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

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The subject of the study was vendace Coregonus albula *L. This species is a typical planktivore and inhabits the pelagic zone of Lake Pluszne (area - 903 ha, 51 m - maximum depth) located in northeastern Poland. Acoustic measurements were taken with a Simrad EY-500 type split beam echosounder at a frequency of 120 kHz, with beam divergence of 7x7 degrees and a pulse duration of 0.3 ms. The data were analyzed using the trace tracking method with the EP 500 program and 5696 fish traces. A total of 3092 vendace individuals were caught in various water layers with a pelagic trawl during control fishing. The study involved determining the dependence between the acoustic size of vendace TS in dB, body length L in cm and specimen weight. The measurements were carried out in June and October 2003 under varied environmental conditions that limited spatial distribution, density and the condition of the examined fish. The dependencies of TS (dB) on fish body length L (cm) were determined for the average values of* $TS_{S.A.} = 20 \log L - 65.4 \pm 0.1$ *SE and* $TS_{max} = 20 \log L - 63.8 \pm 0.1$ *SE*

INTRODUCTION

The aims of monitoring the state of fish resources in aquatic ecosystems are to optimize exploitation and to evaluate the quality of the environment. Fish can contribute to the decrease or increase in the eutrophication rate of aquatic ecosystems. Changes in fish assemblages are a good indicator of environmental quality. The biomanipulation of assemblages can be achieved through selective fishing and stocking. In this context, information on juvenile fish concentrations and typical planktivore fish, which play a key role in the matter and energy cycles, are very important. They utilize zooplankton to the greatest degree, which, in turn, play a key role in the elimination of phytoplankton blooms responsible for accelerated eutrophication [15, 16].

Hydroacoustic methods are becoming more and more popular among fish resource monitoring methods, as they allow for the quick evaluation of fish distribution, numbers and size structure. In order to recalculate fish numbers into biomass and acoustic size (dB) into body length (cm), it is necessary to determine the "target strength" TS (dB), i.e., the acoustic properties of the reflecting fish. The target strength depends mainly on length and the anatomical characteristics of a given fish species.

To date, fish resource monitoring in the fresh waters of Poland has been conducted through acoustic-fishing methods. The distribution of fish concentrations and numbers are determined using hydroacoustic methods, while biomass is determined by the fish species composition and specimen weight in control catches [15, 16, 17]. However, control catches of the appropriate magnitude are not always possible or are labor intensive, thus there is a need to be able to directly evaluate biomass based on a previously determined dependence between target strength and fish body length.

The aim of the studies was to estimate *in situ* the TS (dB) of vendace (*Coregonus albula* L.) in pelagic areas of deeper lakes in the northern part of Poland. This data would then be used to derive the dependence between vendace acoustic size (TS in dB) and its body length (L in cm) and specimen weight (W in g) according to the formula $W = a\ L^n$ in lake areas with varied trophy, seasons (June and October), depths of fish occurrence and fish condition.

1. MATERIALS AND STUDY AREA

The measurements focused on vendace *(Coregonus albula L.)*. This species inhabits deeper areas of lakes in northern Poland that have a well-oxygenated hypolimnion. It often occurs with smelt *(Osmerus eperlanus L.)*, a fellow salmonid. This species is a planktivore that feeds exclusively on zooplankton throughout its life. More and more frequently this species is recognized as an environmental quality indicator in the lake eutrophication process. Unlike other lake fish, this species spawns in fall during the period when the water is thermally stable.

