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AN INVESTIGATION ON SWIMBLADDER RESONANCE IN FISHES

by

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1. INTRODUCTION

The swimbladder resonance in fishes has been studied by several scientists for different reasons. Biologists [1,2] have used the swimbladder resonance as a tool to get more information on the hearing mechanism of fishes and their ability to absorb or secrete gas into the swimbladder in order to obtain neutral boyancy.

The engineering aspects have been to clearify "scattering layer" and try to use the swimbladder resonance for the classification of fish [3,4]. In co-operation with the Institute of Marine Research we are running a study on this last problem. This study involves two different problems:

The first is to determine the nature of the swimbladder resonance as function of depth and adaptation to depth for various species and seizes.

The second problem is engineering and involves mainly the design of a low frequency echo sounding equipment of sufficient power and bandwidth, and the implementation of data processing tools in order to extract the required information. This paper is devoted to the first problem presenting the results of a serie of measurements on fishes of 6 different species. We have performed the measurement in three stages:

Starting with the ring hydrophone technique, originally used by Mc Cartney and Stubbs, [5] proceeding to echo measurement on fishes in a cage and finally echomeasurements on free swimming fishes.

This paper consentrates on the first two stages and gives some of the obtained results.

2. MEASUREMENTS

The ring measurement were done during the summer of 1976 and 1977 from a small raft located in deep water near Bergen.

The experimental set up is shown in figure 1.

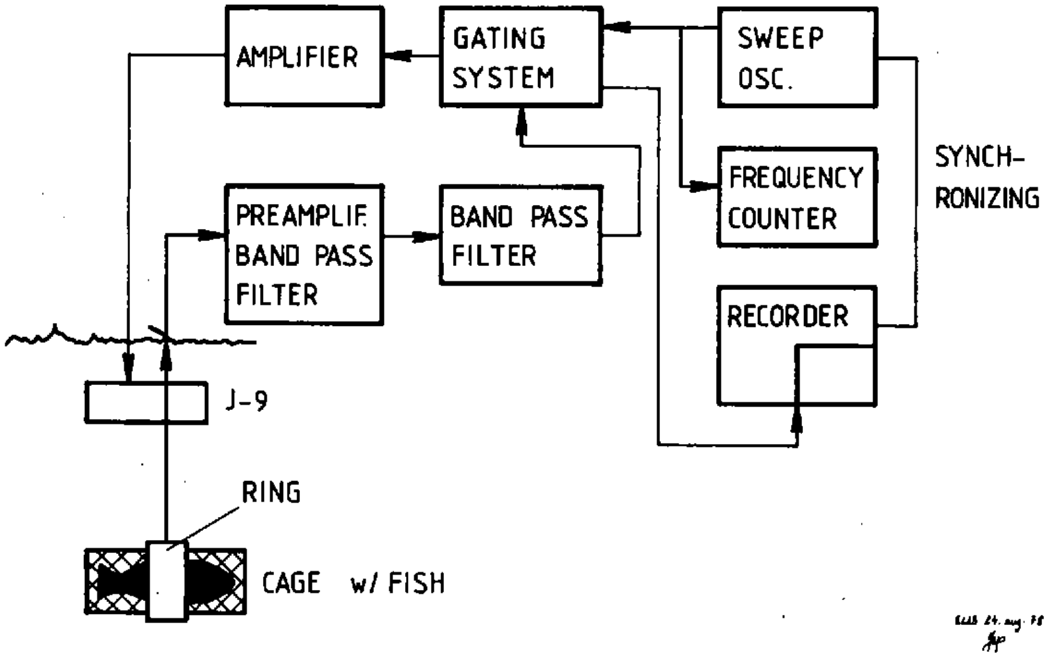

Figure 1. Ring measurement.

The ring was insonified from above or beneath by a J - 9 underwater load speaker and the voltage over the hydrophone was measured. The measurements were done pulsed, reducing any influence of the water surface and bottom.

The target strength of a fish measured with this technique can be expressed as:

$$TS = 20lgR + 20lg\frac{S_p}{S_s} + 20lg\,\frac{V_1}{V_2} + 20lg(1-\frac{V_2}{V_1}) \qquad (1)$$

where

R: effective distance from the fish to the point where the scattered pressure p_s is measured

S_p: plane wave sensitivity of the ring

S_S: spherical inside sensitivity of the ring

and

V_1: voltage developed over the ring with a fish inside.

