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EFFECTS OF HYDROPOWER PLANT ACTIVITIES ON FISH POPULATION, ABUNDANCE AND DISTRIBUTION

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ABSTRACT. The results of hydroacoustical monitoring in three water ecosystems exposed to anthropogenic pressure are presented. One is Żarnowieckie Lake, where a hydroelectric power station is operating, the second is a system of three lakes that are periodically included in the cooling system of the Konin-Pątnów power plant, and the third, the Solina Reservoir, is a typical dam reservoir situated in a recreational, mountainous area. In all three ecosystems, the fish distribution, biomass and migrations showed different patterns dependent on the environmental conditions and their changes due to human activity. In Żarnowieckie Lake, fish abundance increased during summer about four-fold as the probable result of fish migration from littoral to pelagic water, while in the Konin lakes it decreased 2.7 times as the result of fish migration to the lakes affected by the power plant's operation. In the Solina Reservoir, fish abundance was 20 times lower than in the other two ecosystems, which was probably due to high fluctuations in the water level. This prevented the development of the littoral and affected fish breeding grounds.

Key words: HYDROPOWER PLANTS, HYDROACOUSTICAL MONITORING, FISH DISTRIBUTION, MIGRATION

INTRODUCTION

Over the last 30 years, hydroacoustical methods have become the most popular method of obtaining information about fish abundance and distribution both in oceans and fresh water basins (McLennan and Simmonds 1992). Thanks to the fast coverage of large areas, continuous recording, high resolution and reliability these methods are ideal for detecting changes caused by either anthropogenic pressure or natural processes. In this paper, hydroacoustical methods combined with mid-water trawl survey (further referred to as acousto-fishing monitoring) were used to study fish abundance and distribution in three reservoirs that were used in different ways by the energy producing sector. The most spectacular result of power plant activities is the fish mortality caused by turbines. This problem has already been discussed in various publications (Heisey et al. 1992, Bartel et al. 1993, Bieniarz 1997). The aim of this work was to study the impacts of hydropower plants on the environment, fish population, abundance, spatial distribution, and in consequence, on the water quality of such reservoirs.

MATERIAL AND METHODS

STUDY SITES

SOLINA DAM RESERVOIR

Solina is the largest Polish dam reservoir of high quality water comprising 18.6% of the total fresh water storage in Poland. It is situated in the east Carpathian mountains and serves as a tourist and recreational center in addition to its basic functions such as water supply, hydroelectric power generation and flood control. The principal morphometric characteristics of Solina at maximum water level are as follows: surface area 2105.0 ha; volume 472.0 million m^3; maximal depth 65.0 m; average depth 22.5 m; reservoir length 26.6 km; shore line 150.0 km. Cold water from the Solina hypolimnion is discharged from the 25 m level above the bottom onto the turbines of the pumped – storage power station (138 – MW). As a result of the discharge and subsequent back-pumping of water, the water level in the reservoir varies up to 10 m during the

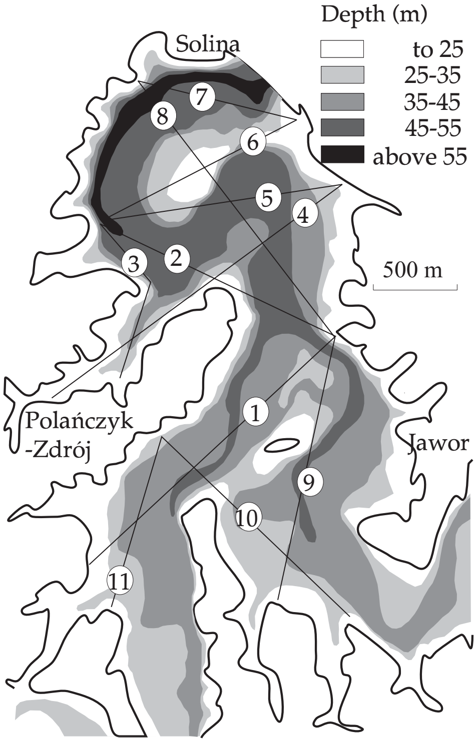

Fig. 1. Transects of the acoustic survey in the main basin of the Solina Reservoir.

