TARGET STRENGTH OF FRESHWATER FISHES AT 420 KHZ MEASURED IN CAGES

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The target strength of freshwater fishes was measured in cages using Biosonics 101 dual-beam echosounder. The TS-length and TS-weight relationships were determined for the mixed population of the Dobczyce reservoir and separately for roach, perch, ruffee, bream and pike. The results for small and larger fish suggest that TS for small fish decreases much faster than could be expected from the general 20LogL relationship.

INTRODUCTION

Fish target strength (TS) is a key quantity in the acoustic assessment of fish abundance and distribution. TS is not only a function of fish size, but also depends on fish species, behaviour, physiological condition, changes in vertical position etc. (Olsen and Ahlquist 1989, Ona 1990). Some of these parameters change diurnally or seasonally increasing a degree of variation of TS. Although attempts to determine target strength of different species have a long history (see reviews by Foote 1991, McLennan and Simmonds 1992, McClathie et al 1996) the problem has not been solved satisfactorily. Majority of measurements were done on marine species at much lower frequencies: 38, 70, 120 or 200 kHz. Data for freshwater species at 420 kHz are practically lacking, apart from juvenile perch (Frouzova & Kubecka 2003) and side aspect (used in horizontal applications) for common species of riverine fish (Kubecka & Duncan 1998).

Much of the early target strength research focused on dorsal-aspect measurements performed on immobilized specimen placed on the acoustic axis. This arrangement has the advantage that one can easily manipulate the location of the animal, centering it over the transducer. However such approach does not include the effect of fish behaviour, leading to much higher target strength for a given fish size than the mean value observed in the field. Therefore, two other approaches for considering fish behaviour were developed:

measurements *in situ* and measurements in cages. The primary advantage of the first method is that the behavioural and physiological source of variation is accurately contained in the echo amplitudes, however the difficulties with discriminating single fish echoes and with getting unbiased capture of samples from the insonified population, make this method possible only in special conditions, rarely met in practice. For the proper *in situ* measurement of the target strength it is essential that only one target occupies the acoustic resolution volume. Sawada et al (1993) concluded that an empirical value of 0.04 fish per sampled volume is effective as a limit above which *in situ* target strength measurements would be unreliable. A critical approach therefore should be applied to TS data collected *in situ* (especially at larger depths), at least until technological advances have improved the performance of single target detectors.

The measurements in cages are more practicable in a sense that they provide some compromise between the advantages and disadvantages of the other two methods. We have exact knowledge of all the parameters of the fish we put into the cage, but the main assumption that behavioural patterns in cages are similar to those occurring in wild is still questionable (Edwards et al. 1984). In this work preliminary results of the controlled experiment in cages to investigate the target strength and its fluctuations for the freshwater fishes typically occurred in Polish lakes and reservoirs are presented. A special attention is paid to small fish, less than 10 cm long, for which few data exist in literature (Ponton & Meng 1990, Nielsen and Lundgren 1999, Rudstam et al. 2002, Frouzova & Kubecka 2003).