V_2: voltage developed without fish.

Knowing the ratio of the sensitivities the target strength may be found by measuring the voltages V_1 and V_2. Since the phase difference between V_1 and V_2 is unknown, the experiment is arranged so that $V_1 >> V_2$, and the last term in (1) is neglected. This can cause an error with maximum value given as

$$\Delta TS = 20lg\ |1 \pm \frac{V_2}{V_1}| \qquad (2)$$

Figure 2 shows a typical example of the measured voltages, and figure 3 gives an indication of the maximum errors involved.

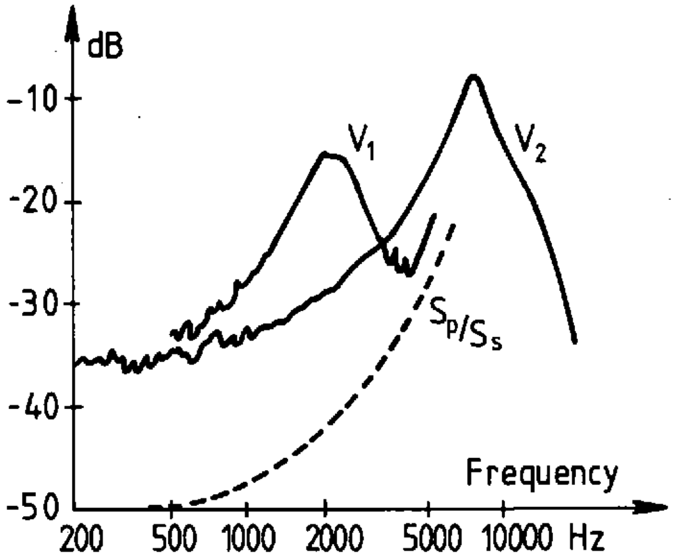

Figure 2. Measures voltages with V_1 and without V_2 fish in the ring.

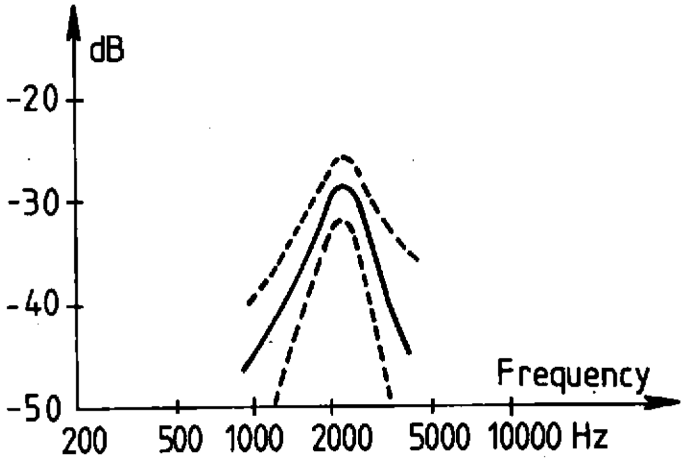

Figure 3. Target strength with error limits.

From figure 3 it is seen that the error does not seriously effect the determination of the resonance frequency. Values for the target strength outside the resonant region are however uncertain.

The arrangement for the echomeasurement are shown in figure 4.

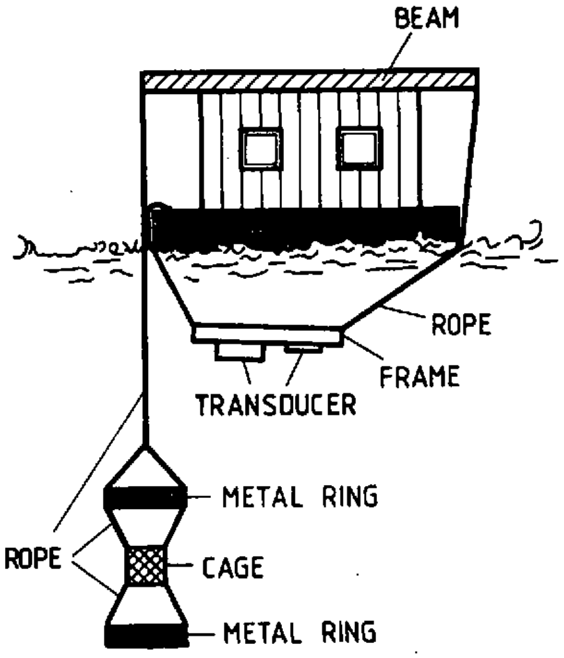

Figure 4. Echo measurement.

