CAN WE PRECISELY ESTIMATE FISH SIZES USING ACOUSTICS?

MAŁGORZATA GODLEWSKA[1], ANDRZEJ ŚWIERZOWSKI[2], VLADIMIR MENSHUTKIN[1], JOSEF WANZEBÖCK[3]

1 – International Centre for Ecology,Polish Academy of Sciences,
Tylna 3, 90 364 Łódź, Polandemail
email: margogod@wp.pl
2 – Inland Fisheries Institute,
Oczapowskiego 10, 1- 719 Olsztyn, Poland
email: a.swierzowski @infish.com.pl
3 – Institute for Limnology, Austrian Academy of Sciences,
Mondseestrasse 9, A - 5310 Mondsee, Austria,
email: josef.wanzenboeck@oeaw.ac.at

Fish target strength (TS) is the key quantity in the acoustic assessment of fish abundance and biomass. Since TS is the function not only of fish length, but also depends on species, physiological state, behavior, and environmental parameters, calculation of fish real length on the basis of acoustical data is not a trivial task. Commonly fish size distribution is estimated from TS distribution using Love's formula. In the present paper fish target strengths for typical European freshwater species were determined experimentally and based on these results a mathematical model has been constructed. The model accounts for the TS/L relationship for a given species and for fish behavior. From the single fish measurements in cages three types of fish behavior were distinguished and incorporated into the model. Fish size distributions resulting from the model were compared with those obtained using directly Love's formula and from the net catches.

INTRODUCTION

There is an increasing use of acoustical methods in the fish population studies of lakes and reservoirs. Two basic problems to be resolved by fisheries acoustics are: what is the size of fish stock and what is the proportion of different length classes in the fish population. To answer these questions detailed knowledge of the fish target strength, TS is necessary.

However, even though a considerable body of literature exists on TS as a function of fish size (for reviews see Foote 1991, MacLennen & Smmonds 1992, Mc Clatchie et al. 1996) there is a continuing need for target strength data to be collected on fish that are objects of commercial or monitoring surveys. Especially this relates to freshwater species at different frequencies, because of very limited data available. It is only in recent years that modern calibrated equipment is able to provide reliable numeric values for the target strength of live fish in different conditions. Presently used dual beam and split beam techniques provide the best estimate to scale integrator outputs (MacLennan & Simmonds, 1992, Foote 1987). Particularly valuable are *in situ* measurements as they represent the acoustical scattering properties of fish under actual conditions of survey. However, several potential biases limit the use of *in situ* TS. Especially at high fish concentrations the poor resolution of single targets leads to inaccurate estimate of TS (Sawada et al. 1993, Soule et al. 1997). The ideal conditions for *in situ* measurements i. e. when study area contains only one size class of a single species are very rare in practice and *ex situ* techniques still have to be used in many situations. Fish target strength is a function not only of fish length, but also species, physiological state, acoustic frequency and the most difficult to account for – the complex nature of fish behaviour. This includes variation in tilt angle distribution and changes of TS as a consequence of vertical migration, and the avoidance of boat or towed body, but also natural movements of fish between consecutive pings. It is mainly the fish behaviour that is responsible for “dynamic nature” of TS and for difficulties in appropriate attribution of a given TS to the real fish size. Therefore, despite the significant effort aimed to calibrate acoustic and real sizes of fish under different conditions, the successful comparisons are still rare (Lindem, 1983, Parkinson et al. 1994, Rudstam et al. 2002, Mehner & Schults 2002). Objectives of the present study were to 1) determine the TS – length relationship for freshwater species dominating in European lakes, to 2) access the applicability of existing equations to estimate fish size from TS and to 3) preliminarily examine the effect of fish behaviour on the prediction of fish length from the acoustical measurements by using simple mathematical model. This was done in two steps: first - investigation of the single fish target strength variability to receive the regressions between TS and length and to distinguish characteristic “types of behaviour”. Second – to build a model, which uses the TS – L relationships and incorporates received patterns of fish behaviour. The results were compared with the commonly used Love’s model (Love 1977).

