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INSTITUTE OF TECHNOLOGY

DEPARTMENT OF PHYSICS

MAJOR REPORT ON THE PROJECT

To Improve Echosounder Performance in Australian Prawn Fisheries

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PREFACE AND ACKNOWLEDGEMENTS

The fisheries acoustics research program described in this document was begun in mid 1974 and has been the subject of three previous annual reports. The present document constitutes the major report on the overall program. As a result of the research undertaken, a modified sounder installation has been prepared for operation in the 1978 Gulf of Carpentaria banana prawn fishery. A subsidiary report on the field operation of this equipment will be presented to the Fishing Industry Research Committee in 1978 and will form the final report in the series.

The major support for this program has come from funds provided by the Fishing Industry Research Committee. Additional support, notably for equipment purchase, has been provided by the Department of Physics and the Marine Studies Group of the Western Australian Institute of Technology. The Public Works Department of Western Australia provided the use of jetty facilities for the duration of the project. Mr. D. Cartledge and Mr. N. Sofoulis have made major contributions to the work done and a number of students have helped at many points throughout the program.

Advice has been sought and received from so many fishermen, fisheries scientists and others that acknowledgement to all would be inappropriate here. Special thanks are due, however, to Mr. J. Robins, of the Western Australian Department of Fisheries and Wildlife, as well as Mr. E. A. Purnell-Webb, Mr. P. D. Lorimer, Mr. S. Hynd and Mr. J. Hill, who were particularly helpful during 1976 in helping to formulate the approach taken to the final year of the project.

Thanks are due to the fishing industry personnel who made the five field trips possible. These include Mr. W. Poole, Mr. G. Jensen, Mr. B. Evers, Mr. D. Mathiot, Mr. W. Allen and Mr. P. Finch. Most recently, Mr. P. Arbuthnot and Mr. M. G. Kailis have enabled the practical implementation of a new sounder system to proceed.

Finally, thanks are due to my hosts at the Scripps Institution of Oceanography for support in the production of this report.

John D. Penrose
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SUMMARY

A review of marine acoustics practice in the Australian Prawning industry has suggested four specific problem areas for attention. The first concerns the detection efficiency of echo sounders, particularly the Koden SRM681 unit, in sensing single prawn targets. Measures of the target strengths of prawns, and of the influence of other variables, including pulse rate, have been made. The target strengths of penaeid prawns do not vary with frequency, over a useful frequency range, although preliminary estimates of noise spectra suggest that some advantage may be obtained if operating frequencies are above 150 kHz. Pulse rate is shown to be important in the detection of marginal targets, by the use of a mathematical model. The Koden sounder has several near-optimum features, but may allow improvement if manipulation of the signal to noise ratio is possible, and if beam stabilization is undertaken.

Two other problems call for optimization of vertical resolutions. Near bottom targets and some cases of trash fish interference are most likely to give useful sounder records when the sounder system can accurately reproduce closely spaced vertical variations in target strength. This calls for short pulse lengths, small beam angles, bottom lock display and ideally, a sounder beam stabilized against roll and pitch. The cost of providing such beam stabilization merits further attention.

Several fisheries provide examples of the fourth problem considered, i.e. that of beam coverage. The Carpentaria banana prawn fishery is the most notable of these, because of the important role echo sounding plays as a search tool in this fishery. A prototype twin beam sounder system has been designed and built with a view to providing some increase in beam coverage as well as information on the orientation of target schools encountered. A target warning system has also been developed to reduce the operator fatigue associated with continuous monitoring of echo sounder charts.

Attention has been given to the use of sonar and to the use of echo sounding for the remote assessment of sediment porosity.

1.0 INTRODUCTION

The original research proposal associated with this program specified the aims as follows:

> To establish a laboratory and field program to optimise echo sounder and sonar performance in the Australian prawn fishing industry. This would involve measuring the target strengths of selected species under various bottom conditions. From these results, recommendations as to gear selection and/or modification would follow. The proposal is based upon a similar British program and would have as a longer term aim the establishment of a resource centre in marine acoustics at W. A. I. T. to provide a general service to the fishing industry.

The proposal arose from a series of discussions involving W. A. I. T. personnel and members of the fishing industry. Since that time, and as a result of the work undertaken, it has been possible to define the role of marine acoustics in the prawn fishing industry more closely and to evaluate specific needs and problems more accurately. These developments are reflected in this first chapter of the report, which contains the following sections:

Section 1. 1 - which reviews some aspects of current acoustics practice in the industry,

Section 1. 2 - which outlines the specific problems addressed in the present work, and

Section 1. 3 - which briefly reviews the steps undertaken and progress made on the problems selected. The section also outlines the organization of the remaining chapters in the report.

1.1 MARINE ACOUSTICS PRACTICE IN THE AUSTRALIAN PRAWNING INDUSTRY

The use of echo sounding devices in the Australian industry is widespread. The mode of use, and the effectiveness of echo sounding appears to vary considerably, however, from one fishery to another and sometimes between skippers within a fishery. As a result of the five field trips undertaken in the research program, and from discussions with fisheries personnel, a number of separate echo sounder usage patterns can be defined.

In some fisheries, echo sounder records would appear to be used essentially only as depth indicators. Trawling is carried out on a semi-continuous basis over relatively well defined grounds. Also, the relevant prawn populations may be difficult to detect using sounders because of low prawn densities, prawn burial and/or interference from other species. In such areas, search programs using echo sounders may be undertaken during exploratory fishing and essentially abandoned once a productive trawling regime has been established. Of the fisheries studied in the present program, those at Shark's Bay and Exmouth Gulf in Western Australia would appear to approximate to this pattern. Unless new areas or techniques are sought, the use of existing sounders in such fisheries may well be restricted to determining depth and possibly detecting bottom types likely to provide net damage.

Another usage pattern is exemplified by the Spencer's Gulf fishery visited twice during the research program. Here, despite varying proportions of trash fish in the water column, information on prawn location can often be obtained by sounders. Although trawling is carried out semi-continuously, information on prawn density is valuable as a guide to the trawl path chosen, so that maximum effort can be directed to areas of high population density. Accurate sounder information provides more rapid feedback on prawn densities than that available from the inspection of main trawl catches, and is less arduous than try netting.

The Gulf of Carpentaria fishery provides several usage patterns. Most notable is that associated with the banana prawn season. During this the banana prawns form dense schools of relatively limited extent and continuous trawling is no longer effective. The schools are located, customarily by acoustic means, before the nets are lowered. The use of echo sounders is thus crucial to this fishery. At other times of the year, when banana prawn schools are not in evidence, semi-continuous trawling for other species, such as tiger or endeavour prawns may take place. These are widely and thinly distributed and present relatively poor targets. Again, detection is useful in guiding trawl path location.

1.2 SPECIFIC NEEDS AND PROBLEMS

Even in the fisheries where acoustic techniques are currently useful, various problems reduce the effectiveness of echo sounders and sonar. In the present work, attention has been directed to a number of these difficulties with a view to developing, where possible, ways and means of effecting improvements appropriate to specific trawling regimes. The problems addressed may be summarised as follows:

1.2.1 Detection Efficiency

The prawn is a relatively poor acoustic target and in many fisheries, is widely and thinly distributed. Many echo sounders will not show evidence of prawns until the density of animals exceeds figures commonly encountered in non-schooling varieties. Information is needed on the variables which affect detection efficiency, so that optimum specifications may be employed in acoustic gear selection.

1.2.2 Near-Bottom Resolution

Since many prawn species exist in or near the bottom, it is useful to optimise for near-bottom resolution.

1.2.3 Resolution from Other Species

A continuing feature of many fisheries is the presence of small fish, crustacea and other organisms in, or adjacent to, the water column regions occupied by prawn populations. When this occurs, interpretation of echo records is often difficult and it may not be possible to separate prawn and competing echoes.

1.2.4 Beam Coverage

This problem is most clearly seen in the banana prawn fishery, when acoustic techniques are used in a search mode. Common beam geometries interrogate relatively small volumes of the water column and thus have low probabilities of encountering prawn schools. A related problem concerns the operator fatigue arising out of the need to monitor echo sounder chart outputs over long periods of time.

Other difficulties also occur e.g. the periodic net damage arising from some bottom types. The greater part of the present research program has, however, been devoted to the problems outlined in Sections 1.2.1 ⟶ 1.2.4 above.

1.3 PROJECT OUTLINE

The research work undertaken falls into three main categories. Beginning in 1974, a laboratory test tank and equipment was developed. This equipment has been used, in particular, to measure target strengths and has been steadily improved since its inception. In its current form, the test equipment operates on line to a PDP 11/10 computer which has also been used to simulate the nature of echoes from arrays of target animals. Associated with this work, a series of tests have been made to determine the form of the chart record from several sounders for varying distributions of received pulses. This work has been primarily concerned with detection efficiency, and is largely dealt with in Chapter 2 of this report.

In 1975, a jetty test facility was established and used to investigate near-bottom resolution and the relationship between sea bottom properties and associated echoes. This work is described in Chapters 3 and 4.

During 1976/77 five field trips were undertaken and information from these appears throughout the report. As a result of a trip to the Gulf of Carpentaria, and of earlier work, a modified sounder system for use in banana prawn trawling has been devised and a prototype system built. This work appears in Chapter 4, which also includes a discussion on some aspects of sonar usage. Chapter 5 summarises the conclusions reached, outlines areas which would repay further attention, and lists the publications which have been and are emerging from the program.

Throughout the report, and where examples are required, frequent use is made of data from a Koden SRM 681 multistylus sounder. These units have a history of success in several fisheries and, in order to relate laboratory and field measurements whenever possible, one such machine was purchased by the Department of Physics in 1976 and used extensively in several areas of the project.

2.0 DETECTION EFFICIENCY

2.1 THE TARGET STRENGTHS OF SINGLE PENAEID PRAWNS

The first report (1974) on the project included a suite of target strength measurements for selected target animals. Since that time, as suitable targets have become available, additional measurements have been made and the measuring system has undergone steady improvement. Figure 1 outlines the present form of the system which includes an on-line connection to a PDP-11/10 computer housed in the WAIT Physics Department. The measuring system electronics have been retained in a demountable form to facilitate transportation and are built around Hewlett Packard electronic units, modified and augmented by purpose-built electronics. Slide 1 shows a view of the measuring system less chart recorder and computer.

The target strength measuring technique has been fully described by Sofoulis (1977) and the later stages of the development of the measuring system by Fallon (1977).

During the course of the program, target strength measurements were made of tiger, banana and western king prawns. No significant variation in target strength between these species was found which could not be directly attributed to differences in animal weight or length. Accordingly, in the discussion which follows, target strength values will be assigned to these species collectively and ascribed to penaeid prawns generally.

The animal lengths chosen for the target strength measurements were selected so as to be representative of those encountered in trawling practice. Figure 2 shows smoothed frequency distributions of prawn lengths taken from a field trip trawl to the Exmouth Gulf (WA) fishery in May 1977. The lengths vary from 10 cm to 23 cm with the majority lying in the range 12 cm to 18 cm. Similar statistics from a representative tiger prawn catch in the Gulf of Carpentaria area in July 1977 yielded animal lengths from 13 cm to 23 cm with 78% of the catch having lengths in the range 15 cm to 18 cm. Banana prawn lengths for the same area would appear to be slightly greater. During field trips to the Spencers Gulf (SA) fishery in January and March 1977, catches of Western King Prawns were made. These were not subject to detailed measurement but appeared to have similar length distributions to those represented in the total curve of Figure 2.

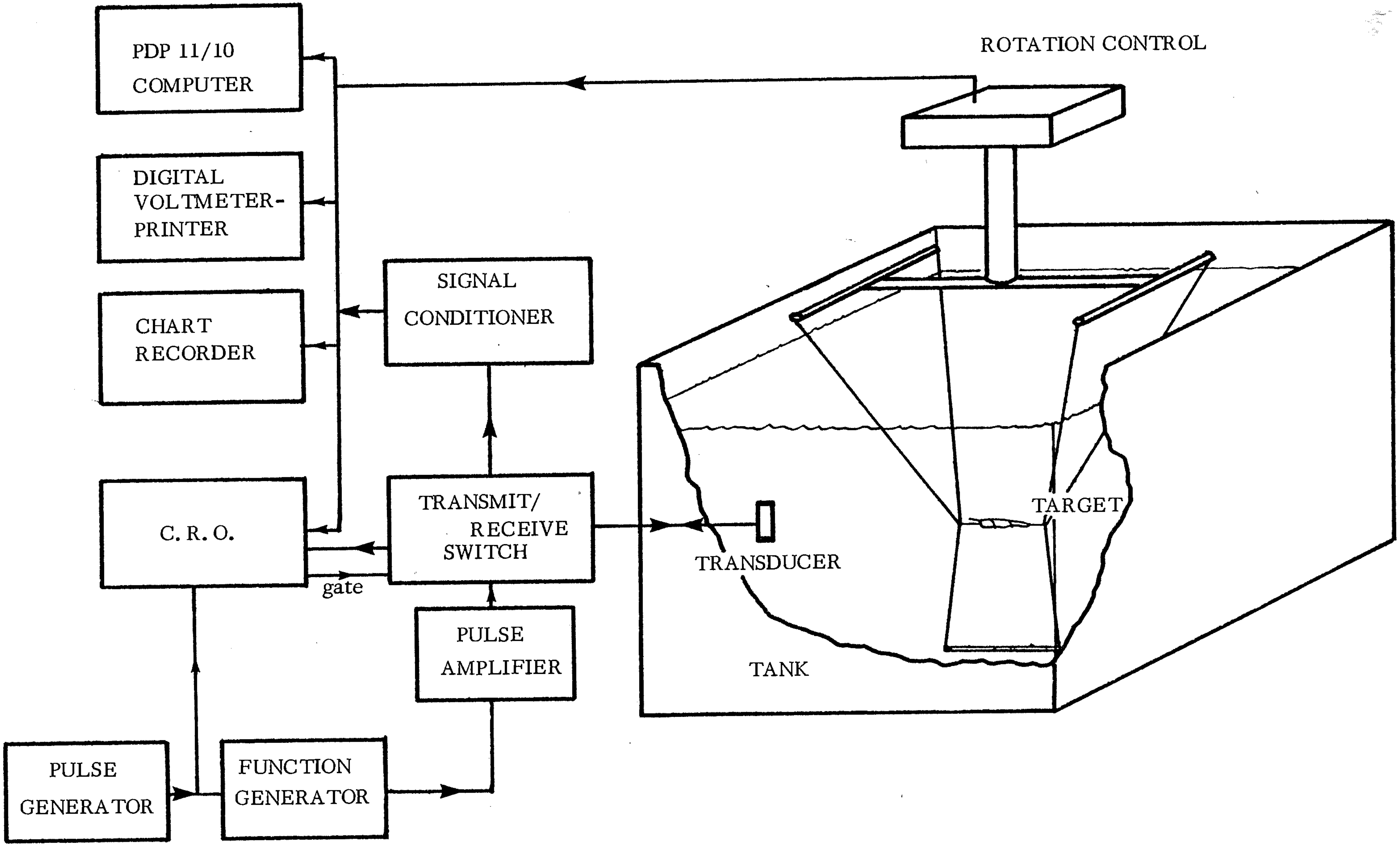

FIG. 1 MEASURING SYSTEM

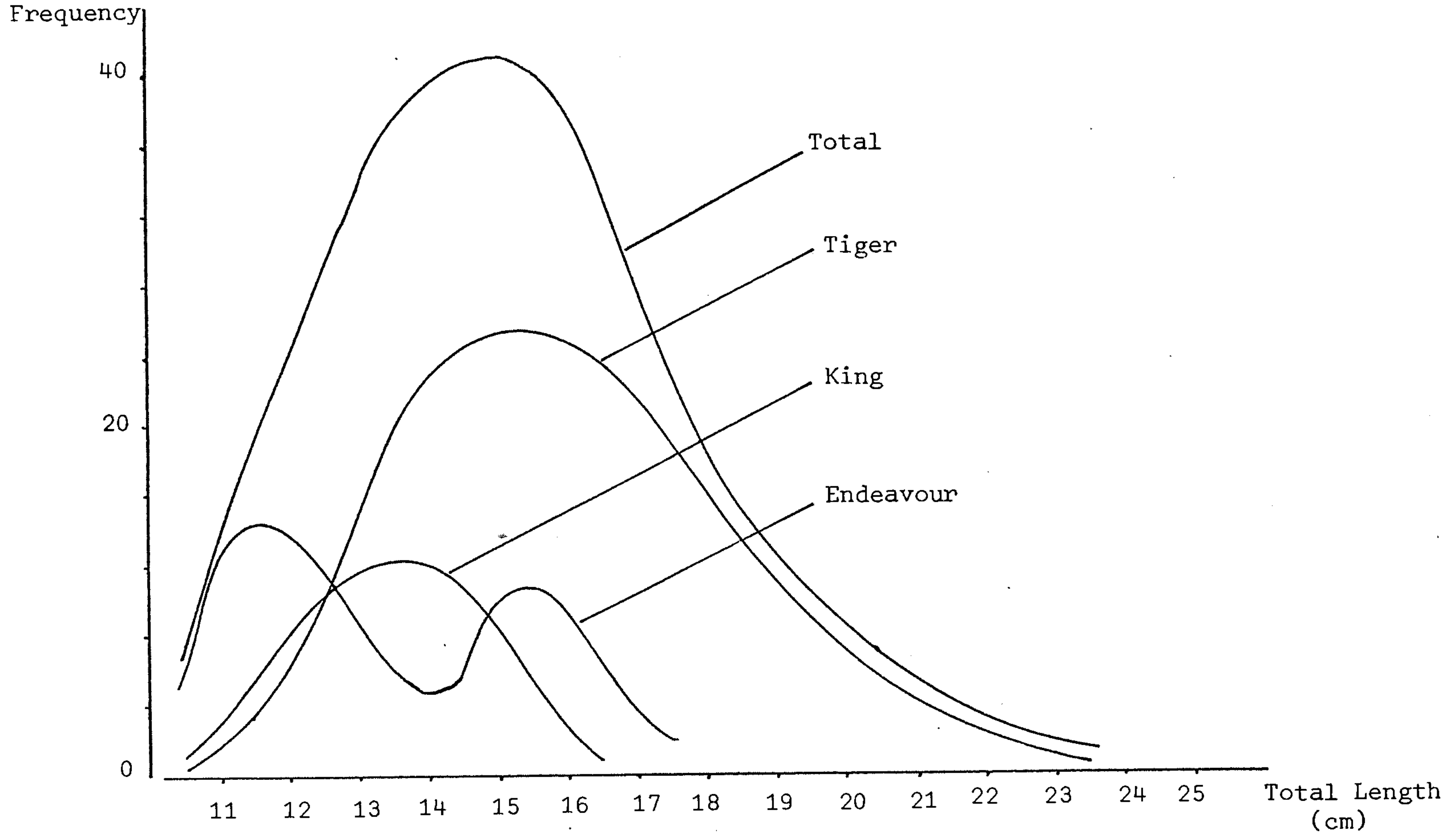

FIG. 2 - Frequency Distribution of Prawn Lengths for a Typical Trawl in the Exmouth Gulf Area.

.This information suggested that target strength measurements covering the range of prawn lengths 11 cm ⟶ 25 cm would account for most sizes of commercially useful animals encountered in Australian prawning practice.

Target strength measurements were made as outlined in the First Report (1974), on animals suspended in the fresh water filled test tank. Fresh water is commonly used in such target strength work, and offers considerable working advantages over sea water. Since, however, target animals used were directly frozen after capture and thawed out immediately prior to measurement, it was necessary to allow the prawns to stabilize in the tank for approximately four hours. This allowed the animals to come to a quasi equilibrium state with fresh water just as in the field they are in equilibrium with salt water. Once this had taken place, target strength measurements did not vary over target immersion periods of up to two days, after which variation occurred which we presently attribute to tissue degradation. Before insonation, all animals were inspected to check for bubbles forming under the exoskeleton, If formed, such bubbles were removed by manipulation of the exoskeleton segments to allow the gas to escape.

The measure of target strength used here is -

$$\underset{\text{(in dB re 1m)}}{\text{TS}} = 20 \log \frac{\text{Sound pressure at receiver due to reflections from target}}{\text{Sound pressure incident on target}} \qquad (1)$$

where the receiver is at a distance of one metre from the target.

Sound pressures were linearly related to transducer voltages from the piezoceramic transducers used throughout. The reflected signal was measured using a single transducer with combined transmit-receive functions. Incident sound pressure was measured at the target location using an identical transducer to the transmit-receive unit. Overall system calibration was checked by using the air-water interface in the tank as a reference reflector.

In general, pulses of 200 μsec duration were employed in tank tests. The reflected signal estimate was made from a 50 μsec segment gated out of the middle of the returning pulse. Test animals were rotated in pitch, roll and yaw planes while this process proceeded. Figure 3 shows the form of a typical pitch plane record. The received signal has been displaced across the oscilloscope screen during target rotation. Although the detailed angular structure varies according to which plane of rotation is employed, values of target strength may be adequately derived from all three. In what follows, pitch plane results

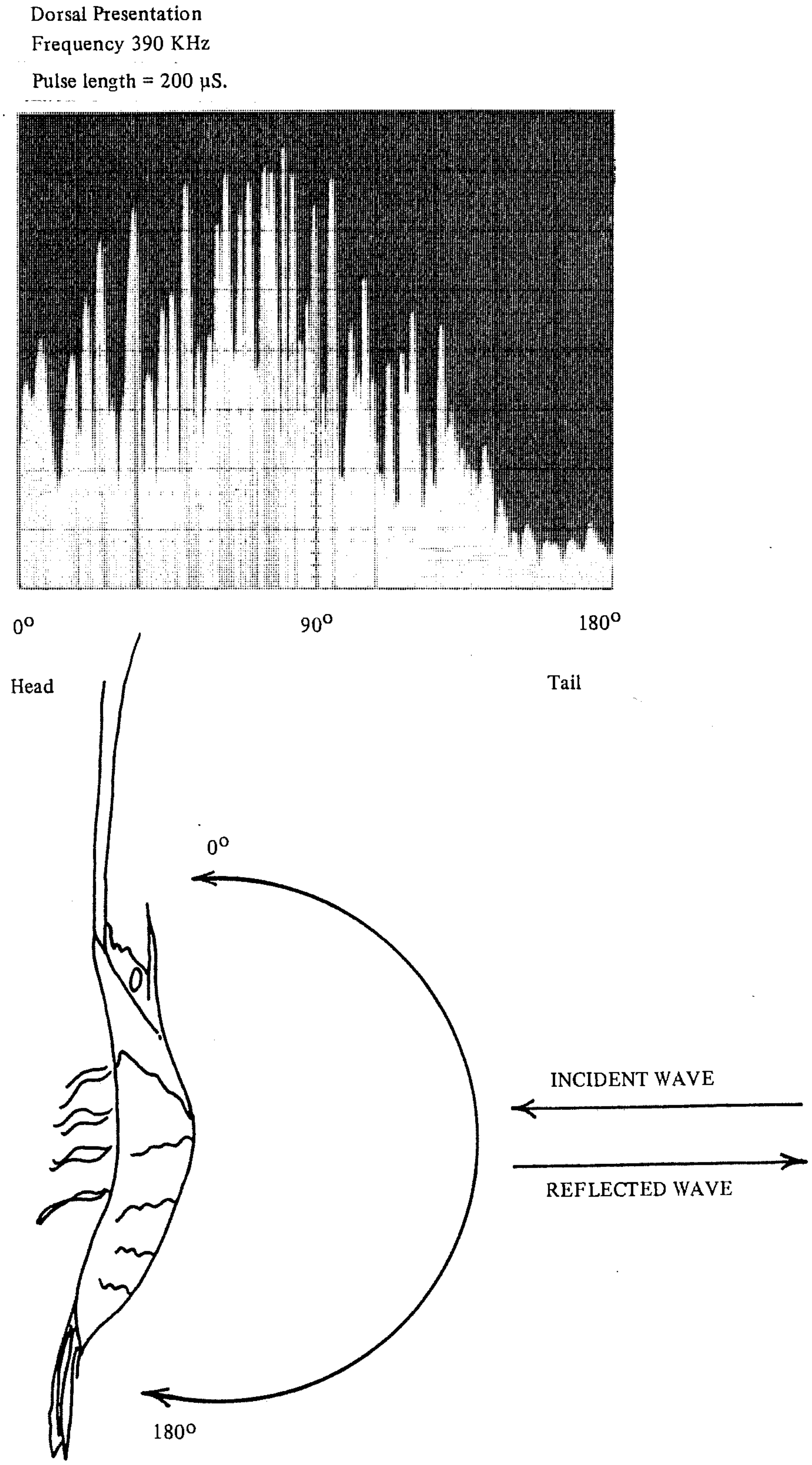

FIG. 3 - RECEIVED VOLTAGE vs ANGULAR POSITION.

are presented throughout.

