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Acoustical estimates of fish and zooplankton distribution in the Piaseczno reservoir, Southern Poland

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Abstract

Hydroacoustical surveys in the Piaseczno reservoir were performed in May and September 2002 using a Biosonics 101 dual beam echo sounder. They have revealed very scarce fish populations in pelagic waters with twice-higher abundance in autumn (530 fish ha^{-1}) as compared with spring (280 fish ha^{-1}). Small and very small fish (below 10 cm length) dominated. Apart from fish, *Chaoborus* larvae were producing acoustical echoes of the TS similar or slightly weaker than that of small fish. Invertebrates formed a thin layer, less than 2 m thick at the border of an anoxic zone, and were changing their depth position between 6 and 16 m, both diurnally and seasonally.

Introduction

During recent decades in many countries (Poland, Germany, Ukraine) in places where there were opencast mines in order to eliminate ecologically negative consequences of the extractive industry artificial lakes have been created for a purpose of recreation and fish sports. These flooded opencast mines, especially after sulphur exploitation are unique in the world and as yet very little studied (Zozula and Gaydin 2000; Żurek 2002). Although they look like natural lakes, their ecological features, chemical composition of water, morphology of basin, species composition often differ significantly from those observed in natural lake ecosystems.

Lake Piaseczno is an example of such a large, deep, anthropogenic opencast lake with very specific environmental conditions. Complex hydrochemical and hydrobiological studies of the Piaseczno reservoir were carried out during 2000–2003 on the monthly basis. They included water chemistry (Frankiewicz and Pucek 2006, Żurek 2006a), microbial activity (Mazurkiewicz and Bednarz 2004), sediments (Szarek-Gwiazda et al. 2006), phyto- and zooplankton (Bucka and Wilk-Woźniak 2006; Żurek 2006b), benthic fauna (Dumnicka and Galas 2006), and fish (Amirowicz 2004). These studies have shown that hard waters of strong salinity, high concentration of sulphur hydrogen near bottom and toxic effects of heavy metals create very specific conditions, which are unfavorable for biological life. Phytoplankton, zooplankton and fish were very scarce, both in terms of abundance and of number of species. Also the benthic fauna in lake

Piaseczno was very poor. Unusual ecological feature of the Piaseczno is that it is a meromictic water body in which high density of water due to high solute concentration prevents mixing of the bottom strata. One of the important effects of such water mass dynamics is the permanent lack of dissolved oxygen in the water layer deeper than about 12 m, i.e. in a half of the whole water column. From a biological point of view it is interesting if zooplankton or fish can incidentally penetrate this anoxic zone, and which part of the reservoir space may offer to them the appropriate habitat conditions. Such data of spatial distribution are very difficult to obtain using traditional biological methods, therefore hydroacoustical methods were applied. Hydroacoustics is increasingly used in freshwater lakes for measuring abundance and distribution of open-water fish populations (for review of acoustical applications in fisheries research, see McLennan and Simmonds 1992). Unquestionable advantage of hydroacoustics over traditional fishery methods is its high speed which greatly improves the ability to sample fish on a lake-wide scale and allows to study dynamic changes in fish distributions, such as swarming behavior, diurnal horizontal and vertical migrations, etc. (Freon et al. 1996; Marchal and Lebourges 1996; Steig and Johnston 1996; Comeau and Boisclair 1998; Guillard 1998). Its disadvantages are due to difficulties close to lake surface and bottom and inability to distinguish between species and sometimes even between the fish and other objects such as invertebrates, air bubbles or aquatic macrophytes (Kubecka et al. 1993; Trevorrow and Tanaka 1997; Nealson and Gregory 2000; Trevorrow 2000; Rudstam et al. 2002). If accompanied by control catches, hydroacoustical methods provide a very useful tool, which considerably expands the amount and precision of the information on underwater life, and often enables to detect the organisms that are overlooked by traditional methods.

