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A PRELIMINARY INVESTIGATION OF THE TARGET STRENGTH OF HERRING

by

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Summary

This contribution describes five experiments designed to measure the target strength per kilogram of live caged herring. It describes the experimental method employed, reports the results of each experiment, discusses the probable sources of error and concludes that the mean target strength per kg of herring in the size range 21-25 cm is -31.5 dB.

Résumè

Cette contribution décrit 5 expériences destinées a mesurer la valeur de reflection du cible par kilo des harengs vivants. Elle décrit la méthode expérimentale utilisée, rapport les résultats de chaque expérience, discute les sources probables d'erreur, et conclu que la force objective moyenne par kilo de hareng dans la gamme 21 à 25 cm est -31.5 dB.

Introduction

To enable estimates of area back-scattering strengths to be converted to estimates of biomass, fisheries scientists must know the average target strength for the species of fish under observation. There are several methods of measuring target strength (Goddard and Welsby, 1977; Nakken and Olsen, 1977; Johannesson and Losse 1974). The method reported here follows that developed by Johannesson et al. (1974), Edwards (1975) and Dunn (1979) and has been adapted and applied to measurements of herring.

The fish are free-swimming but confined within an experimental cage. The target strength measured in the experiments reported here is obtained by measuring the area scattering coefficient (steradian^{-1}) of a group of fish and their corresponding density in kg m^{-2}, thus yielding the target strength per kilogram in dB//1 m^{2} steradian^{-1} kg^{-1}.

The five experiments reported here were conducted at Loch Duich on the West Coast of Scotland in November and December, 1979.

Experimental Techniques

The problems associated with the measurement of live caged fish have been investigated in a series of experiments which started in 1975 (Edwards, 1975). The equipment used in these experiments was similar to that described by Dunn (1979). It consisted of an experimental cage rigged within a guard cage, suspended below a transducer platform. The experimental cage was at a range of approximately 6 m from the transducer face. Fish were placed within the experimental cage and the whole rig was lowered on a single suspension wire so that the experimental cage was approximately 17.5 m below the surface. Figure 1 illustrates the experimental equipment. A low-light TV camera was positioned below the experimental cage, which allowed monitoring of the fish during day-light hours without the use of artificial lighting. A reference target (72.4 mm brass ball) was suspended using a three-part suspension at a range of approximately 3 m below the transducer. The position of the brass ball was carefully adjusted to locate it on the acoustic axis of the transducer.

The experimental rig, as described above, was suspended below a raft, moored in 100 m of water and connected by 1 km of cable to a mobile laboratory, sited onshore. The laboratory contained a transmitter, receiver, data logging computer and TV monitoring and recording systems. The raft was equipped with hydraulic lifting equipment to assist in the deployment of the experimental equipment. The general experimental arrangements are illustrated in Figure 2.

The transducer used was a Simrad 38-26/22-E 38 kHz ceramic unit, powered by a 2 kW transmitter which transmitted a 500 μsec pulse. The echoes received were first amplified and then processed by an envelope detector circuit which removed the carrier frequency whilst retaining the shape or envelope of the pulse. The envelope was sampled at a rate of 0.1 msec. Each sample was then converted into a 12 bit binary number. These numbers were read by the computer which then applied a range correction of the form $20 \log R + 2 \alpha R$ and then squared to obtain a number proportional to the returned power. The samples were then range gated and selected portions summed to produce an integrated echo energy. The repetition rate between samples was 0.3 sec. The computer was programmed to collect and analyse 1000 transmissions, which takes five minutes, and then suspended data collection for one minute to produce a summary of the last 1000 transmissions. The summary was presented in the form of histograms on a graphics VDU. It was also printed on a line printer, and the raw data was stored on magnetic tape for further analysis. A sample of the histogram is illustrated in Figure 3. This six minute cycle was repeated throughout the experiment.

The five herring experiments differed from the gadoid experiments reported by Edwards (1975), Dunn (1979), and Forbes, Simmonds and Edwards (1980) in several ways. Adaptations were required to overcome the difficulties associated with handling herring. Herring are very difficult to capture live and keep in good condition. In particular, fish which loose more than about 10% of their scales during the capture and handling processes usually die within a few hours. To overcome this a method of transferring and transporting herring which eliminated contact between fish and container had to be developed. The fish were captured using a two-boat ring netting technique. The herring were encircled in the normal way, but instead of drying out the net and taking the fish on board, the ring net was left as a loose bag. A fish transport barge (Edwards, 1980) was then manoeuvred alongside the net and the herring were transferred using large plastic buckets from the ring net into the barge. The barge was then towed to the experimental site and used to store the herring until required. At the start of each experiment the barge was manoeuvred alongside the experimental rig. A section of the herring population in the barge was isolated using a mobile curtain net and the fish were then transferred to the experimental cage using large plastic buckets. This method of capture, transport and transfer enabled undamaged herring to be introduced into the experimental cage.

The experimental cage was constructed from a nylon-reinforced, resin-coated netting (5 mm bar). The cage was octagonal in plan, 2 m wide measured across the flats and 1 m deep. Netting of this type was found to present an effective boundary which did not damage the fish.

When the required number of fish had been transferred to the experimental cage (between 68 and 250 fish) the cage was lowered in 3 m steps to 17.5 m. Each 3 m increment took approximately 1 minute and the fish were maintained at the intermediate depth for approximately 5 minutes. The process of lowering the fish to 17.5 m took 40 minutes. The closed circuit TV system was used to monitor the behaviour of the herring during this increase in pressure.

The fish remained at 17.5 m throughout the experiment, data being continuously collected using the six minute cycle detailed above. In experiments 7/79, 8/79 and 11/79 artificial lighting was used to supplement natural light and extend the period during which the TV system could be used to monitor the condition and behaviour of the fish. (The experiment numbers refer to the numbering sequence used at the Loch Duich Field Station.)

At the end of each experiment the fish were recovered and individually weighed and measured.

