International Council for the
Exploration of the Sea

C.M. 1985/B:26
Fish Capture Committee

TILT ANGLES OF SCHOOLING PENNED SAITHE

by

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ABSTRACT

Saithe (*Pollachius virens*) of nearly uniform 32 cm length have been photographically observed during the daytime in an apparently free-swimming and schooling state in a pen of dimensions 90 m length, 10 m width, and 7 m depth. The resulting tilt angle distribution is essentially normal, with mean -0.9 deg and standard deviation 5.4 deg.

RÉSUMÉ: ANGLES D'INCLINAISON DE LIEUS NOIRS REGROUPÉS EN BANC DANS UN BASSIN

Des lieus noirs (*Pollachius virens*), d'une taille de 32 cm relativement homogène, ont été observés par photographie de jour nageant apparemment librement en bancs dans un bassin de 90 m de long, 10 m de large et 7 m de profondeur. La distribution des angles d'inclinaison observés est essentiellement normale avec une moyenne de -0,9 degré et un écart type de 5,4 degrés.

INTRODUCTION

Data on fish tilt angles are important to acoustic methods of estimating fish density (Nakken and Olsen 1977, Foote 1980a, Midttun 1984). The most useful data on the tilt angle, or vertical component of orientation, are those gathered *in situ* under actual surveying conditions. These are also among the least accessible of fish behavioural data. In fact, of the three field measurements of tilt angles, two (Olsen 1971, Carscadden and Miller 1980) were made under essentially static conditions; the third (Buerkle 1983) was made with a submerged towed instrumentation vehicle. What the behaviour of the same fish would be under dynamic surveying conditions is anybody's guess (Olsen, Angell, and Løvik 1983, Olsen *et al*. 1983).

Given the extreme scarcity of tilt angle data, direct measurements on fish even under controlled conditions are potentially valuable. This is the simple justification or apology for the present offering.

MATERIALS AND METHODS

The observations were made on 2 May 1985 near Uggdalseidet on the island of Tysnes, about 50 km south of Bergen. The fish pen was located in an inlet of a bay where the water was about 50 m deep. The pen was 90 m long, 10 m wide, and 7 m deep. It contained about 2000 saithe of similar lengths in the range from 31 to 33 cm. Conditions were still, with direct sunlight on the pen area. During the photography, the fish passed the camera as a loosely organized school.

A PHOTOSEA 1000 35 mm Underwater Camera System was suspended at 4 m depth inside the pen, roughly halfway along the long dimension, near the net wall, and pointing towards the opposite side wall. The vertical was defined by a heavily weighted plumb line suspended about 20 cm directly in front of the lens. The thickness of the line guaranteed its visibility on the photographs despite being unfocussed.

Picture-taking was facilitated by positioning the camera immediately under a wide-angle, HYDROPRODUCTS underwater television camera covering nearly the same field of view. Observation of fish on the television screen provided the cue for picture-taking. In the bright daylight, the flash produced no evident reaction, but pictures were not taken more frequently than at 10 s intervals.

The entire series of photographs was taken in the course of 10 minutes in the early evening. Additional observations were made in the later evening and night, through the daylight-to-darkness transition, and again in full daylight the following morning. However, a camera malfunction totally destroyed the photographic record of all but the first series of photographs, which are reported here. It is nonetheless important to note that substantial differences in fish behaviour, and in tilt angle distribution, were observed, with the underwater television, with feeding activity.

Following development of the photographs, the tip of the upper jaw and root of the tail of fully visible fish, judged to be oriented to within 10 deg of the plane normal to the photographic axis, were marked with ink dots. These were digitized together with the displayed plumb line and stored on a computer for further processing. The tilt angle was computed according to its usual definition (Olsen 1971): the angle between the fish centerline, or imaginary line running from the root of the tail to the tip of the upper jaw, and the true horizontal.

An example of the raw material is shown in Fig. 1. The original print size as used for the digitization was 67% larger than that shown here.

RESULTS

The complete data set consisted of 22 photographs containing a total of 223 unobscured fish images in near-side view. Reduction of the individually measured tilt angles revealed an essentially normal distribution with mean of -0.9 deg and standard deviation of 5.4 deg. A histogram of the 223 data is shown in Fig. 2.