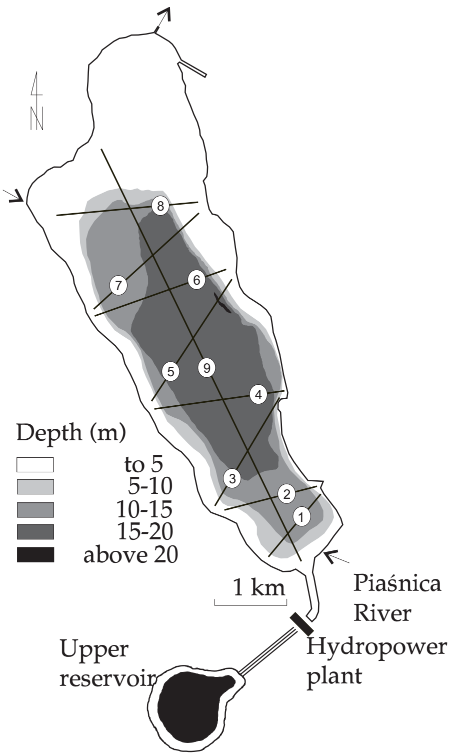

Fig. 2. Żarnowieckie Lake - bathymetry and transects of the acoustic survey.

year and the total water volume is exchanged twice yearly. Acoustical measurements were performed along a zigzag transect in the main basin of the reservoir (Fig. 1).

ŻARNOWIECKIE LAKE

Żarnowieckie Lake, with a maximal depth of 19.4 m and a mean depth of 8.4 m, is the northernmost freshwater lake in Poland and is located only 5 km from the Baltic coast. A pumped-storage power station was constructed there in 1983. The station uses the lake as its lower reservoir (Fig. 2). Water is pumped at night from the lake to an artificial upper reservoir, from which it is directed to the power-station turbine (at a rate of about 14 million m^3 daily). This induces water flow and the mixing of the entire lake. Daily variations of water level reach about 1 m, changing the lake area within the range of 1330 to 1500 ha. The whole water volume of the lake is exchanged within 17 months.

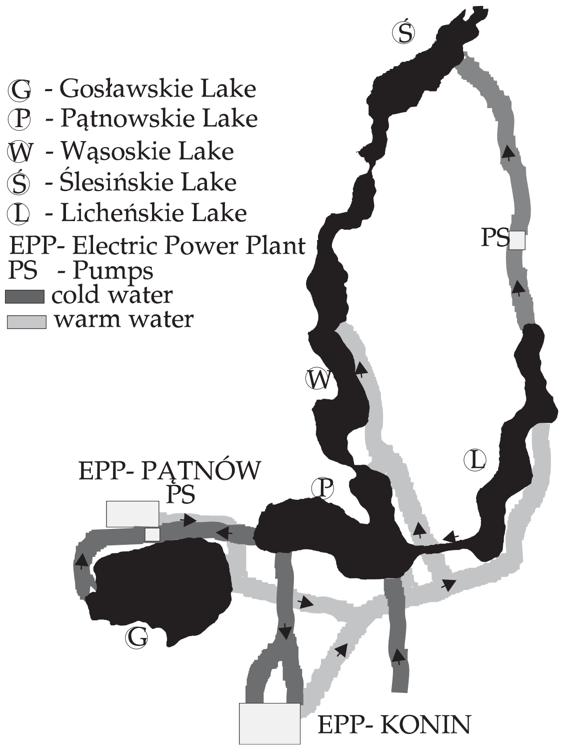

Fig. 3. Water cooling circulation scheme in the Pątnów-Konin power plant system.

KONIN LAKES

Three lakes were selected from the complex of the five heated Konin lakes - Licheńskie Lake (area 153.6 ha, maximal depth 13.3 m), Ślesińskie Lake (area 148.1 ha, maximal depth 25.7 m) and Wąsoskie Lake (area 245.3 ha, maximal depth 38.0 m). The lakes differ with regard to their morphometry and composition of ichthyofauna; however, the degree of heating is the most pronounced differentiation (Fig. 3).

