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TARGET STRENGTH OF POLARIZED FISH

by

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ABSTRACT

The effect of behaviour on target strength is simulated through computation of the average target strength with respect to a range of normal orientation distributions $N(\bar{\theta},s_\theta)$. The mean tilt angle $\bar{\theta}$ is varied from -30 to 30 deg for each of two values of the standard deviation s_θ, 2 and 5 deg. The object fish are assumed to be uniformly distributed over the beam of a transducer with effective 10-deg vertex angle. The basic data consist of measurements of the tilt angle dependence of target strength of immobilized and tethered fish. Average target strengths are regressed on the logarithm of fish length. Several statistical tests are performed to determine the similarity of the length coefficients to 20 and similarity of regressions for difference species.

INTRODUCTION

Questions continue to be asked about the effect of behaviour on the target strengths of fish (Olsen 1987a and b). For example, what is the cause of the apparent dissimilarity in mean *in situ* target strengths of cod and saithe reported by Foote, Aglen and Nakken (1986). Insofar as behaviour can be characterized by the tilt angle distribution (Nakken and Olsen 1977, Foote 1980a), an answer can be given by reference to tabulated data on target strength, granted their validity (Foote 1983).

It is the simple aim of this work to present regression analyses, in systematic fashion, of averaged target strengths on fish length for polarized or parallel-oriented fish.

MATERIAL AND METHODS

The basic target strength data were gathered by Nakken and Olsen (1977) on tethered, anesthetized fish. A subset of the tabulated dorsal aspect target strength functions of tilt angle (Foote and Nakken 1978)

is used. This consists of the data at 38 kHz on cod (Gadus morhua), saithe (Pollachius virens), pollack (Pollachius pollachius), herring (Clupea harengus), and sprat (Sprattus sprattus). Numbers and length ranges are described in Table 1.

Table 1. Numbers and length ranges of averaged target strength functions, with values of the t-statistic for testing the equality m=20.

Species	No. fish	Length range (cm)	$t_{0.05(2),(n-2)}$
Cod	68	6.7-96.0	1.997
Saithe	59	9.1-68.0	2.002
Pollack	44	19.7-61.0	2.018
Herring	25	10.0-32.4	2.069
Sprat	21	6.6-17.6	2.093

The functions were averaged with respect to tilt angle in the usual fashion (Foote 1985). The behaviour was quantified by the normal distribution of tilt angle $N(\bar{\theta},s_\theta)$, where $\bar{\theta}$ is the mean and s_θ the standard deviation. Since the present interest is with "polarized" or aligned fish, s_θ is restricted to 2 or 5 deg, consistent with a recent observation (Foote and Ona 1987). The fish were assumed to be uniformly distributed in the horizontal plane across an ideal conical beam of 10 deg vertex angle. Therefore, in order to perform the averaging operation as simply as possible and without loss of accuracy, the three-dimensional integration (Foote 1980b) was reduced to one dimension through use of a larger, effective standard deviation. For the particular values s_θ=2 and 5 deg, the corresponding effective measures are 3.2 and 5.5 deg, respectively.

All averaging is performed in the physical, intensity domain, hence with respect to the backscattering cross section σ. This is related to the target strength TS by Urick's definition (1975),

$$TS = 10 \log \frac{\sigma}{4\pi} \quad , \qquad (1)$$

but with SI units. The average backscattering cross section is

$$Av(\sigma) = \int \sigma(\theta)\, f(\theta)\, d\theta \quad , \qquad (2)$$

where $f(\theta)$ is the probability distribution function of tilt angle θ, assumed to be normal over the integration range $[\bar{\theta}-3s_\theta, \bar{\theta}+3s_\theta]$ and vanishing otherwise.

The average backscattering cross section is computed for each target strength function for each value of s_θ for each mean tilt angle $\bar{\theta}$ in the range {-30,-25,...,30} deg. The corresponding average target strengths, defined by direct substitution of $Av(\sigma)$ in equation (2) for σ in equation (1), are regressed on total fish length ℓ in centimeters according to each of two equations,

$$\overline{TS} = m \log \ell + b \qquad (3)$$

and

$$\overline{TS} = 20 \log \ell + b_{20} \quad . \qquad (4)$$

Both analyses are performed according to the usual least-mean-squares criterion.