Three measures were used to describe the magnitude of the received signals from records of the Figure 3 type; peak reading, average reading and average over an angular excursion of ±40° to the normal to the animal axis. Averages were at first determined graphically, and later using on-line computer processing. Figures 4 → 6 show results of target strength versus frequency of sound used for three representative animals in the length range 14 cm to 18 cm. The solid line represents in each case the form of a linear expression fitted to the data using the method of least squares. In all cases no significant dependence of target strength on sound frequency is seen. It should be noted that, even at the highest frequency used here, no significant absorption losses are applicable. Repeated experiments of this type have essentially replicated the results seen here.

The observed invariance of target strength with frequency is a conclusion of significance, representing an important factor in the choice of sounder operating frequency. Attention has been directed to the treatment of this issue in the literature, as discussed below.

The dependence of target strength on prawn length is best displayed using the largest range of lengths available. Figure 7 shows peak target strengths at 200 kHz for animals in the length range 12 cm → 25 cm. The linear relationship fitted has the form -

$$TS = 1.20L - 62 \tag{2}$$

where TS is in dB re 1 metre and L is in centimetres.

These results, showing variation of target strength with length but not frequency have been the subject of an extensive literature review. Some details are included here to consolidate the conclusions reached.

The scattering of sound from small targets depends in part on the relationship between the sound wavelength λ, and some critical dimension ℓ related to the target size. Various dimensional parameters have been used in the literature. These include the total target length, dorsal-ventral dimension, and radius of a spherical target of equivalent volume.

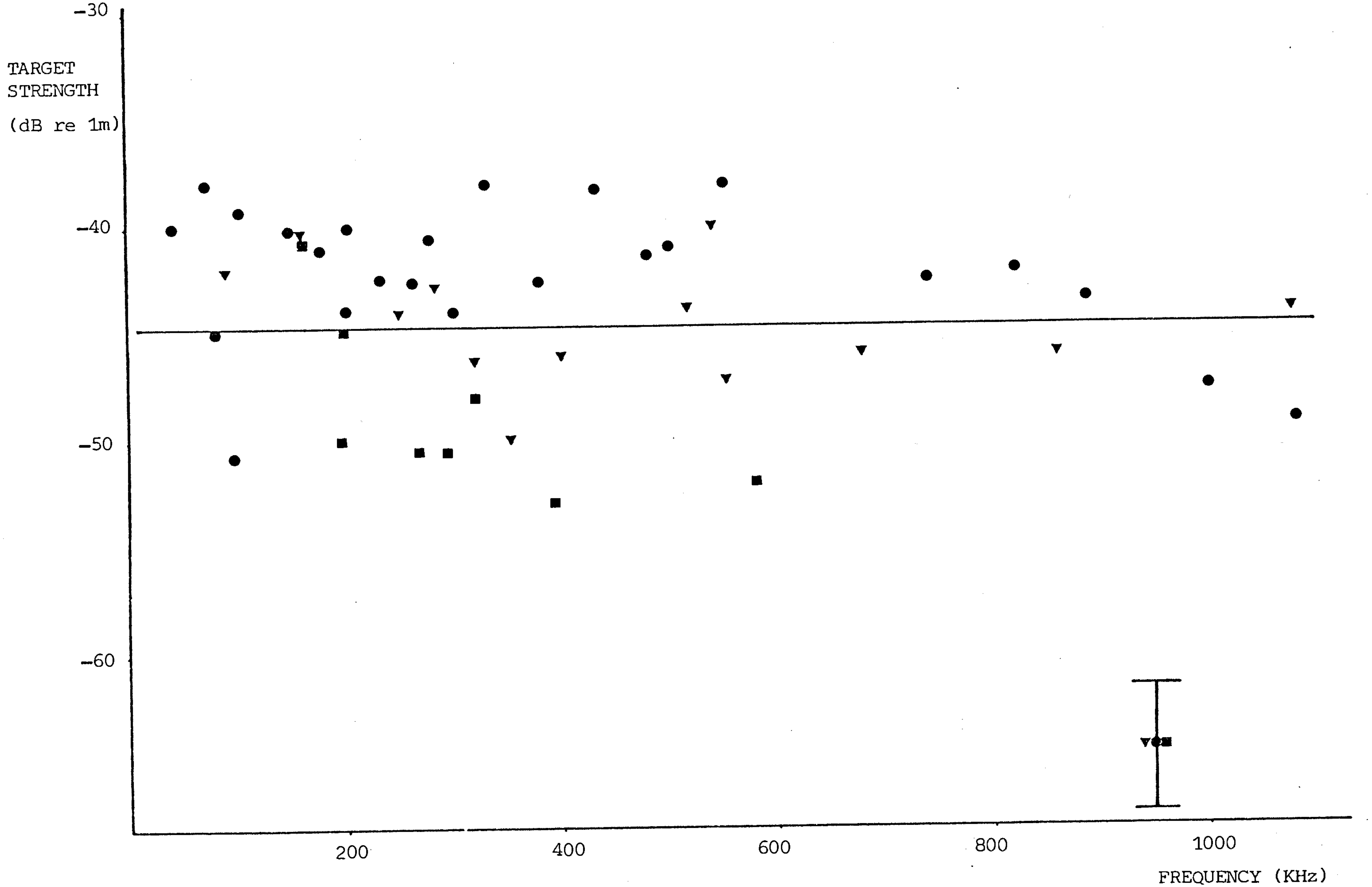

FIG. 4 Peak Target Strength Versus Frequency - Prawn

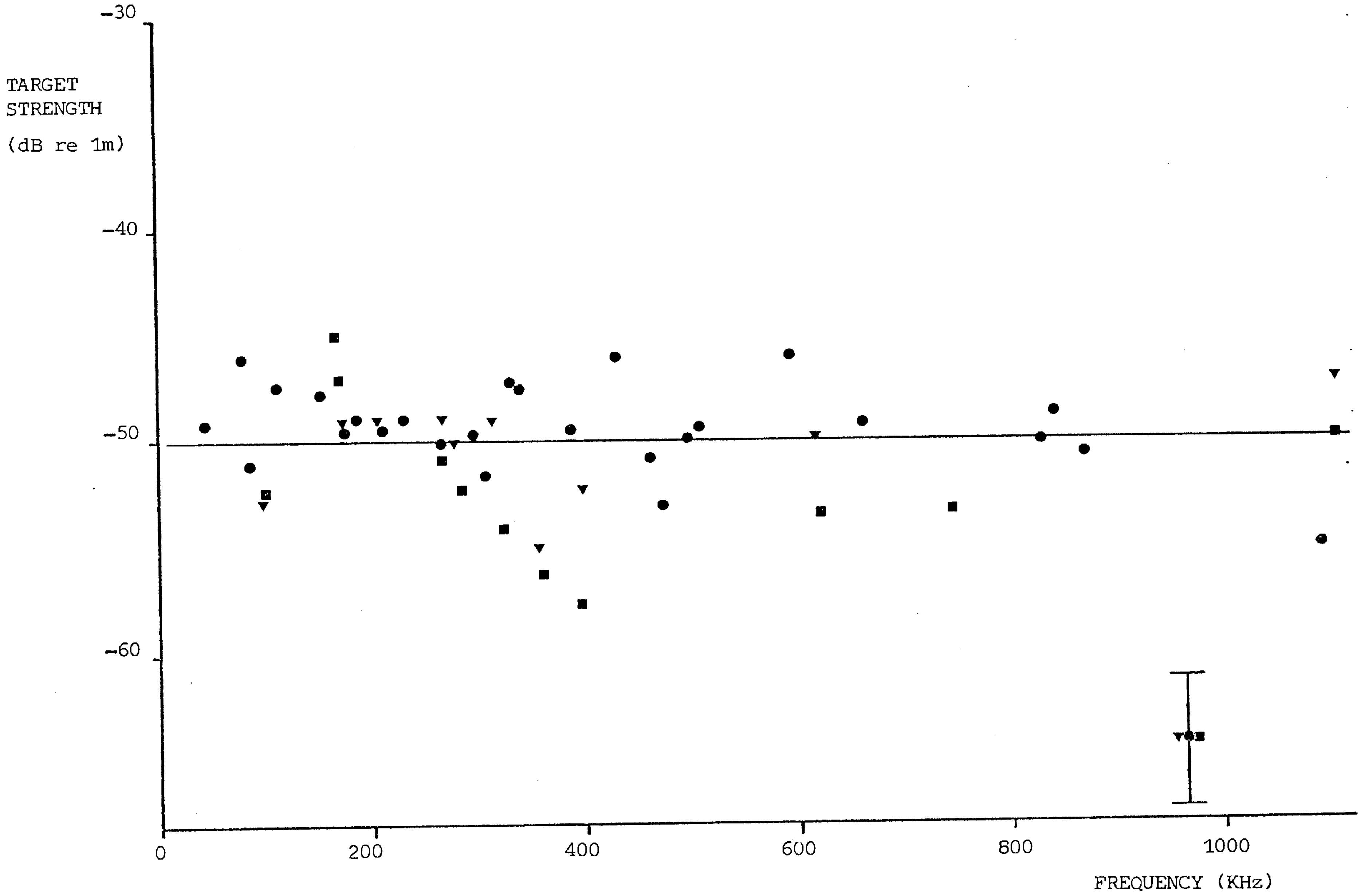

FIG. 5 Average Target Strength Versus Frequency - Prawn

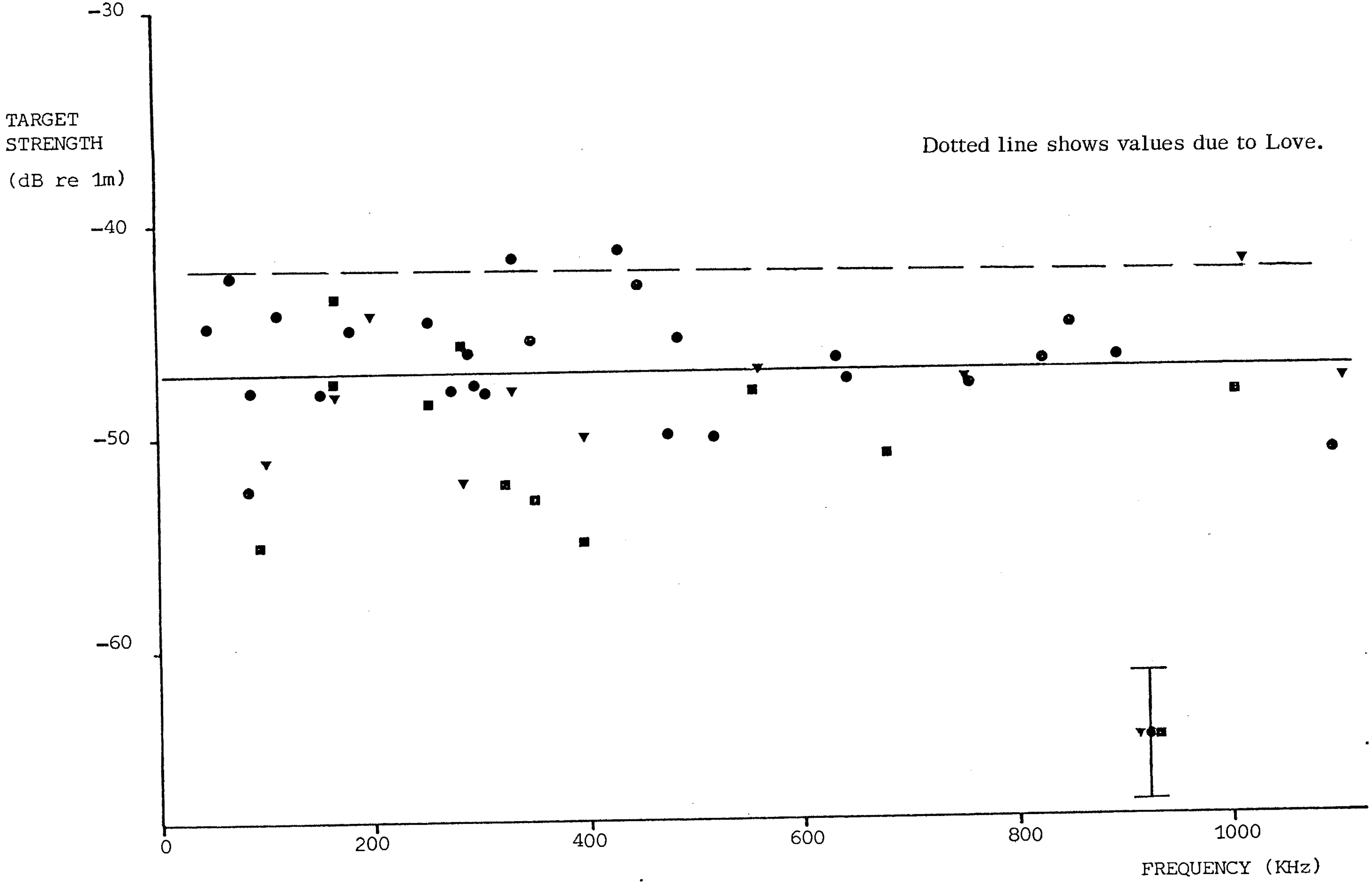

FIG. 6. Average Target Strength (±40°) Versus Frequency - Prawn

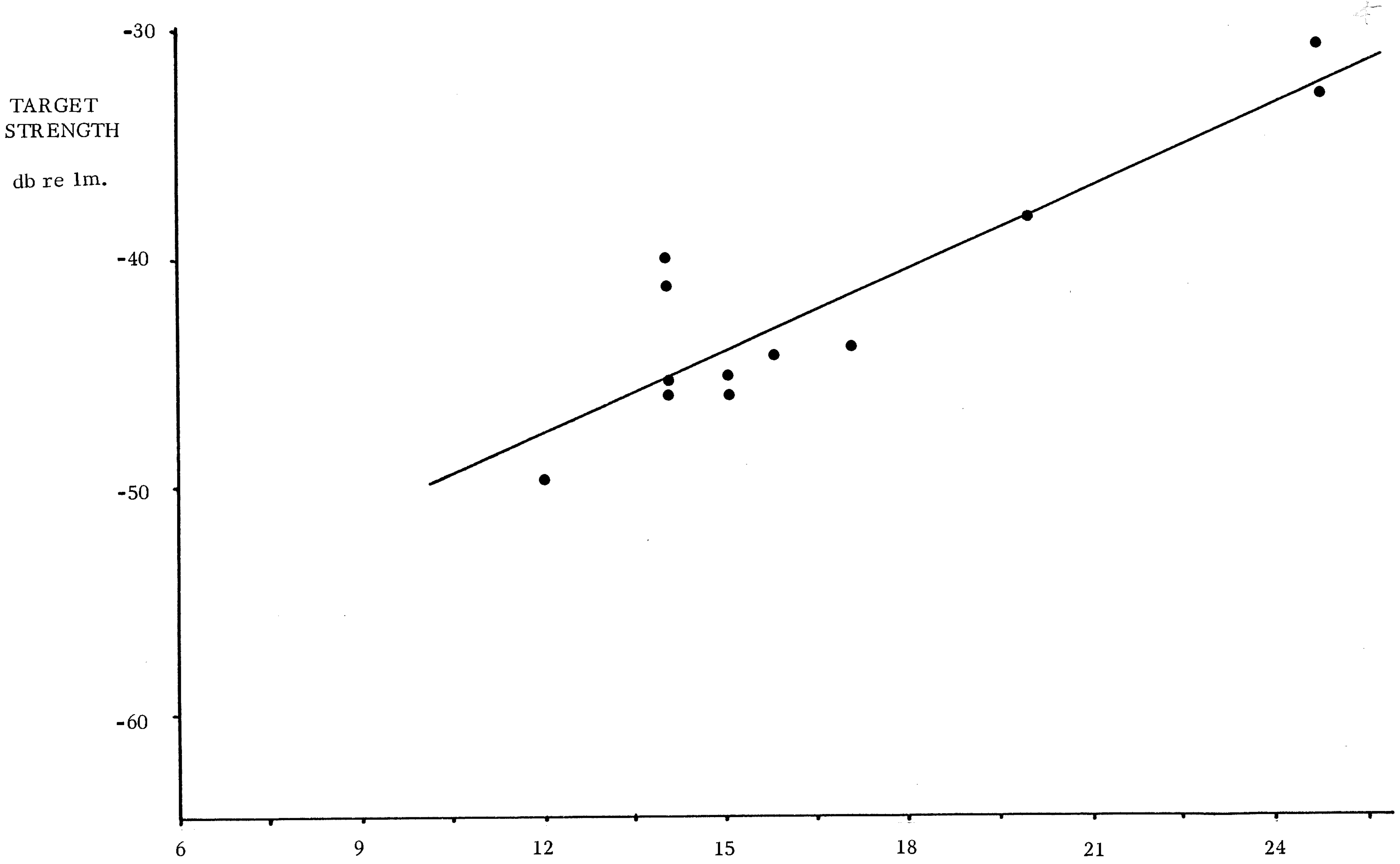

FIG. 7. TARGET STRENGTH vs LENGTH

It is common to define three scattering regions in terms of the ℓ/λ ratio. For $\ell/\lambda << 1$, backscatter increases sharply with ℓ/λ; this is the so-called Rayleigh scattering region. For ℓ/λ in the region $0.1 \rightarrow 1.0$, backscatter behaviour varies in a complex way with ℓ/λ and this is termed the intermediate region. For $\ell/\lambda > 1$, backscatter varies with ℓ/λ much less than for the Rayleigh case; this is called the geometric scattering region.

Depending on the approximation used to calculate ℓ for the target animals in the present work, most or all of the results seen in Figures 4 ⟶ 7 are in the range $\lambda \ll \ell$, i.e. the geometric region. Although it is generally recognised that in the ranges of wavelengths and target sizes of interest in fisheries, the frequency dependence of target strength is complex and difficult to establish, some predictions and measurements do appear in the literature. Haslett (1965) has proposed a universal graphical method of representing target strengths over a wide range of wavelengths and target lengths. Results presented using this method suggest that for the geometric region the target strengths of both fish swim bladders and backbones should increase by about 10 dB per decade increase in frequency. Because of the dominant role swim bladders play in echo formation from fish with these organs, some increase in whole fish target strength is expected. Haslett estimates, however, that no increase of target strength with frequency is to be expected from the fish flesh component alone. Forbes and Nakken (1972), in the well known F. A. O. handbook on fisheries acoustics, indicate for a 22.5 cm long fish target, a probable increase in geometric region target strength (here, for frequencies above approximately 200 kHz) of approximately 11 dB per decade increase in frequency.

Recently an extensive review of fish target strength measurements, due to Love (1971), has become available. By combining the results from a large number of investigators (including Haslett), Love has produced an expression for dorsal aspect target strengths, as follows -

$$TS = 19.4 \log L + 0.6 \log \lambda - 24.9 \qquad (3)$$

where L and λ are in metres.

The majority of the data used to establish this expression would appear to apply to the intermediate and geometric regions as defined above. Table 1 compares 50 kHz and 1000 kHz values of target strength, for target length L = 0.16m, derived from the present work, and from equation 3.

TABLE 1. Target Strengths - Dorsal Aspect

	50 kHz	1000 kHz
Present work, 16 cm prawn (peak values)	-45	-45
Love, 16 cm fish	-41.25	-42.03

The expression derived from Love's analysis of fish data involves a change of less than -1dB over the range 50 kHz ⟶ 1000 kHz, i.e. his target strengths in contrast to the trends suggested above, are essentially constant with frequency. Since most results in Love's survey would have had swimbladders, it is to be expected that his predicted values should exceed those for crustacea by several dB, as indicated in Table 1. These features are demonstrated in Figure 6 where the dotted line indicates the values corresponding to equation 3.

The results of the present work would appear to correlate well with the extensive review undertaken by Love for fish targets. It is therefore concluded -

> for penaeid prawns of total length 16 ± 2 cm, and for sound frequencies in the range 50 kHz ⟶ 1000 kHz, target strengths do not vary with frequency and have values of -
>
> -45 ± 5 dB re 1 m for peak returns
>
> -50 ± 5 dB for returns averaged over the pitch plane
>
> and
>
> -47 ± 5 dB for returns averaged over ±40° from the normal in the pitch plane.

The dependence of target strength on prawn length as determined in the present work is somewhat greater than that predicted by Love. Table 2 shows the target strength for lengths of 12 and 24 cm determined at 200 kHz according to Love (equation 2.3) and from the present work (equation 2.2).

TABLE 2. Target Strength Variation with Length

	12 cm	24 cm
Present work, prawn (peak values)	-47.6	-33.2
Love, fish	-44.0	-38.2

It is therefore concluded that over the range of total lengths 12 cm to 24 cm the target strengths of penaeid prawns increase by ~14 dB for frequencies in the 200 kHz region.

Further information relating target strength to animal length is presented in Chapter 4.

2.2 THE TARGET STRENGTHS OF MULTIPLE PRAWN TARGETS

Often only one target animal can be expected to be in the sounder beam at any one time and the echo received will then be related to the target strength of an individual animal. In banana prawn trawling, the dense concentrations of animals present in schools makes it likely that many targets will be in the beam simultaneously and further, that more than one will be present in some range slices of the beam. Here the term range slice applies to a section of the beam cone from which target returns necessarily mingle and overlap. Figure 8 represents this diagramatically. The thickness of the range slices for a pulse of length τ, is given by $\frac{c\,\tau}{2}$. In the case of a Koden SRM 681 sounder, with $\tau = 100\,\mu s$, the range slice thickness is 7.5 cm. If several targets were to be present within the range slice volume shown shaded in Figure 8, their returning echoes would interfere and add together to present a composite signal to the sounder. It seems clear that this behaviour is encountered when schooling species, such as banana prawns or certain trash fish species are encountered. Slide 2 shows the echo record taken on a Koden SRM 681 sounder in the Spencers Gulf fishery in January 1977. Details of slide interpretation are in Appendix 1. Try net returns taken during this segment of the trawl clearly identified the species responsible for the major echo trace seen as leatherjacket fish of 10 - 15 cm length. Detailed examination of the record suggests that most echoes from the school arose from multiple scatterers within range slices in the lower half of the water column. Slide 3 shows a record segment taken when light hauls of prawns were made. Even in this case the elongate form of several chart marks suggests that some of the relatively few targets were grouped close together, although most marks can be attributed to only one target within the appropriate range slice. Slide 4 shows a representative chart record segment taken during a field trip in the northern area of the Spencers Gulf fishery in March 1977. Here heavy catches (often 10 lb/min. from two 12 fathom nets) largely of western king prawn were being made in the virtual absence of trash fish. The near-bottom echo marks seen in Slide 4 may thus be attributed to the prawn population and the form of this record strongly suggests that multiple targets existed within a number of near-bottom range slices.