Results

The results were calculated on the basis of a direct comparison between the standard reference target (a brass ball at a range of 3.3 m) and a table tennis ball placed at the same range as the fish. Both targets were adjusted to be on the acoustic axis of the transducer. The table tennis ball was taken to have a target strength of -42 dB. The comparison gave a target strength of -31 dB for the standard target. All the results quoted below are based on this comparison.

The effective beam angle for the transducer (10 log Ø) was calculated to be -17.14 dB. This calculation takes into account the limited size of the experimental cage.

The equivalent area scattering coefficient of the inner experimental cage was measured over a period of two days as -39.4 dB//steradian^{-1}. The data were corrected by subtracting the corresponding energy from the energy of the fish echo.

The data from the five experiments on herring performed in November and December, 1979, are summarised in Table 1. The best estimate of the target strength per kg was calculated after a close examination of the mortality and condition of the fish as monitored on the low-light TV system, combined with the information extracted from the acoustic data. Before data was included in the best estimate it had to satisfy the following criteria:-

1 The herring had to be in good condition with less than 5% mortalities or escapes.

2 The distribution of the herring within the cage had to be uniform.

3 The 12 and 24 hour running means of target strength per kg had to be well-behaved.

The data for each experiment is summarised below. One, twelve and twenty-four hour running means are plotted in Figures 3 to 7.

Experiment 7/79 (Figure 3)

The first experiment was terminated after less than twenty-four hours when mortality had reached twenty-five fish out of the original one hundred and eleven placed in the experimental cage. The estimate (-31.2 dB per kg for herring of mean length 22.24 cm) is based on the first nine hours of data during which time only one mortality occurred. The fish showed a tendency to increase their target strength over this initial period by approximately 2 dB per kg. The cause of this increase is not fully understood, but it is thought to result from changes in behaviour due to a decline in the condition of the fish. Overhead lighting was used at various times to enable TV pictures to be obtained at night.

Experiment 8/79 (Figure 4)

This experiment lasted for approximately six days during which time the mortality increased progressively from ten dead at the end of the second day to forty-eight dead out of the original sixty-eight fish at the end of six days. The estimate of target strength (-30.2 dB per kg for herring of mean length 21.77 cm) includes only the first thirty-three hours of data collected, at the end of which four fish were dead. The target strength showed a tendency to decrease by approximately 1 dB during the first four hours of the experiment, remain steady for approximately three hours and then steadily increase as the dead fish lying on their sides at the bottom of the cage contributed an increasing amount to the integration. Again overhead flood lighting was used at various times to enable TV pictures to be obtained at night.

Experiment 9/79 (Figure 5)

Slightly larger fish were used in this experiment, which was terminated after two days when the mortality of the herring had increased to above the 50% level. Data from the first nine hours were used for the estimate of target strength (-32.5 dB per kg for herring of mean length 24.79 cm). At the end of this period eight fish out of the original eighty had died. No artificial light was used during this experiment. The target strength appeared to be stable over the first few hours of this experiment, but as in the previous two experiments it increased gradually as the number of dead fish increased.

Experiment 11/79 (Figure 6)

This experiment used herring which had been handled with improved techniques and increased care to prevent physical damage to the fish. Flood lighting was also used throughout the duration of the experiment. Only five fish died out of one hundred and sixteen over a four day period during which time the target strength (-31.2 dB per kg for herring of mean length 24.07 cm) remained virtually constant, with hourly means varying by less than 2 dB. The target strength showed a tendency to increase over the first few hours of the experiment.

Experiment 12/79 (Figure 7)

The final experiment used approximately twice as many fish (250) as Experiment 11, but unfortunately was plagued by defects in the experimental cage which allowed fish to escape into the guard cage although mortality was low. Once the fish had escaped into the guard cage they were excluded from the integration interval thus causing a progressive drop in apparent target strength during the first half of the experiment. The initial target strength of the herring actually rose slightly and then fell during the first 3 hours of the experiment. Data from the first twenty-eight hours were used in the calculation of target strength (-31.9 dB per kg for herring of mean length 23.79 cm). At the end of this period the number of fish which had escaped was ten, out of the original two hundred and fifity. No artificial lighting was used during this experiment.

Discussion

Previous target strength experiments performed by Marine Laboratory staff at Loch Etive (Edwards, 1975), Loch Hourn and Loch Duich (Dunn, 1978; Forbes, Simmonds and Edwards, 1980) have concentrated on gadoids, especially cod, haddock, whiting and saithe. Both the gadoid and herring experiments shared a similar experimental technique, but two major modifications had to be made to allow the more delicate herring to survive.

Firstly, the method of transport and transfer of live herring had to be completely redesigned so as to minimise the physical damage and loss of scales. The use of large plastic buckets filled with water to transfer the herring from the ring net to the fish barge and subsequently from the fish barge to the experimental rig enabled mortalities to be kept within acceptable levels and ensured that the herring could be measured in good condition. In the light of experience gained in experiments 7/79, 8/79 and 9/79 the transfer techniques were improved for experiments 11/79 and 12/79. This improvement took the form of reducing the number of fish within the bucket for each transfer and carrying out each transfer more slowly and carefully. As a result, the period for which valid target strength measurements could be obtained was extended from approximately one day to four days.

Secondly, the inner experiment cage had to be reconstructed to prevent the more active herring from either escaping or becoming entangled in the mesh. This was achieved by the use of a resin-coated fibreglass netting which was more visible than the netting used in gadoid experiments, had a smaller mesh size to prevent escapes and a smoother texture to prevent entanglement.

