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IN SITU TS OF CAPE HORSE MACKEREL (*Trachurus capensis*)

by

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ABSTRACT

The acoustical target strength (TS) of Cape horse mackerel (*Trachurus capensis*) was measured *in situ* at 38 kHz using a submersible split beam transducer in combination with a SIMRAD EK 500 echosounder. The transducer head was lowered to scattered aggregations of horse mackerel close to the bottom in order to resolve single echo targets at short range (5-30 m). Echograms were printed for a range interval of 5-50 meters from the transducer head. Time of reception, compensated and uncompensated TS, range and alongship and athwardship offset angle were recorded from the EK 500 serial port and stored in ASCII- files at an IBM- compatible computer. Single fish targets were tracked using especially developed software and selected for analysis. The measurements suggest a lower TS than presently applied, but the literature is inconclusive on the matter, and the results should therefore be interpreted with caution.

KEYWORDS: Acoustic target strength, horse mackerel, *in situ*, EK 500, 38 kHz, split beam transducer.

INTRODUCTION

The Cape horse mackerel (*Trachurus capensis*) in the Benguela upwelling system on the Namibian coast has been monitored acoustically since 1990. The south-African stock in the Agulhas upwelling system is monitored by means of bottom trawl surveys (swept area), but this is not feasible in Namibia due to the more pelagic distribution of the fish there. Acoustic surveys or a combination of hydroacoustic and bottom trawl surveys therefore seems to be the remaining alternative. However, acoustic abundance estimation requires knowledge about the acoustical backscattering properties of the fish, specifically the dorsal aspect target strength (TS). Assuming that the target strength increases proportionally to body length, the target strength at a given frequency can be expressed as a function of mean total length (L) in the logarithmic domain using (1):

$$\mathrm{TS} = x \log L + y \quad (\mathrm{dB}) \tag{1}$$

where x and y are linear regression coefficients. If the average acoustic backscattering crossection, σ, of the ensonified population is known, recorded area backscattering coefficient, S_A (m^2/nm^2) can be converted to number of fish (ρ_A) using (2):

$$\rho_A = S_A/\sigma \tag{2}$$

Split beam echosounder systems, like the SIMRAD EK 500/ 38 kHz used in this investigation, combine the signals from four quadrants of the transducer (with individual signal detection and time varied gain amplification) in pairwise fashion by simple summing, forming four half beams (Foote et al., 1986). In order to calculate mean average backscattering crossection, the observations must be converted from the logarithmic domain (dB) to the intensity domain. This can be done assuming (3) (Love, 1971; McCartney and Stubbs, 1971):

$$\mathrm{TS} = 10 \log(\sigma/4\pi) \tag{3}$$

At 38 kHz, σ has been shown to be proportional to the squared total length of the fish for many commercially important species, and equation (1) can thus be modified to a one-coefficient form, keeping x=20, facilitating direct comparison between different data-sets (Love, 1977), giving (4):

$$TS = 20 \log L + b_{20} \quad (\mathrm{dB}) \tag{4}$$

The function presently applied for horse mackerel in Namibia is the one derived by Foote (1987) (see also Foote et al., 1986) for clupeoids (5):

$$TS = 20 \log L - 71.9 \quad (\mathrm{dB}) \tag{5}$$

Applying this TS to length relation for horse mackerel relies on the basic assumption that the acoustical backscattering properties of horse mackerel are identical to the ones for clupeoids. Horse mackerel and clupeoids have however fundamental anatomical differences, as the former is physoclistous (enclosed swimbladder) and the latter physostomous (open swimbladder). The swimbladder constitutes as much as 90 % of the sound reflection from fish (Blaxter and Batty, 1990), and swimbladder volume and shape significantly influence the acoustical target strength of the fish (Olsen and Ahlquist, 1996). Unlike physostomous species, presumably dependent on gasping air at the surface to fill the swimbladder, horse mackerel has the physoclistous ability of regulating swimbladder volume through gas secretion and resorbtion. Thus, if horse mackerel compensates for swimbladder compression with increasing pressure (depth), it should be expected to have generally higher and less depth-dependent target strength than physostomes, but the extent to which, if at all, horse mackerel compensates for swimbladder compression, is not documented in the literature. Being an extremely fast swimmer, maintenance of neutral buoyancy may not always be necessary in terms of swimming. Negative buoyancy is probably advantageous during vertical predator avoidance, and it can therefore not be ruled out that horse mackerel may take advantage from negative buoyancy resulting from swimbladder compression when avoiding predatory species such as hake (*Merluccius capensis*) (Pillar and Wilkinson, 1995; Pillar and Barange, 1998).