Thus, multiple targets as defined here, would appear to apply to some aspects of Australian trawling practice and the relationship between scatterer density and

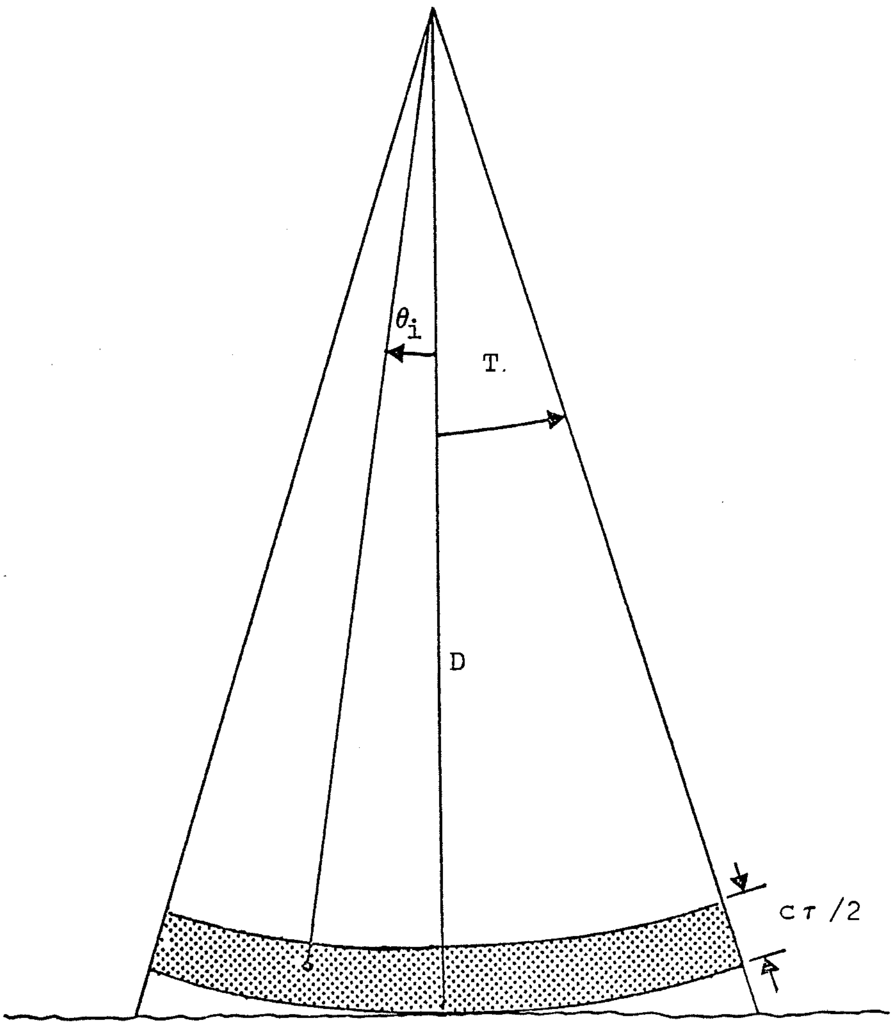

FIG. 8. BEAM PARAMETERS.

resultant target strength is therefore of importance. Two approaches have been used in the present study to study this relationship; jetty tests and mathematical modelling.

The Second Report (1975) on the project described the establishment of a jetty facility in the Fremantle fishing boat harbour. Figure 9 shows the form of the facility. As part of the work described in Chapter 4 the peak target strength measured from randomised arrays of prawns mounted as shown was measured for $\theta = 0°$. Figure 10 shows a plot of the peak echo amplitudes received versus $\sqrt{N}$ from assemblies of N prawns for N in the range 1 → 20. The peak echoes were determined from a full traverse of the sounder-head over the array and would be expected (see e.g. Forbes and Nakken (1972)) to be proportional to the square root of the number of targets (i.e. as shown by the full line in Figure 10). From the data presented it is concluded that -

> the peak target strengths of an assembly of prawns in the source range slice is approximately proportional to the square root of the number of animals in the assembly.

This conclusion needs further examination in the case where, as in sounding for prawns, target echoes often approach the detection threshold of the sounding system. In this case, cognisance must be taken of the statistical nature of echo formation.

2.3 THE STATISTICAL NATURE OF ECHO FORMATION

The amplitude of backscatter from a single prawn target varies considerably with animal orientation, as shown in Figure 3. It is clear that large echoes occur for only a few specific orientations, and that the bulk of the echo returns have amplitudes considerably less than the maximum. This feature is illustrated well by Figure 11 which shows results taken from a single prawn in dorsal aspect, over an angular spread of ±50° about the normal to the prawn axis. The abscissa of Figure 11 shows the backscattered echo amplitude in arbitrary units and the ordinate shows the number of echoes for each amplitude. The two full lines are data from two scans across the same animal placed in slightly different attitudes. The preponderance of low returns (in this case, under three units in magnitude) is clear. The nature of the echo formation process suggests that these curves should have the form of the so-called Rayleigh distribution. This assumption has been adopted in a recent paper by Peterson et al. (1976) dealing with a new

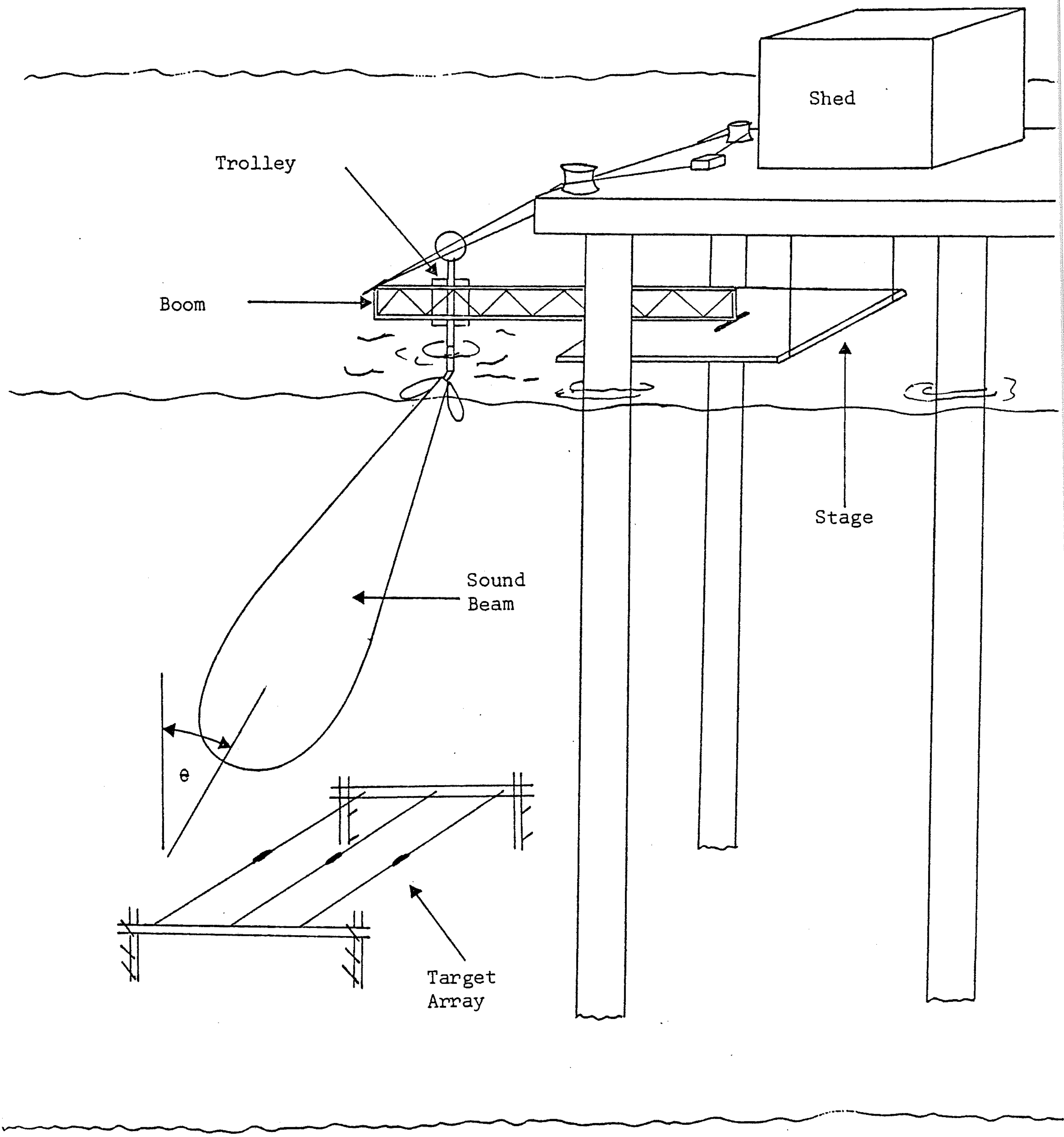

FIG. 9 - Main Features of Jetty Facility.

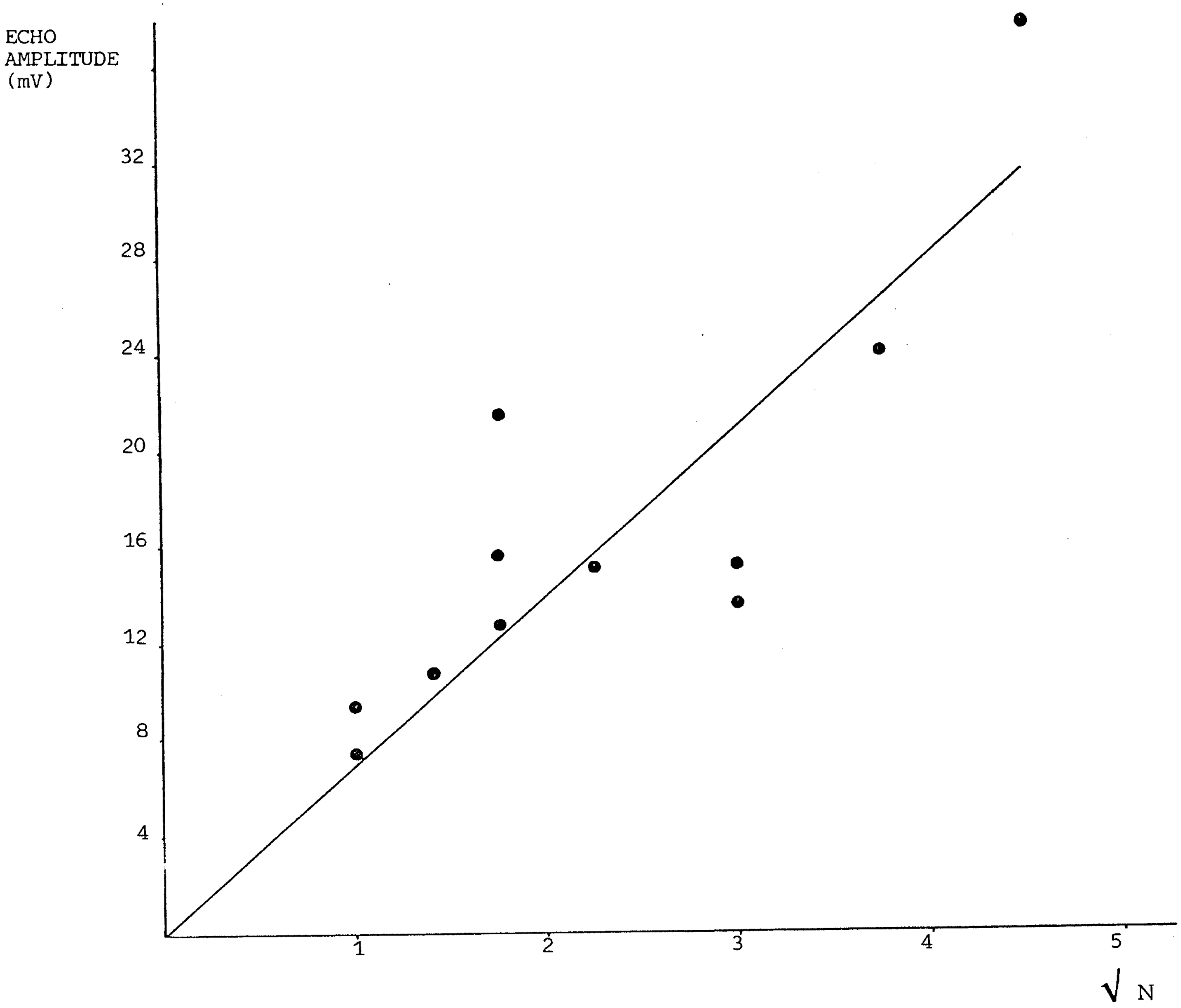

FIG. 10 - Echo Amplitude versus $\sqrt{N}$

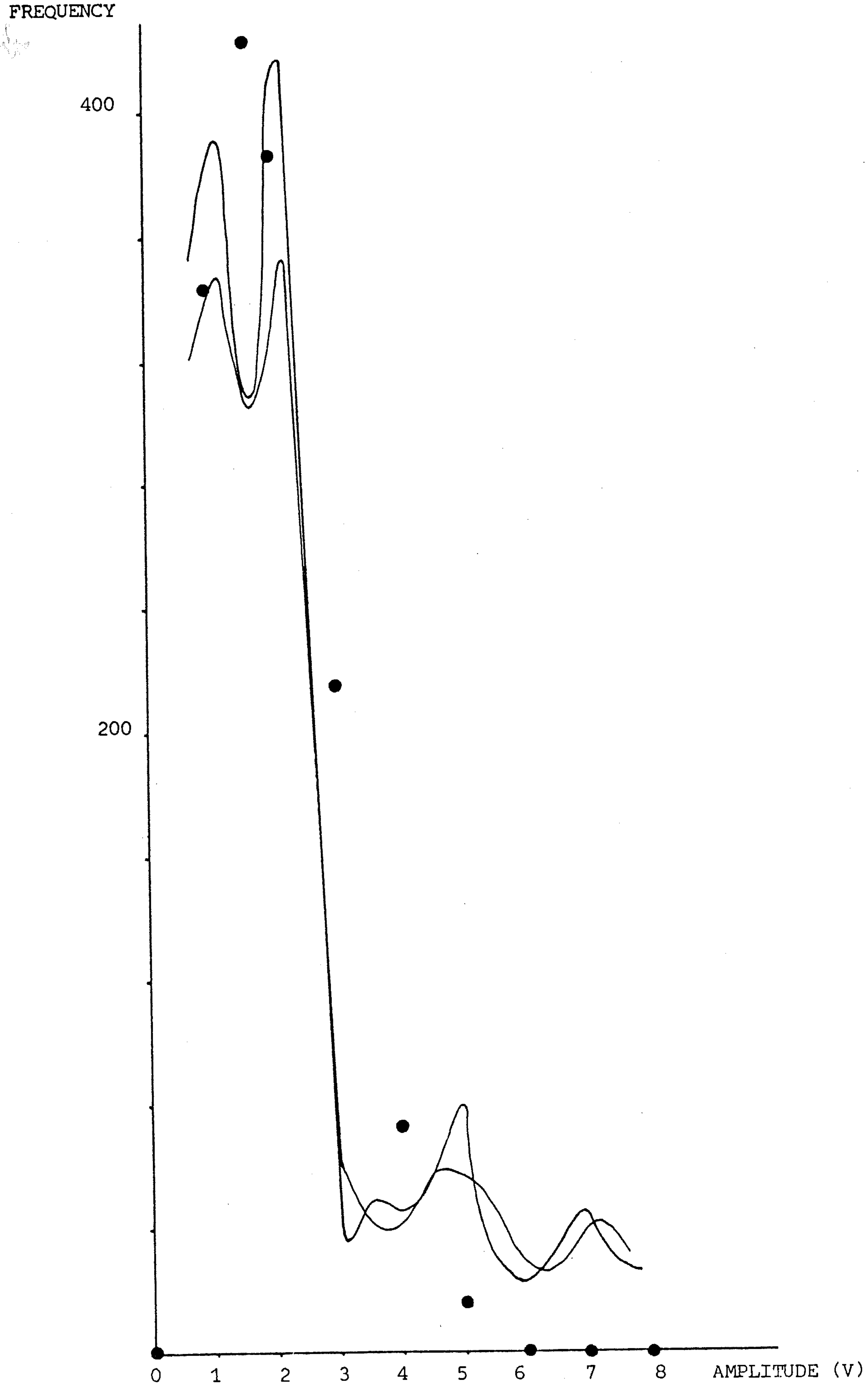

FIG. 11 Frequency Distribution of Backscatter from -50° to 50° with a Theoretical Rayleigh Distribution Superimposed.

method of interpreting echo sounder returns. A suitable Rayleigh distribution has been fitted to the data in Figure 11; its form is indicated by the dotted outline. The Rayleigh distribution fits the low amplitude data fairly well, but does underestimate the number of high level returns, in this case.

Another factor which influences the echo received from a prawn at a given range is the position of the animal within the range slice, i.e., relative to the beam axis, as described by the angle θ_i in Figure 8. As θ_i increases the echo received from the target will fluctuate according to the directivity of the transducer in use.

Finally, the range D (as shown in Figure 8) influences the echo received from the target because of absorption and beam spreading in both transmission and reception. If more than one target is in the range slice at once, the echoes from each target add incoherently to produce the signal at the receiver. Sofoulis (1977) has used a mathematical model to simulate these various effects. Specifically, for N targets in a range slice at range D, the model -

(i) computes a target strength for each target, from a Rayleigh distribution of amplitudes with an average value equivalent to that found in Section 2.1 above,

(ii) locates the N targets randomly within the range slice, and computes the directivity effects on the echo returns from each target,

(iii) adds the resultant amplitudes from each of the N targets incoherently (i.e., randomly with respect to phase) at the receiving transducer, thus obtaining the echo return value expected from one insonification of N targets at a range slice $\frac{c\tau}{2}$ thick located at range D,

(iv) this process is then repeated a number of times and the resulting signals are sorted according to amplitudes.

The following results were computed for the case appropriate to a Koden SRM 681 sounder in a representative water depth, giving D = 20 metres and insonifying targets with average target strength of -47 dB re 1 metre. Values of θ_i were allowed for up to $\theta_i = T = 10.5°$, which ensures that the central and first side lobes of the Koden transducer pattern were included. The transducer is circular, with diameter 9.3 cm, and operates at 200 kHz. The pulse length of the Koden machine is 100 μsec, so that $\frac{c\tau}{2} = 7.5$ cm as before. Figure 12 shows the model result for N = 1 and 1000 iterations of the program, corresponding to 1000 insonifications in the field. The effective target strength values shown are computed as described above and, in addition, include corrections for

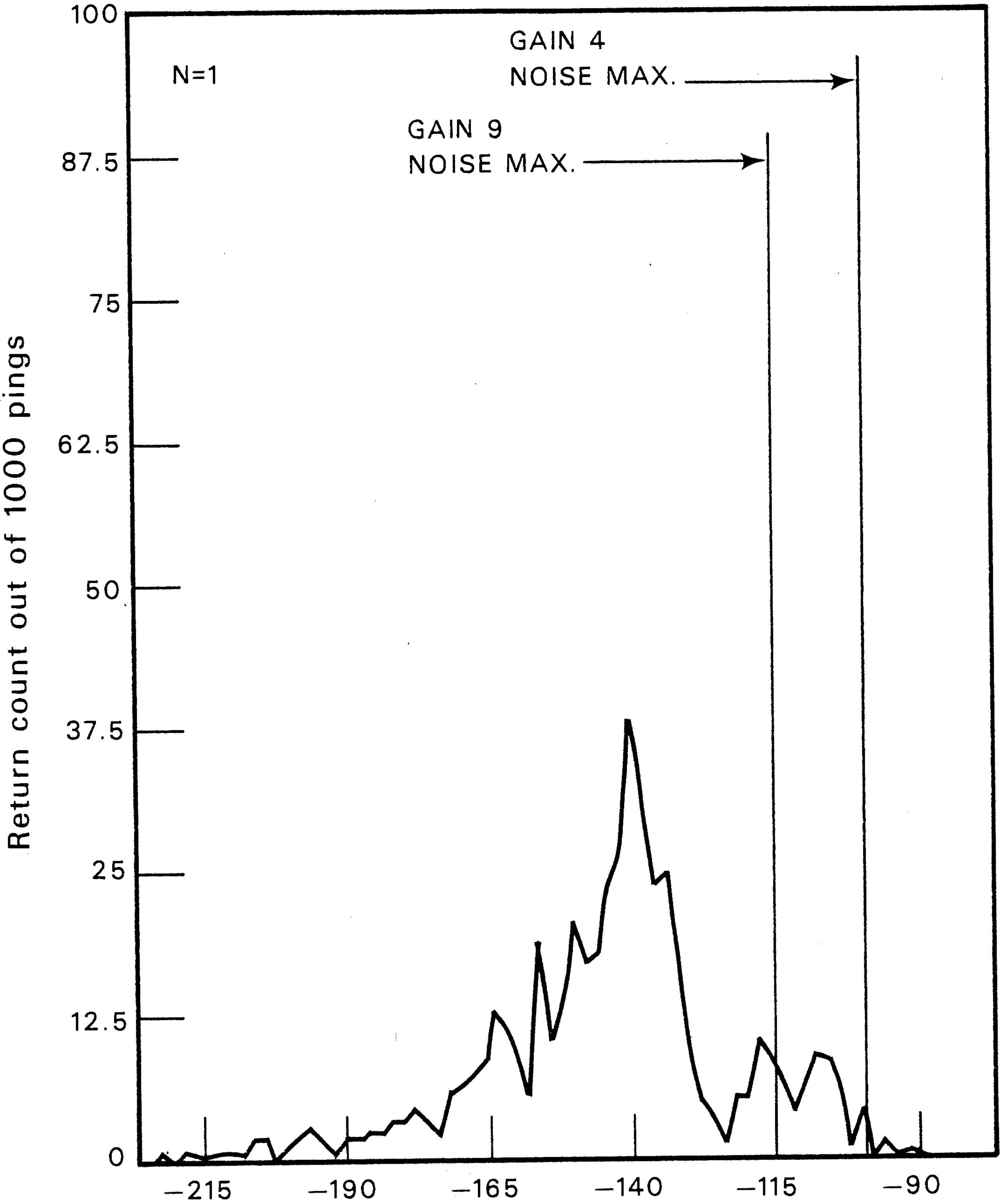

FIG. 12 Effective target strength @ 1 M. in dB - Filt = 2

spreading and absorption losses. The resultant figure can be regarded as the target strength of a notional target at a range of 1 metre, which would give the received echo amplitude. The echoes are sorted using a running mean filter with a 2 dB window width.

The larger echoes, in the -90 dB to -120 dB region, arise primarily from targets in the main lobe, while most echoes fall in the region -120 dB to -190 dB, which is dominated by side lobe returns. The reason for such a large proportion of returns being in this region is the combination of low response in the side lobes and the high probability of a target being in the side lobes.

In order for the target represented in Figure 12 to be detected, sufficient of the echo returns must be received by the sounder during target contact to provide a chart mark visible to the sounder operator. Further, such echoes must have amplitudes in excess of the ambient noise associated with the appropriate range slice. Thus ambient noise and the number of insonifications of the target both emerge as significant parameters in target detection.