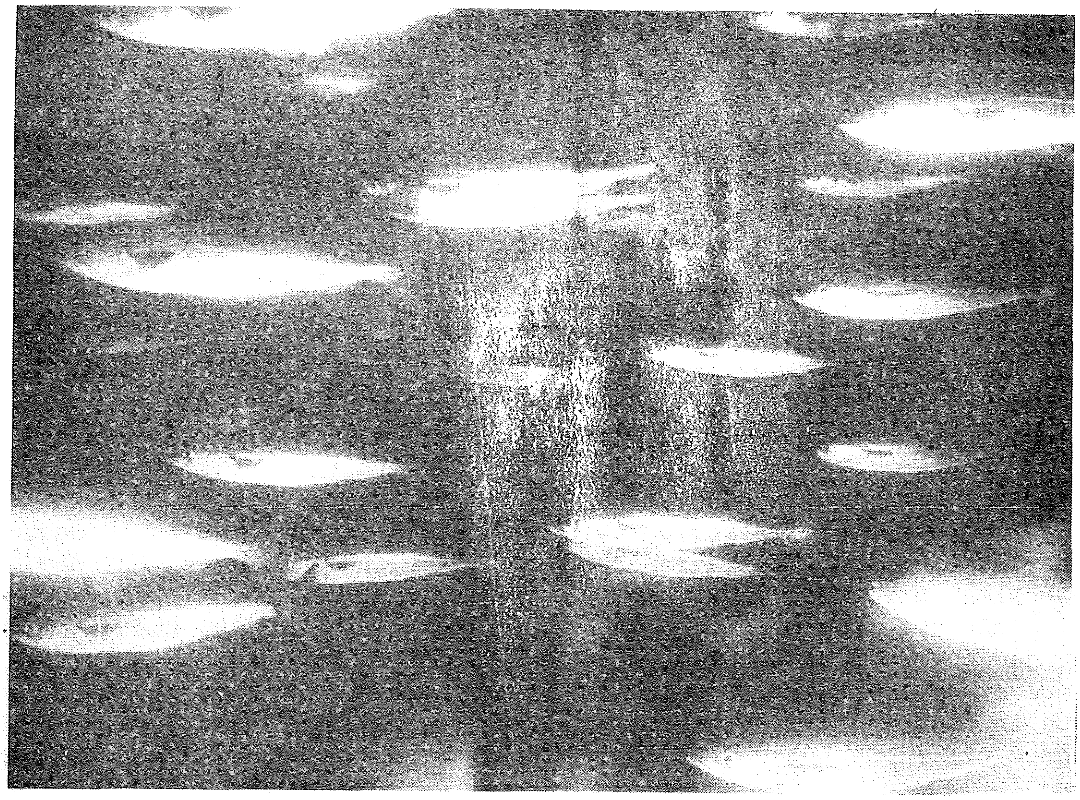

Fig. 1. Photographic print, reduced to 60% of original size, showing schooling penned saithe.

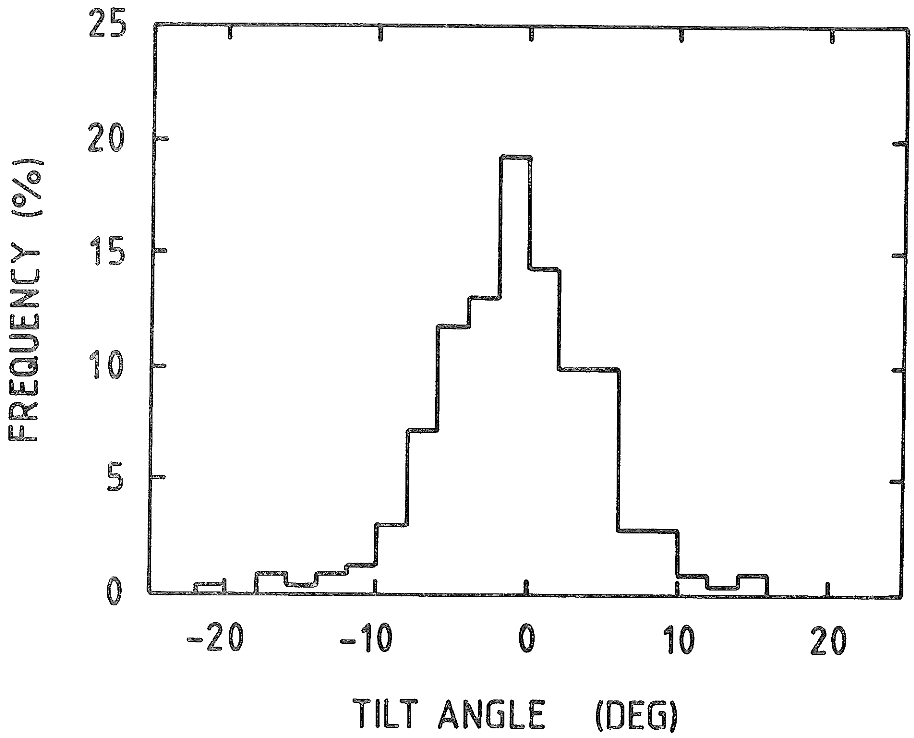

Fig. 2. Histogram of fish tilt angles.