The aim of this large, lasting 3 years project was to study the functioning of this peculiar, anthropogenic, opencast lake, Piaseczno. The aim of this paper, being only a part of a complex study, was to investigate the spatial structure of fish and zooplankton distribution using hydroacoustics.

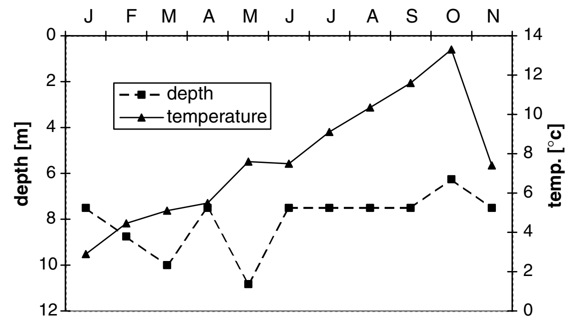

Figure 1. Depth of oxygen concentrations below 2 mg l^{-1} and corresponding temperatures in lake Piaseczno throughout the year.

Materials and methods

Study area

Piaseczno is an artificial lake created in 1971 by inundation of a deep sulphur opencast mine. It is located near the city of Tarnobrzeg in south-eastern Poland, an area that is poor in natural standing freshwater habitats. This is why restoration of these post-exploitation areas by forming an artificial recreation lake is so important.

The total area of Piaseczno reservoir at present is 63 ha with plans to expand it up to 163 ha, and maximum depth at present is 21 m. It is an oligotrophic reservoir with transparency between 1.3 and 5.9 m, and very poor benthos and fish communities. This poverty of biological life is probably due to the presence of hydrogen sulfide and complete lack of oxygen in deeper layers. In 2001 all the environmental parameters of the Piaseczno reservoir were measured on a monthly basis (Żurek 2006a). From the oxygen concentration distributions (Figure 1) it is clear that the depths below 12 m are unsuitable for fish throughout the year. During summer the reservoir is stratified, with a strong thermocline at depths between 2 and 6 m (Figure 2), which leads to further limitation of the different fish habitats.

Hydroacoustical survey

A scientific echo sounder Biosonics 101 was used to record echo-signals from single fish along selected transects (Figure 3). The working parameters of

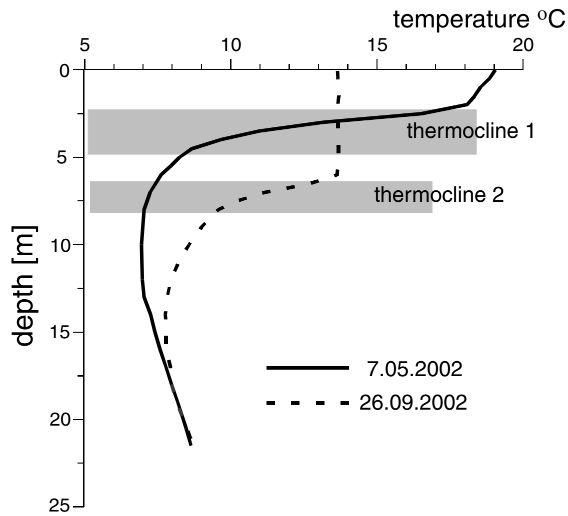

Figure 2. Temperature distribution during acoustical surveys.

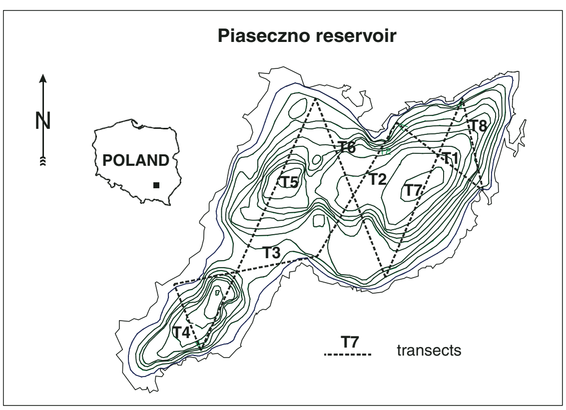

Figure 3. Bathymetry of the Piaseczno reservoir and positions of hydroacoustical transects.