According to Foote (1987), $b_{20} = -67.5$ in equation (5) for physoclists, but with a considerable degree of variation from species to species (3 dB). Although the target strength of Cape horse mackerel has been investigated from both survey data (Barange and Hampton, 1994; Barange et al., 1996; Svellingen and Ona, 1999; Lillo et al., 1996), volumetric considerations of the swimbladder (Torres et al., 1984) and by means of the comparison method (Misund et al., 1997), data are scarce and relatively few attempts have been made to establish an independent target strength-length relation for the species. The published equations are highly inconsistent, and considerable controversy is therefore associated with horse mackerel target strength.

MATERIALS AND METHODS

The Norwegian research vessel R/V "Dr. Fridtjof Nansen" was used in the investigation, which took place at the Namibian continental shelf, at 17°45' S and 11°39' E, in October 1998. Weather conditions were fairly good throughout the experiments, even though relatively strong wind (27 knots prevailing wind force) and high waves (about 2 meters total height) occasionally complicated operations.

The investigation was triggered as loose aggregations of horse mackerel were observed at 85 to 120 m depth (bottom) with the hull mounted 38 kHz split-beam/ EK 500 scientific echosounder. Pelagic and demersal trawl hauls confirmed that the observed population consisted of horse mackerel. Two sets of TS- measurements were carried out at the population on 16 October, from 16h00 to 20h00 (UTC) and from 23h00 to 01h45, respectively.

Acoustical sampling

A submersible 38 kHz split-beam transducer was used in combination with a SIMRAD EK 500 echosounder for the TS- measurements. A standard beam plot calibration was carried out using lobe software prior to the measurements. Calibration coefficients, system parameters and technical specifications for the echosounder are listed in table 1. The transducer was lowered to the top of the fish aggregations at about 85 meters, or approximately 35 meters above bottom. All data from the EK 500 were collected from the parallel port and stored in ASCII files at an IBM compatible computer for further analysis. Echograms were printed for a range interval of 5-50 meters from the transducer head.

The ship was drifting along with the transducer during the measurements, but the vessel drifted faster than the transducer due to the relatively strong wind. The side-thrusts of the vessel were applied in order to keep the transducer wire and thus the transmission angle as vertical as possible. The noise from the side-thrusts may have influenced the behaviour of the fish, as horse mackerel is believed to be sensitive to noise during trawl operations (Barange and Hampton, 1994).

Split-beam transducer technology offers information about alongship and athwardship offset angle. This enables compensation for loss of echoenergy according to the spatial distribution of the ensonified targets within the beam and horizontal and vertical tracking of individual fish from ping to ping. The technique has the obvious advantage that echotraces can be selected for further analysis, offering a high degree of certainty that the measurements actually represent single fish targets, thus avoiding multiple echoes interpreted as single target echoes by the EK 500 TS-detection algorithm to bias the data (Soule et al., 1995). Furthermore, information about ping to ping variation for individual fish and inter-fish variation is made available. Strict criteria for acceptance of the echotraces were applied (table 2), using recently developed software (Ona and Hansen, 1991). In order to gain equal contribution from individual fish, only one target strength value was selected from each trace. The maximum value was selected in order to exclude values obtained from fish when diving or ascending. Average TS was computed in the geometric domain by converting average acoustic backscattering coefficient, σ to TS, rearranging (1). The constant b_{20} was then calculated for mean total length in the trawl samples.

