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TILT ANGLE MEASUREMENTS ON HERRING

by

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ABSTRACT

Tilt angles measured in the course of an experiment to elucidate swimbladder function in herring (Clupea harengus L.) are presented. Large samples of tilt angles of surface-adapted and depth-transferred fish are compared. Significant preference towards positive tilt at depth is believed to be part of a compensatory response to negative bouyancy from swimbladder compression. With reference to near-surface values, the change in tilt angle distribution at depth is, by itself, estimated to reduce the averaged acoustical backscattering cross section of herring by about 25%.

INTRODUCTION

At the frequencies commonly used in acoustic abundance estimation, scattering from fish is highly directive. A small change in fish orientation relative to the transducer surface can have dramatic effects on the backscattering cross section (NAKKEN and OLSEN 1977). If the orientation, or the tilt angle frequency distribution is known, the expected average "field" target strength and factors for converting the integrated echo intensity to fish density can be calculated from experimentally measured directivity functions of individual fish (FOOTE 1980). Earlier reports with measurements of tilt angle distributions (OLSEN 1971; BELTESTAD 1974; CARSCADDEN and MILLER 1980; FOOTE 1983) indicate mean values near to the horizontal for cod, herring and capelin. While the measurements on cod and capelin were made at sea, those on herring were made in holding pens and net cages close to the surface. Because herring has no gas-secretion mechanism connected with the swimbladder, as is common among physoclists (BLAXTER, DENTON and GRAY 1979; ONA 1984), bouyancy is lost at depth during vertical migrations.

It is the purpose of this paper to present some findings from an experiment designed to elucidate swimbladder function in herring. The possible respons of herring to pressure was observed at several depths. This was quantified through measurements of tilt angles, acquired by means of underwater photography.

MATERIALS AND METHODS

The measurements were made in a sheltered fjord west of Bergen. An anchored raft, carrying a laboratory compartment and accommodations for the crew, was supplied with shore power through an underwater cable. Herring in the length range from 17 to 32 cm were caught by shore seine near the raft and carefully "herded" into a large (100 m^3) holding pen. Tilt angle measurements from this were made by using a single-frame UW-camera (PHOTOSEA 1000) at 1.5 meters depth inside the pen.

The herring was adapted to variable depths in a large, cylindrical net cage (volume 38 m^3, diameter 4 m) at a mean density of 6-7 fish/m^3. Through two light-sensitive UTV- cameras (HYDRO PROD. SYST.), fixed at 2 meters distance from the cage in horizontal and ventral directions, the behaviour of the fish was monitored on the raft and stored on high-quality video tape. Analyses of tilt angles from the cage were based on randomly sampled still photographs of the videotaped data. The vertical reference indicated on the photographs was obtained by centering a dark, heavy plumb line in front of the horizontal

UTV-camera. Using a computer connected digitizer with 0.01 inch resolution, the accuracy of the angle measurements is estimated to be within one degree when only fish within ±10 degrees of the normal plane to the photographic axis are used.

The tilt angle is defined as in OLSEN (1971). It is the angle made with the horizontal by the imaginary line from the tip of the upper jaw to the root of the tail of the fish. The convention is made that head up angles are positive.

To facilitate comparisons, the tilt angle samples are taken consistently with the herring in a non-feeding situation. Feeding activity was frequently observed both in the holding pen and in the cage at surface, but not at depth. An example of the photographic material is shown in Figure 1.

RESULTS

The results are presented through the tilt angle frequency distributions of herring in three different situations, with several independent samples within each (Tables 1,2,3; Figures 2,3 and 4). The measurements from the holding pen were made at 1.5 meters depth, where swimbladder volume measurements after anesthetizing had shown the herring to be at perfect neutral bouyancy (ONA 1984). The first cage samples were taken the day after depth transfer, the fish being adapted to the new pressure. Even though some extreme orientations, e.g. ±50 degrees were recorded, the mean orientation was near the horizontal when the fish was near the surface, both in the holding pen and in the net cage. A slightly negative mean value, probably caused by the swimbladders orientation in the fish, was found in all near-surface distributions.