EQUIPMENT USED

Acoustic monitoring was performed using a Simrad EY-M 70 kHz single beam echo sounder. To estimate fish size distribution the echo counting method was applied with a TVG set to 40 log R. The echo-sounding results were analysed using the HADAS (Lindem 1992) software system which produces estimates of target strengths using a modification of the Craig and Forbes (1969) algorithm. In addition to this, the SURFER (Golden Softw. Corp. USA) program was used to map the data and determine fish numbers with the Kriging method.

Measurements of oxygen content and water temperature were performed every 1 m, from the surface to the bottom, in the deepest place using an OXi 196 WTW oxygen meter.

To identify fish species composition and to verify the size distribution obtained using the acoustic method, control fishing was also performed with a pelagic trawl with an inlet surface of 10.8 m^2 and a water filtration rate of 903 m^2 min^{-1} at a towing speed of 83 m min^{-1}. Two 13-panel sets of gill nets (6 and 8 m high) with mesh sizes from 10 to 65 mm were also used. All fish caught were identified to the species, measured (total length) to the nearest 0.1 cm and weighed to the nearest 0.1 g.

RESULTS AND DISCUSSION

SOLINA DAM RESERVOIR

In summer, thermal and oxygen stratification occurred (Fig. 4) throughout the Solina Reservoir; however, good oxygen conditions were maintained down to the bottom.

The fish population structure examined in the pelagic trawl was as follows: bream *Abramis brama* (L.) – 56.7%; bleak *Alburnus alburnus* (L.) – 40.0%; pike-perch *Stizostedion lucioperca* (L.) – 3.3%. In the non-selective gill nets, the dominating species were bleak – 44.5%, roach *Rutilus rutilus* (L.) – 23.7%, bream – 15.0%, ruffe *Gymnocephalus cernuus* (L.) – 7.5%, perch *Perca fluviatilis* L. – 3.5% and others – 5.8%. The present ichthyofauna structure of the Solina Reservoir is evidence of unfavorable changes in fish populations, as the waters used to be typically dominated by trout.

Hydroacoustical surveys were performed in June 1998. The fish distributions show distinct diel vertical migrations from the hypolimnion during the day to the epilimnion at night (Figs. 5 and 6). The overall abundance of fish in the Solina Reservoir is very low, about 40 times lower in comparison to the other lakes (Table 1). The mean concentrations do not exceed a few hundred fish per hectare and are similar during the day and night. The low fish concentrations in spite of the high food and oxygen concentrations (Godlewska et al. 2000) suggest that there are unfavorable conditions for fish development in the Solina Reservoir. One can speculate that very high water level fluctuations (up to 10 m within a year) are responsible for this situation, as they lead to nearly complete absence of littoral and to the destruction of breeding grounds.

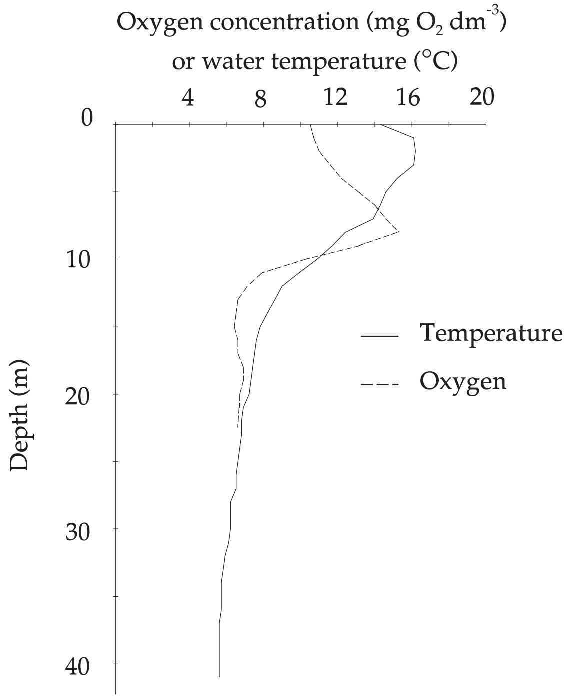

Fig. 4. Vertical distribution of oxygen and temperature in the Solina Reservoir.