Biological sampling

A trawl haul was launched after each measurement session to provide biological samples of the recorded fish. A demersal sampling trawl with 2000 kg Thyborøen doors was used for the purpose. In order to obtain a representative sample of the population, the trawl hauls were launched in the same area as the measurements had been carried out. In order to achieve this, the ship steamed about one nautical mile (nm) in the drifting- direction and made a 180° turn prior to shooting. The trawl was then towed opposite to the drifting direction through the sample area. Hauls were terminated as the SCANMAR stretch sensors indicated that a sufficiently big catch had been collected in the codend.

RESULTS AND DISCUSSION

Fish samples

Two trawl hauls were executed, the first one (station 1) October 16 at 20:30 and the second (station 2) October 17 at 02:15, thus corresponding to TS measurement sessions 1 and 2, respectively. There was a certain bycatch of jellyfish in station 1, but both trawl samples were dominated by horse mackerel (table 3). Jellyfish caught in the first sample were presumably caught during shooting and hauling, as the jellyfish were generally most abundant close to the surface. If the jellyfish are disregarded, horse mackerel constituted more than 90 % of the catch in numbers and weight in both catches. With the exception of the jellyfish, the majority of the other species in the catches were typical bottom dwelling species, thus unlikely to have been prevalent in the depth- range of the measurements (5-30 meters above bottom). Total length of the horse mackerel averaged at 17.2 cm and 18.0 cm for station 1 and 2, respectively. The length frequencies of the horse mackerel samples are presented in figure 1.

TS- samples

The parts of the recorded material appearing to contain single echo targets only were extracted from the material for further analysis by scrutinising the echograms visually. From the remaining material, 10376 pings in 1004 and 594 individual tracks were accepted according to the criteria of acceptance (table 2) for measurement series 1 and 2, respectively. Compensated target strength varied from -55 dB to -28 dB in series 1 and from -55 to -36 dB in series 2 (figures 2 and 3). Both distributions were bimodal, with one peak ranging from -55 to -46 dB constituting the majority of the observations (87 % and 95 %, respectively), and a more elusive peak ranging from -46 dB and upwards.

Minimum TS threshold was set to -55 dB (table 1), and it is evident from the distributions in figures 2 and 3 that the lower part of the distributions may have been lost. Clearly, minimum

TS threshold should have been set considerably lower (at about -65 dB) in order to ensure proper coverage of the distribution range and to eliminate threshold- induced bias, as described by Weimer and Ehrenberg (1975). The decreasing trends towards -55 dB in figures 2 and 3 does however suggest that the majority of the distribution range is covered, and due to the logarithmic dB- scale, the lower tail of the distribution (< -55 dB) would only contribute minutely to mean σ, unless the distribution curve would be severely skewed to the left. In that case average TS may have been overestimated.

Some of the highest recorded TS values are too high to originate from horse mackerel of the length groups in the trawl samples. It is hard to determine a value to be applied as maximum acceptable target strength (TS_{max}), and since even just a few values on this part of the logarithmic scale may significantly affect mean σ, the applied TS_{max} will be of great importance for the resulting TS- length relation. Since most of the values sort under the main-mode, this part of the distribution probably covers the majority of the horse mackerel. TS-data may however often be bi- or polymodal (Williamson and Traynor, 1984), and strict criteria should be applied to define the range of acceptance. TS_{max} was selected at -39.9 dB from a consideration of the highest possible theoretical TS based on the longest specimen in the sample (23 cm) and the highest suggested TS function in the literature (b_{20} = 66.5, table 4). The results were b_{20} = 75.0 and b_{20} = 76.2 for measurements series 1 and 2, respectively. In order to quantify the effect the applied TS_{max} had on the results, b_{20} was also calculated on the entire material, giving b_{20} = 72.1 and b_{20} = 76.1 (table 5), suggesting that relatively large individual targets such as hake or sharks caught in the sample, were recorded in series 1.