At 30 meters depth the herring clearly became negatively bouyant, with a generally increased swimming speed and with pectoral fins extended to a maximum attacking angle relative to water flow. This reaction seemed naturally to force the head upwards in relation to the tail, which is also reflected in the tilt angle frequency distribution. At this depth, mean values from 6 to 11 degrees, head up, were recorded. The bimodal character of these distributions was due to the following individual behavioural sequence: after continous powerful swimming with head up at an angle of 10-20 degrees (higher distribution mode), the herring would sink with a horizontal or slightly negative angle, if not dive at high speed. Particularly during the last sequence, the negative bouyancy was obvious. The merged samples are compared and found to be significantly different at the 0.001 level, both in mean value and variance. Within each group of merged data, the differences were generally not significant at the 5% level.

Since an extremely low gas-producing capacity by the swimbladder is contraindicated by the vertical migration pattern of herring, the measurements were terminated when no recovery could be detected after seven days at this depth.

DISCUSSIONS

The preliminary estimates of herring orientation, together with the behavioural observations, indicate that the loss of bouyancy during swimbladder compression is easily compensated for by swimming activity. On a practical and technical basis the maximum investigation depth was set to 30 meters. This ensured exellent light conditions in 18 of 24 hours with no artificial light necessary. As the swimbladder at this depth is already reduced to 25% of its original volume at surface, little was considered to be gained by working deeper.

The surface tilt angle distributions are very similar to those previously reported on herring by BELTESTAD (1974) and FOOTE (1983) with respect both to mean values and variance. These will probably all be representative for neutrally bouyant herring in an undisturbed situation. Likewise, the similarity of the orientation pattern in the holding pen and in the net cage at surface level confirms that the cage dimensions do not significantly affect the behavioural pattern of herring. Too-narrow net cages, previously used in acoustic cage calibrations, have been reported to cause pronounced behavioural changes on gadoids (ONA 1982).

From the measurements at 30 meters depth it may be concluded that herring during vertical migrations will be at negative bouyancy at depth, and that a slight positive orientation must be expected as a compensatory response.

The maximum acoustic backscattering cross section of herring obtains when the dorsal surface of the swimbladder is oriented toward the transducer surface. From measurements reported by AKSLAND (1982) it is estimated that a change in mean value of the tilt angle distribution from 0 to +10 degrees, in both cases with a standard deviation of about 15 degrees, will reduce the averaged backscattering cross section of adult herring by about 25%. This is comparable to the change in mean tilt angle which is seen here, from surface to 30 meters depth. Together with the perhaps more important effect of swimbladder compression at depth, the combined effect will almost certainly make the conversion factors, mentioned earlier, depth dependent.

Such a depth dependence can be hard to detect acoustically by in situ target strength measurements, as the problem with vessel avoidance behaviour of herring (OLSEN 1979) will tend to act in the opposite way, being strong near the surface and reduced at depth. Despite this, HALLDORSSON (1983) has actually observed a pressure-dependent target strength reduction on herring.

Together with feeding activity, which is seen to change the orientation pattern of herring (BELTESTAD 1974), an increased fat content of the fish may reduce the effect of pressure. In a parallel investigation (ONA 1984), herring at maximum fat content were found to be neutrally buoyant at surface with very low swimbladder volumes.

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Table.1. Tilt angle frequency distributions sampled at 1.5 meters depth from the holding pen, with mean value (MV), standard deviation (SD), number of observations (N), and significance level (p) for test for normality (Kolmogorov - Smirnov, ZAR (1974)), shown.

Sample no.	Date	MV (deg)	SD (deg)	N	p
1	24.6.83	-4.6	12.8	577	0.21
2	26.6.83	-2.6	13.6	528	0.15
3	29.6.83	-4.3	12.3	714	0.59
Merged data		-3.9	12.8	1819	0.21

Table. 2. Tilt angle frequency distributions sampled from the cage at 4 meters depth. Symbols as in Table 1.