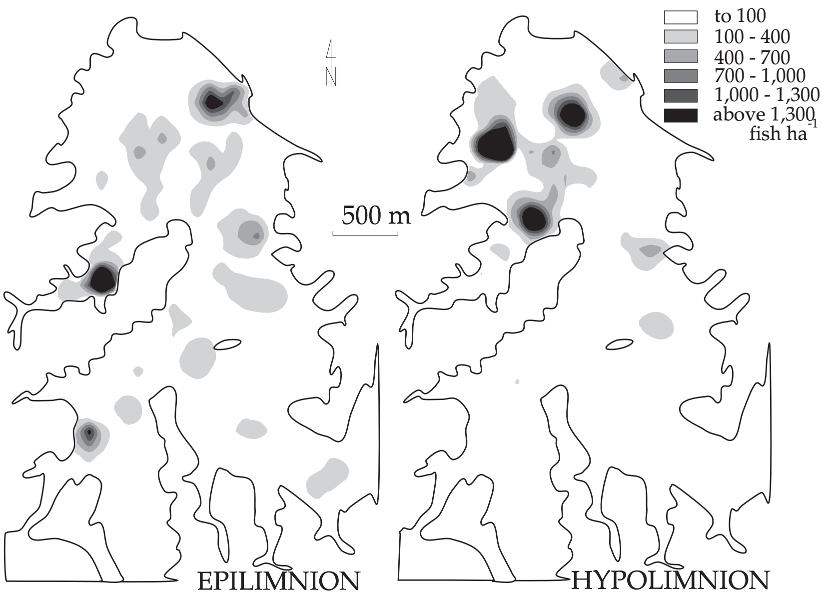

Fig. 5. Day fish distribution in the main basin of the Solina Reservoir.

TABLE 1

Fish density in the different lakes monitored with a Simrad EY-M echo sounder (Świerzowski 1996, 1998, 1999)

Lake	Area (ha)	Date	Fish density (individuals ha^{-1})
Pluszne	580	1992	2,586
		1993	2,414
		June1994	2,079
		August1994	2,326
		October 1995	2,586
Żarnowieckie	920	June 1994	786
	1,220	September 1994	2,325
Licheńskie	154	June 1995	5,334
	180	October 1995	1,638
		October 1997	3,111
Ślesińskie	148	June 1995	3,415
	162	October 1995	1,323
		October 1997	1,052
Wąsoskie	245	June 1995	2,410
	264	October 1995	1,240
		October 1997	3,385
Wulpińskie East	356	September 1995	7,949
Wulpińskie West	295		5,334
Wigry North	655	August 1996	6,330
Wigry South	1,047		2,184
Białe Wigierskie	98	August 1996	5,781
	98	September 1997	4,186
	98		6,652
Mamry North	1,500	June 1997	10,859
Mamry South	1,000		3,493
Święcajty	651	June 1997	2,802
Solina Reservoir	560	June 1998	206
Solina Reservoir	1,554	September 1999	264

ŻARNOWIECKIE LAKE

Acousto-fishing surveys were performed in June and September 1994. Control fishing revealed three major fish species in the lake's pelagic zone, ruffe, perch and roach, with the highest numbers of ruffe both in June (74.3%) and September (62.0%). Taking into account changes of fish biomass, ruffe and perch dominated in June