Table 1. Parameters of the acoustical system (Biosonics 101 dual beam echo sounder) for data collection and analysis.

Operating frequency	420 kHz
Nominal 3 dB narrow beam	6°
Nominal 3 dB wide beam	15°
Pulse duration	0.4 msec
Pulse repetition rate	5 Hz
Threshold for TS	−61 dB
Max. half angle for processing targets	3 dB
Beam pattern factor >0 threshold	6 dB
Single echo detection criteria:	
Min. returned pulse width	0.6 *pulse duration
Max. returned pulse width	1.8 *pulse duration

the system and data acquisition are summarized in Table 1. Hydroacoustical surveys were performed during springtime, on 6 May 2002, and early autumn, on 22 September 2002. Measurements were done at night, when fish are dispersed mainly in the pelagic zone, and for comparison also during daytime. Before each 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).

Fish and zooplankton catchments

To identify fish species and sizes sets of nonselective gill nets were used. Control fish catches were performed in July 2002, September 2002 and April 2003. The sampling was done by a pelagic nonselective set of gill nets of nine different mesh sizes (11–60 mm knot to knot). The nets (2 m deep) were set for 12 h (day, night) within two depth zones: 0–2 m depth and 4–6 m depth. Catch per unit effort (CPUE) was calculated as the number of fish per 1000 m^2 net area per 12 h. This is used as CPUE throughout this paper.

Zooplankton and phytoplankton samples were collected in monthly intervals from February 2000 to February 2002. Water taken by 5 l bathometer on 0; 2.5; 5.0; 7.5; 10.0; 15.0 and 20.0 m levels was filtered by planktonic net # 50 μm. Usually 50 l of water was filtered. Additional samples were taken simultaneously with the acoustical measurements.

Results

Both, extraordinary water composition and meromictic mixing pattern are of great importance for the distribution of all biota existing in the lake. Depending on the season the appropriate conditions for fishes occur only in a surface layer down to the depth of 5–12 m. The fish community of the Piaseczno reservoir consists of 10 species of which the most abundant is roach *Rutilus rutilus* (L.). Only five species have relatively important position. They are, apart of roach, white bream *Abramis bjoerkna* (L.), rudd *Scardinius erythrophthalmus* (L.), bleak, and perch *Perca fluviatilis* L. As the sixth one may be considered pike, *Esox lucius* L. Remaining species (i.e. goldfish *Carassius*

