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Some experiments on the effect on target strength
of fish undertaking vertical migrations

by

Kjell Olsen

Institute of Marine Research
Bergen, Norway

INTRODUCTION

One of the assumptions in the method of fish abundance estimation by echo integration is the possibility of determining mean target strengths of the fish registered. One difficulty in this assumption may be caused by fish which frequently undertake vertical migrations. The echo sounder will compensate for spreading and absorption losses at variable distances to fish, but how true is it that fish will maintain its target strength or at least change it in a predictable way when changing depth.

When a fish change depth, one might expect that volume and shape changes of the swimbladder, which most of our commercial species possess, shall influence the target strength. Such an opinion is supported by investigations made by Haslett (1970), where he estimates the swimbladder commonly to be responsible for in the order of 90 % of the echo of a fish.

Presuming that a fish always will try to equalize difference in buoyancy by keeping his swimbladder volume constant, one critical point in the assumption above will then be the time in which he stays out of buoyancy.

One other factor is, however, to be considered in this relation. That is the change of aspect or tilt of a fish which may take place not only with any active change of depth but perhaps even more important, if this change of tilt is consistent in the period of time needed for adaptation to a new depth. Variation in tilt have thus been shown to have a pronounced effect on dorsal aspect target strength at this frequency in a numerous number of fish specie (Nakken and Olsen, 1973).

From physiological differences of the swimbladder there are to be expected differences between specie in the ability to adjust its buoyancy. Teleost fishes are divisable into two groups (Hawkins 1973):

- a) Physostomatous forms, which possess a duct for gas release from the swimbladder opening into the gut, but with no specilized gas gland for gas secretion.
- b) Physoclistous forms, with a closed swimbladder, but possessing both a secretory gas gland and a gas resorbing system.

Gas secretion into swimbladders have been shown to be a rather slow process and most fish ezamined have taken between 4 and 48 hours to re-fill their swimbladders after deflation (Wittenberg, Schwend & Wittenberg 1964). Some physoclist, like clupoids and salmoids, have been doubted to possess and ability at all to re-fill without swallowing air at the surface. Sundnes and Sand (1975) have, however, by resonance measurements of swimbladders of char (Salmo alpinus), shown that at least this species can re-fill by gas secretion.

During some field experiments in order to obtain resonance characteristics of the swimbladder in fish and to study the time needed for adaptation when exposed to depth changes, also some measurements of the target strength at 38 kHz were undertaken. The experiments were part of a joint experimental program between the Institute of Marine Research in Bergen and The Electronic Research Laboratory (ELAB) in Trondheim. As the data obtained may add some information regarding the question discussed above they will reported separately in this contribution.