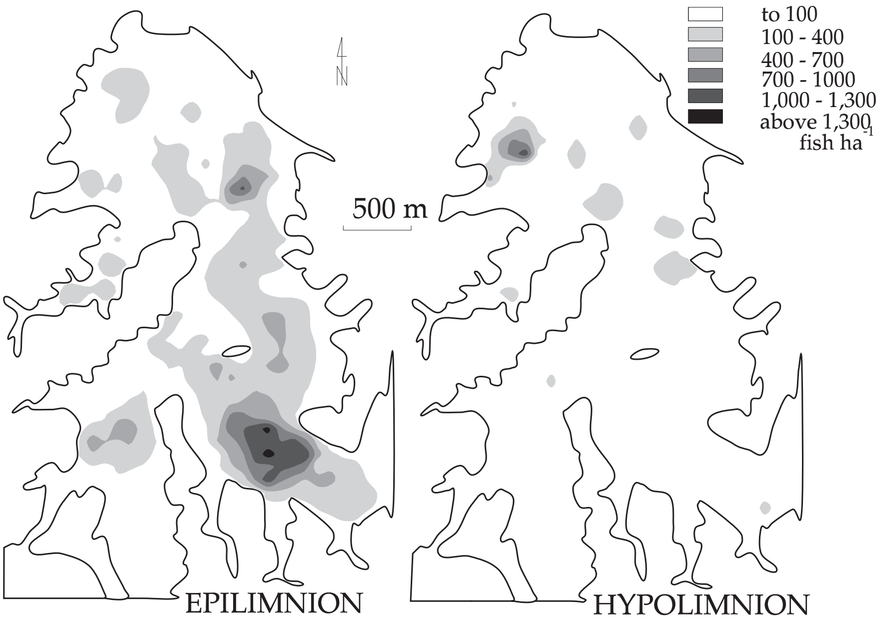

Fig. 6. Night fish distribution in the main basin of the Solina Reservoir.

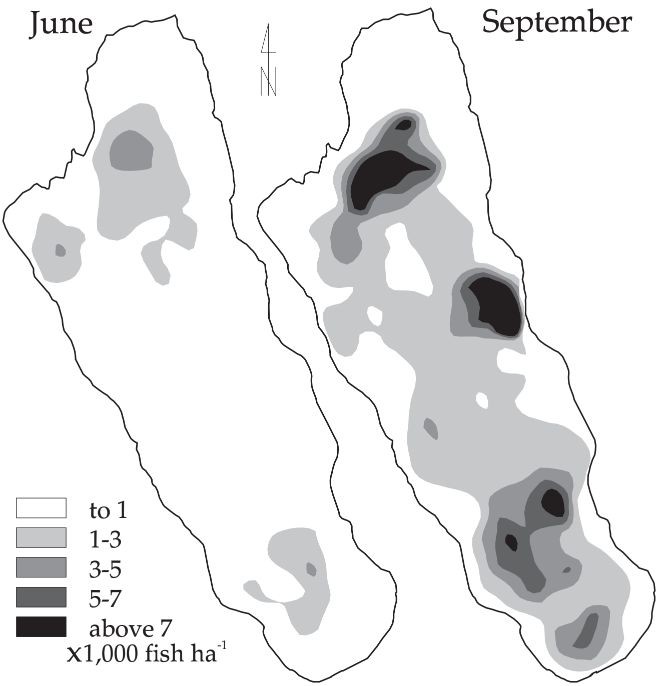

Fig. 7. Distribution and density of pelagic fish in Żarnowieckie Lake.

(together 91%), and roach in September (71%). Fish numbers in the pelagic zone increased considerably in this three-month period, 3.3-fold in the case of ruffe, 4.7-fold for perch, and 70-fold for roach. Fish biomass increased 1.4-fold in the case of ruffe, 2.2-fold for perch, and 113-fold for roach. Total fish numbers increased 4-fold, and the biomass increased 3.3-fold (Table 2). This drastic change of fish distribution and densities was probably of a trophic character; as the fish grew they migrated from the littoral to the pelagic zone. For example, acoustic and fishing surveys performed in September revealed much higher densities of fish than in June (Fig. 7). The lowest values were recorded in both months in the western part of the lake where major pollution sources are located (Czerwionka et al. 1996).

TABLE 2

Numbers and biomass of pelagic fish in Żarnowieckie Lake

Species	Study period	Numbers		Indiv. weight (g)	Biomass		
		Thousand	%		kg	kg ha^{-1}	%
Ruffe	June	532.4	74.9	10.0	5,803	6.4	41.8
	Sept.	1,760.1	62.0	3.6	6,336	7.0	12.5
Perch	June	132.7	18.6	51.3	6,808	7.6	49.0
	Sept.	624.5	22.0	13.5	8,431	9.4	16.7
Roach	June	6.5	0.9	48.6	316	0.3	2.3
	Sept.	454.2	16.0	79.0	35,882	39.9	70.8
Bleak	June	40.0	5.6	23.8	952	1.1	6.9
	Sept.	-	-	-	-	-	-
Total	June	711.6	100.0	-	13,879	15.4	100.0
	Sept.	2,838.8	100.0	-	50,649	56.3	100.0