The transmitting transducer was composed of thirty 7 kHz transducer elements mounted in a rectangular array of 0.9 times 1.1 meter. The receiver was a 38 kHz transducer with dimensions 0.4 times 0.8 meter. The instrumentation shown in figure 5 is a standard echo sounding set up. This instrumentation has also been used for echomeasurements on free swimming fishes, but with other transducers.

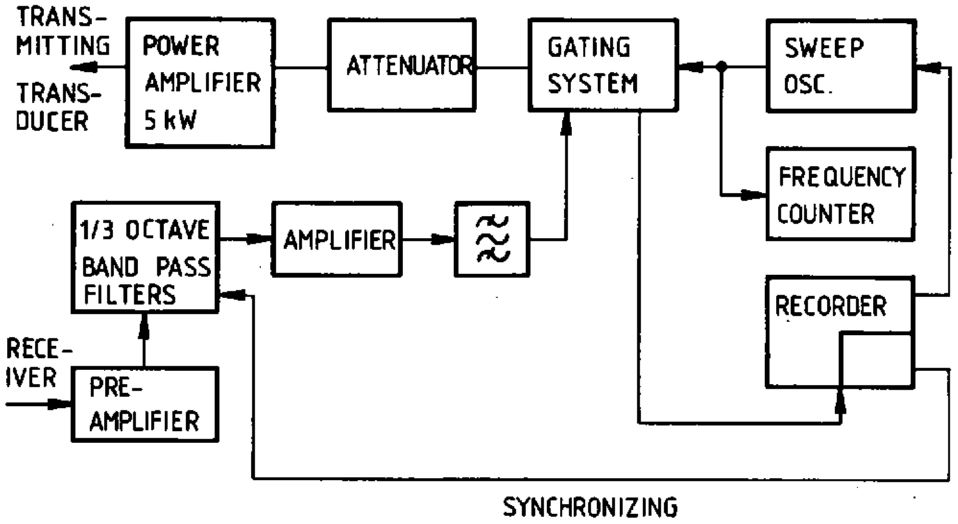

Figure 5. Instrumentation for echo measurements.

3. RESULTS

Measurements with the ring hydrophone have been done on six different species, saithe, cod, pollack, herring, sprat and trout. The results from the ring method are mainly given as resonance frequency and Q-value as function of depth, and time spent at a depth.

The measured targeth strength are compared with a simple theoretical model for a gasfilled sphere where the back scattering cross section is given by

$$\sigma = \frac{4\pi a^2}{[(\frac{f_o}{f})^2 - 1]^2 + \delta^2} \qquad (3)$$

a: radius of the sphere
δ: damping constant = 1/Q

The resonance frequency fo is given as

$$f_o = \frac{1}{2\pi a}\sqrt{\frac{3\gamma P_a}{\rho_s}} \qquad (4)$$

where

γ: ratio of specific heats
P_a: ambient pressure
ρ_s: surrounding density.

The last equation implies that the resonance frequency will vary as the square root of ambient pressure when the bubble volume is constant and with the ambient pressure raised to 5/6 if the gas mass is constant.

For an adapted fish one expects the resonance frequency to follow the law of constant volume, the fish will produce or let out gas in order to maintain neutral boyancy.

3.1. Resonance frequency

Figure 6 shows the resonance frequency for a saithe as function of depth and time spent at a depth. When the fish was rapidly transferred from one depth to a new one, the resonance frequency follows the law of constant mass. At each station one can clearly observe a change in resonance frequency towards the adapted value.

The resonance frequency was measured at regular intervals. During the first one to two hours after transfer to a new depth gradually diminishing oscillations in the resonance frequency were observed.

