C-4744

The Application of Hydroacoustic Methods For Aquatic Biomass Measurements

Preliminary Report of the First Joint USA-USSR Hydroacoustic Experiment in the East Central Atlantic - 14 May to 4 June 1976

By

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* Final Review of this Report has not been completed

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LIST OF ABBREVIATIONS

VNIRO - All Union Research Institute of Fisheries and Oceanography - Moscow, B-140, USSR.

MNFS/NEFC - National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Mass., USA 02543

CSDL - The Charles Stark Draper Laboratory, Inc., Cambridge, Mass., USA, 02139

1.0 Preface

The activities described in this document were made possible through discussions and agreements between the responsible authorities of the Governments of the USA and the USSR.

The successful completion of the first joint USA-USSR Hydroacoustical Experiment in the East Central Atlantic could not have been accomplished without the competent support of operating personnel of the *R/V Khronometer*, V. Kutepov, Master.

2.0 Introduction

The objectives of the joint hydroacoustical experiment were:

1. To obtain hydroacoustical echo signals and other in-situ data from aquatic animals (fishes). These data are to be used to further evaluate the feasibility and potential usefulness of hydroacoustical methods to obtain pelagic and semi-demersal biomass estimations. The initial joint USA-USSR hydroacoustical related activities directed to this purpose began in 1974 and were continued in 1975. Reference 1 and 2 describe these previous activities.

2. To conduct a combined parameter in-situ calibration of hydroacoustical instrumentaiton employing a physical target of known backscattering characteristics. The results of this calibration were to be compared with the results of an individual parameter calibration conducted in 1974.

3. To conduct measurements of the combination of ambient and vessel generated hydroacoustical noise in the operating area. These data are to be used to determine the lower limit associated with the detection, recording and subsequent estimation of the hydroacoustical backscattering characteristics of a sea volume containing aquatic targets.

3.0 Description and Review of the Hydroacoustical Experiment

General

The hydroacoustical experiment area included the principal fishing banks west of Morocco and Spain, e.g., Dacia, Sin, Ampere and Gettysburg. Figure 3.1 depicts the operating area, the transit tracks of the *R/V Khronometer* and the calendar dates for each sub-area.

At each fishing bank except Sin, intensive mid-water trawling operations were conducted. The principal species captured were Mackerel (*Scomber Colias*), Scad (*Trachurus Sp.*), Red Bait (*Emmelichys Sp.*), and Sabre Fish (*Trichiurus Lepturus*). On one occasion a Tuna (*Parathunnus Obsus*) was captured in the trawl net. All of these animals except the Tuna possess a buoyancy regulating organ.

The apparent fish density was low as suggested by the number captured while trawl net towing and virtually no targets were recorded from the HAG 432 transducer terminals. This condition prevailed despite the fact that on a number of occasions the fish captured appeared to be within the resolution capability of the HAG 432, e.g., not masked by the received echo signal from the sea bottom.* A general discussion of the resolution capability of hydroacoustical echo sounding instrumentation is given in Reference 3.

On two occasions excellent hydroacoustical echo signal data was recorded.

The first, while the *R/V Khronometer* was at anchor on Dacia Bank on May 18-19 and the second on 28 May in the vicinity of Ampere Bank.

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*By observing the trawl net foot rope to sea bottom range from the HAG 331 Transducer/Amplifier terminals. It is recognized, however, that under the conditions prevailing at the time of the above observation the spatial reference of the sampling volume of the hydroacoustical instrumentation, the HAG 432, and the trawl net may or may not be similar, but the relative time reference of the samplers is considerably different.

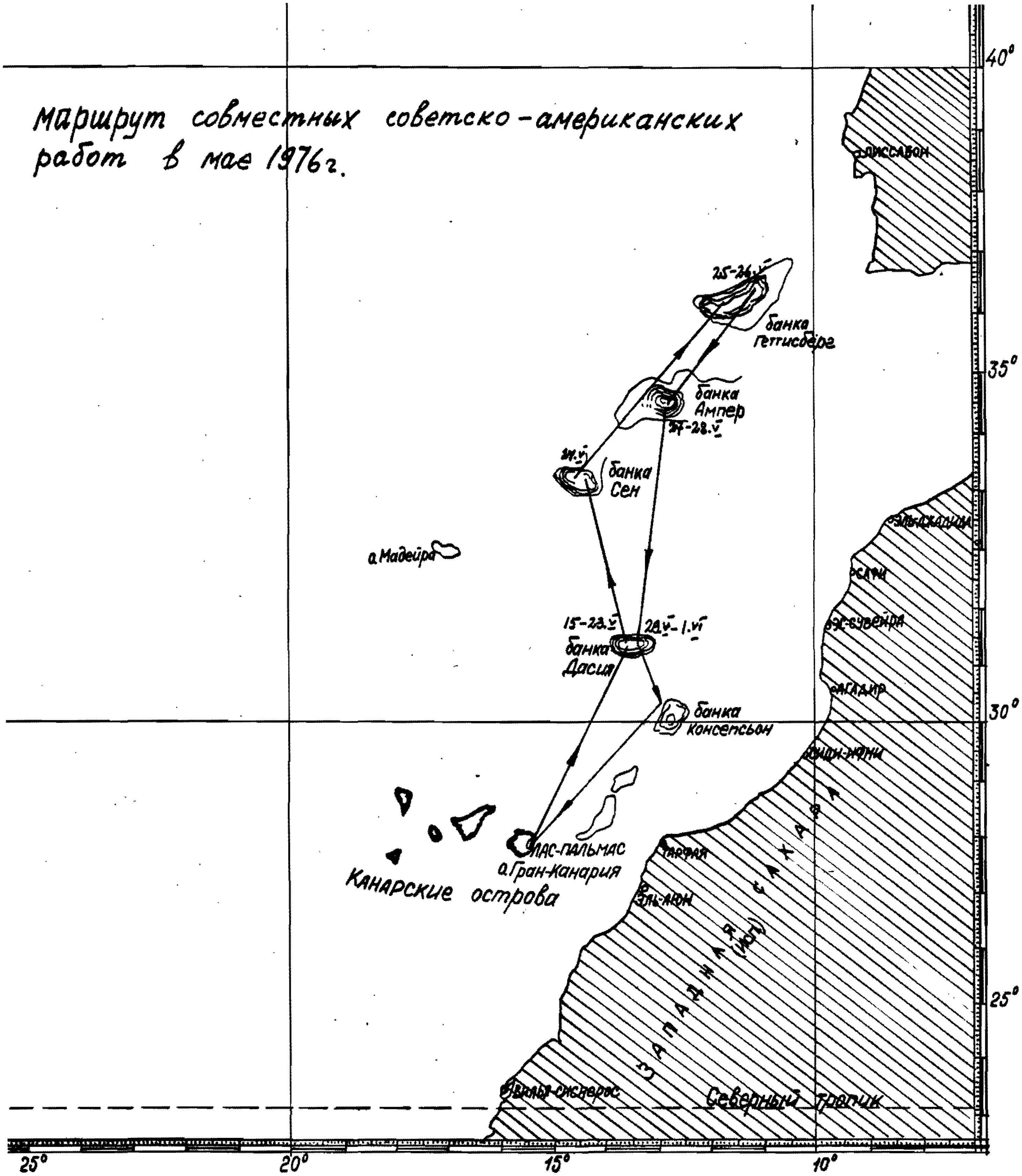


FIGURE 3.1 - OPERATING AREA, TRANSIT TRACKS AND DATES OF THE JOINT USA-USSR HYDROACOUSTICAL EXPERIMENT ACTIVITIES

Calibration activities were conducted on 29 May in the vicinity of Dacia Bank and noise level measurements were conducted on 29-30 May, also in the vicinity of Dacia Bank.

During the conduct of the hydroacoustical experiment period no hydroacoustical equipment or data acquisition equipment failures or malfunctions were experienced.

4.0 Hydroacoustical Equipment Calibration

It was not planned to conduct a comprehensive individual parameter calibration of the hydroacoustical equipment, the HAG 432 (transmitted carrier frequency 20.6 kHz), because of time constraints. It was possible to verify at sea that the transducer isolation, transmitter carrier frequency and transmitter power was, for all practical purposes, the same as those measured in March 1974.

On 29 May, in the vicinity of Dacia Bank, a 118 mm ϕ spherical solid bronze target was deployed below the *R/V Khronometer* via two light plastic lines. The target was positioned approximately on the acoustic axis of the HAG 432 transducer. Finally, the transducer was trained in elevation and azimuth until the maximum received echo signal from the 118 mm ϕ spherical target was observed on the C.R.T. oscilloscope. Figure 4. 1 depicts a photograph of the received echo signal taken at that time. The range from the transducer to the leading edge of the target signal is 44.9 meters. The maximum peak to peak voltage is 1650 microvolts. Using this peak to peak voltage the target strength can be calculated to be -33.6 dB. This value of target strength is at considerable variance with the value of -26.8 dB for the 118 mm ϕ sphere measured at a USSR Hydroacoustical Measurement Laboratory. However, when the received echo signal envelope is integrated over a 0.9 millisecond interval, in

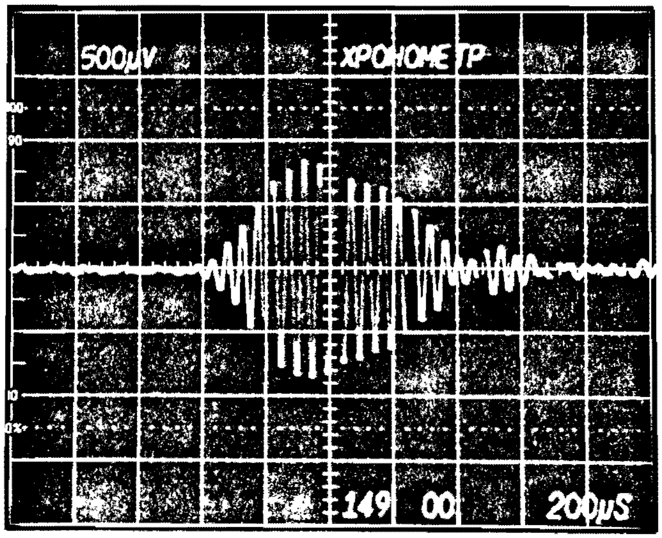


Figure 4.1 - DELAYED AND EXPANDED C.R.T. OSCILLOSCOPE DISPLAY OF MAXIMUM RECEIVED ECHO SIGNAL FROM 118 MM ϕ SOLID BRONZE SPHERICAL TARGET - RANGE 44.9 METERS - 29 MAY 1976 - 1400 HOURS - VICINITY OF DACIA BANK - HAG 432 - *R/V Khronometer.*

Figure 4.1, a target strength of -28.6 dB can be calculated. Given that the difference between the laboratory measurement and the <u>in-situ</u> measurement of the target strength is now 1.8 dB, approximately, it is reasonable to accept that the <u>in-situ</u> combined parameter calibration and the previous individual parameter calibration is within practical hydroacoustical measurement uncertainties. Therefore, it was decided to employ the same hydroacoustical equipment parameters, in the reduction of the recorded data, as in 1974.

The above discussion illustrates a potential problem associated with the derivation of target strength employing peak to peak voltage measurements when employing transmitted hydroacoustical pulses of relatively short time duration.

Also on 29 May, a target arrangement was deployed in the form of a free drifting surface float attached to a weighted line supporting the 118 mm ϕ spherical target. The received echo signal was recorded as the *R/V Khronometer* made successive passages close to the surface float. The recorded data was examined and revealed a maximum received echo signal level that was approximately 70% of the expected value. At no time did the vessel pitch/roll resultant allow the target to be situated on, or nearly on, the transducer acoustic axis at the time of closest approach to the surface float, consistent with the transmission rate of the HAG 432.

On 30 May the HAG 331 transducer was deployed from a surface float with the 118 mm ϕ spherical target located approximately 20 meters from the transducer working face and on the acoustic axis. The received echo signal from the HAG 331 transducer/amplifier was distorted and did not provide data suitable for subsequent analysis.

On 29 and 30 May measurements of the combined ambient and vessel generated hydroacoustical noise voltage, at the terminals of the transducer, were obtained under various conditions of water depth, vessel velocity and sea state. Figure 4.2 depicts a graphical summary of these measurements. It will be noted that in the water depth of 110-120 meters the voltage measured at the transducer is highly variable

Symbol	Sea State	Depth (M)	Date/Time
o	2-3B°	110-120	30 May/1340-1400
†	Calm	110-120	29 May/1100-1300
Δ	2-3B°	800	30 May/1400-1500
∇	Calm	800	29 May/0900-1100

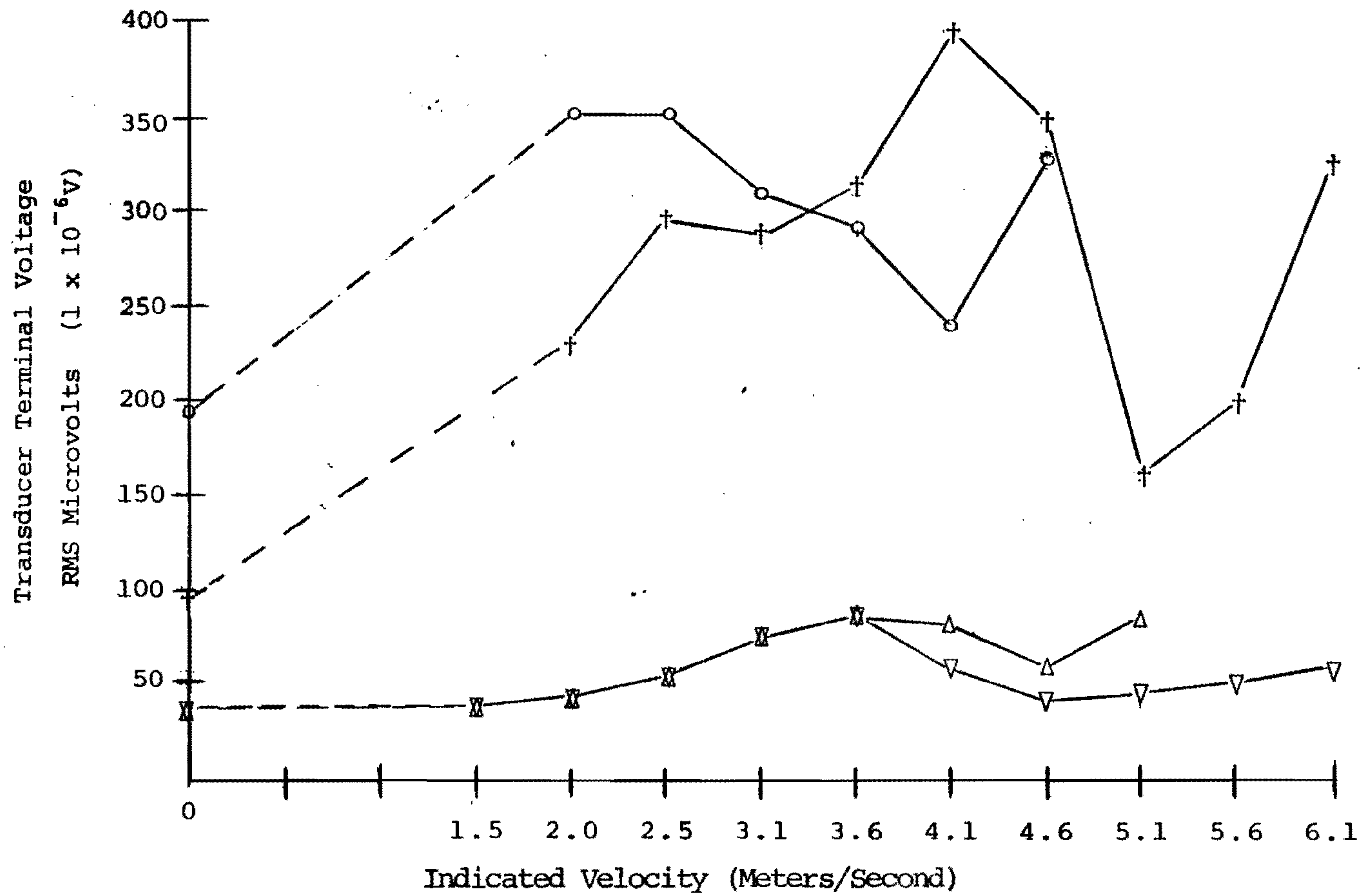


Figure 4.2 RMS VOLTAGE MEASURED AT TRANSDUCER TERMINALS DUE TO AMBIENT AND VESSEL GENERATED NOISE 29-30 MAY 1976, DACIA BANK - HAG 432 - R/V *KHRONOMETER*

versus vessel velocity for both calm and moderate sea states, while in deep water the variability is minimal. This observed variation is the result of the unique topographical conditions of the sea bottom in the measurement area, e.g., rock, coral and coral sand.

The level of the received echo signal, at which the recognition of the presence of bona-fide aquatic targets is certain, is of crucial importance in any subsequent determination of the value of target strength and volume backscatter. If the ambient and vessel generated hydroacoustical noise level is of the same order of magnitude as that from the insonified targets of interest useful information concerning target strength and density of the targets cannot be derived, given the level of sophistication currently employed for the processing of the received echo signals.

An example of this situation is presented in Table 4.1, a tabulation of the minimum value of volume backscatter that may be derived from the received echo signal for various transducer terminal voltages due to ambient and vessel generated noise. An average range of 50 meters to the insonified region and a target signal to noise signal ratio of 10 dB is considered.

5.0 Received Echo Signal Handling and Processing

The received hydroacoustical echo signals were obtained at the transducer terminals, amplified via a broad band linear amplifier and recorded in analog form on magnetic tape. Figure 5.1 illustrates a simplified block diagram of the received echo signal handling instrumentation deployed aboard the *R/V Khronometer*.