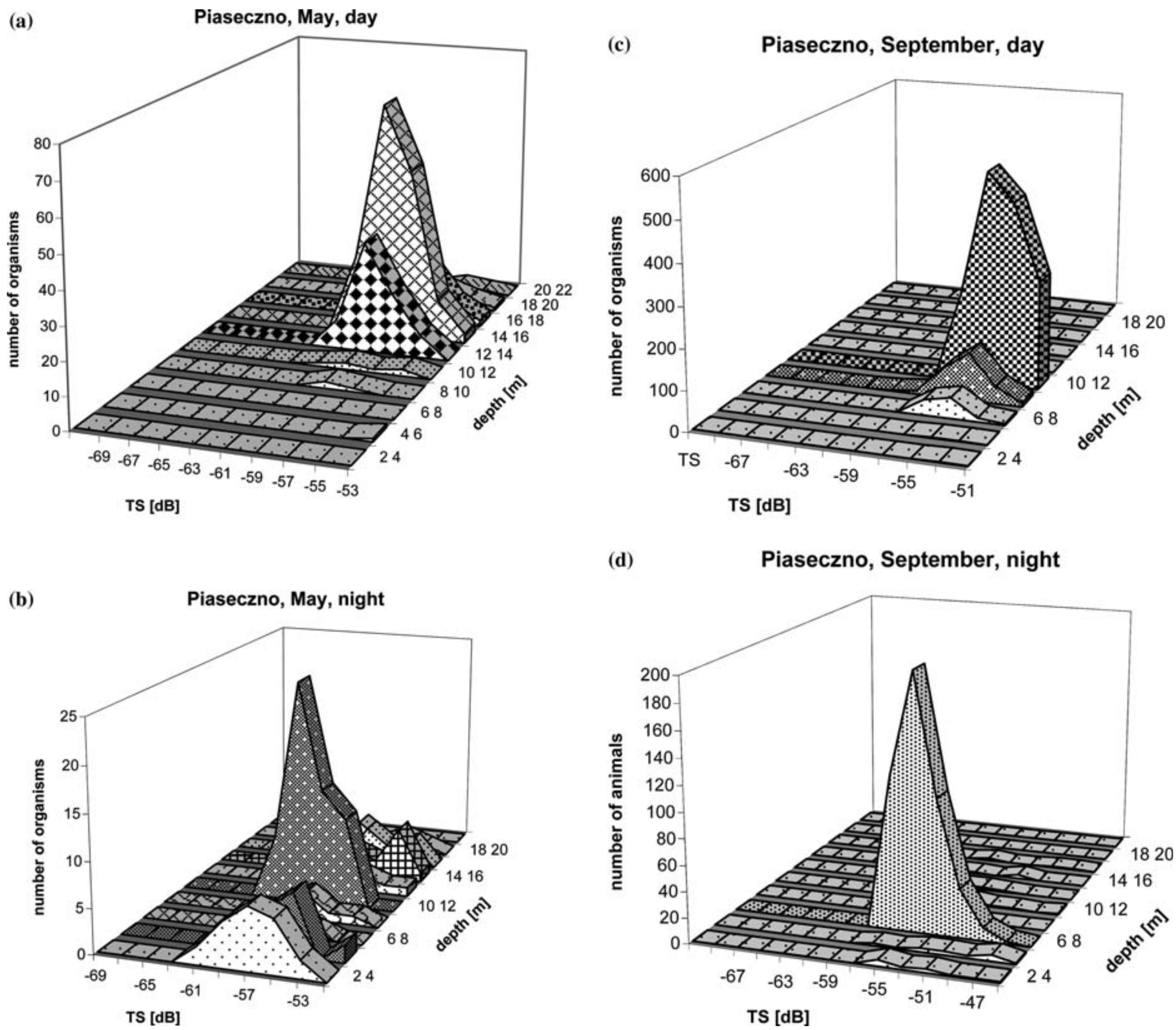

Figure 4. Depth-size distributions of non-fish acoustical targets.

auratus gibelio (L.), chub *Leuciscus cephalus* (L.), dace *L. leuciscus* (L.) and ruffe *Gymnocephalus cernuus* (L.)) are rare in Piaseczno despite that they are common and abundant in Polish inland waters (Amirowicz 2004).

Two categories of acoustical targets were present in the water column. The most frequent type formed a thin layer at the depth corresponding roughly to the lowest limit of oxygen concentration (Żurek 2006a). During spring these targets occupied the depths between 13 and 15 m (mean 14.2 ± 0.9) during the day, and between 10 and 12 m (mean 11.3 ± 0.7) at night (Figure 4). In autumn the layer moved up, with majority of the targets being found at depths 9–11 m (mean 10.1 ± 0.6) during the day, and 6–7 m (mean 6.5 ± 0.3) at night. The objects present in this layer were comparatively weak sound scatterers, with the target strengths peaking at −59 dB in spring and −55 dB in autumn (Figure 5), and thus showing an increase in size of 4 dB, which corresponds to 1.6 times. Also the number of targets has increased considerably between May and September. Their mean day density for spring and autumn was 1322 ind/ha and 2560 ind/ha accordingly (Table 2). The distribution of targets on 8 transects was highly variable, and showed large differences between day and night (Figure 6). From the vertical distribution of the targets (Figure 7) it was evident that some of them were migrating