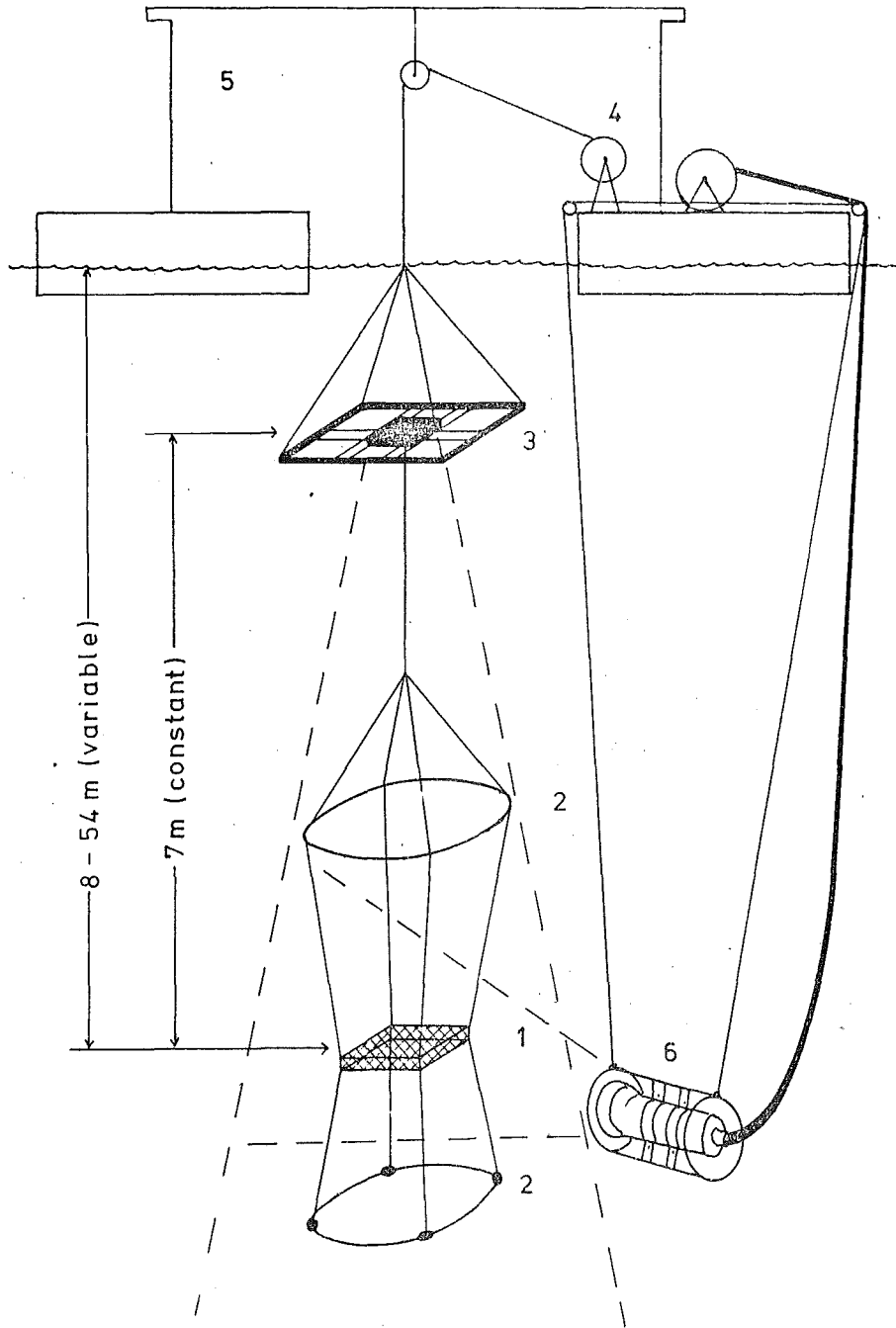


Fig.1 Experimental set up

- 1) Fish cage (nylon curtain), 2) Suspension rings (2 mm steel, tilted r. transducer plane), 3) Transducer suspension,
- 4) Hoisting system, 5) Raft (incl. lab. and accomod)
- 6) Under water television set (Hydr. prod..mod. S1T-125)

Experimental set up

The experiments were undertaken from an anchored raft in a sheltered fjord inlet. The water depth was 60 m. The experimental set up is illustrated on Fig. 1. The fish is kept in position in the beam of the echo sounder by a frame construction and a hoisting device allows an easy change of depth, simultaneously of both the transducer and the fish. Measurements on live fish were undertaken with the fish in a sound transparent cage (nylon curtain, 50 x 50 x 10 cm). In some few measurements on dead fish (recently killed) the cage was replaced by a suspension system of four nylon guts hooked on to the fish. The behaviour and aspect positions of the fish were observed by lowering a UTV camera in the vicinity of the fish cage or the fish suspension system.

The echosounder system used was a SIMRAD EK 38 in combination with a SIMRAD EQII echo integrator which allowed the use of a gating system to avoid disturbing echo from the rigging. The echo level could then be read either from the echo integrator (run on single ping integration) or read directly on an oscilloscope.