Since the regions of the aquatic target activity of interest were confined to the immediate vicinity of the fishing banks it was possible to examine the data tapes on board the *R/V Khronometer* during the transit periods between these

RMS VOLTS ($V \times 10^{-6}$)	MIN. VOLUME BACKSCATTER (dB// 1/M^3)
10	-84.0
50	-70.0
100	-64.0
150	-60.5
200	-58.0
250	-56.0
300	-54.5
350	-53.1
400	-52.0

Table 4.1 - MINIMUM VALUE OF VOLUME BACKSCATTER THAT MAY BE DERIVED FROM RECEIVED ECHO SIGNAL FOR VARIOUS VALUES OF TRANSDUCER TERMINAL VOLTAGES DUE TO AMBIENT AND VESSEL GENERATED NOISE. - AVERAGE RANGE 50 METERS - S/N RATIO 10 dB. HAG 432 - 20kHZ *R/V Khronometer.*

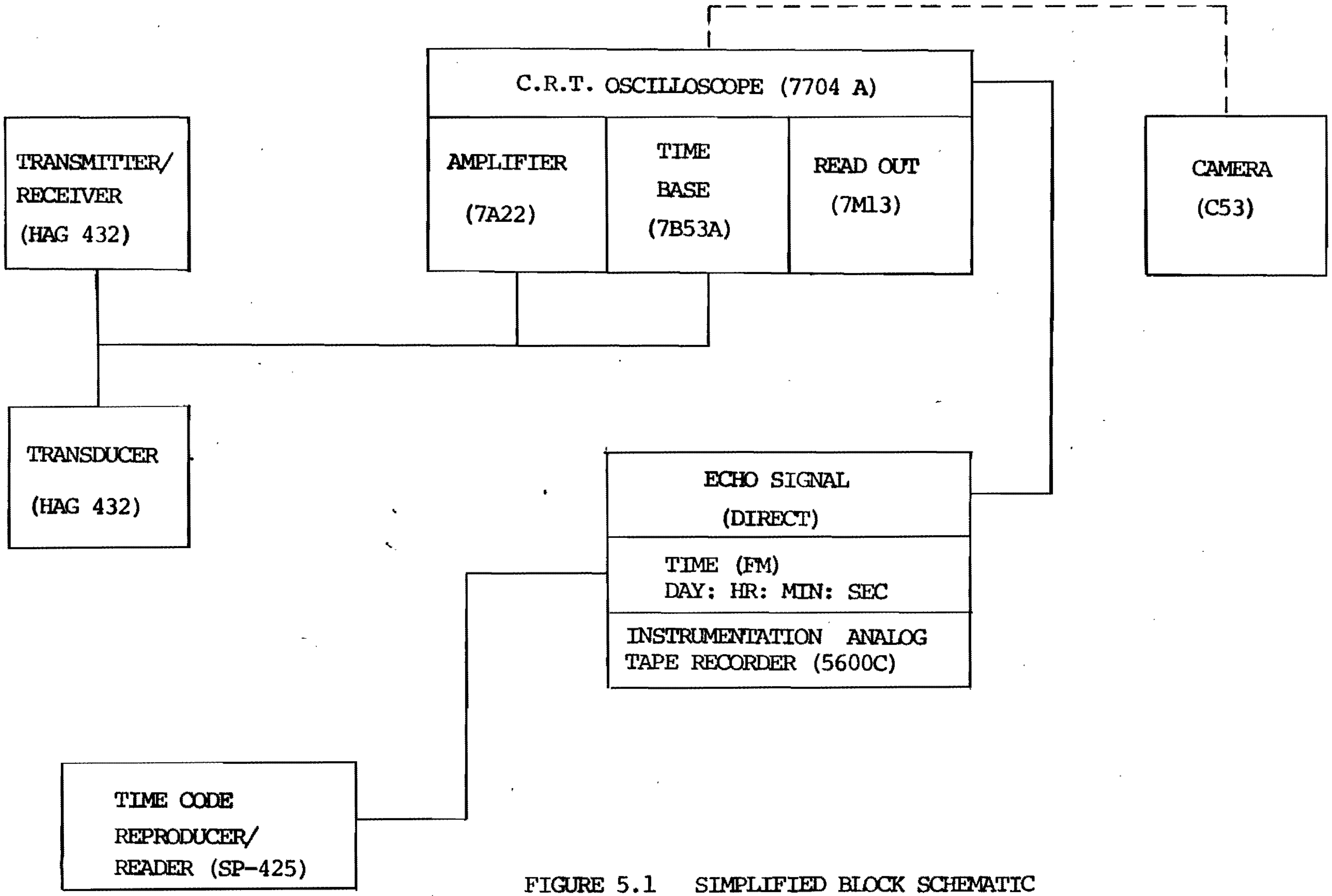


FIGURE 5.1 SIMPLIFIED BLOCK SCHEMATIC DIAGRAM OF RECEIVED HYDROACOUSTICAL ECHO SIGNAL HANDLING INSTRUMENTATION - JOINT USA-USSR HYDROACOUSTICAL EXPERIMENT

areas. A total of nineteen data tapes were recorded. Of this total, four tapes contained data which was considered to be suitable for subsequent processing.

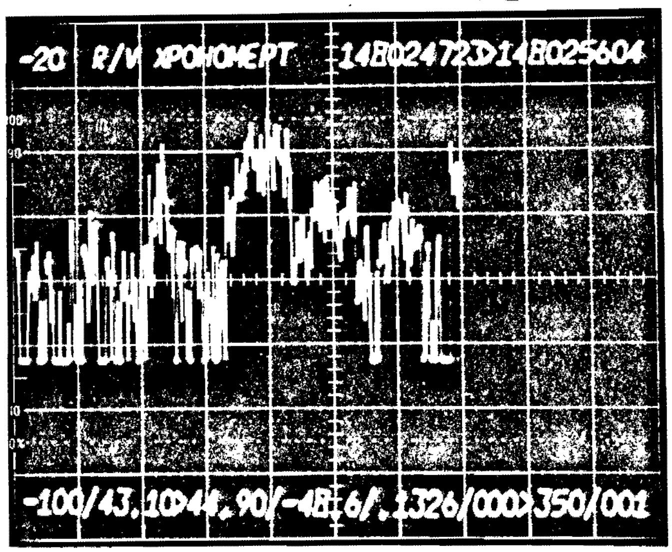
Upon return to the CSDL the on board data acquisition instrumentation was integrated with a microprocessor and a programmable calculator. The analog recorded echo signal was introduced into the digital processing oscilloscope through an envelope detector.* The resulting analog echo signal envelope is digitized via the microprocessor. The digitized echo signal envelope is then amplitude sampled at specific time intervals, according to a program in the calculator, through the microprocessor interface. The calculator performs the necessary arithmetical manipulations to provide a value of the volume backscatter for a hydroacoustical insonification sample. The value of volume backscatter is derived according to the theory and formulae described in References 4 and 5. The calculator is also programmed to calculate a confidence interval statistic for a selectable group or groupings of volume backscatter according to the theory and formulae described in References 1 and 5.

Graphic information showing the value and the variation of the value of volume backscatter, within selectable time and range intervals, is displayed on the C.R. T. oscilloscope from a permanent memory in the microprocessor. A calculator printout of input constants and variables, the values of volume backscatter and the associated confidence interval statistics is also generated..

Figure 5.2 illustrates a typical C.R.T. oscilloscope display automatically generated as the result of data tape processing. The definition of the numerical symbols along the upper and lower edge of this figure are also shown.

In this figure it will be noted that there are several points at which the value of volume backscatter is constant,

*A special trigger control circuit was developed to eliminate the requirement for a separate trigger channel on the data tapes in order to increase the in-situ data acquisition capability for a given number of tapes.



1 - INITIAL DATA SAMPLE

2 - FINAL DATA SAMPLE

3 - SAMPLE INTERVAL PROCESSED AND DISPLAYED

4 - CONFIDENCE INTERVAL (FOR VALUES < 0.1 SCIENTIFIC NOTATION DISPLAYED)

5 - MEAN VALUE OF VOLUME BACKSCATTER DEFINED BY 1, 2 AND 3. (DB// $1/m^3$)

6 - MINIMUM RANGE LIMIT (METERS)

7 - MAXIMUM RANGE LIMIT (METERS)

8 - MINIMUM ORDINATE VALUE OF VOLUME BACKSCATTER (dB// $1/m^3$)

9 - MAXIMUM ORDINATE VALUE OF VOLUME BACKSCATTER (dB// $1/m^3$)

10 - START TIME OF PROCESSING INTERVAL

11 - END TIME OF PROCESSING INTERVAL (DAY:HR:MIN:SEC.)

FIGURE 5.2 TYPICAL DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY AUTOMATICALLY GENERATED AS THE RESULT OF DATA TAPE PROCESSING

-73 dB// $1/m^3$. This represents the minimum value calculated for a received and recorded signal which exhibits no detectable echos and is at the quantization limit of the digitization capabilities of the microprocessor. This limit, or level, is established by examining a portion of the analog recorded data on the C.R.T. oscilloscope, in the superposition and memory modes, to verify the dynamic performance of envelope detector and the subsequent digitization of the echo signal envelope. After the fidelity of the digitized echo signal envelope compared to the raw analog recorded signal is verified, the processing program performs a calibration routine which establishes a "zero" received echo signal level.* It is to be noted that this quantification limit and associated value of volume backscatter is, for all practical purposes, equivalent to the actual noise threshold level in the received hydroacoustical echo signal.

The graphic display has proven to be extremely useful in illustrating the variability of the value of volume backscatter and in the examination of potentially invalid data. For example in Figure 5.1 there is a single value of volume backscatter of -42 dB// $1/m^3$ for insonification sample 102 (2.1 abscissa divisions). This value of volume backscatter is 18 dB above the preceding sample. This single and isolated point with a relatively high value or volume backscatter may be the result of legitimate target activity and/or a noise burst. Examination of the raw recorded data, in this case, indicated a valid data sample which contained the initial increase in the value of volume backscatter shown in the subsequentsamples, e.g., 108 to 130. A similar situation was validated in the last 10 samples, also shown in this figure.

It should be noted that this method cannot completely eliminate corrupted data if the target signal to noise signal ratio is low, <10, the overall characteristics similar, e.g.,

*Detailed examination of this signal handling process showed that the overall degradation of the input to output data was <5%, approximately.

amplitude variation versus time, and continues for several serial insonification samples. However, the availability of the raw recorded data tapes and the ability to reexamine questionable data samples is a singular advantage. If doubt exists concerning the validity of any portion of the recorded data it is a simple matter to eliminate the appropriate samples in the generation of the values of volume backscatter and the associated statistical manipulations.

The following is a discussion of and the results of the processing of the received and recorded hydroacoustical echo signals which were obtained under nearly ideal conditions in the vicinity of Dacia and Ampere Banks.

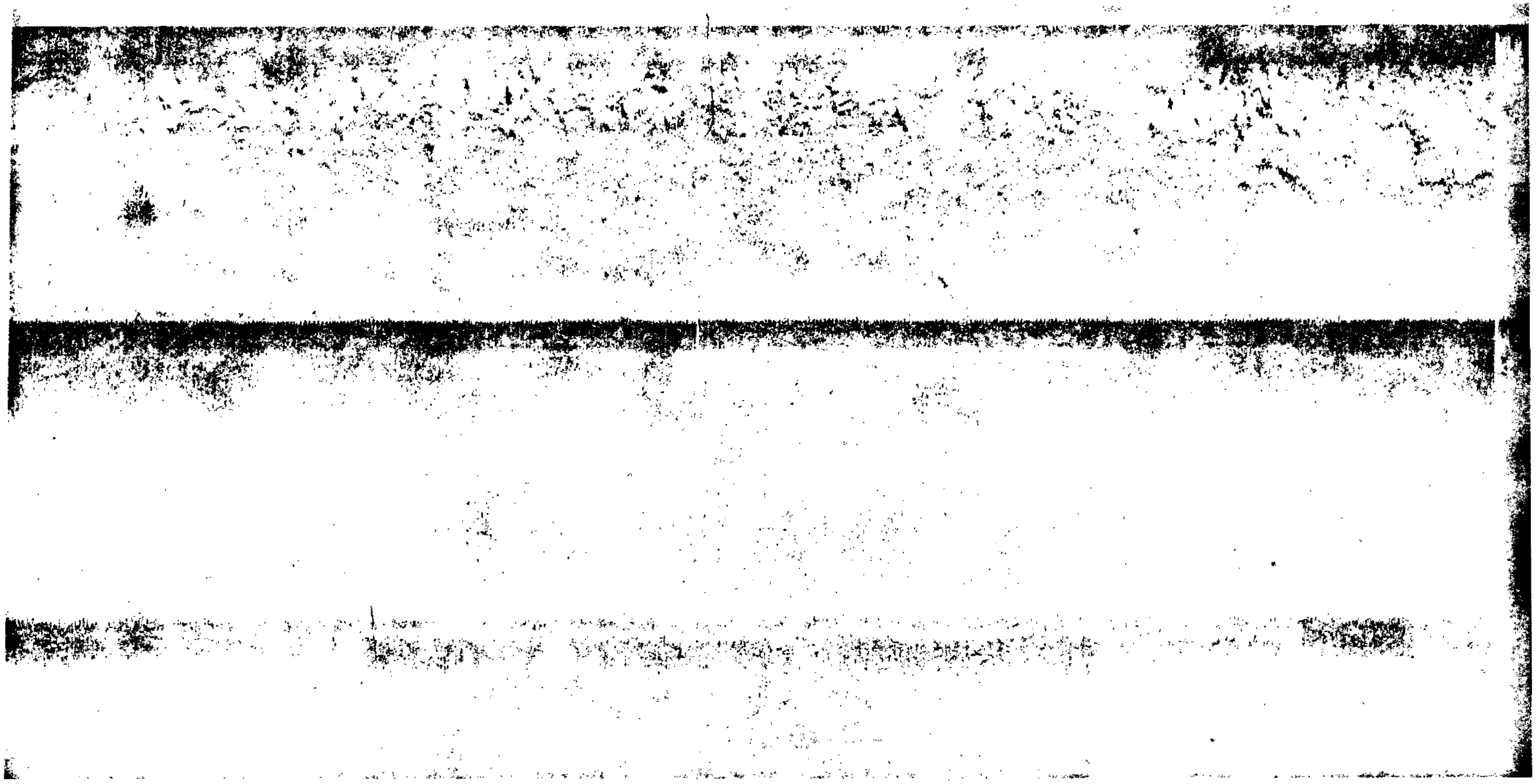
18 May 2110 to 2225 Hours

During this time period the *R/V Khronometer* was at anchor on Dacia Bank. The sea condition was calm, sky clear, vessel motion and hydroacoustical noise level minimal (<10 microvolts rms, measured at the transducer terminals). The vessel heading remained virtually constant and the surface sea water velocity, relative to the vessel, was 0.8 meters.second, approximately.

A copy of the echogram record obtained at this time is illustrated in Figure 5.3. The echogram displays numerous marks which appear to be individual targets and, similarly, marks which appear to be small plankton aggregations.

Examination of the data tape shows that there is a continuous scattering layer which extends in range from approximately 20 to 97 meters.* Within this scattering layer an occasional relatively higher amplitude received echo signal was observed. This condition suggested the presence of small groups of closely aggregated small targets and/or relatively large individual targets.

*High amplitude received hydroacoustical echo signals from the initial 20 meter range interval, the result of the high pressure generated in this region by the transmitted pulse, effectively masked echo signals from aquatic targets that may have been present.



VERTICAL SCALE - 1 mm ≈ 2 METERS   HORIZONTAL SCALE - 1 mm ≈ 20 SECONDS

FIGURE 5.3   ECHOGRAM RECORD - 13 MAY 2110 - 2225, DACIA BANK
HAG 432, - *R/V KHRONOMETER*

Positive identification of resolved individual targets was, except for a very few, extremely tenuous. Generally, only the upper portion of the recieved echo signal envelope exhibited an expected shape. This was a necessary, but not sufficient, condition to identify single targets, because invariably the time duration of the upper portion of the echo signal envelope was either greater or less than that expected.

The criteria for the selection of the expected shape and time duration of the received hydroacoustical echo signal from a resolved individual aquatic target was determined by examination of the signals from the 118 mm ϕ spherical calibration target and similar signals received from aquatic targets. Figure 5.4 depicts a photograph of a delayed and expanded C.R.T. oscilloscope display of the recorded received hydoracoustical echo signal from a typical resolved individual biological target while the *R/V Khronometer* was at anchor on Dacia Bank. Comparison of Figure 5.4 with Figure 4.1 shows that the number of cycles of the carrier frequency, envelope shapes and time durations are practically identical.*

The data tape for specified time interval was processed in three range intervals, 20.5 to 47.5, 47.5 to 74.5 and 74.5 to 97 meters. Figures 5.5(a), (b) and (c) graphically illustrate the mean values of the volume backscatter and the associated confidence interval statistics versus various numbers of insonification samples. The number of echo signal envelope amplitude samples is given in each figure ($\Delta R/c\tau = n$). In all the figures the solid line connects the point values of volume backscatter and the dashed line connects the point values of the confidence interval statistic.

Examination of these figures shows that within each range interval the value of volume backscatter remains nearly constant for all the indicated numbers of insonification samples. Also, the confidence interval statistics show an increase as the number of samples decrease.

*The validity of this comparison is, at this time, uncertain since the actual aquatic targets insonified were not obtained or identified.