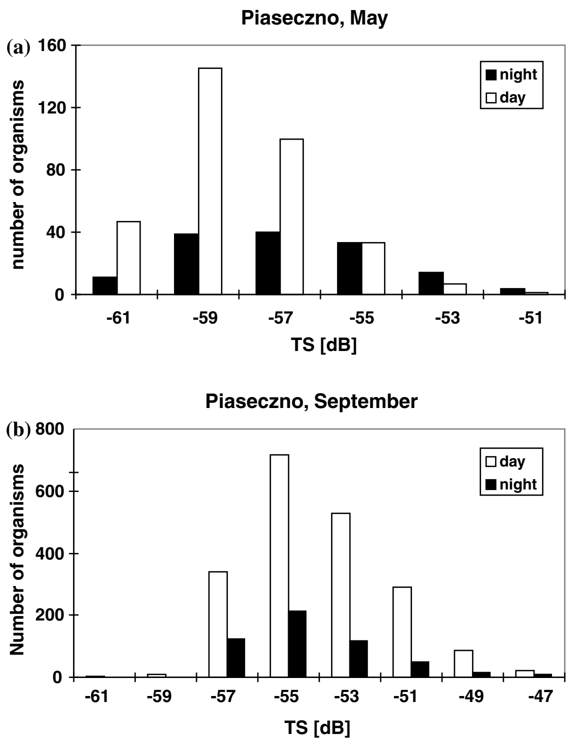

Figure 5. TS distributions of non-fish targets in May and September.

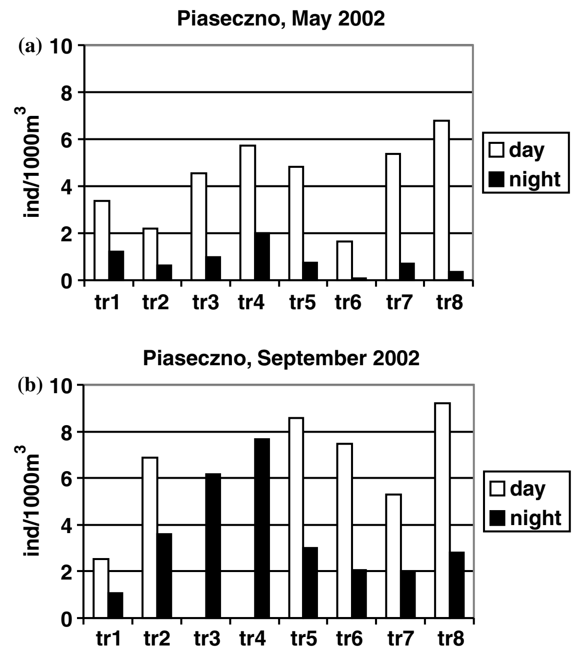

Figure 6. Horizontal distribution of non-fish targets along transects in May and September.

towards the surface at night. The targets that are distributed shallower than 2–3 m depth are poorly registered by the echo sounder due to the depth of the transducer mounting, its dead zone, and very small sampling volume at short distances. Thus, the migration of the targets towards the surface at night might have led to underestimation of their abundance and to observed higher abundance during the day than at night. Acoustics alone is not capable to determine what acoustical targets are made of. The fact, that they were migrating within a diurnal circle, suggests that they must have a biological origin, however the depths of their occurrence (anoxic zone) exclude the possibility that they were fish. The only species encountered in biological samples (Żurek 2006b) that are known to reflect sound were *Chaoborus* larvae (Eckmann 1998), so probably this thin layer was made of them. The studies of bottom fauna of lake Piaseczno (Dumnicka and Galas 2006) have shown that *Chaoborus flavicans* was abundant beginning from the 5 m station and its highest share was found at 10 m (57% of the total benthic

Table 2. Acoustically estimated parameters of fish and zooplankton.