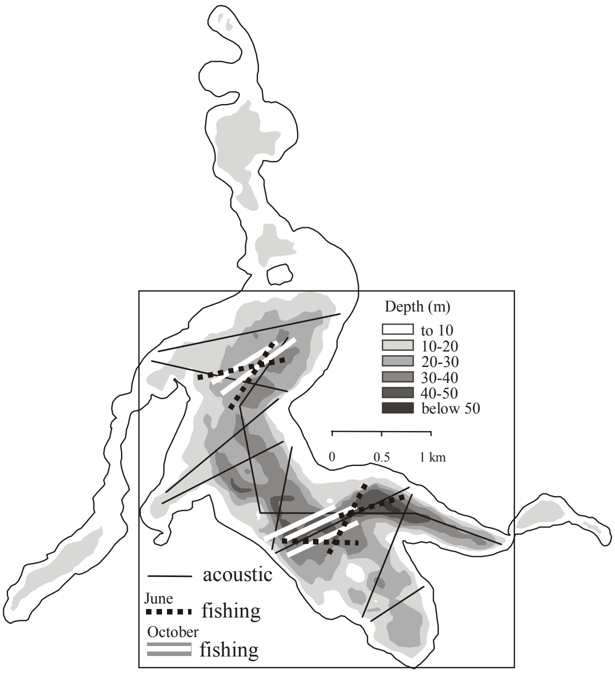

Fig. 1. Bathymetric map and positions of the acoustic and fishing transects in Lake Pluszne.

The studies were conducted in 2003 in the largest (600 ha) and deepest (51 m) area of the Lake Pluszne, which has an area of 903 ha and is located in northeastern Poland (Fig. 1). The lake is mesotrophic, and the current water purity class is II. There are periodic oxygen deficiencies in the deeper hypolimnion areas.

2. METHODS

Since only *in situ* methods are recognized as reliable enough to determine pelagic fish target strength, the *in situ* estimation of vendace target strength was done directly with a split beam (7x7 deg) Simrad EY-500 echosounder. The machine had a frequency of 120 kHz, and the pulse duration was 0.3 ms. Estimating target strength using the split beam method requires extracting echoes from single fish. This method is loaded with the smallest error in estimating target strength and permits determining the actual angular position of the fish [5, 12, 13, 14].

The echosounder was calibrated using copper balls with target strengths of 40.4 dB and according to the lobe calibration program method. The acoustic investigations were done at night when the vendace are most widely dispersed. Measurements were taken along thirteen transects during both study periods - June and October (Fig. 1). The trace tracking data analyses system of the EP 500 program was used to derive the TS (dB) from fish traces which were designated by the system as single targets. There was an average of four traces per fish. The TS (dB) of traces and the average and maximum values of TS for the fish that were designated by the system as single specimens was determined for given samples and depth layers.

Control catches were conducted simultaneously using a pelagic trawl at depths from 4 to 26 m in 4 m water layers. The trawl inlet area was $11m^2$, and water filtration was 850 m^3 min^{-1} at a hauling speed of 77 $m \cdot min^{-1}$. Fourteen hauls were conducted and a total of over 3000 specimens were caught, of which 93.5% were vendace. All of the fish caught were measured (*lt* in cm) and weighed (g). The average body weights and lengths were estimated, including SD and SE.

3. RESULTS AND ANALYSES

The recent years there has been a significant increase in the number of vendace in Lake Pulszne, and this species has displaced smelt (*Osmerus eperlanus* L.) in their food niche. Vendace constituted 95.1% of control catches in 2001 and 2002 (19). The creation of a virtually single-species population that inhabits the pelagic zone was advantageous for *in situ* measurements of TS. Target strength fluctuations among a single species can depend on many factors. These include the physiological state of the fish, digestive tract content and gonad developmental stage, depth of occurrence, alignment of the fish in the acoustic beam (dorsal or pectoral aspect), and echosounder frequency [6, 8, 9, 10, 13, 14, 17].

The TS (dB) of 5696 traces that corresponded to 1426 fish inhabiting four different depth layers were analyzed. On average, there were four traces per fish specimen. The data were obtained from 18000 echosounder pings. The average TS (dB) value was calculated from fish and their traces at different depth layers including SD and SE. The results of these calculations are presented in Table 1.

In order to obtain the average body lengths of vendace that inhabit various water layers in June and October, ten hauls were selected that were made at the same locations and times as the acoustic measurements. A total of 3092 fish from five water depths from 4 to 26 m were analyzed (Table 2).