As evident from table 5, b_{20}- constants ranging from 66.7 to 73.4 have been suggested in the literature, and the findings from the present study is therefore not supported by any of these. Lillo et al. (1996) and Barange et al. (1996) extracted their TS measurements from survey data. This approach introduces two main problems, the target strength measurements may being highly susceptible for positive bias caused by multiple echoes interpreted as single fish echoes in the EK 500 (Foote, 1987; Barange et al., 1996; Soule et al., 1995, 1997) and the representativety of trawl samples. Torres et al. (1984) derived their TS- data from tank experiments and considerations of swimbladder volume compared to fish length. This *ex situ* approach has the advantage of a controlled experimental setup, but suffers the disadvantage of potential bias caused unnatural behaviour of the fish. Due to the large impact natural behaviour may have on measured target strength (Foote, 1987), *in situ* techniques are generally preferable whenever possible (MacLennan and Simmonds, 1992; Foote, 1987). Another approach is the comparison method (MacLennan and Simmonds, 1992; Misund et al., 1995, 1997), where acoustic backscattering crossection, σ is calculated from the area back scattering coefficient S_A and the school volume, calculated from sonar and echosounder measurements, and density, obtained from catching the entire school using a purse seiner. This technique has the great advantage of more or less eliminating the problem of unrepresentative fish samples, but some uncertainty may be associated with the calculation of the school volume. Using the comparison method, the resulting TS- length relation is only valid while the fish is schooling, which tends to be slightly higher than whilst shoaling (Foote, 1987), due to the fish swimming in a more synchronised and polarised manner (Pitcher, 1983) and thus tilt angle distributions being more uniform (Blaxter and Batty, 1990).

Barange et al. (1996) concluded that b_{20} = 66.8, which is in agreement with Torres et al. (1984) and with the general relation for physoclist (Foote, 1987), within the frames of species to species variation. It is however in disagreement with Lillo et al. (1996), the general relation for clupeoids (Foote, 1987) presently applied for horse mackerel in Namibia, and vastly contrasting Misund et al. (1997) as well as the present study. Misund et al. (1997) suggested that b_{20} = 73.4, which is the reported estimate closest to the present one. The b_{20} resulting from their study might also be expected to be slightly higher than in the present study, due to the typically higher TS for fish schooling compared to when dispersed, and can thus be considered to be in general agreement with the present study, within the frames of experimental uncertainty.

The main advantage of using a submersible transducer is the ability of resolving layers and shoals into single fish targets by reducing the pulse volume compared to the hull mounted transducer. This ensures a high signal to noise ratio and reduces the probability of multiple echoes being accepted as single fish targets. The method also enables measurement of natural concentrations of fish at deep water, out of the range where the ship should be expected to modify the natural behaviour of the fish. However, avoidance from a submersible transducer can not be ruled out.

Generally, the studies based on survey data or measurements of caged fish seem to be estimating a higher average TS than the ones based on in situ direct measurements (table 5). In a survey situation, traces of individual fish can not be obtained due to the high passage speed, and a representative distribution of TS measurements is hard to obtain (Barange et al., 1996). The resolution of echosounders is inversely related to the range, and increased range may thus cause multiple targets to be detected as individual ones, potentially introducing a positive bias to the measurements (Barange et al., 1996). Close to the surface, bias is associated with negative swimming angles due to the fish diving. One explanation to the great gap between b_{20}- constants obtained form survey data and the ones from direct measurements may thus be that the former tend to overestimate the target strength due to bias caused multiple echoes. Other explanations may be natural variation from species to species (Foote, 1987), avoidance behaviour/ tilt angle and depth dependence (Vabø, 1999; Olsen et al., 1982). Physiological factors are also known to significantly affect fish target strength (Ona, 1990). The relationship between target strength and total fish length has, to the author's best knowledge, not been elucidated for horse mackerel. Clearly, further investigations are required to unravel horse mackerel target strength is needed, with a critical review of the methods applied, specially emphasising on avoidance behaviour and depth dependence.