1. METHODS

For the very small fish an experiment has been performed in lake Mondsee in Austria with the objective to describe relationships between acoustic and real body size of perch (*Perca fluviatilis* L.) during larval development. The perch was selected for this study because it is a common European fish that is abundant in almost all types of water bodies and it serves as a model fish in many ecological studies. Fertilized perch eggs were collected from the lake and put into a small tank in the laboratory. Perch larvae were reared in the tank from spawning to the age of 10 days (when they reached about 8 mm length) and than transferred to the net cage situated in the lake, some 500 m from the shore. The net cage had a diameter of 4 m and height of 5 m and it provided nearly “natural” conditions for the juvenile fish, limiting however their distribution to the space where they could be registered using hydroacoustics. The scientific echosounder SIMRAD EY500 with a frequency 120 kHz was used for measurements. Two transducers were applied: one mounted just under the surface and looking down and second mounted at the lower end of the net and looking up. Hydroacoustical measurements were performed in a diurnal cycle on 6, 12, 20 and 26 of June and 3 and 17 of July 2003. They were stopped at fish length about 5 cm, because heavy storm had damaged the cage. Simultaneously with acoustical measurements each time a sample of fish was removed from the cage, measured and weighted. Data for regression analysis were selected to include only echoes from individual fish, which was guaranteed by detailed visual inspection of amp–echogram in 3D space using Sonar 5 software (Balk & Lindem 2000). For the larger fish, individuals of roach (*Rutilus rutilus*), perch (*Perca fluviatilis* L.), pike (*Esox lucius*), bream (*Abramis brama*) and ruffee (*Acerina cernua*) were caught by trawl in the Dobczyce reservoir (Poland). Fish were first acclimated in the large tank and than transferred one by one to the net cage of 2 m diameter and 4 m depth situated in open water. Acoustical measurements were performed with Biosonics 101 dual beam echosounder working at frequency 420 kHz. After acoustical measurements were finished fish were killed, measured and weighted. The parameters of both echosounders for data collection and analysis are summarized in Table 1.

Tab.1 Parameters of the acoustical systems for data collection and analysis

Parameter	Biosonics 101	Simrad EY500
Operating frequency	420 kHz	120 kHz
Nominal 3 dB narrow beam	6°	7°
Nominal 3 dB wide beam	15°	7°
Pulse duration	0.1 msec	0.1 msec
Pulse repetition rate	5 Hz	fast
Threshold for TS	-80 dB	-80 dB
Max half angle for processing targets	3 dB	
max phase dev.		2
Beam pattern factor >0 threshold	6 dB	
Max beam compensation		4
Single echo detection criteria:		
Min returned pulse width	0.8*pulse duration	0.8*pulse duration
Max returned pulse width	1.5 *pulse duration	1.5 *pulse duration

2. RESULTS AND DISCUSSION

Experimental results

Fish lengths used in experiments ranged from 0.8 to 47 cm. In case of roach and perch regressions were calculated separately, for small and large specimens and for other species just one common regression for all sizes was received. The TS values were fitted into commonly used formula:

$$TS = a \, Log10\,(L) + b$$

where TS is a mean target strength in dB, calculated ether in logarithmic domain (further used as TS_{mean}), or linear domain (denominated TS_{sigma}), and L is a mean fish length in cm. The parameters for all the regressions are summarized in Table 2. These results should be treated as preliminary, because they are based on not very many individuals, since we were mainly interested in studying the behavioural pattern of a single fish.

Examples of three types of fish behaviour are shown in Fig. 1. TS characterizing each of these types have a different probability density function (PDF). For the calm fish, which did not move very much, echoes from repeated pings were nearly the same, and they centered on a mean value (Fig. 1, A, B). For the diving fish or swimming strongly up, two-peak distribution was normally observed (Fig. 1, C, D). And for the vigorously moving fish TS values had more or less the same probability within quite wide range of values (Fig. 1, E, F). The behavioural pattern seem to be independent of fish species and size, although for small fish the variability (SD) is much smaller (note the different *x* scale in the figures).