The most striking difference between the acoustic properties of herring and gadoids is the relatively small long-term variation in the herring target strength data. The short-term variation, as measured by the standard deviation of a single six minute data block (1000 samples), is in the region of 80%, a similar value to that obtained from gadoid experiments. However, the gadoid experiments were characterised by an acclimatization period associated with the increase in depth. This period lasted between one and a half and seven days, during which time the target strength increased by between 4 dB and 11 dB. A typical cod experiment is illustrated in Figure 8, when 4.47 kg of cod were subjected to an increase in pressure from one atmosphere to 2.75 atmospheres, produced by lowering the fish from near the surface where they had been kept, to 17.5 m where the measurements were made. The herring measured in the experiments reported here were subjected to a similar increase in pressure but no long-term acclimatization effects are evident in the data. The initial variations in target strength do not demonstrate any conclusive trend. Of the five experiments reported, two (7/79 and 11/79) showed a tendency for the target strength to increase for the first few hours of the experiment, and one (8/79) showed a tendency for the target strength to decrease. In experiment 9/79 the target strength remained constant, whilst in experiment 12/79 it rose and fell within the first few hours of the experiment.

Changes in the target strenghts of gadoids when subjected to increased pressure have been attributed to changes in swimbladder size. The acoustic mis-match between the gas contained within the swimbladder and sea water is thought to account for a large proportion of the energy reflected from the gadoids. Thus a change in the size of the swimbladder in response to a change in pressure would cause a change in target strength. Although the structure of the swimbladder in herring and gadoids is different in that gadoids have a large unvented swimbladder while herring have a smaller vented one, it might be expected that they would react to an increase in pressure in a similar way. The target strength of herring would be reduced as the pressure increased rapidly, but not to the same extent as in gadoids. This does not appear to be the case and the reasons are not yet clear. Four possible explanations are outlined below:-

1 That the tilt angle (that is, the angle which the axis of the fish makes with with the horizontal plane) in gadoid experiments is responsible for the change in target strength and that the variations in target strength caused by changes in swimbladder size are small.

2 That the relatively small size of the swimbladder in herring has little effect on the target strength of the fish.

3 The herring can acclimatize very quickly.

4 That conditions within the experimental cage prevent the herring from acclimatizing.

Further experiments on the target strength of herring are planned for November and December, 1980, in an effort to clarify this question.

At the latitude of Loch Duich (57°20'N) there are only about 7 hours of daylight in November and December and the prevailing weather conditions further reduce natural light levels. These conditions restricted the proportion of the day during which TV pictures could be taken. Thus it became necessary to use artificial lighting to obtain a more continuous monitoring of the behaviour and condition of the fish. However, the reaction of caged herring to artificial lighting is not fully understood and the use of artificial lighting was restricted in the knowledge that it was likely to cause unnatural behaviour and hence influence the target strength measurements.

Initial observations on the effects of changes in light level were made during experiments 7/79 and 8/79. Switching the flood lights on and off caused a distinct increase in the activity of the fish. The disturbances lasted approximately five minutes after the lights were either switched on or off. Observations on the effects of switching the lights off were made when light levels were just above the minimum required for the TV system to operate without artificial light. In experiments 9/79 and 12/79 no artificial lighting was used, but in experiment 11/79 the artificial lighting was used throughout. Subjectively, the one and twelve hour running means in experiment 11/79 (Figure 6) are more constant than the corresponding means for experiments 9/79 and 12/79 (Figures 5 and 7). This suggests that light levels affect the behaviour of the herring in a way which results in differing long-term target strengths. The association between light levels and target strengths is not understood. However, one or a combination of the following factors could be responsible.

1 The herring may adopt different tilt angles at different light levels, thus a more constant light level induced by the continuous use of artificial light might cause a more constant target strength.

2 The size of the herring's swimbladder may be affected by different light levels. In the wild, herring tend to live in deeper water in daylight and come to the surface at night. This migration, which might be stimulated by changing light levels, involves a change in pressure and a probable change in swimbladder size, which would result in a change in target strength. Thus a more constant light level might cause a reduction in the variation in target strength by suppressing the stimulus which triggers the vertical migration.

3 The distribution of the fish in the cage may change with varying light levels. Unfortunately it was not possible to monitor the distribution of the fish without using flood lighting . Recent developments in monitoring systems using stroboscopic lighting may make it possible to observe fish in the dark without using general flood lighting. Experiments to investigate this approach are planned for December, 1980.

The results presented in this paper indicate that the variation in target strength was smaller when artificial lights were used throughout the experiment. However, experiments 9/79, 11/79 and 12/79 were considerably different in other respects, with mortality affecting experiment 9/79 and fish escapes changing the apparent target strength per kg in experiment 12/79. Further experiments to investigate the effects of light levels are planned for November and December 1980.

The reverberation levels associated with the experimental cage should ideally be low enough to be ignored, that is, less than 1% of the average energy returned from the fish. Unfortunately, the experimental cage used in the herring experiments contributed approximately 5% of the energy returned during the cage integration interval. However, measurements on the empty cage indicated that its target strength was reasonably constant ($\pm$0.25 dB) over a period of two days. In all the calculations of target strength, the energy returned from the empty experimental cage was subtracted from the energy returning from the fish before the target strength of the fish was calculated. Recent improvements in the construction and materials used for experimental cages should reduce this problem in future experiments.

The absolute accuracy of the measurements presented in this paper is dependent on several assumptions, the most important of which are outlined below. These have been analysed in detail by Forbes, Simmonds and Edwards (1980) and are listed here to point out the limitations of the data:-

1 That the target strength of a table tennis ball is -42 dB.

2 That the calculated equivalent beam angle (10 log Ø) is correct. The value used is based on a theoretically perfect transducer of dimensions equal to the nominal dimensions of the transducer used. (Equipment is under construction which should enable 10 log Ø to be measured accurately. If the measurements are successful this source of systematic error will be removed.)

3 That the target strength and position relative to the acoustic axis of the standard target do not alter throughout the duration of the experiments.

4 That the fish are evenly distributed within the experimental cage. Analysis of the video recordings indicates that during daylight hours the fish distribution is not obviously non-uniform. However, the precision with which these measurements were made was limited by the quality of the video recordings and processing equipment available, neither of which was sufficiently good to provide an unambiguous answer. The distribution of the fish during the hours of darkness cannot be assessed with equipment currently available.

Conclusions

Four conclusions are drawn from these experiments:-

1 That it is possible to capture, transport and transfer herring in a way which allows target strength experiments to be successfully made on live fish in captivity.