The effective ambient noise levels appropriate to the prawning industry certainly include components due to volume reverberation, i.e., scattered sound from other species in the water column. It will be useful, however, to leave discussion of echoes from small fish, crabs, etc. until Section 3.2 and here consider the noise which arises when no other species longer than a few centimetres are present, i.e., when the echo returns and trawl results show a relatively "clean" area.

Figure 13, taken from Albers (1965) shows measured deep-water ambient noise levels for various sea states. These apply to the region 1 → 24 kHz and are extrapolated above 24 kHz in Figure 13. Mellen (1952) has proposed that a noise component exists associated with thermal effects in the ocean. This is included in Figure 13 where it is seen that the extrapolation of experimental curves (-5 dB/octave) shows intersection with the thermal noise curve (+6 dB/octave) between 50 kHz and 200 kHz, depending on sea state. It should be noted that these estimates apply to deep-water operation using omnidirectional hydrophones. Albers cites a working rule established by British scientists on the basis of observations in deep and shallow water. This proposes that the noise level in shallow water for a given sea state is 9 dB higher than the corresponding deep-water value. It is likely, however, that this estimate has been derived from low

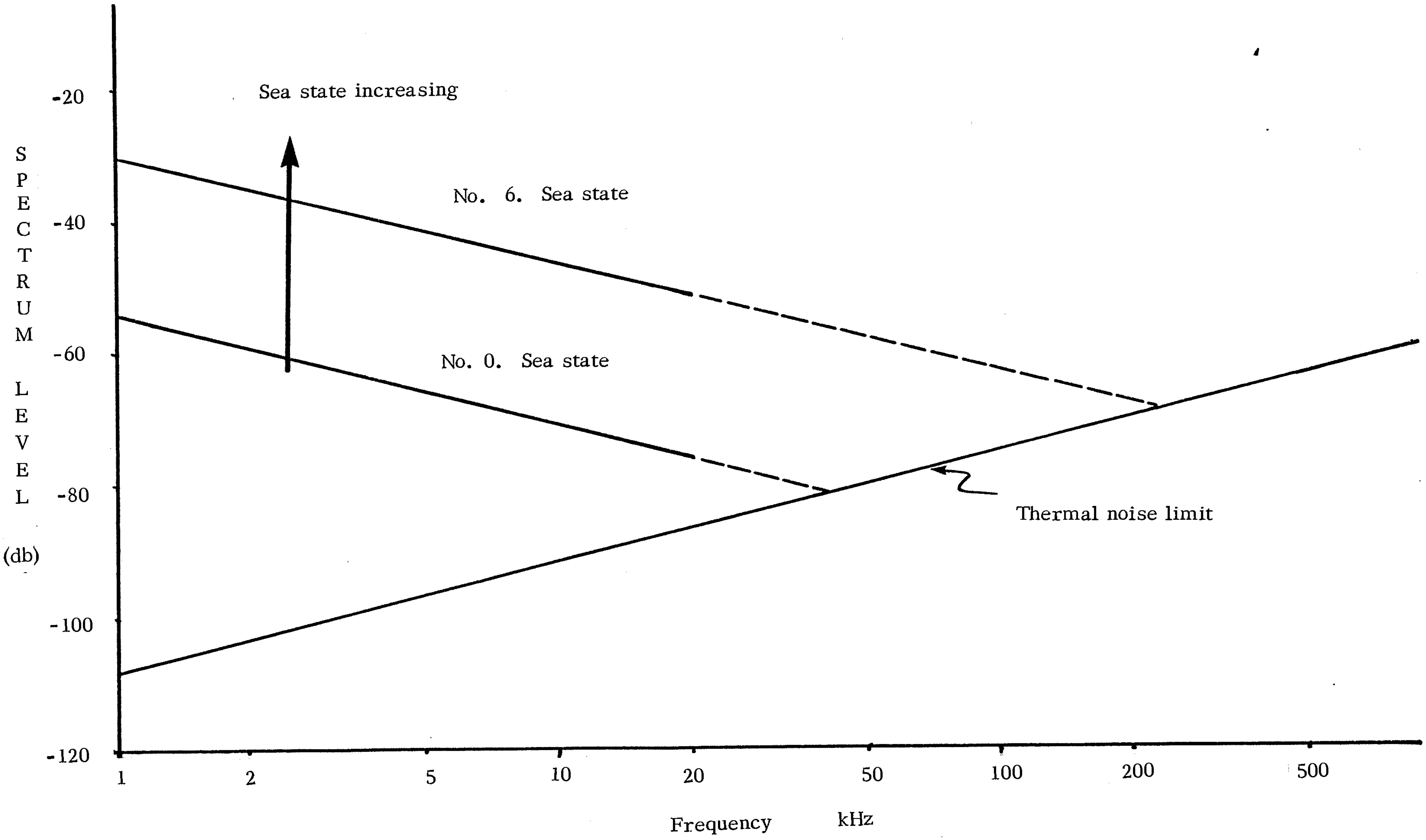

FIG. 13. DEEP WATER AMBIENT NOISE LEVELS.
(after Albers, 1965)

frequency data. In general, the nature of oceanic noise above about 30 kHz is not well understood and remains an active area of inquiry. It is presently necessary, as a working hypothesis, to adopt the estimates noted above, which place the sea state - thermal noise intersection frequencies, and hence the noise minima into the range 150 kHz → 700 kHz.

Measurements on a Koden SRM 681 echo sounder in the laboratory indicate that the self noise of this unit is negligible compared to the background noise level experienced on a working trawler. Although much trawler noise is well below the operating frequency range of the Koden, enough high frequency energy is generated from within the vessel and/or from within the water flow regime past the hydrophone, to affect the sounder. On a number of trawlers, the background noise level, as indicated by the amplifier gain setting at which the chart became heavily marked due to noise, was seen to vary with vessel speed thus revealing the presence of a noise component associated with trawler machinery and/or movement, which was in excess of the ambient sea noise.

Many biological sources can be expected to have noise outputs restricted to the audio range of frequencies. However, at least one important source, the snapping shrimp, produces sounds which have frequency components as high as 200 kHz (Cato and Ranicar, private communication). A densely populated bed of these animals could be expected to register noise signals on a nearby sounder, but the effect would be relatively localised.

Although a guide to expected ambient sea noise behaviour can be derived from the literature, the important noise inputs from an operating trawler, which may often dominate background noise levels, can only be estimated by empirical means. A detailed study of trawler noise sources would constitute a major study in itself and was not attempted in the present work. Some measure of overall noise levels was obtained, however, by noting the amplifier gains associated with noise level chart markings in the field using a Koden sounder, and comparing these results with calibrated laboratory measurements on the instrument.

Slide 3 shows a typical low target density Koden record. The upper few metres of the main display show heavy marking associated with, in particular, air bubbles generated by the breaking sea surface. The major area of interest, the near-bottom region, is relatively unmarked. Increasing the amplifier gain setting would eventually mark the whole record including that section corresponding to the near-bottom. This gain setting is an approximate measure of the background noise level which now includes inputs from sea state, thermal and any biological sources as well as the volume reverberation associated with small scattering centres such as plankton and detritus. The gain setting on the Koden is modified by the STC (time varied gain) and White Line controls. We presently assume both controls to be turned off and consider that heavy noise marking appears on the 20 metre section of the chart for gain settings of four (heavy noise) and nine (very light noise). Field trip experimentation suggests that these gain settings are an approximate guide to commonly experienced field conditions.

Maximum chart marking on the Koden occurs when approximately 12 volts is delivered to the chart stylii. Laboratory tests show that this signal would be provided by a target of target strength of -119 dB situated one metre from the transducer when the sounder gain control was set to maximum. After allowing for spreading and absorption losses calculation shows that a -64 dB target at 20 metre range would again give maximum chart marking on maximum gain. Larger targets are required to give maximum chart marking as the gain control is decreased as shown in Table 3.

TABLE 3. Target Strengths to Give Maximum Chart Marking (12 volts to Stylii)

Gain Control Setting	Full Gain	Gain 9	Gain 4
Minimum target at 1 m range (i. e., equivalent noise level)	-119	-116	-100
Minimum target at 20 m range (to give equivalent noise level)	-64	-61	-45

These figures give an approximate measure of the range of noise levels experienced in practice. For a depth of 20 m, noise which marks the chart heavily on gain setting 4 is equivalent to that which would be returned from a target of target strength -45 dB, situated at 20 m. Thus, against such a noise background, a prawn target would be difficult to resolve. If, however, the background noise only became apparent on the chart at gain setting 9, because this level is only equivalent to that returned from -61 dB targets, a prawn would be discernible if it were located near the beam centre and able to return some moderate-to-high amplitude returns. Thus, even when the effective target strength ratio prawn/noise is favourable, detection is dependent on a relatively few high amplitude returns, as shown in Figure 12 for N = 1.

Figure 14 shows the computed results for 1000 pings and N = 15 targets, i.e., when the prawn density is such that 15 targets are in the range slice at D = 20 m, at any one time. The distribution of amplitudes now extends over a much smaller range and the main and side lobe contributions have now merged to a considerable extent. These trends are a reflection of the increasing N value alone, so that in principle the shape of the distributions seen in Figures 12 and 14 can be used to estimate the number of scatterers in the range slice. Such an estimate would not require knowledge of the target strength of the scattering species. This topic is receiving further attention and is also the subject of research at the Scripps Institution of Oceanography, in California.

The number of ping returns exceeding both the "gain 4" and "gain 9" noise maxima when N = 15 is clearly much greater than for the N = 1 case. Thus, in a field situation, the probability of a high amplitude return increases with the number of scatterers, yielding, on average, the $\sqrt{N}$ dependence determined in Section 2.2.

Repeated calculations using different sets of random numbers to implement the program have shown little variation in the form of Figures 12 and 14. Calculations for N= 3, 30 and 50 have also been carried out and Table 4 gives the percent of returns exceeding the two noise levels for the various N values. In each case, the computed values have been derived from six 1000 ping computations, i.e., from a total of 6000 pings. These values approximate to the probability P that a given return will exceed the stated noise level.

TABLE 4. Percentage of Return Echoes Exceeding Noise Thresholds. D = 20 m.

Number N of Targets in Range Slice	% Exceeding Noise Level		Target Density Number/metre^3
	Gain 4 Noise	Gain 9 Noise	
1	0.38	10.0	0.32
3	1.23	26.3	0.95
9	5.20	58.5	2.84
15	10.30	75.6	4.74
30	24.30	92.2	9.48
50	40.40	96.9	15.79

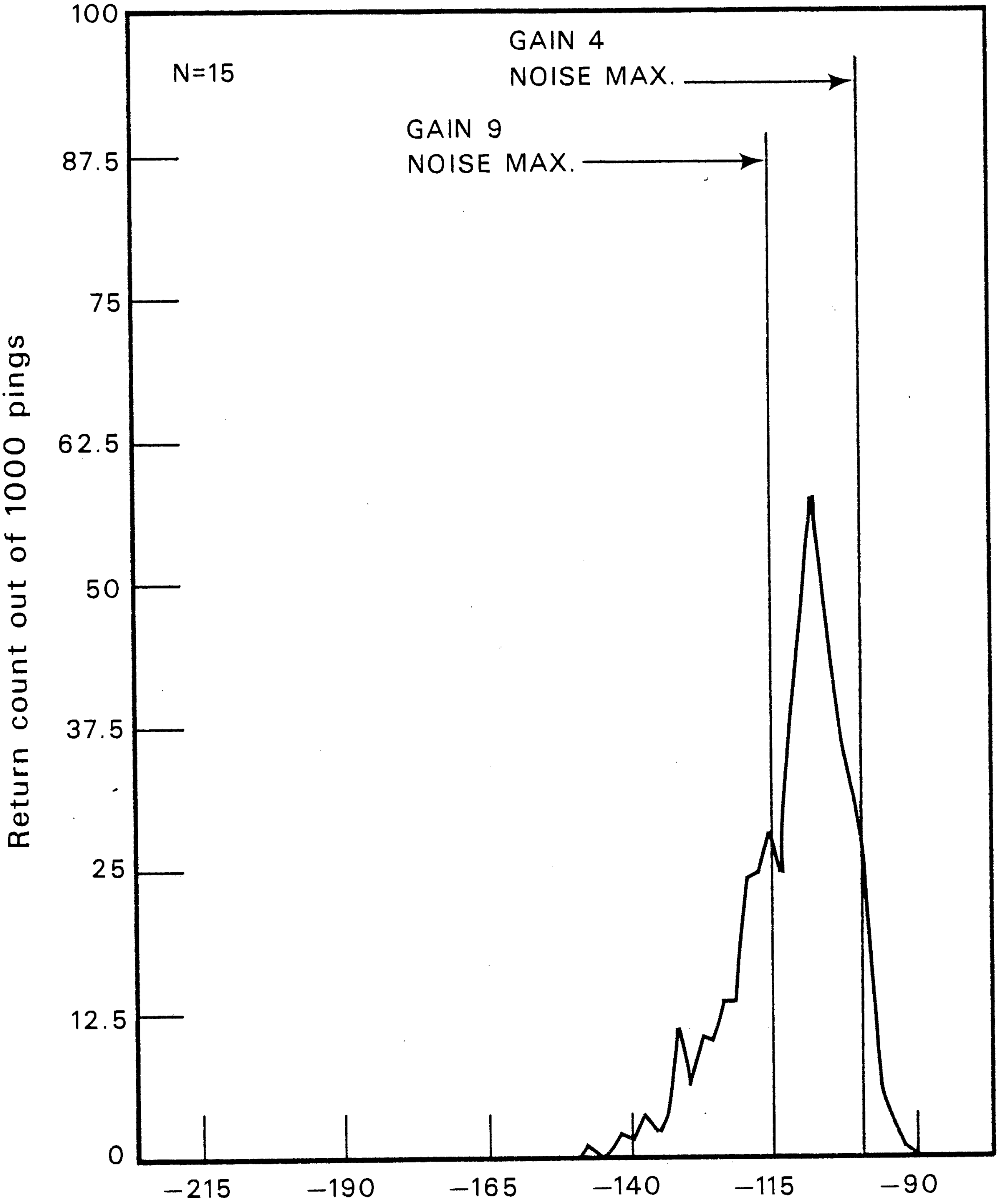

FIG. 14 Effective target strength @ 1 M. in dB - Filt = 2

Thus, the detectibility of a representative penaeid prawn, of average target strength -47 dB, at a depth of 20 m and using a Koden sounder, depends critically on the overall noise regime. For low noise levels, a prawn situated within the main or first side lobes of the beam pattern has a 10% chance of returning a backscattered signal in excess of noise. This likelihood is clearly chiefly associated with main lobe returns. For high noise levels, a very small proportion of returns, even from the main lobe, are in excess of the maximum noise and target detectibility is severely reduced.

In order to relate the probabilities listed in Table 4 to overall detection efficiencies, it is necessary to estimate two parameters affecting chart marking. Firstly, an estimate is required of the minimal signal input which will produce visible chart marking. Secondly this must be compared with likely signal regimes expected in the working environment.

For present purposes we define a parameter termed "detection efficiency" such that -

$$\text{Detection Efficiency (DE)} = \frac{\text{Number of Returns in Excess of Noise}}{\text{Number of Returns to Provide Visible Chart Marking}} \qquad (4)$$

While this expression does not account for all variables involved, it is clear that, for appropriate echo returns, a DE value less than unity corresponds to a target magnitude and/or location which are below the detection threshold. Conversely, DE values greatly in excess of unity mean that the targets can be expected to mark clearly.

Equation 2.4 can be expanded -

$$\text{DE} = \frac{\text{Pulse Rate (PR)} \times \text{Duration of Target in Beam (TB)} \times \text{Probability of Return Exceeding Noise (P)}}{\text{Number of Returns Required to Provide Visible Chart Marking (NV)}} \qquad (5)$$

where -

$$\text{TB} = \frac{\text{Mean "Path Through Beam" Length}}{\text{Boat Speed}} \qquad (6)$$

In what follows, the performance of the Koden sounder is discussed in terms of these relationships.

2.4 THE DETECTION EFFICIENCY OF A KODEN SOUNDER

The size and clarity of an echo sounder chart marking from an isolated target depends on the magnitude and duration of the echo return from the target and the signal requirements of the sounder display system. The echo return may be made up of one or more pulses, depending on how many complete insonifications strike the target while a given favourable ship-target configuration is maintained. In order to assess the chart marking characteristics of the Koden SRM 681 sounder an electronic echo-return simulator was built in the WAIT laboratory. This enables trains of pulses to be generated and fed into the Koden circuitry in order to simulate various echo returns. Figure 15 shows an example of the pulse train generated. Here a number $m = 4$ consecutive $100\,\mu$sec pulses, of 200 kHz voltage oscillations are depicted. The amplitude, 12 volts, represents the saturation voltage of the Koden wet-paper system. Thus, Figure 15 represents the echo return from a target which permitted four consecutive insonations to take place before the boat-target spacing was varied by target or boat movement. Figure 15 also simulates the situation when the noise level is sufficiently low that the echo return may be boosted to saturation by the sounder gain control without apparent noise amplification. Slide 5 shows the chart markings produced on the Koden paper by various pulse trains, for $m = 10$, 5, 2 and 1 and for signal amplitudes equivalent to saturation and half saturation. The markings under R were produced by $m = 1$ signals subject to a simulated random perturbation of boat-target separation comparable to that to be expected in rough weather.

Slide 6 shows results for $m = 5$ and saturation signals. The dark trace is a simulated bottom echo and the effect of boat movement due to regular wave motion and wave plus random perturbations has also been added. This simulates the echo return to be expected on main scale operation, i.e., not on bottom lock. Slide 7 shows the result for the $m = 1$ case. Here the trace is barely visible even with a saturating signal. In Slide 8, which uses quarter saturated signals for which $m = 1$, essentially no main trace record is visible at all. The bottom lock amplifier, however, commonly gives extra gain which can extend system performance in the absence of noise. The bottom lock mechanism cancels out vertical surface wave effects, as simulated here. If however, roll and pitch beam movement and/or rapid target movements are sufficiently great some randomisation in marking position can be expected, and an example is depicted in Slide 8.

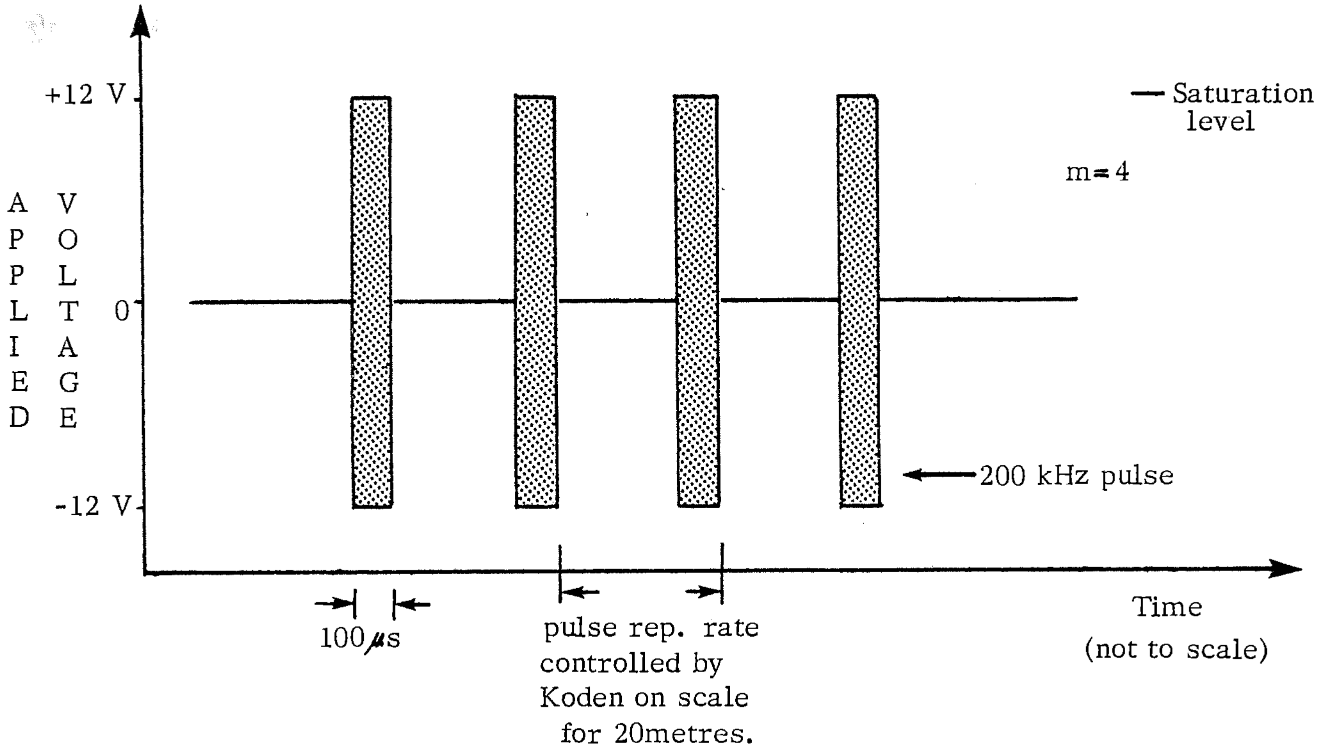

FIG. 15. TYPICAL PULSE TRAIN FOR CHART MARKING TESTS.

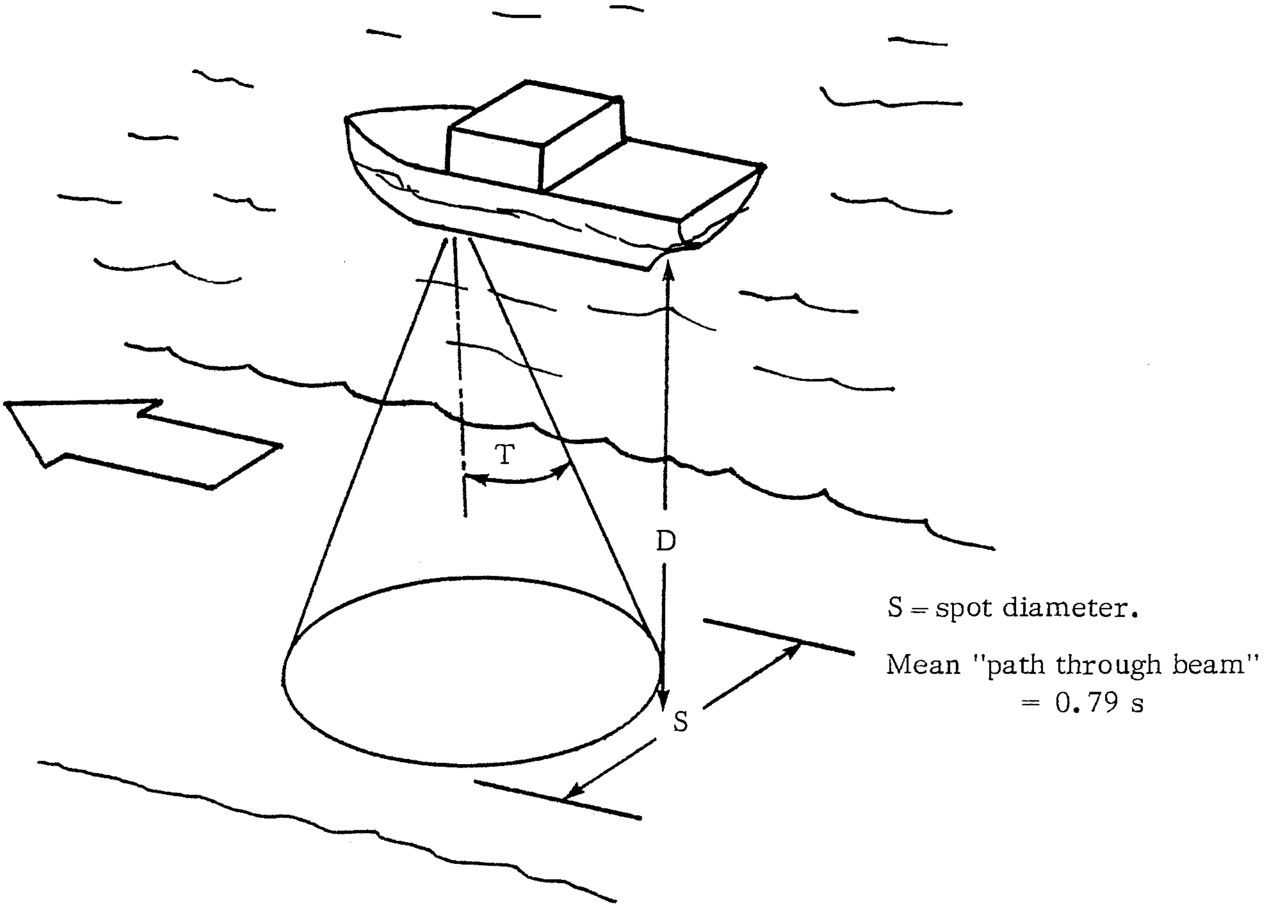

FIG. 16. BEAM PARAMETERS AND GEOMETRY.