Tab. 1. Comparison of average $TS_{S.A.}$ (dB) of single specimens (mainly vendace) and their traces

Body of water	Depth layer (m)	Fish		Traces	
		N	T_{SA}±SD (SE)	N	$T_{S.A.}$±SD (SE)
June					
South	4- 8	32	-38.4 ± 2.6 (0.5)	97	-38.8 ± 3.4 (0.3)
	10-14	242	-39.4 ± 4.6 (0.3)	874	-39.7 ± 5.0 (0.2)
	18-22	136	-42.1 ± 5.7 (0.5)	675	-42.4 ± 6.1 (0.2)
North	10-14	256	-40.4 ± 4.7 (0.3)	987	-40.9 ± 5.3 (0.2)
	10-14	122	-38.5 ± 3.7 (0.3)	407	-39.1 ± 4.7 (0.2)
Total	4-22	788	-40.0 ± 4.8 (0.2)	3040	-40.6 ± 5.4 0.1)
October					
South	14-18	257	-42.8 ± 4.2 (0.3)	971	-43.1 ± 4.6 (0.1)
	22-26	270	-42.7 ± 3.9 (0.2)	1224	-43.0 ± 4.2 (0.1)
North	12-16	111	-43.9 ± 4.0 (0.4)	461	-44.4 ± 4.6 (0.2)
Total	4-22	638	-42.9 ± 4.1 (0.2)	2656	-43.3 ± 4.5 (0.1)
Total June and October					
Total	4-22	1426	-41.3 ± 4.7 (0.1)	5696	-41.8 ± 5.1 (0.1)

Tab. 2. Details of control fishing for vendace using pelagic trawl in Lake Pluszne in June and October 2003 (N – total fish numbers, P – vendace portion)

Body of water and depth of fishing layer (m)	Tow No	Time (min.)		CPUE ($ind \cdot min^{-1}$)	P %	Mean body lenght ±SD (cm)	Mean ind. weight±SD (g)
South				**June**			
4-8	1	6	37	6.2	80.4	13.5 ± 1.1	17.0 ± 4.4
10-14	2	6	214	35.7	98.2	15.2 ± 1.4	23.3 ± 5.8
18-22	3	6	147	24.5	99.3	16.0 ± 2.0	28.3 ± 12.5
North							
4-8	4	6	3	0.5	21.4	13.7 ± 1.3	19.1 ± 5.5
10-14	5	5	220	44.0	95.2	15.8 ± 1.3	26.1 ± 13.1
South				October			
4-8	3	6	-	-	-	-	-
14-18	4	6	1589	264.8	99.6	16.3 ± 1.4	26.4 ± 9.1
22-26	5	6	719	119.8	98.2	16.2 ± 1.0	24.6 ± 5.1
North							
4-8	1	6	-	-	-	-	-
12-16	2	6	166	27.7	89.2	16.6 ± 1.3	27.2 ± 7.7