Measurements on live fish

A 36,5 cm trout (Salmo trutta), adapted for several days at shallow water (4-5 m) was put into the cage, brought to a depth of 6 m and after 2 hours of further adaptation rapidly taken down to 22 m (1.6 atm.pres.incr. to 3.2 atm.). After 20 hours the cage was lifted, first to 14 m and then up to 6 m again. After allowing 2 hours of adaptation the fish was once more brought down to 22 m depth. During this period frequent measurements of target strength and observations of behaviour of the fish were undertaken.

In a second experiment 100 small saithe (8-11 cm) also adapted at shallow water, were put in the cage and brought down to 11 m. After $\frac{1}{2}$ hour the cage was lowered to 32 m (2.1 atm.pres.incr. to 4.2 atm) and the fish left there for adaptation in 12 hours (over night). Next day the cage were lifted again to 11 m and after 45 minutes once more lowered to 32 m.

Measurements on dead (recently killed) fish.

5 fish, adapted at 5 m depth for several days were killed and their target strength measured one at a time by suspending them at 8 m beneath the transducer. The suspended fish was then carefully lowered and target strength measured at increasing depth from 8 to 54 m.

The fish measured were 1 herring 29,5 cm, 1 trout 36,5 cm and 3 pollack 22,5, 23 and 32,5 cm. The 32,5 cm pollack was also measured after being dead (accidentally) in the cage and these measurements were observed to be undertaken with the fish at an approximate side aspect position.

Because of the suspension system used, with poor horizontal alignment, the obtained target strength of individual fish can not be regarded comparable and only the absolute fluctuation of target strength of each fish at different depths is of interest.

RESULTS

In Table 1 is presented target strength data obtained in the measurements on the live trout. As the back scattering strength undergoes continuous fluctuations, mean values of 2 min. recordings (300 pings) are used. The target strength of the cage alone was - 53 dB/ μ Bar and - 50 dB is then chosen as minimum detectable signal of the fish.

The tendency seems to be that whenever a depth excursion have taken place, some immediate drop in target strength occurs, followed by a slow increase when time for adaptation is allowed. The maximum target strength recorded at the start of the experiment, with the adapted fish swimming slowly at 6 m, was -34 dB with a mean value of -37dB (90% of readings). Occasionally the fish were seen to settle down at the cage bottom and this gave an immediate fall in target strength of 5-6 dB. After the fish was brought down to 22 m depth, the target strength when swimming fall off drastically (10-12 dB), but whenever settling down at the bottom this caused an increase in target strength to the approximate value in this position before.

		↓ 6-22 m	↑ 22-14 m	↑ 14-6 m	↓ 6-22 m
Adaptation time	1-3 min	-48,5	-48,5	-47	< -50
	15 min	-38,5	-47/-41 ^{x)}	-45,5	< -50
	30 min	-45,5		-44,5	< -50
	2 hrs.				-41
	6 hrs.	< -50 - -44	-46,5		
	15 hrs.	< -50 - -39			-42

Table 1. Target strength (dB/1 μ Bar) obtained on a live 36,5 cm trout (Salmo trutta) when exposed to depth excursions.

x) -47 dB corresp. to the fish swimming,
 -41 dB measured when laying quiet on the bottom

		↓ 5-11 m	↓ 11-32 m	↑ 32-11 m	↓ 11-32 m
Adaptation time	1-3 min	-28	-29,5	-29	-36
	15 min	-27	-33,5	-28,5	-38,5
	30 min	-27		-28	
	45 min			-27,5	-39
	1½ hrs.			-26,5	
	11 hrs.		-33		

Table 2. Target strength (dB/1 μ Bar) obtained on 100 saithe (Pollachius virens) (8-11 cm) when exposed to depth excursions.

Depth, m	Herring, 29 cm	Trout, 36,5 cm	Pollack 22,5 cm	Pollack 23 cm	Pollack 32,5 cm	Pollack 32,5 (side asp.)
8	-37	-49	-29	-34	-32,5	-24,5
17		-46,5	-30	-37	-34,5	
26	-35,5		-30			-26
35	-37	-43	-33	-33	-31	
44			-33,5			
53	-32,5	-37	-31,5	-32	-27,5	-35,5

Table 3. Obtained target strength (dB/1μBar) at different depths of dead fish.