Several other sounders were tested using this equipment and Slide 9 shows one example taken from a Raytheon dry-paper recorder. This unit requires a much higher saturation voltage to be applied to the paper and has a limited dynamic range. The result is that if a signal marks at all, it marks clearly. The Slide 9 record is for a set of m = 1 pulses of 100 μsec length, but at the frequency suited to the Raytheon machine. The marks are clear and well resolved and, in contrast to the Koden wet-paper system, do not fade. It should be noted that all the Koden records depicted here were photographed immediately after chart marking had taken place. Experience in the field has indicated that mark fading, coupled with other factors such as limited light during night-time trawling, means that some low level returns are missed during trawling operations. Thus, to ensure adequate marking from an isolated target in a low noise situation requires at least one and preferably two saturating pulses on the main scale (see Slides 5 and 7). If noise levels are low enough to permit the extra bottom lock gain to be employed, single (m = 1) pulses as low in amplitude as quarter saturated will mark successfully, although only on the bottom lock display. If beam position randomisation is present, notably from boat pitch or roll, the return from a single target will appear to be at different depths even on the bottom lock display and the clarity of the record will be reduced (Slides 6, 7 and 8). We presently estimate that a minimum of two consecutive or near-consecutive returns within 6 - 10 dB of saturation are required to give a useable chart marking, i.e., NV = 2.

The duration of the target in the beam (TB) depends on boat speed, water depth, beam angle and target location, as depicted in Figure 16. Putting the beam angle T = 10.5° , as before (Section 2.3) includes both main and first side lobes for the Koden unit. For an effective depth D = 20 metres, the mean path length of a target through the beam is approximately 5.8 metres. A vessel trawling at 5 km/hour will move over such a distance in 3.6 seconds. The maximum sounding ratio of the Koden SRM 681 is 4500 min. or 75/sec (on the HD setting, range 1) so that the average number of insonations of a single target is therefore 75 x 3.6 = 270.

Thus, in this case, at maximum pulse rate, the detection efficiency becomes -

for gain 4 noise (-100 dB equivalent)

$$DE = \frac{75 \times 3.6 \times .004}{2} = 0.54$$

and for gain 9 noise (-116 dB equivalent)

$$DE = \frac{75 \times 3.6 \times 0.098}{2} = 13.23$$

Normal pulse rate operation at D 20 m would halve these figures. Thus, in the noisy case, one target is unlikely to be visible, while a single prawn at D = 20 m should be discernible in the low noise case.

This analysis, using equations 4, 5 and 6 links detection efficiency as defined to a number of variables, some of which offer some scope for optimisation. It will be useful to review each of the variables used in establishing detection efficiency.

(i) Pulse Rate (PR). It is clearly valuable to use the highest manageable pulse rate in order to enhance the probability of generating high amplitude returns from marginal targets. The Koden machine currently employs pulse rates which, at several depths, are close to the maximum possible without signal overlap.

(ii) Duration of Target in Beam (TB). Reducing boat speed will enhance TB, but reduce the rate at which a search area can be covered. The use of a wide beamwidth will enhance TB, but reduce vertical resolution, an effect which may be unsatisfactory, as discussed in Chapter 3 below.

(iii) Probability of Return Exceeding Noise (P). This factor may allow for some improvement. The major noise background experienced in the field would appear to be associated with ship functions and motion. An analysis of the spectral nature of the total background noise field on working trawlers may suggest the use of operating frequencies above 200 kHz, since sound absorption effects are relatively small in shallow water, amounting, for instance, to less than 5 dB at 470 kHz for a round trip distance of 40 metres. As previously noted, prawn target strengths are essentially constant for frequencies up to 1 MHz.*

(iv) Number of Returns to Mark Chart (NV). The Koden and other charts appear to be relatively effective in registering near-saturation level pulses. Lower amplitude pulses, even if they exceed the background noise level, can be difficult to resolve, particularly if boat pitch and roll scatters marks on the chart record. For such returns, the bottom lock mechanism is useful and beam stabilisation could be expected to further aggregate the associated chart markings, and thereby enhance their visibility.

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* A side effect of increasing sounder frequency above 200 kHz would be to provide some increase in the volume reverberation from small scattering centres such as larger zooplankton.

3.0 TARGET RESOLUTION

3.1 NEAR-BOTTOM DETECTION

A number of prawn species are known to bury themselves in bottom sediments during at least part of their life cycle. Even when not buried, many prawns stay very close to the bottom so that resolution of prawn and bottom signals in echo sounding can become difficult. During the field trip to the Gulf of Carpentaria (July, 1977), no clear sounder evidence of tiger prawns was obtained during trawling which yielded up to 0.5 kg/minute from two nine fathom nets. It is not clear in this case whether the prawns were buried or simply uniformly scattered, which would allow only single targets in the beam at a time and make detection difficult if noise levels were high, as discussed in Chapter 2. Other field trips have yielded interesting returns from near-bottom sections of the water column. During the Exmouth Gulf field trip (May, 1977) a number of chart segments showed considerable marking within 50 cm of the bottom, in areas where western king and tiger prawn catches of 0.4 → 1 kg/min. were made. The prawns constituted between 27% and 51% of the catch (by number), the remainder being fish, largely leatherjackets of less than 20 cm length (Simpson, 1977).

There seems little likelihood of using echo sounders to detect buried prawns. The reflection coefficient, at $\theta = 0°$, of even a very soft sediment (see Section 4.4 below) corresponds to a target strength of approximately -42 dB and values can rise to approximately -10 dB for some sediments. In order for buried prawns to show echoes clearly distinguishable from adjacent sediment features, it is estimated that their reflected echo would need to exceed the bottom echo by at least 20 dB. In the case of the soft sediment cited below, this calls for a prawn aggregate target strength of about -20 dB, which in turn requires more than 100 prawns in a range slice within the beam spot area. This estimate does not account for the statistical effects noted in Chapter 2 or for sound absorption in the sediment and is therefore almost certainly low. Harder sediments would call for higher prawn densities. In general, it would appear that prawn densities sufficient to allow buried animals to provide clear echo contrast against bottom sediments are unlikely to arise.

Attention was directed during the program to two factors which can affect the resolution of target and bottom echoes for prawns which are close to, but not buried in, the sea bottom. These factors are pulse length and beam geometry. It is clear that short pulse lengths offer the best resolution, (see Second Report, Figures 9 and 10 and Third Report, Figure 2, for a demonstration of this feature). Sofoulis (1977) has further shown that no reduction in prawn echo amplitude occurs due to the target alone as pulse width is reduced. Two limiting factors applying to short pulse lengths do arise, however. The first involves the bandwidth of the sounder receiving system. Shorter pulses require larger transmitter and receiver bandwidths so that the sounder becomes more susceptible to the background noise level discussed in Chapter 2. Secondly, a shorter pulse length produces echo records more susceptible to chart scatter (see Section 2. 4 above) produced by vertical motions of the vessel, although this problem can be largely overcome by use of a bottom lock facility. The Koden SRM 681, with a pulse length of 100 μsec, has an associated range slice thickness of 7. 5 cm. It would seem unlikely that much further reduction of these values would be fruitful, particularly in view of the bandwidth increase necessary if the same operating frequency were maintained. Some advantage may occur, in fact, for targets away from the bottom if the pulse length were increased.

Beam geometry effects include the effect of beam width and beam angle. The Second and Third Reports describe jetty based experiments concerning the effects of beam angle on near-bottom resolution. Figure 9 shows the experimental arrangement used. The use of beam angle (θ) values other than zero can, in principle, enhance target to bottom contrast in two ways. Firstly, the bottom backscatter signal for a sedimented sea bottom can be expected to decrease more rapidly than the signal from a near-bottom target as θ is increased. Secondly, some slight apparent enhancement of target-to-bottom distance will occur. These features have been demonstrated by Sofoulis (1977) but practical utilisation of these effects would be severely limited by boat motion except in the case of large beam width systems. Figure 17 shows a suggested beam orientation for such a system. By adjusting the beam angle as shown in the diagram, the bottom echo arrival times from main and side lobes would, on average, approximately coincide from a flat bottom.

The use of large beamwidth systems, means, however, that the effective volume of each range slice is large, the sounder samples more water volume at a high directivity value than would a narrow beam unit. Thus near-bottom targets have

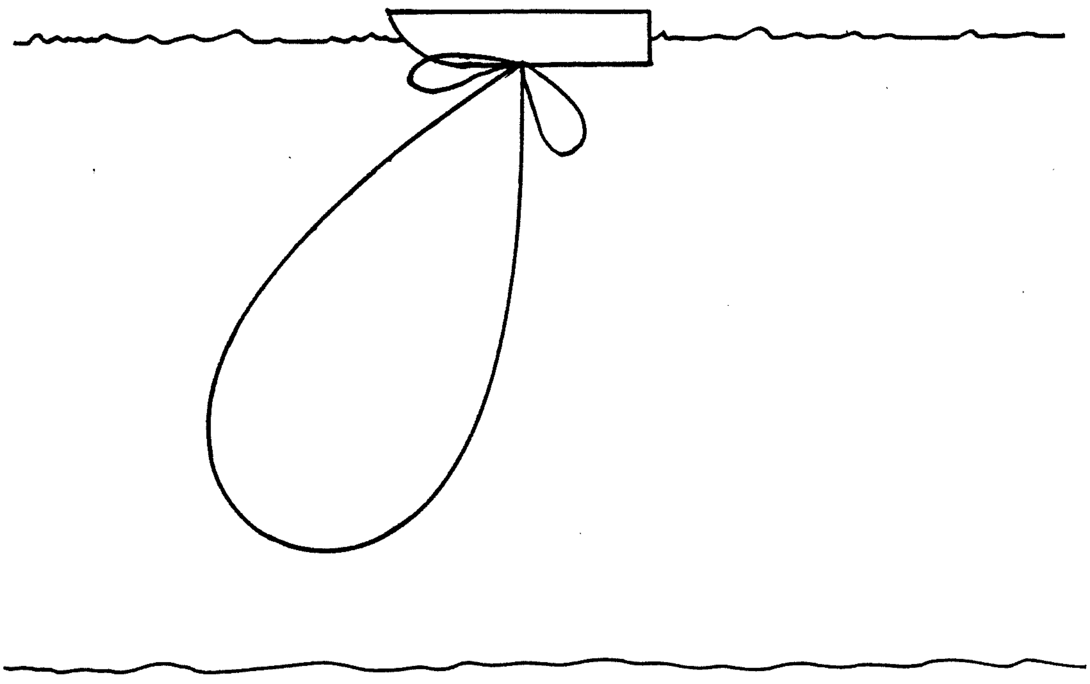


FIG. 17. FOR AND AFT SECTION OF ANGLED BEAM

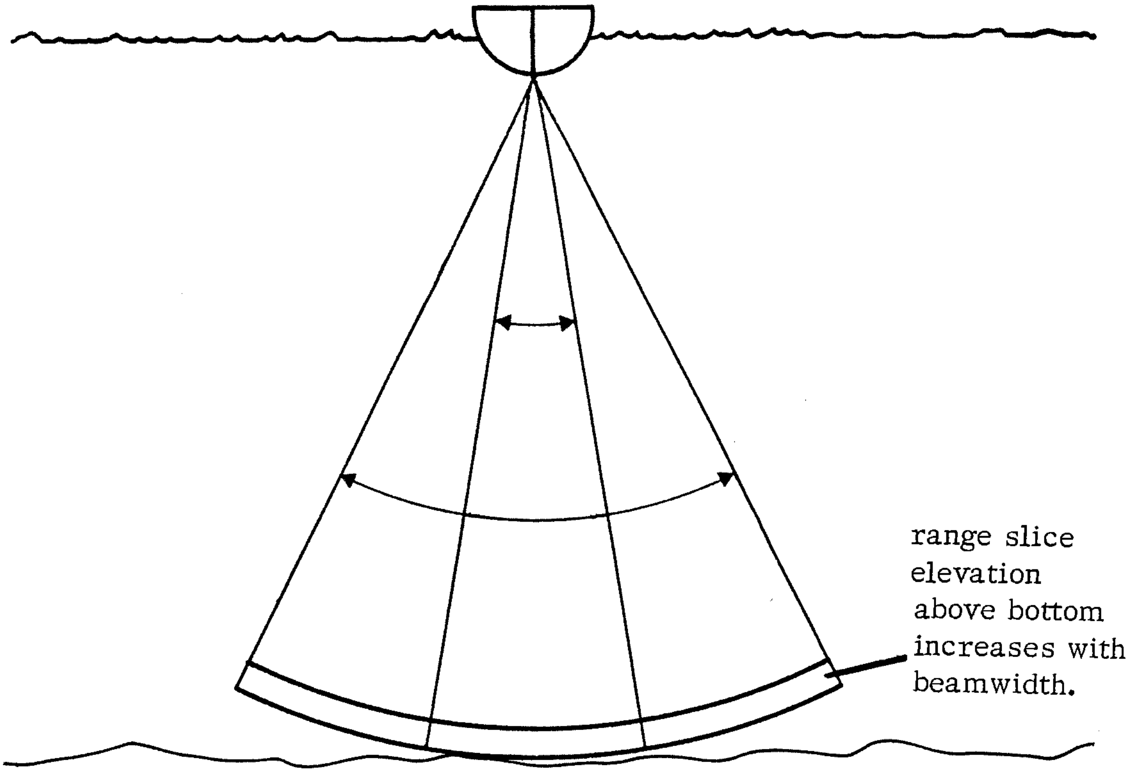


FIG. 18. RANGE SLICE VOLUME DEPENDS ON BEAMWIDTH

a higher probability of echo competition from targets away from the bottom, but at higher θ_i values, as shown in Figure 18. This consideration suggests that, for good near-bottom resolution, the smallest practicable beamwidth should be employed. This in turn calls for operation at $\theta = 0°$, i.e., vertically, as no significant advantage is then obtainable from the angled beam orientation seen in Figure 17.

Boat motion limits the extent to which beams can be effectively narrowed. If the beamwidth becomes appreciably narrower than the roll or pitch excursions of the vessel, the time the beam spends insonifying a target with successive pings is reduced, with consequent loss of detection efficiency, as discussed in Section 2.4. Secondly, the search efficiency of the unit is decreased as less of the bottom and water column is interrogated (see Chapter 4 below). During the field trips undertaken no accurate determination of roll and pitch excursions were made, but preliminary estimates suggest that a twin beam trawler with both trawls out (and hence partly stabilised in roll mode) can have pitch excursions of up to ±8° in moderately rough weather. The Koden sounder has a beamwidth (between the 3 dB points on either side of the beam axis) of 7.6°. Some improvements in the resolution of near-bottom targets could be expected if such a beam were stabilised against pitch and roll. It is unlikely that further beamwidth reduction would be useful.

3.2 RESOLUTION FROM COMPETING SPECIES

Slide 2 shows an example of an echo record from a heavy concentration of leatherjacket encountered during the first field trip to Spencers Gulf (January, 1977). A group of sample fish were taken from this area and were measured for target strength values in the WAIT test facility. Figures 19 and 20 show how peak and mean target strengths for leatherjackets and prawns vary with length and weight. Each fish was dissected after testing to check for swimbladder damage. Samples with collapsed swimbladders give relatively low target strengths, as expected. It is apparent that both prawns and fish exhibit similar length/target strength trends. On each field trip where substantial leatherjacket competition was experienced, the average leatherjacket length was a few cm less than the average prawn length, so that the average target strength from each population would be very nearly equal. This in turn means

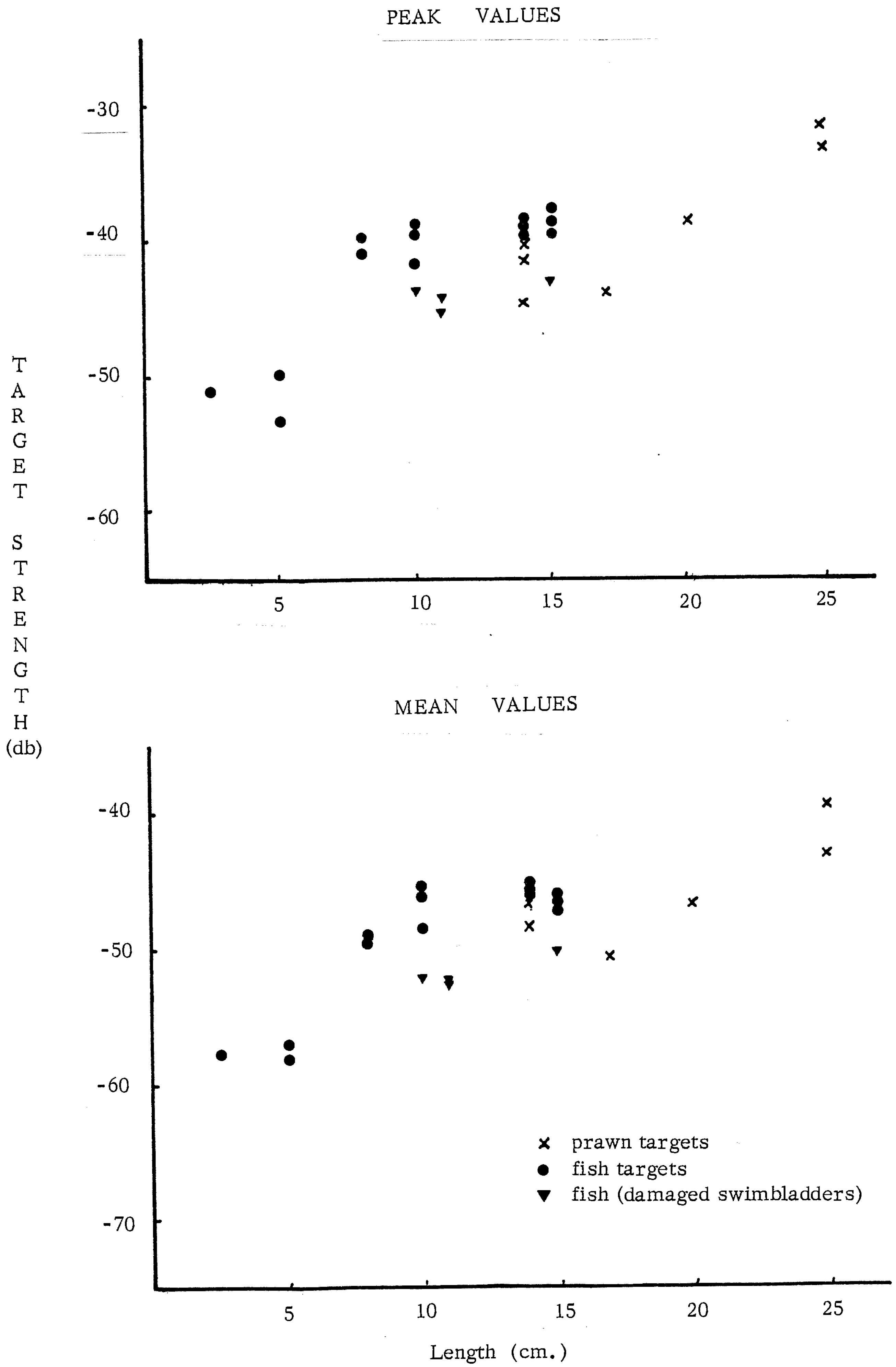


FIG. 19. TARGET STRENGTH vs LENGTH.

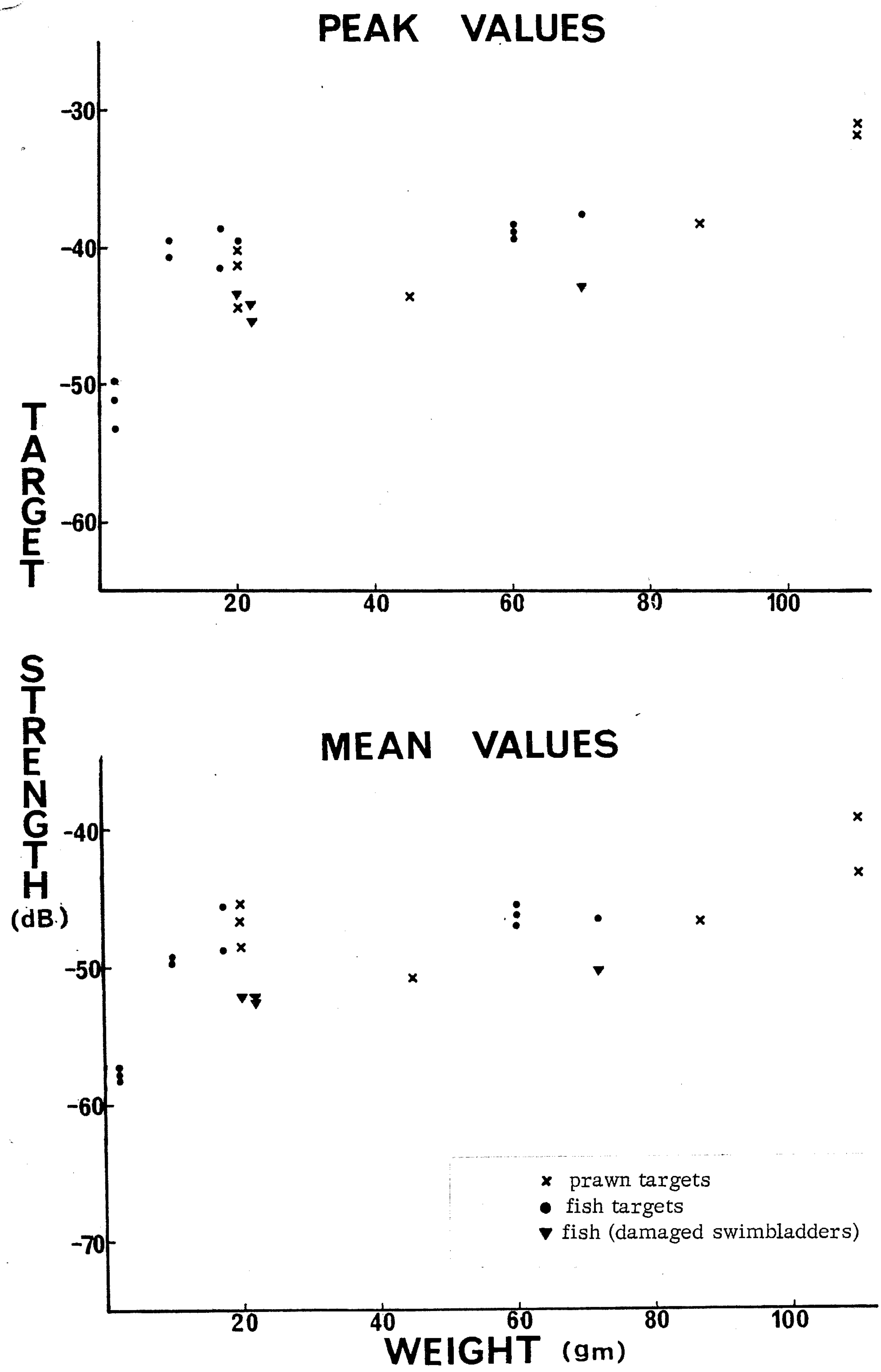


FIG. 20. - TARGET STRENGTH vs WEIGHT.

that to distinguish between individual prawn and small fish echoes is very difficult. Some distinction may be drawn between the echoes from groups of prawns and fish, however. The record shown in Slide 2 extends well up into the water column and therefore less likely to be derived from the western king prawn being fished in the area, than from the pelagic leatherjackets. In Slide 4, the uncommonly high density of king prawns is still concentrated near the bottom of the water column. The field trips undertaken suggest that, while on occasions non-schooling prawns may be found vertically dispersed, they are most commonly found in the bottom few metres of the water column. Where fish or small crabs and prawns are completely intermingled, there seems little likelihood of distinguishing between them acoustically. Where, however, a school of fish is concentrated slightly above a prawn population, as is apparently shown in some field trip records, acoustic separation of the two echo producing regions is possible. Here again, however, as in the case of near-bottom targets, it becomes important to maximise vertical resolution. This again calls for narrow beam operation and possibly beam stabilisation. Other fisheries apparently periodically find large densities of small crabs in trawl catches. No information on crab distribution in the water column was obtained during the field trips or discussions.