2 That subject to the possible errors discussed, the mean target strength for caged herring in the 21-25 cm range is -31.5 dB per kg.

3 That no short term acclimatization effects on the target strength of herring were observed, although these would have been expected from the mechanism thought to account for the acclimatization effects observed in experiments on gadoids.

4 That sudden changes in light level, although affecting the activity of the fish, do not seem to affect the target strength of fish. However, long term exposure to constant artificial light appears to reduce the fluctuation in target strength.

Acknowledgements

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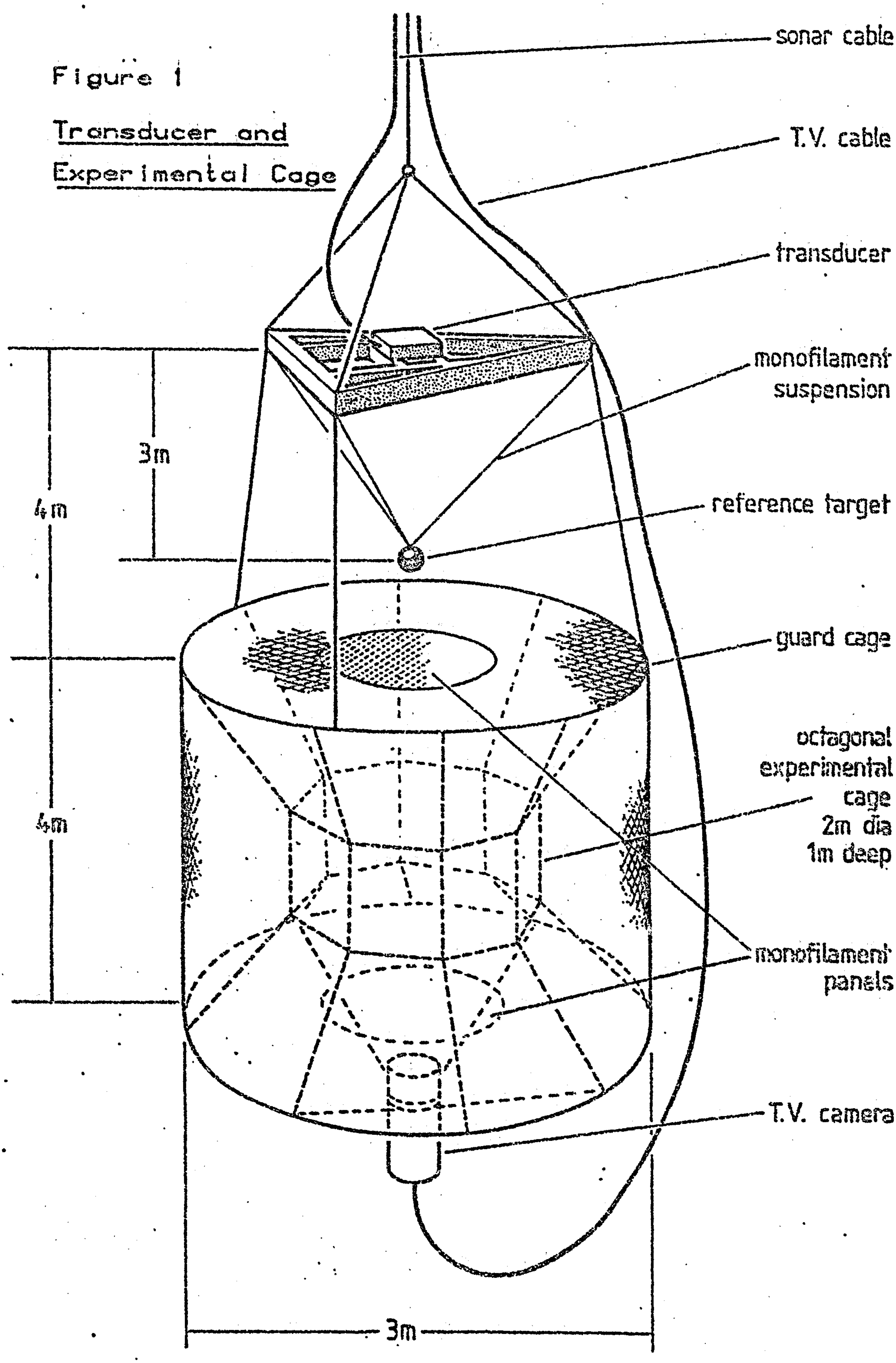
TABLE 1 - SUMMARY OF RESULTS

Exp.No.	No. of Fish	L(Mean) (cm)	L(SD) (cm)	W(Total) (kg)	W(mean) (gm)	W(SD) (gm)	Best estimate of TS per kg	Period for which best estimates calculated (hrs)
7	111	22.2411	1.77696	8.52	76.0714	20.9529	-31.2	9
8	68	21.7761	2.23486	5.803	86.6119	25.9329	-30.2	33
9	80	24.7875	1.6435	9.12	114.075	22.3402	-32.5	9
11	116	24.0727	2.50746	17.344	104.824	29.8175	-31.2	100
12	250	23.792	3.0387	24.92	99.676	33.7536	-31.9	28