Tab.2 Regression analyses of the target strength TS in dB (in the order TS_{mean}/TS_{sigma}, explanation see in text) on fish total length in cm in vertical plane according to equation TS =a*Log (L) + b

Fish species	a	b	Range of L, cm
All fish pooled	21.8/24.7	-74.6/-73.9	4.5-47
Small roach	20.8/25.9	-77.2/-80.4	5-15
Large roach	8.7/20.7	-57.1/-69.7	15-30
Large perch	20/20	-71.3/-66.3	20-30
Pike	20/20	-73.0/-69	5-10
Bream	20/20	-72.6/-68.4	15-35
Ruffee	20/20	-75.8/-73.1	5-10

Model description

The input data to the program are those received directly from the echosounder, i.e. the TS distribution of measured fish:

$$n = \Phi(TS) \quad .(1)$$

where TS – target strength in dB, n – frequency of occurrence in %. Function ϕ has resolution of 1 dB. This function can be either read from the file containing all measured TS values, by using key "input data" and choosing the appropriate disc where the data are stored, or it may be introduced directly from the keyboard by pressing keys „up" and „down" to increase or decrease the percentage contribution of each TS class.

In program there is a small database of our own and literature dependences between the target strength in dB and fish length in cm for different fish species, which are presented in a usual form:

$$TS = a \log(L) + b, \quad (2)$$

where „a" and „b" are empirical parameters. The operator can also use its own values for these parameters introducing these values directly from the keyboard.

Determination of the fish length distribution on the basis of acoustical measurements is a difficult task since the target strength depends not only on fish species and size, but to a great degree also on its behaviour i. e. the way in which fish is moving within the acoustical beam. The model should be able to reflect "aliveness" of a free-swimming animal. This aliveness appears in the probability density function of fish echo amplitudes. By taking many repeated measurements of live fish, one can measure the probability density function for TS. The program allows to choose between the three types of behaviour, which are represented by different TS distribution for a single fish of a given species and size (Fig. 1). The first type (A, B) is close to normal distribution, the second (C, D) accounts for two-peak distribution and the third (E, F) represents the equal probability of different TS. All these types were observed during measurements performed on single fishes in cages. The operator can also determine its own type of behaviour by introducing the TS distribution directly from the keyboard.

The assumption is made that the TS distribution of the whole population is a summary of TS of single fishes with different proportion of each type of behaviour. All the calculations are performed in a linear domain which means that each TS value is recalculated to sigma:

$$\sigma = 4\pi 10^{0.1TS} \quad (3)$$

Thus the three types of fish behaviour are represented by linear values σ_A, σ_B, σ_C. We further assume, accordingly with the results received, that the type of behaviour is independent of the fish length, so that the resultant sigma can be written as:

$$\sigma_s = \sum_{i=1}^{40}\sum_{k=1}^{8}\left(A\sigma_a + B\sigma_b + C\sigma_c\right)F(\lambda(k)) \tag{4}$$

Coefficients A, B and C correspond to the share of each type of behaviour, and

$$A + B + C = 1 \quad .(5)$$

Summary in equation (4) is performed over all TS values from equation (2) recalculated to linear domain according to (3) (from 1 to 40 TS classes) and over 8 classes of fish sizes.

In equation (4) the coefficients A, B and C, and the function of fish length distribution λ(k) are unknown. The program finds all these values on the basis of random search. It calculates the mean fish length from the mean TS value of the introduced distribution, than takes the random set of all unknown parameters and according to equation 4 calculates new TS distribution. This new distribution of course differs from the one introduced, and the program calculates this difference as an error E:

$$E = \sum_{i=1}^{40}\left(\sigma_s - \sigma_{s1}\right)^2 \tag{6}$$

The value of error is than minimized by generating the successive sets of parameters and keeping in memory only those which give smaller value of error E. The program does this operation 10 000 times which usually is enough for good convergence. If it is necessary the number of operations can be increased. The resulting fish length distribution as well as TS distributions corresponding to all three types of fish behavior can be stored on the disc and used by Excel or other programs for further analyses and comparisons.