4.0 BEAM COVERAGE

4.1 SINGLE AND TWIN BEAM SOUNDING

Slide 10 shows part of a Koden echo record from the Gulf of Carpentaria field trip, undertaken in July 1977, at the end of the bana prawn season, but at a time when isolated catches of banana prawns were still being made. The dark traces most clearly visible on the bottom lock display were associated with a catch of approximately 220 Kg of banana prawns, with very little trash fish. A vessel following closely behind observed no sounder marks and, on setting the trawls, encountered no prawns. Discussion with the skippers involved suggested that banana prawn schools often were relatively dense and compact, and that while the Koden sounders commonly in use in the fishery were effective in detecting a school in the beam, the small volumes insonified by the Koden beams meant that many usable schools were probably not contacted. Vessels can apparently cruise very close to a banana school and receive no acoustic evidence of its presence - the beam simply misses the school. Even when a banana prawn school is seen on the sounder chart, no information is available as to the school orientation to the trawling path. Specifically, since the vessel must often go past the mark and double back before shooting the nets away, it would be useful to have an indication as to which side of the trawl path contains the bulk of a school. Such information is not available using a single sounder beam.

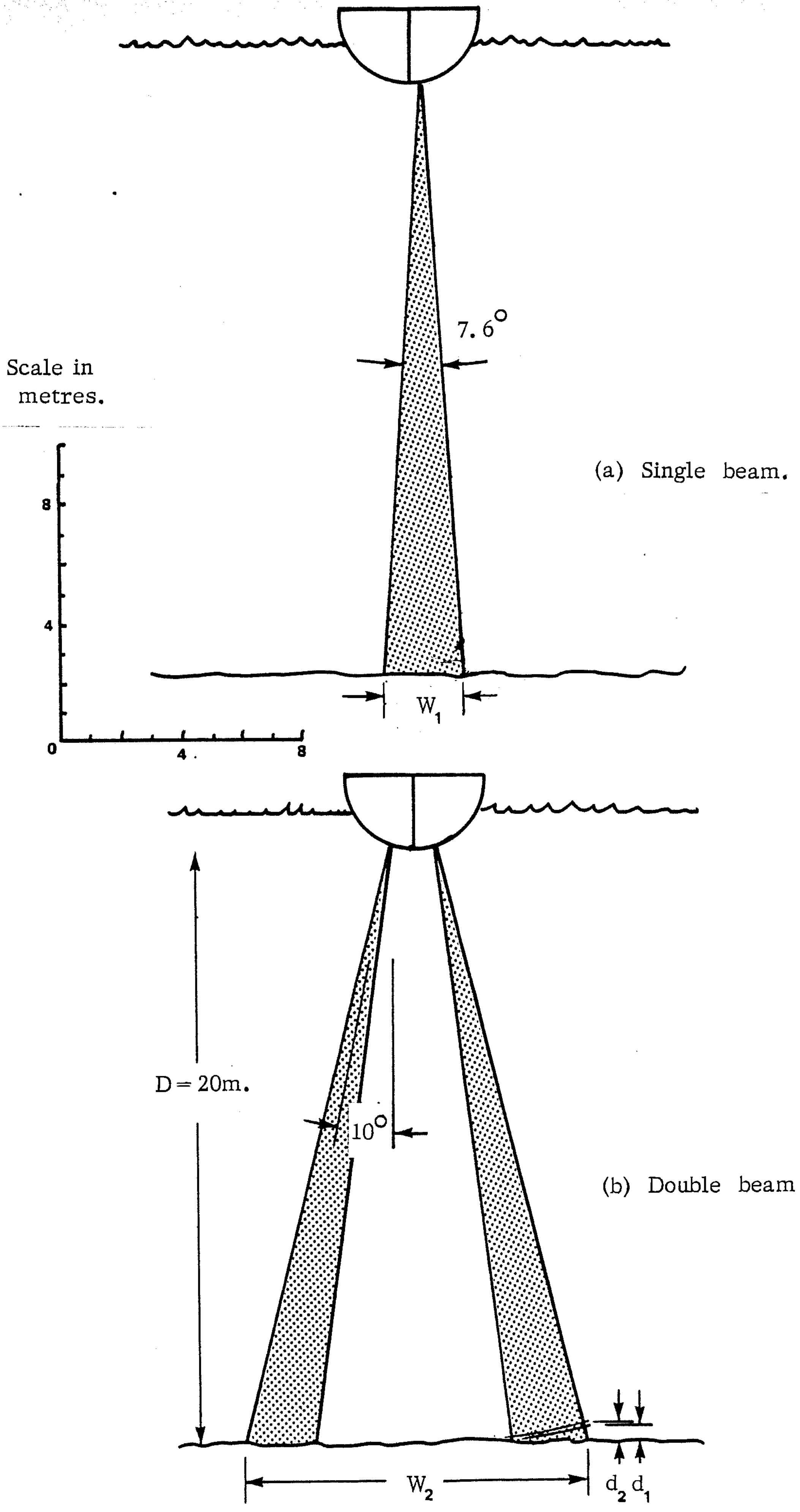
Figure 21(a) shows the beam geometry appropriate to a Koden SRM 681 beam in a 20 metre water depth. The beam width can be quoted in several ways - viz as

(a) the angle between the 3 dB points on the main lobe - this is the figure cited by the manufacturer and is 7.6°

(b) the angle between the first minima on either side - this is approximately 11.4°

(c) the angle between the second minima on either side - this is approximately 21°

It should be noted that the combination of transmit and receive directional sensitivities appropriate to sounding with such a transducer means that targets in the side lobe regions return echoes much below those in the main lobe. For the Koden transducer the side lobes are about - 35 dB down (see Chapter 2 also on this point) by calculation. Measurement on the W.A.I.T.



(a) Single beam.

(b) Double beam

FIG. 21. SINGLE AND DOUBLE BEAM PARAMETERS.

transducer yielded values closer to - 30 dB. Thus target densities in the side lobes must be between two and three orders of magnitude greater than in the main lobe in order to present comparable chart markings. Since the noise level is likely to be high during a search for banana prawns, as the vessel moves faster than trawling speeds, the side lobe input is likely to be overshadowed by background noise, even at the highest densities discussed in Chapter 2. We presently assume, therefore, that even with the relatively densely populated banana school as target, most of the echo return will be derived from the main lobe. In what follows the common convention of describing the sounder beam as having a simple cone shape associated with the main lobe between the 3 dB points, will be adopted; i.e. we adopt the beamwidth description noted in (a) above. The resultant beamwidth of 7.6° yields, for an effective water depth D (transducer to sea bottom) of 20 metres, a beam diameter of $W_1 = 2D \tan 3.80 = 2.66$m. Table 5 lists values of W_1, which is the effective width interrogated by the sounder beam as the vessel proceeds for D values between 10 and 30 metres, depths which would appear to cover much of the range experienced in Carpentaria trawling. It is clear that the beam coverage of water column and sea bottom is, in practical terms, very small.

In August 1977, a proposal was developed in conjunction with Mr. P. Arbuthnot and Mr. M. G. Kailis of Territory United Fisheries, to plan and build a modified sounding system designed to overcome some of the difficulties noted above. Figure 21b shows one essential feature of the system. Here two Koden transducers are depicted, each 1 metre from the keel line, and directed outwards at 10° to the vertical. The overall width W_2 of the insonified region is now given by $W_2 = 2 + 2D \tan 13.8°$ which gives, for D = 20 m, $W_2 = 11.82$ m. This figure is 4.44 times larger than the W_1 value for the same depth. Table 6 lists W_2 values from 10 to 30 m, together with the comparable W_1 figures.

One consequence of an angled beam is that part of the near bottom region on the outer edges of the beam is obscured by the bottom echo from the inner edges of the beam. The result is a loss of bottom detection capacity over a region rising to a maximum height shown in Figure 21(b) of d_1 or d_2. The distance d_1 is calculated assuming that only the main beam is involved, while d_2 allows for the possibility that the bottom echo from the inner side lobe will control this effect. Table 2 shows d_1 and d_2 values calculated according to

$$d_1 = D(1 - \frac{\cos 13.80}{\cos 6.20}) \tag{7}$$

$$d_2 = D(1 - \cos\ 13.80) \tag{8}$$

and for D values of 10 to 30 m. For D = 20 m,

$$d_1 = 0.46 \text{ m}$$

$$d_2 = 0.58 \text{ m.}$$

Thus an inevitable consequence of an off-vertical beam is the partial loss of bottom detection capacity represented by these d_1 and d_2 values. The average loss over each beam width can be expected to be approximately half this value. Discussion with trawler skippers suggest that these values are tolerable, if not desirable in regard to banana prawn schools at least up to D = 20 m, because the schools almost always extend up from the bottom for at least 1 metre. The single beams used presently are, of course, continuously fluctuating in orientation due to boat movement. This is particularly so in the pitching mode for a twin beam trawler with both stabilisers out and observations in the field have indicated that the angular deflections about the mean may approach the values considered here. Such motion, however, does not contribute effectively to enhancing the area interrogated by the sounder beam.

TABLE 5

$D_{(metres)}$	$W_{1(metres)}$
10	1.33
12	1.59
14	1.86
16	2.13
18	2.39
20	2.66
22	2.92
24	3.19
26	3.45
28	3.72
30	3.99

TABLE 6

(All dimensions in metres)

D	W_1	W_2	d_1	d_2
10	1.33	6.91	0.23	0.29
12	1.59	7.89	0.28	0.35
14	1.86	8.88	0.32	0.40
16	2.13	9.86	0.37	0.46
18	2.39	10.84	0.42	0.52
20	2.66	11.82	0.46	0.58
22	2.92	12.81	0.51	0.63
24	3.19	13.79	0.56	0.69
26	3.45	14.77	0.60	0.75
28	3.72	15.75	0.64	0.81
30	3.99	16.74	0.69	0.87

As the beam angle is increased, some variation in bottom echo presentation can be expected. For the system proposed to function successfully, it is important that the usual form of the Koden record be essentially maintained. That this is so for beam angles of 10° is demonstrated in slides 11 and 12, which emerged from the field trip undertaken to Spencer's Gulf in January 1977. As part of this program, experiments were undertaken which involved varying the beam angle in the fore and aft plane. Slide 11 shows the main chart record for a series of beam angle (θ) values from 0° to approximately 45° taken while the vessel was at anchor in shallow water. For θ values at least up to 14° the bottom echo record is as well defined as the normal incidence marking. Slide 12 shows a record undertaken at several θ values while the vessel was underway in very rough weather. For $\theta = 20°$, the main and bottom lock records are still usable, as compared with the $\theta = 40°$ record in which both records are becoming diffuse. It is apparent that for the 10° beam angles proposed, the bottom echo traces will vary little in appearance from those obtained from beams directed vertically downwards.

At least one attempt to use multiple beam sounders has been made before, but interference between the sounder beams made the experiment unsuccessful. The present proposal involves an electronic timing system which controls two separate sounder units so that they operate alternately, each receiving its own pulse and not functioning in receive mode during the operation of the other sounder. Thus two complete sounder units are required. Some boats in the Carpentaria area carry two units, with one as a spare, so that for these vessels no additional outlay for sounder purchase is required.

With these considerations in mind, a set of specifications for two beam sounding were drawn up. In what follows it is assumed that Koden SRM 681 sounders are to be employed. They have a history of successful operation in the Carpentaria fishery and are particularly suited to the modifications proposed. It is nonetheless true that the present proposals are not restricted in principle to the Koden machines and could, with modifications be employed with other sounders.

The specifications for twin beam operation, using the beam geometry of Figure 21(b) and two Koden sounders, were established as follows:

(a) Each sounder must be capable of independent operation.

(b) The system should be fail safe - one set remaining operable should the other become faulty.

(c) The original operating specifications should not be impaired.

(d) The operation of the system must be as straight forward as possible. Preferably involving nothing more than switching on each set and adjusting range controls to the same settings.

(e) Should connections betweeen units be removed for the repair of one of them, then the other must still operate.

(f) The inter-wiring of internal circuits should be non-existent or at least minimised to simplify future in-field servicing by technicians in remote areas.

During search fishing for banana prawns, virtually continuous monitoring of chart records is required. The use of two sounders requires that the units be put as close together as possible to facilitate interrogation. The form of the Koden circuitry, however, lends itself to a number of convenient signal processing modifications. Accordingly an automatic warning systems to give both aural and visual warning of selected changes in echo population was devised. It is not intended that this will replace operator surveillance, but reduce the need for completely continuous monitoring and hence reduce operator fatigue. As an extra feature it was proposed that a shallow water warning system be added. The warning system specifications adopted were:

(g) To give aural and/or visual warning when the sounder receives a certain bio-mass return in a selected depth segment. Additionally to provide shallow water warning capability.

(h) The alarm out puts are to suit trawler bridge conditions for sound level & visibility.

(i) A mark indicator is to be available for the operator to see his depth segment selection on the sounder paper.

(j) The alarm must not interfere with the normal operation of the sounder.

(k) Construction must be sufficiently robust to complete at least 12 months marine operation without deterioration of performance.

4.2 TWIN BEAM PROTOTYPE DEVELOPMENT

In September 1977, an agreement was reached with Mr. M. G. Kailis and Mr. P. Arbuthnot, of Territory United Fisheries, to develop a prototype system for installation in a new vessel then under construction at Coogee, in Western Australia. Component parts of the agreement were as follows:

(a) Territory United Fisheries to supply and fit two sounder units and transducers as outlined in 4.1, and in consultation with Dr. J. Penrose and Mr. D. Cartledge of the W.A.I.T. Physics Department.

(b) Dr. Penrose and Mr. Cartledge to supply; develop and fit all necessary electronics to implement the system. Associated costs to be covered by the W.A.I.T. Physics Department pending a supplementary submission to the Fishing Industry Research Committee.

(c) Mr. Cartledge to participate in Perth-based sea trials and to spend 1-2 weeks with the vessel during the 1978 banana prawn season in the Gulf of Carpentaria. Mr. Cartledge's transport to be arranged by Territory United Fisheries. Mr. Cartledge's time to be funded by the W.A.I.T. Physics Department pending a supplementary submission to the Fishing Industry Research Committee.

(d) Mr. P. Arbuthnot to be responsible for trials of the system during 1978 season, with consultation with Dr. Penrose and Mr. Cartledge as required.

(e) Dr. Penrose and Mr. Arbuthnot to produce an evaluation and report to be presented to the Fishing Industry Research Committee, before the end of 1978.

At the time of writing, the sounders and electronic assembly have been installed on the vessel. Supply difficulties have required that Denmar sounders, which are similar to Koden machines, be fitted. Full details of the system electronics are discussed by Cartledge (1977). Dual sounder operation is attained by having one set act as a master (set A) which synchronises the other (set B) in antiphase during "DUAL" operation. This is done by the "SYNC NETWORK" shown in Figure 22, which shows a schematic representation of the whole system "DUAL" operation is obtained by simply switching both sets on. Either set can function separately and when "DUAL" operation occurs both sounders operate continuously with full display of target echoes on all but the "HD" range. This range allows for doubling the shallowest depth range pulse rate. While the highest pulse rate is in principle advantageous for low density targets (see Chapter 2) it is not as significant in detecting the relatively high density banana prawn schools. The continuous mode of operation in the "DUAL" configuration is possible because of an existing timing regime in the Koden/Denmar circuitry.

The alarm function comprises three separate systems. One is associated with the main scale display of sounder A and the other two operate on the bottom lock displays of each sounder. The "NORMAL" alarm shown in Figure 22 operates when echoes within a selected depth range exceed selected values of duration and intensity. Figure 23 shows a general view of the completed prototype unit. The three controls at the left allow values of depth, width of range slice, and overall signal level to be preset. The two "BOTTOM" alarms operate on the bottom lock displays and have similar controls. The control panel also contains port and starboard alarm lights and echo level meters to assist in setting the controls. The alarm output provides flashing light signals which will endure till the reset button is pressed, and three different pulsed tones, for the three alarm types. The pulse tones are adjustable for volume and will stop automatically after a preset time, or on the pressing of reset. This arrangement gives immediate warning when triggered and an indication that the system has fired, if left unattended, the sound not continuing

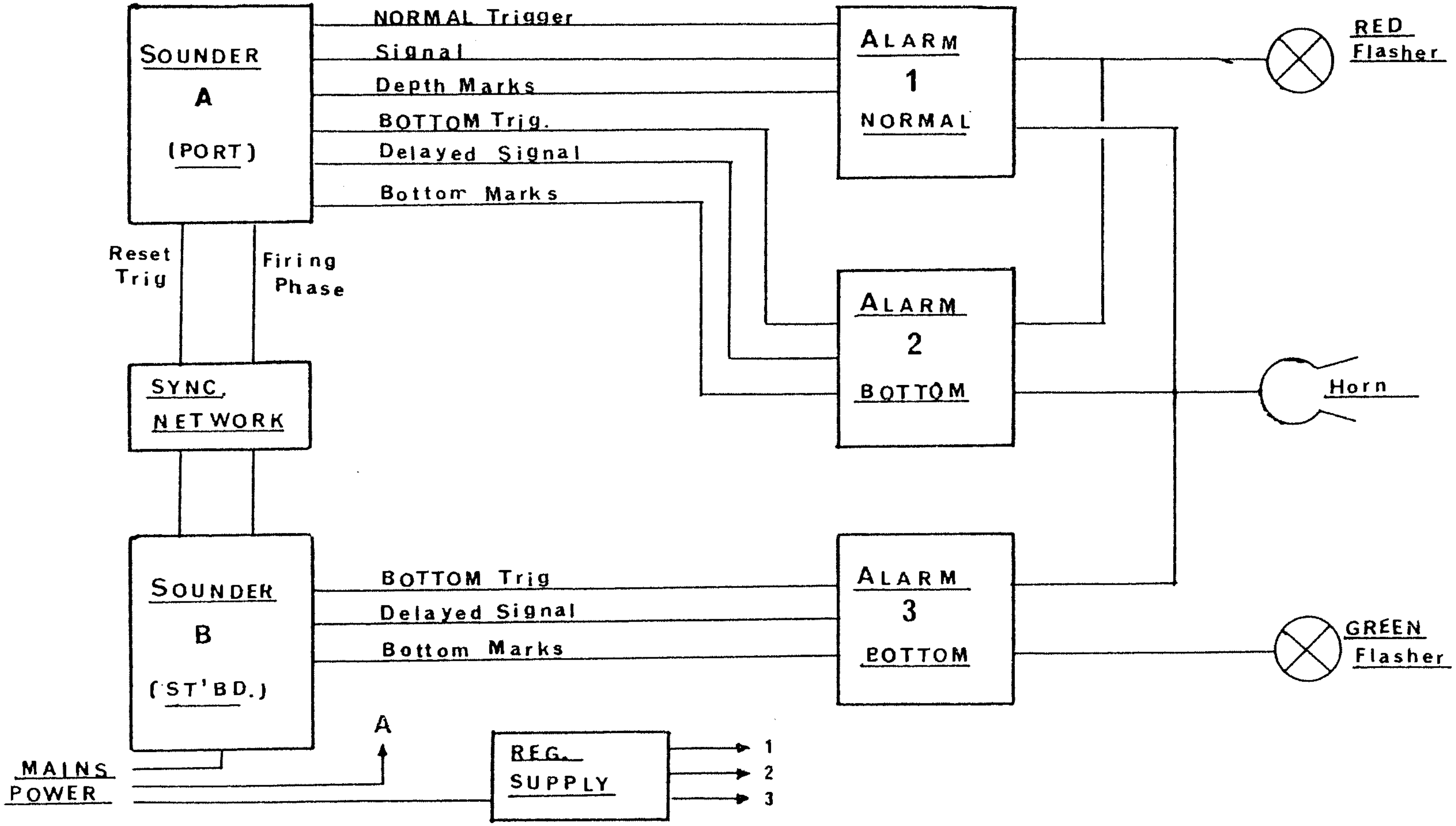


FIG. 22 - SCHEMATIC OF DUAL SOUNDER AND ALARM SYSTEMS.

FIG. 23 - PROTOTYPE DUAL SOUNDER CONTROL
AND ALARM SYSTEM - SPEAKER
CAN BE MOUNTED REMOTELY.

unnecessarily when the time for action has passed. The position of each range slice being tested is made visible on the chart display, as is the location of any regions providing alarm outputs.

The prototype system has been made with a large number of control functions in order to allow the most effective combinations of in field parameters to be employed. It is important for the alarms to sound only when relatively substantial target volumes are encountered, and not on isolated large targets such as sharks and turtles. It is anticipated that, should the system prove operationally viable, some reduction in the number of control functions may be possible, thus providing a simpler device

4.3 THE USE OF SONAR

One function of the dual beam system is to provide some increase in the area covered during the search phase of banana prawn trawling. Much greater bottom areas can clearly be interrogated using sonar which is thus, in principle, of great value in carrying out search operations for in particular, banana prawns.

Discussion with a number of fishery personnel have revealed that the performance of at least one fishing sonar in the banana prawn fishery has been unsatisfactory. In 1976 Mr. S. Hynd of CSIRO sent a Wesmar SS150 unit, which had a record of unsatisfactory performance, to the W.A.I.T. laboratories. It was intended that detailed tests on its performance would be undertaken at the Fremantle jetty facility. Unfortunately the unit was not quite complete, and information on circuit details and system parameters was lacking. The Australian suppliers were unable to provide directly relevant material, and, at the time of writing, information is becoming available from the American based manufacturer. In December 1977, discussions were undertaken with several sonar users in the Southern California tuna fishery and, by telephone, with the manufacturer. The comments below are based on these discussions and on experience gained in the Gulf of Carpentaria.

(i) The role of technical and training support services in facilitating optimum use of sonar equipment, is very significant.

A number of San Diego skippers cited poor installation, training and servicing as the major cause of sonar malfunction and downtime in their tuna fishery.