Figure 1

Transducer and Experimental Cage



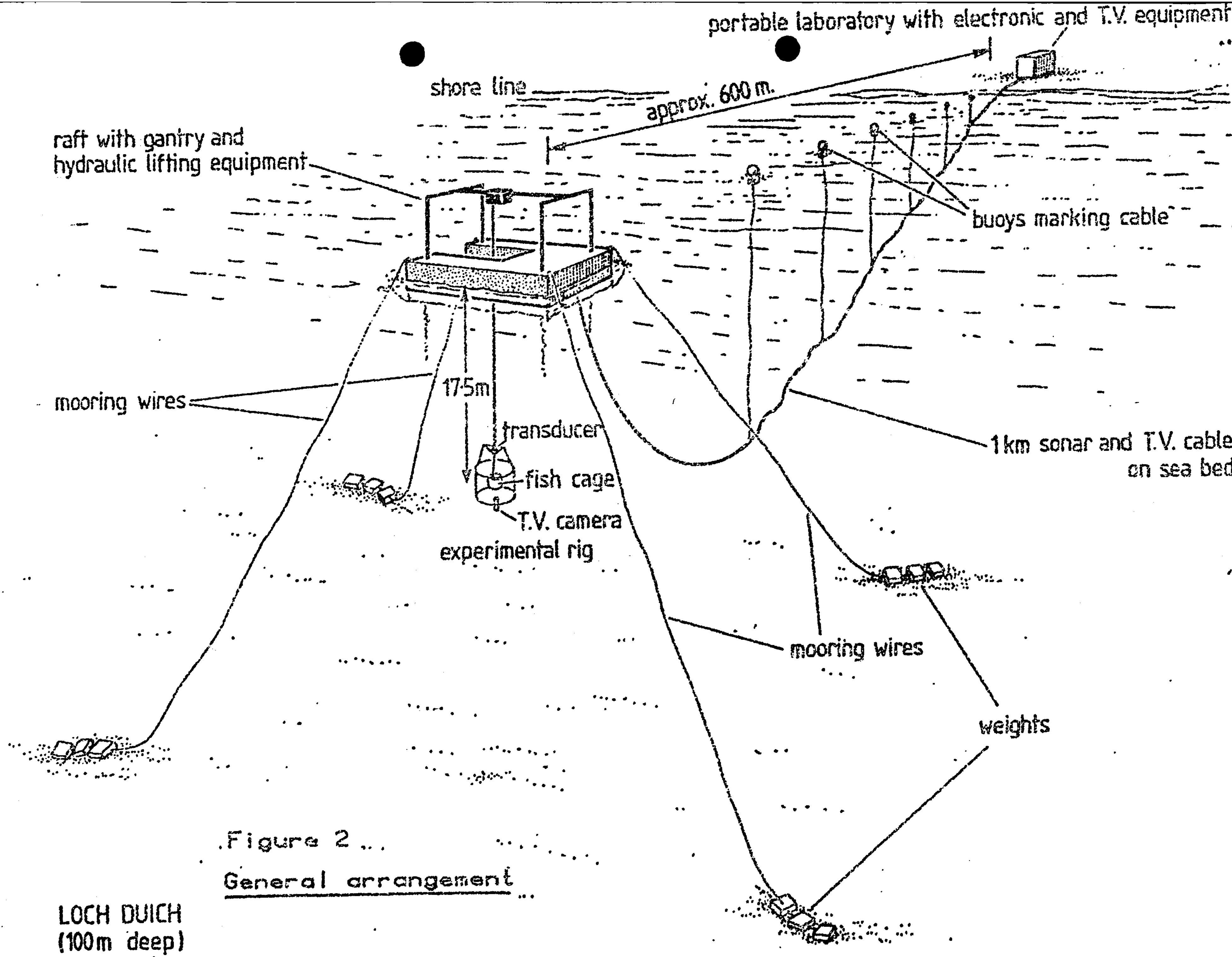


Figure 2

General arrangement

Figure 3

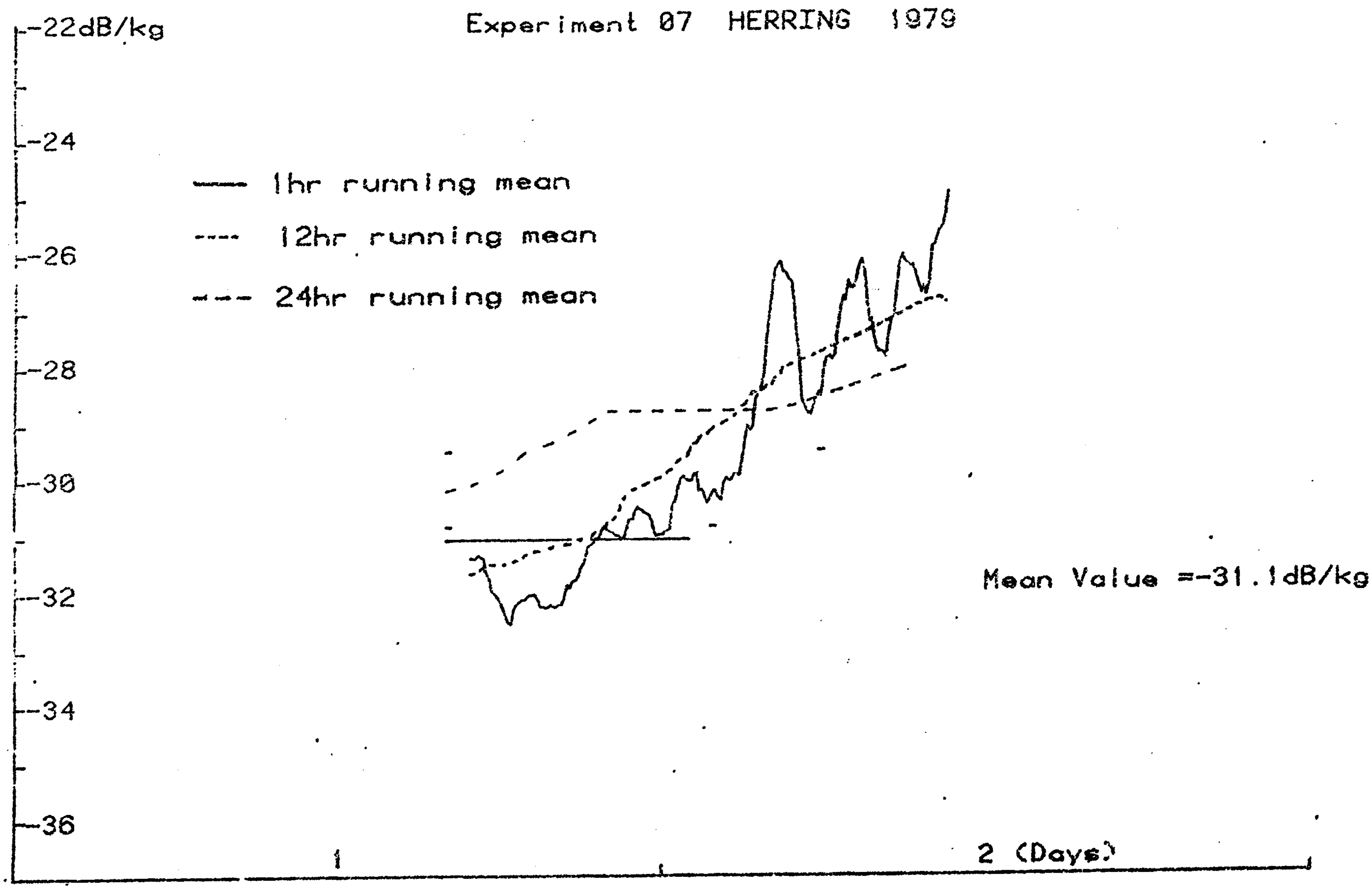
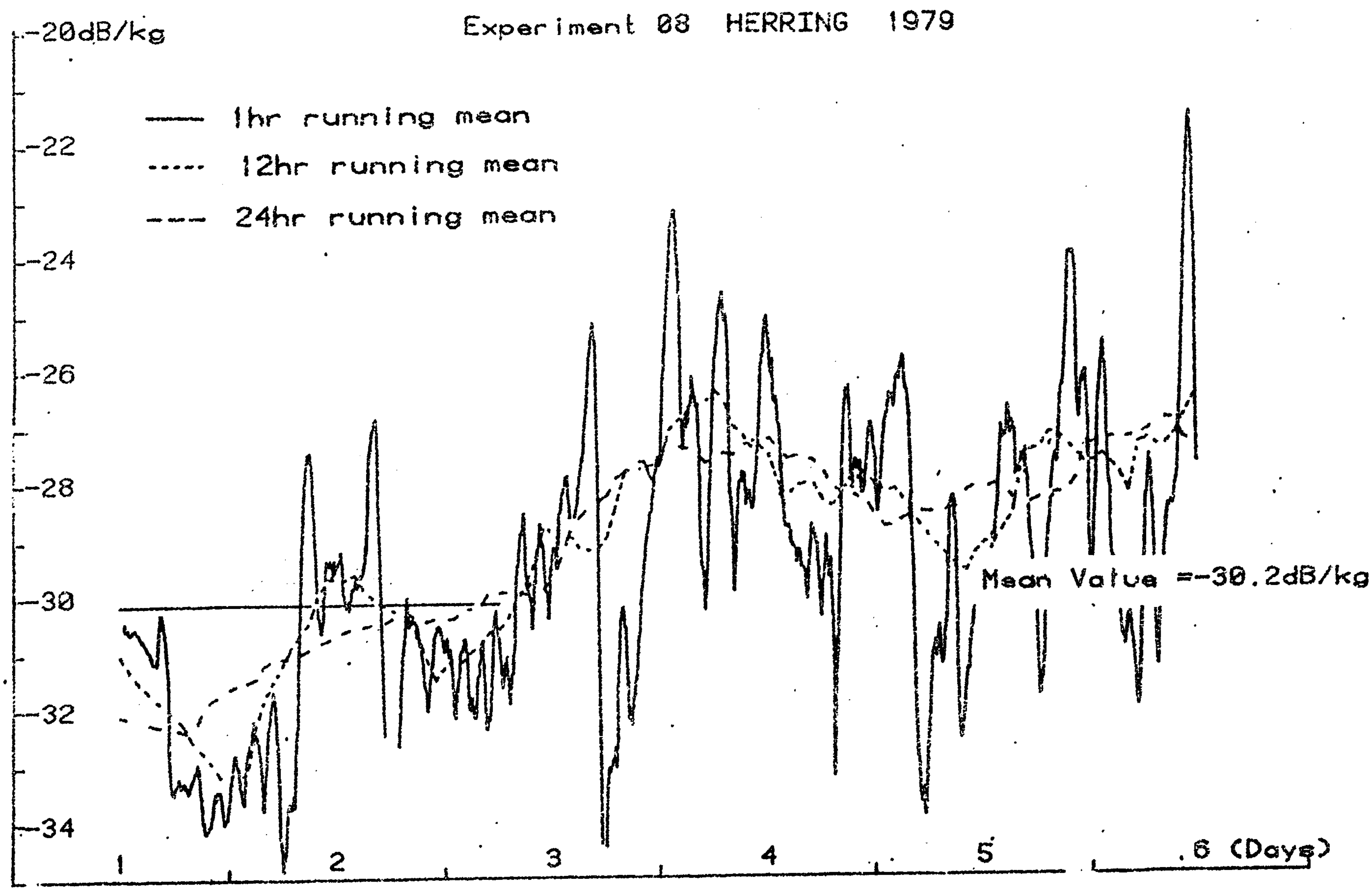

Experiment 07 HERRING 1979
-22dB/kg
-24
-26
-28
-30
-32
-34
-36
1hr running mean
12hr running mean
24hr running mean
Mean Value =-31.1dB/kg
1
2 (Days)

Figure 4



Experiment 08 HERRING 1979
-20dB/kg
-22
-24
-26
-28
-30
-32
-34
1hr running mean
12hr running mean
24hr running mean
Mean Value =-30.2dB/kg
1
2
3
4
5
6 (Days)

