IN SITU MEASUREMENTS OF THE TARGET STRENGTH OF VENDACE (Coregonus albula L.) IN LAKE PLUSZNE

ANDRZEJ ŚWIERZOWSKI [1], MAŁGORZATA GODLEWSKA [2]

[1] Inland Fisheries Institute
ul. M. Oczapowskiego 10, 10-719 Olsztyn, Poland
a.swierzowski@infish.com.pl

[2] International Centre of Ecology
ul. M. Konopnickiej 1, 05-092 Łomianki, Poland
mce-pan@mail.unicom.pl

The paper presents a preliminary discussion of the results of the first Polish attempt to estimate the in situ target strength TS (dB). The subject of the study was the freshwater fish vendace Coregonus albula *L. This species is a typical planktivore which inhabits the pelagic zone of Lake Pluszne (903 ha area, 51 m maximum depth) located in northeastern Poland. A Simrad EY-500 type split beam echosounder at a frequency of 120kHz and with a beam width of 7x7 degrees and pulse duration of 0.3 ms was used for acoustic measurements. The trace tracking method with an EP 500 program were used to analyse the data. Control fishing in various water layers was conducted made using pelagic trawl. The dependencies of TS (dB) on fish body length L (cm) were determined for the average values of* $TS_{S.A.} = 20 \log L - 66.8 \pm 0.3$ *SE,* $TS_{SA\ traces} = 20 \log L - 66.4 \pm 0.2$ *SE and* $TS_{max} = 20 \log L - 65.7 \pm 0.3$ *SE.*

INTRODUCTION

The aim of monitoring the fish stocks in water ecosystems is to optimize their exploitation at a level of maximum sustainable yield (MSY) and to evaluate the quality of the environment. Fish can either contribute to the deceleration or acceleration of eutrophication in aquatic ecosystems. Changes in fish assemblages are good indicators of environmental quality. Biomanipulation can be applied through selective catches and stocking programs. In order to perform such activities information is necessary regarding the densities of young forms and typical planktivores as both play a decisive role in matter and energy cycles. They consume zooplankton to the greatest degree and it is zooplankton, in turn, which plays a key role in eliminating the phytoplankton blooms responsible for accelerated water deterioration [21, 22, 24].

Hydroacoustic methods are used with increasing frequency to monitor fish stocks because they are superior in many ways to traditional control fishing and biostatistical methods. Hydroacoustic methods allow fish distribution, numbers and size structure to be evaluated quickly. In order to recalculate fish numbers into biomass and acoustic dimensions (dB) into body length (cm), it is necessary to know the target strength TS (dB), i.e. the acoustic reflection properties of the fish. The target strength depends mainly on the length and anatomy of a given fish species. The swim bladder, which sometimes reflects 90% of the total echo energy, is the greatest cause of variability in the reflection properties of fish. Thus, significant differences can occur when measuring the TS of fish with the same body size but different relative swim bladder size. The difference is especially remarkable for the fish with open swim bladder which migrate vertically. TS fluctuations within one species can depend on the physiological state of the fish, the digestive tract content, the maturity stage of the gonads, the depth of occurrence, the placement of the fish in the acoustic beam (dorsal or side effect) and the frequency of echosounder [8, 12, 14, 15, 20, 21, 24].

To date, acoustic methods have been coupled with control fishing to monitor fish stocks in Polish inland waters. The distribution of density and fish numbers are determined using hydroacoustic methods, while biomass is determined from the species structure and specimen weight data obtained during control fishing. It sometimes occurs that control fishing is either impossible, not recommended or very time consuming, and in these instances the biomass has to estimated directly using the previously determined dependencies between target strength and fish body length [22, 23, 24].

The aim of the current study was to make the first Polish attempt at estimating the TS (dB) of freshwater fish *in situ*. Vendace, which inhabits the pelagic zones of deeper lakes in northern Poland, was chosen for the study. The study involved determining the dependence between the acoustic size of vendace TS in dB, its body length L in cm and its specimen weight W in g using the formula $W = a\ L^n$. The discussion of the results obtained is preliminary.

1. STUDY SUBJECT AND AREA

The studies focused on vendace (*Coregonus albula* L.), a species which inhabits the deeper zones of lakes with a well-oxygenated hypolimnion in northern Poland. This species often occurs with smelt (*Osmerus eperlanus* L.) from the same Salmonidae family. It is a typical planktivore which consumes zooplankton exclusively throughout its life. The significance of vendace in lake eutrophication processes is not yet fully understood. Unlike other lake fish, vendace spawn in fall during thermal equalization. It is commercially important because of its good taste.