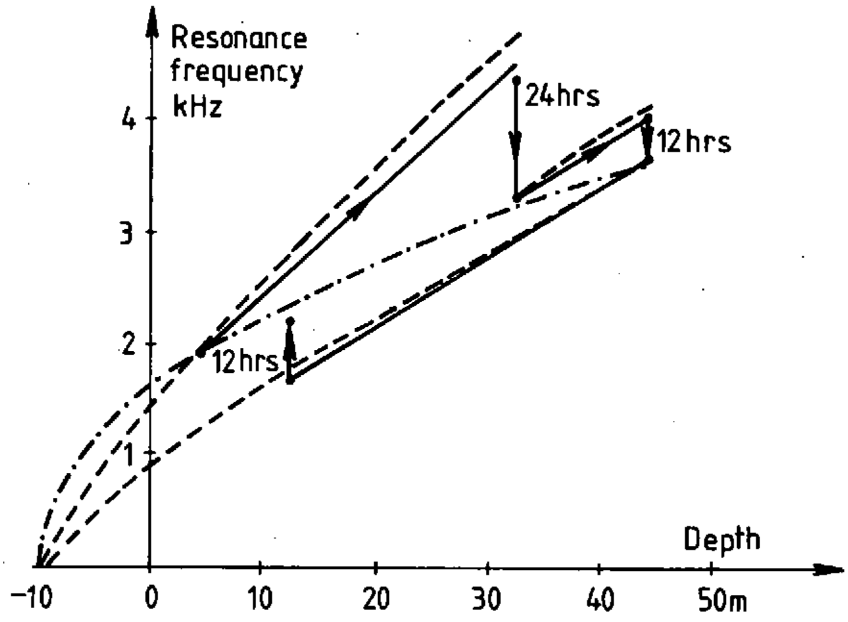

Figure 6. Resonance frequency versus depth for a 77 mm saithe.

It is also interesting to note that the necessary time for adaption increased with increasing relative change in pressure. The time to absorb gas seems to be smaller than for producing it.

Figure 7 shows resonance frequency versus depth for saithe, sprat and herring. All of the fishes were adapted to a shallow depth at the beginning of the measurement and were not given time to adapt at other depths. There is no significant difference in down- and up-way measurements, and all values seems to agree with the constant gas mass law.

Figure 8 shows the same observation for a cod. Here there is a different behaviour at low frequencies, and a difference in the values going up and down.

This phenomena has also been observed by Hawkins and Sand who suggest that this behaviour is due to the part played by the swimbladder in hearing.

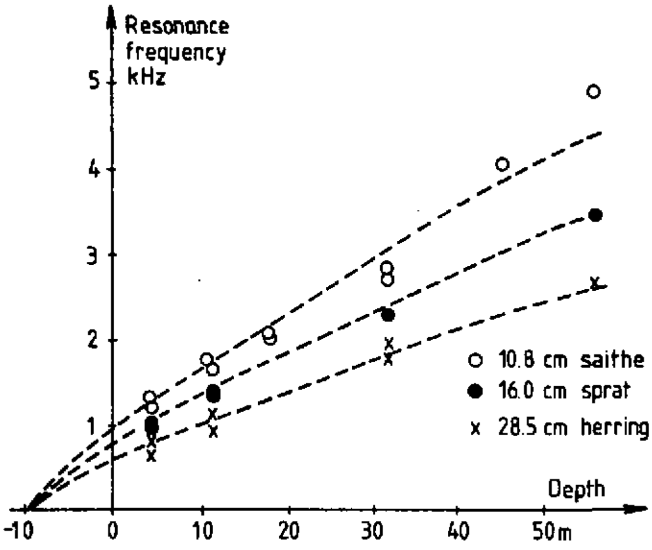

Figure 7. Resonance frequency as function of depth for unadapted fishes.

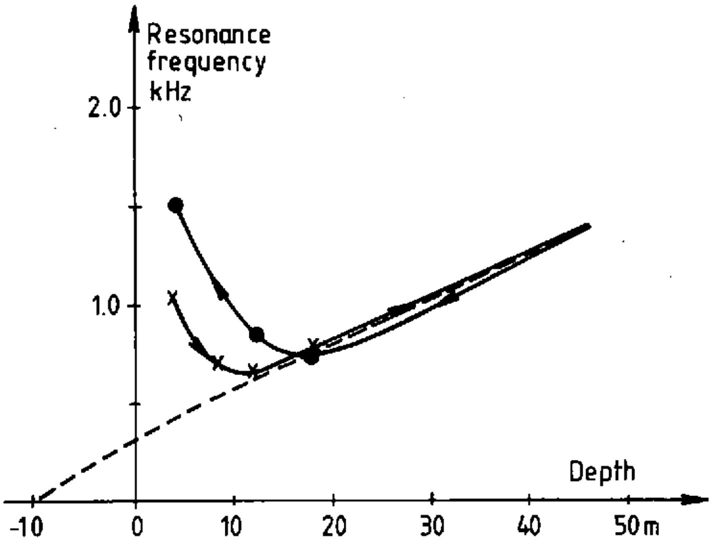

Figure 8. Resonance frequency for 250 mm cod.