DISCUSSION

The fish observations, while limited in number and kind, benefited from the distinctness of the behaviour mode: directed swimming by a loosely organized school, and the favourable placement of the camera. Almost without exception, the fish were observed to pass in front of the camera in full side view. Thus, if both ends of the same fish were visible, the tilt angle datum could be registered.

Three errors are associated with the present method of tilt angle measurement by means of a single camera. (1) Error due to non-normal aspect. For small aspect angles ϕ, measured with respect to the plane normal to the photographic axis, this is $(\phi^2/2)\tan\theta$, where θ is the true tilt angle. For example, if the largest approved non-normal fish aspect is 10 deg, and if this occurs for the most extreme observed tilt angle, namely, -22 deg, then the greatest error due to non-normal aspect is -0.32 deg. (2) Error due to judging the fish centerline. The error incurred in judging the tip of the upper jaw and root of the tail is estimated to be ±0.25 mm in each case. The maximum effect on the tilt angle is thus ±0.5/R, where R is the fish image length in millimeters. Since the smallest image length was 24 mm, the largest expected error due to judging the centerline is ±1.2 deg. A more realistic figure for the error is based on a cumulative judging error of ±0.25 mm and use of the mean of the least and greatest image lengths, 24 and 99 mm, respectively, hence, ±0.23 deg. (3) Digitization error. The nominal positioning accuracy of the cursor on the particular digitizing board is nominally 0.01 mm. Physical positioning of the cursor occurs with an error of about ±0.1 mm. In fact, repetition of the digitization of nine different fish from two different photographs indicated a maximum error of ±0.2 deg.

Thus a single tilt angle datum is estimated to be accurate to within ±0.5 deg in the mean. This is small compared with the standard deviation of the distribution, which is reduced only negligibly by it.

Statistical analysis of the tilt angle distribution is straightforward. Using t statistics, the mean, -0.9 deg, is determined with 95% confidence to within ±0.7 deg; using chi-square statistics, the standard deviation, 5.4 deg, is determined similarly to within -0.5 and 0.6 deg (Zar 1974). Chi-square testing for the normality of the distribution can suggest the presence of one or several spurious data in the set of 223 tilt angles. If, however, the two classes containing the most extreme positive and negative tilt angles are required to contain at least five data each, then the hypothesis of normality cannot be rejected with even 50% confidence.

The new tilt angle data, described by the distribution N(-0.9,5.4), interestingly support earlier uses of the distribution N(0,5) for averaging the target strength functions of gadoids (Foote 1979, 1980a). Other postulated distributions, for example, N(0,2) (Foote 1980a,b) and N(0,10) (Foote 1980c, Aksland 1983), may in the present context be viewed as representing more or less tightly organized schooling behaviour.

As noted at the outset, quantitative measurements of fish tilt angles are few, although increasing. For comparison purposes, therefore, the bulk of published data on teleost tilt angles is presented in the table. An important criterion for inclusion is that the measurement volume, if limited, be sufficiently large so that the range of adopted tilt angles not be artificially limited (Ona 1982).

Table. Direct measurements of tilt angle distributions of mostly free-swimming teleosts. Data presented in several source references have been supplemented by personal communication with the authors.

Species	Mean length (cm)	Location	Depth (m)	Day/ Night	Parameters (deg) of tilt angle distribution mean	s.d.	Number of data	Reference
Cod	80	Sea	75-125	Both	-4.4	16.2	230	Olsen (1971)
Herring	13	Large pen	2-5	Day	-3.2	13.6	174	Beltestad (1974)
				Night	3.8	6.0	216	
Capelin	17	Sea	44	Day	3.3	18.4	280	Carscadden and Miller (1980)
Herring	(Mature)	Sea	20	Day	-3.4	10.3	158	Buerkle (1983)
				Night	12.0	23.5	470	
Herring	27	Small cage	2.5	Day	2.9	14.2	737	Foote (1983)
				Day	-3.1	11.5	424	
Herring	24	Small pen	1.5	Day	-3.9	12.8	1819	Ona (1984)
		Large cage	4	Day	-0.2	11.9	898	
		Large cage	30	Day	8.1	16.9	874	
Saithe	32	Large pen	4	Day	-0.9	5.4	223	Present study

ACKNOWLEDGEMENTS

A. Beltestad is thanked for making possible the experimental part of the investigation. N. Diner is thanked for rendering the abstract into French.

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