The study was conducted in 2001 and 2002 in the largest (600 ha) and deepest (51 m) basin of Lake Pluszne (area of 903 ha) located in northeastern Poland (Fig. 1). This is a mesotrophic lake with class II water purity. There are periodic oxygen deficiencies in the deeper layers of the hypolimnion.

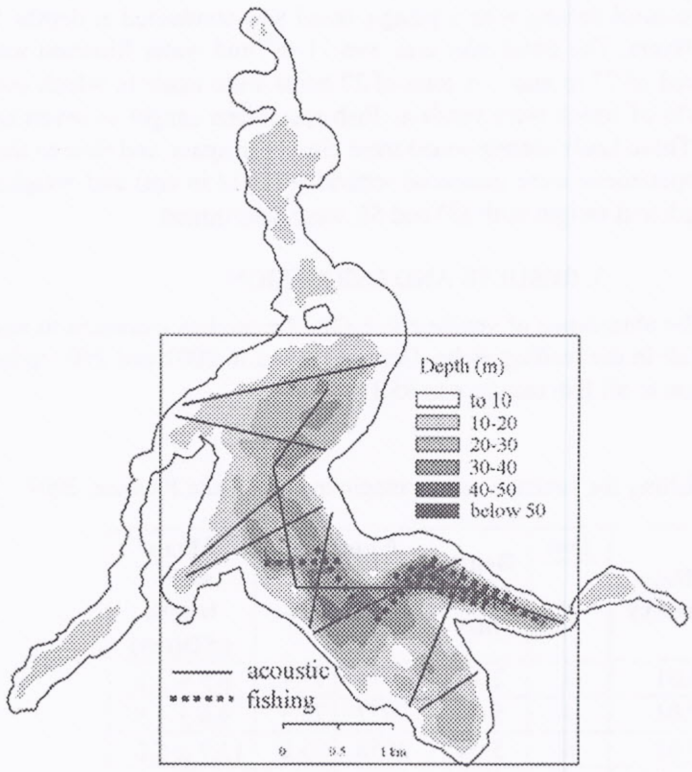

Fig. 1 Bathymetric map and positions of the acoustic and fishing transects in Lake Pluszne.

2. METHODS

TS *ex situ* measurements under controlled conditions usually do not correspond with results of *in situ* methods, and, as a result, differences in fish population estimations can vary up to 50%. It is generally accepted that only *in situ* methods are reliable enough to determine the target strength of pelagic fish [20, 21]. During the present study an *in situ* method of directly estimating the target strength of vendace was applied. Namely, a Simrad EY-500 type split beam echosounder (7x7 degrees) with frequency of 120 kHz and a pulse duration of 0.3 ms was used. Direct of estimation the target strength using the split beam requires extracting echoes from single fish specimens. This method gives the least error in the estimation of the target strength, usually of the order of 0.1 dB, as it permits the real angular position of the fish specimens to be determined [5, 18, 20, 21].

The echosounder was calibrated using a copper ball with a target strength of –40.4 dB. The acoustic surveys were conducted at night (when the vendace are most widely dispersed) in June, July, August and October (Fig. 1) each time along the same 13 transects. Using the EP 500 trace tracking program, the TS (dB) from fish specimen traces were obtained and qualified by the system as single fishes. An average of 3.7 traces were observed for each fish. The data were selected from 11,000 registered pings. The TS (dB) of traces was determined for selected samples and water layers, and the average and maximum values of TS were determined for single fish specimens selected by the system.

Simultaneously control fishing with a pelagic trawl was conducted at depths from 2 to 32 m in 2-4 m water layers. The trawl inlet area was 11 m^2, and water filtration was 850 m^3 min^{-1} at a trawling speed of 77 $m \cdot min^{-1}$. A total of 27 hauls were made in which over 11,000 fish were caught, 95.1% of which were vendace. Fish specimens caught in seven hauls were selected for analyses. These hauls corresponded most closely in space and time to the acoustic surveys. All the fish specimens were measured individually (*Lt* in cm) and weighed W (g). The average body length and weight with SD and SE were determined.