The TV observations indicated that the trout even before the excursion to 22 m was in a condition of negative buoyancy. When swimming, the body took a position of 5-10° tilted head up and whenever the fish stopped swimming, it sunk down to the cage bottom resulting in a clearly visible tension of the net. The recordings, however, gave no clear indications of how the back scattering fluctuations were correlated with the swimming movements, except in the settled down position on the bottom when the back scattering always approached a certain value. (-41 - -42 dB).

In Table 2 is presented target strength data obtained in the measurements on the live 100 small saithe. When the fish were taken down there seems to be a significant immediate drop in target strength. Several hours of adaptation did not seem to reduce this fall off in target strength. At the start of the experiment (at 11 m) the maximum target strength frequently reached a level of -20 dB, but when taken down the corresponding maximum level was about -24 dB even after 11 hours.

TV observations did not indicate such a degree of negative buoyancy of the fish when taken down, but when raised a great number of the fish showed significant signs of a high degree of positive buoyancy. Some adaptation apparently took place within 15 min., but the behaviour in general always indicated a preference to swim down if possible.

In Table 3 is presented the obtained target strengths of the 5 dead fish measured at variable depths. No clear trend of the fluctuations can be observed. The trout have got a 12 dB increase in target strength when submerged from 8 to 53 m as the 22,5 cm pollack gets a 3 dB reduction during the same excursion. The 32,5 cm pollack measured at side aspect got a 11 dB reduction in target strength when brought down from 8 to 53 m depth.

Inspection of the condition of the swimbladders after the measurements showed that all the bladders were intact but the bladders of the herring had only approximately 25% of full gas content and the trout bladder only approximately 20%.

