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PROGRESS IN TARGET STRENGTH MEASUREMENTS ON LIVE GADOIDS

by

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Summary

This paper describes experiments designed to measure the target strength of caged gadoids at 38 kHz which were carried out in the period 1976 to 1979. It reports the experimental method, presents a summary of all the results obtained, discusses sources of error and concludes that the acclimatized target strength per kilogram for the gadoids measured is not significantly dependent on length.

Sommaire

Ce mémoire décrit des expériences conçues pour mesurer la valeur de réflection du cible des gadoïdes en cage à 38 kHz effectuées pendant le période 1976 à 1979. Le mémoire fait un rapport sur la méthode expérimentale, présente un sommaire de tous les résultats obtenus, discute les sources des erreurs et aboutit à la conclusion que la valeur de réflection du cible acclimatée, par kilogramme, pour les gadoïdes mesurés ne dépend pas effectivement de la longueur.

Introduction

A series of 31 experiments has been conducted on cod, haddock, saithe and whiting. These experiments were designed to investigate the target strength at 38 kHz of members of the gadoid family and in particular its variation with time, pressure, species and fish length. The experiments utilised the Marine Laboratory Sonar Section's field station on the shores of Loch Duich and took place between July 1976 and November 1979. Some of the data have already been reported by Dunn (1979). This contribution presents the maximum quantity of data for the convenience of other workers in this field. A minimum of analysis has been performed, a more detailed analysis will be presented when the series of experiments is complete.

Experimental Method

The experimental technique used in this series of experiments has been developed from that reported by Johannesson and Losse (1974) and Edwards (1975). The fish under observation are free swimming but confined within an experimental cage. The experimental cage is protected by a guard cage which prevents 'wild' fish from entering the measurement system. The rig is suspended below a 38 kHz transducer, which is in turn suspended from a raft. By adjusting the length of the suspension wire between the raft and the transducer it is possible to place the experimental cage at any depth within the 100 m water column. The condition and behaviour of the fish are monitored in silhouette by a low light TV system attached to the lower section of the guard cage. Figure 1 illustrates the essential features of this rig.

The raft is moored approximately 600 m from the shore and is connected to a mobile laboratory by 1000 m of cable. The laboratory contains the electronic equipment and the TV monitoring and recording system. The electronic equipment was reported by Dunn (1979) but a brief description is included in this paper. It consists of a 2 kW transmitter producing a 500 µsec pulse and purpose built fixed gain receiver connected to the transducer via a transmitter-receiver switch through 1000 m of cable. The receiver feeds a Computer Automation LSI 2/20 computer which is programmed to apply range correction and to record and analyse the data. The signal was ranged-gated so that only the power returned from (a) the reference target and (b) the fish and experimental cage, contribute to the respective integrals. The electronic system samples and records 10 000 transmissions every hour. Summaries are presented every 6 min, and raw data is recorded on digital magnetic tape for further analysis. The data presented here were collated from that recorded on magnetic tape.

The electronic equipment was calibrated by placing a table tennis ball on the acoustic axis at the same range as that normally occupied by the fish, the calibrations are then cross-checked with a Bruel and Kjaer hydrophone system. A continuous check on the system's sensitivity is made by placing a reference target, suspended by three strands of monofilament nylon, on the acoustic axis of the transducer at a range of approximately 3 m. The echoes from this reference target are continuously measured and long term variations in the energy returned are taken to be proportional to changes in the system's sensitivity and appropriate corrections have been made.

The closed circuit TV system is used to monitor the behaviour and condition of the fish throughout the experiments. Any abnormalities are noted and the relevant data carefully scrutinised before inclusion in the final results. The TV system is also used to check the distribution of the fish within the cage.

Results

Dunn (1979) presented a summary of the species and depth dependence of target strength based on data collected in 1976 and 1977. This contribution contains a summary of all the data collected from July 1976 to November 1979 and concentrates on the length dependence of target strength expressed in dB with reference to 1 m^2 $steradian^{-1}$ kg^{-1}.

All the original data tapes have been analysed to produce summary tapes which contain information on the energy returned from the fish and from the reference target for each 1000 transmissions. Data for the reference target (72.4 mm diameter brass sphere) has been used to correct the fish data for variations in the sensitivity of the measurement system. However the data from the reference target has first been scrutinised to ensure that it does not contain any anomalies. When the target strength measurement system is operating normally, the standard deviation calculated for the energy returning from the reference target is usually in the region of 1% for 1000 transmissions. In data sets where the standard deviation for the reference target is less than 2.5% the maximum value is assumed to occur when the standard target is nearest to the acoustic axis of the transducer. In data sets which have a standard deviation for the reference target greater than 2.5% an anomaly is said to have occurred.

There are two probable causes of an anomaly; the first is the presence of wild fish in the vicinity of the reference target, this caused spurious maximum values to occur whilst not significantly affecting the mean value. The second is caused by the reference target swinging away from the acoustic axis during part of the measurement period, this may occur during periods of either strong winds or spring tides. In this case the maximum values are probably correct, however the mean values are reduced. An algorithm has been devised which will correct both these situations: if the standard deviation of the reference target is greater than 2.5%, the major mode of the distribution was calculated to within $\pm$ 1%, data which lay outside a $\pm$ 10% limit were then rejected and the mean of the truncated distribution calculated. The new mean was used to replace the original mean. The maximum value from the original distribution is accepted as a system reference provided it lay within plus 10% of the valid mean. If this condition was not satisfied the previous valid maximum was substituted. In practice only a small proportion of the data required correction.

The acoustic system was calibrated by placing a table tennis ball on the acoustic axis of the transducer at the same range as the fish would normally be placed. The table tennis ball is assumed to have a target strength of -42 dB//1 m^2 steradian^{-1} (Welsby and Hudson 1972). The relative sizes of the echoes from the table tennis ball and the reference target were combined with the differences in range and the apparent target strength of the reference target was calculated. For the experiments reported here the target strength of the reference target is -31 dB//1 m^2 steradian^{-1}. This calibration was cross-checked using a Bruel and Kjaer hydrophone system and the results agreed to within 1 dB.

The reverberation levels measured within the range intervals associated with the fish and the reference target were at least 30 dB below mean fish echo and 50 dB below the reference target echoes respectively.

Calculations of target strength per kg require an accurate knowledge of the effective beam angle corrected to take into account the size and range of the experimental cage. The effective beam angles (Ψ) for the transducers used in these experiments were calculated by evaluating the integral of the beam function, the expression for the beam function being developed theoretically from the manufacturer's mechanical specifications. The integrals were calculated for the angles subtended by the experimental cages.

Table 1 summarises the data collected and Figures 6 to 31 present 12 hour (dotted line) and 24 hour (solid line) moving averages for each experiment. All the experimental results have a common form, a rise in target strength at the start of the experiment which ranges in value from 4 to 11 dB and takes between one and three days as the fish acclimatise to the increase in pressure, followed by a cyclic variation in the 12 hour running mean. In several experiments the pressure was increased still further by lowering the rig to a greater depth and then reduced by raising the rig towards the end of the experiments. A similar pattern can be seen as the pressure increases, however, when the pressure decreases the target strength does not appear to increase.

Figures 2, 3 and 4 are plots of target strength against length. The horizontal bars are plus-and-minus one standard deviation about the mean value of the length. Figure 4 excludes experiments 3 and 4/77 which only lasted a few days and it is not certain that the saithe reached their acclimatised value of target strength and experiment 3/78 during which the cod lay on the bottom of the cage. Figure 5 includes only the cod data (excluding experiment 3/79).

Discussion and Conclusions

The data presented here confirm Dunn's (1979) conclusion that the target strength per kg of the gadoids measured is independent of species. No further information is available on depth dependence.

Data presented in Figure 5 has been analysed to determine the relationship between log(length)and target strength (dB per kg). A linear regression with target strength as the independent variable and log(length)as the dependent variable results in a length dependance of the form L^{-4} with a coefficient of 0.3, which would suggest that for these experiments target strength is independent of length. The regression equation derived by Nakken and Olsen (1973) for cod combined with the length-weight relationship measured by Anon (1976), shown in Figure 5,predicts a target strength variation of 2 dB for the length range used in the experiments reported here (21.8 cm - 63.7 cm). The curve in Figure 5 represent Nakken and Olsens' measured target strength per kg for maximum dorsal aspect of cod. The '*' represent the mean target strength per kg for 10 cm (Table 2) length groups reported in this paper, they lie close to Nakken and Olsen's curve but have less dependence on length.

Table 2 presents the mean target strength by 10 cm length groups; for cod only excluding experiment 3/78; and for all species excluding experiments 3/78, 3/77 and 4/77. The overall mean for cod was -27.8 dB per kg and that for all fish -27.7 dB per kg.

The experiments were designed to produce target strength information on gadoids which could ultimately be applied to echo integration surveys. Before the figures reported here are used it is important to consider factors which may affect their validity.

The absolute value of the target strengths derived depends on two factors, firstly the combined axial sensitivity in transmit and receive. This has been measured using both table tennis balls and hydrophone systems at regular intervals over four years. The results have been compared with the echo returning from a reference brass ball. The same reference ball has been used throughout all the experiments to monitor the system's performance and provides a constant factor by which all experiments can be compared. A critical review of all the calibration data suggests that the overall absolute calibration accuracy is within and probably better than +1 dB, -2 dB. However, the short term relative accuracy of the experiments is considerably better than this, with 0.005 dB being typical for a 10 hour period and 0.35 dB being typical for a 6 month field season.

The second factor concerns the calculation of the effective beam angle of the transducer. This has been done using theoretical calculations of the beam pattern based on the nominal dimensions of the transducers in which the integral has been curtailed to account for the finite size of the experimental cage. The beam pattern produced by the transducers used may be different from the ideal. Further, the octagonal cages have been assumed to be circular with a diameter equal to the distance across the flats and concentric with the acoustic axis of the transducer. The assumption that the effective shape of the cage is circular is derived from TV observations of the fish distribution, the fish rarely swim into the corners of the octagon. TV observations of the table tennis ball calibrations suggest that the geometric axis of the experimental cage is aligned with the acoustic axis of the transducer to within 1°. The variation between the real and ideal behaviour of the transducer is not known. However, equipment has been designed which will be able to measure the actual beam pattern used and this will eventually enable an accurate effective beam angle to be calculated.

Fish confined within an experimental cage are unlikely to behave in an identical way to wild, free-swimming fish. Unfortunately, little information is currently available on exactly how wild fish behave and consequently it is impossible to identify differences between the behaviour of wild and caged fish. However, there are several possible differences.

The caged fish are constrained both vertically and horizontally. This may affect the fishes' tilt angle, the angle between the axis of the fish and the horizontal plane. Nakken and Olsen (1973) demonstrated that small changes in tilt angle cause large changes in target strength. Confined fish are also forced to change direction more frequently and this may also cause variations in target strength. The target strengths quoted in this paper are thought to be those of fish which have fully adapted to the ambient pressure level. If fish measured during an acoustic survey are pursuing some form of vertical migration it is unlikely that they will be fully adapted to their current depth. As a result their target strength may be different to that indicated by these experiments. For the duration of the target strength experiments reported here the fish were not fed, although they may have foraged for plankton, and thus their condition might have deteriorated as the experiments progressed. Figure 13, (experiment 9/78) illustrates a progressive drop in target strength. However, Figure 18 (experiment 4/78), on the same species of fish does not show any reduction in target strength as the experiment progressed. Thus, although the condition of the fish may affect target strength, the data available from this set of experiments is inconclusive.

The behaviour of the fish within the experimental cage, and in particular their distribution and its variation with time, will affect the accuracy of the target strength measurements. The method used assumes that on average the fish are uniformly and evenly distributed throughout the experimental cage. Simulations have shown that variations in the vertical distribution are unlikely to significantly affect the accuracy. However, variations in the horizontal distribution will cause inaccuracies. If the fish concentrate in the centre of the cage, the energy returned will be greater than that expected and this will result in a higher target strength being measured. Conversely, if the fish swim around the perimeter of the cage, the target strength will be underestimated. Superficial analysis of the caged fish distributions has been undertaken using video recordings. Lack of precision has prevented firm conclusions from being drawn, however the results indicate that it is not possible to show that the distribution of fish is non-uniform.

The factors outlined above summarise some of the authors' reservations concerning the measurement of target strength on caged fish. The measurements presented are probably accurate for acclimatized fish; however care should be exercised when applying these results to wild fish.

Acknowledgements

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References

Anon 1976 Length/weight data, from market sampling 1970 to 1975. Marine Laboratory, Aberdeen.

Dunn, W. I. 1979 Depth and species dependence of the target strength of gadoids. Marine Laboratory Working Paper No 80/4.

Edwards, J. I. 1975 A preliminary analysis of the variations in target strength of multiple fish targets at various depths. Proceedings of the specialist meeting on Acoustic Surveying of fish population. Inst. of Acoustics 17 December 1975 mimeo.

Johannesson, K. A. and Losse, G. F. 1973 Some results of abundance estimates obtained in several UNPD/FAO resource survey projects. Rapp. P-v. Reun. Cons. Int. Explor. Mer 170 296-318.

Nakken, O. and Olsen, K. 1973 Target strength measurements of fish. Rapp. P-v. Reun. Cons. Int. Explor. Mer 170 52-69.

Welsby, V. G. and Hudson, J. E. 1972 Standard small targets for calibrating underwater sonars. J. Sound. Vib., 20: 399-406.

TABLE 1 SUMMARY OF LOCH DUICH TARGET STRENGTH DATA

EXPT	SPECIES	Number of fish	LENGTH (MEAN)	LENGTH (STANDARD) (DEVIATION)	WEIGHT (MEAN)	WEIGHT (STANDARD) (DEVIATION)	WEIGHT (TOTAL)	TARGET STRENGTH PER KILO	APPROXIMATE PERIOD FOR TS MEASUREMENT
			cm	cm	gm	gm	kg	dB// m^2 $sterad^{-1}$ kg^{-1}	DAYS
17/76	HADDOCK	52	27	2.61	171.3	51.42	9.03	-31.2	2.6
18/76	COD	18	35.33	1.97	335.8	92.16	6.04	-27.9	0.75
19/76	COD	19	35.95	4.35	410.4	160.4	7.79	-27.6	1.5
20/76	WHITING	45	23.33	1.79	99.64	25.80	4.48	-27.2	1.5
21/76	COD	26	34.38	3.63	351.9	109.5	9.15	-28.4	4.5
1/77	HADDOCK	30	28.43	2.27	193.4	52.25	5.60	-29.1	12
2/77	HADDOCK	15	29.2	1.69	242.1	35.81	3.63	-28.9	3.0
3a/77	SAITHE	56	25.66	1.99	171.9	36.82	8.78	-30.0	1.1
3b/77	SAITHE	23	25.13	2.07	165.6	36.49	3.80	-29.1	1.2
3c/77	SAITHE	9	24	1.73	165.3	42.8	1.48	-27.6	2.5
4a/77	SAITHE	216	25.48	1.45	177.8	29.18	38.43	-29.7	4.5
4b/77	SAITHE	111	25.94	1.39	181.9	29.31	20.03	-29.5	3.7
5/77	COD	54	28.7	3.40	259.3	94.34	12.97	-28.2	4.5
1/78	COD	10	41.9	2.92	687.5	118.9	6.87	-27.1	16.5
2/78	COD	7	63.72	3.09	2567.0	451.1	17.97	-28.4	5.5
3/78	COD	7	57.85	2.41	1798	320.3	12.59	-29.9	3.6
4/78	COD	26	29.15	1.95	254.2	53.85	6.61	-27.7	9
5/78	SAITHE	40	34.42	2.07	316.3	62.07	12.97	-27.6	7.5
6/78	COD	18	38.83	2.83	576.9	106.9	10.38	-26.6	5.5
7/78	SAITHE	17	39.37	5.72	628.7	252.2	9.76	-24.4	5.5
8/78	COD	17	41.12	6.24	662.6	257.2	11.56	-27.2	7.5
9/78	COD	19	51.42	4.22	1302	296.6	24.75	-27.5	11
10/78	COD	41	28.49	3.21	250	78.49	10.27	-28.1	7.1
11/78	COD	16	54.31	2.84	1500	196.4	24.00	-28.9	8.5
1/79	COD	56	24.32	2.90	139.0	47.68	7.78	-27.5	9.5
2/79	COD	17	35.12	3.27	420.4	132.3	7.16	-27.0	5.5
3/79	COD	30	24.53	2.95	139.6	42.10	4.38	-27.6	9.5
4/79	COD	47	21.45	2.00	87.40	22.56	4.18	-26.9	8.5
5/79	COD	28	25.78	1.42	160.46	28.85	4.47	-27.4	7.0
10/79	SAITHE	85	12.54	0.93	15.41	3.536	1.311	-27.6	1.3