The results of multidisciplinary studies of Żarnowieckie Lake, carried out before the power station had been constructed and again after it had been in operation for a decade (Świerzowski 1996), showed that the thermal and oxygen conditions in the lake had been modified. Water mixing induced by the power station improved water quality in the deeper layers; this was confirmed by the results of acoustic studies on fish distribution and densities. On the other hand, variations of water level and an increase in surface pollution destroyed some of the spawning grounds of pike *Esox lucius* L., roach and perch (Ciepielewski, unpublished data).

Only acousto-fishing surveys made it possible to register seasonal changes in fish distribution and enabled the assessment of fish resources in the pelagic zone, i.e. over 60% of the lake's area. It was not known that the lake possessed such abundant

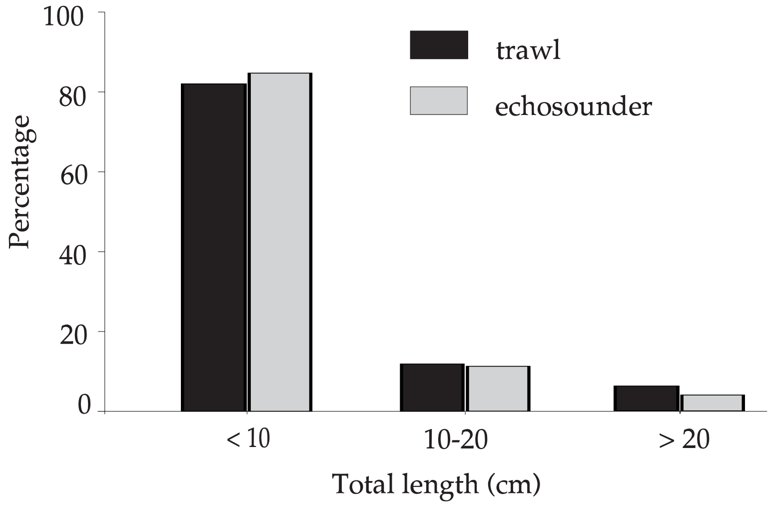

Fig. 8. Comparison of the percentage distribution of fish size based on acoustic monitoring and fish catches in Żarnowieckie Lake.

resources of ruffe, a species which is a food competitor for many economically valuable fish species, on the one hand, but also the prey and a valuable food source for eel *Anguilla anguilla* (L.), on the other. This suggests the possibility of intensifying eel management in the lake.

Maps of fish distribution and density in particular water layers based on acoustic surveys revealed areas of water pollution which possibly has an affect on fish reproduction, development and growth. The precision and reliability of acoustic data was confirmed by the sufficient comparability of the data on the frequency distribution of fish in three length classes obtained from acoustic monitoring and control net fish catches (Fig. 8).

KONIN LAKES

The lakes differ with regard to morphometry and ichthyofauna composition, but the most pronounced differences (Fig. 9) are in the thermal structure which is dependent on power plant activity.

Studies were carried out for the first time in June when heated effluents affected all five lakes of the Konin complex, and in October 1995 when three lakes were excluded from the cooling system. Studies continued in the next two years.

When heated effluents reached lakes Licheńskie and Wąsoskie, significant differences were observed in water temperature between the epilimnion and hypolimnion