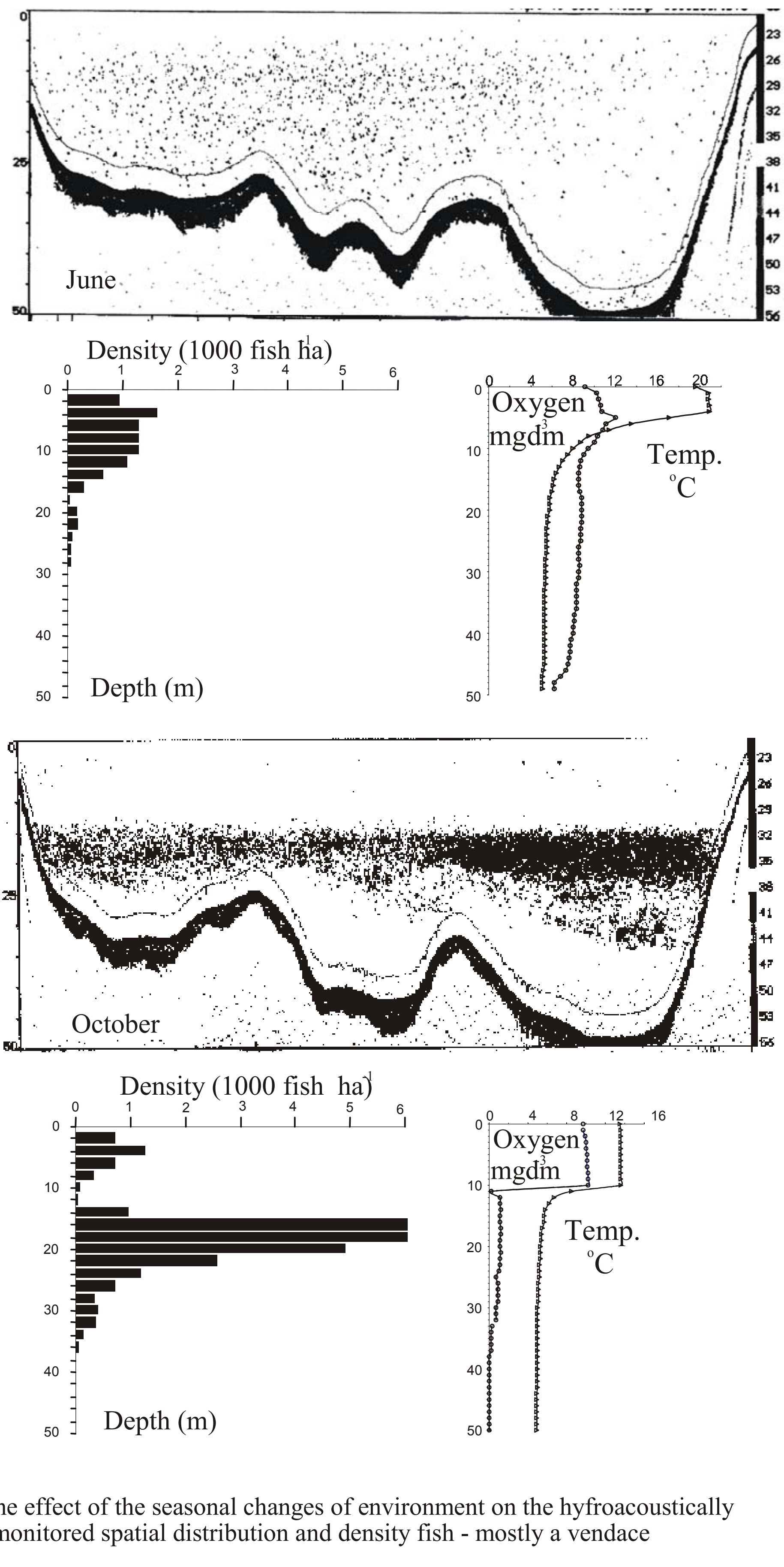

Fig. 2. The effect of the seasonal changes of environment on the hyfroacoustically monitored spatial distribution and density fish - mostly a vendace

One haul made at a depth of 14-18 m yielded 1589 vendace during six minutes. Given the trawl working parameters and its estimated efficiency of 80% to 50%, fish concentration was high at between 387 to 620 fish·1000 m^{-3} and from 15.5 to 24.8 thousand fish·ha^{-1}, respectively. With different vendace numbers in subsequent depth layers (DL), the average length of fish in the shallowest depth layer (DL = 4-8 m) was L = 13.5±1.1 cm, and in the deepest layer (DL = 22-26 m) it was L = 16.2±1.0 cm. The average body length for 3092 vendace specimens was L = 16.0±1.3 cm (Table 2, Fig. 2).