TABLE 2 MEAN TARGET STRENGTH PER KILOGRAM

LENGTH cm	TARGET STRENGTH (dB/kg) COD	GADIODS
10 - 20	-27.6	-27.6
20 - 30	-27.5	-27.8
30 - 40	-27.1	-27.3
40 - 50	-28.2	-27.1
50 - 60	-28.4	-28.2
60 - 70		-28.4
MEAN	-27.8	-27.7

FIGURE 1

TRANSDUCER AND EXPERIMENTAL CAGE

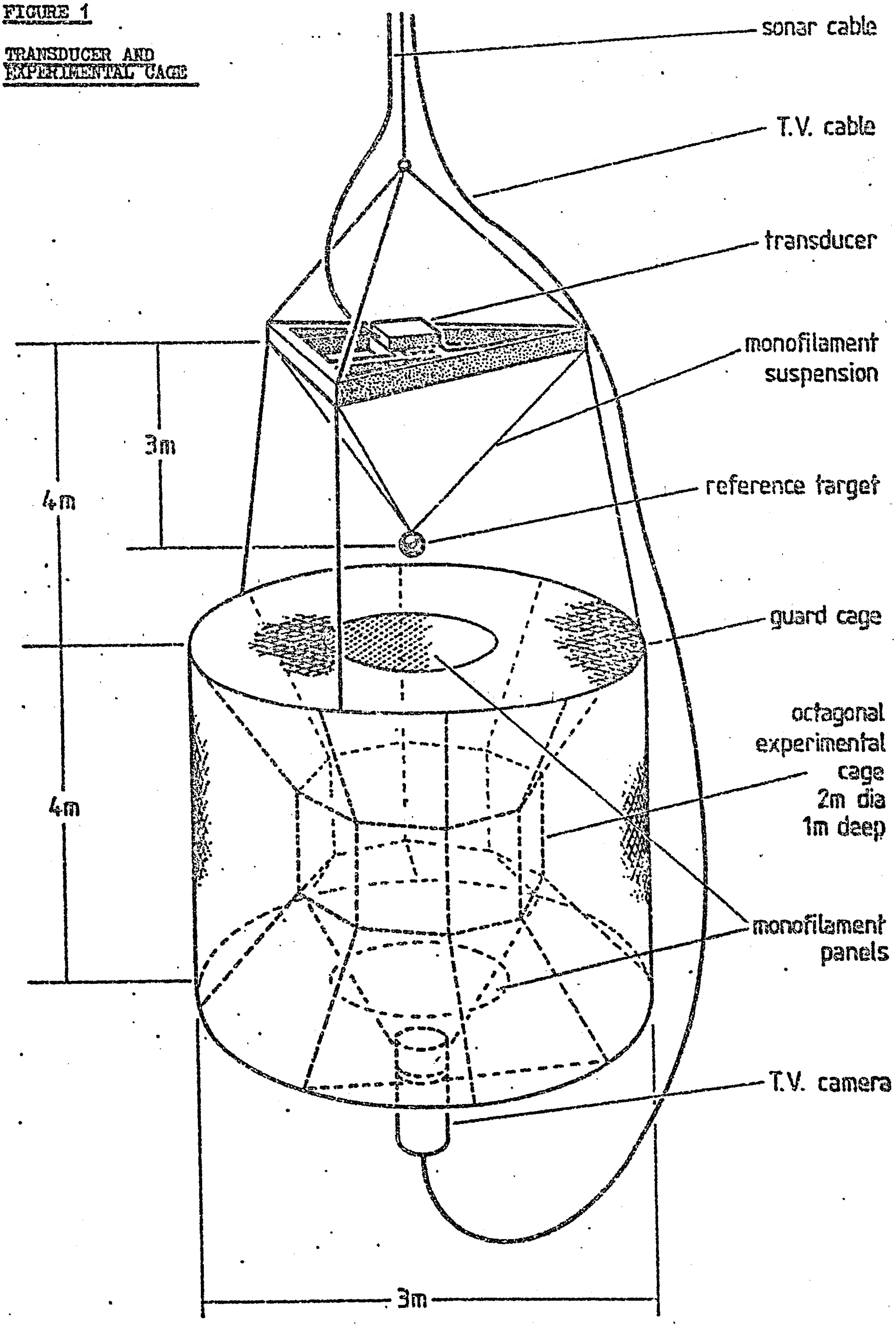

Figure 2   Target Strength (dB/Kg) against mean length (cm) plus and minus one standard deviation for all experiments 1976 - 1979.

C = Cod,   H = Haddock,   W = Whiting,   S = Saithe

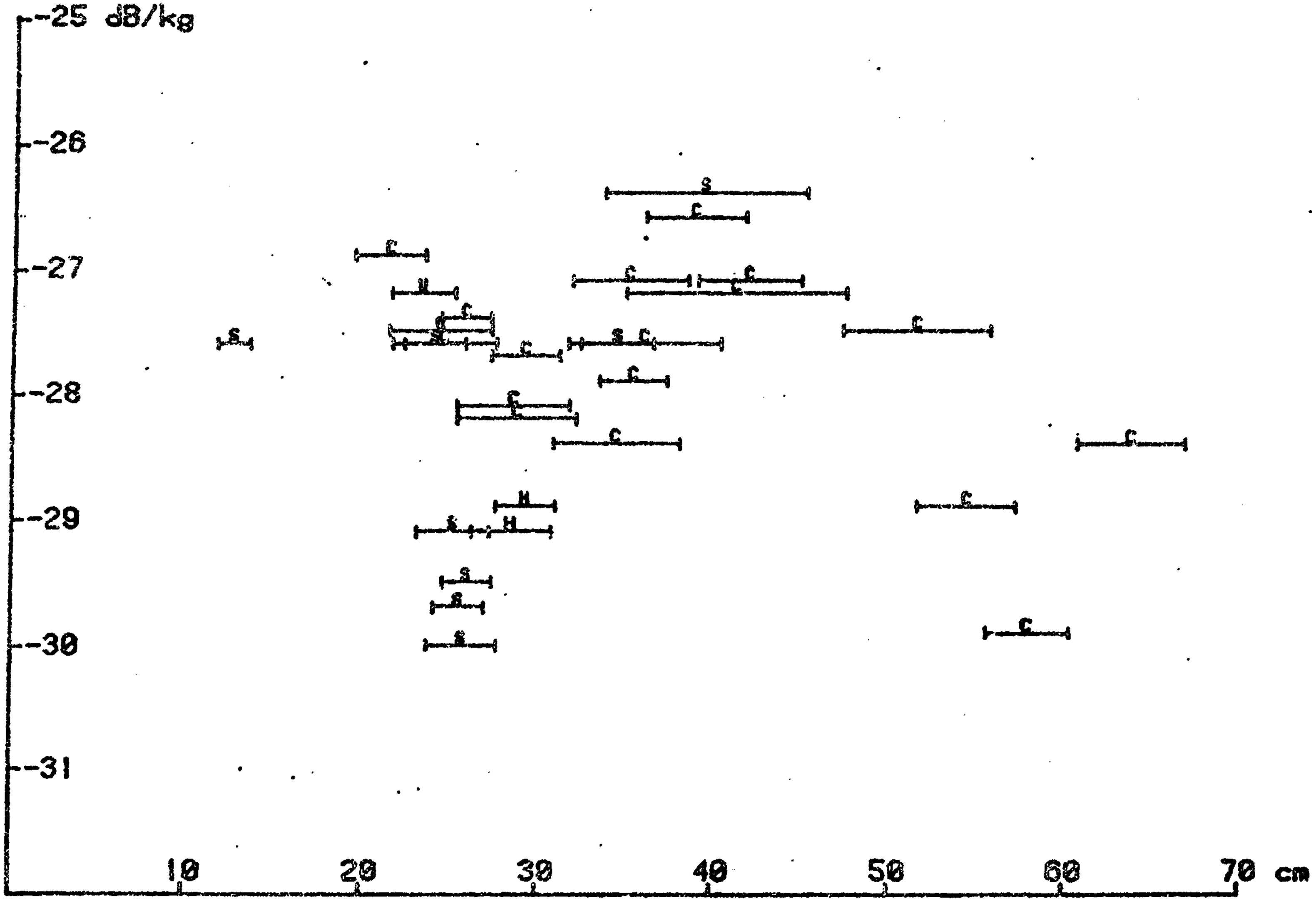

Figure 3 Target strength (dB/kg) against mean length (cm) plus and minus one standard deviation for excluding experiment No 3, 4/77, 3/78.

C = Cod, H = Haddock, W = Whiting, S = Saithe

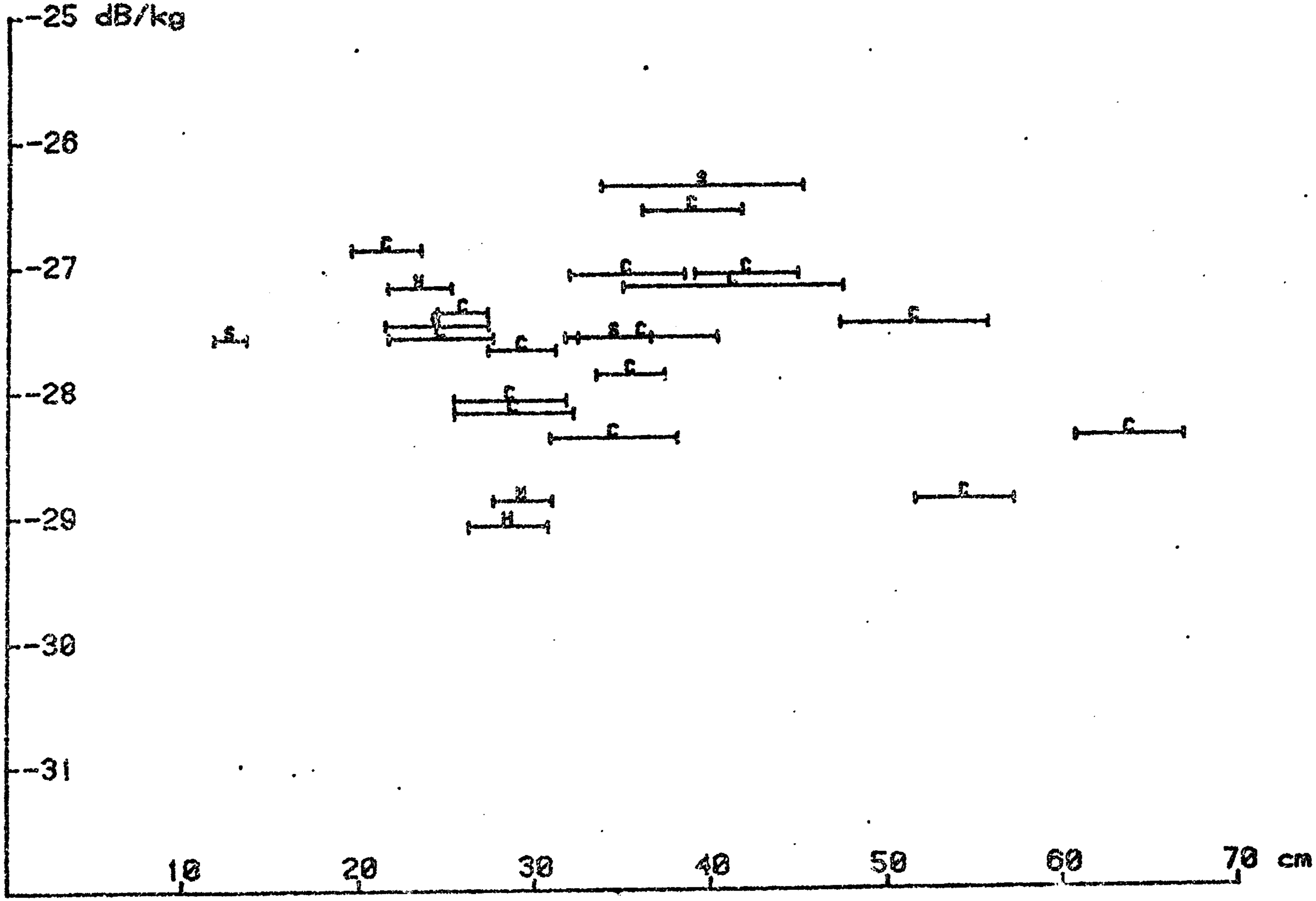

Figure 4   Target strength (dB/kg) against mean length (cm) plus and minus one standard deviation for Cod

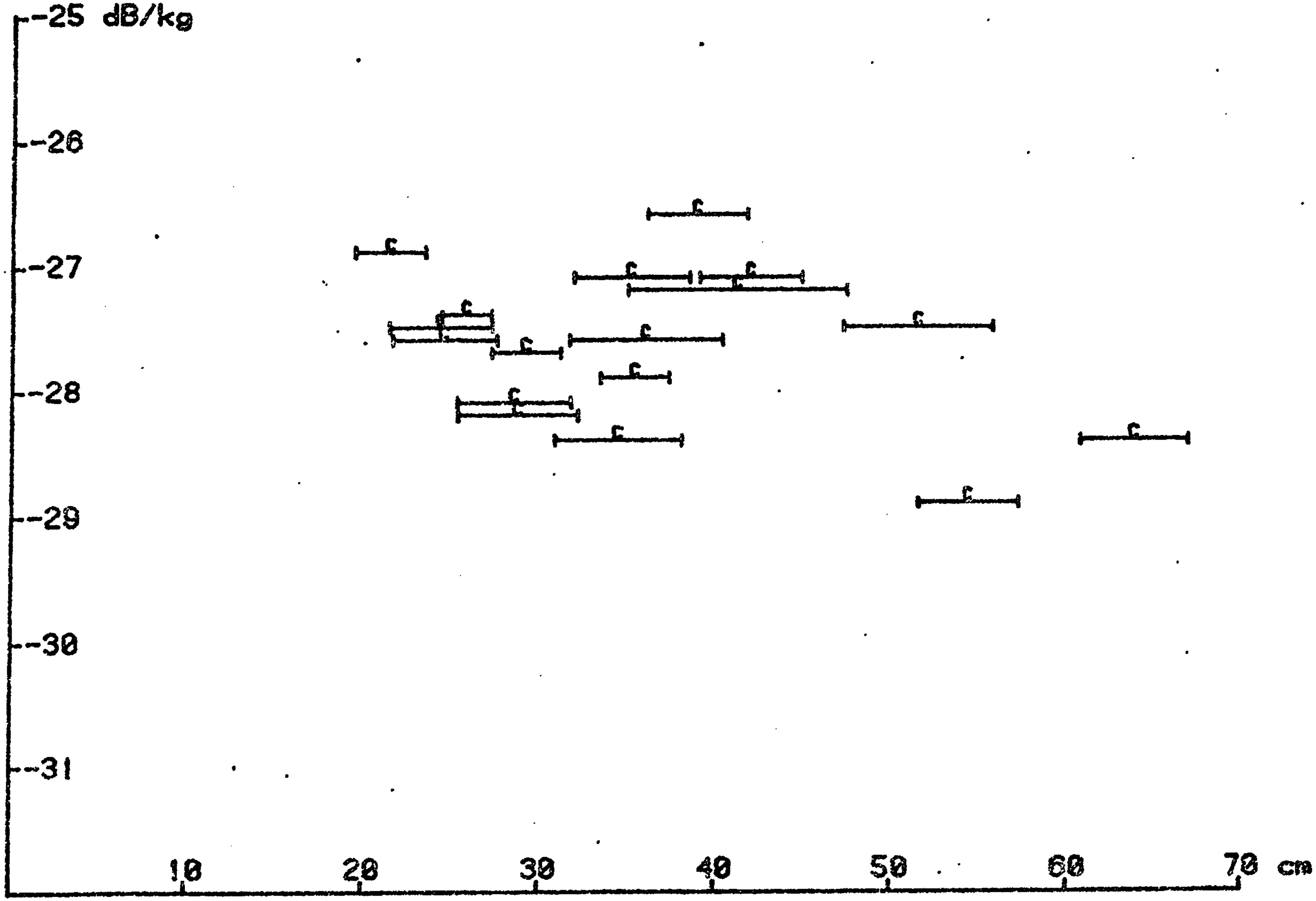

Figure 5 Mean Target Strength of Caged Cod (dB/kg) for 10 cm length groups (*) compared with Maximum Dorsal Aspect Target Strength predicted by TS = $24.6 \log_{10} L - 66.6$ (Nakken and Olsen 1977) and Marine Laboratory length weight relationship $W = 0.01754\ L^{2.856}$

