea," Marine Biology, vol. 3, no. 2, 1969, pp. 87-106.

REFERENCES (Cont'd)

23. J. Badcock, "The Vertical Distribution of Mesopelagic Fishes Collected on the SOND Cruise," J. Mar. Biol. Assoc., U. K., vol. 50, 1970, pp. 1001-1044.

24. J. Badcock and N. R. Merrett, "On the Distribution of Midwater Fishes in the Eastern North Atlantic," Oceanic Sound Scattering Prediction, Plenum Press, NY, 1977, pp. 249-282.

25. W. G. Pearcy and R. M. Laurs, "Vertical Migration and Distribution of Mesopelagic Fishes Off Oregon," Deep-Sea Research, vol. 13, 1966, pp. 153-165.

INITIAL DISTRIBUTION LIST

ADDRESSEE	No. of Copies
COMSECONDFLT	1
COMSIXTHFLT	1
COMASWFORSIXTHFLT	1
COMNAVSURFLANT	1
COMSUBLANT	1
COMTRALANT	2
COMNLONTEVDET	1
COMFLETRAGRU CHASN	2
COMCRUDESGRU 8	1
COMCRUDESGRU 12	1
COMSUBRON 2	1
COMSUBRON 10	1
COMSUBDEVGRUTWO	1
ASN(R&D) (D. Hyde)	1
ONR, Code 102-OS, 412-3, 484(2), 485, 460	6
CNO, OP-02, -03EG, -095, -098(981), -201, -901, -952, -953, -96, -961, -982	11
CNM, MAT-08T, ASW-14, -22, -23	4
DDR&E (G. Cann)	2
NAVSHIPRANDCEN, ANNA	2
NAVSHIPRANDCEN, CARD	2
NRL	1
SUBASE LANT	1
OCEANAV	2
NAVOCEANO, Code 02, 3000, 7200, 9320(R. Lone)(2)	5
NAVELECSYSCOMHQ, Code 03, PME-124	2
NAVSEASYSCOMHQ, SEA-03C, -06H1-4, -06H5, -09G3(4), -660C, 661C	9
NAVAIRDEVCEN	1
NOSC (R. Vent, W. Friedl, W. Batzler)	3
LANTFLEASWTACSCOL	5
NAVSUBSCOL	1
NAVPGSCOL (E. Traganza)	1
NAVDESCOL	1
FWC, Monterey, (LDCR R. Miller)	1
APL/UW, Seattle	1
ARL/PENN STATE, State College	1
DDC, Alexandria	12
MARINE PHYSICAL LAB, Scripps (V. Anderson)	1
WOODS HOLE OCEANOGRAPHIC INSTITUTION (R. Backus, M. Orr)	2
Engineering Societies Library, United Engineering Center, 345 East 47th Street, New York, NY 10017	1

INITIAL DISTRIBUTION LIST (CONT'D)

ADDRESSEE	No. of Copies
Division of Fishes, Smithsonian Institution, Washington, DC (Dr. R. Gibbs, C. Karnella)	2
Division of Molluscs, Smithsonian Institution, Washington, DC (Dr. C. Roper)	1
National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, MA (Dr. R. Edwards)	1
University of Rhode Island, Zoology Dept., Kingston, RI, (Dr. W. Kreuger, R. Kleckner)	2
National Marine Fisheries Center, Ahlstrom Laboratory, La Jolla, CA 92038 (Dr. E. G. Barham)	1
Southwest Fisheries Center, La Jolla, CA 92038 (Dr. P. Smith)	1
Fisheries Research Board of Canada, Biological Station, St. Andrews, New Brunswick, Canada (Dr. R. G. Halliday)	1
Defence Research Establishment, Victoria, British Columbia, Canada (Dr. J. Scrimger)	1
Admiralty Research Laboratory, Middlesex, England (D. E. Weston)	1
University of South Florida Marine Science Institute, St. Petersburg, FA 33701 (T. L. Hopkins)	1
Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8. 5UB, England (Dr. J. Badcock, M. V. Angel)	2
Hawaii Institute of Marine Biology, Kaneohe, Hawaii 96744, (Dr. T. A. Clarke)	1
Systematics Laboratory, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560(Dr. D. Cohen)	1
NSF - IDOE (D. E. Holt)	1
Allan Hancock Foundation, University of Southern California, Los Angeles, CA 90007 (Dr. R. E. Pieper)	1
Florida State Museum, University of Florida, Gainsville, FA (Dr. G. B. Deevey, Dr. E. S. Deevey)	2
Bermuda Biological Station, St. George, Bda	5
Tracor, Inc., 2923 Canon St., San Diego, CA 92016 (Dr. D. V. Holliday)	1
Bolt, Beranek & Newman, 50 Moulton St., Cambridge, MA 02138 (Dr. P. T. McElroy)	1
Kelvin Hughes, Smiths Industries Ltd., Hainault, Essex, England (Dr. R. W. G. Haslett)	1
California State University, Dept. of Biology, Fullerton, CA 92634 (M. H. Horn)	1
British Museum (Natural History), London, England (Dr. N. B. Marshall)	1
Defence Research Establishment Pacific Esquimault, British Columbia, Canada (Dr. R. P. Chapman	1

INITIAL DISTRIBUTION LIST (CONT'D)

ADDRESSEE	No. of Copies
School of Oceanography, Oregon State University, Corvallis, OR (Dr. W. Pearcy, R. Johnson)	2
University of Rhode Island, Graduate School of Oceanography, Kingston, RI (Dr. T. A. Napora)	1