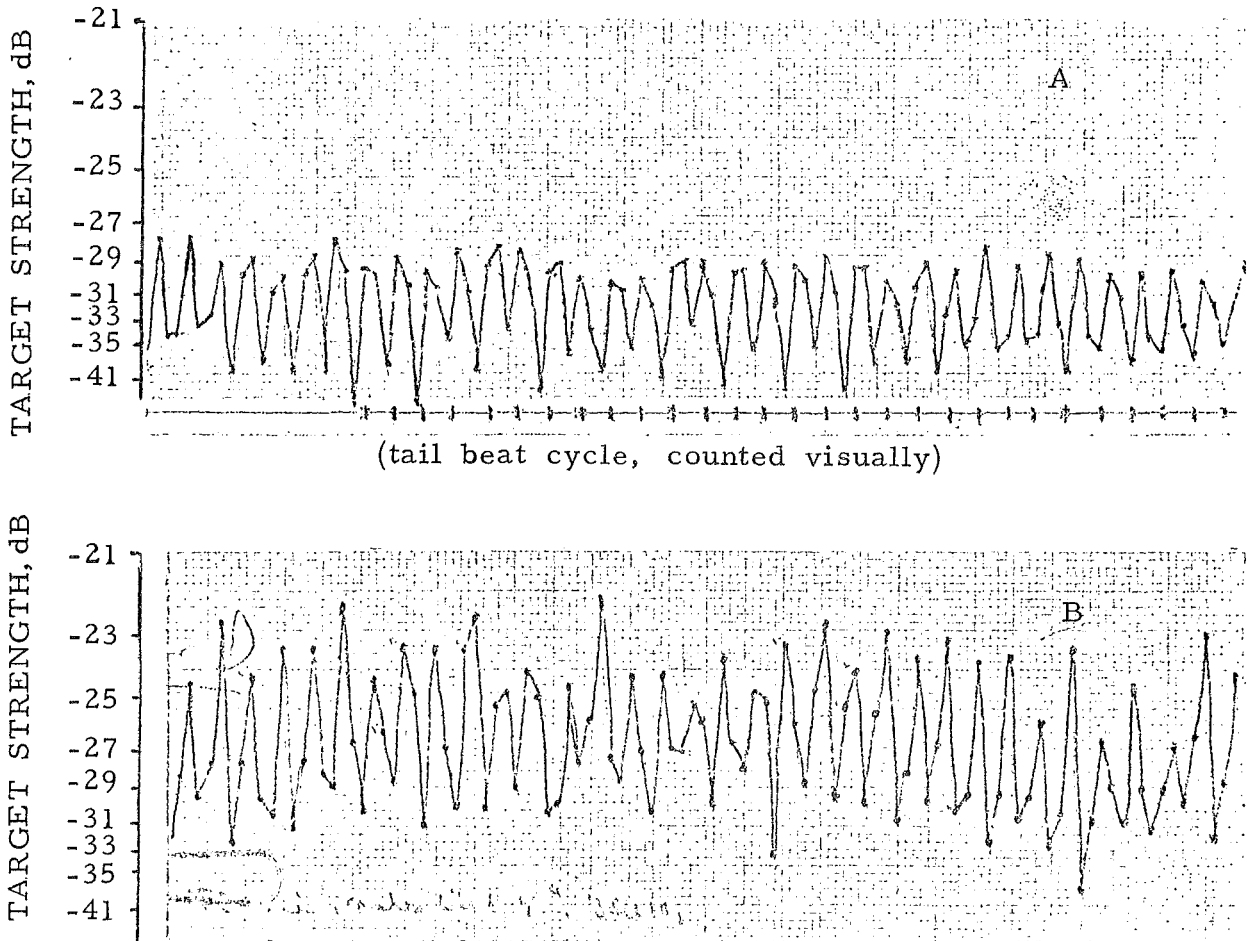


Fig. 2 Observations of dorsal aspect target strength of a swimming saithe (52.5 cm). A) At zero tilt angle and B) at tilt angle of maximum target strength (4° , head down). (Unpublished figure, Nakken and Olsen, 1973).

DISCUSSION

The few experiments undertaken and the small number of fish investigated allow us only to look upon the obtained results as hints in the understanding of a rather complexed problem. As most clearly summarized by Welsby (1975) there are three main causes of fluctuations in target strength, and of which two are involved in the subject dealt with in this contribution. These are:

- a) Changes in orientation of the target (fish/swimbladder)
- b) Changes in shape and character of the target (fish/swimbladder)
- c) Changes of acoustic frequency

As reported by Nakken and Olsen (1973) swimming movements itself may introduce great variation in target strength without any change of tilt of a fish (Fig. 2). When a fish comes into a stage of negative and positive buoyancy as were seen in the experiments of live fish, some change of tilt is most likely to occur and consequently a change of target strength will be introduced. A dramatic example of such a situation have been observed on a school of sprat in net container (Bakken, Nakken and Olsen 1975) which was submerged from 5 to 12 m (through the summer thermocline) and were the fish at least for a period of 6 hours kept a swimming position of 45-60° head up). The target strength of the school was estimated to be 10-15 dB reduced compared to what should have been expected with the fish in an adapted situation.

The observed indications of a change in tilt accompanying excursions in depth of the fishes, are interesting at least because of the difference between the two species. As the trout seems to find a state of negative buoyancy useful and only seems to reach when exposed to a further increase by a perhaps slow down in swimming activity, the saithe seems to be forced to undertake some adaptation in buoyancy.

However, if we apply the resonancement by Edwards (1975) of assuming an ellipsoidal geometric scattering of a swimbladder, the observed fall in target strengths are still difficult to interpret from verifiable observations of changes in behaviour. Even exact estimates of tilt are unfortunately not possible due to the at that moment, available lens system of the UTV.

The measurements on dead fish kept at an approximate fixed tilt position may have throughn some light on to what extent volume changes/shape changes alone may affect target strength. The apparent, and perhaps surpricing results of significant increase in target strengths in several occations at increasing depth, might be given an geometrical explanation by the way the swimbladders commonly are attached in the body cavity. When tightly attached on both sides, an excess pressure will tend to "flatten" the bladder dorsally-verifically, with the consequence of hardly any reduction in scattering cross section. And if the dorsal curvature of the bladder in some way also is reduced, this may cause even a considerable increase in the target strength.