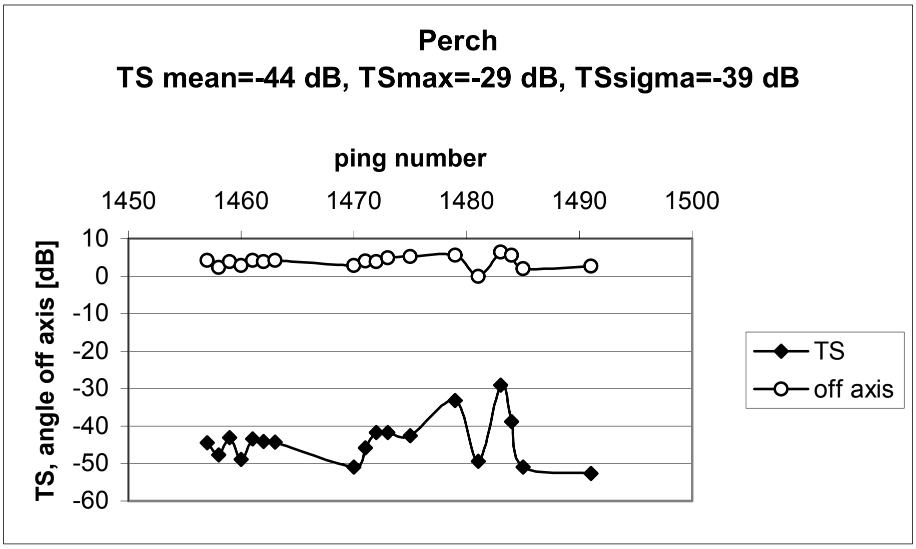
1. MATERIALS AND METHODS

By using presently the most common dual-beam and split-beam systems the fish target strength can be directly measured. However, these measurements show a wide range of TS values. This is explained by the stochastic nature of TS, which is highly variable even for the same species and size of fish. Therefore for an estimate of TS a statistical approach is required. For the TS-length relationship different characteristics can be taken: mean, max or mode value. Additionally, the "mean" may be averaged either in a linear domain (which is the reasonable solution from the scattering mechanism point of view) or logarithmic domain (better from the statistical point of view, as TS has normal distribution). Any of these values are used by different authors, the worst and the most common being the case that there is no information which value was taken, which makes much confusion. Therefore in our experiments we decided to analyze all these descriptors and the relationship between them.

All measurements of target strength were made with a 420 kHz dual-beam Biosonics echo sounder transmitting 10 times per second a 0.1-0.4 ms signal through a 6 (at the –3dB points) element and receiving through 6 and 15 elements. Transducer was mounted on a floating structure within a cage and aimed downward. No limits for single targets were applied as only one fish at a time was placed in a cage. Small specimens were measured in a cage made of a plexi-glass tube, 30 cm in diameter and 150 cm long, mounted firmly in a far field of the transducer. This was to keep fish close to the axis of transducer and at the same time to avoid reflections from the walls (it was checked that with applied threshold of –75 dB plexi-glass was practically transparent for sound). Larger fish were measured in a cage made of nets stretched over plastic rings, this cage had a diameter of 2 m and depth of 4 m. Both cages were placed into water from the boat anchored in the middle of the reservoir from which fish were caught by trawl the previous night. All measurements were done during the day time only. At the beginning of the study the whole system was calibrated *in situ* using the tungsten-carbide calibration sphere of 21.2 mm and –43.5 dB target strength, according to the procedure described in Foote et al. (1987).

2. RESULTS

Measurements were performed in the Dobczyce reservoir. The fish caught by nets were: roach, perch, ruffe, bream, pike-perch and pike, with the wide range of sizes only for roach. The other species were represented only by two to four different sizes. Fish body lengths ranged from 45 to 470 mm. Fish size, weight, TS max, TS sigma (averaged in linear domain), TS mean (averaged in logarithmic domain) and a standard deviation (as a measure of variability since TS mean has normal distribution) were taken. The ping-to-ping variability of TS and degree off axis (in DB) for the same fish during consequent passes through the beam (Fig. 1) shows that it really is a stochastic value influenced by fish position in a beam and its behaviour.



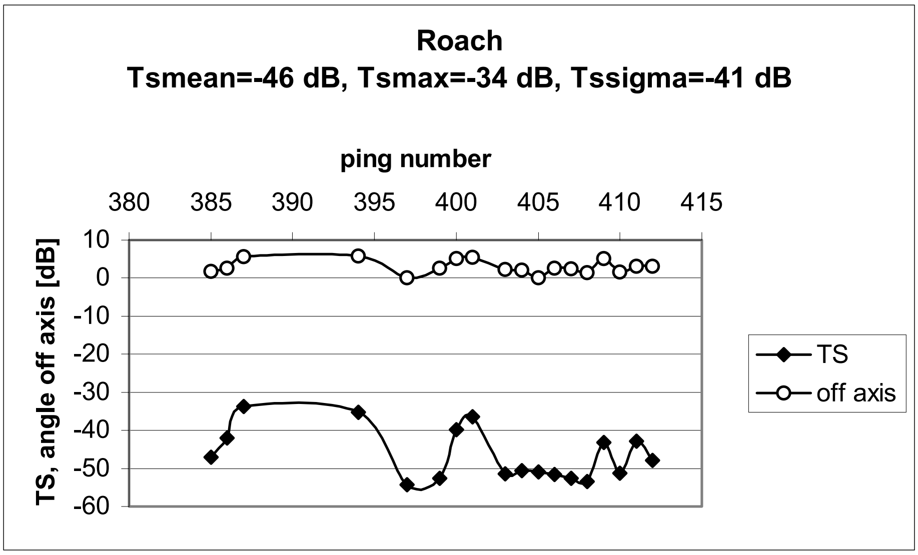


Fig. 1. An example of ping-to-ping variability of TS and degree off axis (in DB) for perch and roach during consequent fish passes through the beam