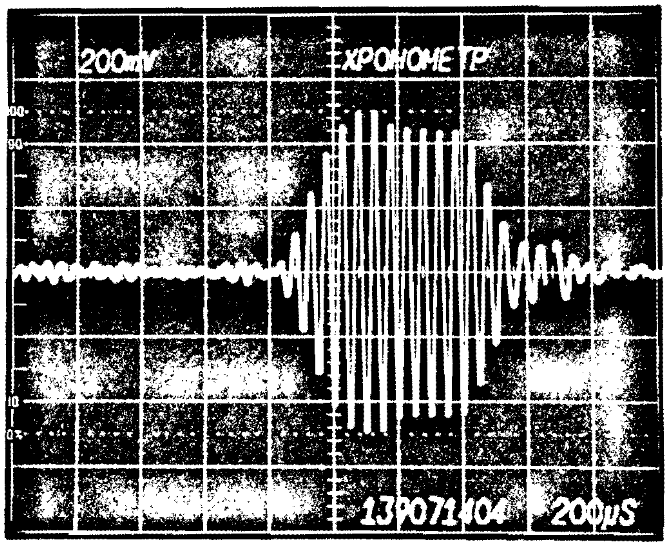


FIGURE 5.4 DELAYED AND EXPANDED C.R.T. OSCILLOSCOPE DISPLAY OF A RESOLVED INDIVIDUAL AQUATIC TARGET - RANGE 33 METERS - 19 MAY 0174, DACIA BANK - HAG 432 - *R/V KHRONOMETER*

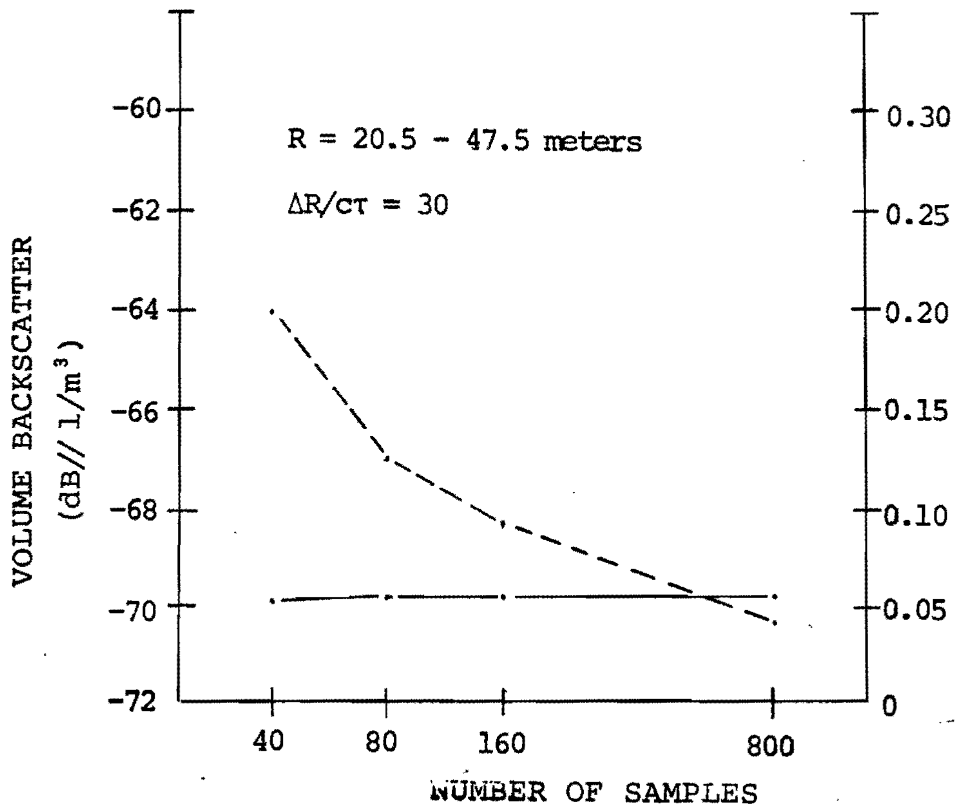


FIGURE 5.5(a) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 18 MAY 2110 - 2225 - DACIA BANK - HAG 432 - *R/V Khronometer*

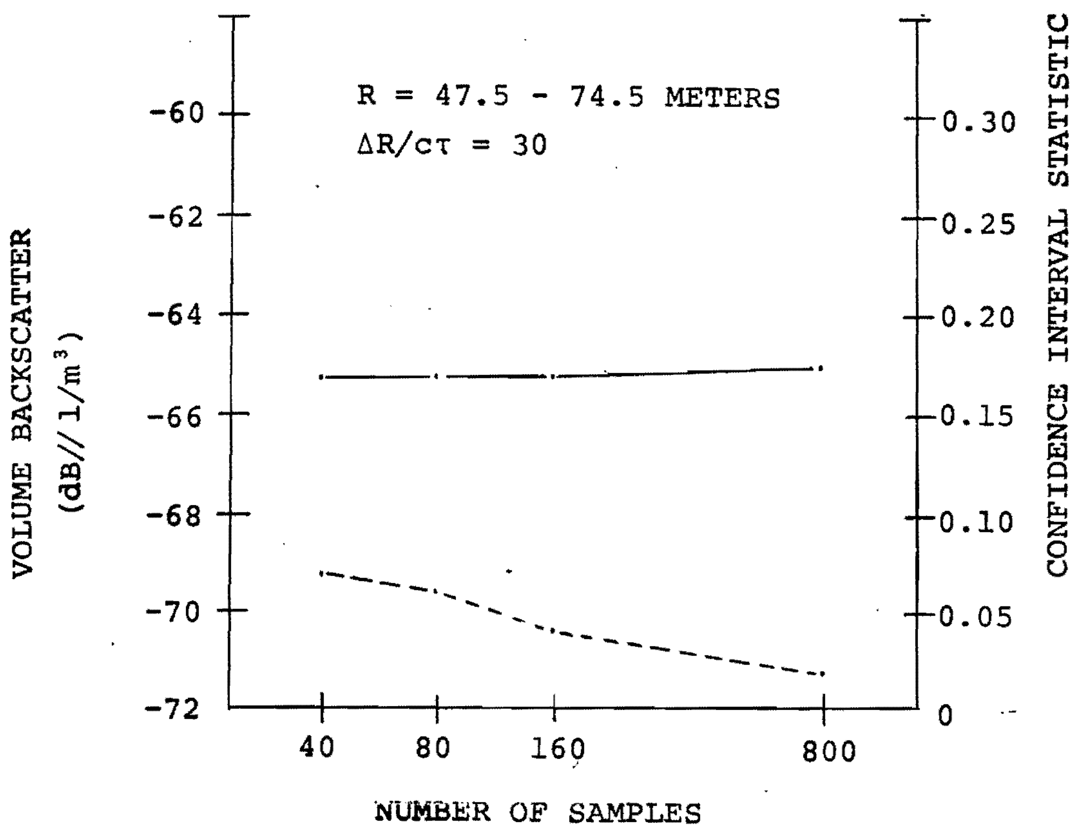


FIGURE 5.5(b) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 18 MAY 2110 - 2225, DACIA BANK - HAG 432- *R/V Khronometer*

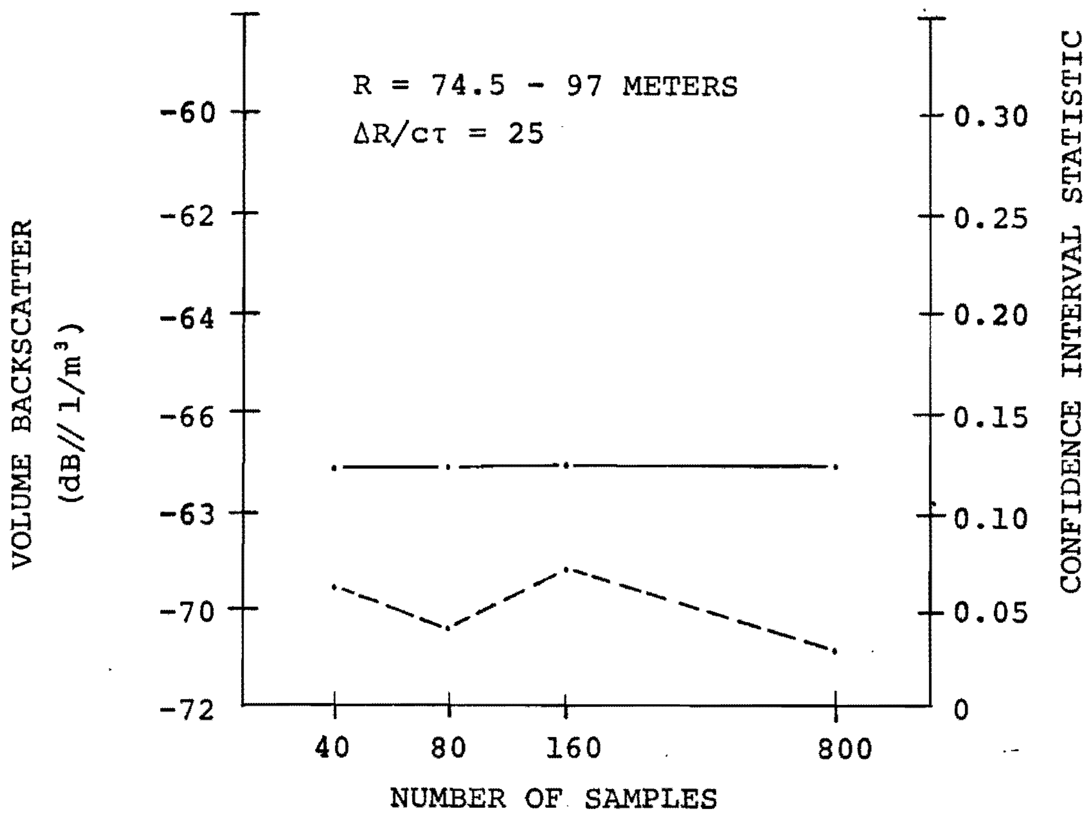


FIGURE 5.5(c) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF SEA VOLUME - 18 MAY 2110-2225, DACIA BANK - HAG 432 - *R/V Khronometer*

The minimal variations in the value of volume backscatter and the general trend of the confidence interval statistics suggest that the received and recorded hydroacoustical echo signals were from insonified volumes containing a fairly uniform distribtion of recorded targets.

Figure 5.6 illustrates a batched mean value of the volume backscatter and confidence interval statistic for the total depth interval and the entire data period. The range interval from 74.5 to 97 meters ($\Delta R/c\tau = 25$) was appropriately weighted relative to the other range intervals. It can be seen that the value of backscatter varies <0.5 dB// $1/m^3$ and the confidence interval statistic varies from 0.06 to 0.02 from 40 to 800 insonification samples. The latter values suggest that it may have been possible to derive an estimate of the target density and ultimately the aquatic biomass in the insonified volume from $\pm 15\%$ to $\pm 30\%$ in relation to the true biomass with a probability confidence of better than 95%.

However, it should be specifically noted that, given the received hydroacoustical echo signal envelope sampling process is a valid technique to derive an estimate of the density of the insonfied targets and the confidence interval statistics a valid measure of the relative error, the following conditions must also be met in order to give credence to the above statement.

1. The average target strength of the individual scatterers in the insonified volumes is known to at least the precision of the derived value of volume backscatter.

2. The degree of envelope amplitude time and the spatial correlation between serially received and processed insonification samples does not invalidate the statistical processes employed.*

* See next page.

The first condition cannot be met since an insufficient number of clearly identifiable resolved individual targets appear in the insonification sample data. The second condition has not been investigated at this time.

It is also of interest to examine the value of volume backscatter for each insonification sample. Figures 5.7(a) through (l) illustrate the digital processing C.R.T. oscilloscope display automatically generated as the result of processing the data tape. These displays were employed to locate the relatively high amplitude received echo signals for subsequent detailed examination of the data tape to investigate the possible presence of resolved individual targets.

19 May 0800 to 0914 Hours

During this time period the *R/V Khronometer* remained at anchor on Dacia Bank. The sea condition was calm, sky clear, vessel motion and hydroacoustical noise level minimal (<10 microvolts rms, measured at the transducer terminals). The vessel heading remained virtually constant and the surface sea water velocity relative to the vessel was 0.7 meters/second, approximately.

A copy of the echogram record obtained at this time is illustrated in Figure 5.8. This record obtained, approximately 12 hours later, from the same insonified region as the previous discussion, appears considerably different, (see Figure 5.3). In Figure 5.8 there are clusters of marks which suggest the presence of target aggregations and numerous marks suggesting the presence of single targets.

*Time correlation refers to $t = R/c$, spatial correlation refers to $\Delta V = \pi(c\tau)R^2\phi^2$ as a function of the insonification sampling rate of the hydroacoustical instrumentation. Detailed discussion of the terms employed in these expressions is given in References 3 and 4.

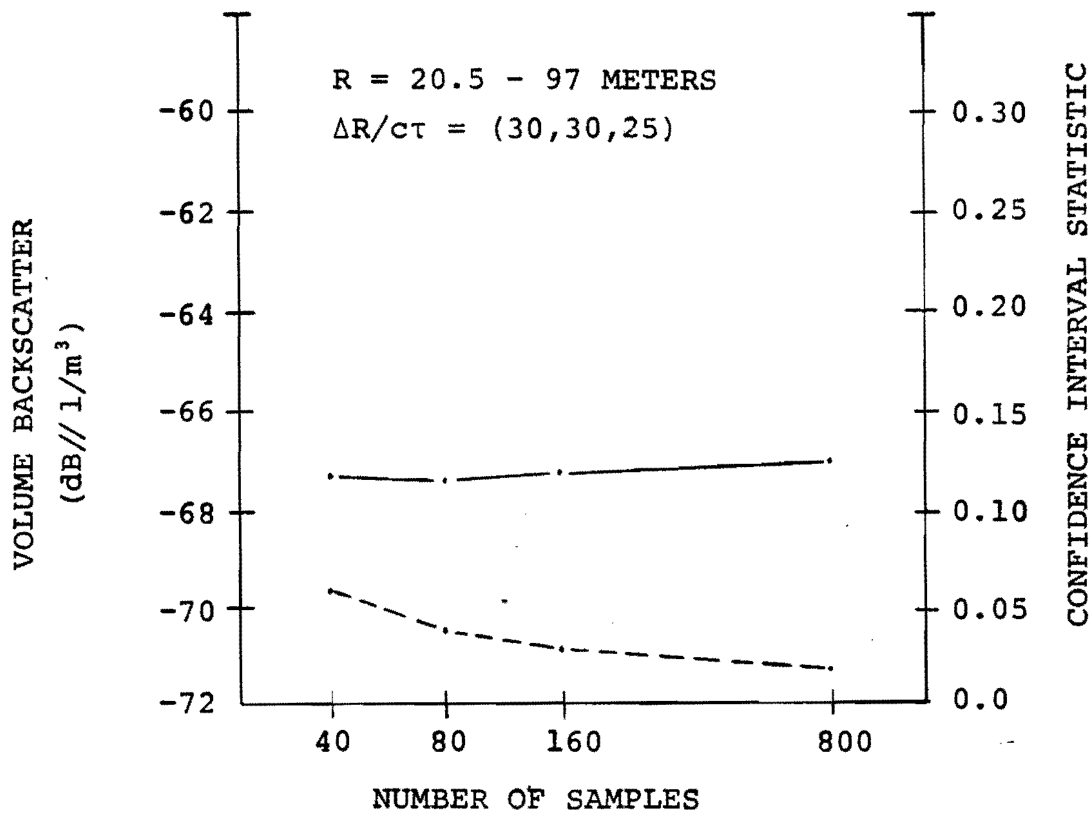
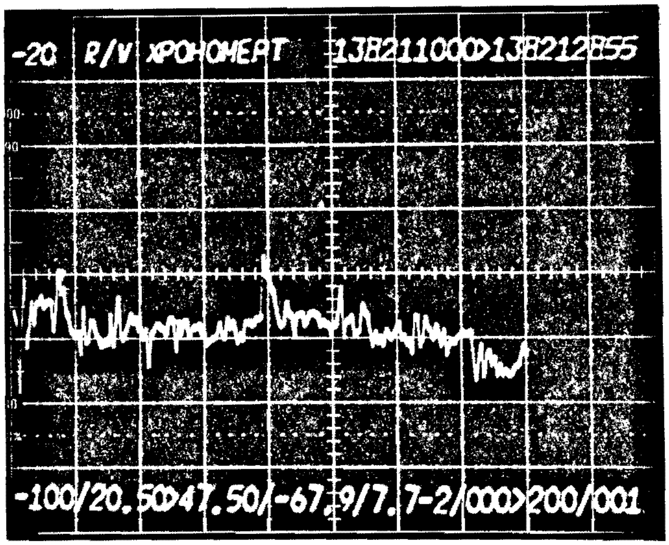
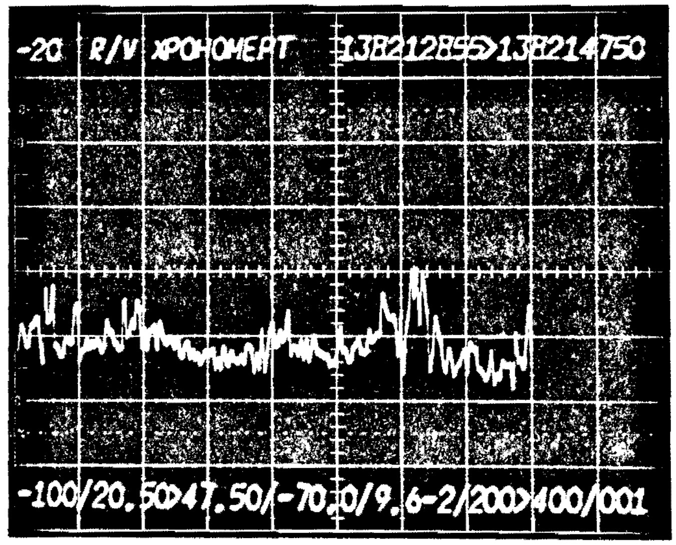


FIGURE 5.6 <u>BATCHED MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF SEA VOLUME - 18 MAY 2110 - 2225, DACIA BANK-HAG 432 - *R/V Khronometer*</u>



(a)



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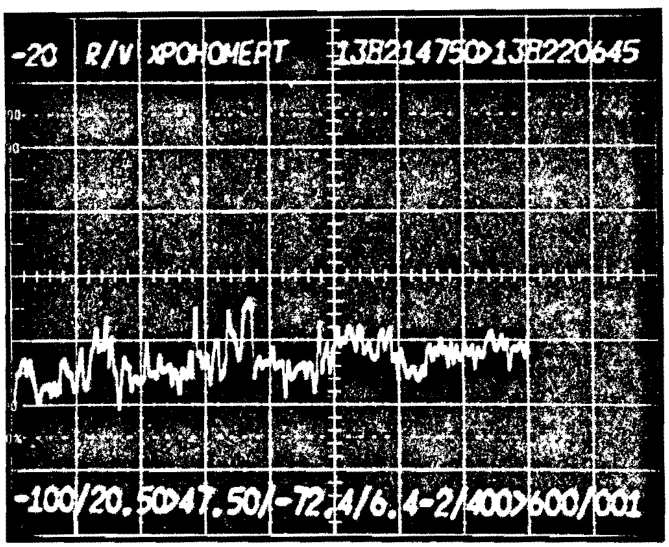