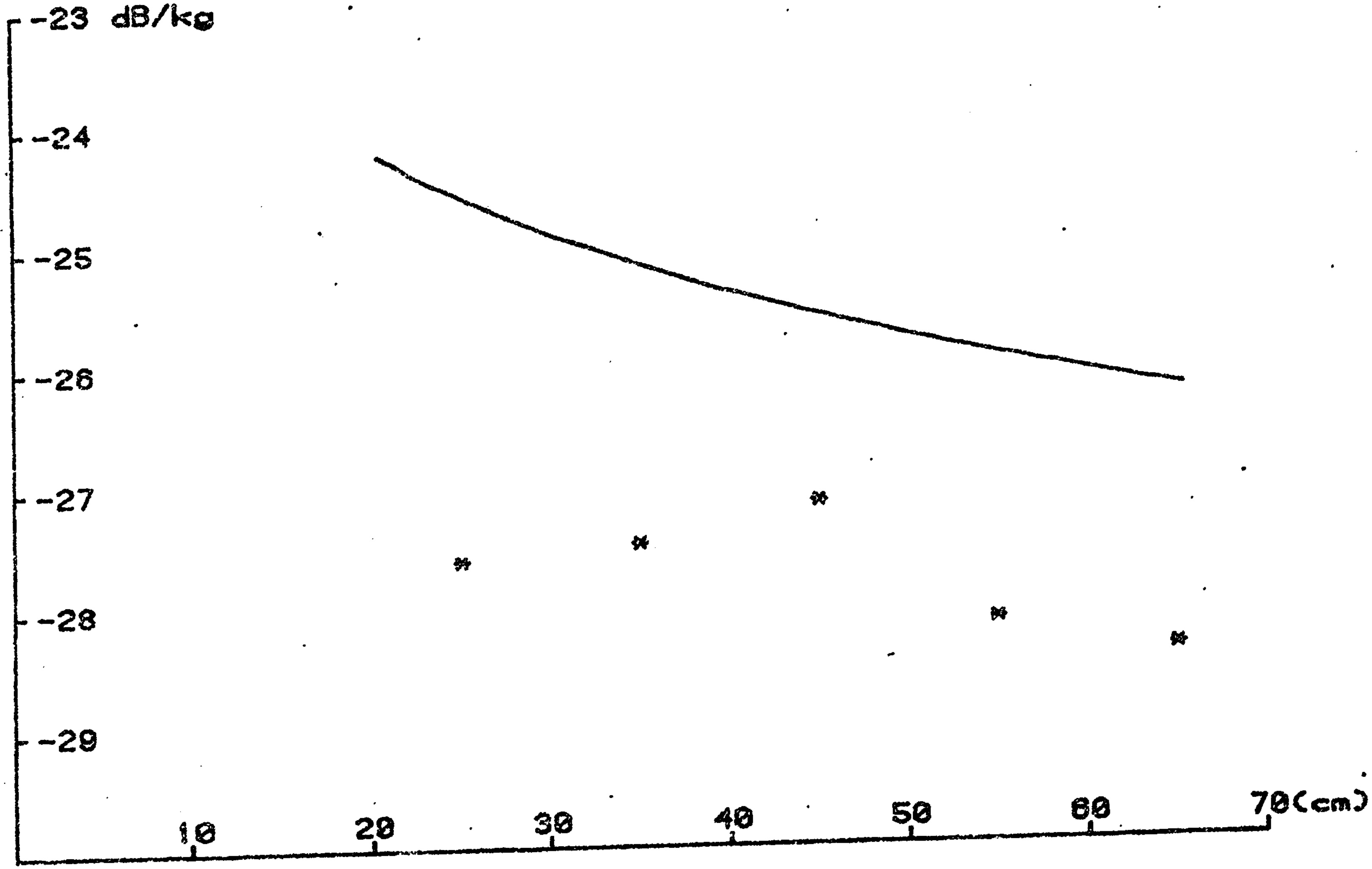

Figure 6 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means. For complete experiment fish at 17.5 m

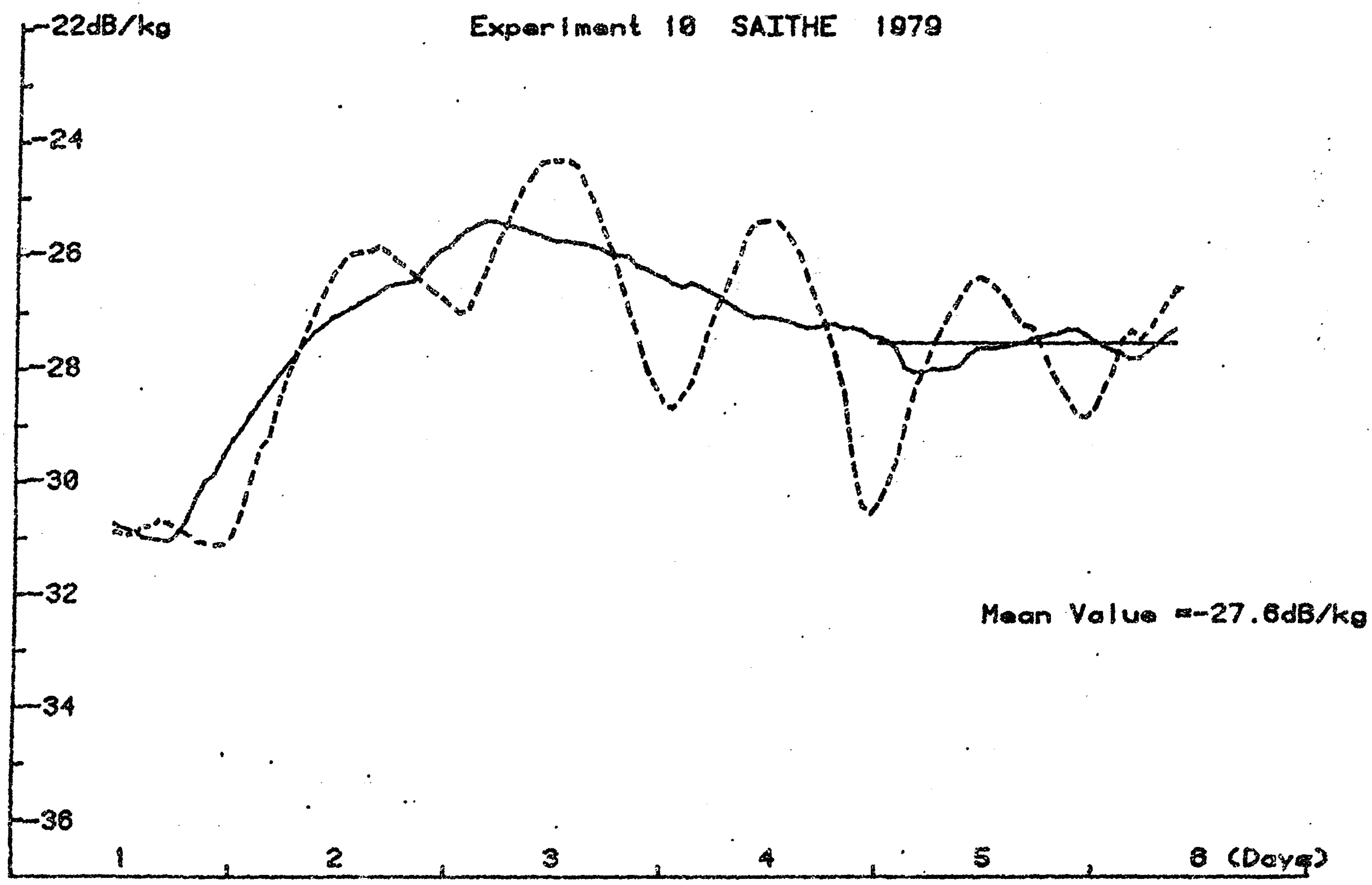

Figure 7 Steady mean value and 12 hour (dotted), 24 hour (continuous) running means.
For complete experiment fish at 17.5 m

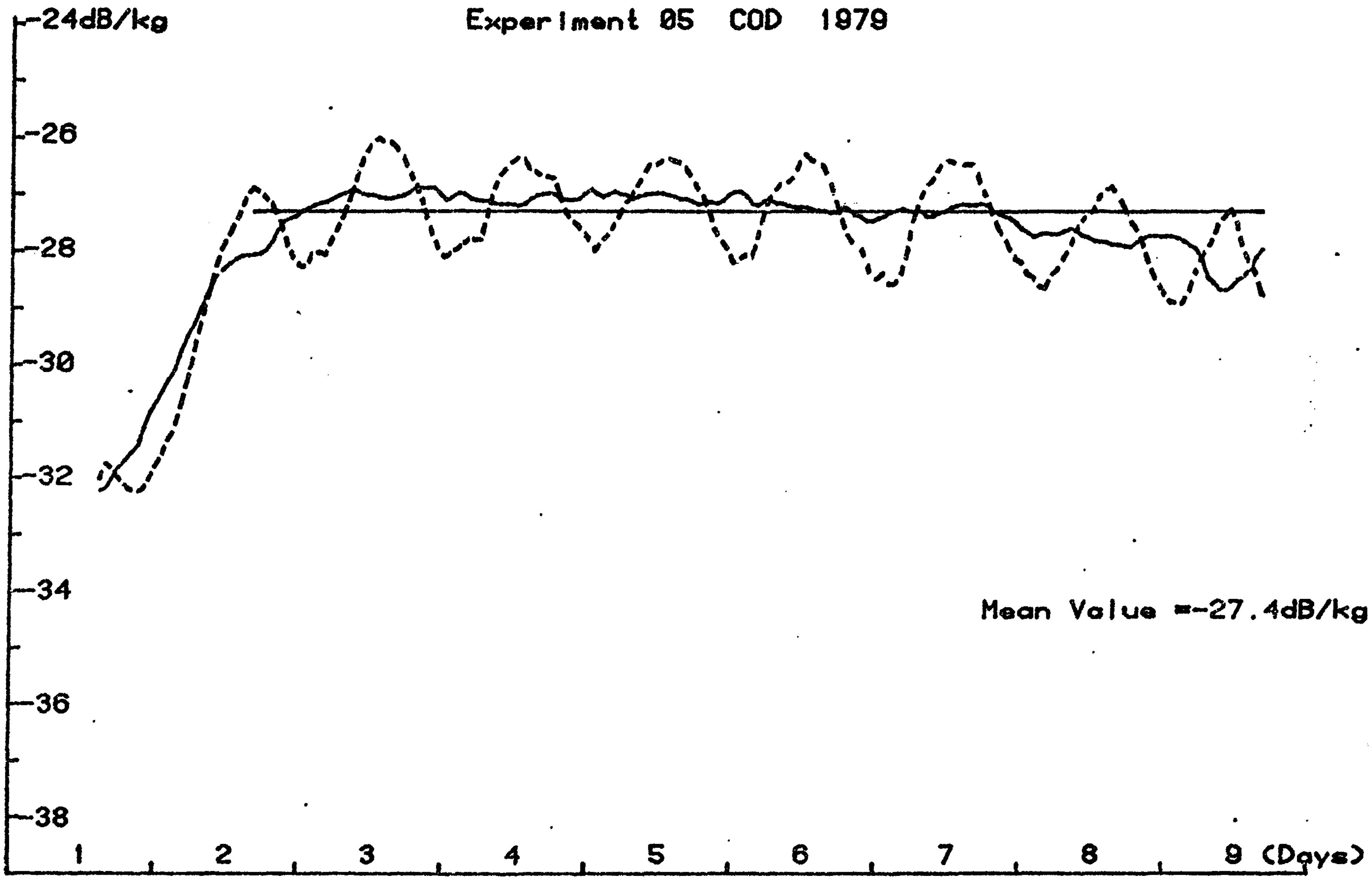

Figure 8 Steady state mean value and 12 hour (dotted), 24 (continuous) running means.
For complete experiment fish at 17.5 m

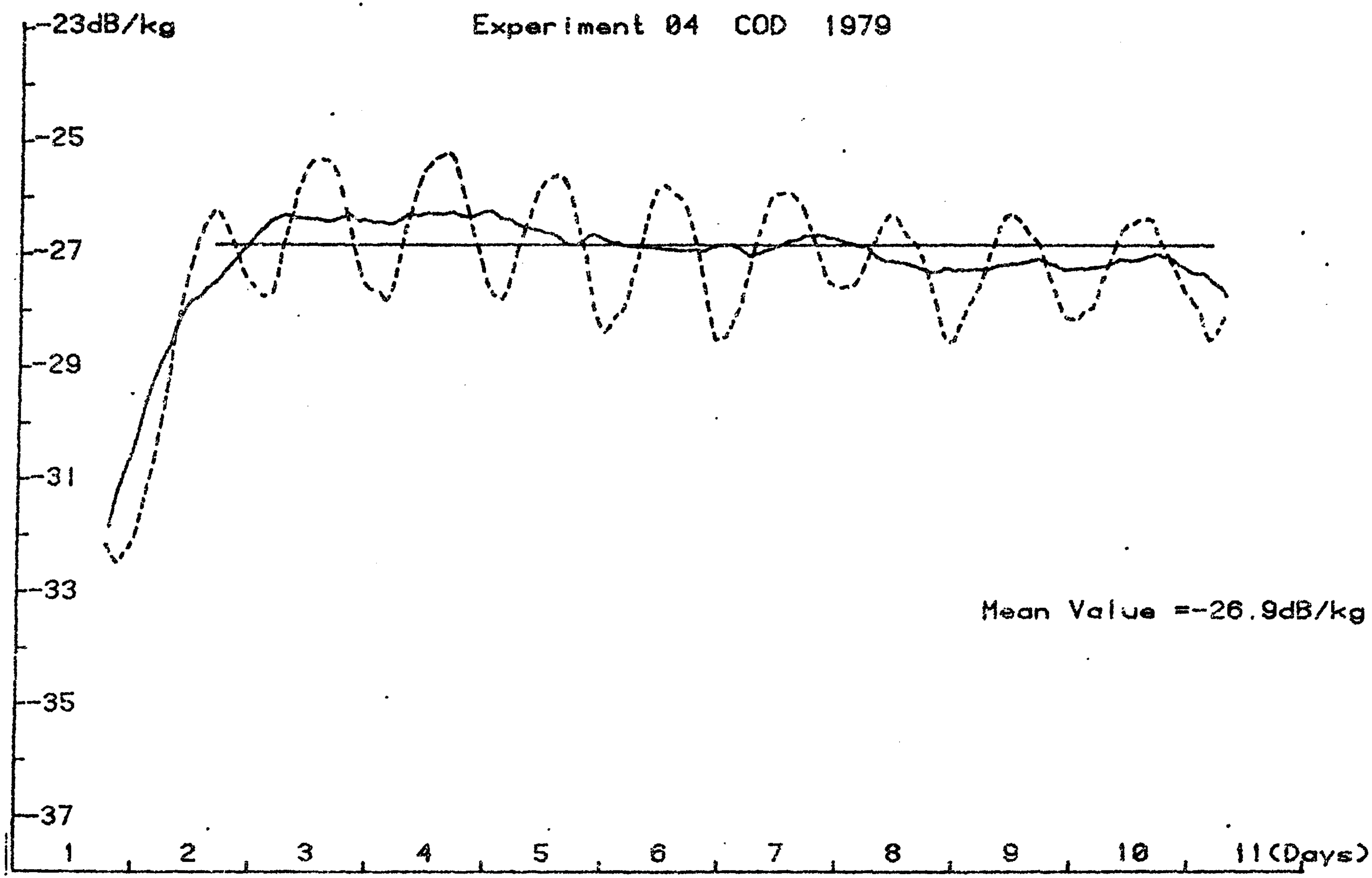

Figure 9 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running minus. For complete experiment fish at 17.5 m