Figure 5

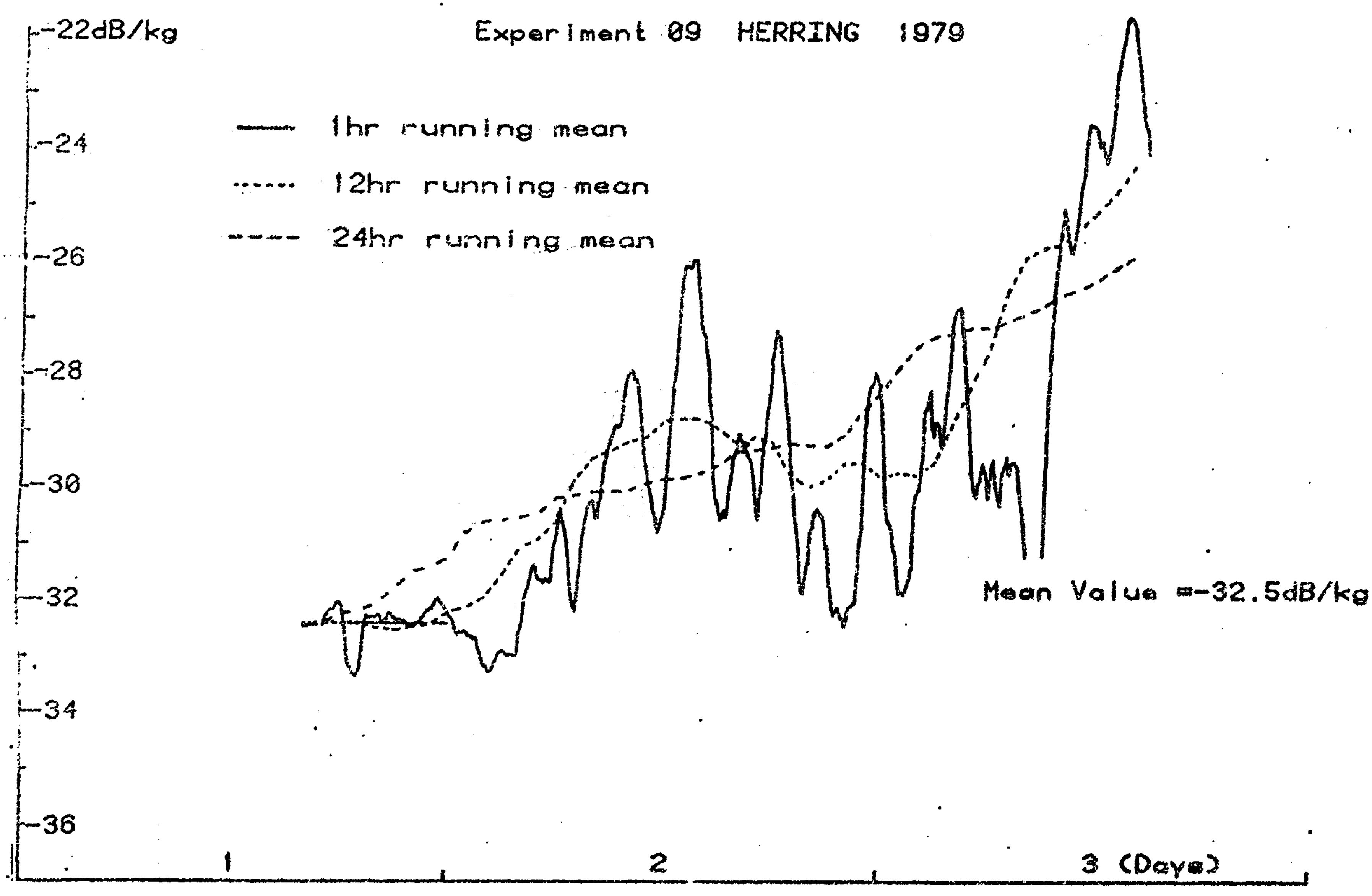
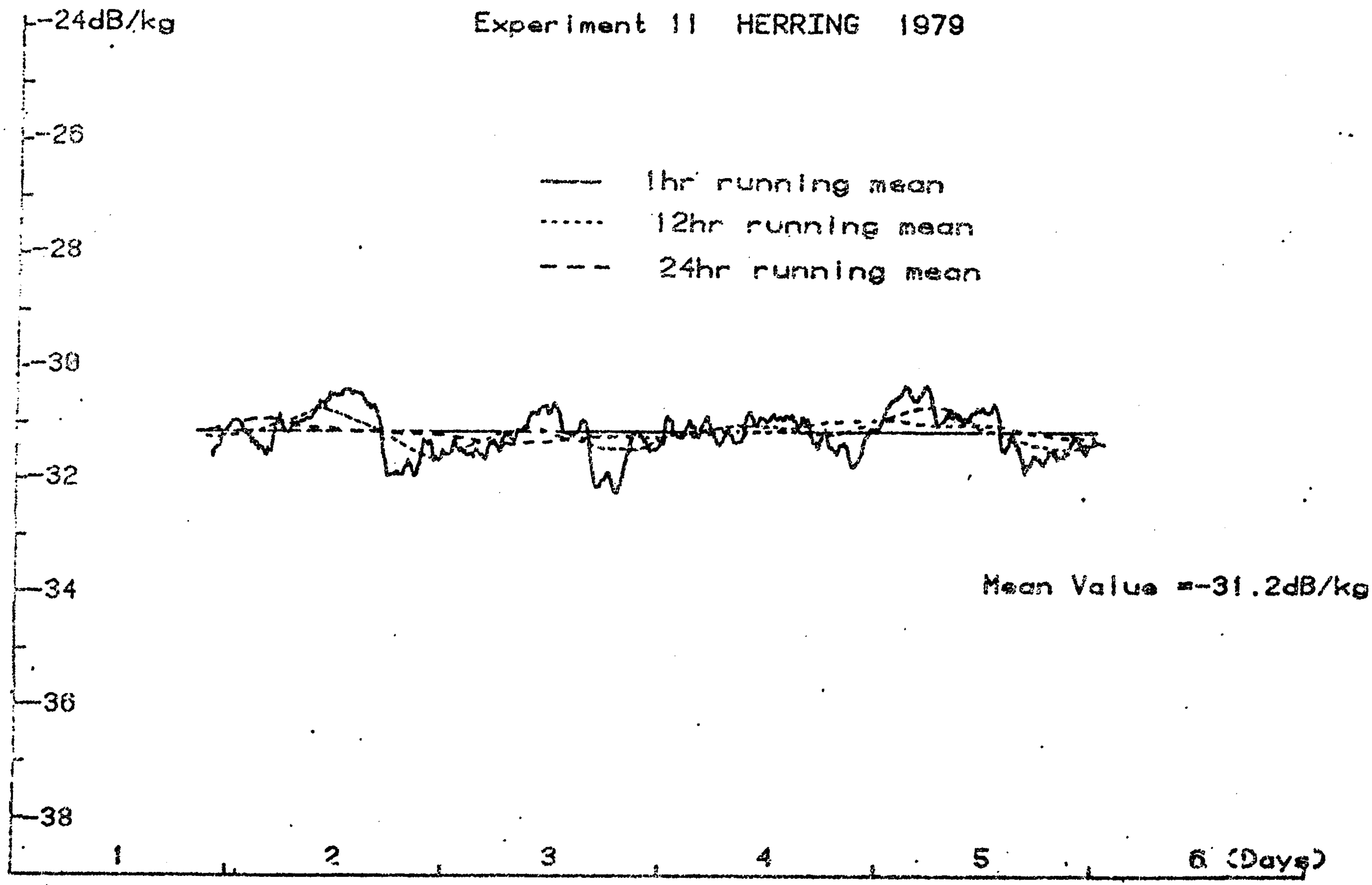