Comparison of the three descriptors of the target strength (max, mean and sigma – Fig. 2) shows that consistently the TS mean has the lowest value, while TS max has the highest, but the curves are not parallel, and the difference increases with fish size. The TS sigma is the closest to the Love (1977) formula for dorsal aspect (TS=19.1logL-0.9logf-62), where L is in cm and f is a sound frequency in kHz. Love's expression was received for a large sample of different fish species and at different frequencies and is the most commonly used by investigators. Our results for mixed species also confirm its usefulness. The TS – length relationships received in this study for a mixed Dobczyce reservoir population is:

$$\begin{aligned} &TS\ sigma = 24.7\ Log\ L_{tot} - 73.9\ dB && (R = 0.63) \\ &TS\ max = 28.7\ Log\ L_{tot} - 68.8\ dB && (R = 0.65) \\ &TS\ mean = 21.8\ Log\ L_{tot} - 74.6\ dB && (R = 0.59) \end{aligned} \quad 1)$$

Since the parameter in front of Log is close to 20, to enable easy comparisons it is often set to 20, i.e.

$$\begin{aligned} &TS\ sigma = 20\ Log\ L_{tot} - 68.5\ dB && (R = 0.60) \\ &TS\ max = 20\ Log\ L_{tot} - 58.7\ dB && (R = 0.59) \\ &TS\ mean = 20\ Log\ L_{tot} - 72.4\ dB && (R = 0.58) \end{aligned} \quad 2)$$

Also the relationship between TS – weight for the given population was received:

$$\begin{aligned} &TS\ sigma = 7.2\ Log\ W - 34.8\ dB && (R = 0.56) \\ &TS\ max = 8.4\ Log\ W - 23.2\ dB && (R = 0.58) \\ &TS\ mean = 6.4\ Log\ W - 39.9\ dB && (R = 0.53) \end{aligned} \quad 3)$$

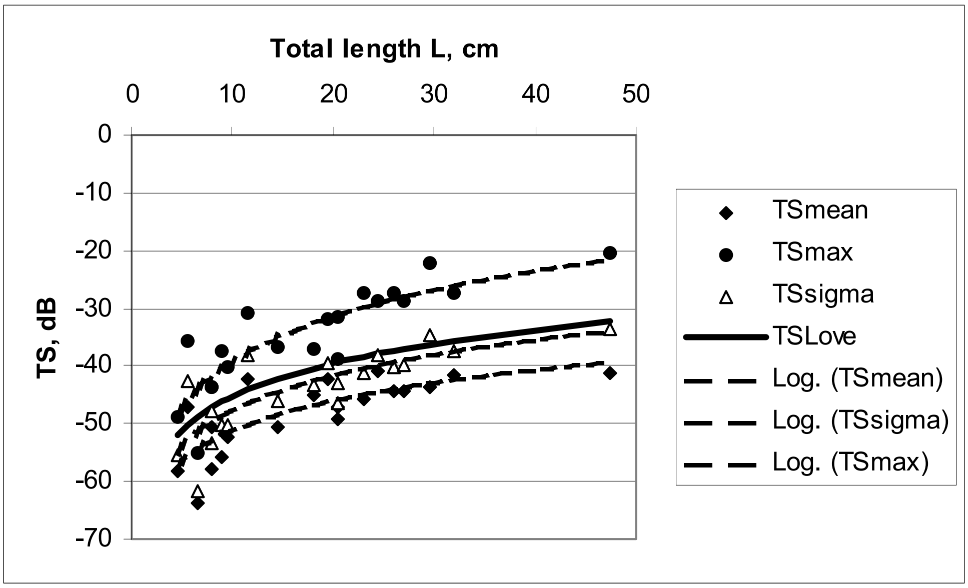


Fig. 2. Target strength-length relationship for the Dobczyce reservoir fish population and the curve of Love (1977)

All three descriptors: TS sigma, TS mean and Ts max show similar degree of correlation with fish length and weight, explaining about 50-65 % of their variability. There was no dependence between the target strength and condition factor of fish defined as $100*W*L^{-3}$ which means that we can use either of the relationships, for fish length or weight, whichever is more convenient.