Sample no.	Date	MV (deg)	SD (deg)	N	p
4	24.6.83	-0.4	11.5	425	0.95
5	29.6.83	-0.2	12.0	423	0.28
Merged data		-0.2	11.9	898	0.62

Table 3. Tilt angle frequency distributions sampled at 30 meters depth. Symbols as in Table 1.

Sample no.	Date	MV (deg)	SD (deg)	N	p
6	1.7.83	10.9	17.3	248	0.22
7	4.7.83	6.0	17.0	427	0.39
8	7.7.83	9.0	15.5	199	0.11
Merged data		8.1	16.9	874	0.04

Fig. 1. An example of the photographic material. Note the vertical reference line across the central part of the picture (plumb line out of focus).

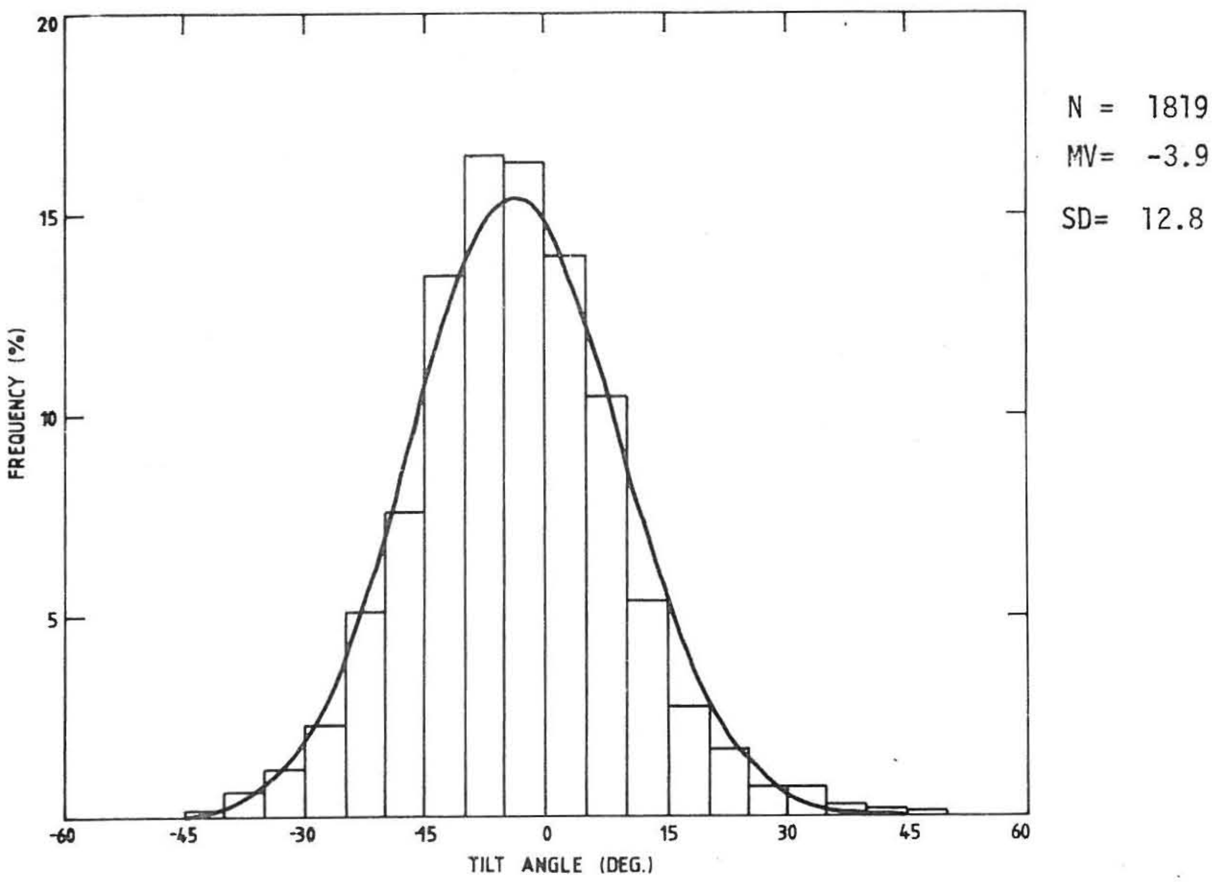

Fig. 2. Tilt angle frequency distribution of herring at 1.5 meters depth in the holding pen. Merged data from 24 to 29 June 1983. Number of observations, (N), mean value (MV), standard deviation (SD) and fitted truncated Gaussian curve are indicated.