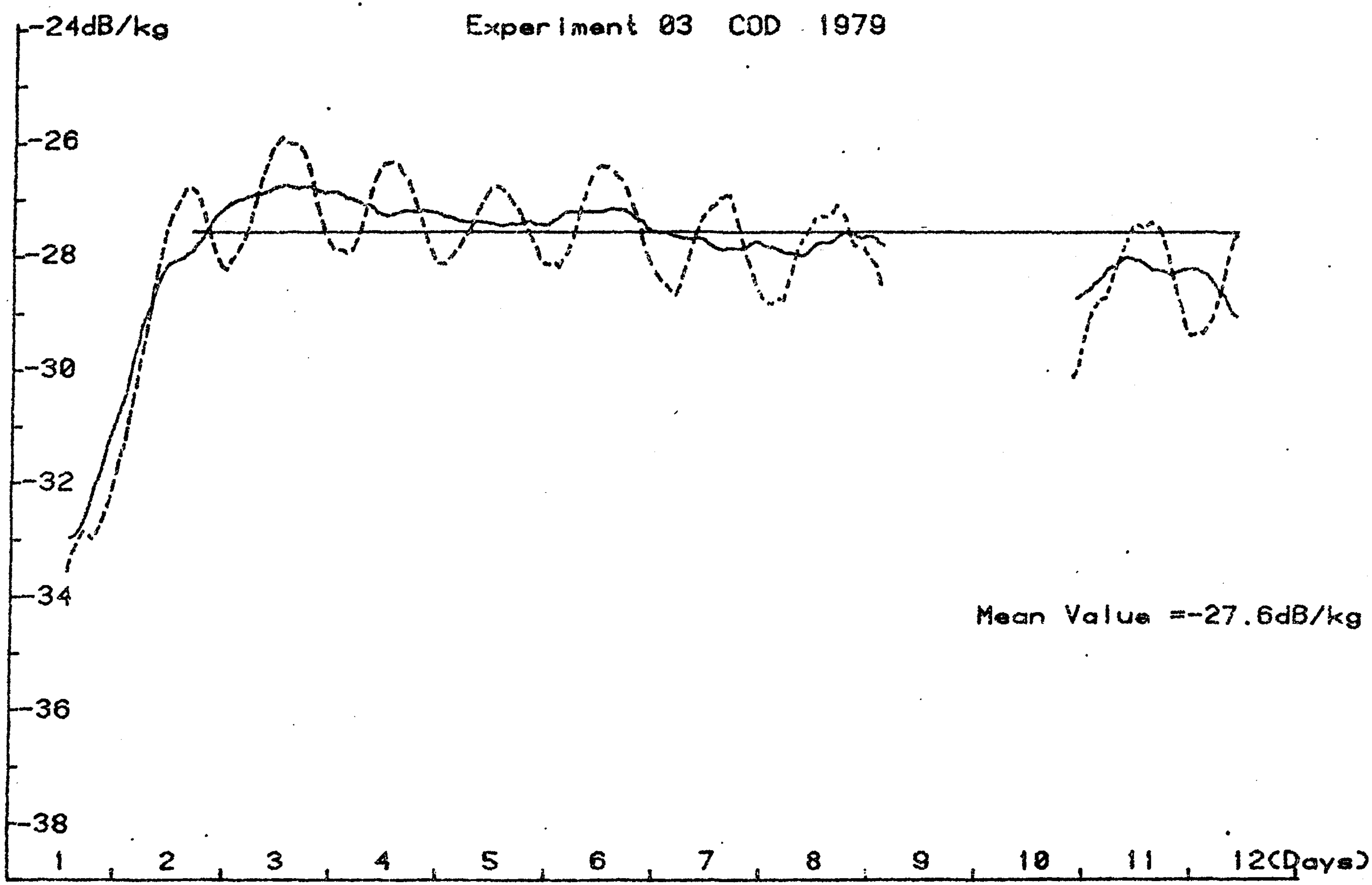

Figure 10 Steady state mean value (1) and 12 hour (dotted), 24 hour (continuous) running means.
For complete experiment fish at 17.5 m

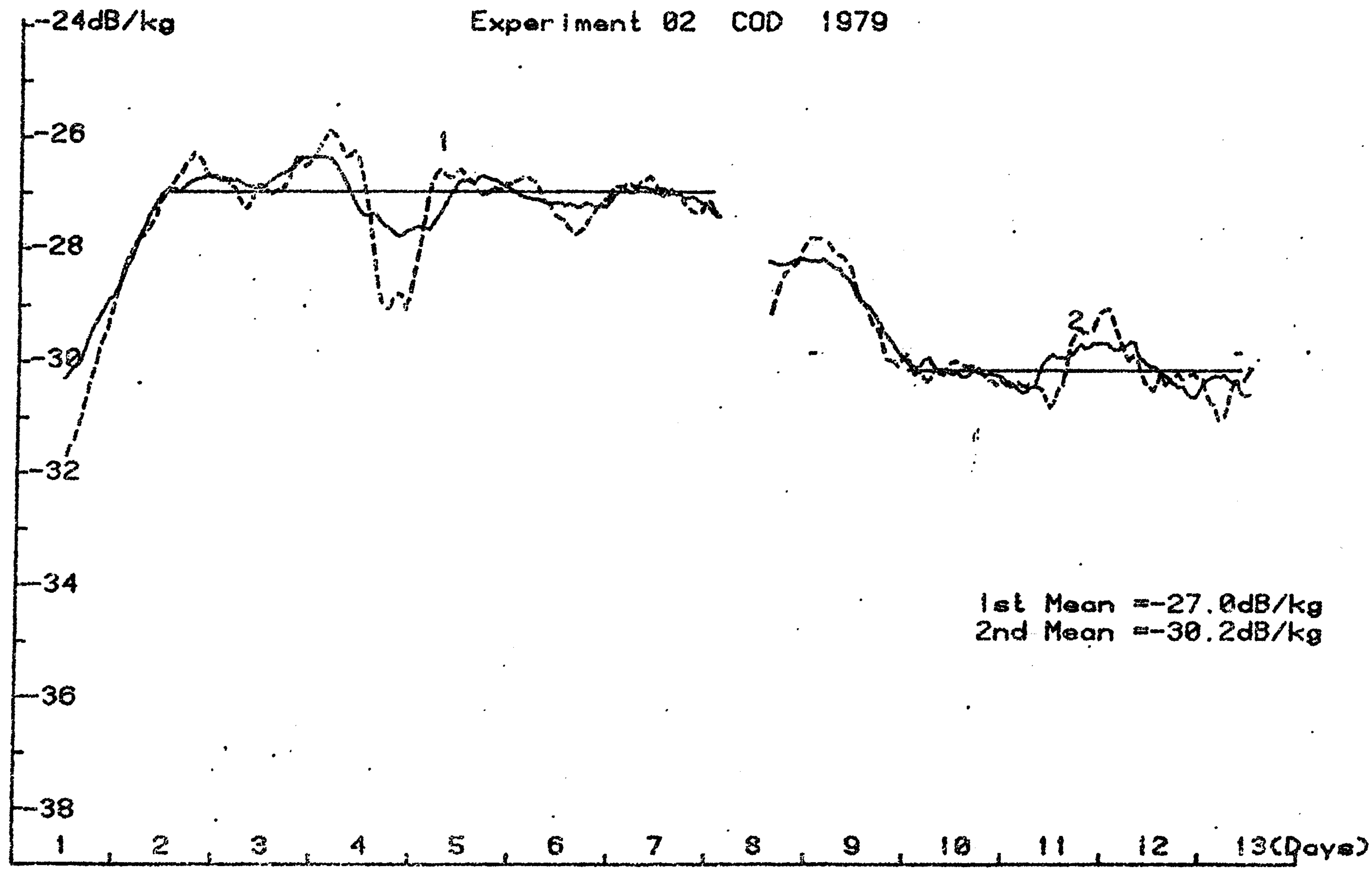

Figure 11 Steady state mean value and 12 hour (dotted), 24 hour (Continuous) running means
For complete experiment fish at 17.5 m

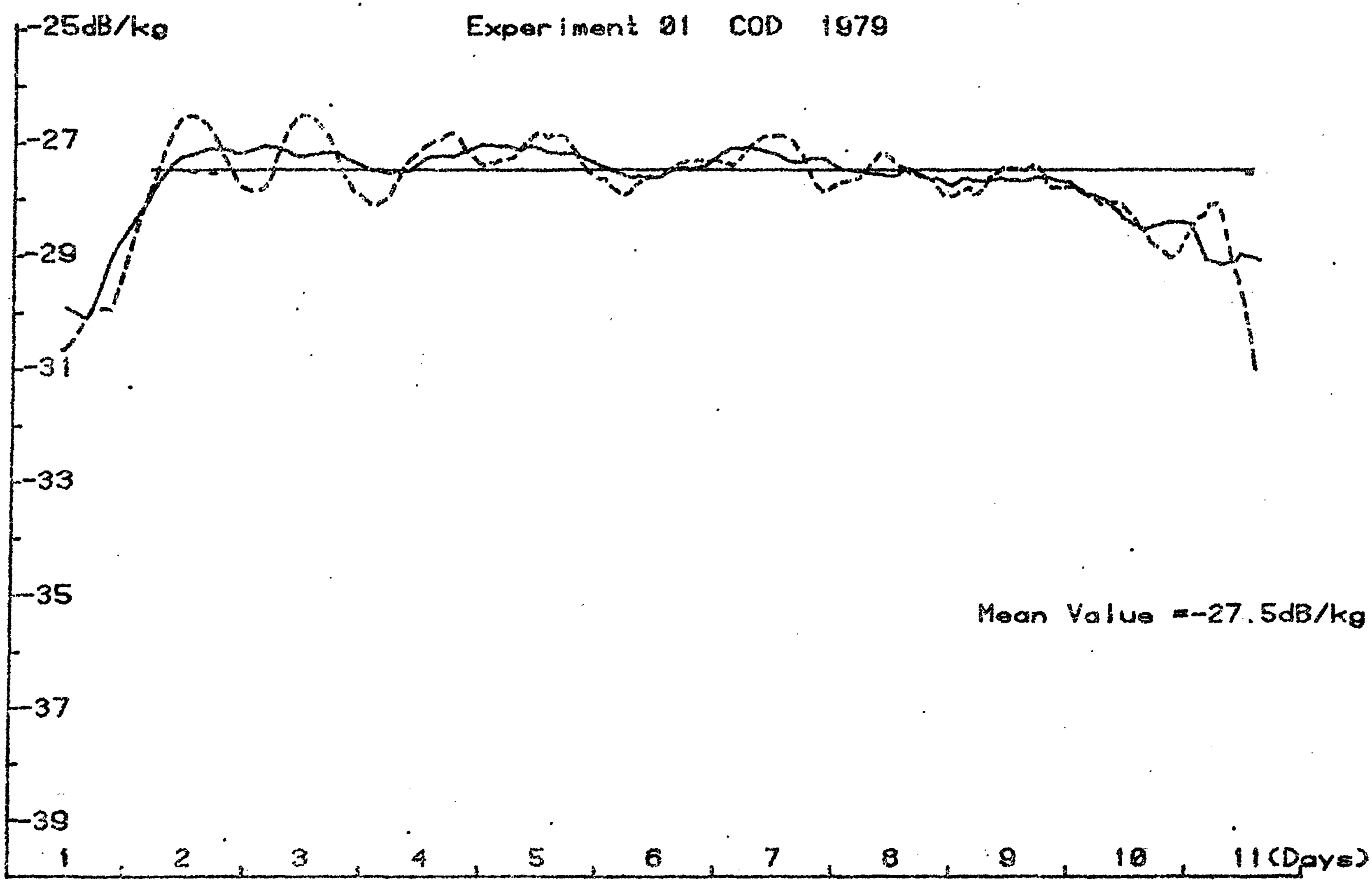

Figure 12 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

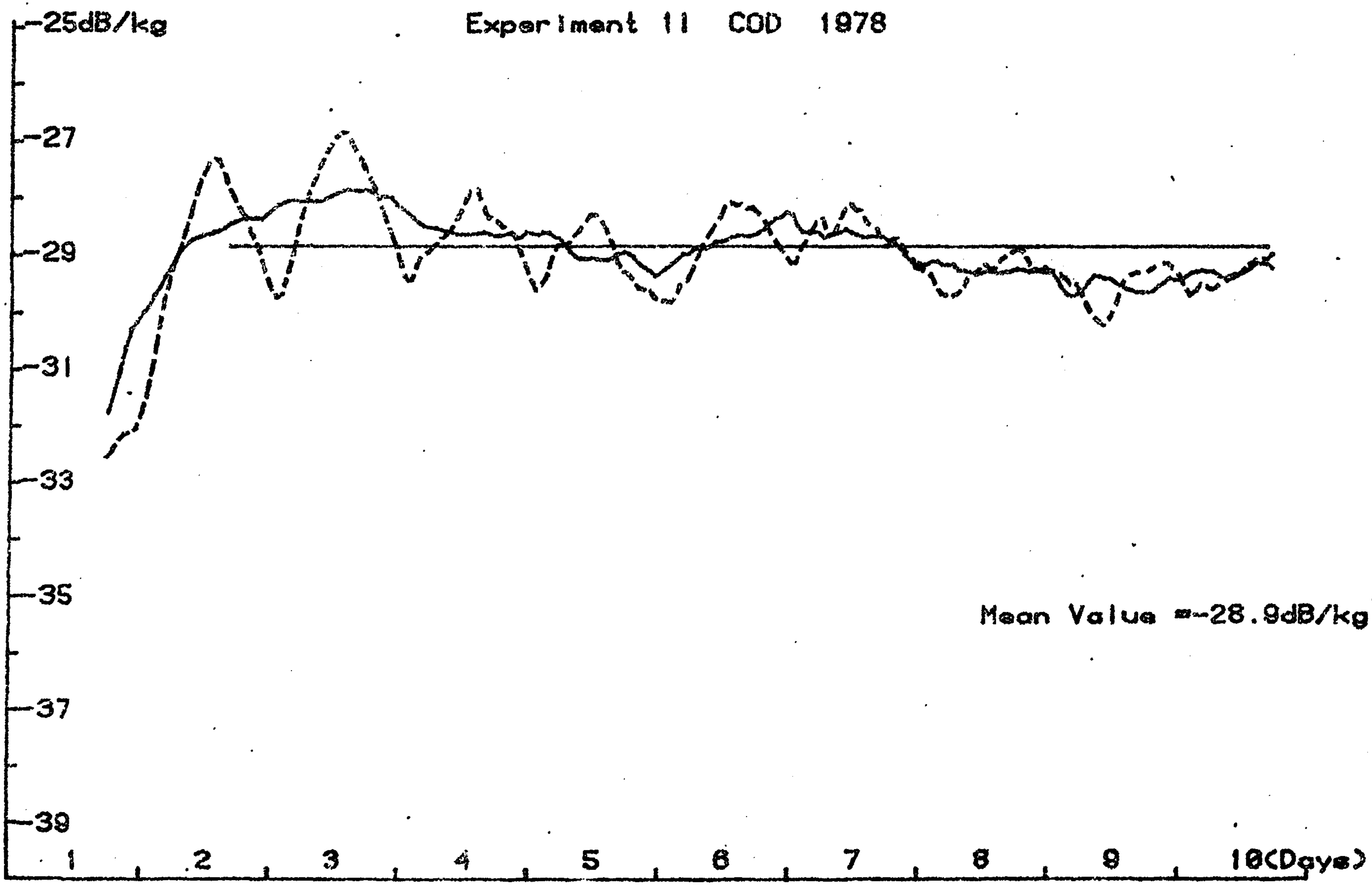

Figure 13 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means For the complete experiment fish at 17.5 m