The similarity of the slope m in equation (3) to the value 20 assumed in equation (4) is tested through the statistic

$$t = \frac{m-20}{s_m}$$

where s_m is the standard error of m. This is compared against the t-statistic $t_{\alpha(2),(n-2)}$, where $\alpha(2)$ is the two-tailed level of significance and n is the number of averaged target strength functions. Values of the statistic are included in Table 1.

To test for coincidences among the slopes and intercepts of regression analyses for gadoids or clupeoids, analysis of covariance is used. In particular, the similarity of slopes m is tested according to the procedure in Zar (1974). For those cases where coincidence is not excluded at the 0.05 significance level, the similarity of intercepts b may also be tested.

The general form of the statistic for testing for coincidences among k regressions is the following: for slopes, $F_{\alpha(1),(k-1),(n_t-2-k)}$, and for intercepts, $F_{\alpha(1),(k-1),(n_t-k-1)}$. The level of significance is denoted by α, the test being one-sided, and n_t is the total number of mean target strengths used in the regression, hence number of basis target strength functions.

For testing for coincidences among the three gadoid regressions, $F_{0.05(1),2,166}=3.05=F_{0.05(1),2,167}$. For testing for coincidences between the cod and saithe regressions, $F_{0.05(1),1,123}=3.92=F_{0.05(1),1,124}$. For the paired clupeoid regressions, $F_{0.05(1),1,42}=4.07=F_{0.05(1),1,43}$.

RESULTS

The regression analyses are presented in Tables 2 and 3 for the gadoid data for the respective standard deviations in tilt angle, $s_\theta=2$ and 5 deg. Tables 4 and 5 contain the corresponding analyses for the clupeoid data. Results of testing the regressions for coincidences of slopes and, if appropriate, intercepts, are given in Table 6.

DISCUSSION

A prominent finding from the results in Tables 2 and 3 is that the regression coefficient m for the slope is, for the most part, not significantly different from 20. This confirms a number of suspicions and a frequent practice of regressing in situ target strengths through equation (4) (Foote, Aglen and Nakken 1986).

The present data for clupeoids, in Tables 4 and 5, indicate a slope or length dependent coefficient that is significantly less than 20. Clearly, if only beacuse of the ICES use of the regression equation $TS=20 \log \ell - 71.2$ for herring (Anon. 1983), more data need to be brought to bear on the matter.

The general coincidence of slopes of the gadoid regressions, indicated in Table 6, is consistent with earlier work, although performed for a

Table 2. Regression analyses of $\overline{TS}$ on fish length for cod, saithe and pollack, assuming behaviour characterized by the tilt angle distribution $N(\bar{\theta},2)$, with t-statistics for testing the equality m=20.