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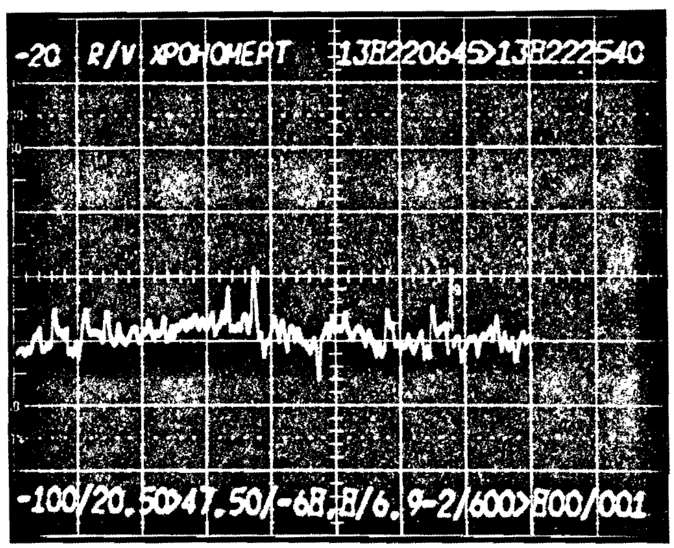
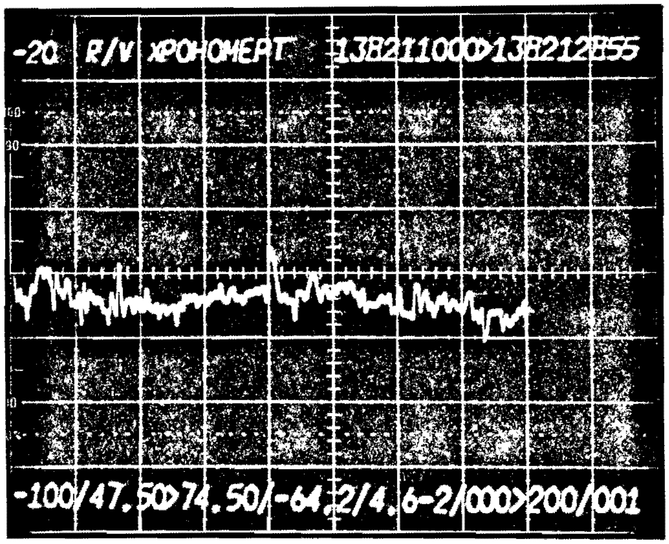


(d)

R = 20.5 - 47.5 METERS

$\Delta R/c\tau = 30$

FIGURE 5.7 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 18 MAY 2110 - 2225, DACIA BANK - HAG 432 - *R/V Khronometer*



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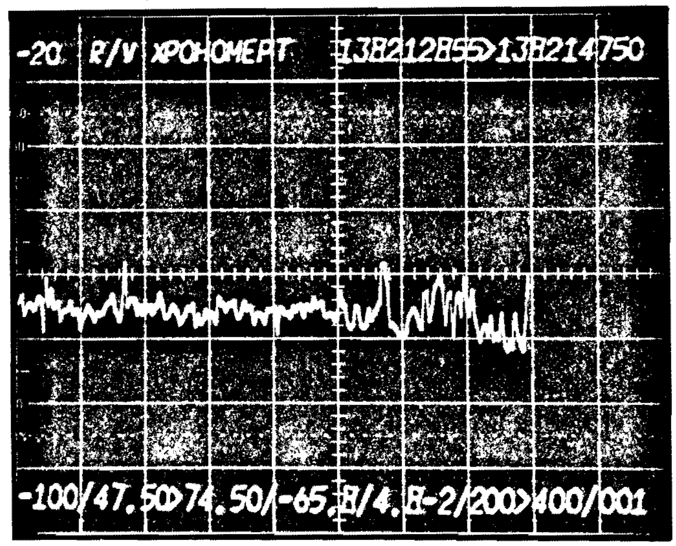
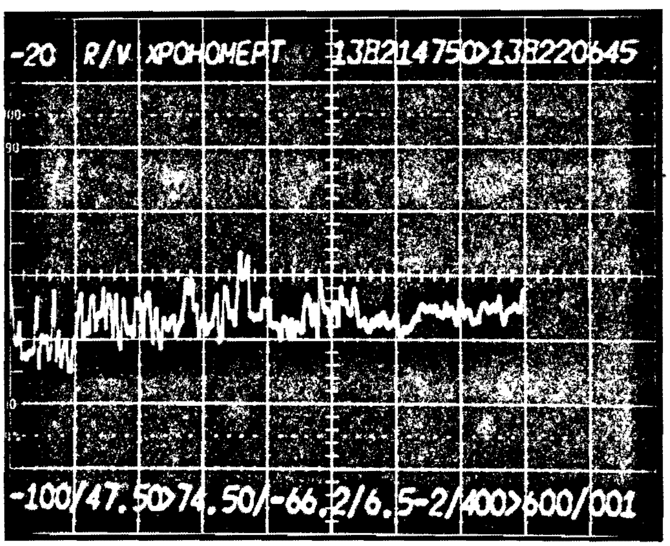
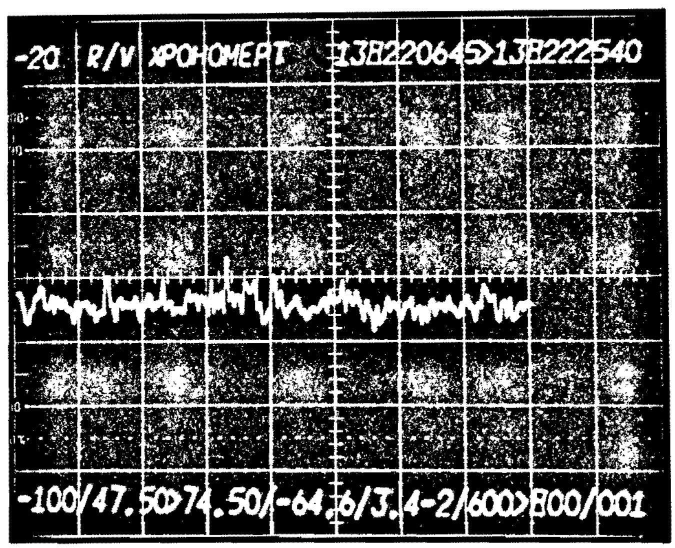


(f)



(g)

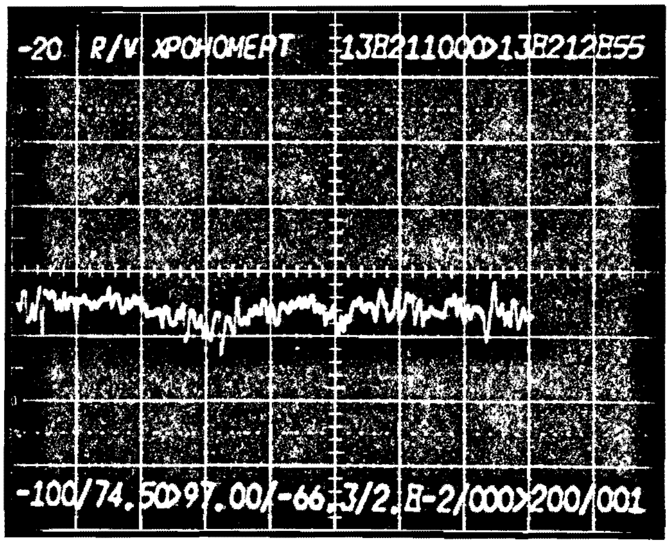


(h)

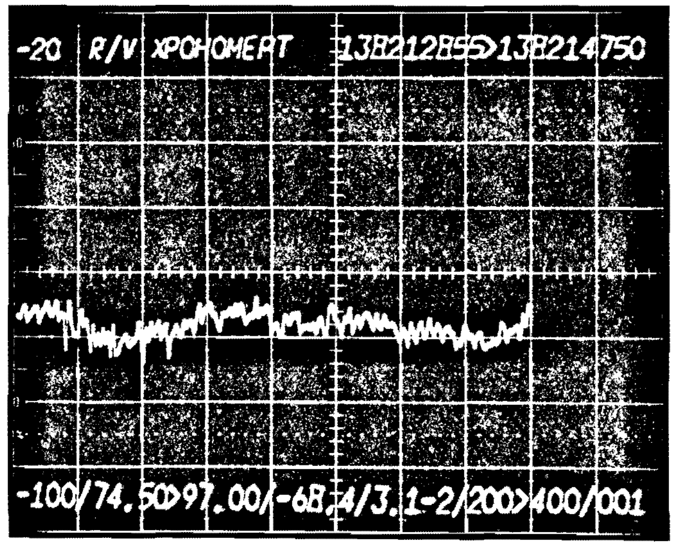
R = 47.5 - 74.5 METERS

$\Delta R/c\tau$ = 30

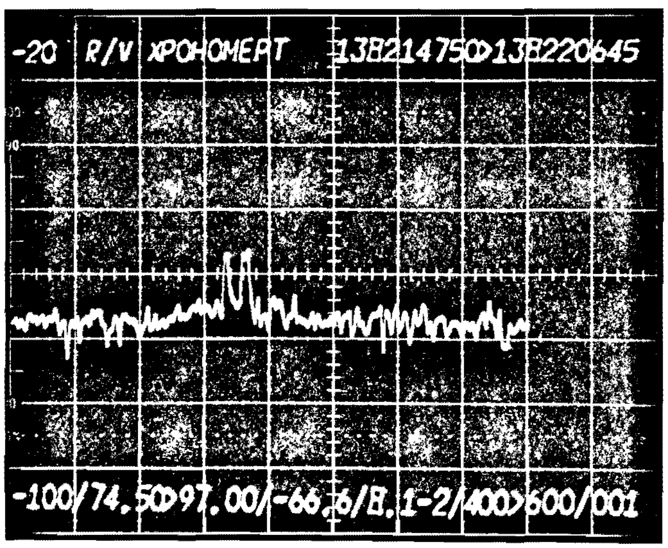
FIGURE 5.7 <u>DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 18 MAY 2110 - 2225, DACIA BANK - HAG 432 - *R/V Khronometer*</u>



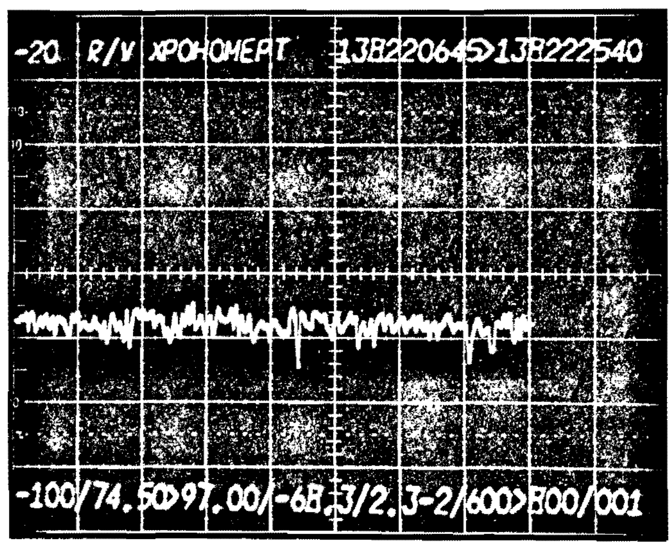
(i)



(j)



(k)

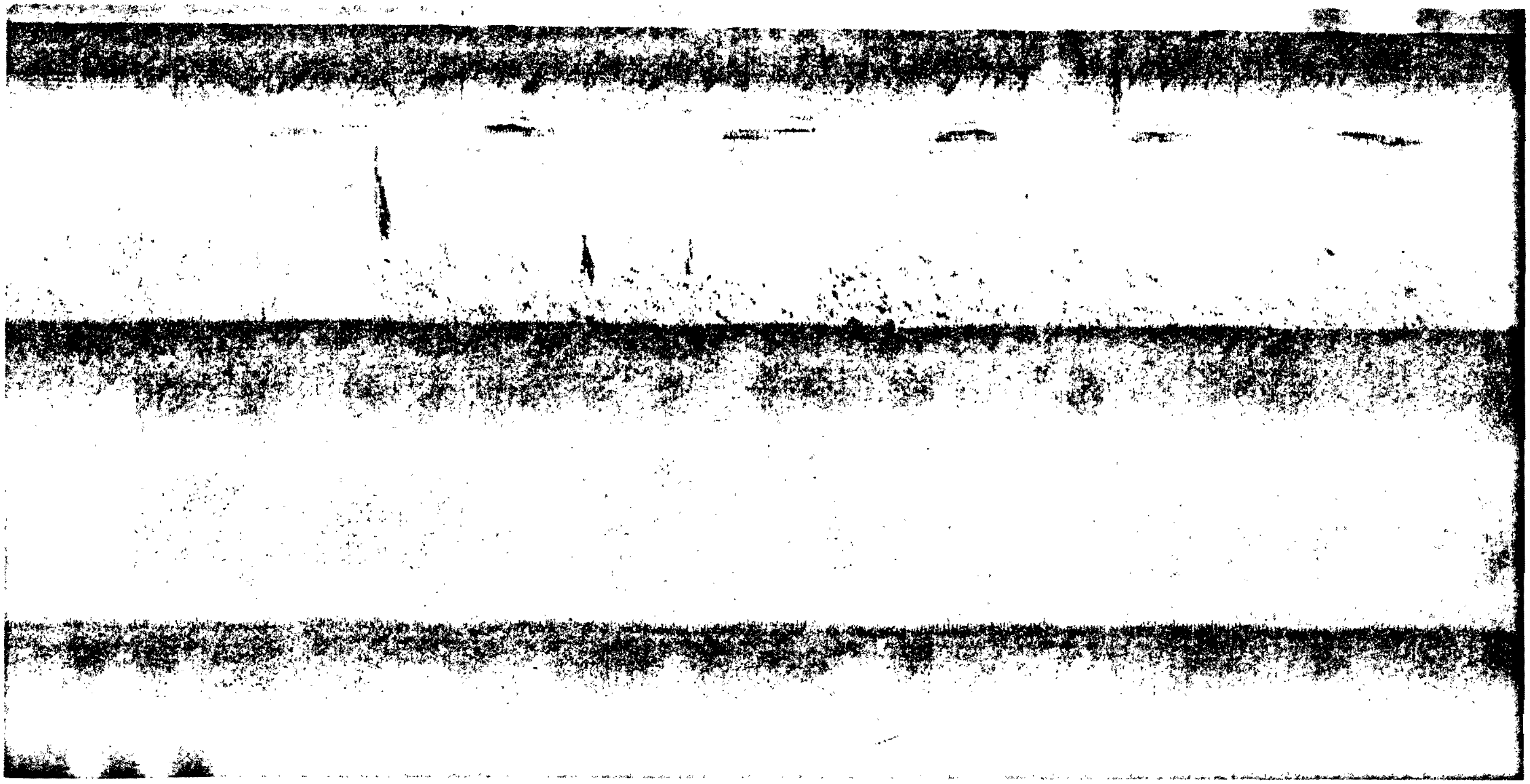


(l)

R = 74.5 - 97 METERS

$\Delta R/c\tau$ = 25

FIGURE 5.7 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 18 MAY 2110 - 2225, DACIA BANK - HAG 432 - *R/V Khronometer*



VERTICAL SCALE - 1mm ≈ 2 METERS   HORIZONTAL SCALE - 1mm ≈ 20 SECONDS

FIGURE 5.8 ECHOGRAM RECORD - 19 MAY 0800 - 0914, DACIA BANK
HAG 432, - *R/V Khronometer*

Examination of the recorded data shows small aggregations of targets which occur at a nearly uniform time interval, at a range of approximately 34 meters. It appears that these aggregations consisted of targets with minimal backscattering characteristics due to the relatively low amplitude of the received echo signals.*

The two prominent clusters of marks in the mid-water region in Figure 5.8 appear as target aggregations on the data tape. The larger aggregation exhibits two high amplitude signals approximately 12 and 15 dB higher than the sourrounding value of volume backscatter. These echo signals could be received from a closely spaced group of small targets or a single target or targets with a greater than the average backscattering characteristics of the surrounding aggregation.** Also, the possibility of the echo signal being recorded twice from the same targets cannot be ruled out. None of the possibilities could be verified with any degree of confidence because, as discussed earlier, only the peak portion of the signals could be observed above the surrounding received echo signal envelopes.

Examination of the received and recorded echo signals from the region immediately above and to 10 meters above the sea bottom signal showed a considerable number of high amplitudes, a few of which could be positively identified as resolved individual targets.

The data tape was processed according to the same range and number of insonification sample intervals as in the previous discussion.

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*It seems reasonable to assume that these recorded aggregations of targets were, in fact, the result of a single aggregation maneuvering to remain in the shadow cast by the *R/V Khronometer*.

**The received echo signal from closely spaced targets can exhibit amplitudes proportional to the square of their number i.e., coherent scattering. A brief discussion on hydroacoustical echo signal components and their effect of fish target density estimations is found in Reference 6.

Figures 5.9(a), (b) and (c) graphically illustrate the mean values of volume backscatter and the associated confidence interval statistics versus various numbers of insonification samples. Examination of these figures shows that within each range interval the mean value of volume backscatter is nearly constant. The confidence interval statistic shows an expected trend, i.e., increasing as the number of samples decreases, except for th mid-water range interval (47.5 - 74.5 meters). In Figure 5.9(b) the effect of the presence of the target aggregations on the selection of the number of insonification samples is indicated as a widely varying confidence interval statistic.

Figure 5.10 illustrates a batched mean value of the volume backscatter and confidence interval statistic for the total depth interval and the entire processing interval. It can be seen that the value of volume backscatter varies $<0.5 // 1/m^3$ and the confidence interval statistic varies from 0.19 to 0.04 from 40 to 800 insonification samples.*

The latter values suggest that it may have been possible to derive an estimate of the target density and ultimately the aquatic biomass in the insonified volume from approximately ±15% to within a factor of 2 in relation to the true biomass with a probability confidence of better than 95%.

As it was noted earlier the average target strength of the individual scatterers in the insonified volume must be known to at least the precision of the derived values of volume backscatter. It was not feasible to derive an average value of the target strength of the insonified animals in the range interval from 20.5 to 74.5 meters since positively identifiable resolved individual targets were not observed. In the range interval from 74.5 to 97 meters it is possible that a sufficient number of resolved individual targets may be extracted from

*The presence of the two mid-water target aggregations and their effect upon this final result is unrecognizable.