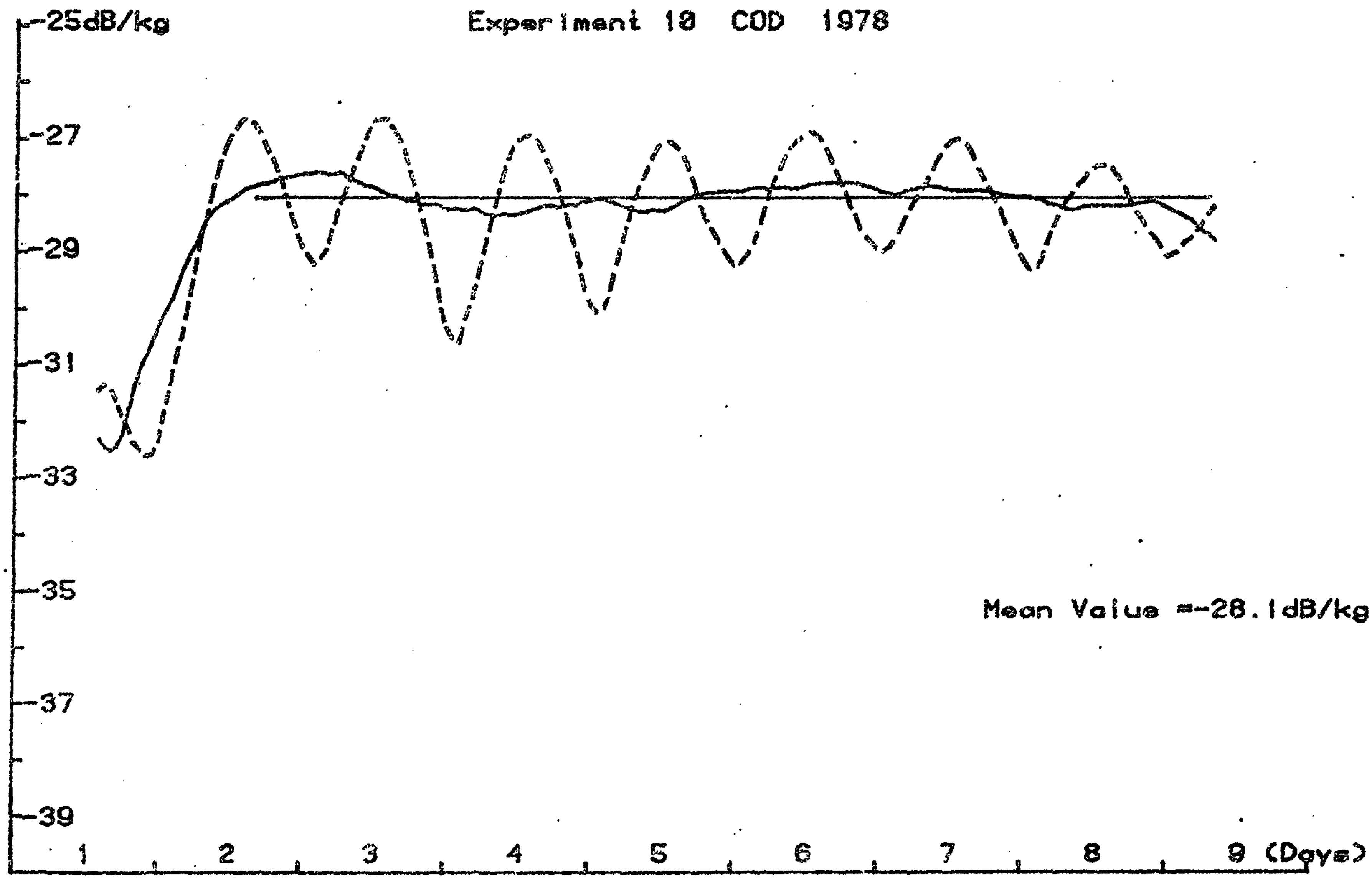

Figure 14 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

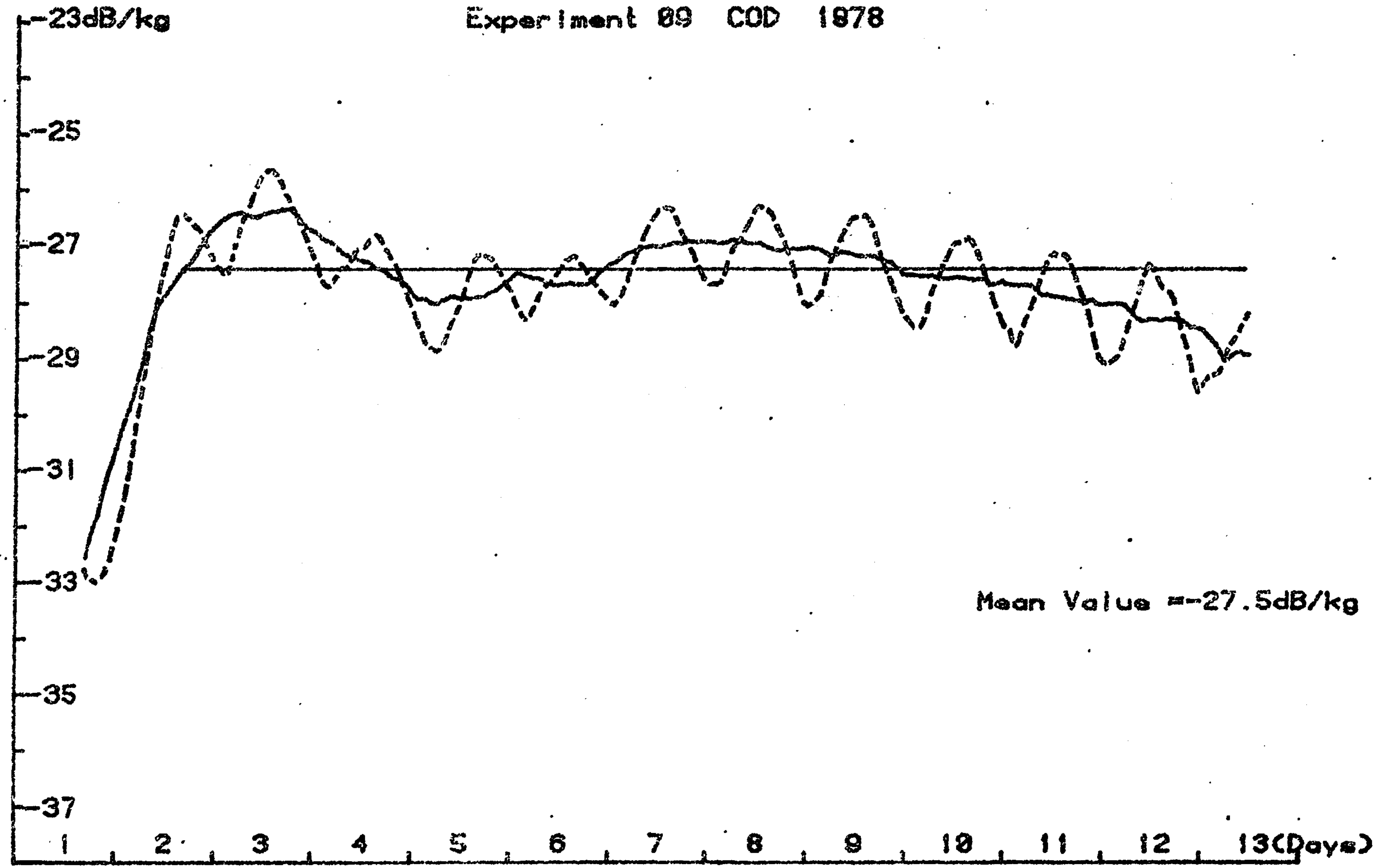

Figure 15 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17 .5 m

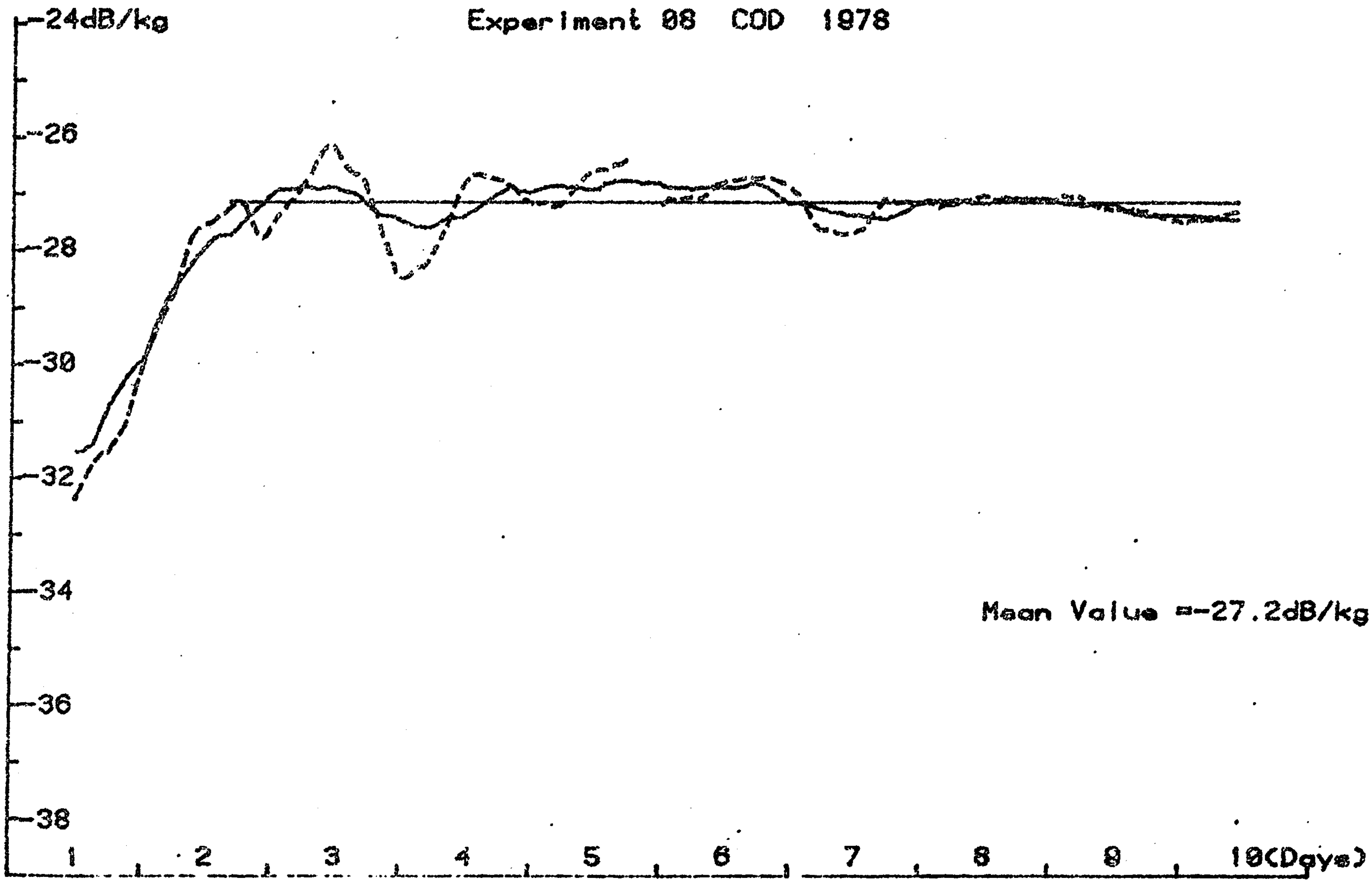

Figure 16 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means For complete experiment fish at 17.5 m

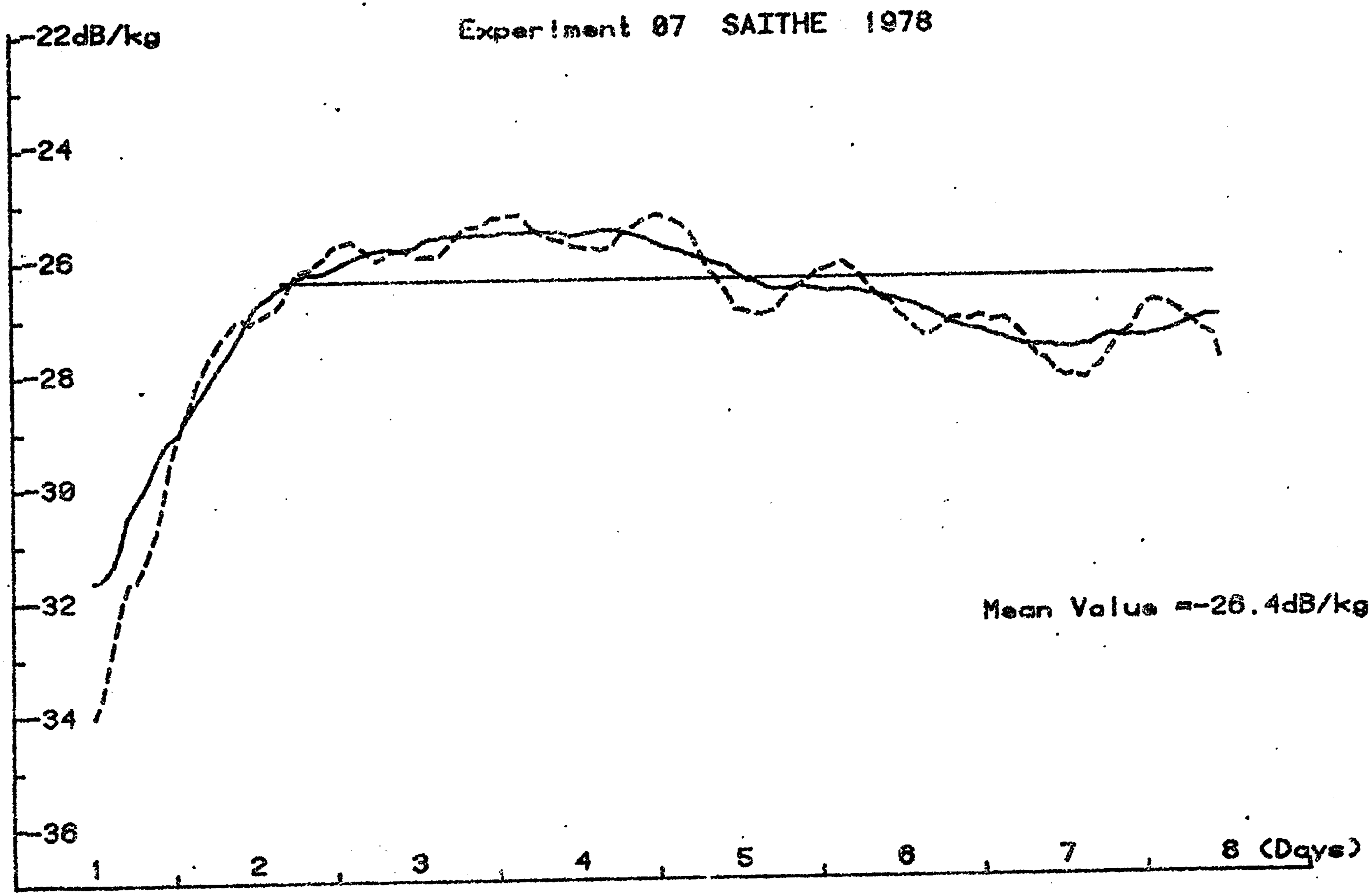

Figure 17 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means For complete experiment fish at 17.5 m