Species	No. data	$\bar{\theta}$ (deg)	$\overline{TS} = m \log \ell + b$ m	b	SE	$\overline{TS} = 20 \log \ell + b$ b	SE	t
Cod	68	-30	24.7	-82.1	4.0	-74.2	4.2	2.92
		-25	22.4	-76.8	3.9	-73.3	4.0	1.49
		-20	20.9	-71.7	3.9	-70.4	3.9	0.55
		-15	21.1	-68.3	3.3	-66.7	3.3	0.80
		-10	22.4	-67.3	2.8	-63.7	2.9	2.11
		-5	22.2	-65.9	2.0	-62.3	2.1	2.68
		0	20.2	-64.2	2.7	-63.9	2.7	0.20
		5	19.5	-65.8	3.4	-66.7	3.4	-0.40
		10	20.1	-69.4	3.8	-69.5	3.8	0.07
		15	21.7	-73.6	3.9	-71.0	4.0	1.06
		20	25.2	-80.6	3.9	-72.7	4.2	3.25
		25	28.5	-87.5	4.6	-74.6	5.3	4.59
		30	27.7	-87.9	5.6	-76.1	6.0	3.42
Saithe	59	-30	30.1	-92.0	5.4	-77.4	6.0	3.89
		-25	24.9	-83.8	5.2	-76.7	5.3	1.96
		-20	20.9	-76.0	4.1	-74.6	4.1	0.47
		-15	19.1	-68.9	3.1	-70.2	3.1	-0.59
		-10	20.7	-66.1	2.2	-65.2	2.2	0.62
		-5	21.3	-64.3	1.5	-62.5	1.6	1.75
		0	18.4	-60.9	1.7	-63.3	1.7	-1.99
		5	16.9	-61.7	2.8	-66.2	2.9	-2.31
		10	22.6	-72.5	2.8	-68.7	2.9	1.89
		15	30.5	-86.9	3.4	-71.7	4.5	6.41
		20	32.4	-91.2	3.5	-73.2	4.9	7.36
		25	29.7	-88.2	3.7	-74.2	4.6	5.38
		30	29.9	-90.5	4.6	-76.2	5.4	4.42
Pollack	44	-30	14.8	-63.5	3.9	-76.0	3.9	-1.10
		-25	12.6	-65.6	4.5	-76.3	4.6	-1.36
		-20	12.3	-64.8	4.7	-75.9	4.8	-1.35
		-15	16.5	-66.6	3.2	-71.7	3.2	-0.91
		-10	19.4	-65.7	2.4	-66.6	2.4	-0.22
		-5	20.0	-63.7	2.2	-63.8	2.2	-0.01
		0	17.5	-60.8	1.9	-64.5	1.9	-1.12
		5	18.7	-67.0	2.0	-68.9	2.0	-0.55
		10	22.5	-76.4	3.9	-72.8	3.9	0.53
		15	15.1	-67.6	4.6	-73.3	4.6	-0.71
		20	14.7	-67.3	5.7	-75.0	5.7	-0.77
		25	14.5	-69.0	6.9	-77.0	6.9	-0.66
		30	9.9	-64.2	7.9	-78.9	8.0	-1.06
Gadoids	171	-30	26.6	-85.8	4.6	-76.0	4.9	4.80
		-25	23.6	-80.5	4.8	-75.2	4.8	2.53
		-20	21.6	-75.7	4.3	-73.5	4.3	1.15
		-15	21.1	-70.9	3.3	-69.2	3.3	1.09
		-10	22.1	-68.0	2.7	-64.9	2.8	2.53
		-5	21.3	-65.5	2.0	-62.9	2.0	3.00
		0	19.3	-62.8	2.2	-63.9	2.2	-1.06
		5	18.6	-65.0	3.1	-67.1	3.1	-1.57
		10	21.4	-72.1	3.9	-70.0	3.9	1.24
		15	25.0	-79.2	4.2	-71.8	4.4	4.14
		20	27.5	-84.6	4.5	-73.5	4.9	5.60
		25	28.1	-87.0	5.2	-75.1	5.5	5.27
		30	27.6	-88.1	6.1	-76.[illegible]	6.6	4.17

Table 3. Regression analyses of $\overline{TS}$ on fish length for cod, saithe and pollack, assuming behaviour characterized by the tilt angle distribution $N(\overline{\theta},5)$, with t-statistics for testing the equality m=20.