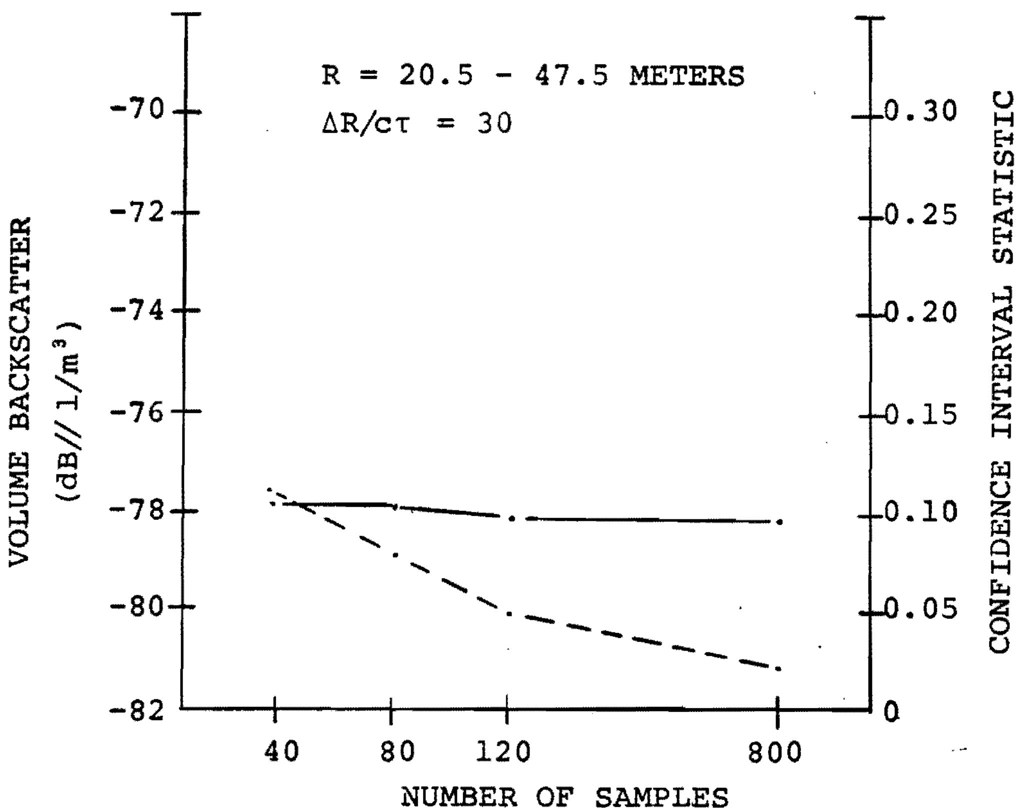


FIGURE 5.9(a) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*

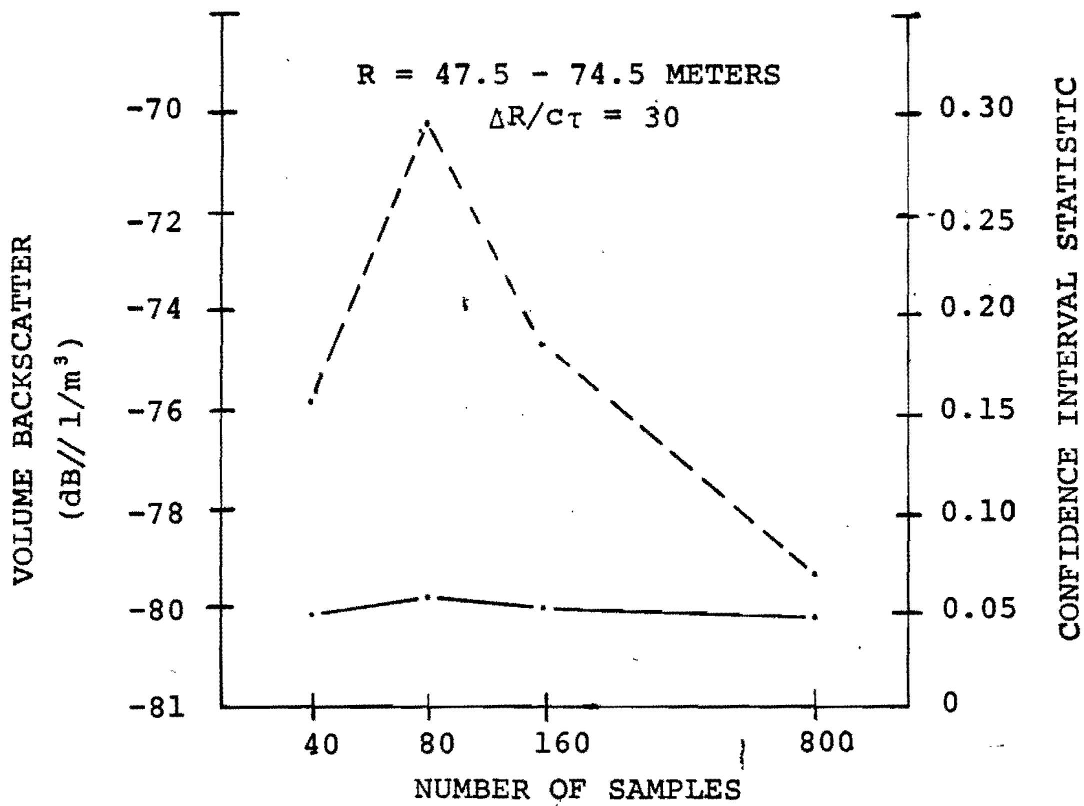


FIGURE 5.9(b) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V. Khronometer*

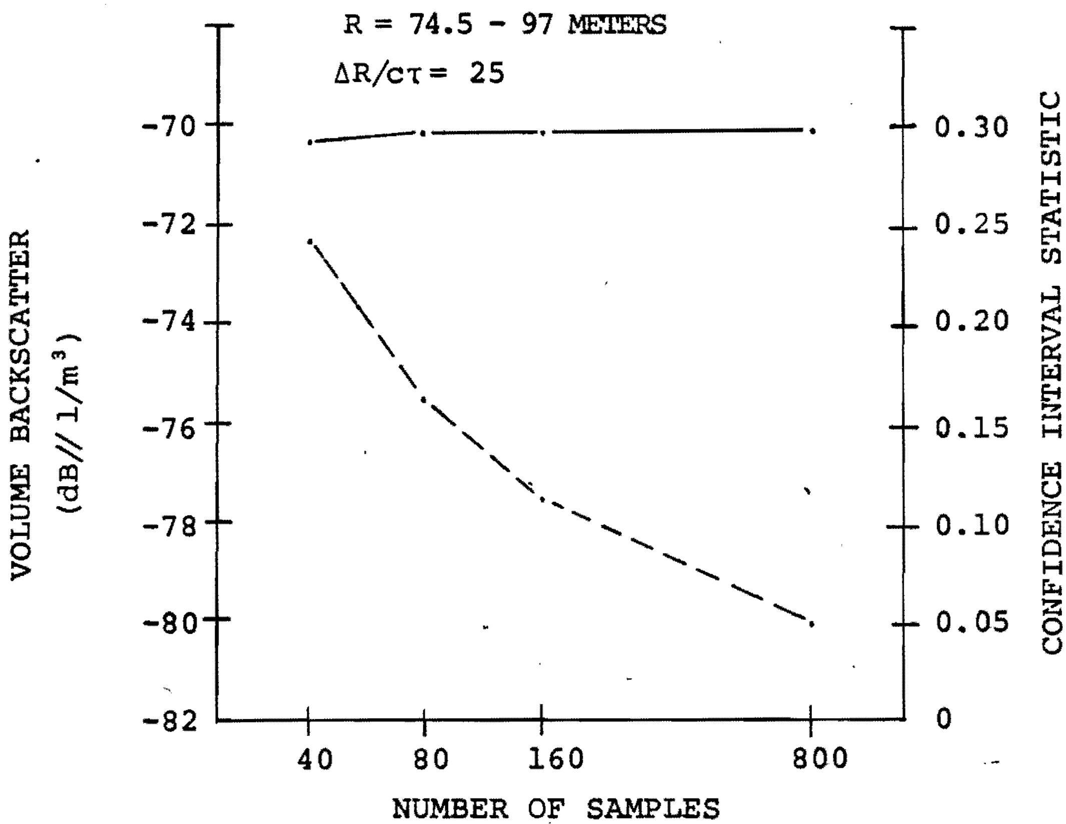


FIGURE 5.9(c) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*

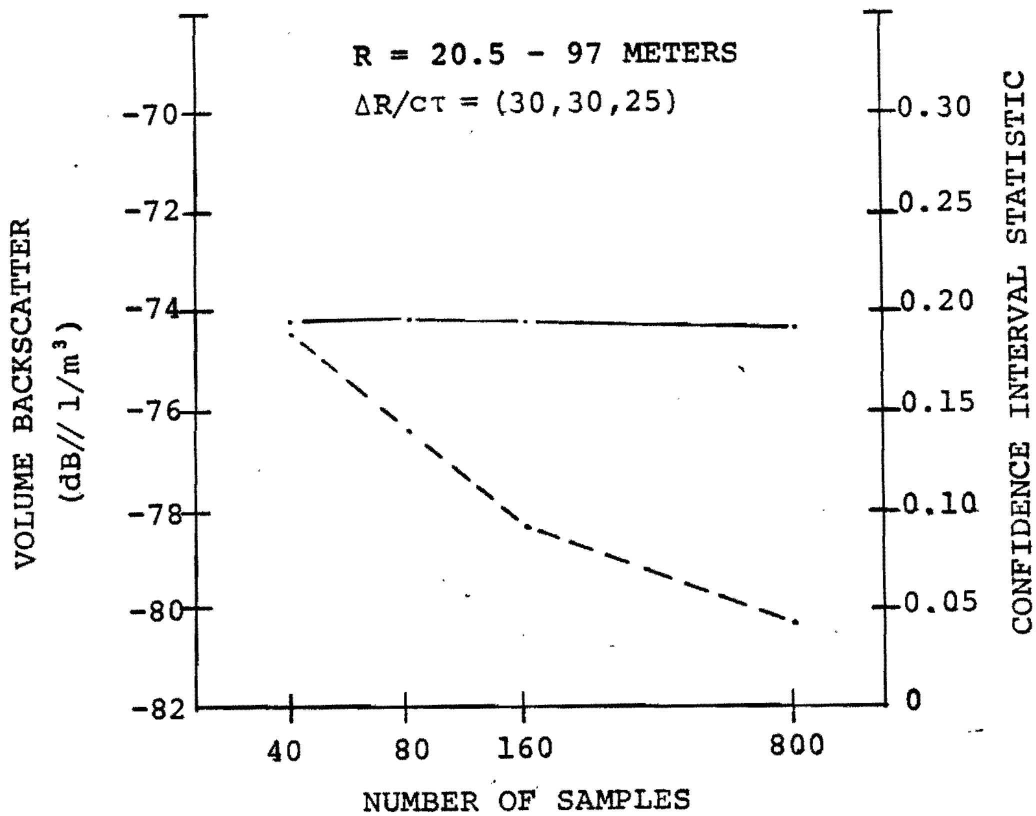
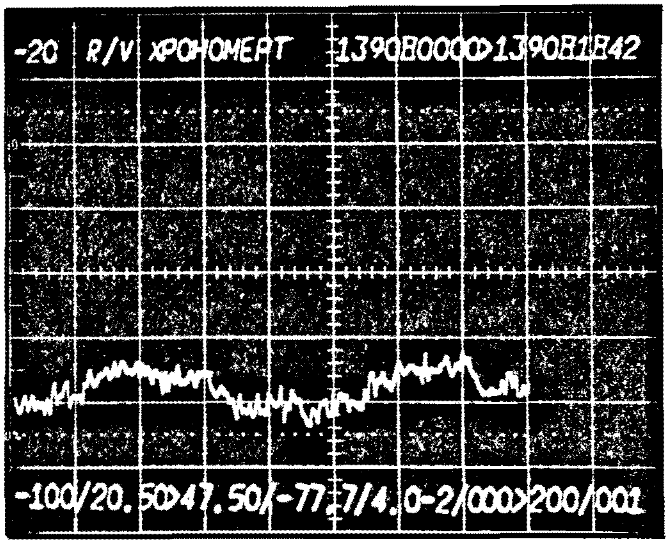
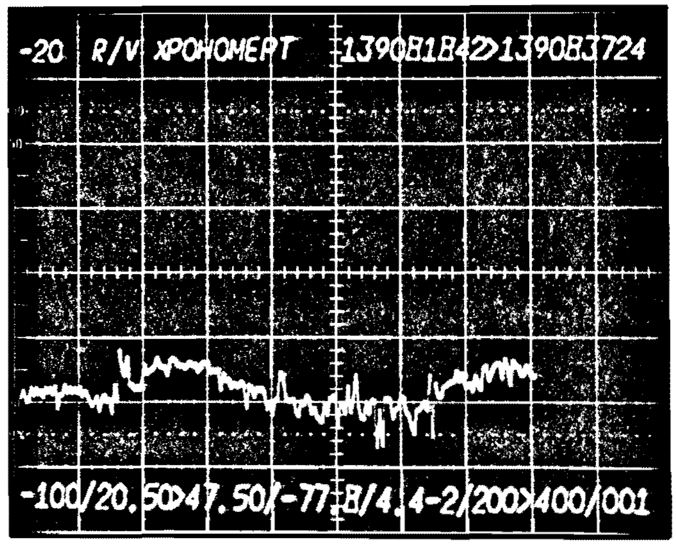


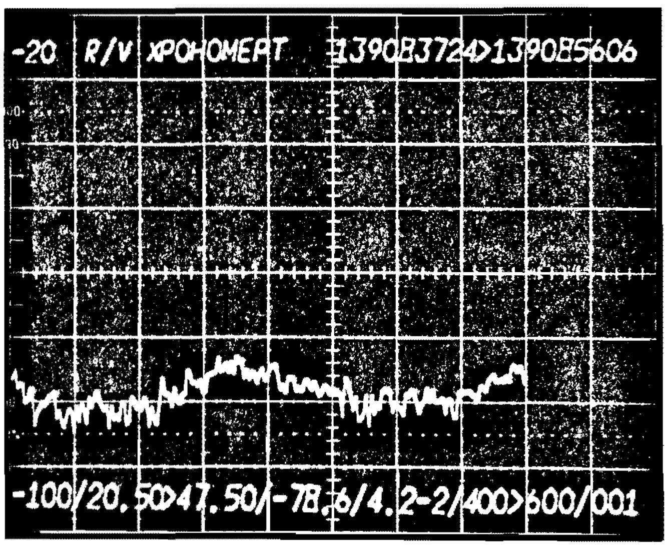
FIGURE 5.10 BATCHED MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF A SEA VOLUME - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*



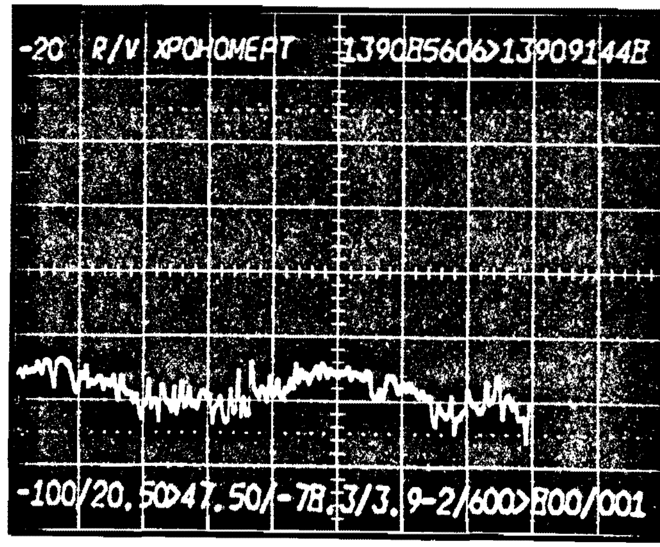
(a)



(b)



(c)



(d)

R = 20.5 - 47.5 METERS

$\Delta R/c\tau$ = 30

FIGURE 5.11 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*

the data tape to provide a mean value and associated confidence interval statistic, however, the species identification and composition is unknown.

The time and spatial correlation of the insonification samples has not been investigated at this time.

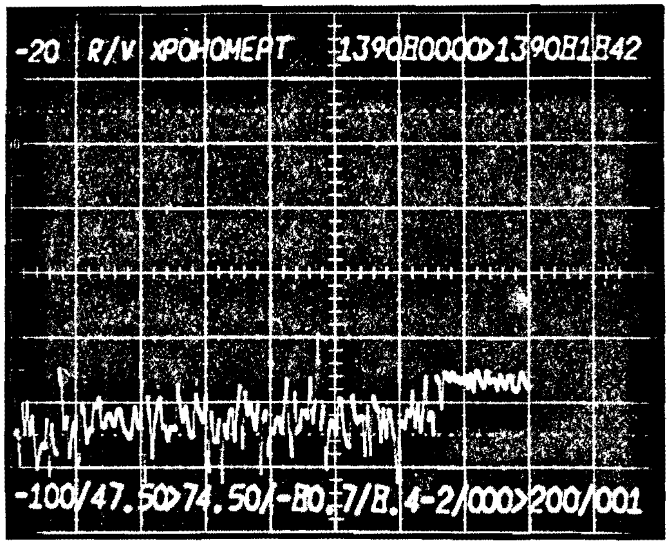
Figures 5.11(a) through (l) illustrate the digital processing C.R.T. oscilloscope display automatically generated as the result of processing the data tape. The nearly regular occurrence of the small target aggregation at 34 meters is clearly shown in Figures 5.11(a) through (d). The two high amplitude echo signals received and recorded within the larger mid-water target aggregation, discussed above, are shown in Figure 5.11(f). The presence of the other mid-water target aggregation also appears in this figure.

It should be noted that although the echogram record, Figure 5.8 and Figure 5.11 appear similar, a detailed comparison shows significant differences. For example, the time duration of the presence of the larger mid-water aggregation in the echogram, Figure 5.8 is approximately 1 minute and in the display of the processed data, Figures 5.11(e) and (f), approximately 10 minutes.

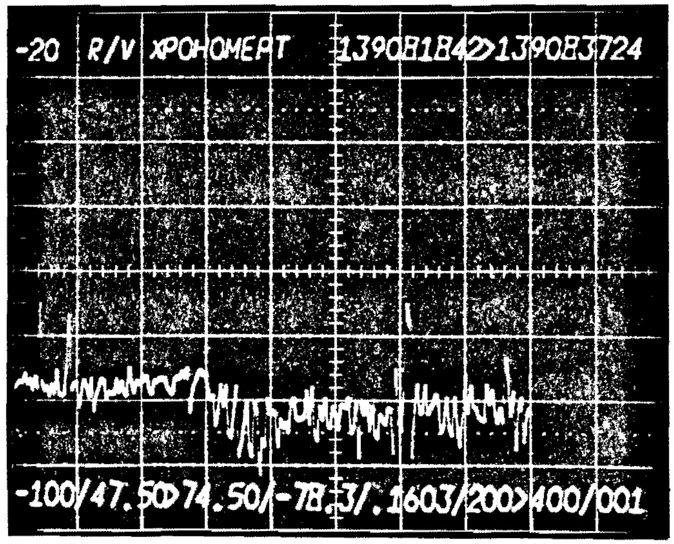
This situation illustrates the potential difficulty in attempting to assess the presence and extent of target aggregations, from an echogram display, when value of the volume backscatter from the aggregation is approximately 10 to 12 dB, (a factor of 10 to 16), greater than the ambient and vessel induced noise level.