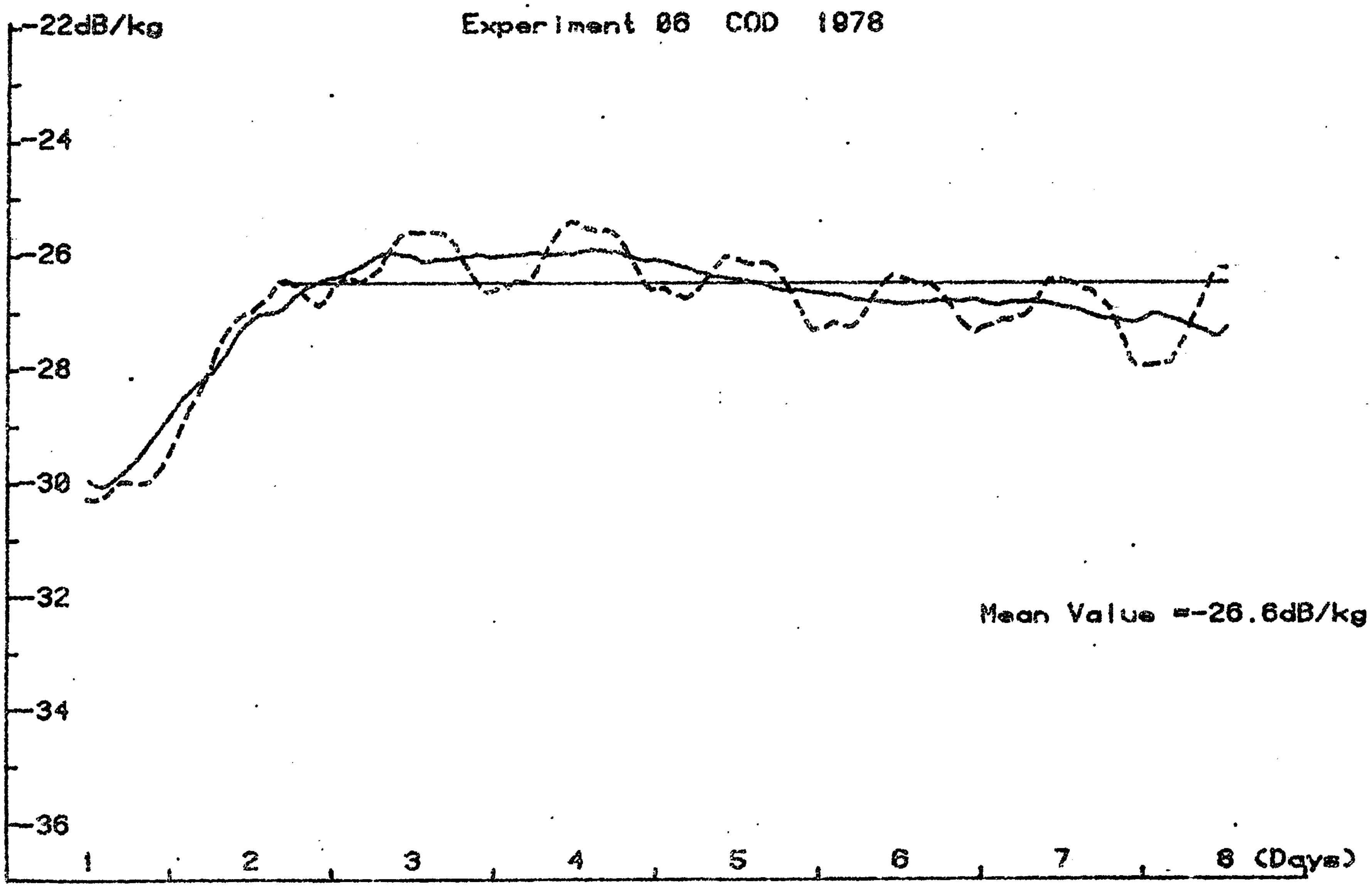

Figure 18 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

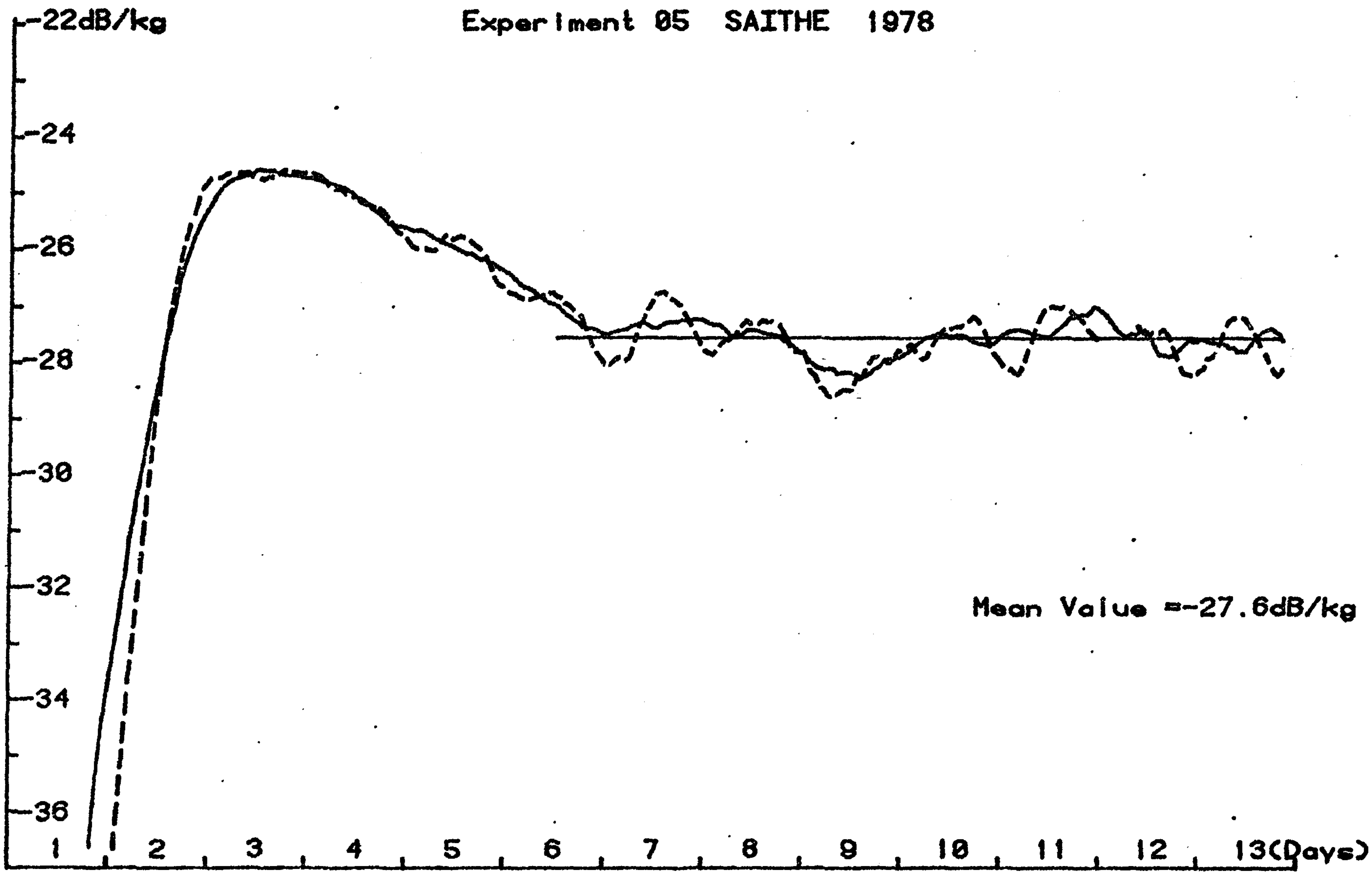

Figure 19 Steady state mean value and 12 hour (dotted), 24 hour(continuous) running means For complete experiment fish at 17.5 m

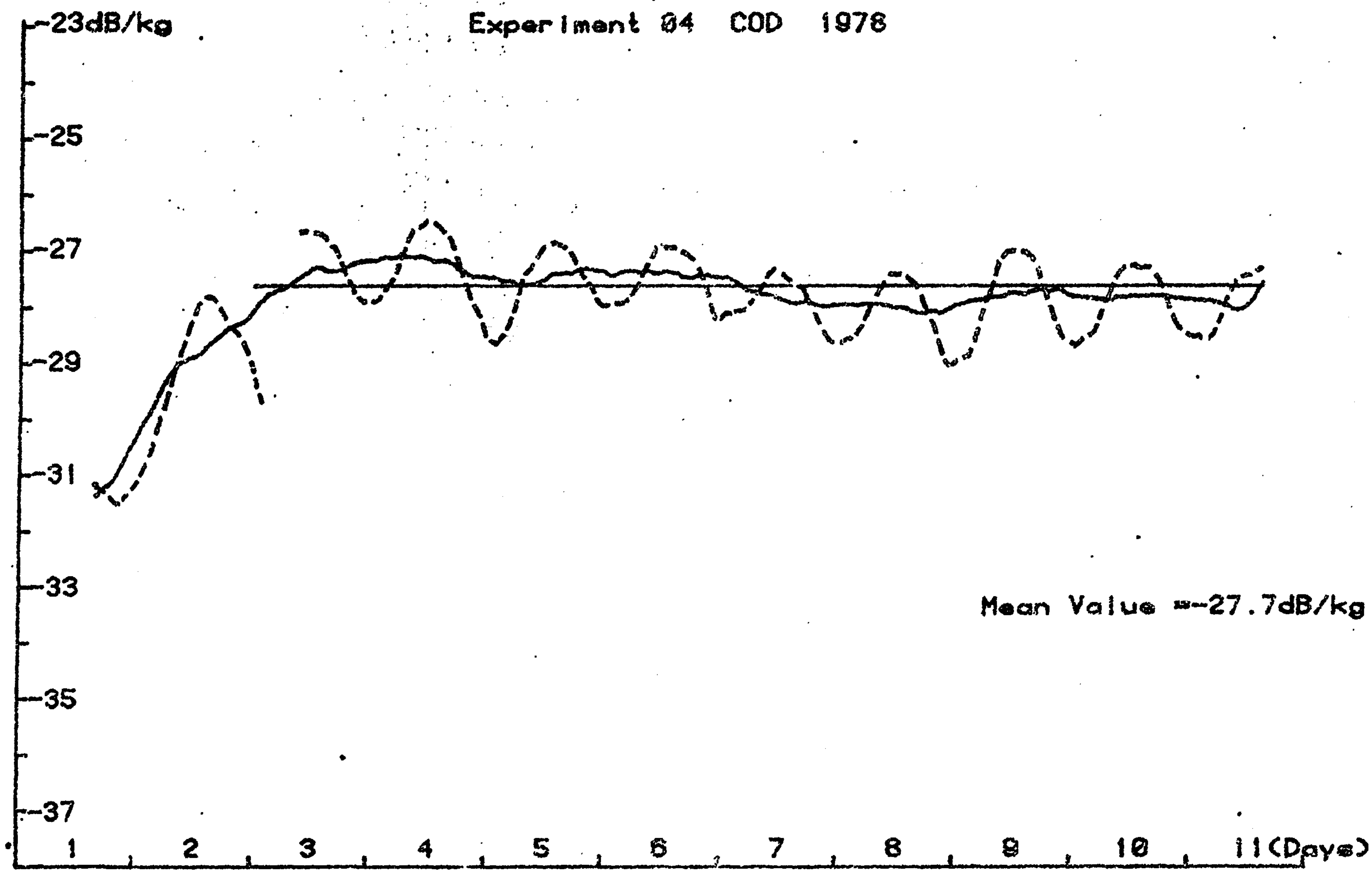

Figure 20 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

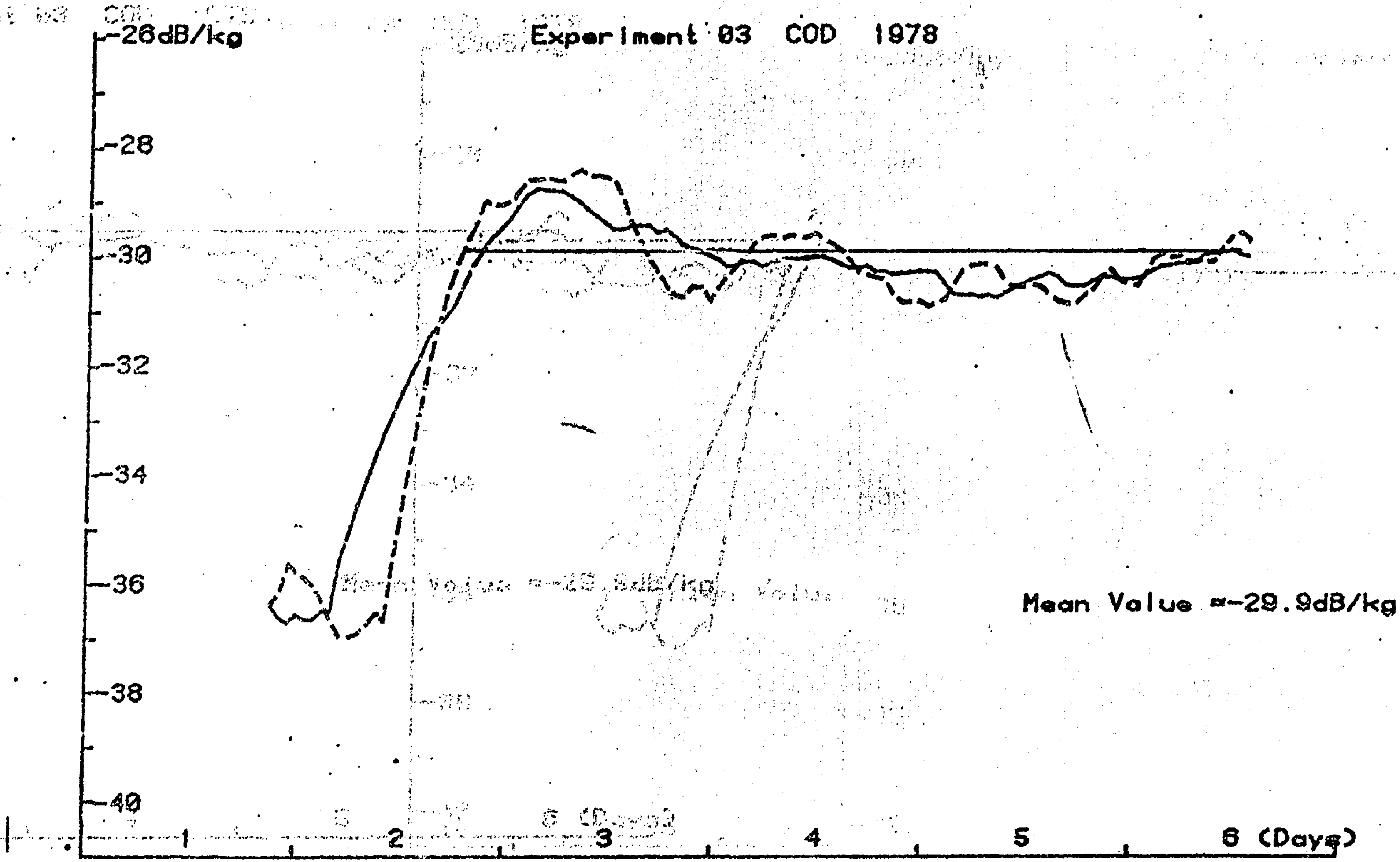

Figure 21 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

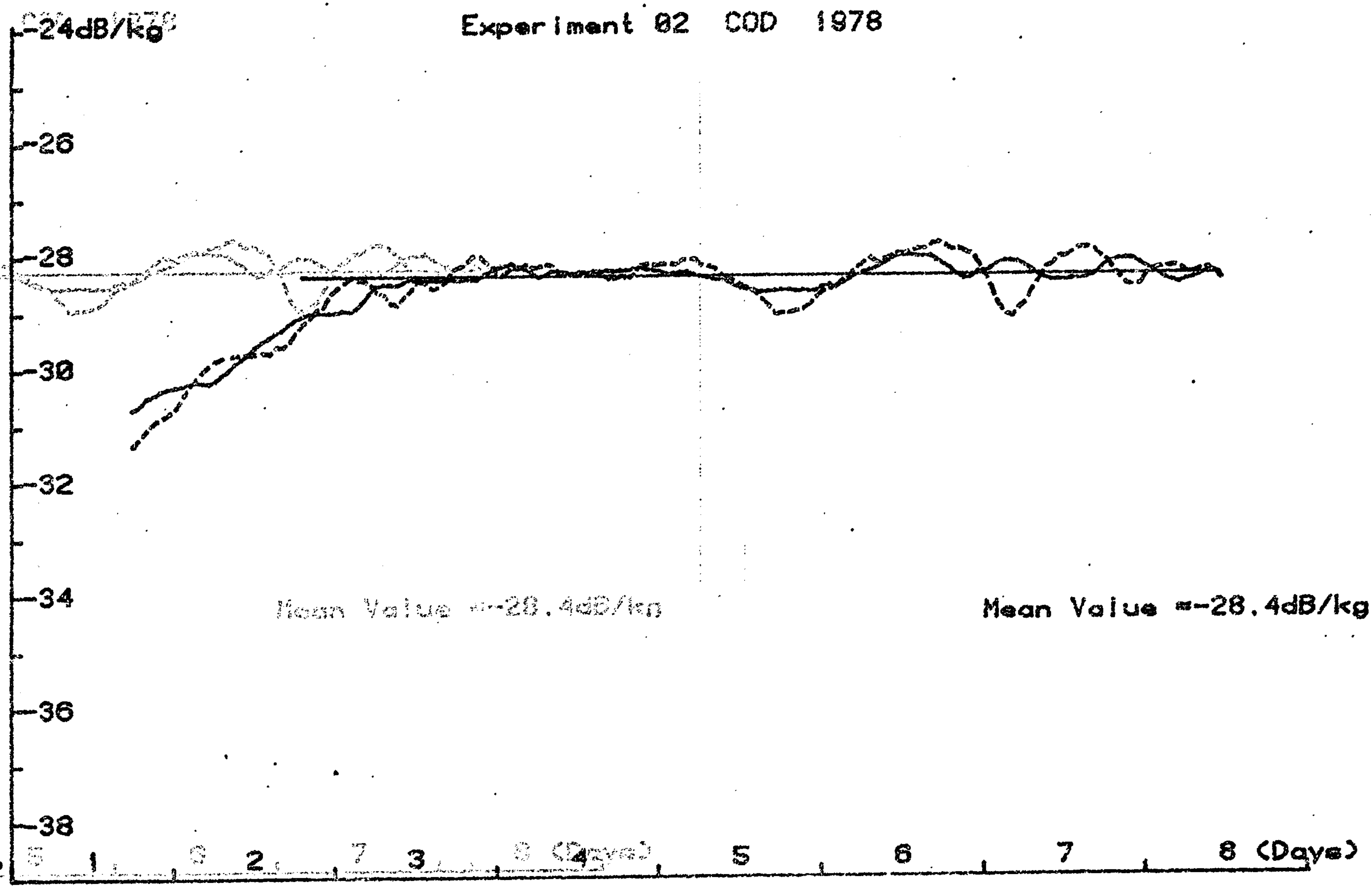

Figure 2: Steady state mean values and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