CONCLUSIONS

The presented material suggests a considerably lower target strength ($b_{20} = 75$) than what is presently applied in Namibia ($b_{20} = 71.9$) and what has been suggested for horse mackerel in literature ($b_{20} = 66.8$ through 73.4). A new method has been applied, and the measurements may be negatively biased due to avoidance of the vessel due to the use of side-thrusts. The results should therefore be interpreted with caution. Potential depth- dependence has not been elucidated. Repeated experiments with special emphasis on avoidance behaviour/ tilt angle and depth dependence are recommended prior to modification of the TS- function presently applied for abundance estimation purposes. Comparison with controlled experiments in sea-cages may be of good help in this work. It should be emphasised that the conditions under which the measurements are carried out are prerequisite for how the results are interpreted. In a survey situation, the target strength during such conditions is relevant, but then horizontal and vertical avoidance as well as depth dependent target strength may bias the data. Ideally therefore, a TS- function relevant for an undisturbed situation should be applied, given that the recorded S_A- values first can be corrected for effects of avoidance behaviour and depth dependence, if any (Vabø, 1999; Olsen et al., 1982).

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Table 1 Technical specifications, calibration coefficients and system parameters for the echosounder.

Transducer type	ES 38 D
Transmission frequency	38 kHz
Transmission effect (terminals)	2000 W
Estimated speed of sound	1505 $m \cdot s^{-1}$
Absorption coefficient	10 $dB \cdot km^{-1}$
Pulse duration	1.0 ms
Band width	3.8 kHz
Angle sensitivity	-21.9 dB
Vertical resolution	10 cm
Equivalent transmission angle	-21.0 dB
TS Gain (transducer)	-24.3 dB
Min TS threshold (transducer)	-55 dB
3 dB beam width	6.7° / 6.7°
Alongship offset	-0.02°
athwardship offset	0.12°

Table 2 Criteria for acceptance of echotraces.

Max β	5°
Min range (from transducer to fish)	5 m
Max range (from transducer to fish)	30 m
Min distance from fish to bottom	5 m
Min number of pings pr. trace	4
Max number of missing echoes in one track	1
Max distance between consecutive pings in a track	10 cm

Table 3 Catch data from bottom trawl stations 1 and 2.

	Station 1		Station 2	
Species name	kg	n	kg	n
Aequora aequora	211.51	128		
Argyrosomus hololepidotus			29.00	11
Atractoscion aequidens	4.59	10	6.99	23
Callorhinchus capensis	3.42	1		
Chelidonichtys capensis	4.91	24	3.38	23
D. coneata			0.70	35
Galeichtys feliceps	0.50	3		
Lepidopus caudatus	0.19	5		
Loligo reynaudi	0.17	1		
Loligo vulgaris			1.63	23
Maja spp.			3.96	466
Merluccius capensis	4.10	29	2.90	35
Pterothrissus belloci	1.32	17	6.87	140
Raja alba	35.00	1		
Raja miraletus	0.92	1		
Raja straeleni	1.79	1		
Synagrops microlepis			0.23	46
Todaropsis eblenae			0.35	11
Trachurus capensis	862.95	19177	571.60	14073
Total catch	1131.4	19398.0	627.6	14886.0
% T. *capensis*	76.3	98.9	91.1	94.5

Table 4 Overview of published values of the b_{20}- constant relevant for horse mackerel.

b_{20}	Method	Species	Reference
73.4	Comparison method	T. trachurus	Misund et al. (1997)
71.9	Various in situ methods	Clupeoids	Foote (1987)
68.9	In situ survey data	T. symmetricus murphyi	Lillo et al. (1996)
67.5	Various in situ methods	Physoclists	Foote (1987)
66.8	In situ survey data	T. capensis	Barange et al. (1996)
66.8	In situ survey data	T. capensis	Svellingen and Ona, 1999
66.7 *	Swimbladder volume	T. symmetricus murphyi	Torres et al. (1984)
65.2	In situ survey data	T. capensis	Svellingen and Ona, 1999

* this figure was not presented in Torres et al. (1984), it is calculated in the present study for comparison from average TS and for two groups of fish averaging at 38.7 and 31.4 cm total length.