			$\overline{TS} = m \log \ell + b$			$\overline{TS} = 20 \log \ell + b$		
Species	No. data	$\overline{\theta}$ (deg)	m	b	SE	b	SE	t
Cod	68	-30	23.4	-79.1	3.4	-73.2	3.6	2.48
		-25	22.1	-75.0	3.1	-71.3	3.2	1.66
		-20	21.6	-71.3	2.9	-68.3	3.0	1.40
		-15	22.1	-69.0	2.4	-65.2	2.5	2.09
		-10	22.4	-67.4	1.9	-63.8	2.0	3.11
		-5	22.1	-66.2	1.6	-63.1	1.8	3.14
		0	21.0	-65.4	2.0	-63.2	2.1	1.24
		5	20.2	-66.1	2.5	-65.3	2.5	0.21
		10	20.3	-68.5	2.9	-68.1	2.9	0.25
		15	21.3	-72.2	3.1	-70.2	3.2	1.05
		20	23.5	-77.2	3.2	-71.9	3.3	2.71
		25	25.7	-82.1	3.5	-73.5	3.9	3.96
		30	26.6	-85.1	4.3	-75.1	4.7	3.77
Saithe	59	-30	28.0	-88.2	4.3	-76.6	4.9	3.81
		-25	25.3	-79.9	3.4	-75.1	3.5	2.03
		-20	20.8	-73.2	2.6	-72.1	2.6	0.65
		-15	20.5	-68.3	1.9	-68.1	1.9	0.53
		-10	20.7	-65.9	1.5	-64.9	1.5	1.01
		-5	20.4	-63.9	1.3	-63.3	1.3	0.61
		0	19.3	-62.5	1.3	-63.6	1.3	-1.13
		5	18.7	-63.5	1.8	-65.4	1.8	-1.49
		10	20.8	-63.9	2.2	-67.7	2.2	0.72
		15	25.7	-78.4	2.5	-70.2	2.9	4.72
		20	30.0	-85.8	2.9	-72.4	4.0	7.12
		25	30.4	-89.0	3.3	-74.0	4.4	6.43
		30	29.3	-88.9	3.8	-75.5	4.6	5.05
Pollack	44	-30	15.7	-70.0	3.7	-76.3	3.7	-0.96
		-25	14.4	-67.4	3.8	-75.6	3.8	-1.23
		-20	16.2	-67.7	3.0	-73.3	3.0	-1.06
		-15	18.4	-67.1	2.0	-69.4	2.0	-0.67
		-10	19.1	-65.0	1.9	-66.2	1.9	-0.38
		-5	19.3	-65.6	1.8	-64.7	1.8	-0.34
		0	19.0	-63.7	1.6	-65.1	1.7	-0.49
		5	19.3	-66.3	1.5	-67.4	1.5	-0.40
		10	19.3	-71.2	2.2	-70.5	2.2	-0.07
		15	17.8	-69.7	3.8	-72.9	3.8	-0.49
		20	15.9	-63.5	4.8	-74.5	4.8	-0.71
		25	14.6	-68.1	5.6	-76.0	5.6	-0.80
		30	12.3	-66.7	6.5	-77.9	6.6	-0.97
Gadoids	171	-30	25.6	-85.3	4.0	-75.4	4.3	4.46
		-25	23.0	-78.6	[illegible]	-73.9	3.9	2.48
		-20	[illegible]	[illegible]	[illegible]	-71.1	3.4	1.97
		-15	21.9	-70.4	2.6	-67.5	2.6	2.53
		-10	22.0	-67.7	2.0	-64.8	2.1	3.31
		-5	21.4	-65.7	1.7	-63.6	1.7	2.82
		0	20.3	-64.5	1.3	-64.1	1.3	0.54
		5	19.7	-65.5	2.2	-66.0	2.2	-0.51
		10	20.6	-69.5	2.7	-68.6	2.7	0.75
		15	23.0	-75.3	3.3	-71.9	3.4	3.00
		20	25.0	-81.2	3.8	-72.7	4.1	5.08
		25	27.0	-84.7	4.3	-74.3	4.6	5.51
		30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4. Regression analyses of $\overline{TS}$ on fish length for herring and sprat, assuming behaviour characterized by the tilt angle distribution $N(\overline{\theta},2)$, with t-statistics for testing the equality m=20.