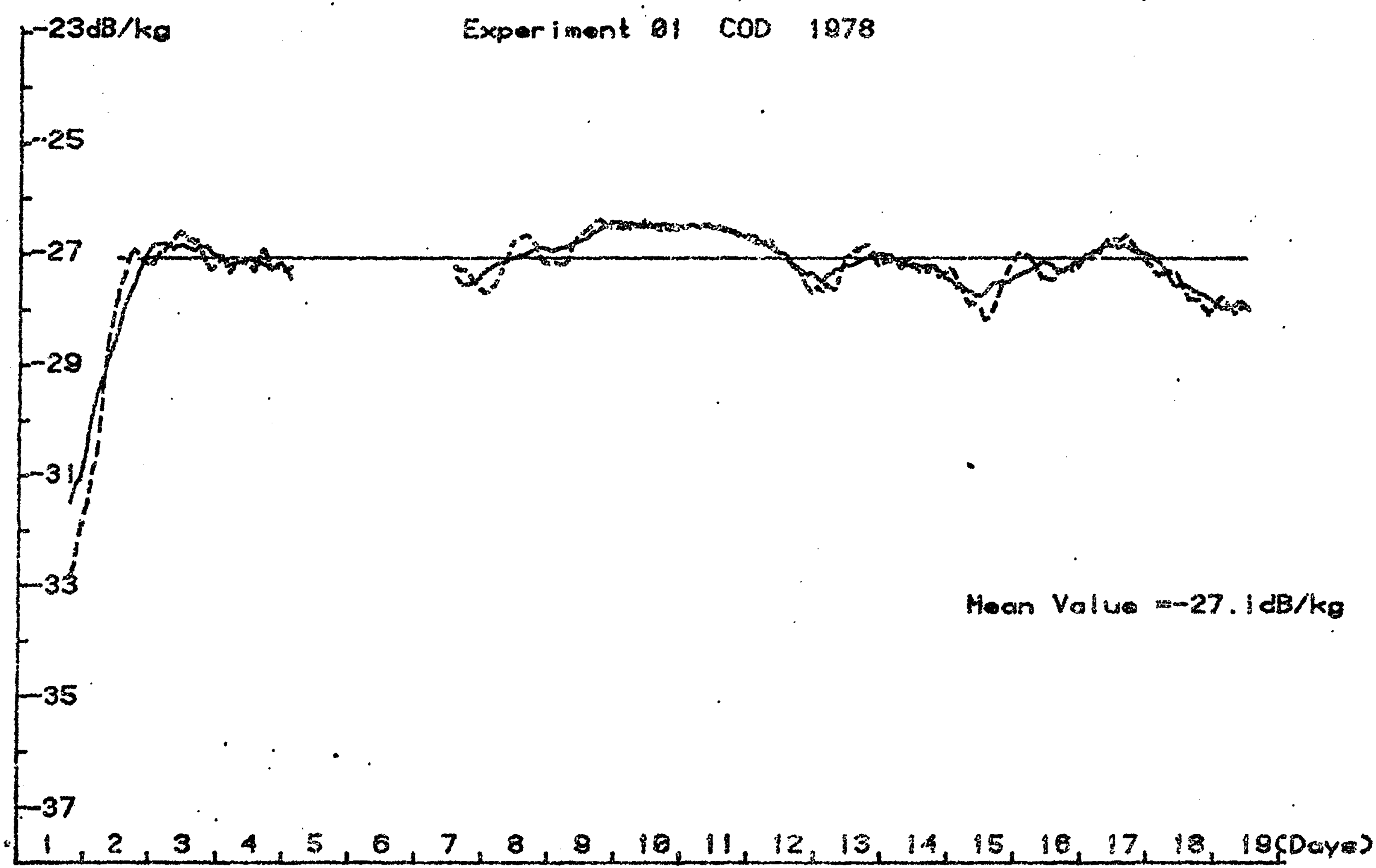

Figure 23 Steady state mean values for fish at 1:17.5 m; 2:70 m; 3:17.5 m and 12 hour (dotted) 24 hour (continuous) running means

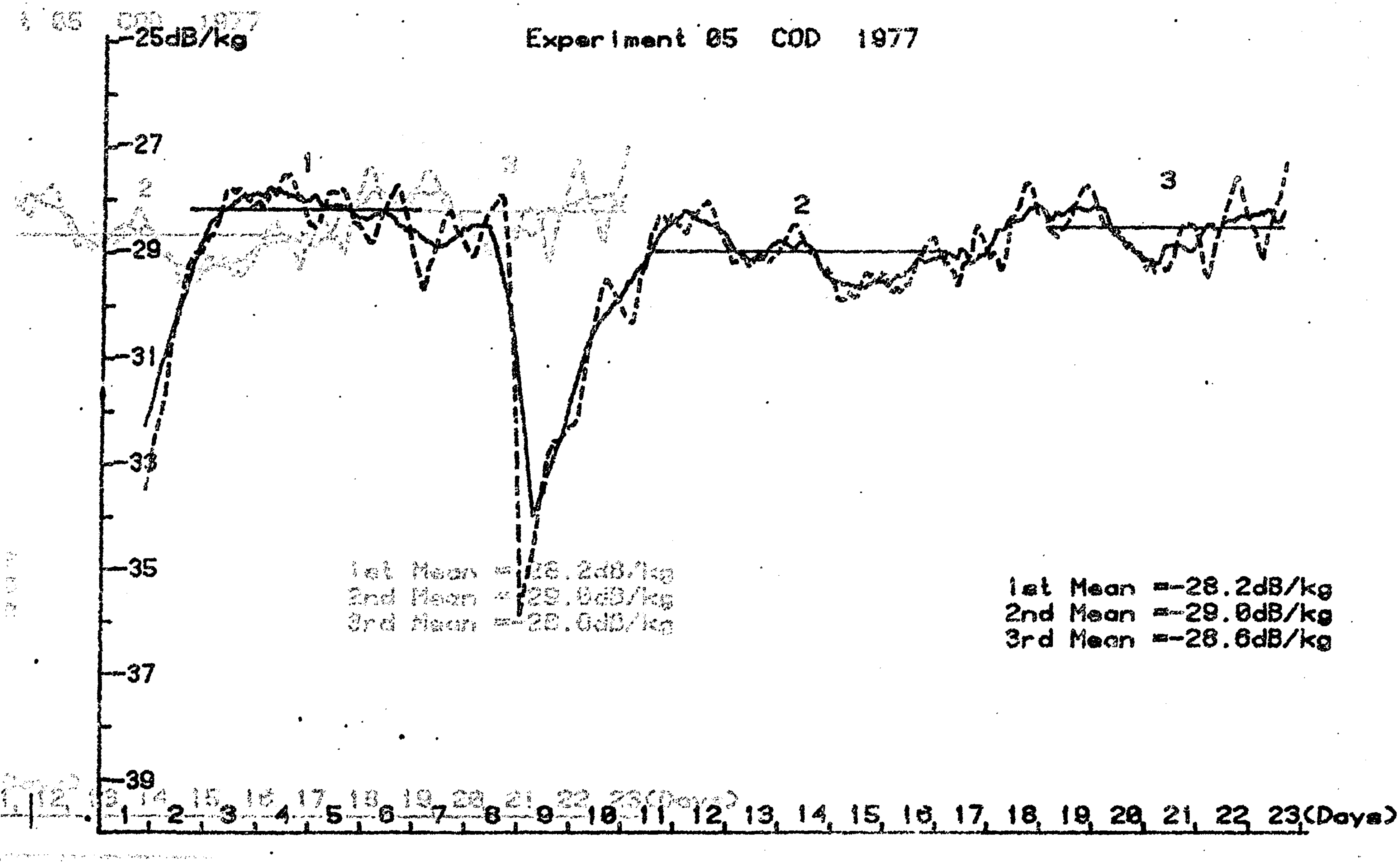

Figure 24 Steady state mean value for two different densities of fish and 12 hour (dotted), 24 hour (continuous) running means. Fish brought to surface on day 8 and day 12 for the rest of experiment fish at 17.5 m

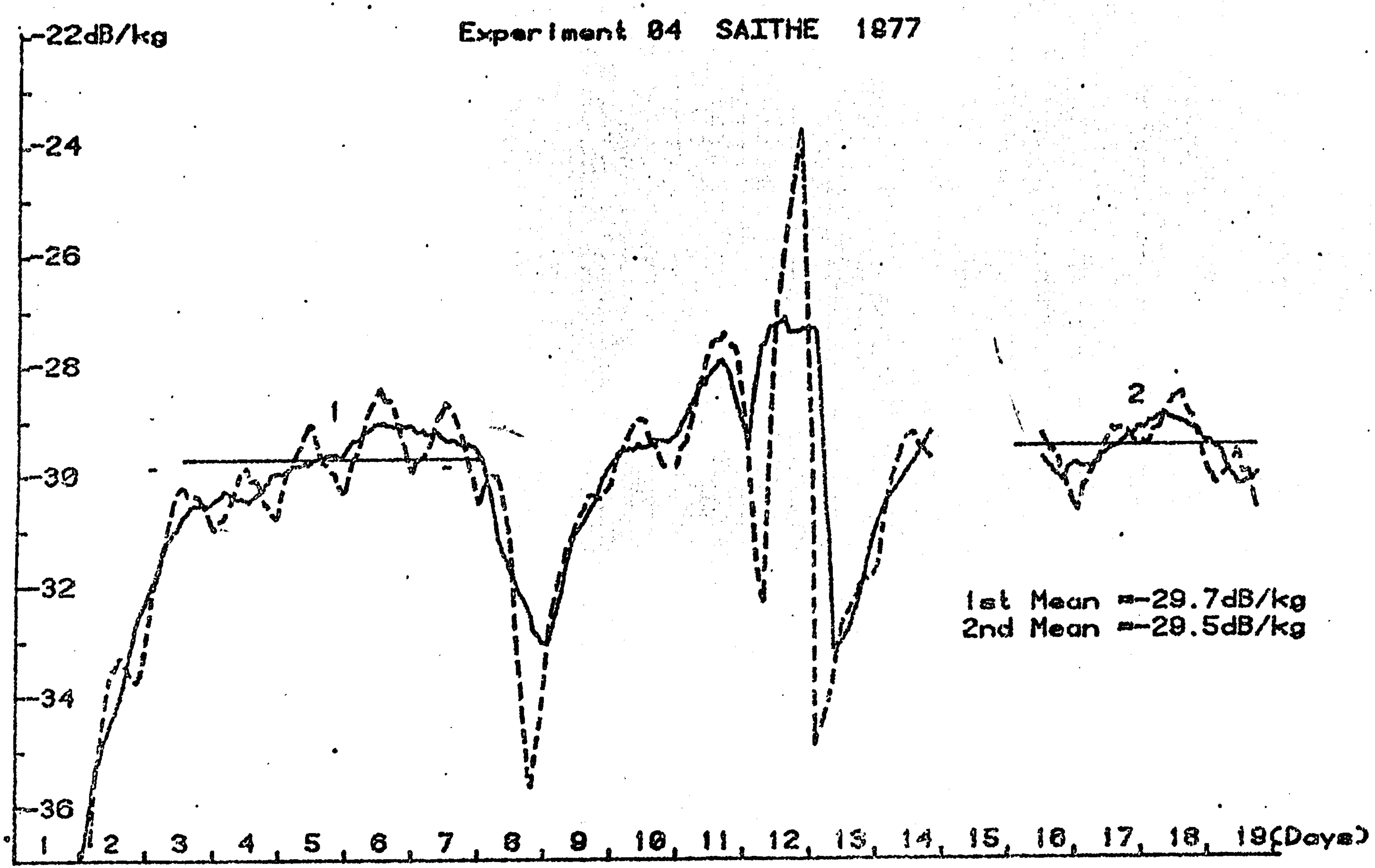

Figure 25 Mean values from three different densities of fish (data excluded from main analysis)
12 hour (dotted) and 24 hour (continuous) running means

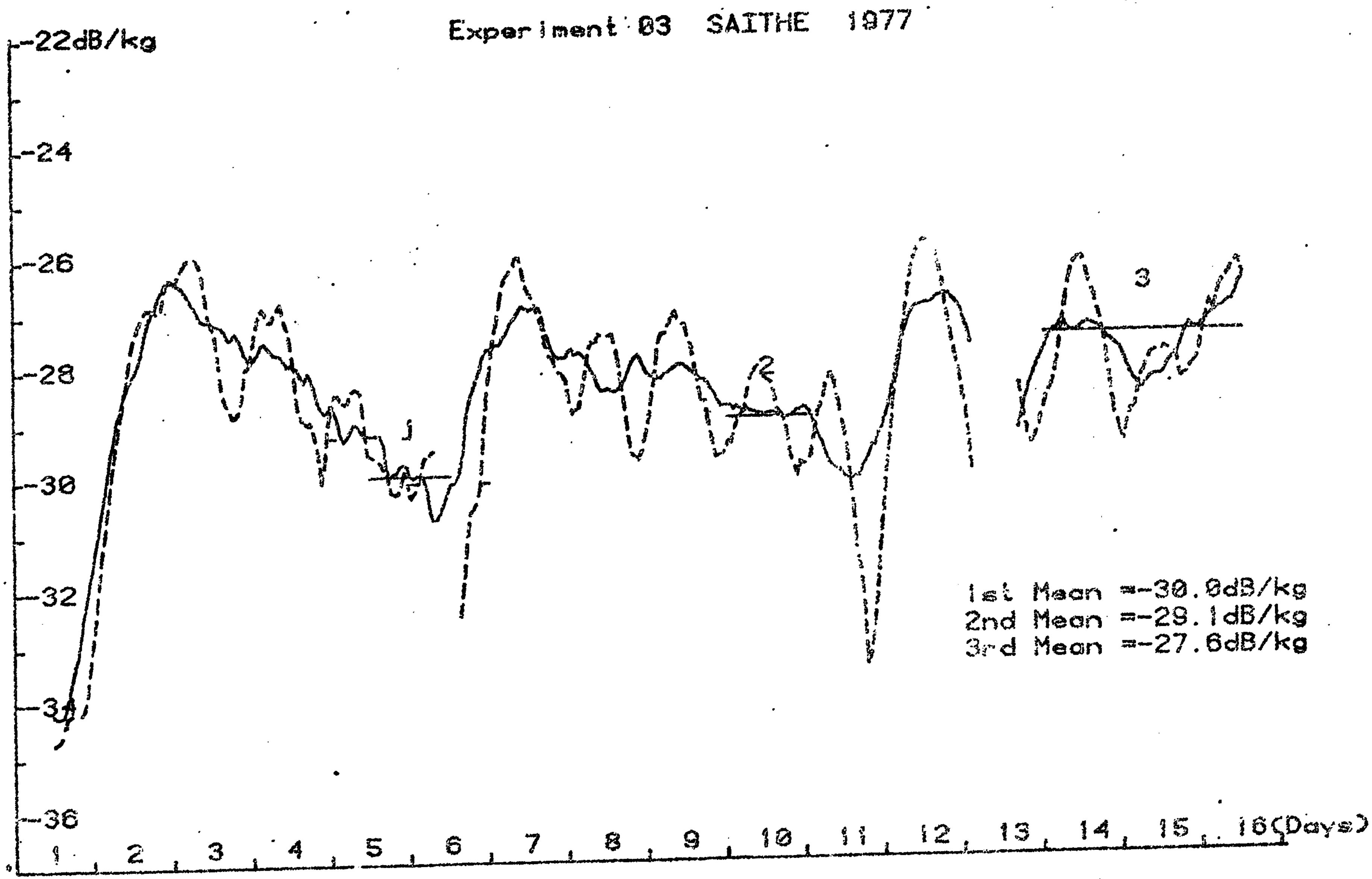

Figure 26 Steady state mean values for fish at 1: 17.5 m; 2: 70 m; 3: 17.5 m and 12 hour (dotted) 24 hour (continuous) running means

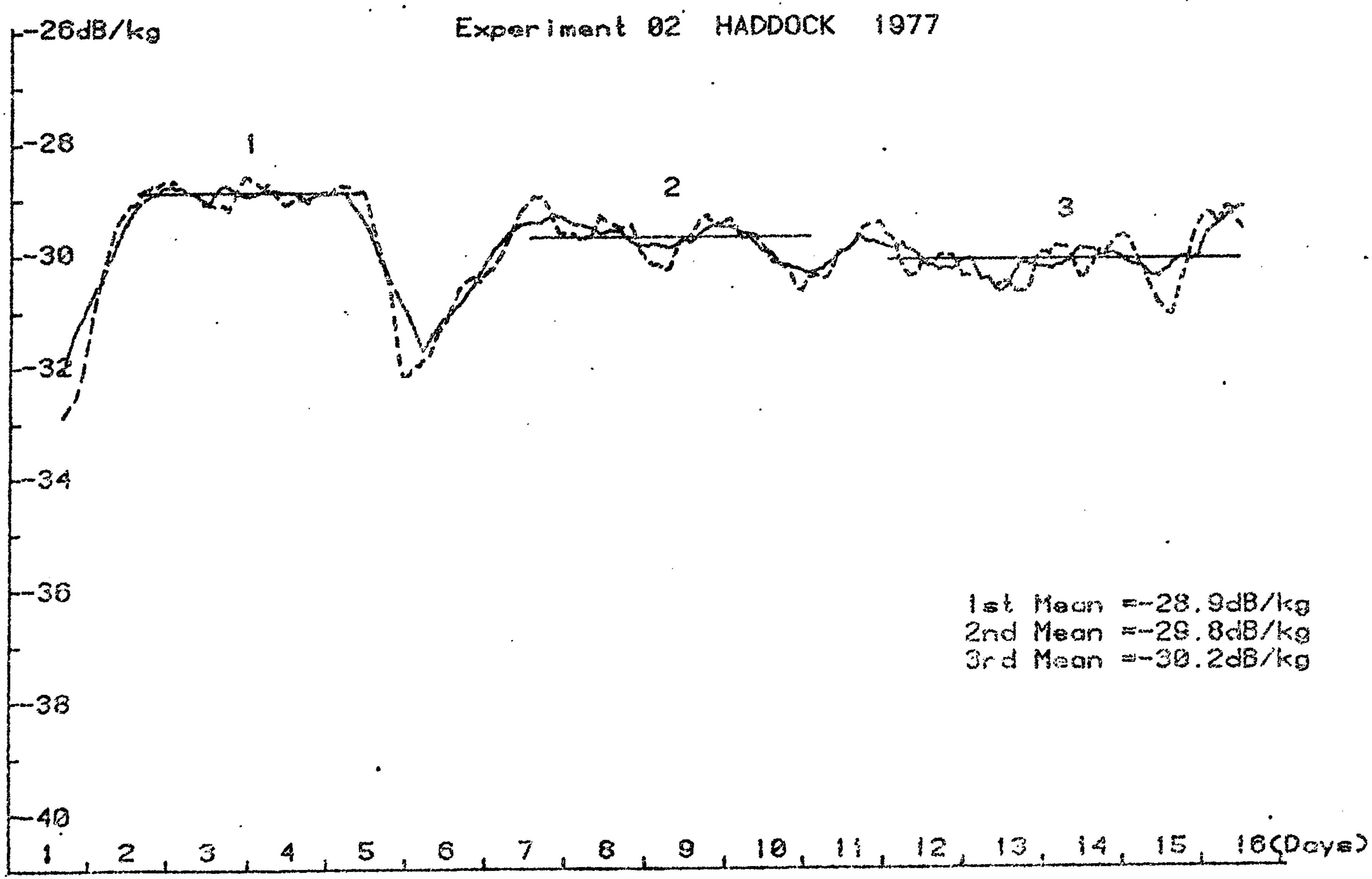

Figure 27 Steady state mean value and 12 hour (dotted), 24 hour (continuous) running means
For complete experiment fish at 17.5 m