For roach alone (Fig. 3, equations 4-6) the dependence between fish length and its target strength (characterized by R-squared) was much stronger, and between fish weight and target strength much weaker than for the mixed population.

$$TS\ sigma = 39.8\ Log\ L_{tot} - 93.7\ dB \quad (R = 0.82)$$
$$TS\ max = 41.9\ Log\ L_{tot} - 88.1 dB \quad (R = 0.96) \qquad 4)$$
$$TS\ mean = 28.6\ Log\ L_{tot} - 84.7\ dB \quad (R = 0.98)$$

$$TS\ sigma = 20\ Log\ L_{tot} - 70,0\ dB \quad (R = 0.61)$$
$$TS\ max = 20\ Log\ L_{tot} - 61.8\ dB \quad (R = 0.70) \qquad 5)$$
$$TS\ mean = 20\ Log\ L_{tot} - 74.3\ dB \quad (R = 0.89)$$

$$TS\ sigma = 1.5\ Log\ W - 39.8\ dB \quad (R = 0.14)$$
$$TS\ max = 4.6\ Log\ W - 26.5\ dB \quad (R = 0.52) \qquad 6)$$
$$TS\ mean = 1.1\ Log\ W - 43.9\ dB \quad (R = 0.11)$$

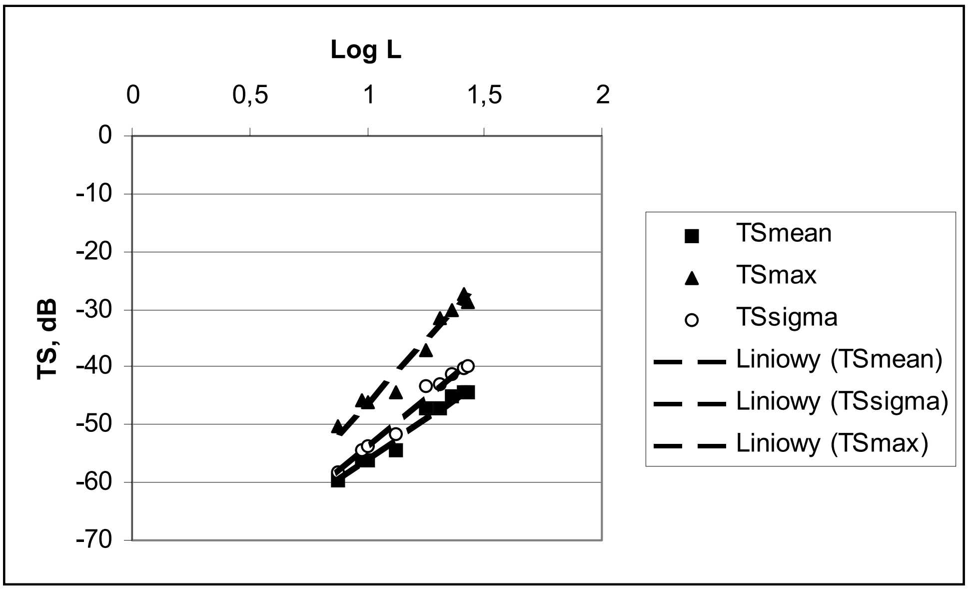


Fig. 3. Target strength-length relationship for roach (Rutilus rutilus)

Regressions calculated separately for small and large specimens of roach (measured in plexi-glass tube or net cages, equations 7-10) show about 4-6 dB difference, i. e. the TS of small animals is smaller than expected from general equations 4-5.

Small roach: 5-15 cm total length:

$$TS\ sigma = 25.9\ Log\ L_{tot} - 80.4\ dB \quad (R = 0.94)$$
$$TS\ max = 22.7\ Log\ L_{tot} - 69.2\ dB \quad (R = 0.81) \qquad 7)$$
$$TS\ mean = 20.8\ Log\ L_{tot} - 77.2\ dB \quad (R = 0.92)$$

$$TS\ sigma = 20\ Log\ L_{tot} - 74.5\ dB \quad (R = 0.89)$$
$$TS\ max = 20\ Log\ L_{tot} - 66.5 dB \quad (R = 0.80) \qquad 8)$$
$$TS\ mean = 20\ Log\ L_{tot} - 76.4\ dB \quad (R = 0.91)$$

Large roach : 20-30 cm total length:

$$TS\ sigma = 20.74\ Log\ L_{tot} - 69.7\ dB \quad (R = 0.95)$$
$$TS\ max = 49.42\ Log\ L_{tot} - 97.4\ dB \quad (R = 0.77) \qquad 9)$$
$$TS\ mean = 8.73\ Log\ L_{tot} - 57.1\ dB \quad (R = 0.28)$$

$$TS\ sigma = 20\ Log\ L_{tot} - 68.7\ dB \quad (R = 0.94)$$

TS max = 20 Log L_{tot} – 57.6dB (R = 0.50) 10)
TS mean = 20 Log L_{tot} – 72.8dB (R = 0)

The relationships for other species since they are based just on few data are presented only in the form of 20 LogL to enable comparisons with results of other authors:

Pike (5-10 cm):
TS sigma = 20 Log L_{tot} – 69.0 dB
TS max = 20 Log L_{tot} – 59.1 dB 11)
TS mean = 20 Log L_{tot} – 73.0dB