			$\overline{TS} = m \log \ell + b$			$\overline{TS} = 20 \log \ell + b$		
Species	No. data	$\overline{\theta}$ (deg)	m	b	SE	b	SE	t
Herring	25	-30	55.3	-127.9	6.5	-81.2	9.0	4.51
		-25	31.7	-94.3	6.8	-79.2	7.1	1.40
		-20	10.3	-63.9	5.4	-76.4	5.6	-1.47
		-15	2.3	-50.5	4.1	-72.8	5.0	-3.44
		-10	4.9	-50.1	2.9	-69.5	3.9	-4.23
		-5	7.4	-51.8	1.7	-68.0	2.7	-6.00
		0	7.3	-51.9	2.1	-68.3	3.0	-4.88
		5	8.5	-55.5	3.1	-70.3	3.6	-3.94
		10	12.3	-64.5	3.9	-74.4	4.1	-1.58
		15	22.2	-81.0	4.6	-78.2	4.6	0.39
		20	24.4	-84.9	5.0	-79.2	5.1	0.72
		25	20.7	-80.1	4.2	-79.2	4.2	0.14
		30	24.1	-85.7	5.2	-80.5	5.2	0.64
Sprat	21	-30	17.5	-75.3	5.6	-78.1	5.6	-0.27
		-25	10.6	-65.2	3.5	-75.3	3.7	-1.60
		-20	16.1	-67.9	3.0	-72.1	3.0	-0.78
		-15	12.0	-60.6	2.6	-69.2	2.9	-1.80
		-10	9.1	-55.0	2.0	-66.7	2.5	-3.24
		-5	13.2	-53.1	1.8	-65.4	2.0	-2.25
		0	14.8	-60.3	2.0	-65.9	2.1	-1.54
		5	10.6	-58.4	2.6	-68.5	2.9	-2.19
		10	1.7	-53.1	2.8	-72.8	3.7	-3.96
		15	1.5	-57.6	5.5	-77.5	6.0	-2.02
		20	22.9	-83.8	6.9	-80.7	6.9	0.25
		25	31.6	-94.0	7.8	-81.6	8.0	0.98
		30	25.3	-88.4	8.2	-82.7	8.2	0.39
Clupeoids	46	-30	30.2	-91.9	7.4	-79.8	7.6	1.70
		-25	16.7	-73.5	6.0	-77.4	6.0	-0.69
		-20	8.0	-69.1	4.5	-74.4	5.0	-3.30
		-15	5.0	-55.2	3.5	-71.1	4.5	-5.31
		-10	6.5	-52.2	2.5	-68.3	3.5	-6.68
		-5	8.8	-55.5	1.8	-66.8	2.7	-7.85
		0	9.5	-54.3	2.1	-67.2	2.2	-6.15
		5	9.2	-57.4	2.8	-69.5	3.4	-4.47
		10	9.9	-61.6	3.5	-73.6	3.9	-3.60
		15	15.6	-72.7	5.1	-77.9	5.2	-1.06
		20	25.1	-86.0	5.8	-79.9	5.9	1.08
		25	26.8	-88.5	6.0	-80.5	6.2	1.39
		30	24.6	-89.4	6.6	-81.5	6.7	1.24

Table 5. Regression analyses of $\overline{TS}$ on fish length for herring and sprat, assuming behaviour characterized by the tilt angle distribution $N(\bar{\theta},5)$, with t-statistics for testing the equality m=20.

Species	No. data	$\bar{\theta}$ (deg)	$\overline{TS} = m \log \ell + b$ m	b	SE	$\overline{TS} = 20 \log \ell + b$ b	SE	t
Herring	25	-30	37.6	-101.7	5.5	-7[illegible]	6.3	2.56
		-25	22.7	-81.5	4.5	-76.8	4.3	0.51
		-20	11.6	-62.3	3.8	-74.4	4.1	-2.01
		-15	6.1	-53.9	3.2	-71.7	3.9	-3.57
		-10	5.7	-52.3	2.2	-69.4	3.2	-4.84
		-5	7.8	-52.7	1.5	-68.4	2.5	-6.49
		0	8.5	-55.6	1.8	-68.6	2.6	-5.59
		5	9.1	-56.1	2.4	-70.2	3.1	-3.63
		10	11.4	-61.8	3.1	-72.9	3.4	-2.27
		15	16.6	-71.5	3.4	-75.9	3.5	-0.81
		20	21.6	-80.2	3.9	-78.1	3.9	0.33
		25	22.3	-82.1	4.2	-79.1	4.2	0.45
		30	22.2	-82.7	4.4	-79.3	4.4	0.41
Sprat	21	-30	11.9	-67.7	3.7	-76.4	3.9	-1.31
		-25	11.0	-64.1	2.5	-73.8	2.8	-2.18
		-20	12.7	-65.2	2.2	-71.0	2.4	-2.00
		-15	12.3	-60.3	1.9	-68.6	2.1	-2.47
		-10	11.9	-58.0	1.7	-66.7	2.0	-2.92
		-5	13.0	-58.3	1.7	-65.9	1.9	-2.51
		0	13.5	-59.3	1.8	-66.3	2.0	-2.13
		5	11.9	-59.4	2.0	-68.1	2.3	-2.39
		10	8.5	-53.6	2.0	-71.0	2.6	-3.41
		15	6.0	-59.6	2.7	-74.7	3.3	-3.05
		20	11.3	-68.9	4.6	-78.2	4.7	-1.13
		25	20.0	-81.5	6.5	-80.5	6.5	0.08
		30	23.4	-87.7	7.6	-81.8	7.7	0.42
Clupeoids	46	-30	21.7	-79.2	5.4	-77.8	5.4	0.41
		-25	14.2	-68.5	3.8	-75.4	3.9	-1.90
		-20	8.9	-59.6	3.2	-72.9	3.3	-4.35
		-15	7.3	-55.1	2.6	-70.3	3.5	-5.95
		-10	8.1	-54.1	2.0	-68.2	3.0	-7.39
		-5	9.2	-54.4	1.6	-67.2	2.6	-8.32
		0	9.9	-55.5	1.8	-67.6	2.6	-7.01
		5	11.1	-57.5	2.2	-69.2	2.9	-5.40
		10	13.7	-63.9	2.6	-72.0	3.1	-4.44
		15	13.4	-67.5	3.2	-75.4	3.4	-2.59
		20	18.8	-76.4	4.2	-78.2	4.2	-0.34
		25	23.5	-83.9	5.3	-79.3	5.3	0.82
		30	25.4	-87.2	6.0	-80.7	6.1	1.12