3.2. Q-value

Measurements of the damping constant or Q-value are more uncertain because of the error limits previously discussed.

Figure 9 shows the Q-value as function of depth for the 77 mm long saithe, shown in figure 6.

There is a clear difference between adapted and unadapted Q-value. When the fish is adapted the Q-value tends to be constant, but when the fish is not adapted it will have a high Q-value when the resonance frequency is higher than the adapted and a low Q-value when the resonans frequency is lower than the adapted resonance frequency.

This suggest that the Q-value depends on the relative size of the bladder, and that a compressed bladder has a weaker coupling to the surrounding fish tissue.

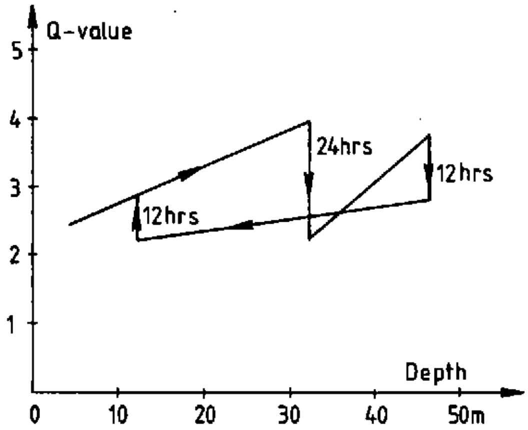

Figure 9. Q-value for 77 mm saithe versus depth.

This observation is further supported when Q-values are plotted versus resonance frequency for unadapted fishes, figure 10.

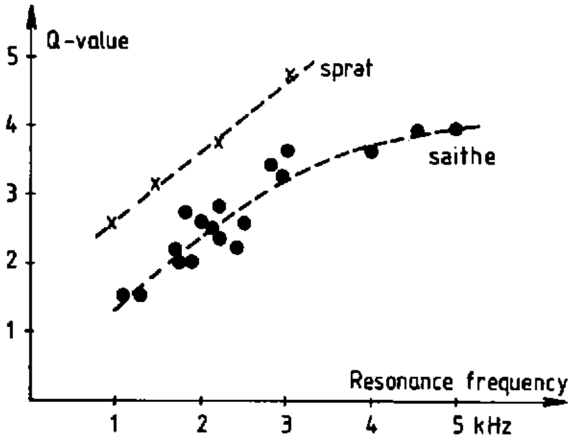

Figure 10. Q-values versus resonance frequency.

This figure shows observations on a large number of saithe and a few values for sprat.

The values indicate a linear relationship with a possible saturation at high Q-values for saithe.

3.3. Echo measurements

Echo measurements with the equipment described was done on a collection of N=80 saithe of nearly the same size at a depth of 56 meters. The fishes were first kept at 4 meters and then transferred directly to 56 meters.

Figure 14 shows the measured target strength reduced by 10lgN to give an estimate of the traget strenght of a single fish.

The theoretical curve is drawn using a Q-value of 3 and an equivalent radius giving the right mean measured swimbladder volume for the fishes. The agreement between the measured and theoretical values are good both in absolute value and in frequency dependency.