Parameter	Fish				Zooplankton			
	May		September		May		September	
	Day	Night	Day	Night	Day	Night	Day	Night
ρ[ind/ha]	96	280	214	530	1322	204	2560	1058
N total (fish + zoopl.)	2452	933	8422	1763	2452	933	8422	1763
N accepted	7	34	19	57	337	150	2013	540
TS logarithmic mean	−51.24	−54.79	−47.35	−49.14	−57.97	−56.26	−53.77	−53.90
TS arithmetic mean	−40.56	−50.83	−42.57	−42.29	−54.56	−53.40	−52.49	−50.05
SD (of TS in dB)	9.33	4.49	6.32	6.18	2.42	3.58	2.47	3.23

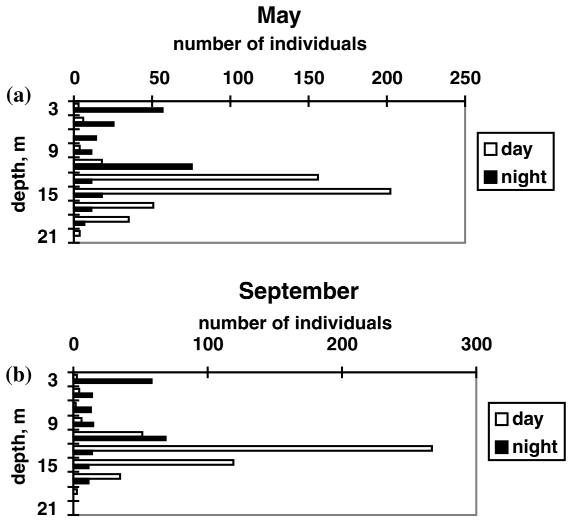

Figure 7. Vertical distribution of non-fish targets.

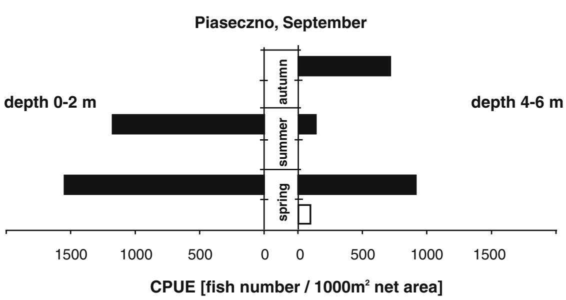

Figure 8. Fish distribution in layers 0–2 m and 4–6 m from gill nets in spring, summer and autumn.

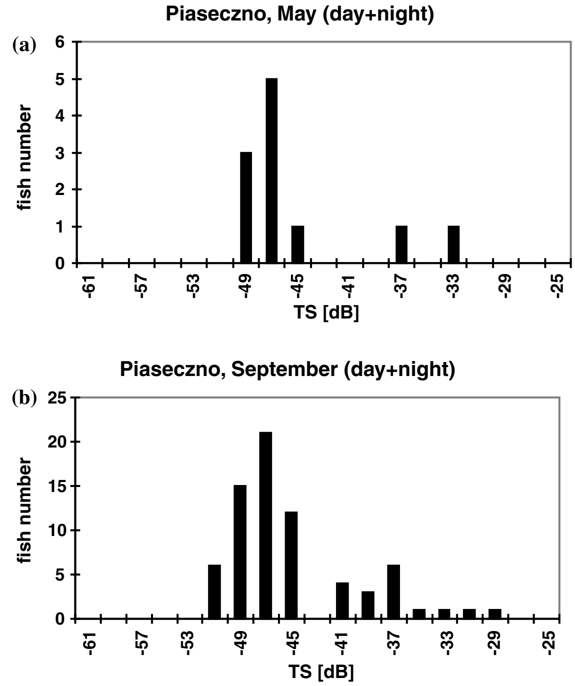

Figure 9. TS distributions of fish in May and September.