3. RESULTS AND DISCUSSION

In recent years the abundance of vendace in Lake Pluszne has increased to such extent, that it has replaced smelt in the feeding niche. Control fishing in 2001 and 2002 indicated that the vendace contribution to all fish caught was 95.1% (Table 1).

Table 1.
Details of control fishing for vendace using pelagic trawl in Lake Pluszne, 2001 - 2002

Date mm-yy	Tow	Depth layer (m)	Numbers		Mean body length ±SD(cm)
	N		N	%	
06.01	4	2-13	1031	97.7	6.5 ± 3.8
07.01	4	5-21	977	75.3	9.6 ± 1.5
08.01	8	5-32	2058	95.8	13.7 ± 5.0
10.01	4	5-25	973	96.8	11.3 ± 2.3
06.02	6	3-21	751	90.5	13.4 ± 3.2
10.02	1	14-18	5353	99.5	16.2 ± 0.8
Total	**27**	**2-32**	**11143**	**95.1**	**13.6 ± 4.1**

This is the result of successful natural spawning, stocking and feeding conditions which are advantageous for hatching. The formation of a nearly single-species population in the pelagic area was beneficial for *in situ* TS measurements of vendace. However, a significant increase in fish density (8-10 thousand ha^{-1} on average, but periodically and locally even two-fold higher) was disadvantageous for discrimination of single fish, which is necessary for this type of measurements.

The echograms which were selected for analyses had the highest possible contribution of registrations of single specimens and were those which referred spatially to the control fishing areas. Due to the very high vendace density, registrations of single specimens were not numerous. The TS (dB) of 969 traces of 262 fish specimens inhabiting seven water depth layers were analyzed. An average of 3.7 traces were observed for each fish specimen. Data were chosen from the 11,000 echosounder pings registered. The average TS (dB) for single fishes, for all the traces, and for maximum values of TS, together with their SD and ES were calculated. The results of these calculations are presented in Table 2.

In order to obtain the average body lengths of vendace which inhabit the various water layers, seven out of 27 control fishing hauls were chosen which concurred spatially and temporally with the acoustic surveys. A total of 7,510 fish specimens caught in seven water layers from 8 to 32 m were analyzed (Table 3). During one ten-minute hauling

Table 2
Comparison of average TS_{SA} and TS_{max} (dB) of single specimens (mainly vendace) and their traces

Date mm-yy	Depth layer (m)	Fish			Traces	
		N	TS_{SA} ± SD (SE)	TS_{max} ± SD (SE)	N	TS_{SA} ± SD (SE)
06.01	8-10	50	-50.0 ± 5.4 (0.8)	-49.3 ± 5.6 (0.8)	126	-49.8 ± 5.5 (0.5)
10.01	9-11	5	-46.8 ± 5.5 (2.4)	-45.7 ± 6.3 (2.8)	15	-47.1 ± 5.1 (1.3)
07.01	13-15	6	-45.7 ± 6.3 (2.6)	-44.4 ± 6.2 (2.5)	23	-45.8 ± 6.4 (1.3)
06.02	10-12	64	-42.6 ± 3.9 (0.5)	-41.5 ± 3.8 (0.5)	224	-42.8 ± 4.2 (0.3)
06.02	12-14	91	-41.8 ± 3.4 (0.4)	-40.6 ± 3.4 (0.3)	351	-41.9 ± 3.7 (0.2)
10.02	26-30	31	-42.2 ± 4.3 (0.8)	-40.8 ± 4.1 (0.7)	162	-42.4 ± 4.3 (0.3)
08.01	30-32	15	-37.4 ± 3.4 (0.9)	-36.2 ± 3.5 (0.9)	68	-37.5 ± 3.7 (0.4)
Total	**8-32**	**262**	**-43.5 ± 5.3 (0.3)**	**-42.4 ± 5.5 (0.3)**	**969**	**-43.1 ± 5.2 (0.2)**

Table 3.
Comparison of average TS_{SA} and TS_{max} (dB) of vendace and their traces as well as fish body length (cm) and the b_{20} coefficients derived for TS=20 log L- b_{20}