Model verification

The model was based on the results of caged fish and for its verification *in situ* measurements of vendace (*Coregonus albula* L) were used (Swierzowski and Godlewska 2003). Coregonids are very good objects for *in situ* TS measurements as they are rarely mixed with other species (in our case 95.1% of caught fish were vendace) and their size groups are separated by depth. As can be seen from Fig. 2 the model significantly improves our predictability of fish length distribution. The distribution based solely on the regression of TS-length relationship is very wide, as all the echoes of different strength due to fish movements are treated as fishes of different sizes. Taking into account the TS distribution of single fish considerably narrows the resultant fish distribution. It is not surprising that the results received with regression of Świerzowski and Godlewska are closer to real fish distribution than received with regression of Love. Regression by Świerzowski and Godlewska was received specifically for vendace at the same frequency as used during the survey, while Love collected his data on many species from 14 different families, using echosounders operating at a wide range of frequencies from 15 to 1000kHz. Although MacLennan and Simmonds (1992) state that Love's equation is now mainly of historical interest it is still widely used to convert acoustical fish size into centimeters just because more appropriate data are often lacking. As was shown by Godlewska (2004) when we deal with mixed population of different freshwater species and pull all the data together, the resulting regression is very close to one of Love. So, when specific data for a given fish species, size classes, or frequency are lacking the Love's equation is a pretty good approximation, however, if we want to estimate fish lengths precisely, appropriate data are necessary.