Experiment 09 HERRING 1979
-22dB/kg
-24
-26
-28
-30
-32
-34
-36
1hr running mean
12hr running mean
24hr running mean
Mean Value =-32.5dB/kg
1
2
3 (Days)

Figure 6



Experiment 11 HERRING 1979
-24dB/kg
-26
-28
-30
-32
-34
-36
-38
1hr running mean
12hr running mean
24hr running mean
Mean Value =-31.2dB/kg
1
2
3
4
5
6 (Days)

Figure 7

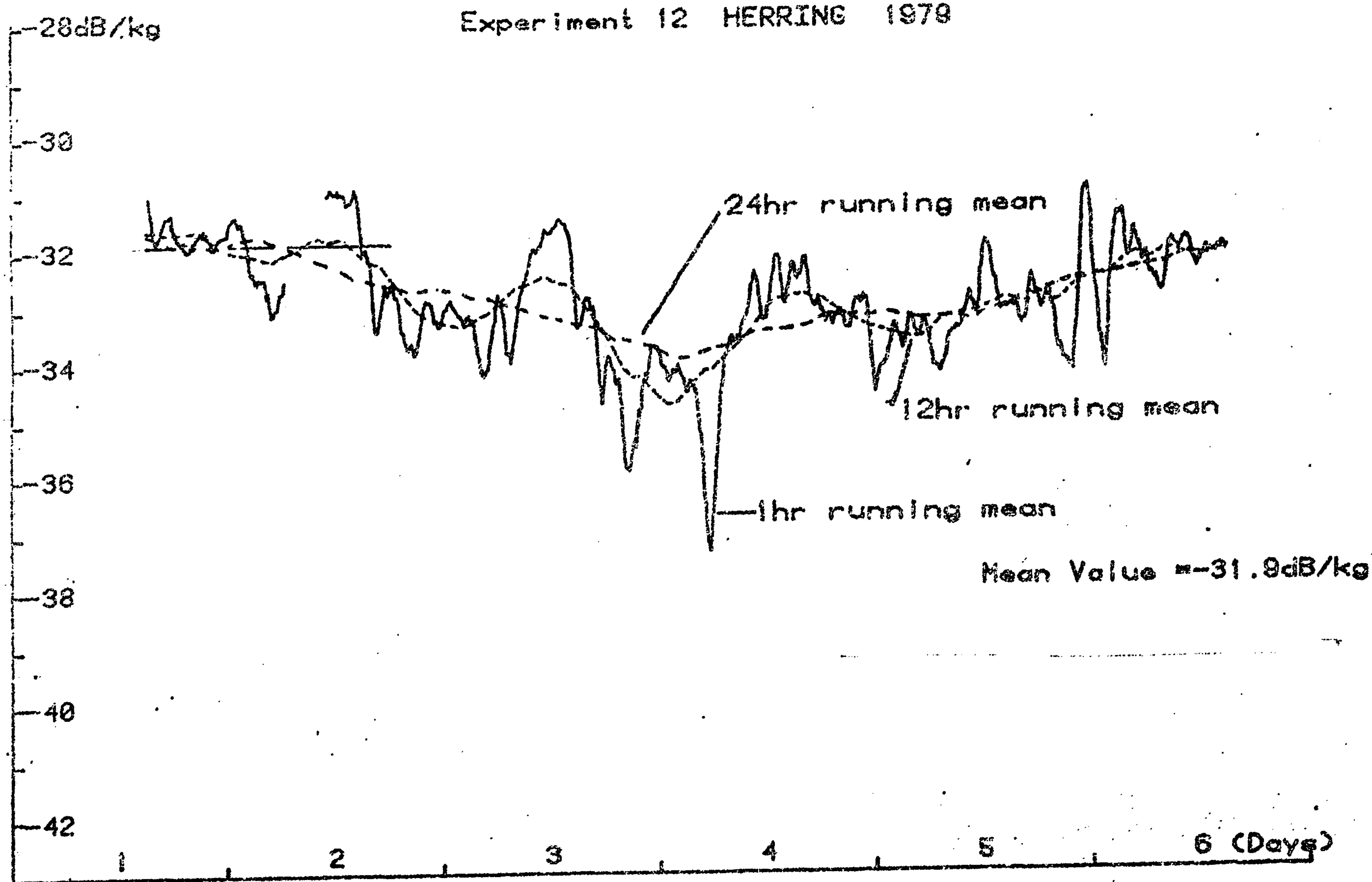

Experiment 12 HERRING 1978
-28dB/kg
-30
-32
-34
-36
-38
-40
-42
24hr running mean
12hr running mean
1hr running mean
Mean Value =-31.9dB/kg
1
2
3
4
5
6 (Days)

Figure 8

Experiment 05 COD 1979