Date mm-yy	Depth layer	N	Mean body length ±SD (cm)	Fish					Traces		
				N	TS_{SA}	b_{20}	TS_{max}	b_{20}	N	TS_{SA}	b_{20}
06.01	8-10	617	5.6 ± 1.5	50	-50.0	65.0	-49.3	64.3	126	-49.8	64.8
10.01	9-11	408	11.0 ± 0.9	5	-46.8	67.6	-45.7	66.5	15	-47.1	67.9
07.01	13-15	606	9.6 ± 1.1	6	-45.7	65.3	-44.4	64.0	23	-45.8	65.4
06.02	10-12	89	14.3 ± 2.3	64	-42.6	65.7	-41.5	64.6	224	-42.8	65.9
06.02	12-14	99	14.1 ± 2.5	91	-41.8	64.8	-40.6	63.6	351	-41.9	64.9
10.02	26-30	5353	16.2 ± 0.8	31	-42.2	66.4	-40.8	65.0	162	-42.4	66.6
08.01	30-32	338	20.6 ± 2.2	15	-37.4	63.7	-36.2	62.5	68	-37.5	63.8
Total	**8-32**	**7510**	**14.6 ± 3.7**	**262**	**-43.5**	**66.8**	**-42.4**	**65.7**	**969**	**-43.1**	**66.4**

period in the 26-30m depth layer a total of 5,353 vendace specimens were caught, the majority of which were age 1+. The working parameters of the trawl and its 50 to 80% effectivity were the basis for estimating vendace density at 788 to 1,260 specimens·1000 m^{-3} and 15,760 and 25,200 specimens·ha^{-1}, respectively. At different vendace numbers in subsequent water layers (DL), the average body length in the shallowest water layer DL = 8-10 m was L = 5.6±1.5 cm and in the deepest layer DL = 30-32 m it was L = 20.6±2.2 cm. The average body length of 7,510 vendace specimens was L = 14.6±3.7 cm (Fig.2).

Comparisons of the average TS (dB) from the measurements of traces and that for fish, as well as the averages from the maximum TS within the various depth layers are presented in tables 2 and 3. The results in both tables indicate that average vendace body length increased from 5.6 to 20.6 cm as the catch depth increased from 8 to 32 m; this corresponds to the increase of the average TS_{SA} from –50.0 to –37.4 dB, TS_{SA} trace from –49.8 to –37.5 dB and TS_{max} from –49.3 to –36.2 dB. At the average vendace body length from

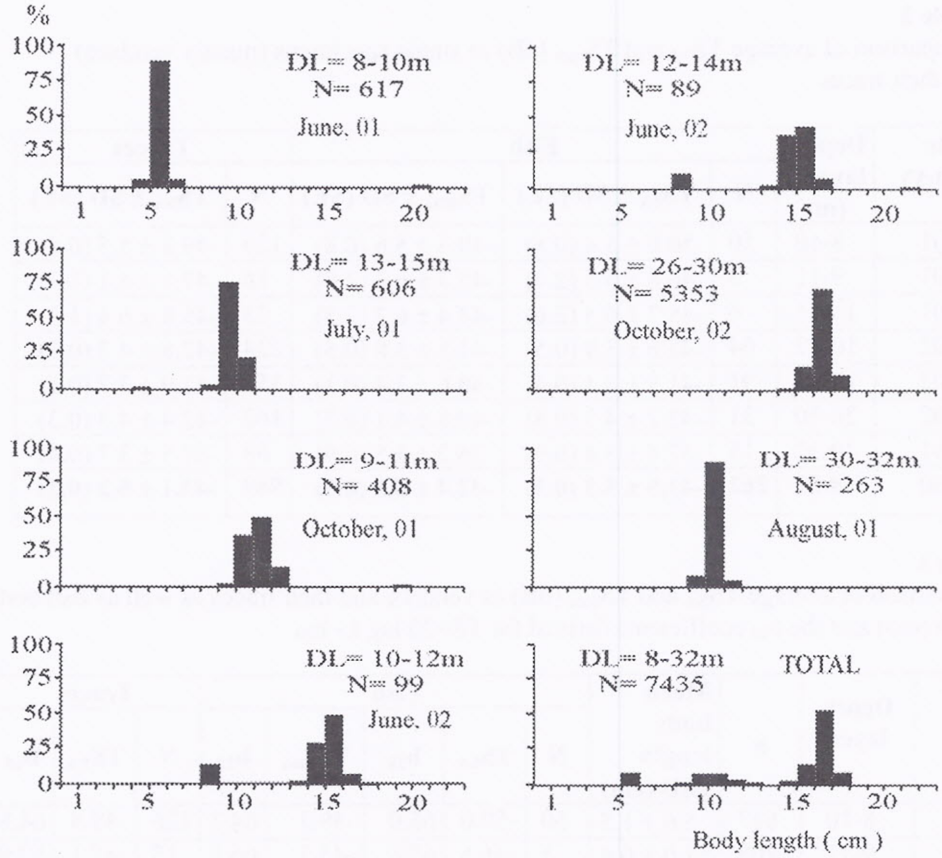

Fig. 2 Structure of control fishing for vendace with a pelagic trawl in different periods and water depth layers (N-numbers, DL-depth layers).