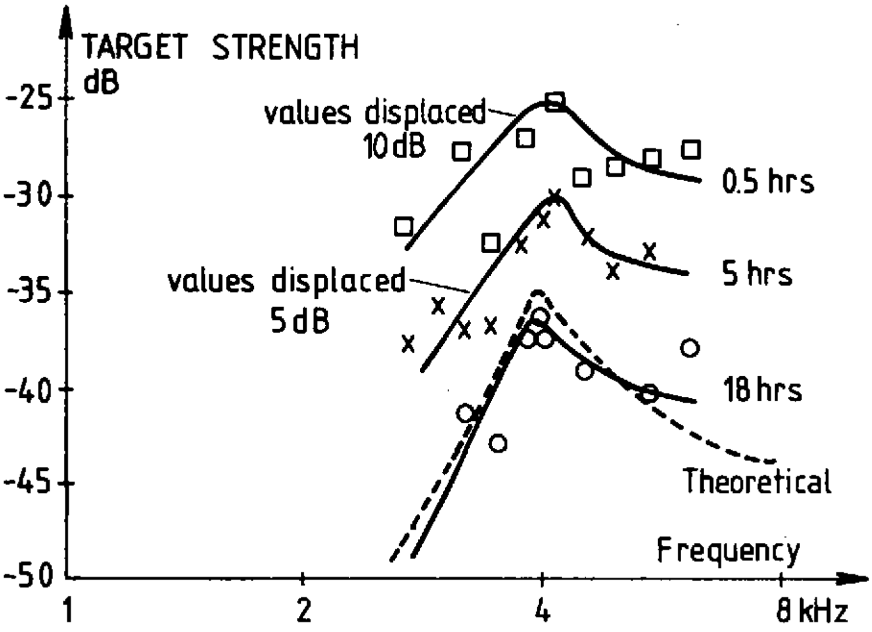

Figure 11. Measured target strenght of 12 cm long saithe at a depth of 56 meters.

3.4. Resonance frequency versus length

In order to be able to classify fishes by use of swimbladder resonance, it is of prime importance to establish the relationship between fish size and resonance frequency.

Figure 12 summarize the results from the ring hydrophone measurements. The resonance frequency is reduced to an equivalent frequency at the sea surface.

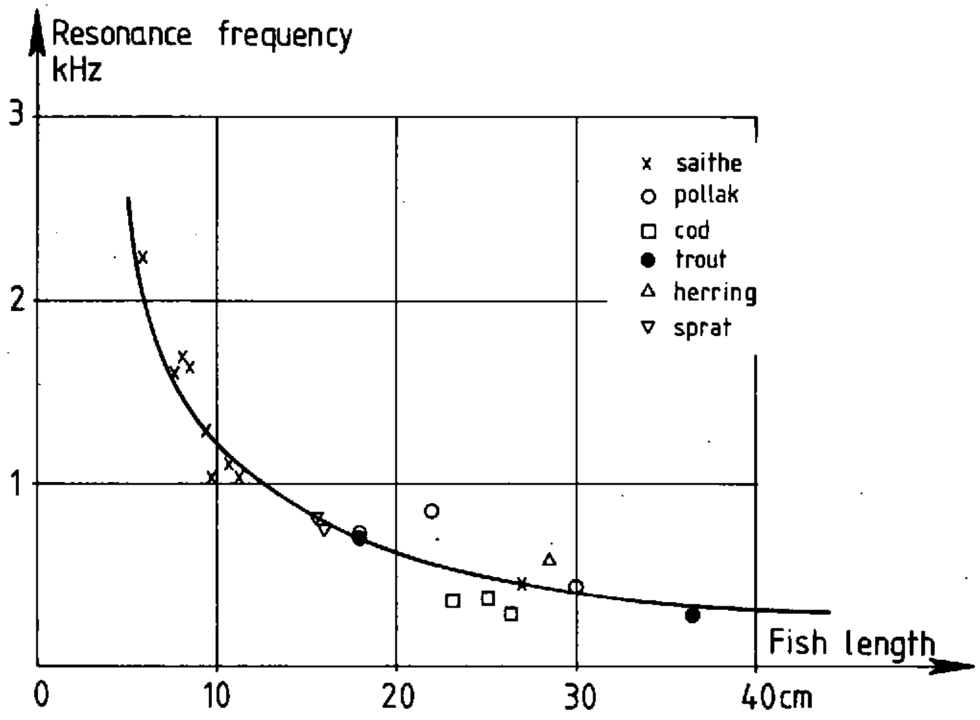

Figure 12. Resonance frequency versus fish length reduced to 0 meter.

The drawn curve in figure 12 may serve as an approximation to the relationship between the resonance frequency f_o [Hz] and the fish length L [m] and is given by

$$f_o = \frac{120}{L} \tag{5}$$

4. CONCLUSIONS

The results obtained by the ring hydrophone method and by echomeasurements are in good agreement.

The resonance frequency generally increases with depth, but it is also strongly dependent on the state of adaptation. A sudden transfer to a new depth requiers for the depth intervals investigated, a time for adaptation from 12 to 24 hours.

The Q-value for adapted fishes tends to be constant and independent of depth. An unadapted fish will have a higher or lower Q-value depending on whether the resonance frequency is higher or lower than the adapted resonance frequency. It is further found that the resonance frequency is inversely proportional to the length of the fish, when accounting for adaptation and depth variation.

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