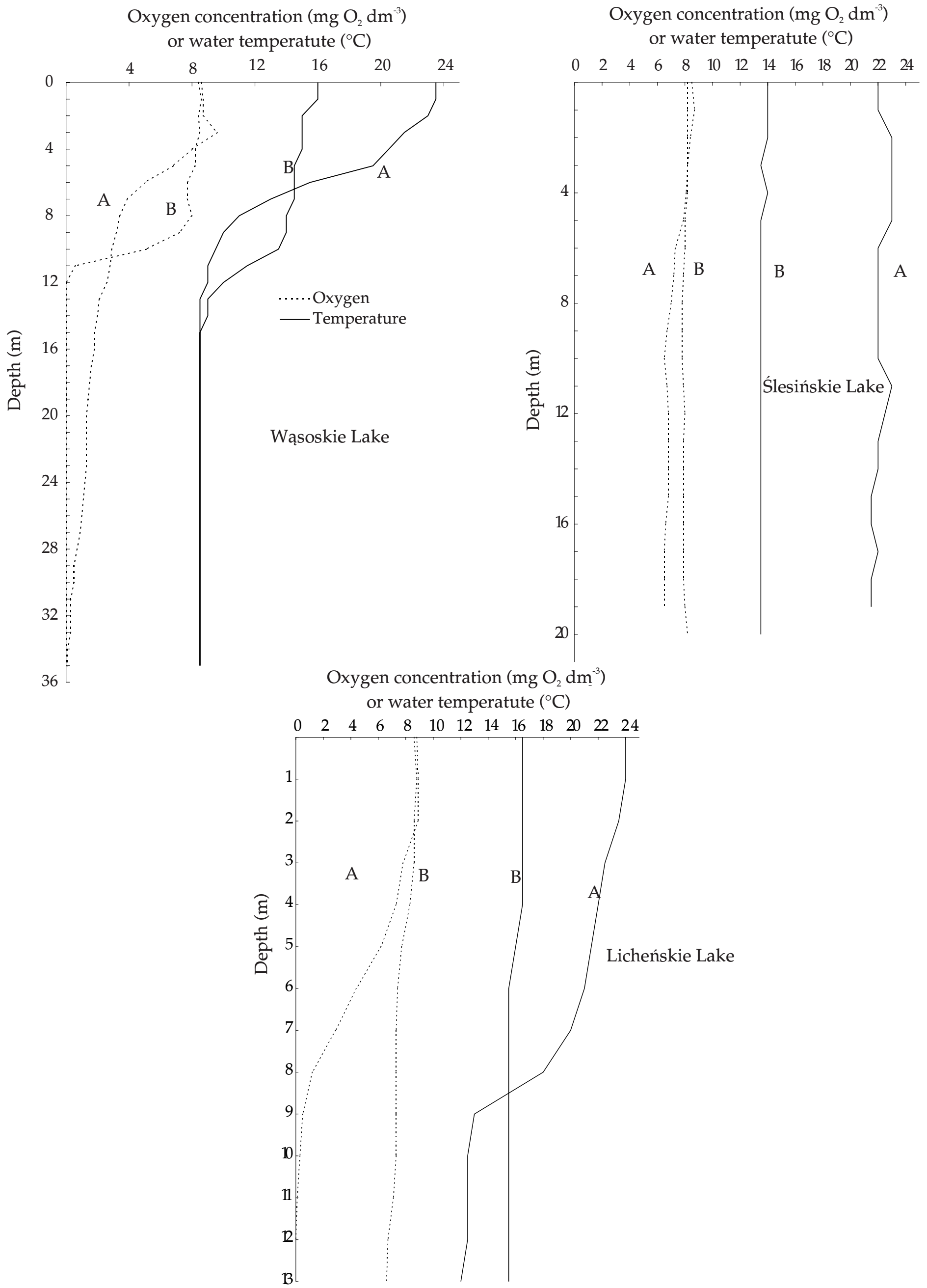

Fig. 9. Vertical distribution of water temperature and oxygen content in the Konin lakes during heating (A) and without heating (B).