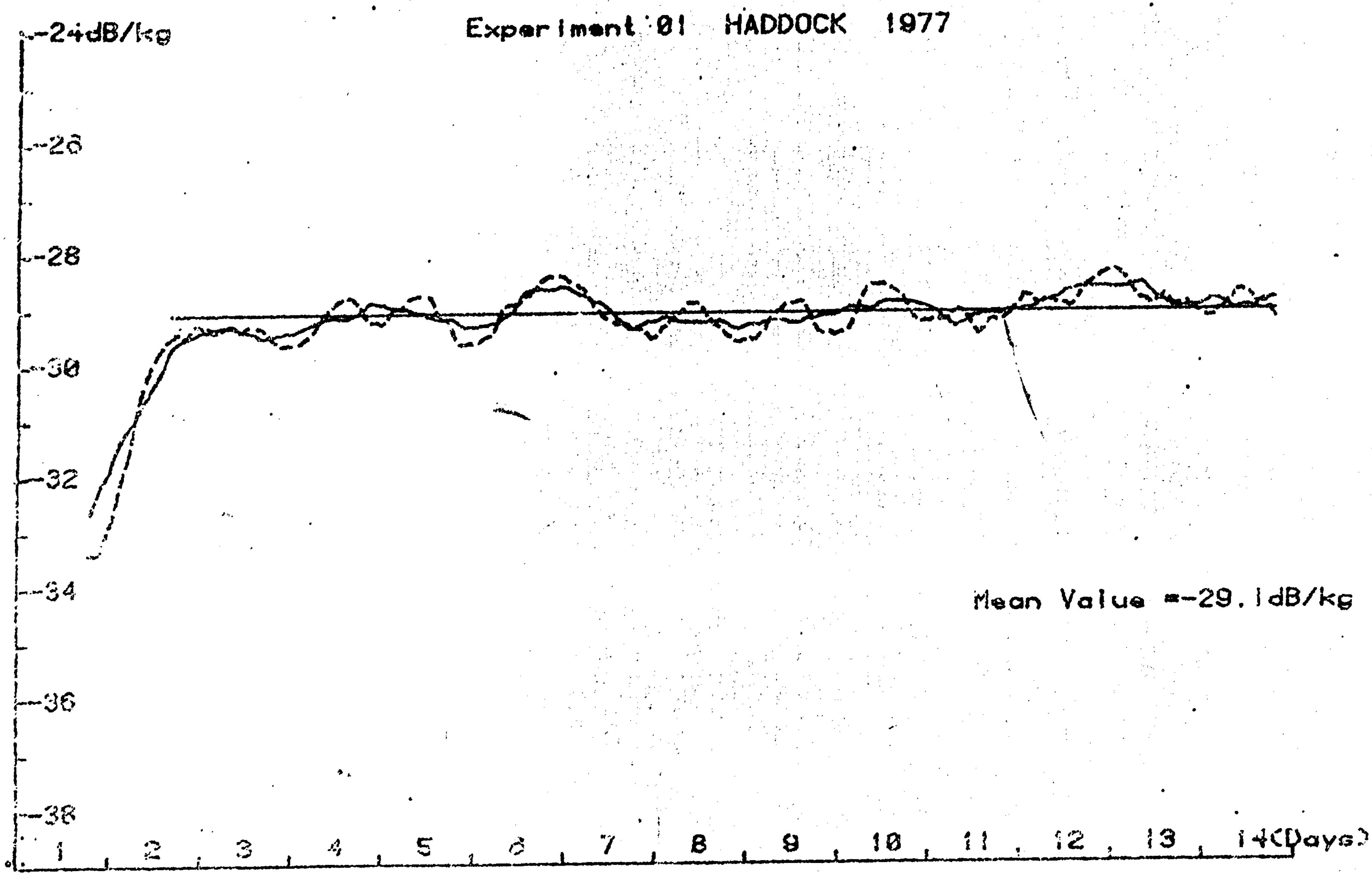

Figure 28 Steady state mean values for fish at 1:20 m; 2:70 m, 3:20 m and 12 hour (dotted), 24 hour (continuous) running means

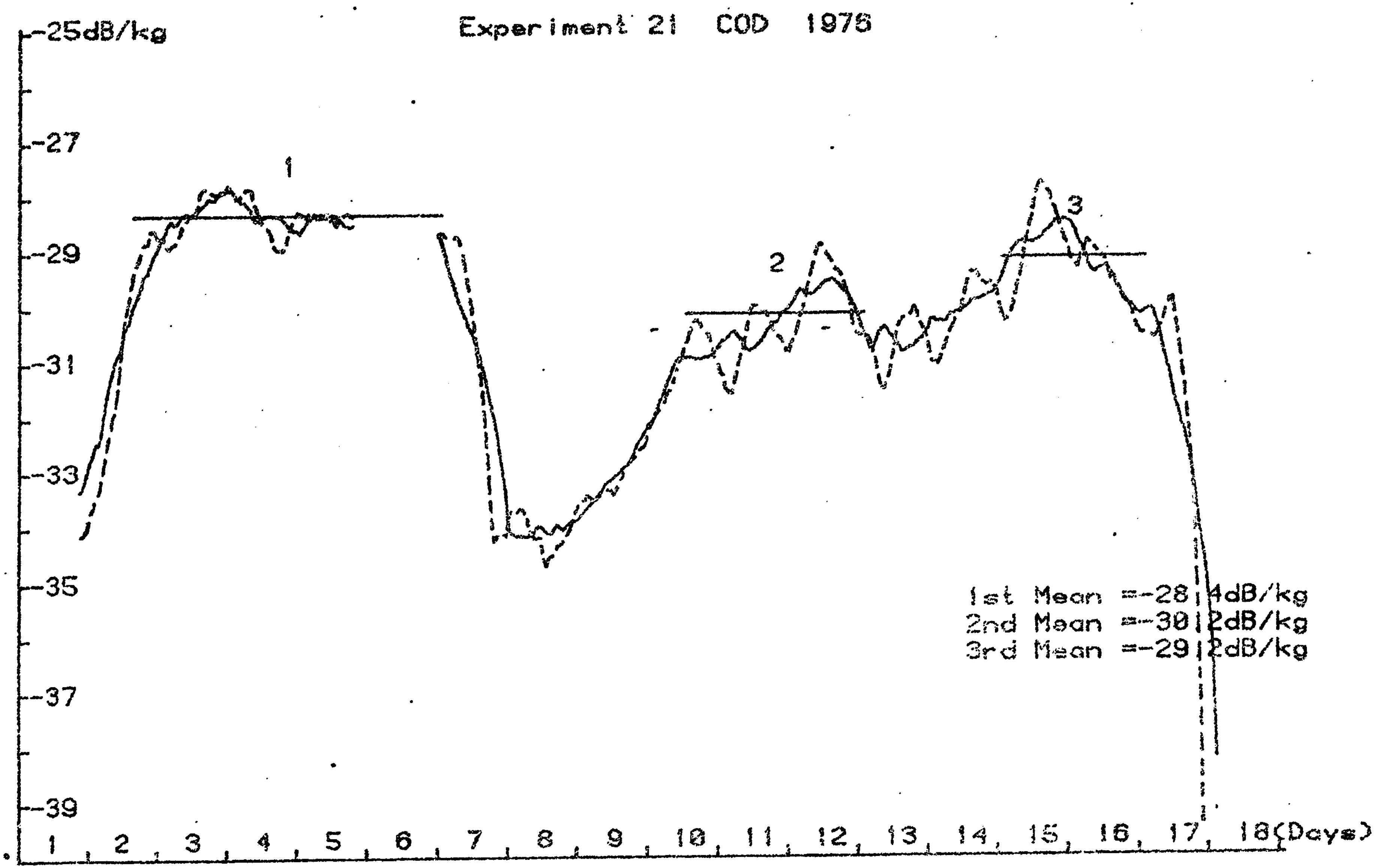

Figure 29 Steady state mean values for fish at 1:20 m; 2:70 m; 3: 20 m and 12 hour (dotted), 24 hour (continuous) running means

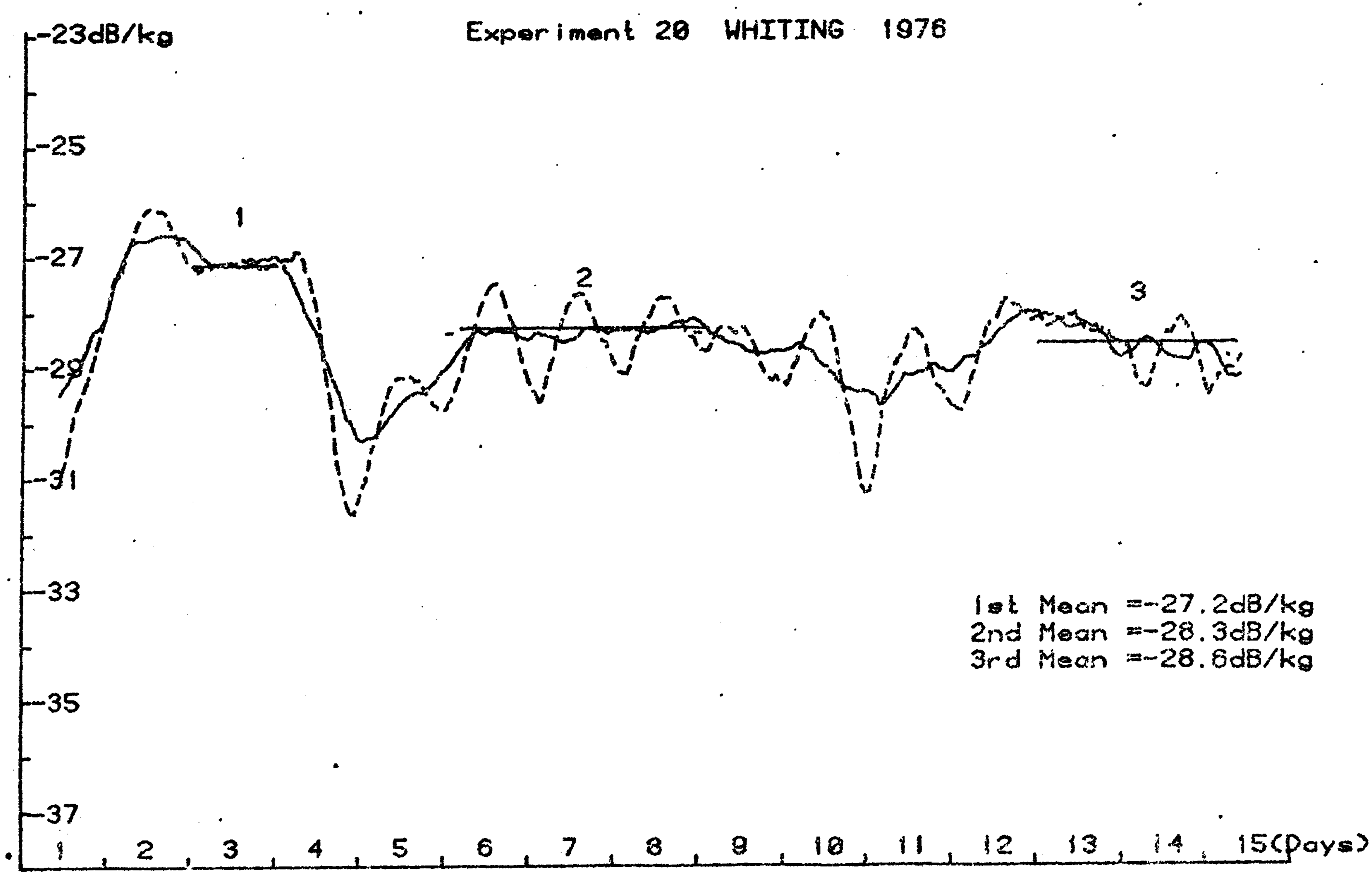

Figure 30 Steady state mean values for fish at 1:20 m; 2:70 m; 3:20 m and 12 hour (dotted), 24 hour (continuous) running means

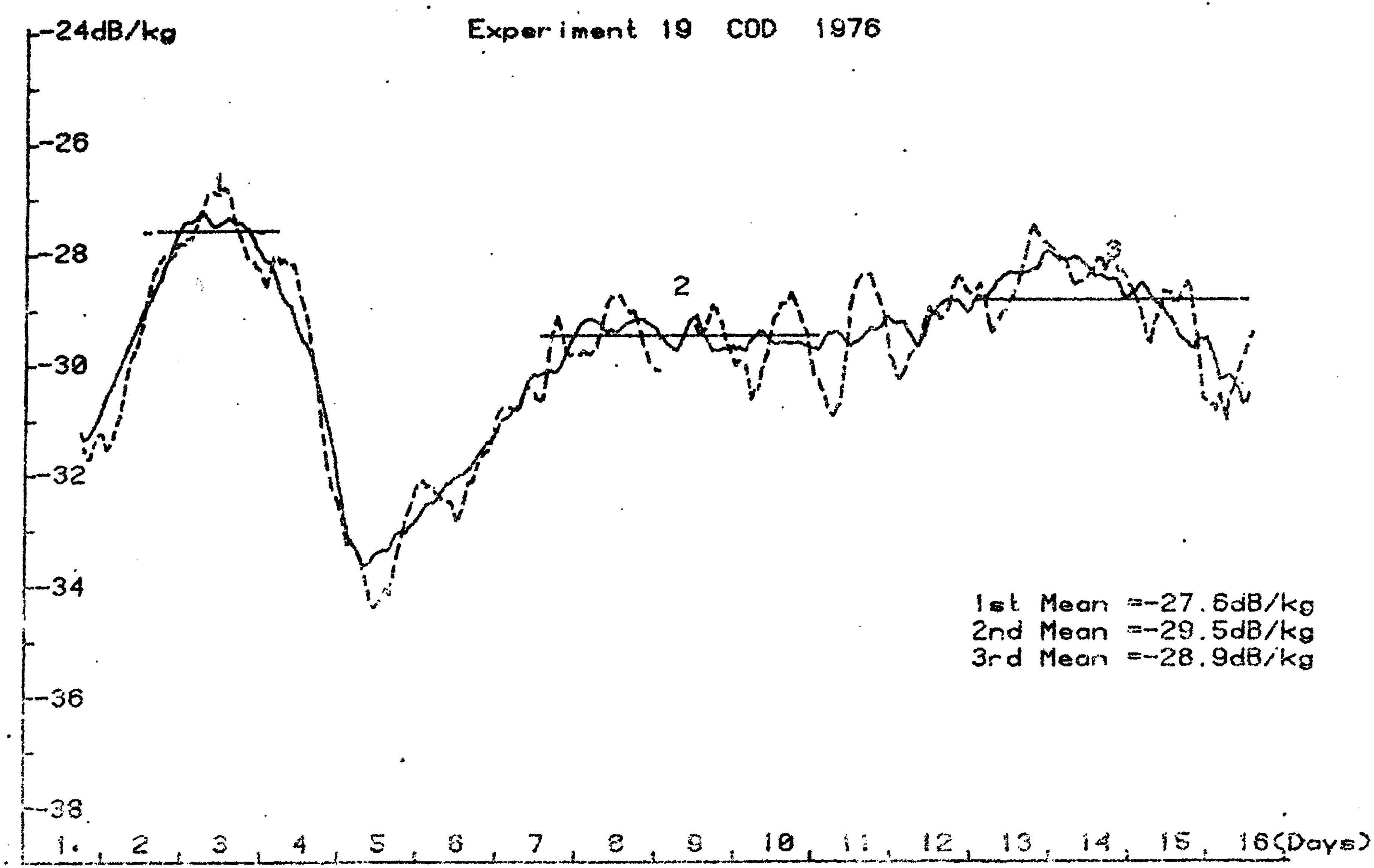

Figure 31 Steady state mean value at 12 hour (dotted), 24 hour (continuous) running means.
For complete experiment fish at 20 m.