Table 6. F-testing for coincidences among regressions.

$\bar{\theta}$ (deg)	s_θ (deg)	Cod, saithe, pollack F_m	Cod, saithe, pollack F_b	Cod, saithe F_m	Cod, saithe F_b	Herring, sprat F_m	Herring, sprat F_b
-30	2	4.12	3.08	3.31	5.36	9.20	10.55
-25	2	2.22	9.25	0.79	15.41	3.34	5.51
-20	2	1.35	27.45	0.00	34.70	0.40	2.97
-15	2	0.91	36.41	0.93	35.52	1.62	0.25
-10	2	0.87	17.57	1.15	9.45	0.63	0.01
-5	2	0.57	6.63	0.61	0.81	2.55	0.41
0	2	1.16	3.76	1.64	1.85	2.98	0.09
5	2	1.01	11.98	1.71	0.33	0.13	0.15
10	2	0.68	18.69	1.36	1.11	2.20	0.40
15	2	8.09	3.17	14.35	0.12	3.97	0.05
20	2	6.69	2.73	9.53	0.02	0.02	0.13
25	2	2.72	3.86	0.19	1.88	0.74	0.42
30	2	3.34	2.92	0.46	0.50	0.01	0.30
-30	5	3.81	6.71	3.49	11.01	6.58	5.46
-25	5	2.05	20.17	0.36	29.75	2.45	4.45
-20	5	1.17	36.83	0.23	40.52	0.11	1.85
-15	5	1.32	37.49	1.31	29.10	1.24	0.42
-10	5	1.83	23.62	2.39	10.01	1.55	0.12
-5	5	2.07	14.05	3.35	0.26	2.40	0.18
0	5	1.48	10.51	2.54	0.39	1.90	0.07
5	5	0.67	13.44	1.16	0.97	0.36	0.02
10	5	0.07	17.58	0.09	0.74	0.27	0.04
15	5	3.36	11.46	5.78	0.20	2.63	0.06
20	5	6.76	5.67	11.37	-0.01	1.38	0.12
25	5	4.94	4.02	4.78	0.05	0.02	0.29
30	5	3.64	3.69	1.11	0.35	[illegible]	0.36

somewhat different geometry. Testing for the coincidences of intercepts in those allowed cases where the slopes are coincident reveals significant differences in the overall data sets, a finding anticipated by Midttun and Hoff (1962).

Repetition of the covariance analysis for the cod and saithe data reveals a basic agreement of slopes and intercepts for fish with mean orientations near the horizontal. Given the 2+ dB discrepancy in mean in situ target strengths of the two fishes (Foote, Aglen and Nakken 1986), it appears very unlikely that the fish had the same orientation distribution, at least for the kind of near-horizontally oriented distribution and state of swimbladder adaptation expected at the particular observation depths. These were 70-165 m for cod and 105-130 m for saithe.

For the clupeoid data, the regressions are coincident for nearly all behaviour modes. The target strength data are essentially indistinguishable and may therefore be merged for purposes of determining a combined herring and sprat relationship of mean target strength and length.

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