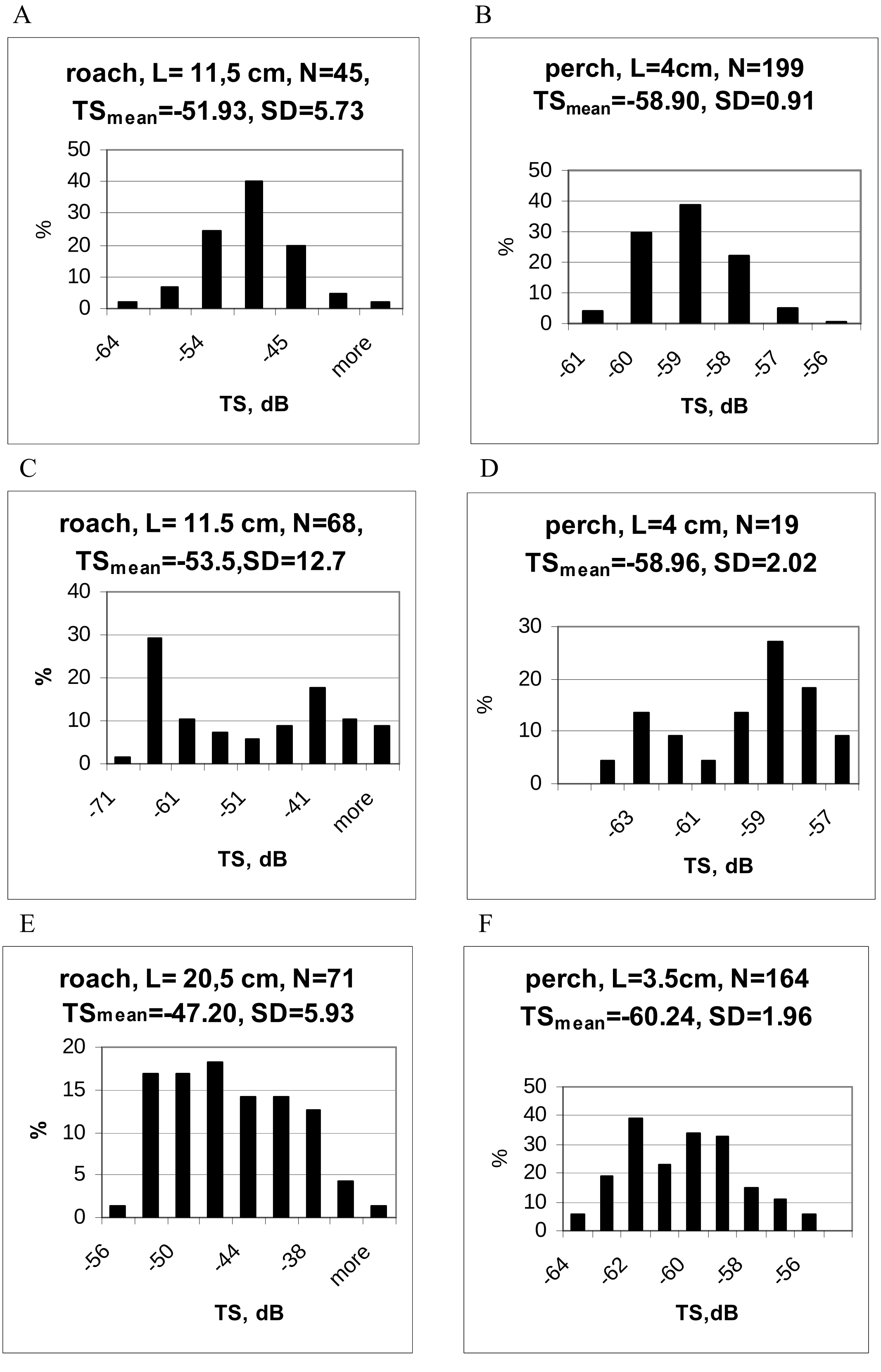

Fig.1 Three types of fish behavior for roach and perch represented by three different probability density functions of TS