It is indeed difficult to make any conclusion regarding the time needed for adaptation in the fish investigated. The idea of the experiments was by continuous target strength measurements to obtain some guidelines in the question of adaptation time for the work on resonance characteristics of the fish swimbladder. The results indicate that a reverced attitude to the question was much more valid. From the obtained data on swimbladder resource it seems that a saithe (of this size) is able to compensata at least 90% of a swimbladder volume change of $\pm 50\%$ in 20-30 minutes. Greater depth excursions need considerable larger time for adaptation, if a full adaptation takes place at all.

This last observation may be of great importance as there séems to be some clear evidence that the degree of adaptation to neutral buoyancy which a fish will undertake, will depend strongly on the situation itself, not only upon the state of buoyancy. In the experiments on trout (and in some other on herring and sprat) there were observed no sign of adaptation by gas secretion within time periods up to 22 hours (a more detailed report is under preparation). Compared with the observations of Sundnes and Sand (1973) and Sundnes and Bratland (1972), this result may be due to the situation exposed for the fish.

To summarize what is believed to be the important conclusion to draw from the experiments is to focus the attention on the behaviour aspects. The above obtained results may indicate that changes in target strength of fish which undertake vertical migrations, to a great extent will be ruled by the eventual change in swimming behaviour or swimming activity. At the moment far too little information exist to indicate how important this might be. If, in the future this turns up to be a critical point in the method of echo integration, one solution might perhaps be sought by applying echo sounders which work with a sufficient low frequency to reduce the directivity in this scattering of sound by fish.

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REFERENCES

- BAKKEN, E., NAKKEN, O. and OLSEN, K., 1976. Three methods for estimation of sprat (Sprattus sprattus) abundance by echo integrator. Rep. Norw. Fishery Mar. Invest. (1976, in prep.).
- EDWARDS, J.I., 1975. A preliminary analysis of the variation in target strength of multiple fish targets at various depths. Proc. of the Specialist Meeting on Acoustic Surveying of Fish Populations. Inst. of Acoustics 1975. Univ. of Birmingham.
- HASLETT, R.W.G., 1970. Acoustic Echoes from Targets under Water in Underwater Acoustics, 129-197 ed. R.W. Stephens, London, Wiley - Interscience 268 pp.
- HAWKINS, A.D., 1973. Fish sizing by means of swimbladder resonance. ICES/FAO/ICNAF Symposium on Acoustic Methods in Fisheries Research, paper no.29, 22 pp.
- NAKKEN, O. and OLSEN, K., 1973. Target strength measurements of fish. ICES/FAO/ICNAF Symposium on Acoustic Methods in Fisheries Research, paper no.24, 31 pp.
- STEEN, J.B., 1971. The swimbladder as an hydrostatic organ. In Fish Physiology, 4:413-43 Ed. W.S. Hoar and D.J. Randall, New York: Academic Press, 532 pp.
- SUNDNES, G. and BRATLAND, P., 1972. Notes on the gas content and neutral buoyancy in physostome fish. Rep. Norw. Fishery Mar. Invest., 16: 89-97
- SUNDNES, G. and SAND, O., 1975. Studies of a physostome swimbladder by resonance frequency analysis. J. Cons.int. Explor. Mer. 36(2): 176-182. Mai 1975.

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S. Mitchell

WELSBY, V.G., 1975. Fluctuations in amplitude of sonar echoes:
Some basic acoustic theory. Paper from Specialist meet.
on Acoustic Surveying of Fish Populations. Inst. of
Acoustics 1975. Univ. of Birmingham.

WITTENBERG, J.B., SCHWEND, M.J. and WITTENBERG, B.A., 1964.
The secretion of oxygen into the swimbladder of fish.
J. gen. Physiol. 48, 337-55.