<u>23 May 0240 to 0247 Hours</u>

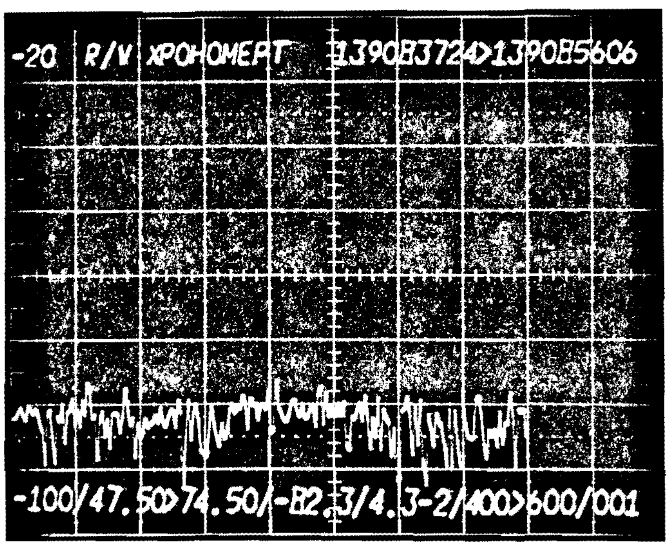
During this time period the *R/V Khronometer* was in the vicinity of Ampere Bank. The sea condition was calm, sky clear, vessel motion and hydroacoustical noise level low (<50 microvolts rms measured at the transducer terminals). The vessel heading remained approximately constant and the



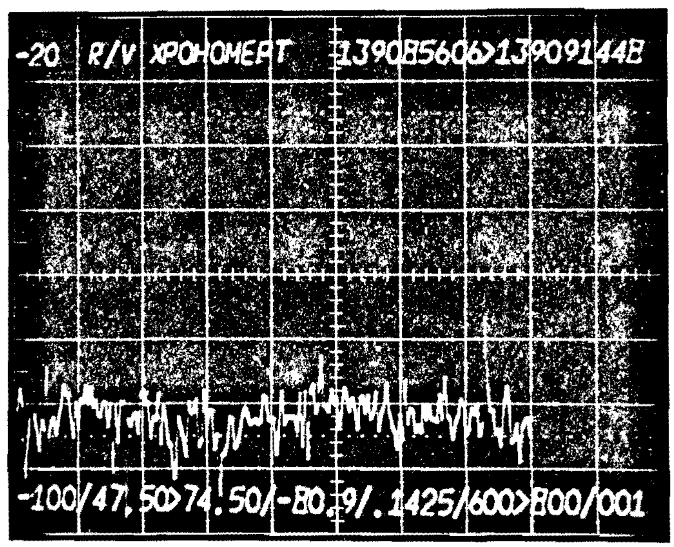
(e)



(f)



(g)

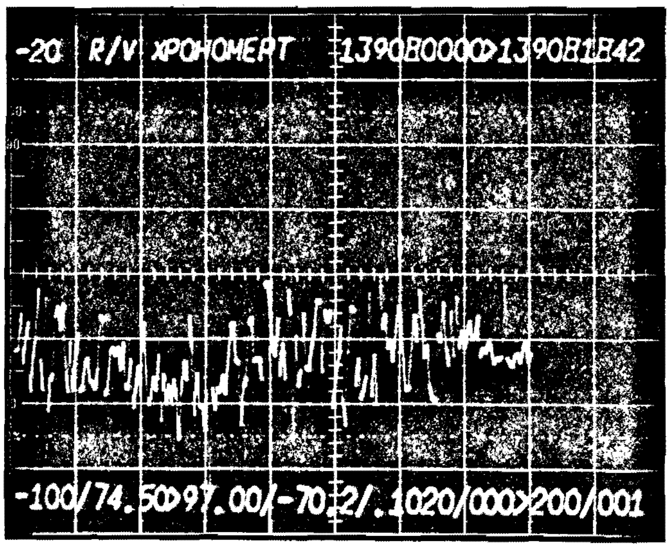


(h)

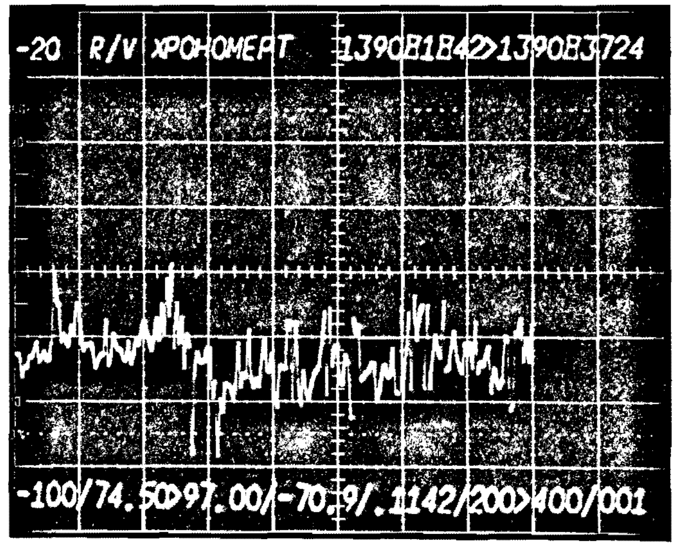
R = 47.5 - 74.5 METERS

$\Delta R/c\tau$ = 30

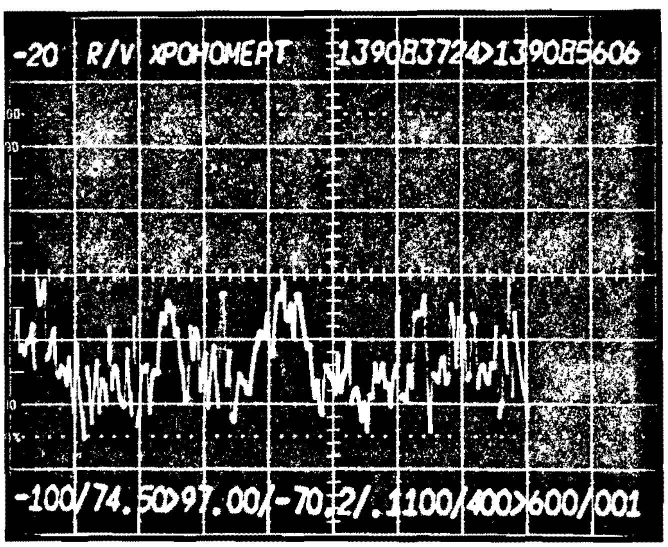
FIGURE 5.11 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*



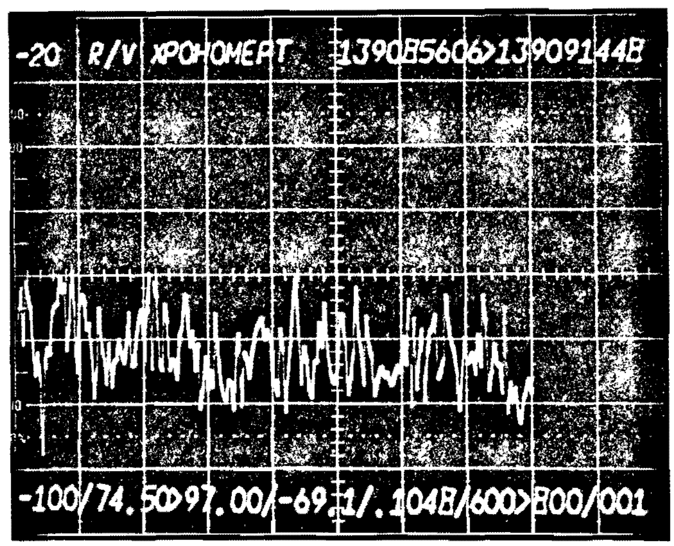
(i)



(j)



(k)



(l)

R = 74.5 - 97 METERS
$\Delta R/c\tau$ = 25

FIGURE 5.11 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 19 MAY 0800 - 0914, DACIA BANK - HAG 432 - *R/V Khronometer*

velocity relative to the sea surface was 0.9 to 1.2 meters/second.

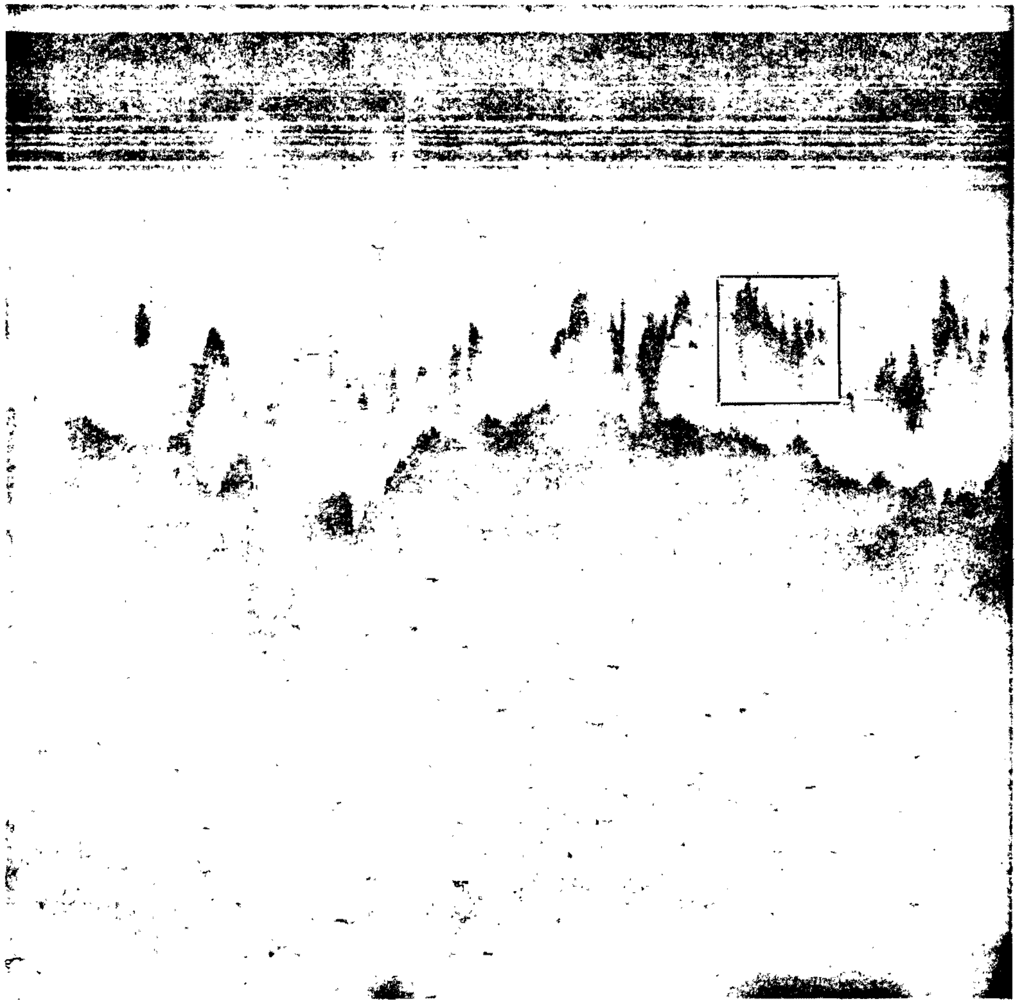
A copy of the echogram record including this time is illustrated in Figure 5.12. The echogram displays prominent clusters of marks which appear to be aggregations of unresolved targets. It should be noted that during the time period represented in Figure 5.12 the *R/V Khronometer* was maneuvering to provide the maximum amplitude received hydroacoustical echo signals. For this reason a number of the clusters of marks are from successive passages with rapidly changing vessel headings over the same region. The cluster of marks outlined in Figure 5.12 represents the received echo signals from an insonified volume at which time the heading of the *R/V Khronometer* was constant.

Examination of the data tape revealed a target aggregation exhibiting relatively high amplitude received and recorded echo signals (maximum values of 1.0 volt). No positively identifiable resolved individual targets were observed from a detailed examination of the data tape.

The recorded and received echo signals were processed in several combinations of insonification and envelope samples.* Figures 5.13(a), (b), (c) and (d) graphically illustrate the mean value of volume backscatter and the associated confidence interval statistics versus the various indicated insonification and envelope samples.

Examination of these figures shows that the values of volume backscatter varies 3 dB (a factor of 2) and the confidence interval statistic varies from 0.06 to >0.3 . The latter values suggest that it may have been possible to derive an estimate of the target density and ultimately the aquatic biomass in the insonified volume from ±35% to greater than a factor of 2 in relation to the true biomass with a probability confidence of better than 95%.

*Envelope samples defined by $\Delta R/c\tau = n$



VERTICAL SCALE - 1mm ≃ 1 METER

HORIZONTAL SCALE - 1mm ≃ 20 SECONDS

FIGURE 5.12 ECHOGRAM RECORD - 28 MAY 0215 - 0300, AMPERE BANK - HAG 432 - *R/V Khronometer*

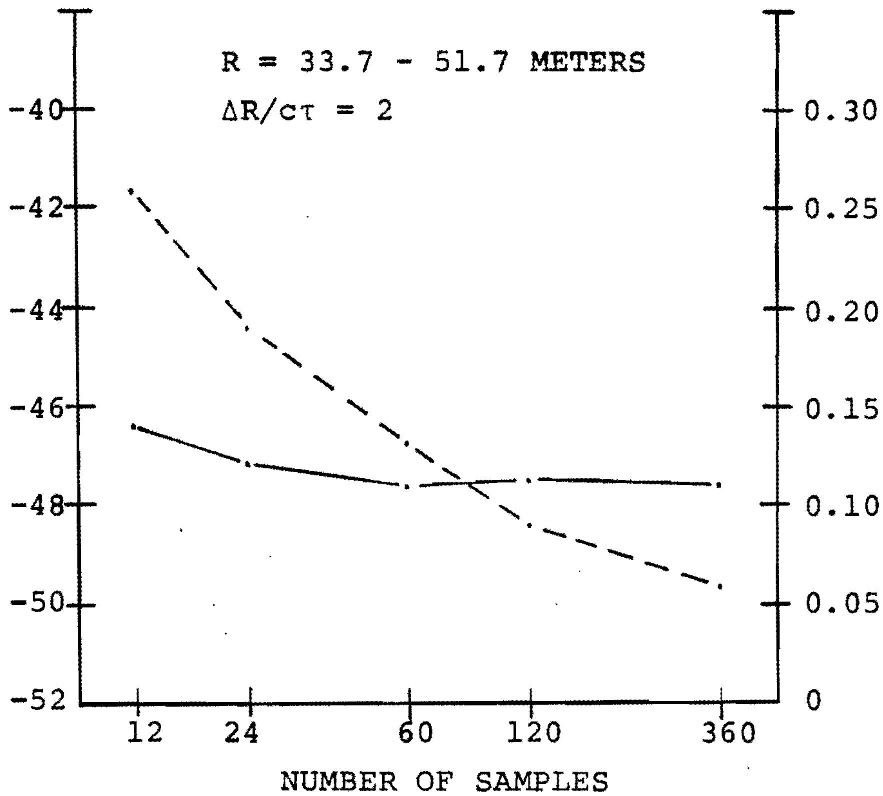


FIGURE 5.13(a) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF AN AQUATIC TARGET AGGREGATION - 28 MAY 0240 - 0247, AMPERE BANK - HAG 432 - *R/V Khronometer*

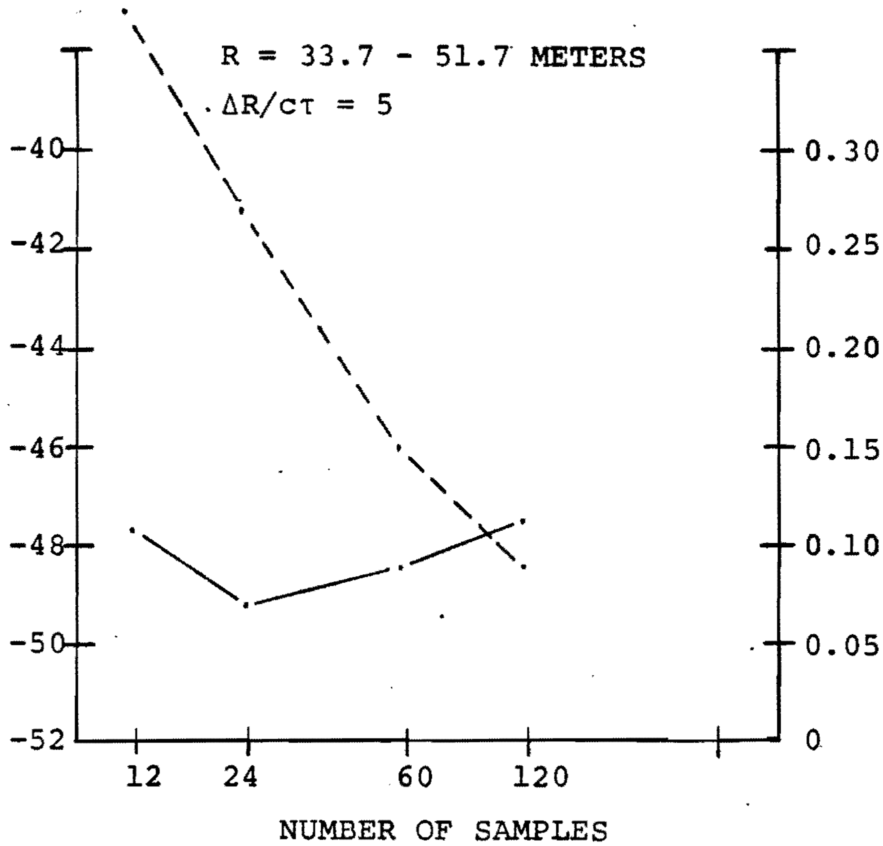


FIGURE 5.13(b) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF AN AQUATIC TARGET AGGREGATION - 28 MAY 0240 - 0247, AMPERE BANK - HAG 432 - *R/V Khronometer*