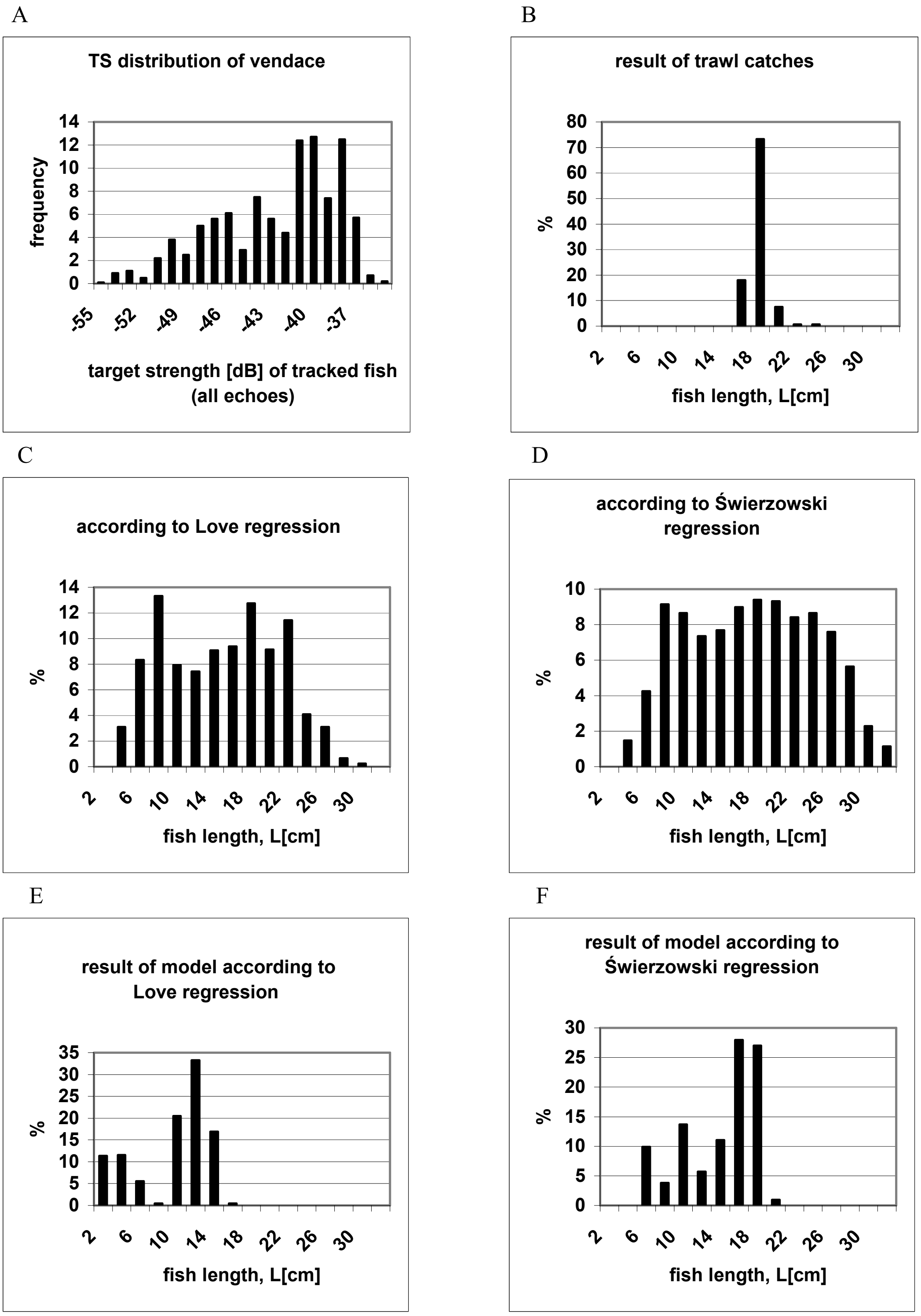

Fig.2 Comparison of TS distribution of tracked fish (A), fish length distribution from net catches (B), fish length distribution estimated from the Love (1977) formula (C), fish length distribution estimated from the Świerzowski & Godlewska (2003) formula (D), fish length distribution estimated from the model using Love (1977) formula (E), fish length distribution estimated from the model using Świerzowski & Godlewska (2003) formula

AKNOWLEDGEMENTS

This study was supported by the State Committee for Scientific Research of Poland, Grant Nr. 6 P04F 007 20 and an award to Godlewska and Wanzeböck for the Polish-Austrian cooperation. We are very grateful to Bill Acker for lending us the BIOSONICS echo sounder and to Helge Balk for providing the key for Sonar 5. We also appreciate very much the help of Lech Doroszczyk and Bronisław Długoszewski in data collection and analysis.

REFERENCES

[1] H. Balk, T. Lindem, Improved fish detection in data from split beam transducers. Aquatic Living resources, 13(5):297-303. 2000

[2] K. G. Foote, Fish target strength for use in echointegrator surveys. J. acoust. Soc. Am. 82: 981-987, 1987

[3] K. G. Foote, Summary of methods for determining fish target strength at ultrasonic frequencies. ICES Journal of Marine Science 48: 211-218, 1991

[4] M. Godlewska, Target strength of freshwater fishes at 420 kHz measured in cages. Hydroacoustics, 7: 55-62, 2004

[5] R. H. Love, Target strength of an individual fish at any aspect. J Acoust. Soc. Am. 62: 1397-1403, 1977

[6] D. N. MacLennan, E. J. Simmonds, Fisheries Acoustics. Chapman and Hall, London, 325 pp. 1992

[7] T. Lindem, Success with conventional in situ determinations of fish target strength. FAO Fisheries Report 300: 104,111, 1983

[8] S. McClatchie, J. Alsop, R. F. Coombs, A re-evaluation of relationships between fish size, acoustic frequency, and target strength. ICES Journal of Marine Science, 53: 780-791, 1996

[9] T. Mehner, M. Schultz, Monthly variability of hydroacoustic fish stock estimates in a deep lake and ist correlation to gillnet catches. Journal of Fish Biololgy, 61: 1109-1121, 2002

[10] E.A. Parkinson, B.E. Rieman, L. G. Rudstam Comparison of Acoustic and Trawl methods for Estimating Density and Age Composition of Kokanee. Transactions of the American Fisheries Society, 123: 841-854, 1994

[11] L. G. Rudstam, A. J. VanDeValk, M. D. Scheuerell, Comparison of acoustic and Miller high-speed sampler estimates of larval fish abundance in Oneida Lake, New York. Fisheries Research 57:145-154, 2002

[12] K. Sawada, M. Furusawa, N. J. Williamson, Conditions for the precise measurement of fish target strength *in situ*. Fish. Sci. (Tokyo), 20: 15-21, 1993

[13] M. Soule, M. Barange, H. Solli, I. Hampton, Performance of a new phase algorithm for discriminating between single and overlapping echoes in a split-beam echosounder. ICES Journal of Marine Science 54: 112-124, 1997

[14] A. Świerzowski, A. Godlewska, In situ measurements of the target strength of vendace (*Coregonus albula* L.) in Lake Pluszne. Hydroacoustics, 6: 59-68, 2003