The average TS (dB) values for traces and fish, and the average, maximum TS values of fish in various water layers are presented in Tables 1 and 3. The data show that the average vendace body length increased from 13.5 to 16.6 cm as catch depth increased from 4 to 26 m. This corresponds to a decrease in the average values of TS_{SA} from –38.4 to –43.9 dB. For the average vendace body length from the entire set (N=3092) - L = 16.0 cm, the respective values of TS were as follows: $TS_{S.A.}$ = -41.3 dB, TS_{max} = -39.8 dB (Tables 1, 3 and Figure 3).

In order to express the dependence of TS (dB) on body length L (cm) of vendace, the widely used, simplified formula TS = 20 log L – b_{20} was applied (7, 8, 9, 12, 15). Using data from Table 3, the b_{20} coefficients were calculated and are as follows for the entirety of the material collected:

$$TS_{SA} = 20 \log L - 65.4 \pm 0.1 \text{ SE} \qquad TS_{max} = 20 \log L - 63.8 \pm 0.1 \text{ SE}$$

The difference between TS_{SA} and TS_{max} is relatively small at 1.6 dB. This might indicate that vendace usually assumes a position corresponding to the dorsal aspect, or that with this species the difference between the TS of the dorsal and pectoral aspects is insignificant. In order to use the TS (dB) dependence on L (cm) to determine fish biomass in an aquatic ecosystem, the relation between the individual weight and body length of a given species has to be determined. The dependency $W = a L^n$ was determined based on a total of 1959 vendace specimens caught in June and October 2003 in Lake Pluszne; the results are presented in Figure 4. The dependence derived can be described by the formula $W = 0.01192 L^{2.634}$ for the June and $W = 0.01677 L^{2.634}$ for the October populations of vendace and indicates the condition of fish of a given species in both of the study periods. Based on data from studies conducted in the same lake in 2001 and 2002, parameter b_{20} for $TS_{S.A.}$ was – 66.8 ± 0.3 SE and for TS_{max} it was –65.7 ± 0.3 SE. The b_{20} parameters obtained for that year are higher by 1.4 for $TS_{S.A.}$ and 1.9 dB for TS_{max} (19).

The data presented in figures 3 and 4 indicate that there are significant differences in the TS (dB) dependence on body length L (cm) and individual weight W (g) in the June and October vendace populations. The reason for this is limited areas of occurrence and feeding in October that were caused by oxygen depletion in the hypolimnion. This meant that the vendace were in better condition in June, as was confirmed by studies on zooplankton aggregations (Świerzowski and Tunowski, unpublished data) and the contents of vendace digestive tracts (Świerzowski and Żbik, unpublished data). Determining the dependence of TS (dB) on average fish body length L (cm) such as TS = 20 log L – b_{20} may be insufficient and should be supplemented by a dependence such as TS = a log W – b (where W denotes individual weight) or by the dependence $W = a L^n$.

In comparison, Peltonen et al. [17] derived a b_{20} parameter of 60.0 – 63.5 for vendace. The TS was greater than that obtained in the current work by an average of 1.9 dB, and was similar to that derived for smelt. In their study of the target strength of pelagic fish assemblages (smelt, alewives, cisco) in Lake Michigan at an average individual weight of 2 to 71 g, Fleischer et al. [6] obtained average TS values ranging from –54.9 to –38.0 dB. They confirmed that fish of genus *Coregonidae* reflect less energy than other planktivore species do.

Tab. 3. Comparison of average $TS_{S.A.}$ and TS_{max} (dB) of vendace as well as fish body lenght (cm) and the b_{20} coefficients derived for TS = 20 log L – b_{20} (N – fish numbers)