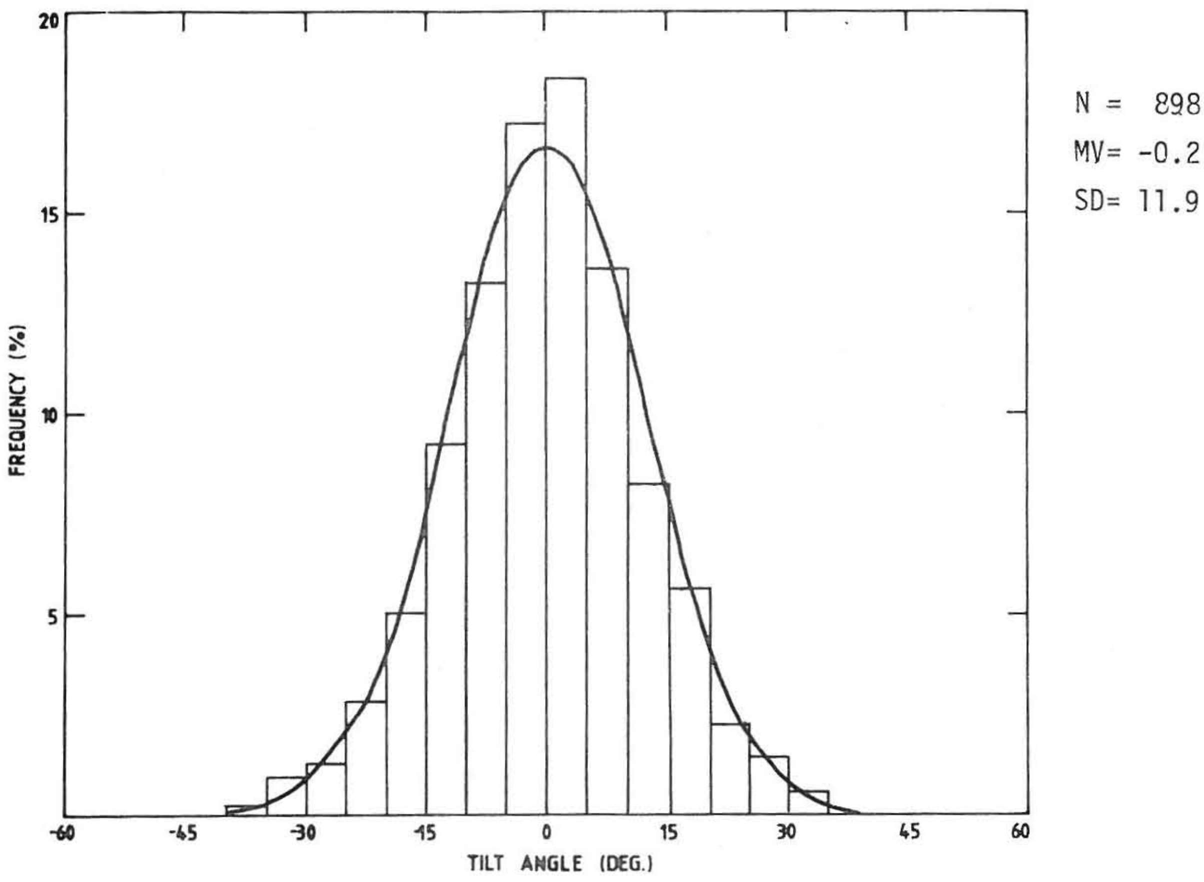

Fig. 3. Tilt angle frequency distribution of herring in the cage at 4 meters depth. Merged data from 24 and 29 June 1983. Other explanation as in Fig. 2.