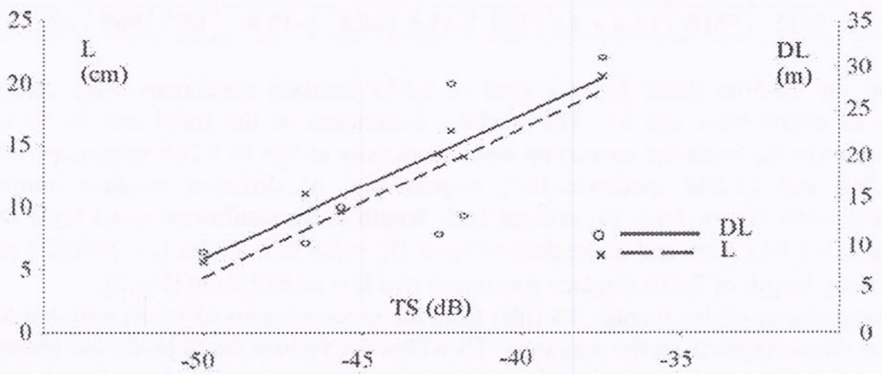

Fig. 3. Dependence of TS (dB) on body length L (cm) and the depth layer DL (m) inhabited by vendace.

the whole set (N=7,510), which was L = 14.6±3.7 cm, the TS values were as follows: $TS_{S.A.}$ = -43.5 dB, TS_{max} = -42.4 dB and TS_{traces} = -43.1 dB (Table 2, 3 and Fig. 3).

In order to describe the dependence of the TS (dB) on vendace body length L (cm), the following widely used formula was applied: TS = a log L – b, or, in its simplified form of TS = 20 log L – b_{20}. Coefficients b_{20} were derived from the data in tables 2 and 3. For the total material collected the regressions were as follows:

$$TS_{SA} = 20 \log L - 66.8 \pm 0.3 \text{ SE}$$
$$TS_{SA\ traces} = 20 \log L - 66.4 \pm 0.2 \text{ SE}$$
$$TS_{max} = 20 \log L - 65.7 \pm 0.3 \text{ SE}$$

The difference between TS_{SA} and TS_{max} is relatively small at 1.1 dB. This may indicate that vendace usually places itself dorsally or that no significant difference between dorsal and side TS occurs. The practical application of the derived dependencies of TS (dB) on L (cm) in determining fish biomass in the aquatic ecosystem requires defining the relationship between the weight and body length of specimens of a given species. The dependence of the type W = a L^n was derived from measurements of over 11,000 vendace specimens caught in 2001 and 2002 in Lake Pluszne and is presented in Figure 4.

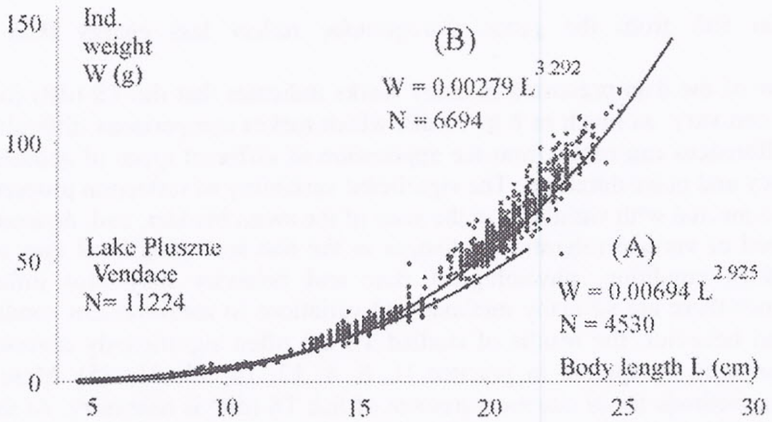

Fig. 4 Dependence of individual weight (W) on body length (L) vendace ($W=aL^n$) caught in Lake Pluszne in 2001-2002.
A - young of year (L= 4.5÷12.5 cm, W= 0.6÷13.3 g)
B - two year old and older (L= 12.5÷25.0 cm, W= 13.5÷122.3 g).