(ii) The particular problems of shallow water and near-bottom targets, make the Carpentaria prawn fishery a more difficult area in which to successfully use sonar than, e.g. a deep water pelagic fishery. For such shallow water situations it is convenient to consider three separate beam angle-target regimes. Firstly, the sonar may be used with small beam angles, i.e. with near-vertical beam directions. This is essentially the system proposed for dual sounder operation in 4.2 and does not exploit the major capabilities of a sonar system. The two other beam-target regimes call for more detailed comment.

Figure 24(a) and (b) depict two beam-target configurations applicable when large θ values are employed. In both cases, a small, dense school of banana prawns is located at a bearing of 45° in water of effective depth 20 metres. It is assumed for present purposes that no significant trawler movement takes place during school insonification. The school extends from the bottom up to a height of h metres. The vertical beamwidth employed, 8°, is that appropriate to the Wesmar SS150, and side lobe effects are presently ignored.

In Figure 24(a), the school is intercepted at slant range OA, before the main lobe reaches the bottom along slant range OB. Thus the CRT sonar display will represent the school before the bottom echo - the school and bottom marks will be separated by a spacing equivalent to AB metres.

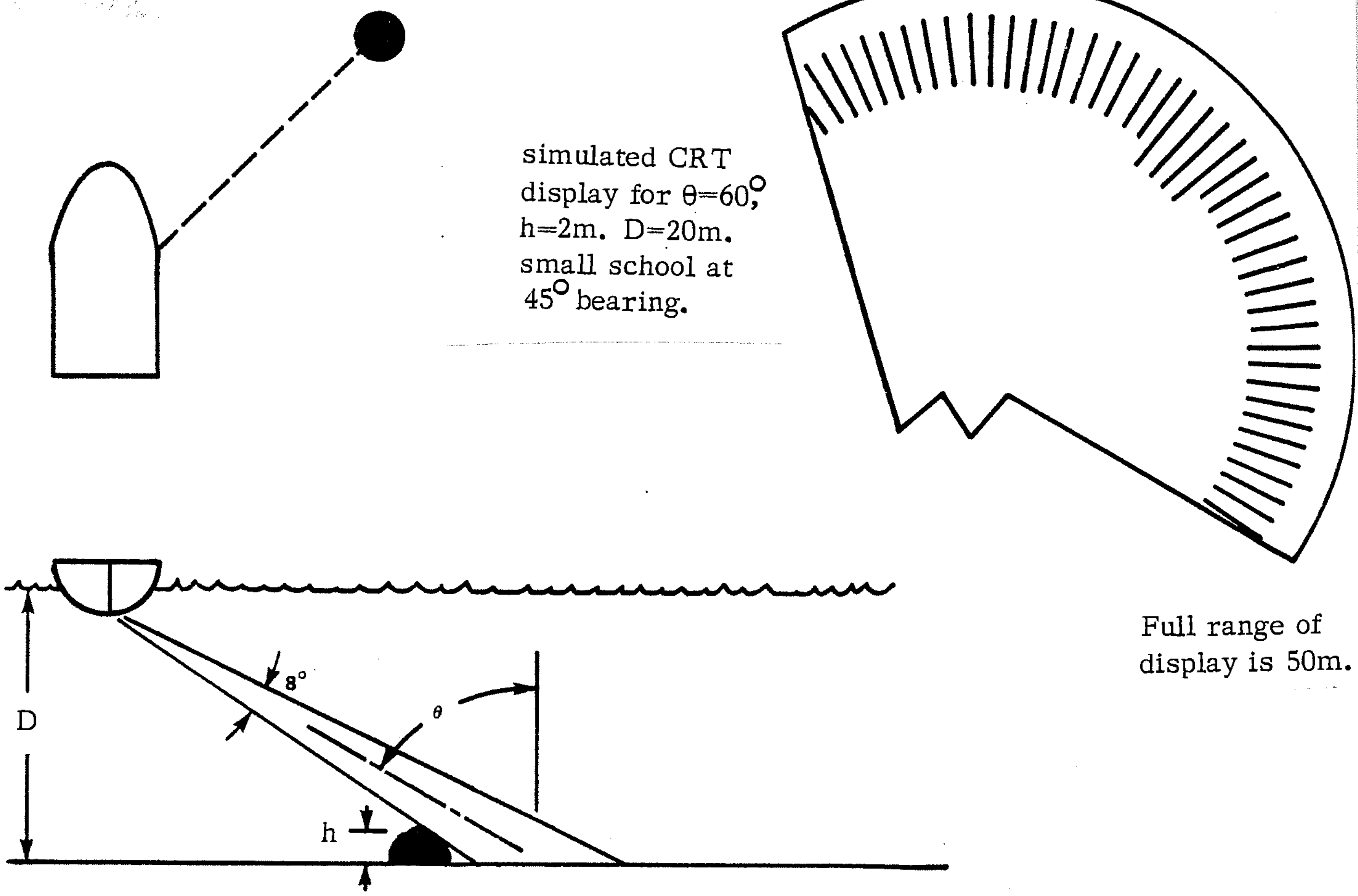
Thus Bottom Slant Range $OB = D/\cos\ (\theta - 4°)$

$$\text{and spacing} = AB = \frac{h}{\cos\ (\theta - 4°)}$$

and the spacing expressed as a fraction of the bottom range is always given by:

$$\frac{AB}{OB} = \frac{h}{D} \tag{9}$$

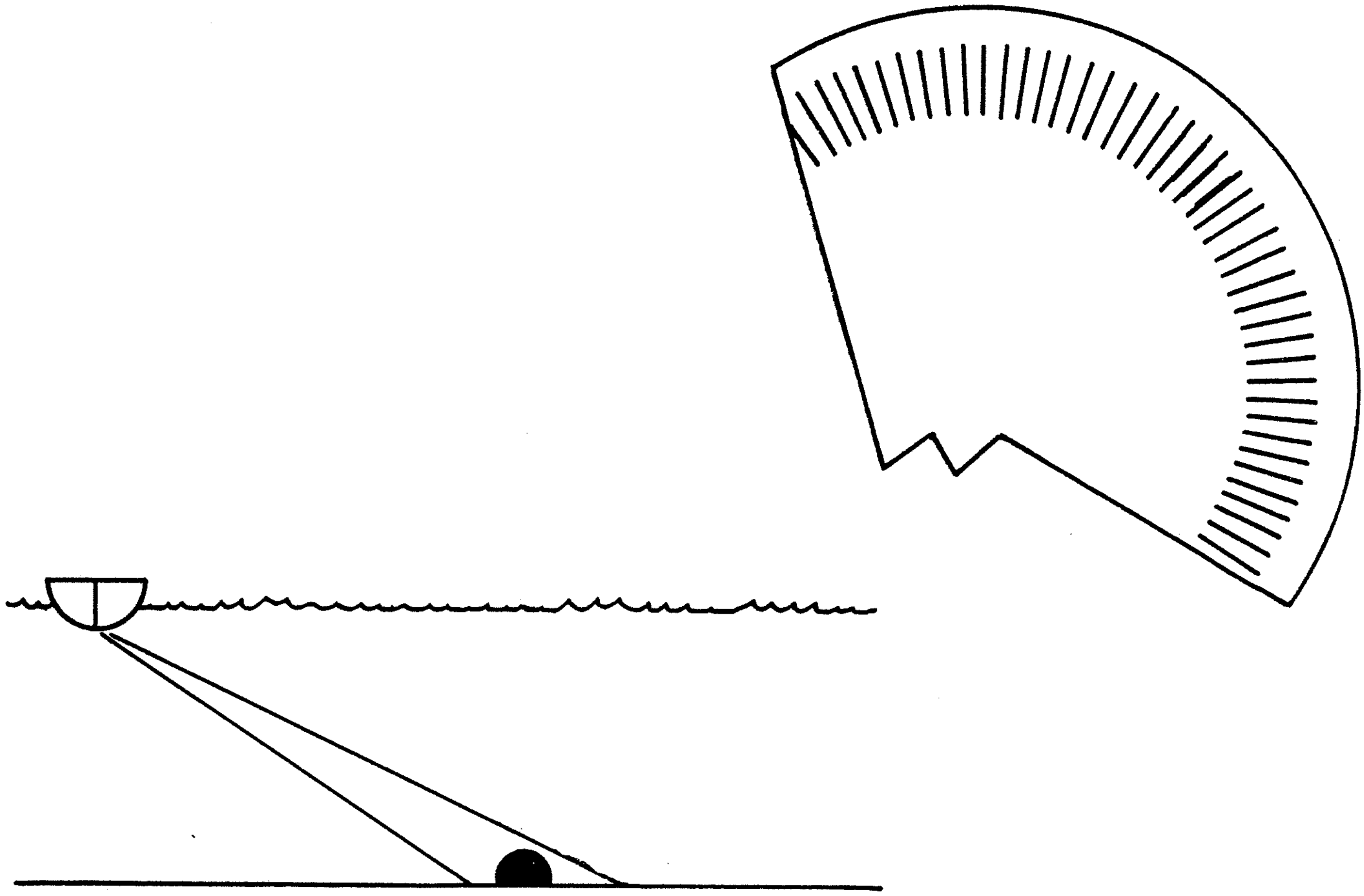
Table 7 shows OB and AB values for D=20 metres and two values of h, 2 metres and 4 metres



simulated CRT display for θ=60°, h=2m. D=20m. small school at 45° bearing.

Full range of display is 50m.

(a) Beam intercepts target before bottom



(b) Target hidden in bottom echo

FIG. 24. SIMULATED SONAR DISPLAYS

TABLE 7. Sonar Range Variables

θ (deg)	OB	AB (h=2m)	AB (h=4m)
10	20.11	2.01	4.02
20	20.81	2.08	4.16
30	22.25	2.23	4.45
40	24.72	2.47	4.94
50	28.79	2.88	5.76
60	35.77	3.58	7.15
70	49.17	4.92	9.83
80	82.67	8.27	16.53
85	127.85	12.78	25.57

For h = 2m, the spacing as defined is always 10% of the bottom slant range and for h = 4m, it is 20% of that value. The importance of these factors is illustrated in the simulated CRT display associated with Figure 24(a). Here a perfectly flat bottom and stabilised beam is assumed, for a value of 0 = 60°. The h = 2m school would appear as a small feature at bearing 45°, where the radius of the CRT display is slightly reduced. Such a perturbation in the bottom pattern could well arise from relatively minor variations in bottom topography. For h = 4m, the display would be more marked but, in all cases, if in order to resolve a near-bottom target from the bottom, it is necessary to have an echo spacing as defined above, then a fraction of the displayed slant range equal to the ratio h/D is the only section of the CRT display which is effectively useful. While for large h, and targets well elevated in the water column and separated from the bottom, thus problem is not significant, targets with small h values will be discernible on only small segments of the CRT will be difficult to display, and will be difficult to resolve out of echoes from even moderately undulating bottom.

Figure 24(b) represents the prawn school at a slightly greater range, so that its echo now falls within the bottom echo envelope. If the school provides a sufficiently large echo, it can show above the general bottom backscatter. In section 4.4 below, results are cited showing that the backscatter level for one particular sediment drops off sharply with θ. These show that sample backscatter voltage amplitudes for θ between

70° and 75°, fell by between 23 dB and 31 dB compared to $\theta = 0$ values. This type of behavior is referred to in the second report and is represented visually in the chart records seen in slide 11. There is thus a higher probability that a dense school of prawns can provide an echo in excess of that returned by the bottom as the beam angle θ increases. This feature may well repay careful field experimentation. Some attention has been directed to the use of sonar in this way, however, but preliminary estimates and results have not been encouraging (J. Hill - private communication). Recently this issue has been raised with a representative of the Wesmar factory in Seattle U.S.A. He advised that Wesmar do not expect to show near bottom prawns on sonar displays, but see the role of sonar units in such fisheries as being primarily indicators of bottom type. It is not clear at the time of writing, however, whether this applies to schooling prawn species. It is certainly true, for both sonar regimes represented in Figure 24, that fluctuations in beam angle caused by vessel motion would make sonar interpretation extremely difficult, if not impossible. For this reason high grade beam stabilisation capability should be regarded as a necessary feature of any sonar used for prawn searching.

Several other features of sonar operation have been given attention during the research program. A check was made to determine if refraction effects due to temperature variation could be expected to influence sonar performance on prawning grounds. Several bathythermograph estimates of water temperature vs depths were made on two of the field trips and a ray tracing computer program developed. Because of the short ranges involved, and, to a lesser extent, because the shallow water in prawning areas is often well mixed, it seems clear that sonar refraction is not a significant factor in prawn trawling.

During several of the field trips a cathode ray oscilloscope was used to present a dynamic "A scan" of the return echo signals. This feature appears in various forms in most sonars and some echo sounders. Although the traces obtained appeared to be useful during the second Spencer's Gulf field trip (March 1977) they did not prove of great value during the Exmouth (May 1977) or Carpentaria (July 1977) trips because of the high levels of volume reverberation experienced.

Considerable operator fatigue is involved in monitoring such displays and, over long periods of time similar difficulties could be expected to arise in normal sonar viewing, because of the dynamic CRT display. Sonar equipment used in this way requires audio output and an associated chart recorder to assist long term monitoring. The WESMAR sonar currently located at W.A.I.T. has an associated dry paper recorder which has apparently been used to supply a permanent sonar record.

Thus, in summary, it would appear that sonar does not appear to be a promising tool in prawn detection, although its performance in respect of banana prawn schools may warrant further attention. The WESMAR factory has apparently recently sold several units to Australian prawning interests, so that sonar sets may continue to appear in the industry, perhaps being used primarily as bottom type sensors. Where prolonged sonar viewing is envisaged, audio and chart display aids should be employed.

4.4 SEA BOTTOM PROPERTIES

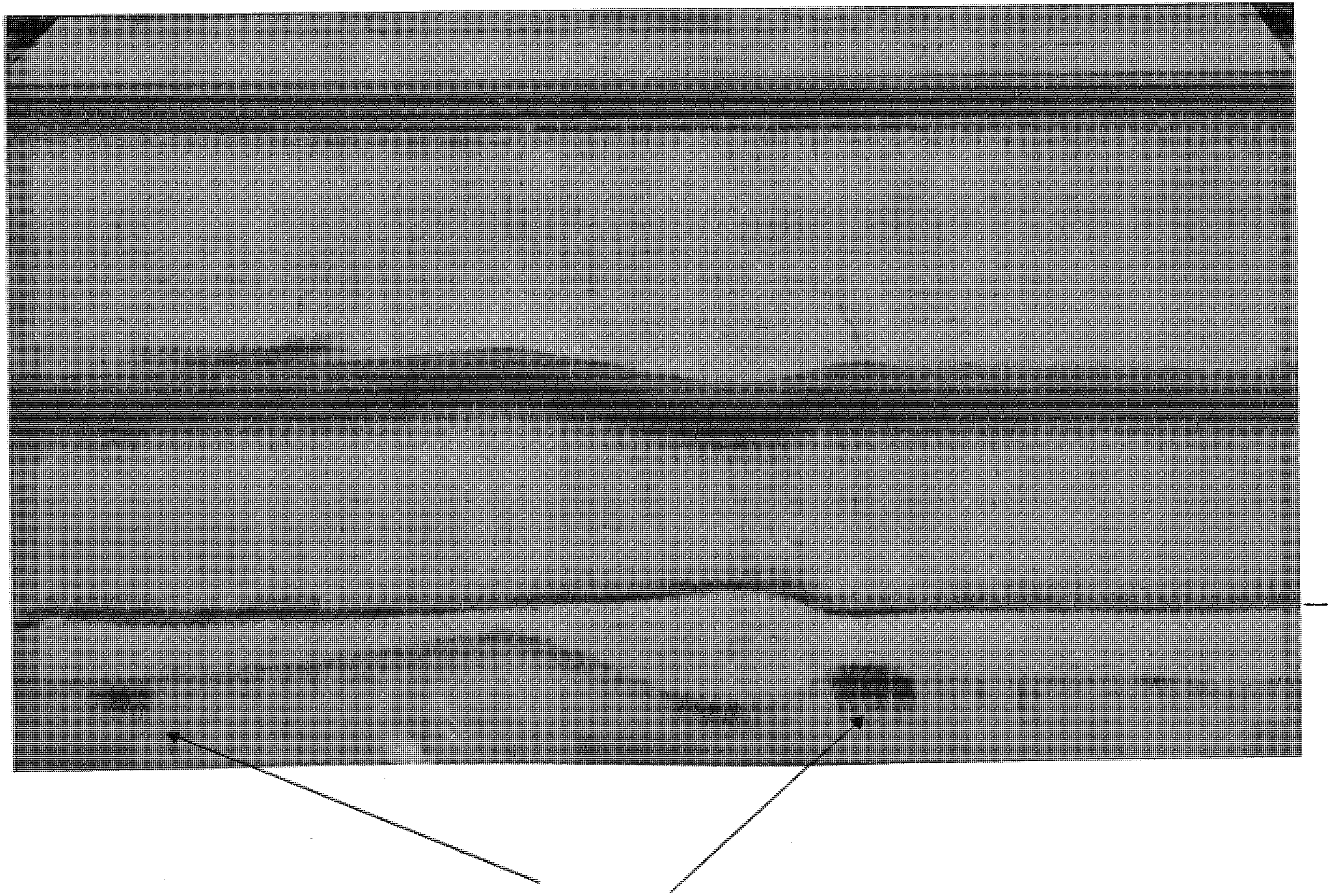
Sea bottom properties are of importance to prawn trawling in at least two ways. Firstly, the nature of the bottom, in particular its mechanical and organic material properties may be important in controlling its suitability in terms of habitat for various parts of penaeid prawn life cycles. Secondly, some bottom types can impose severe damage to bottom trawling nets so that acoustic detection of such areas has a potentially valuable warning function.

As part of the research program undertaken a detailed study was made of the sedimented bottom surrounding the Fremantle jetty facility. One of the major aims of this work was to develop an understanding of realistic acoustic interactions with the sea bottom, in order to aid an evaluation of the very extensive literature on the subject of acoustic classification of sea bottom types. Horton (1972), has reviewed the subject, finding 165 papers published in the period 1960-1970 in the two leading acoustics journals, the Journal of the Acoustical Society of America and Soviet Physics - Acoustics. Much of the endeavour has arisen within the geophysical context and is characterised by the use of relatively low sound frequencies and the interrogation of large areas of the sea bottom, often in deep water. In some areas of work, uncertainties have not been resolved, and it is sometimes unclear how much deep ocean results may be applied to shallow water operation. The experimental program undertaken in the present work has aided in resolving much of these problems, and is described fully by Penrose (1977). The discussion below deals with some of the features of the study.

Current sounder usage allows two methods of sounder interpretation which can in principle yield some information about bottom type. The first, which involves essentially an estimate of the magnitude of the bottom echo, is used from time to time within the fishing industry to distinguish between so called "hard" and "soft" bottoms. The second, which involves an estimate of bottom scattering behaviour can in principle provide a distinction between "rough" and "smooth" surfaces. The extent to which such categories inter-relate and their value as bottom descriptors is to some degree, uncertain.

(i) Bottom Echo Level

Echoes from the sea bottom arise primarily because of an effective acoustic impedance contrast between the bottom and the overlying water column. A number of factors contribute to the magnitude of this effective contrast, and hence to the magnitude of the echo returned to the sounder. Thus, for a given water depth, variations in bottom echo arise which should give rise to differing chart markings. Most sounders are not equipped with the facility to measure the magnitude of echo returns in an absolute way, but for a suitably adjusted machine, relative variations in bottom echo marking can be expected to give information regarding relative variations in the effective acoustic impendance of the sea bottom. Most sounders using charts however, have limited graphic display dynamic ranges, commonly 12 - 20 dB. Also, in order to observe targets in the water column, it is common for amplifier gain settings to be adjusted at a level which means that all bottom signals, from any bottom type, saturate the display on the first bottom reflection, which thus has limited usefulness for the purpose of bottom categorisation. Under such conditions, the weaker bottom signals obtainable from multiple bottom reflections may be of value. Figure 25 shows a chart segment



trace
from
reversed
paper
usage

FIG. 25 - ECHO TRACE SHOWING ENHANCED SECOND ECHO AREAS.

which includes a double echo, parts of which are substantially enhanced. This enhancement occurs at essentially an unchanged depth and would therefore be interpreted as evidence that several patches of higher bottom reflectivity were included in the region under study.

(ii) Width of Bottom Echo

The width W, of the bottom echo seen in Figure 25 arises as a consequence of the pulse length and beamwidth of the sounder beam. At high frequencies the beamwidth effect is usually dominant and arises because sound rays on the outer perimeter of the beam have a longer return trip path to follow than rays in the vertical beam centre, which give rise to the strongest echo, marking the upper edge of the region W in Figure 25. Thus the magnitude of W is related to the beamwidth. over which discernible echo returns occur, and, for a given transducer and beam pattern, will be related to the roughness of the sea bottom. In principle, the rougher the sea bottom surface, the greater the width W, because significant echo returns now appear at larger beam angles, which involve longer pulse transit times.

Experience to date has not clearly demonstrated this effect in the relatively narrow beam Koden records, but it could be expected to be more significant with broad beam sounder units. Certainly the variation of backscatter with beam angle will be an important factor if sonar is used as a detector of roughness variations in the sea bottom. Thus, these two chart features, second echo magnitude and echo width W are qualitative measures of the normal incidence reflection coefficient R of the sediment, and the variation of R with beam angle. They give, respectively, information about bottom "hardness" and "roughness". These two measures appear also, in refined forms, in the scientific literature. Measure of R have been used to estimate sediment density and porosity (see e.g. McLeroy, 1972) and the behavior of R with θ and its relationship to surface roughness has provoked considerable activity (e.g. McKinney and Anderson, 1964)

It would appear that, while reliable estimates of surface roughness are difficult to establish, greater reliability can be attributed to accurate measures of R, as a description of sedimentary characteristic. To some extent, however, a measurement of the coefficient of reflection R is itself affected by surface roughness and the extent to which the bottom interface is clearly defined. To minimise these effects, and hence give an R value which is related most closely to, for instance, sediment porosity, it is important to use a wide beamwidth and a relatively long wavelength. This is illustrated by the results of R measurements made at the Fremantle site under controlled conditions. Measurements were made using three beam - frequency continuations as shown in Table 8 below. In each case R was calculated from jetty site backscatter data, averaged from approximately 300 returns over a 2.5 metre sample of the bottom, and using a still air-water surface as a reference reflector.

TABLE 8. Bottom Reflectivity Measurements
- Fremantle Site

Transducer Type	Frequency kHz	Beamwidth (between first minima)	R
Koden	203	11.4°	.015 ± .003
Marlin	208	28°	.080 ± .016
Furuno	51	69°	.179 ± .04

The great variation in apparent reflection coefficient arises from several sources, the most significant being the surface roughness of the sediment. Measurements were made of bottom topography and showed that while the area was very flat on the scale of tens of metres, detailed variations occurred of the order of centimetres in elevation and tens of centimetres in horizontal spacing. Thus the narrow Koden beam loses more energy through random scattering than does the very broad beam of the Furuno, which also has what is, in this instance, the advantage of a longer wavelength. The very low value of R found with the Koden beam is close to a similar value reported by Bezdek (1973), using 75 kHz signals in the San Diego trough area.