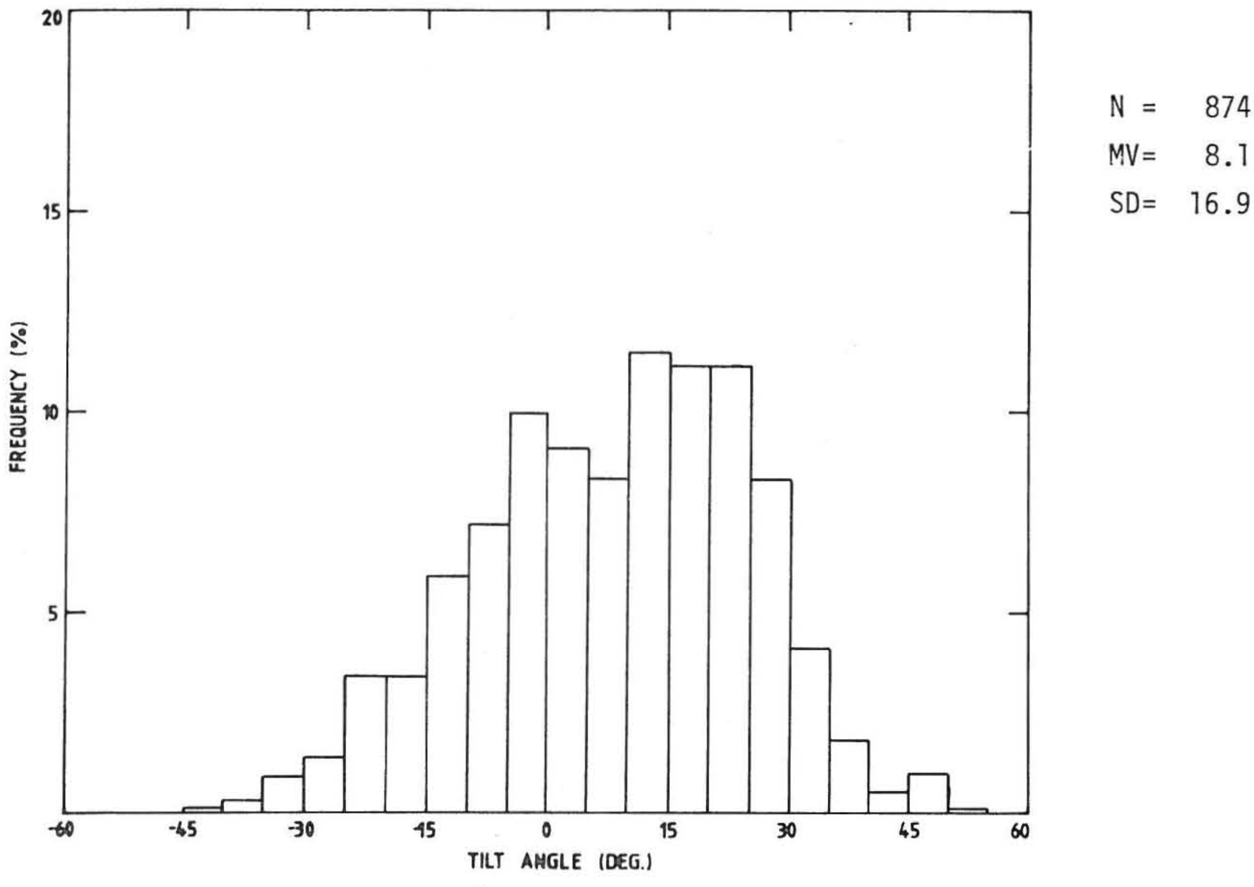

Fig. 4. Tilt angle frequency distribution from 1 to 7 July 1983 of herring in the cage at 30 meters depth. Merged data 1-7 July 1983