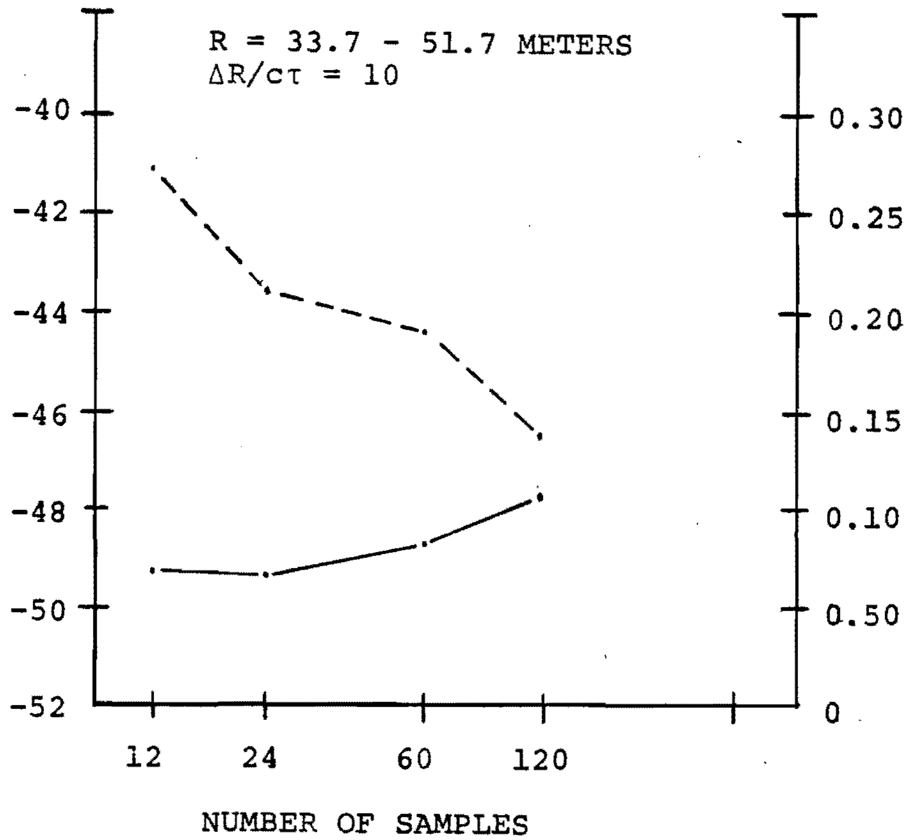


FIGURE 5.13(c) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF AN AQUATIC TARGET AGGREGATION - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*

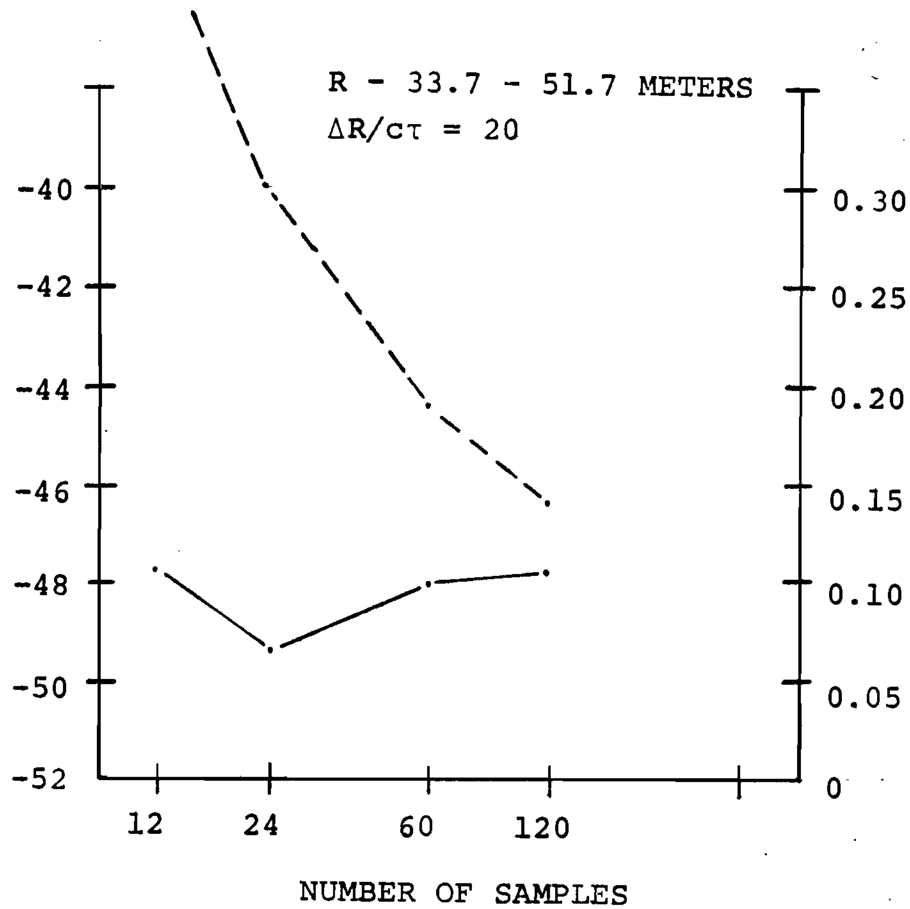


FIGURE 5.13(d) MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF INSONIFICATION SAMPLES OF AN AQUATIC TARGET AGGREGATION - 28 MAY 0240 - 0247, AMPERE BANK - HAG 432 - *R/V Khronometer*

Figure 5.14 graphically illustrates the values of volume backscatter and associated confidence interval statistics for various echo signal envelope sampling intervals for 120 insonification samples. Examination of this figure shows that the value of volume backscatter remains essentially constant, <0.5 dB// $1/m^3$, and the confidence interval statistic varies from 0.09 to 0.14. The latter values suggest that it may have been possible to derive an estimate of the target density and ultimately the aquatic biomass in the insonified volume from ±50% to within a factor of two with a probability confidence of better than 95%.

Comparison of Figure 5.14 with Figure 5.13(a) shows that the value of volume backscatter is for all practical purposes equivalent and for 360 insonification samples and $\Delta R/c\tau = 2$ the precision of the estimate of this value is somewhat better, i.e., ±35%.

Again it should be noted that the average target strength of the individual scatterers must be known to at least the precision of the value of the derived value of volume backscatter and the degree of envelope amplitude time and the spatial correlation between serially received and processed insonification samples does not invalidate the statistical processes employed.

Since resolved individual targets were not observed on the data tape the first condition above cannot be met. The second and third conditions have not been investigated at this time.

Figures 5.15 through 5.18 illustrate the digital processing C.R.T. oscilloscope display automatically generated as the result of processing the data tape. The envelope sampling intervals are indicated in each figure along with other details. An examination of these figures shows a considerable variation in the value of volume backscatter

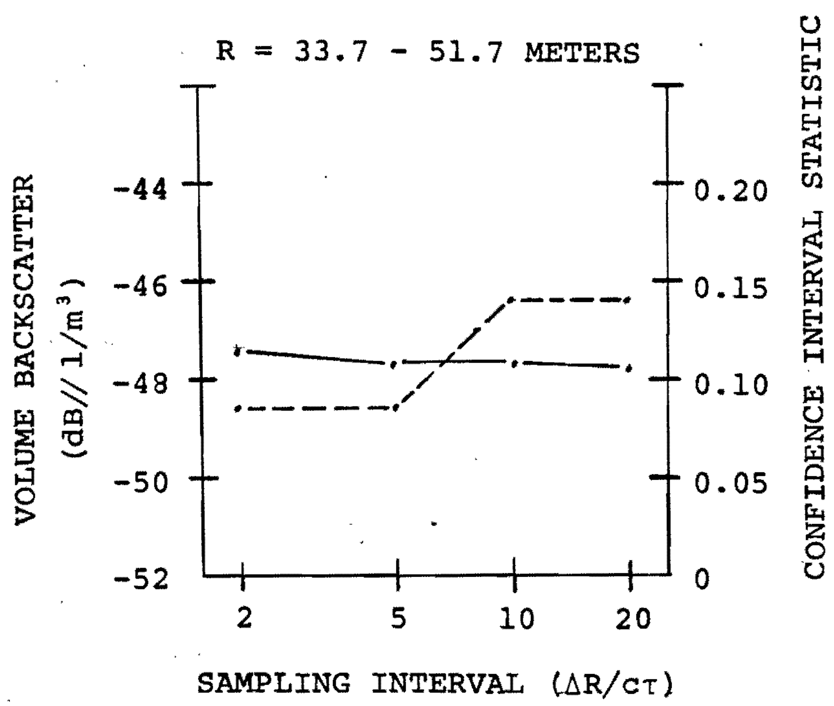
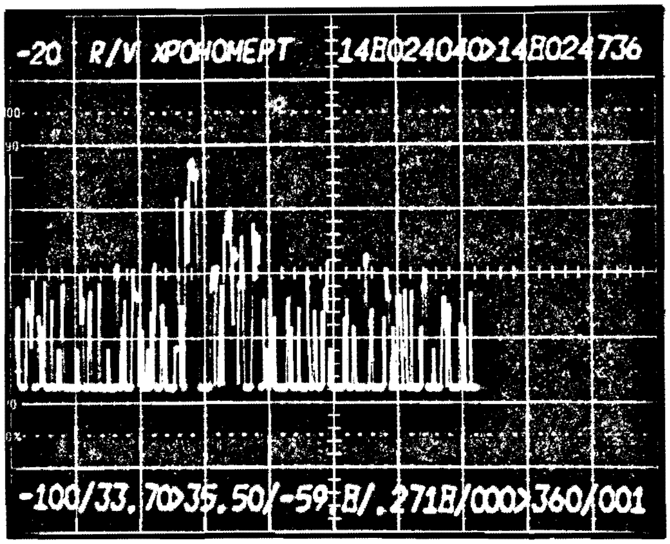
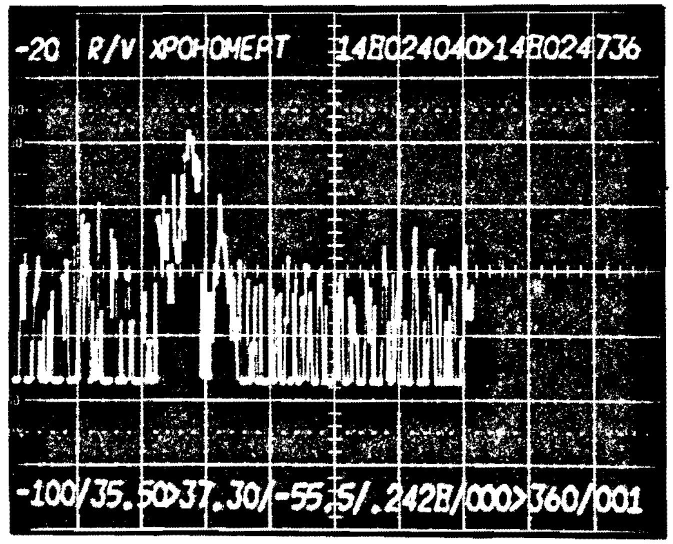


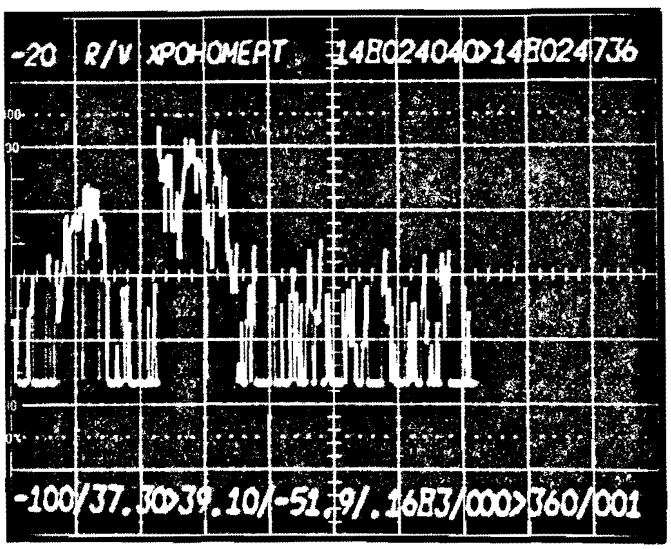
FIGURE 5.14 MEAN VALUE OF VOLUME BACKSCATTER AND CONFIDENCE INTERVAL STATISTIC VERSUS NUMBER OF RECEIVED ECHO SIGNAL ENVELOPE SAMPLES FOR 120 INSONIFICATION SAMPLES OF AN AQUATIC TARGET AGGREGATION - 28 MAY 0240 - 0247, AMPERE BANK - HAG 432 - *R/V Khronometer*



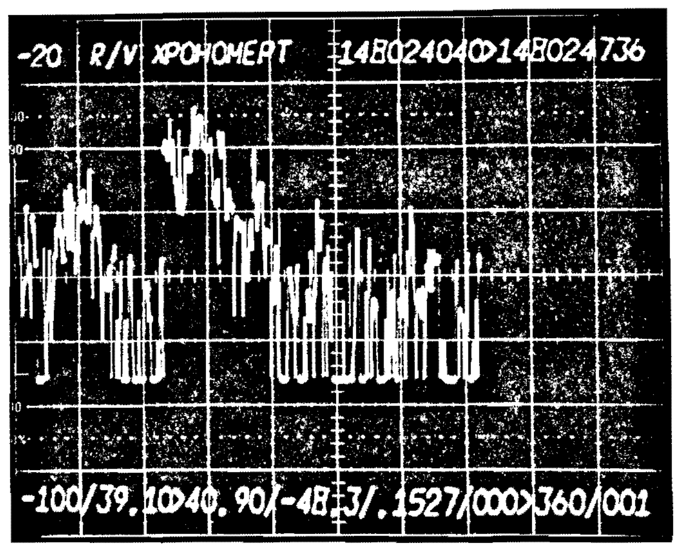
(a)



(b)



(c)

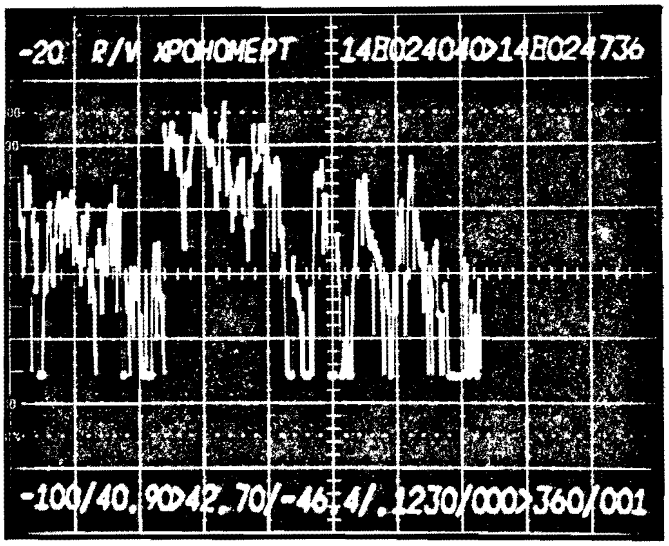


(d)

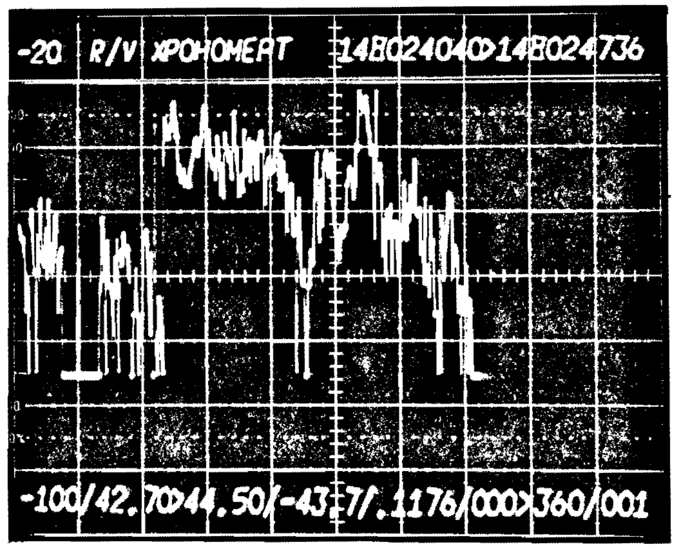
R = 33.7 - 40.90 METERS

$\Delta R/c\tau = 2$

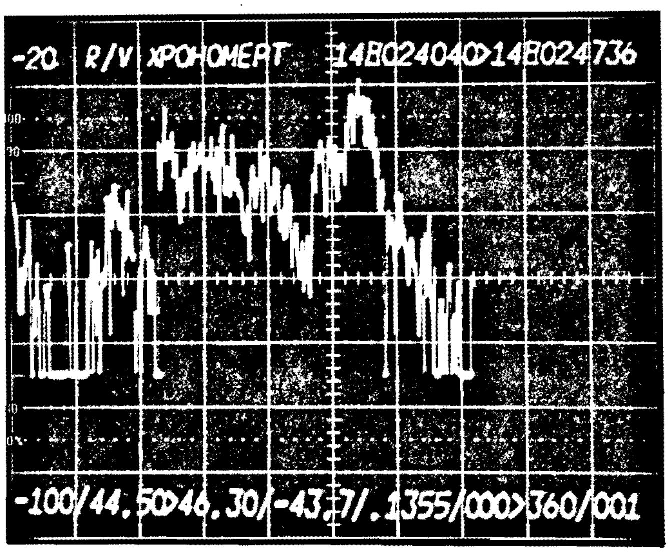
FIGURE 5.15 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*



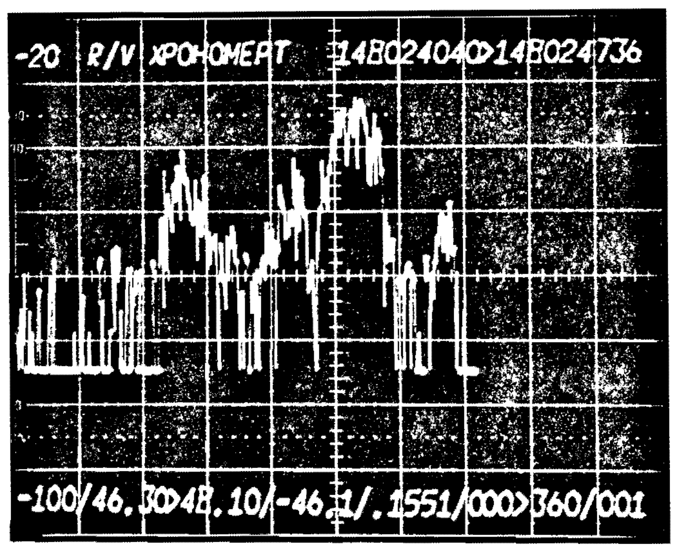
(e)



(f)



(g)