Experimental values of R may be related to sediment porosity by several empirical relationships. Faas (1969) analysed 244 sediment and acoustic measurements obtained from various marine and non-marine environments by previous investigators and sought the relationship between sediment porosity and acoustic measurements of R. R throughout is treated as though it is a reflection coefficient for a simple planar interface. Faas fitted the expression

$$R = 0.6468 - 0.6456\ \eta \qquad (10)$$

to the data, with correlation coefficient $r = 0.97$. The sediment porosity η, expressed in the range 0 - 1, is the ratio of the volume of voids between the grains of a sediment sample to the total volume of the sediment aggregate. It has been related to wet sediment density ρ by a number of workers, including Hamilton (1956), who related η and ρ for a series of shallow water marine sediments off San Diego. While the precise nature of the η - ρ relationship depends on detailed sediment properties, data for all his sediments followed similar trends. In general, high porosity correlates with low density and vice versa.

Table 9 shows values of η computed from the measured R values by using equation 10, and predicted values of wet density derived by inserting the computed η values into Hamiltons graphical relationships between η and ρ.

TABLE 9. Predicted Porosity and Wet Density Values

Transducer Type	Porosity η (Equation 10)	Wet Density ρ (From Hamilton) gm/cm^3
Koden	$.98 \pm .05$	$1.05 \pm .02$
Marlin	$.88 \pm .03$	$1.23 \pm .06$
Furuno	$.72 \pm .06$	$1.53 \pm .08$

Values of wet density were obtained experimentally using diver operated coring tools which sampled to depths of 7.54 cm and 15.40 cm respectively. Ten samples were taken with each sampler and yielded densities as follows

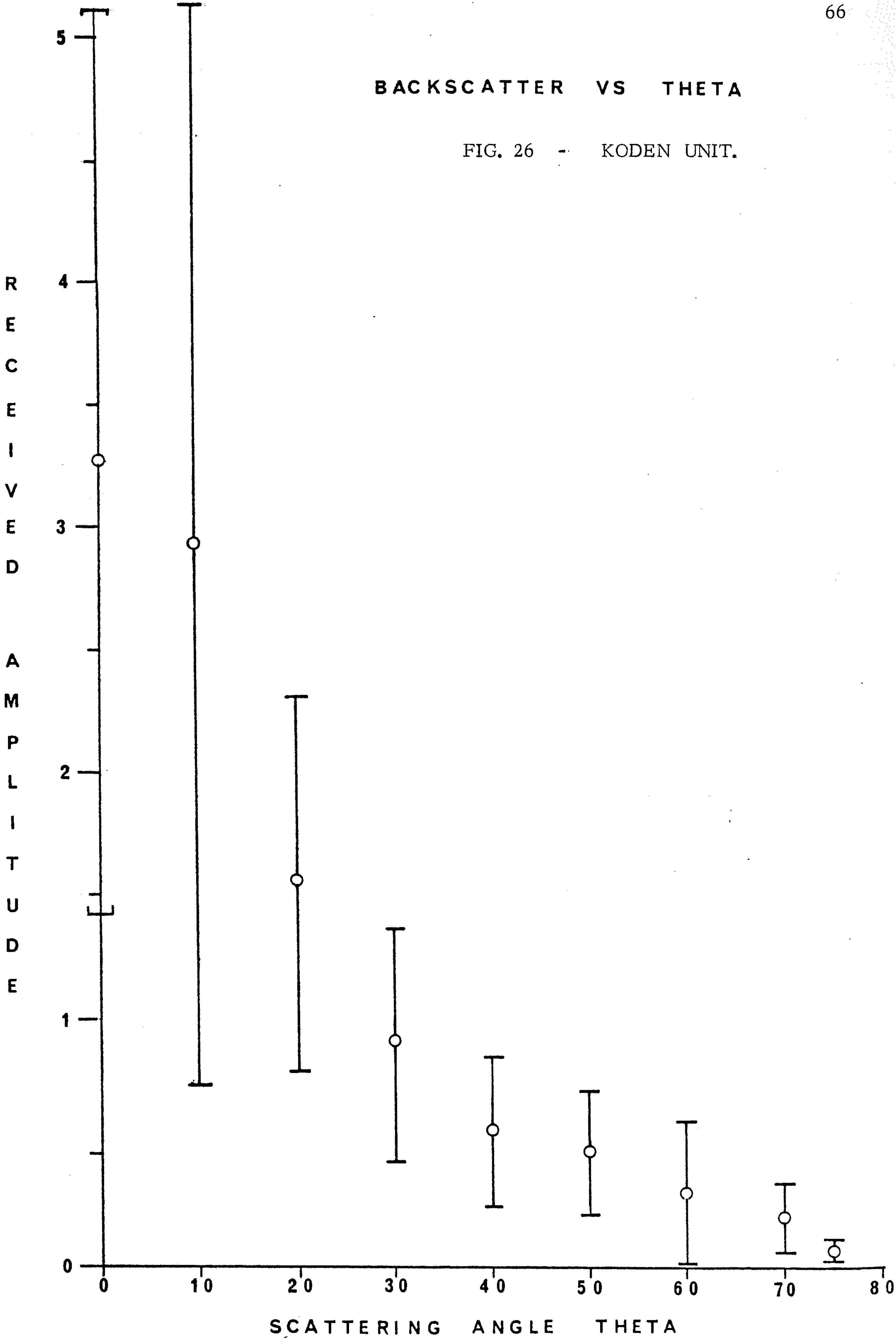
Average wet density over top 7.54 cm = $1.62 \pm .11$ gm/cm^3

Average wet density over top 15.40 cm = $1.69 \pm .11$ gm/cm^3

It is clear that the Furuno unit provided the best prediction of the wet density at the Fremantle site and the literature suggests that the accuracy of such estimates could be improved. This subject is presently receiving further attention.

In summary, it would appear that wide angle, low frequency sounder beams could be used to provide quantitative R values which would be relatively insensitive to topographic effects in a sedimented sea bottom area. Such R values could provide information on sediment porosity and/or wet density. This technique amounts in essence to quantifying and refining the existing technique used by skippers to reveal variations in bottom hardness. The relationship between prawn species and sediment type is currently a subject of research in Western Australia, although establishing the form, if any, of such a relationship may call for more catchrate data than is readily available. (J. W. Penn - private communication). Should a relationship between habitat probability and physical sediment parameters emerge, however, it would appear likely that sediment mapping by acoustic means could aid in rapidly surveying for favourable habitat regions.

The variation of backscatter with θ was also studied in the Fremantle program and is discussed fully in Penrose (1977). For present purposes it will be useful to show the measured backscatter versus θ for a set of experiments using the Koden transducer. Figure 26 shows the data from these experiments. The mean backscatter voltage is plotted (circular points) and the fluctuations about the mean indicated by error bars. The error bars indicate ± one standard deviation about the mean, assuming the fluctuations are normally distributed. Results from thus and other beam angle work have been cited in section 4.3



BACKSCATTER VS THETA

FIG. 26 - KODEN UNIT.

5.0 REVIEW AND CONCLUSIONS

5.1 SUMMARY OF CONCLUSIONS

In Section 1.2 of this report, four problem areas were outlined. The major conclusions reached for each of these may be summarised as follows:

5.1.1 Detection Efficiency (see Section 1.2.1)

(i) The target strengths of penaeid prawns, of total length 14 - 18 cm have values, averaged over ±40° in the dorsal plane, of -47 ± 5dB re 1 metre.

(ii) Target strengths increase with animal lengths by approximately 14 dB over the length range 12 cm to 24 cm.

(iii) The peak target strength of an assembly of N prawns in a range slice can be expected to vary as $\sqrt{N}$ when the signal to noise ratio is high for all N values considered.

(iv) Shallow water ambient sea noise spectra are not well understood, especially at frequencies above 25 kHz. It is presently estimated that a minimum in shallow water ambient noise may occur at frequencies in excess of 150 kHz.

(v) For many working trawlers, the total background noise will be dominated by ship and ship motion generated components.

(vi) Because the Koden SRM 681 sounder provides relatively high pulse rates, the level of background noise, due to ship and ambient sources, is the major factor limiting the detection efficiency of this unit. In general, a high pulse repetition rate will enhance the probability that a marginal target will be distinguishable from all background noise components except volume reverberation.

(vii) Where total ambient noise levels are low, one prawn at a range of 20 metres has a high probability of providing a visible chart mark on a Koden SRM 681 unit, if the target lies within the main lobe of the sounder beam. Where noise levels are high, it is unlikely that single prawn targets will be resolved from the noise.

(viii) Where beds of snapping shrimp occur, noise interference can be expected, even at frequencies as high as 200 kHz.

(ix) Beam stabilisation, to remove roll and pitch excursions, could be expected to enhance detection efficiency for marginal targets.

Further improvement in the detection efficiency of the Koden sounder may well be possible, by utilising a combination of an improved signal to noise ratio and beam stabilisation. The possibility exists that an operating frequency greater than 200 kHz, by using a different segment of the noise spectrum, may improve the signal to noise ratio, even in the presence of potentially increased volume reverberation.

Improvements in detection efficiency, however, are not relevent in fisheries which experience continual echo interference from competing species.

5.1.2 Near-Bottom Detection (see Section 1.2.2)

(i) Near-bottom detection is enhanced by reduced pulse length. It is unlikely, however, that reduction below the Koden SRM 681 value of 100 μsec would be useful, since that value corresponds to a range slice thickness of 7.5 cm.

(ii) Narrow beam widths provide best near-bottom resolution, although only small areas are interrogated by such beams. Also, boat motion adversely affects the near-bottom resolution of narrow beams. Beam stabilisation can therefore be expected to improve vertical resolution in general, and near-bottom resolution in particular.

(iii) Where wide beamwidth operation is employed, some improvement in near-bottom resolution can be expected by choosing suitable off-axis beam angles. Such operation will not be as effective as (ii) above except on very flat bottoms.

5.1.3 Resolution from Competing Species (see Section 1.2.3)

(i) Many trash fish commonly encountered in several prawning grounds have target strengths essentially indistinguishable from prawns of commercial size. In general, it is not possible to distinguish such competing species from prawns on the basis of the form of individual echo returns.

(ii) Where trash fish occur, and are not completely intermingled with the prawn population, some vertical separation of the two echo producing populations may occur. In order for such separation to be apparent on the chart record, the sounder requires a high degree of spatial resolution in the vertical direction. Again, short pulse lengths, narrow beam angles and beam stabilisation are appropriate.

Thus, where vertical resolution is a critical factor in sounder performance, short pulse length, narrow beam operation is in order. Such beams are particularly susceptible to boat motion effects. Beam stabilisation is a feature of a number of relatively low cost sonar systems and at least one manufacturer offers this facility on an echo sounder. The inclusion of beam stabilisation may thus become a cost-effective measure where echo sounding is used in a valid search role for the widely distributed species.

5.1.4 Bottom Coverage (see Section 1.2.4)

(i) Where echo sounding is used as a major tool in target searching, as in the banana prawn fishery, the small areas and volumes interrogated by single beam sounders reduce search effectiveness and efficiency.

(ii) The effectiveness of the Koden SRM 681 sounder can, in principle, be enhanced by the use of two units, angled beams and suitable control circuitry.

(iii) Because of the operator fatigue associated with lengthy monitoring of chart records, advantage is seen in providing an automatic target warning function to augment operator monitoring of echo sounder records.

(iv) A prototype device has been developed to implement (ii) and (iii) above.

(v) The difficulties associated with interpreting sonar records from shallow water, near-bottom targets may well preclude successful implementation of sonar in e.g., the Gulf of Carpentaria fishery. However -

(vi) It may be possible, by suitable attention to beam geometry, signal processing and methods of graphic display, to provide useful sonar records in the Carpentaria banana prawn fishery. Such a program would require a thorough analysis of a working sonar system.

(vii) Experimentation and a literature review carried out on sea bottom classification by acoustic means suggest that useful quantitative information on the porosity of bottom sediments is obtainable from suitably treated echo returns.

5.1.5 General Conclusions

Several potentially useful topics have emerged from the study. Further attention to the form of signal/noise ratios, the use of beam stabilisation and double beam sounding each appear to offer some advantage. Of these, the double beam proposal has been the simplest to implement and possibly has the most potential as a factor influencing profitability. Accordingly this proposal has been pursued as vigorously as possible. The remaining proposals are discussed in Section 5.2 below.

5.2 FURTHER WORK

As discussed in Section 4.2 above, the prototype twin beam and target warning system is due to undergo field trials during the 1978 banana prawn season, and a report to the Fishing Industry Research Committee is planned for the end of the year.

The author is undertaking marine acoustics research during 1978 at the Scripps Institution of Oceanography and at several locations in Britain. Much of this work will be directly relevant to Australian echo sounder and sonar practice.

Part of the original aims of the present research program involved the development of a resource centre in marine acoustics at the Western Australian Institute of Technology to provide a general service to the fishing industry. The experience built up during this program, and the equipment and information collected, suggest that some progress towards this goal has been made. Several issues have emerged from the present program, which may well merit closer consideration. These include -

- a detailed study of noise sources affecting sounder operation in the prawning industry. This would involve, in particular, an examination of shallow water, high frequency ambient noise behaviour, of the detailed effect of transducer mountings related to the hull shapes of Australian trawlers and of the electrical and mechanical noise sources present on a number of working trawlers,
- a review of the technology and costs associated with beam stabilisation applied to echo sounding, and
- a detailed review of shallow water sonar performance, including a survey of sonar usage in the Gulf of Mexico shrimp fishery.

5.3 PUBLICATIONS

The present report draws on a series of theses and reports which, in sum, describe most facets of the research program in detail. These are listed in the References and are -

Cartledge, D. (1977) - detailed electronic design related to the prototype device (Section 4.2).

Fallon, G. (1977) - Project Report, describing signal and data processing related to the target strength measurement program (Section 2.1).

Penrose, J. (1977) - Project Report, dealing with bottom properties (Section 4.4).

Simpson, C. (1977) - Project Report, dealing primarily with aspects of penaeid prawn biology

Sofoulis, N. (1977) - Master's Thesis, currently undergoing examination (Sections 2.0 and 3.0).

Subject to approval from the Fishing Industry Research Committee, it is intended that material be prepared for publication in "Australian Fisheries". Several publications suited to academic journals are currently in preparation.

During the research program, a series of publications dealing with various aspects of marine acoustics have been produced. These are -

Booth, C., Beer, Tom and Penrose, J. D. "The Diffusion of Salt in Tap Water" to be published in American Journal of Physics.

Penrose, J. D. (1976) "Marine Acoustics at WAIT" The Australian Physicist, April, 63.

Penrose, J. D. and Beer, Tom (1977) "Acoustic Reflection from Estuarine Pycnoclines" Technical Report PD136/1977/ES10, Physics Department, Western Australian Institute of Technology.

Meyer-Rochow, V. B. and Penrose, J. D. (1974) "Sound and Sound Emission Apparatus in Puerulus and Postpuerulus of the Western Rock Lobster (Panulirus Longipes)" Journal of Experimental Zoology 189, 283.

Meyer-Rochow, V. B. and Penrose, J. D. (1976) "Sound Production by the Western Rock Lobster Panulirus Longipes" J. Exp. Mar. Biol. Ecol. 23, 191.

Oldfield, B. P., Penrose, J. D., Bailey, W. J. and Meyer-Rochow, V. B. "Sound Induced Behavioural Modification in the Western Rock Lobster Panulirus Longipes" submitted for publication.

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Albers V. M. (1965) "Underwater Acoustics Handbook II" Pennsylvania State University Press, Pennsylvania.

Bezdek H. F. (1973) "Reflection of High Frequency Sound at Normal Incidence from the Ocean Bottom" Journal of Geophysical Research 78, 3390.

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Fallon G. (1977) "Acoustic Scatter from Random Targets" Undergraduate Project Report UG104/1977/ES2 Physics Department, Western Australian Institute of Technology

Forbes S. T. and Nakken O. (1972) (Eds) "Manual of Methods for Fisheries Resource Survey and Appraisal" Part 2 "The use of acoustic instruments for fish detection and abundance" F.A.O. Rome.

Hamilton E. L., Shumway G., Menard H. W. and Shipek C. J. (1956) "Acoustic and other Physical Properties of Shallow-Water Sediments off San Diego" J.A.S.A. 28, 1.

Haslett R. W. G. (1965) "Acoustic backscattering cross sections of fish" Brit. J. Appl. Physics 16, 1143.

Horton C. W. (1972) "A Review of Reverberation, Scattering and Echo Structure" J.A.S.A. 51, 1049.

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McKinney C. M. and Anderson C. D. (1964) "Measurements of Backscattering of Sound from the Ocean Bottom" J.A.S.A. 36, 158.

McLeroy E. G. (1972) "Measurement and Correlation of Acoustic Reflection and Sediment Properties off Panama City, Florida" Informal Report NCSL-112-72 Naval Coastal Systems Laboratory Panama City, Florida, U.S.A.

Penrose J. D. (1977) "Some Aspects of Acoustic Scattering from the Sea Bottom" Technical Report PD138/1977/ES11 Physics Department, Western Australian Institute of Technology.

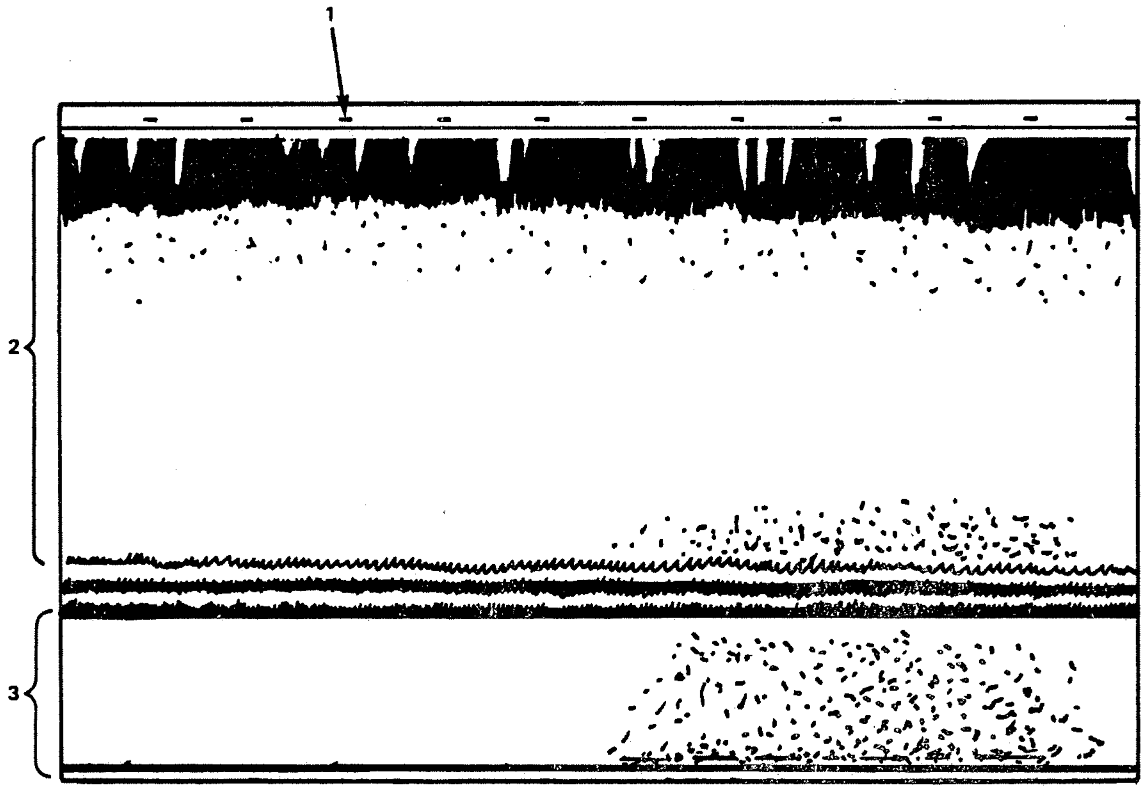
Peterson M. L., Clay C. S. and Brandt S. B. (1976) "Acoustic Estimates of Fish Density and Scattering Function" J.A.S.A. 60, 618.

Simpson C. (1977) "The Use of Echo Sounders in the Western Australian Prawning Industry" P. G. 1 (Natural Resources) Project Report Western Australian Institute of Technology.

Sofoulis N. G. (1977) "A Study of the Acoustic Target Strengths of Small Targets relevant to the Prawning Industry" MSc Thesis Physics Department, Western Australian Institute of Technology.

APPENDIX I - NOTES ON THE INTERPRETATION OF KODEN CHART RESULTS

The diagram below gives, in outline form, the main features which appear on Slide 2, an example of the chart record resulting from the use of the Koden SRM 681 sounder in the bottom lock mode.



1. Timing marks, which appear at 1 minute intervals
2. Main chart display. This is a conventional wet-paper display, with white line control influencing the form of the bottom representation.
3. Bottom lock display. Here, the bottom 3 metres of the main chart display is presented in a vertically expanded form, and with the bottom presented as completely flat. Note that "ringing" of large near bottom signals produces line echoes within the heavy near bottom fish echoes. The horizontal line drawn half way up the bottom lock display indicates the approximate limit of the region sampled by the try net used during the recording of thus chart result, assuming that the net remained in contact with the sea bottom.

APPENDIX II - NOTES ON BIOLOGICAL TERMINOLOGY

Throughout the text of this report, several commercially fished prawn species are described by their common names. The common and scientific names for the species cited are:

Banana Prawn	Penaeus Merguiensis
Western King Prawn	Penaeus latisulcatus
Endeav~~eav~~our Prawn	Metapenaeus endeavouri
Tiger Prawn (Typically) the brown tiger prawn)	Penaeus esculentes

The term "trash fish" has been used in several occasions in the report, and refers to various competing species in several fisheries, notably the leatherjacket fish (paramonacanthus oblongus).

Throughout the report, total lengths are used to describe specimen size. In the case of the prawns used, total length has been measured from the tip of the rostrum extension to the end of the tail, with the animal in a fully extended position.

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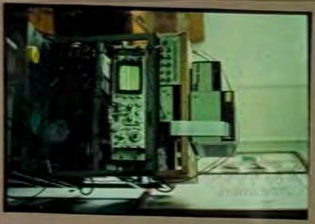

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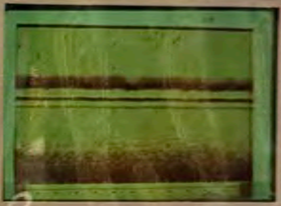

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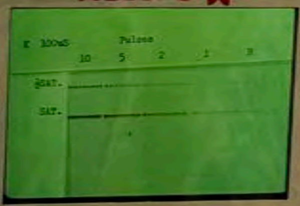

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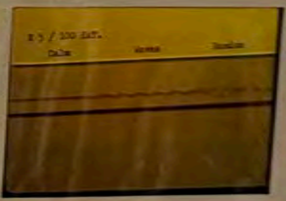

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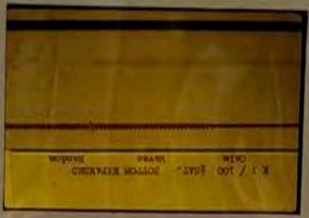

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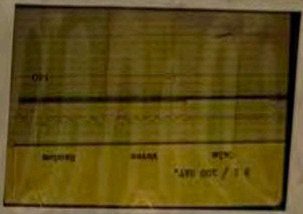

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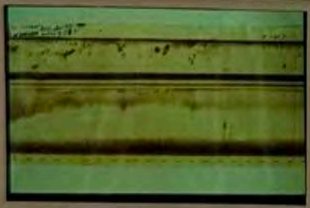

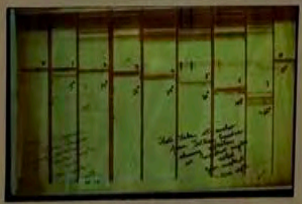

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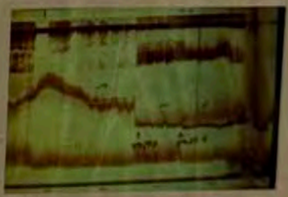

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