Ruffee (5-10 cm):
TS sigma = 20 Log L_{tot} – 73.1 dB
TS max = 20 Log L_{tot} – 64.4 dB 12)
TS mean = 20 Log L_{tot} – 75.8 dB

Perch (20-30 cm):
TS sigma = 20 Log L_{tot} – 66.3 dB
TS max = 20 Log L_{tot} – 57.4 dB 13)
TS mean = 20 Log L_{tot} – 71.3 dB

Bream (15-35):
TS sigma = 20 Log L_{tot} – 68.4 dB
TS max = 20 Log L_{tot} – 58.7 dB 14)
TS mean = 20 Log L_{tot} – 72.6 dB

From equations 8-14 it is clear that for the class of smaller fishes the intercept is lower than for the larger fishes. This means that using the same equation for both: small and large fish we acoustically overestimate the size of small ones, and underestimate the size of large ones, which results in decreasing of the total range of fish sizes.

Tab. 1. Dependence of the target strength on the maximum half-angle for processing targets (the parameter set by operator during the analysis)

$\theta/2$	0	2	4	6	8
TSmean	-50.16	-50.44	-47.65	-44.57	-44.15
TSmax	-32.93	-32.93	-32.93	-31.5	27.26
TSsigma	-46.69	-47.20	-44.75	-56.22	-55.11

Estimated TS values were sensitive to maximum half-angle for processing targets which is set by operator during analysis (Fig 1, Table 1). The purpose of this parameter is to eliminate targets that are detected at the edges of the acoustic beam. In the instruction it is suggested that for a typical surveys this parameter should be approximately one – half of the nominal beam-width of the narrow-beam transducer element. For the results presented in this work this parameter was set to 4. The value of this parameter should be always stated if data received by different authors are to be compared. An inspection of TS and angle off axis variability suggests the proportional relationship between these two values.

3. DISCUSSION

Comparison with other results is difficult because instruments and analysis methods differ between investigators and it is quite common that even for fish of constant size in a given environment the corresponding distributions of target strength may span a range exceeding 10 dB (Dawson and Karp 1990). There are two TS-length relationships for roach. Guillard & Gerdeaux (1993) performed *in situ* determination of the target strength of roach using single beam echo-sounder at frequency 70 kHz. They received the formula TS = 20 logL – 64.4 for the fish size ranging from 5.9 to 26.3 cm. This is about 4 dB higher than our data for TS sigma for large roach and about 10 dB higher than our data for small roach. One can expect smaller TS at higher frequency but not so much. The possible reasons for this discrepancy could be the different methodology of estimating TS by single beam and dual beam echosounders and a different angular dependence of fish in cages and *in situ* . The other relationship for roach has a form TS = 29.3 Log L – 96.7 (Kubecka & Duncan 1998) and is difficult to compare with our results as it was received for side aspect of fish which it is known that there are differences between the dorsal and side aspects. Our results for perch are also lower than those received by other authors at different frequencies (Chorier et al. 1995, Frouzova & Kubecka 2003). Guillard et al. (in press) for the 9.7 cm long perch received mean target strength of -44.2 for 70 kHz and –44.6 for 129 kHz, while using our equation it should be –46.5 dB. These results like in the case of roach were also received *in situ*. It can not be excluded that fish behavior was responsible for these differences, with more up and down movements in cages as compared with more horizontal position in natural environment.

The patterns of ping-to-ping variability (Fig. 1) are dependent on the interaction of fish directivity and behaviour. It is apparent that fish behaviour affects the mean backscattering cross-section and disturbs relationship between TS and length, leading to the bias of acoustical estimates of fish size distribution and abundance. This concern has been documented by modeling studies (Foote 1979), but empirical investigations of this effect are lacking. With no doubts many more studies of this kind are required to get proper knowledge of the interaction between fish size and species, acoustic frequency, and behavioural effects.

Our results for small and larger fish show about 2-4 dB difference in the TS-length relationship and suggest that TS for small fish decreases much faster than has been expected from the general 20LogL relationship. A TS lower than that predicted from standard equations for small fish has been observed elsewhere (Nielsen R. & Lundgren B. 1999, Rudstam et al. 2002).

While hoping that the estimates of the TS-length relationships from this study will be of interest in acoustic abundance estimations in Polish lakes and reservoirs, we fully agree with Foote (1987) that “the most suitable target strength measurements for application in echo integrator surveys are those that reflect the situation, specifically, the biological and physical states of the fish, including behaviour, and the external conditions of observation”

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