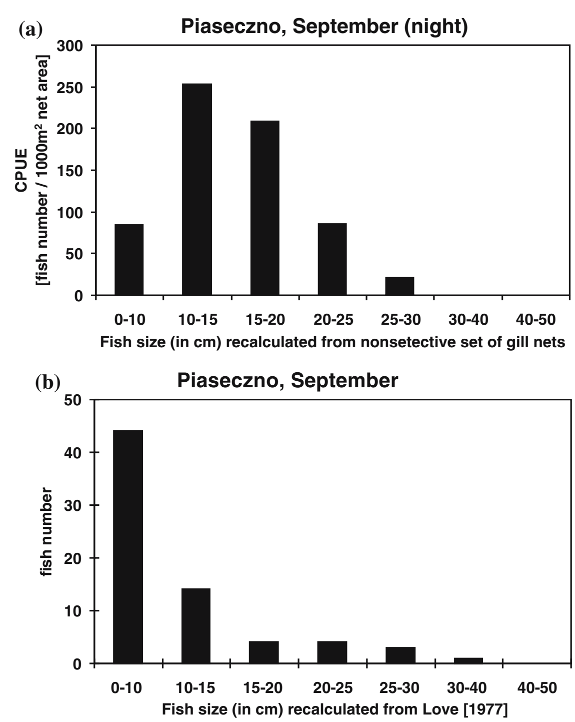

Figure 10. Fish size distribution from nets, and estimated acoustically (recalculated to cm using Love's equation [1977]).

community). It was abundant and frequent also in the pelagial of the lake. During the day *Chaoborus flavicans* concentrated at the top of the anoxic and aphotic layer, using it as a place of shelter (Figure 6 in 2005).

Among the second group of targets much stronger scatterers of sound were present, they varied highly in size and were distributed randomly in the water column down to circa 10 m. There is no doubt that this category consisted of fish. The number of fish registered acoustically was too small for analysis in division by transects or different depth layers (Table 2). The depth distribution from net catches (Figure 8) shows that during spring and summer fish preferably occupied depths 0–2 m, while in autumn they were found exclusively in a deeper layer of 4–6 m. The distribution of fish sizes estimated acoustically was similar in two observed periods (Figures 9a, b), so only data for autumn, which were more numerous are compared with those from gill nets (Figures 10a, b). The smallest fish and the largest non-fish objects had the same range of TS values, and it was not possible to distinguish between them acoustically. Therefore, we assumed that these targets with TS below −50 dB, which were situated at the depth of the layer, belong to invertebrates and those located elsewhere belong to small fish. While doing this, one cannot exclude the possibility of mistaken allocation of the targets. The error will influence much more seriously fish than zooplankton, as fish targets made only a small percentage of all echoes. Comparison of fish size distributions from catches (Figure 10a) and estimated acoustically (Figure 10b) suggests that this wrong allocation could have occurred in this study, under assumption however, that selective gill nets properly reflect fish size distribution in the whole range of sizes.