Table 5 Mean target strength (TS), sigma (σ), mean total fish length (LT) and resulting b_{20} constants calculated for all data, and for the data set where maximum accepted target strength TS_{max} = 39.9 dB for measurement series 1 and 2.

Parameter	Series 1 (16.10)	Series 2 (17.10)
Mean σ, all values	0.00023	0.00010
Mean TS, all values	-47.38	-50.87
Mean LT, all values	17.15	18.03
b_{20}, all values	-72.07	-75.99
Max LT, sample	24.0	24.0
Max TS, theoretical	-39.90	-39.90
Max σ, theoretical	0.00129	0.00129
Mean σ, TS<39.9 dB	0.00012	0.00010
Mean TS, TS<39.9 dB	-50.30	-51.12
b_{20}, TS<39.9 dB	-75.0	-76.2

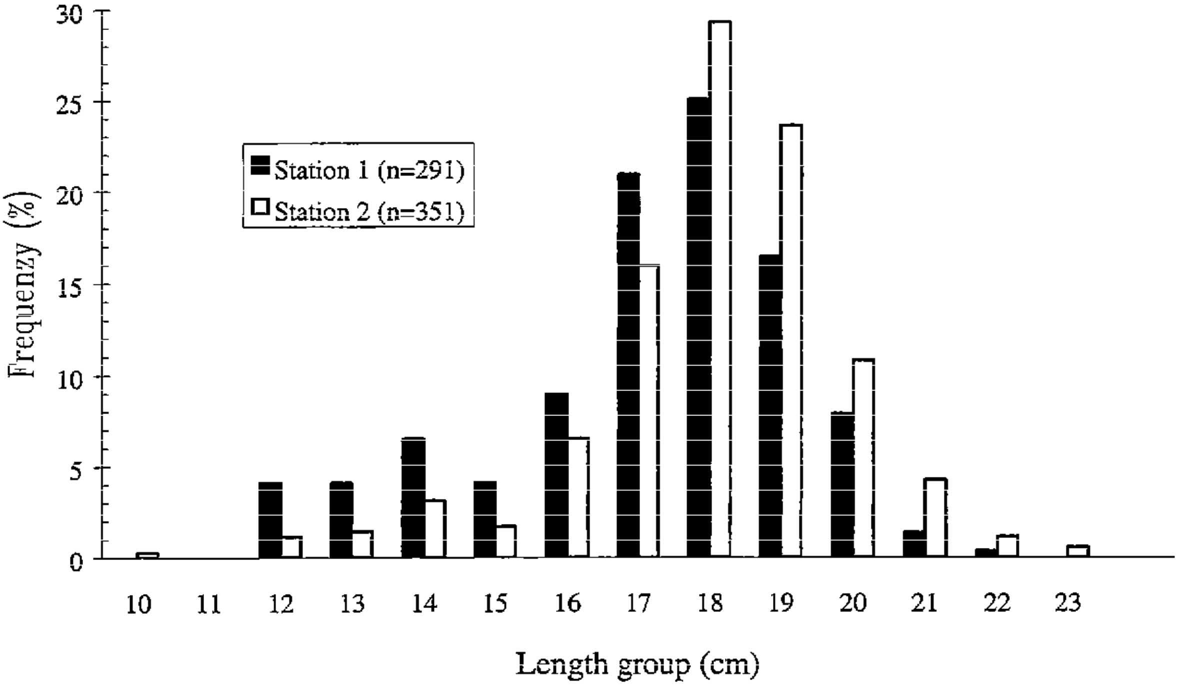

Figure 1 Length frequency distribution of the horse mackerel in sample 1 and 2.