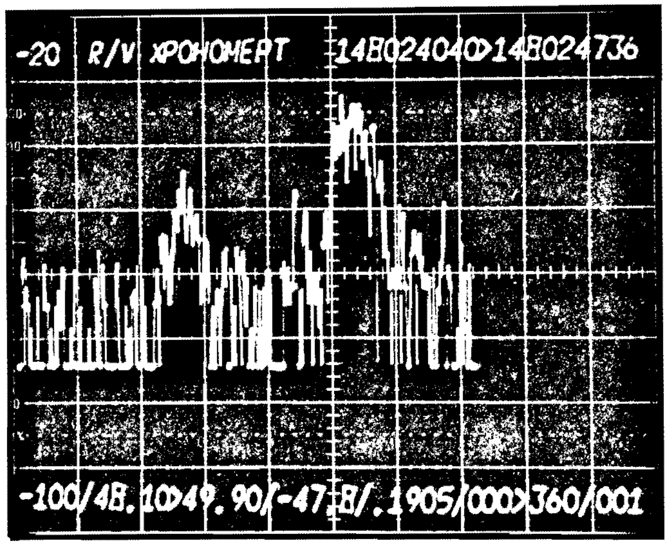


(h)

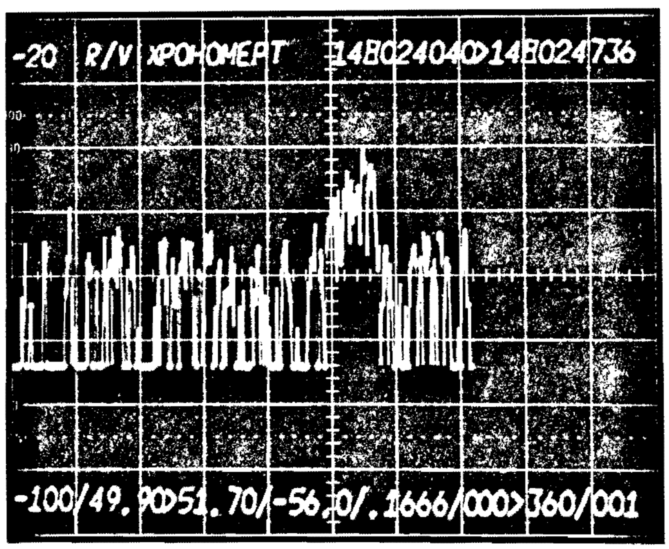
R = 40.9 - 48.1 METERS

$\Delta R/c\tau = 2$

FIGURE 5.15 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*



(i)

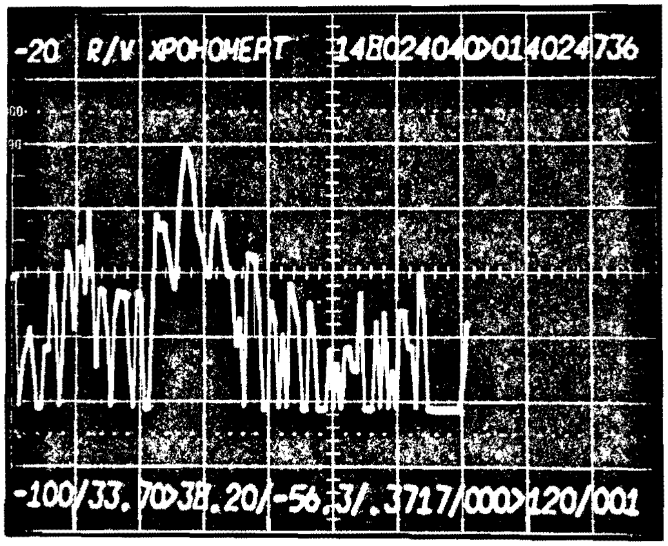


(j)

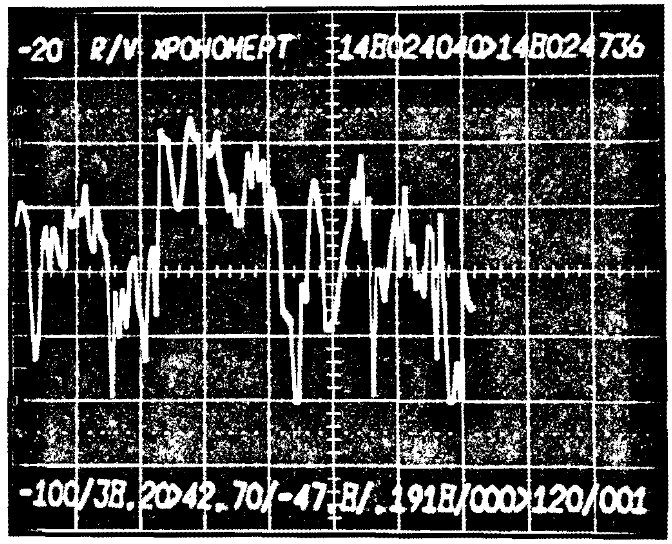
R ≐ 48.1 - 51.7 METERS

$\Delta R/c\tau$ = 2

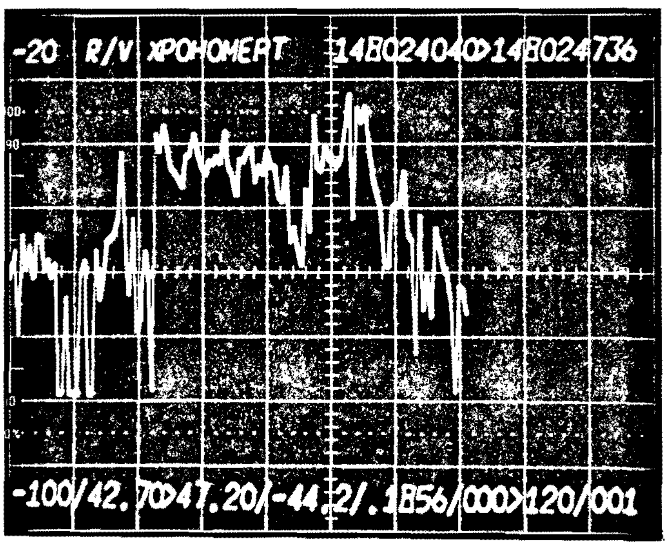
FIGURE 5.15 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*



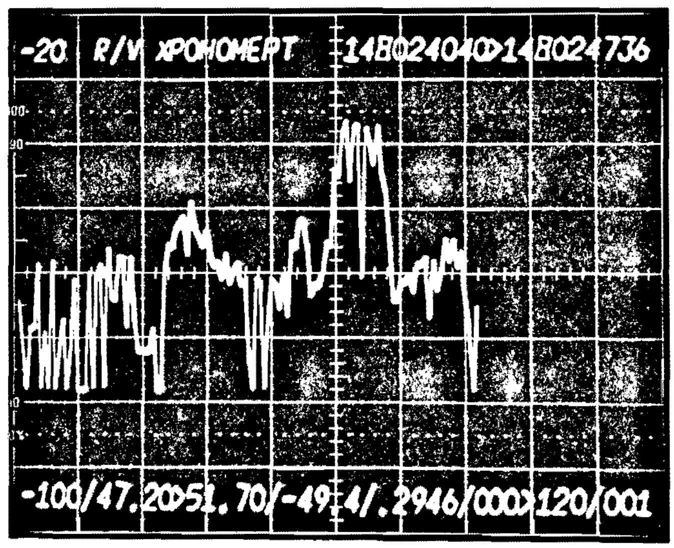
(a)



(b)



(c)

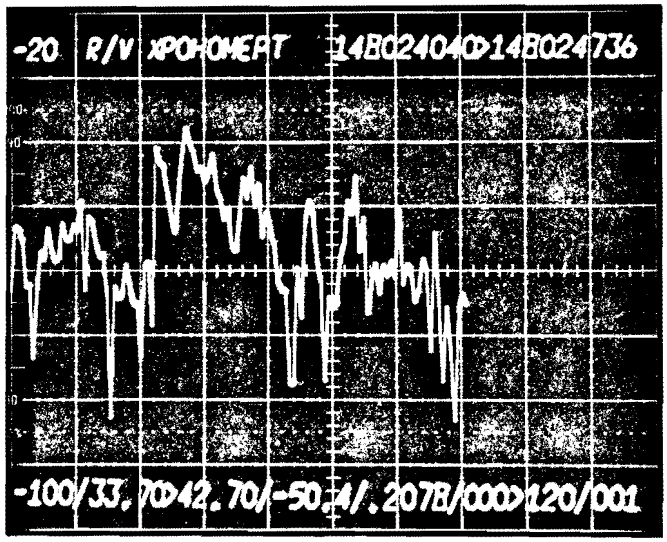


(d)

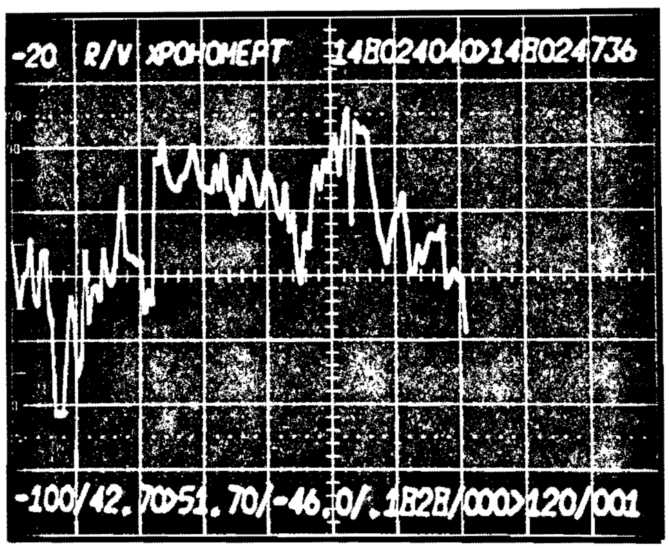
R = 33.7 - 51.7 METERS

$\Delta R/c\tau = 5$

FIGURE 5.16 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - R/V *Khronometer*



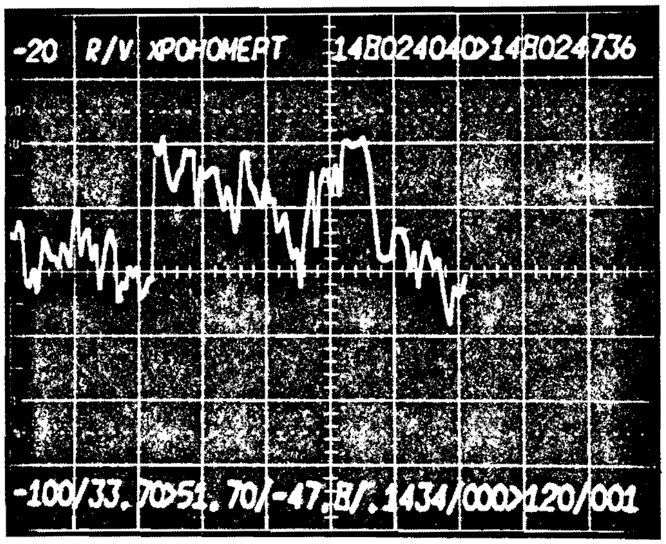
(a)



(b)

R = 33.7 - 51.7 METERS
$\Delta R/c\tau$ = 10

FIGURE 5.17 <u>DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*</u>



R = 33.7 - 51.7

$\Delta R/c\tau = 20$

FIGURE 5.18 DIGITAL PROCESSING C.R.T. OSCILLOSCOPE DISPLAY OF PROCESSED DATA - 28 MAY 0240 - 0247 - AMPERE BANK - HAG 432 - *R/V Khronometer*

within the target aggregation. This variation is the result of differences in target density, size and attitude in reference to the insonifying hydroacoustical wave and, in addition, hydroacoustical propagation and scattering anomalies and movement of the targets relative to the hydroacoustical sensor and to each other between insonification samples, in some unknown combination.

6.0 Summary

In terms of the stated objectives of the joint hydroacoustical experiment,(see Section 2.0), all were achieved with varying degrees of success. The following discussion summarizes the experimental activities in relation to the objectives with appropriate comments.

The objective to obtain hydroacoustical echo signals from insonified aquatic animals was satisfactorily achieved. Raw, unfiltered recorded data of high fidelity was obtained under favorable conditions.

The objective to obtain other *in-situ* biological data was compromised by the lack of positive identification of the insonified targets at the time of insonification.

Subject to the conditions set forth earlier in this report, (see Section 5.0), and the results of the recorded data processed according to the method described, the following comment is given.

> Depending upon the specific environmental conditions encountered and the mandatory requirement for raw, unfiltered recorded data of high fidelity it may eventually be feasible to estimate the aquatic biomass, in an insonified volume of the sea from ±25% to a factor of 2 with a probability confidence of better than 95%.*

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* See next page.

It must be clearly recognized that these values are derived with the unverified supposition that there is a known level of association between an idealized mathematically tractable model of the environment and an in-situ dynamic physical and biological environment. At this time the reasonable and practical bounds of this association are undefined.

The objective to conduct an in-situ combined parameter (source level and receiving sensitivity) calibration was achieved. The possible error associated with measurements of the maximum amplitude of the received echo signal voltage from a known physical calibration target was examined.

In view of the experience to date the following comment is given.

The combined parameter measurement and subsequent derived value should be handled in two ways, e.g., measurement of the maximum amplitude of the received

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*The indiscriminate use of filtering, exponential amplification, frequency shifting and other signal conditioning techniques to simplify handling, recording and/or processing of the received hydoracoustical echo signals may introduce considerable uncertainty in the assemssment of the true information content remaining in the data. Subsequent processing of this modified data, without demonstrable verification of fidelity, tacitly assumes that the true nature of and all of the critical parameters relating to the hydroacoustical environment are known accurately and the final conditioned data retains all the necessary components of information. Further , it is assumed that the knowledge of the accuracy of the critical parameters is considerably better than the expected accuracy of the final result. Reference 7 illustrates a typical result of filtering, exponential amplification, frequency shifting and narrow bandrecording of a signal of known characteristics.

echo signal and integration of the envelope of the received echo signal to avoid potentially significant error.* From these data an effective pulse time interval is derived, (see Reference 5), and employed in subsequent derivations of target strength and volume backscatter. It must be recognized that this procedure employs a specific calibration target for which the hydroacoustical scattering properties are well known and documented.**

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*Clearly, if a combined parameter measurement results in a considerably different value than the product of an individual parameter calibration, this discrepancy will be evident. Valid measurement practice mandates both forms, i.e., combined and individual parameter measurements.

**This situation and others, (see Section 5.0) extrapolated to the in-situ meansurements of aquatic animals suggests that attempts to identify resolved individual targets only by the time duration of the received echo signal and to derive target strength only by the maximum amplitude of the received echo signal may, unless verified, contain significant error. For example, the possible error attributable to the particular situation in Section 4.0 could ultimately result in an over-estimation of aquatic biomass by >300%.

The objective to conduct measurements of the combination of ambient and vessel induced noise in the experiment area was achieved.

In view of the results obtained the following comment is given.

> The limiting factor in the detection and subsequent recording of the hydroacoustical echo signals received from insonified aquatic targets of interest was vessel induced noise, in shallow depth, reradiated from a sea bottom consisting mainly of rock and coral formations. It is to be noted that the results of this investigation may only be applied the experiment area or other areas exhibiting similar topographical and hydroacoustic environmental characteristics.

7.0 Recommendations for Continuing Activities

The following recommendations are presented in relation to the experience to date.

Received Echo Signal Handling and Processing

The realtime recording, in broad band analog form, of the raw, ulfiltered receeved hydroacoustical echo signals from insonified volumes of the sea produces an unimpeachable source from which to examine data for information content.

The use of the digital processing C.R.T. oscilloscope in combination with the programmable calculator to process the recorded data is a simple, convenient, portable and cost-effective method to derive values of volume backscatter and associated statistical parameters.

Recommended:

1. The continued use of the correctly available received hydroacoustical echo signal handling and processing instrumentation for future collaborative research activities.

2. The establishment of collaborative activities by U.S. and USSR engineers to employ the recorded data tapes to develop calculator programs to derive the level of the time and spatial correlation of serially processed received echo signals and the effect upon statistical processes.

3. The establishment of collaborative activities by U.S. and USSR engineers to employ the recorded data tapes to develop interactive C.R.T. oscilloscope display and calculator programs to identify resolved individual target signals and subsequent estimations of target strength.

Hydroacoustical Equipment Calibration

Standard, comprehensive calibration procedures to verify the basic parameters of hydroacoustical equipment, (source level, voltage response, bandwidth, etc.), have been routinely implemented. In addition, an *in-situ* calibration employing a known physical target has been implemented. To date these two procedures have not been performed concurrently.

Recommended:

1. The continuation of the current calibration procedures such that both individual parameter and

in-situ combined parameter calibrations are conducted concurrently.

2. The generation of a formal document by U.S. and USSR engineers which provides guidelines and procedures to be followed for subsequent collaborative activities.

Applied Research

It has been noted that despite considerable rigorous analytical studies on the scattering of the hydroacoustical energy assumed to occur from and within an insonified aggregation of aquatic animals (fishes), there is little direct evidence, in terms of biomass measurements, that the specific theoretical models are representative of the environment. In certain specific situations physical measurements, in-situ or in specially contrived environments, the resulting hydroacoustical measurements have suggested confirmation of some of the theory. However, these confirmations, while indicating trends and magnitudes, have not suggested the order of accuracy of the measurements of aquatic biomass that may be obtained by hydroacoustical methods. In late 1975 U.S., USSR and Polish engineers held discussions which initiated the beginning of a systematic study and critical review of the complex interaction between the biological, technological and physical factors inherent in the measurements of aquatic biomass by hydroacoustical methods. The principal goal of this activity is to establish a definitive and credible estimate of the current state of development of hydroacoustical methods for aquatic biomass measurements, the identification of potential improvements, if any, that may result from further applications and most important, the effectiveness of hydroacoustical methods in relation to other techniques for purposes of fisheries resource assessment. At this time progress has been limited due to the normal working commitments of various individuals.

Recommended:

1. The continuation of the collaborative activities begun in late 1975 and increasing the frequency of meetings to accelerate the understanding of hydro-acoustical processes and the rational application of hydroacoustical methods for aquatic biomass estimations.

8.0 Principal Instrumentation

Hydroacoustical

HAG 432 (20.6 kHz)

Echo Signal Handling and Recording

7704 A	C.R.T. Oscilloscope
7A22	Differential Amplifier
7B53 A	Time Base
SP425 A/B	Time Code Generator
C53	Camera
5600 C	Instrumentation Tape Recorder

Test

VTVM, Signal Generator, DVM
Frequency Counter
Attenuator and C.R.T. Memory Oscilloscope

9.0 ## Participating Personnel

K. I. Yudanov	-	VNIRO, Principal Investigator
J. B. Suomala, Jr.	-	CSDL, Principal Investigator
K. A. Smith	-	NMFS/NEFC, Field Party Chief
V. I. Alshyn	-	VNIRO
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A. G. Bujchikov	-	VNIRO
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V. Dorofeev	-	VNIRO
N. Klimenko	-	VNIRO
I. Zarikhin	-	VNIRO

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