Body of water	**Fishing**				**Acoustics**				
	Depth layer (m)	N	**Mean body lenght (cm)**	**Mean ind. weight (g)**	N	**TS_{SA}**	**b_{20}**	**TS_{max}**	**b_{20}**
June									
South	4-8	37	13.5	17.0	32	-38.4	61.0	-37.0	59.6
	10-14	214	15.2	23.3	242	-39.4	63.0	-38.1	61.7
	18-22	147	16.0	28.3	136	-42.1	66.2	-40.4	64.5
North	10-14	220	15.8	26.1	256	-40.4	64.4	-38.9	62.9
Total	4-22	618	15.5	25.1	666	-40.0	63.8	38.5	62.3
October									
South	14-18	1589	16.3	26.4	257	-42.8	67.0	-41.3	65.5
	22-26	719	16.2	24.6	270	-42.7	69.9	-41.3	65.5
North	12-16	166	16.6	27.2	111	-43.9	68.3	-42.3	66.7
Total	4-26	2474	16.3	25.5	638	-42.9	67.1	-41.4	65.6
Total June and October									
Total	4-26	3092	16.0	25.4	1304	-41.3	65.4	-39.8	63.9

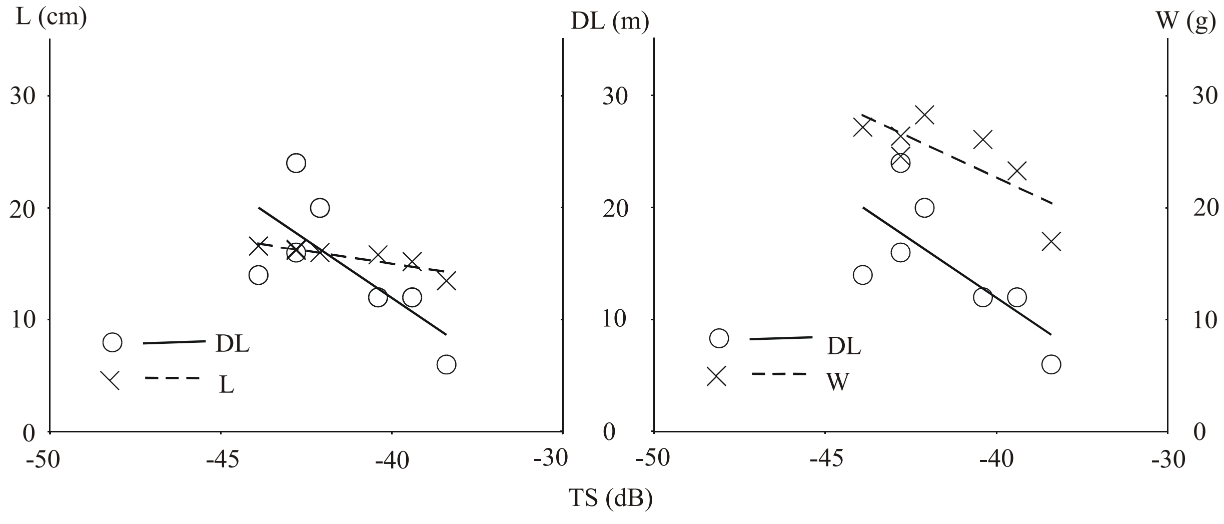

Fig.3 Dependence of TS (dB) in body lenght L (cm) or individual weight W (g) and the depth layer DL (m) inhabited by vendace.

A review of numerous publications indicated that there is significant diversity in TS (dB) values for fish of a given species, which results from the application of different acoustic systems (type, pulse frequency and duration).