Discussion

When performing hydroacoustical surveys investigators have to choose a lower threshold for the size of targets to be included in the estimation. Their choice determines the smallest size of fish that is measured and greatly influences the fish density estimates. This threshold is usually set somewhere between −60 and −50 dB (Burczyński and Johnson 1986; Jurvelius and Sammalkorpi 1995; Świerzowski and Godlewska 2003), where the lower value corresponds roughly to the marginal length for distinguishing between two main categories of acoustical targets – 'fish' and 'invertebrates' (Prchalova et al. 2003). However target strength depends not only on fish size but also on species and the frequency of sound. Therefore in every specific situation the same threshold may correspond to slightly different size of fish. The most widely used equation relating target strength to fish size is one of Love (1977), TS [dB] = 19.4 Log (L [cm]) −0.9 Log (f [kHz]) −63.7, that has been received for a wide range of fish species and sound frequencies. According to this equation (at frequency 420 kHz that was used in this study) the −59 and −55 dB peaks observed in spring and autumn correspond to fish sizes of 23 and 37 mm accordingly. It is hardly possible that such small fish concentrated at large depths, where is low temperature and oxygen concentrations are very low (Figure 1). It seems much more probable that the echoes with target strengths between −61 and −50 dB belong to some invertebrates having the gas inclusions that reflect sound (Kubecka et al. 2000). Although the simultaneous direct sampling did not reveal any enhanced concentrations of *Chaoborus flavicans* corresponding to depths where acoustical targets were observed, it can not be excluded that the bathometer taking samples from discrete depths had never hit the layer, which was less than 2 m thick. In spite of lack of direct proof of the origin of acoustical targets we assume that since *Chaoborus* was present in both, the benthic and pelagic samples, and it is known to be a good scatterer of sound with small oxygen requirements, the echoes reflected from targets within an anoxic layer must have originated from *Chaoborus*. The values −59, −55 dB seem a bit high for *Chaoborus*, for which lower values were reported (Prchalova et al. 2003), but there are no literature data on *Chaoborus* target strength at 420 kHz to compare with. Jones and Xie (1994) observed that the target strength of *Chaoborus* is a function of frequency, and at 200 kHz it is −64.15 dB.

There is no doubt that the objects with the high target strengths (above −50 dB) are fish. The data available from both, acoustics and nets lead to the same conclusion, that fish densities were very low. In the pelagic zone of the reservoir fish densities were 280 fish ha^{-1} in spring and 530 fish ha^{-1} in autumn (Table 2). Nearly doubled fish abundance in September as compared with May can result from seasonal horizontal and vertical migrations of fish from the littoral zone at the beginning of the season to larger depths in the open water later in the season. Such changes in fish distribution are suggested also by results of net catches. Amirowicz (2004), who put gill nets in the surface layer (0–2.5 m) in both littoral and pelagic zones, has caught 116 fish in May and only 22 fish in September. In both cases over 80% of all fish were caught in the littoral zone. Perhaps crucial for the concentration of fish in the littoral is the quantity and quality of food resources in the inshore habitats, i.e. littoral zooplankton, invertebrates inhabiting aquatic vegetation, and benthic macro fauna. Taking into account that the profundal is inaccessible for fish due to anoxia, the only food categories available to non-predatory fish in the offshore zone of a water body are *Chaoborus*, scarce filtrating zooplankton and insect imagines falling down on the water surface. This makes food resources in the pelagial much more limited as compared with the littoral area. In the Piaseczno reservoir with relatively poor food resources the *Chaoborus* can be a very important resource supporting fish fauna.

Vertical distribution of fish received on the basis of catches in gill nets (Figure 8) showed that during spring and summer fish preferably occupied depths of 0–2 m, while in autumn they were found exclusively in a deeper layer of 4–6 m. The deeper layers are very well penetrated by acoustics, while fish present in a surface layer, where sampling volume of the echo sounder is very small, may be undersampled. This could explain why hydroacoustical estimates in autumn were twice higher that those done in spring. Thus the autumn conditions are preferable for acoustical surveys of fish abundance.

Comparison of fish sizes from nets and estimated acoustically (Figures 10a, b) differs significantly in the lowest class of fish lengths. There might be many reasons for this disagreement. Firstly, since the fish echoes in their lower range and non-fish echoes in their upper range overlapped, it is possible that acoustically we overestimated fish in the smallest category. Secondly, to calculate fish lengths (in cm) from the acoustic data the Love's equation was used, which might not be very accurate for the freshwater species present in the Piaseczno reservoir. Thirdly, the number of fish, both caught in nets and measured acoustically was too small for statistically sound comparisons.

Summarizing, it can be concluded that acoustical methods have a high potential for the detailed description of spatial and temporal distributions of aquatic resources (which sometimes can be overlooked using only traditional fishery methods), however, for verification of acoustical targets it is necessary to use control catches. In order to enable proper interpretation of the acoustical echoes more information is required on the results of different systems, different frequencies and the studies of different species.

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