The dependence is described by the equation $W = 0.00499\ L^{3.082}$ which is correct for a given condition of this species. This dependence was derived for the 2001 – 2002 period during which vendace in Lake Pluszne occurred in such high densities that it led to the starvation stage. These estimations are valid for vendace (*Coregonus albula* L.) monitored *in situ* using a Simrad EY-500 split beam echosounder at a frequency of 120 kHz.

Table 4 presents the literature values of coefficients from the formula TS = 20 log L - b_{20} obtained for five species of pelagic, freshwater fish. The b_{20} values obtained for vendace are within the ranges of those obtained for different fish species with different types of echosounders [10, 11, 13, 17, 25]. For example, Peltonen *et al.* [17] obtained a b_{20} = 60.0 – 63.5 coefficient for vendace. Thus, TS was greater, on average, by 3.4 dB than that obtained in the current study and similar to that of smelt. Fleischer *et al.* [6] studied the target strength of the pelagic fish assemblage (smelt, alewives, cisco) in Lake Michigan. The average TS varied from –54.9 to -38.0 dB at an average specimen weight from 2 to 71 g. Fleischer also

Table 4

The comparison of b_{20} coefficients from the TS = 20 log L - b_{20} formula determined *in situ* for selected freshwater fish species by various researchers

Echosounder type	Fish species	b_{20}	Author
single-beam 70kHz	Smelt	68.0	Lindem [11]
dual-beam 120 kHz	Cichlids	67.4	Mac Lennan & Menz [13]
single-beam 70 kHz	Roach	64.4	Guillard & Gerdeaux [10]
split-beam 70 kHz	Alewives	63.6	Warner *et al.* [25]
split-beam 120 kHz	Smelt	65.3 – 67.1	Peltonen *et al.* [17]
split-beam 120 kHz	Vendace	60.0 – 63.5	Peltonen *et al.* [17]

confirmed that fish from the genus *Coregonidae* reflect less energy than do other planktivores.

A review of the data presented in many works indicates that the TS (dB) for fish of a given species can vary as much as 8 to 10 dB, which makes comparisons difficult [1, 6, 14, 25]. These differences can result from the application of different types of acoustic systems (type, frequency and pulse duration). The significant variability of reflection properties of fish may also be connected with variations in the state of the swim bladder, and, depending on the depth and speed of vertical migrations, changes in the fish scattering level may reach even several dB. Fish condition, physiological state and behavior may also influence this variability. Since there are so many methods and variations in measurement conditions, fish physiology and behavior, the results of studied TS are often significantly diverse and thus cannot be compared or applied in practice [1, 6, 8, 12, 14, 15, 21, 25]. More thorough standardization methods for *in situ* measurement of fish TS (dB) is necessary. At the moment for reliable estimation of fish stocks only TS –L relationships received with the same acoustic system and in the same conditions as during biomass evaluation surveys can be used.

4. CONCLUSIONS

- The results of TS (dB) dependence on body length (TS = 20 log L – b_{20}) for vendace *(Coregonus albula L.)* are within the range of the results obtained by other authors.
- The difference between average $TS_{S.A.}$ and TS_{max} was 1.1 dB, that is very low (2.5%). This indicates that either vendace usually swim dorsally, or that there is not much difference in TS values for dorsal and side aspects.
- Both, the TS (dB) and the body length L (cm) of vendace were correlated with the depths inhabited by fish (they increased accordingly with depth).
- *In situ* measurements of TS during summer and fall are not recommended because of too high densities of vendace. They should be conducted in the spring and at night when the fish are most widely dispersed. However, in such conditions control fishing will require much greater effort in order to obtain large enough sample of fish.
- In order to obtain comparable results from various locations and times, it would **be** advisable to standardize the *in situ* methods and measurements of TS (dB).

- For reliable estimation of fish stocks it is recommended that the relationships between the target strength and fish length of a given species are received with the same acoustic system and in the same conditions as later to be performed surveys for monitoring fish resources.

ACKNOWLEDGEMENTS

We would like to thank Mr. L. Doroszczyk, Mr. B. Długoszewski and Mrs. E. Kanigowska from Inland Fisheries Institute for their help in collecting and analysing the data.
The work has been supported by the KBN grant Nr 6 P04F 00720.

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