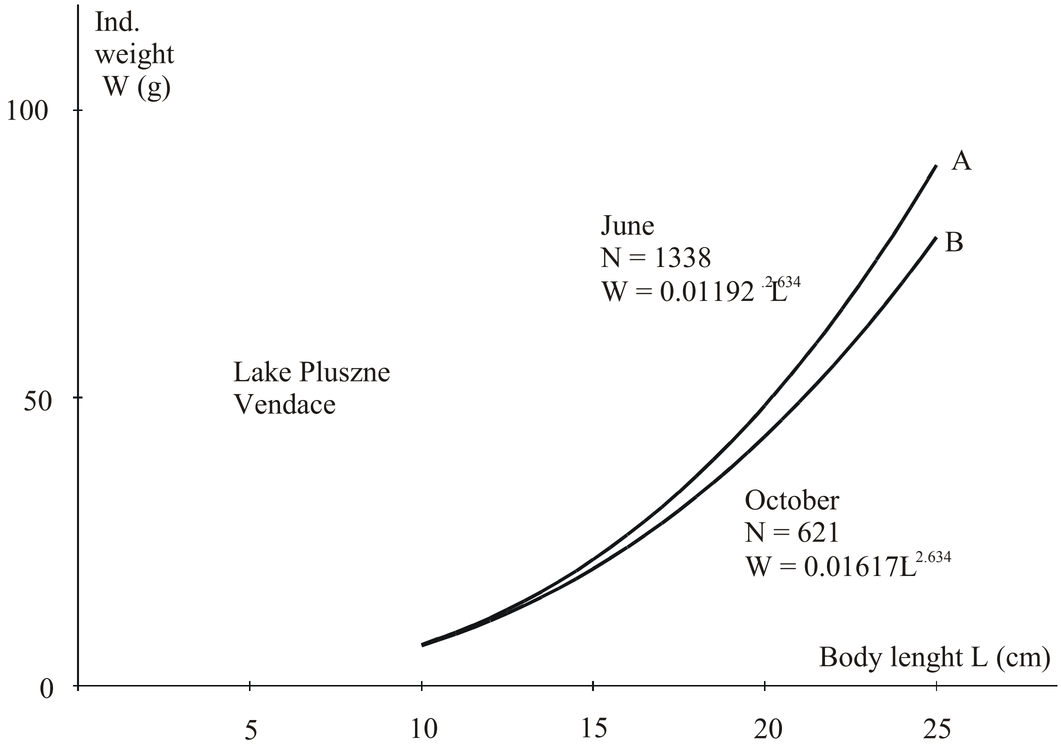

Fig. 4. Dependence of individual weight (W) on body lenght (L) vendace ($W = a \cdot L^n$) caught in Lake Pluszne in June (A) and October (B) 2003.

One significant factor in the variability of the reflective properties of fish is change in the swim bladder depending on depth and the speed
of vertical migrations. Fish condition, physiological state, and behavior also play important roles. With such a significant variety of methods and measurement conditions and the physiological and behavioral aspects of the fish, the results of the studied TS values are diverse, often significantly so, and cannot be compared or used in practice [1, 4, 6, 8, 9, 10, 14, 18]. Therefore, further standardization of the methods of *in situ* measurements of fish TS (dB) is necessary. These measurements should comply with methodological guidelines in a given location and be done with the same acoustic system that will be used for the acoustic evaluation of fish resources, especially biomass.

4. CONCLUSIONS

- The results of the TS (dB) measurements for vendace *(Coregonus albula L.)* and the dependence of this factor on fish length $TS_{S.A.} = 20 \log L - 65.4 \pm 0.1$ SE and $TS_{max} = 20 \log L - 63.8 \pm 0.1$ SE are within the range of the results obtained by other authors.
- The differences in the average $TS_{S.A.}$ and TS_{max} was 1.6 dB and was relatively small. This either means that vendace swims primarily in the dorsal aspect, or that differences in TS between the dorsal and pectoral positions are very small or non-existent.
- The dependency of TS (dB) on body length L (cm) for vendace were negatively correlated with the depth of occurrence in the lake DL (m), and to a greater and clearer extent with individual weight W (g).
- Due to diverse environmental conditions in the reservoir that even occurred in the same season, and that influenced fish condition, it was not only necessary to derive the $TS = a \log L - b$ type of dependency, but also the $TS = a \log W - b$ or $W = a L^n$ types.

- It is still recommended that attempts be made to standardize methods and measurements of TS (dB) *in situ* in order to be able to compare data.
- Until such time, the most appropriate approach will be to use the dependence of target strength on body length and individual weight of a given species, which is derived using the same method and acoustic system under the same conditions as those which will be used for further monitoring of fish resources, mainly biomass.

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