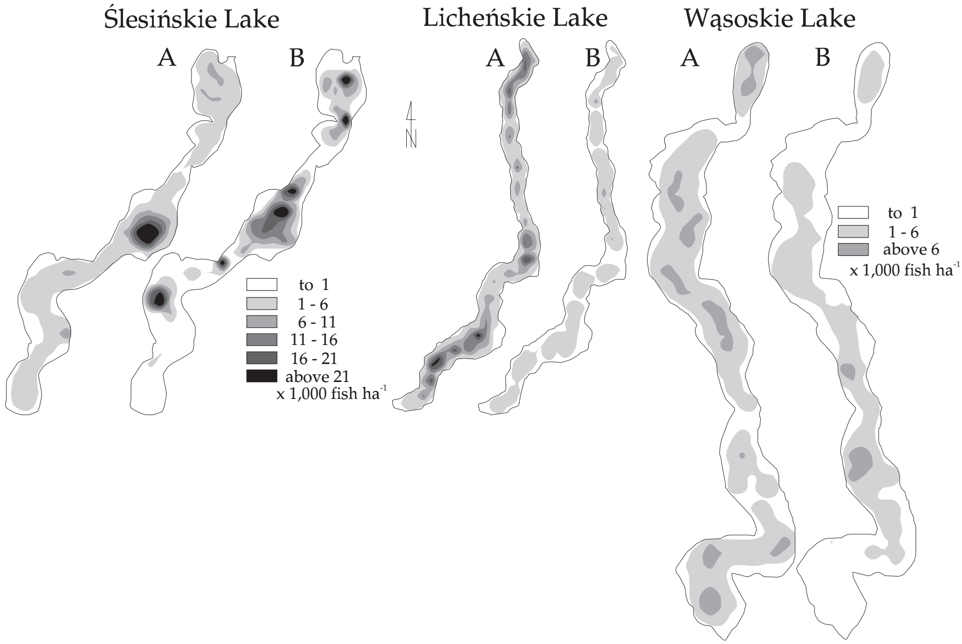

Fig. 10. Variations of the distribution and density of pelagic fish in three Konin lakes during heating (A) and without heating (B).

layers (12 to 16°C). The temperature decrease in surface waters reached 8°C when there was no inflow of heated effluents. In Ślesińskie Lake, heated effluents were discharged as a cascade into the deepest, central part of the lake, where most of the fish gathered (Fig. 10).

The most atypical phenomenon as compared to other natural lakes in which acoustic monitoring have been conducted was the high decrease of fish numbers and densities in all the lakes after three months, when the flow of heated water was cut off (Table 3, Fig. 10). The total pelagic fish numbers in the three lakes in October were 2.7-fold lower, decreasing to 37.3% of the levels observed in June. In the most heated of the lakes, Licheńskie, this decrease was as high as 3.7-fold. The decrease of fish numbers in the lakes was most pronounced in the case of roach. Its share in control catches in the lakes in June was from 28.2 to 56.0%, while in October it decreased to the level of 1.0-2.8% (Fig.11).

The reason for the decrease in fish numbers, and most of all of in roach numbers, was very likely due to the fish migrating to warmer areas of the Konin complex (channels and lakes) (Fig. 3). Mass fish migration to the shallow littoral, or mass fish mortal-

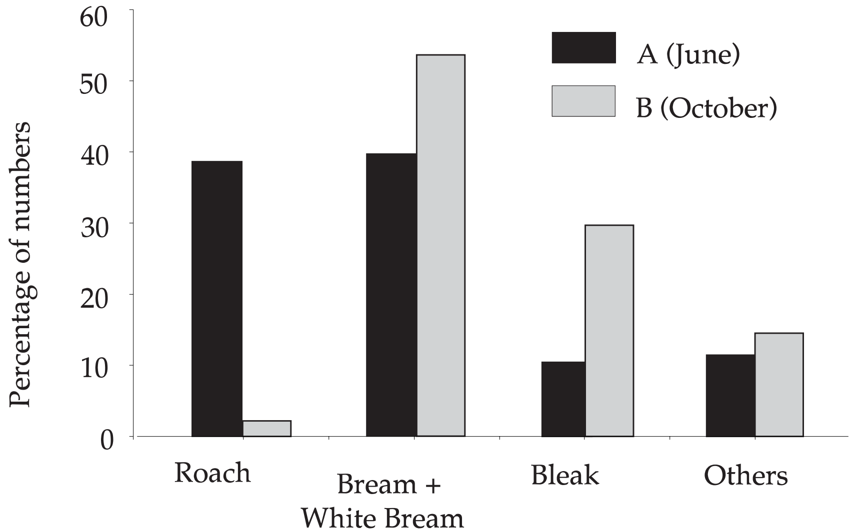

Fig. 11. Distribution of pelagic fish numbers in three Konin lakes during heating (A) and without heating (B).

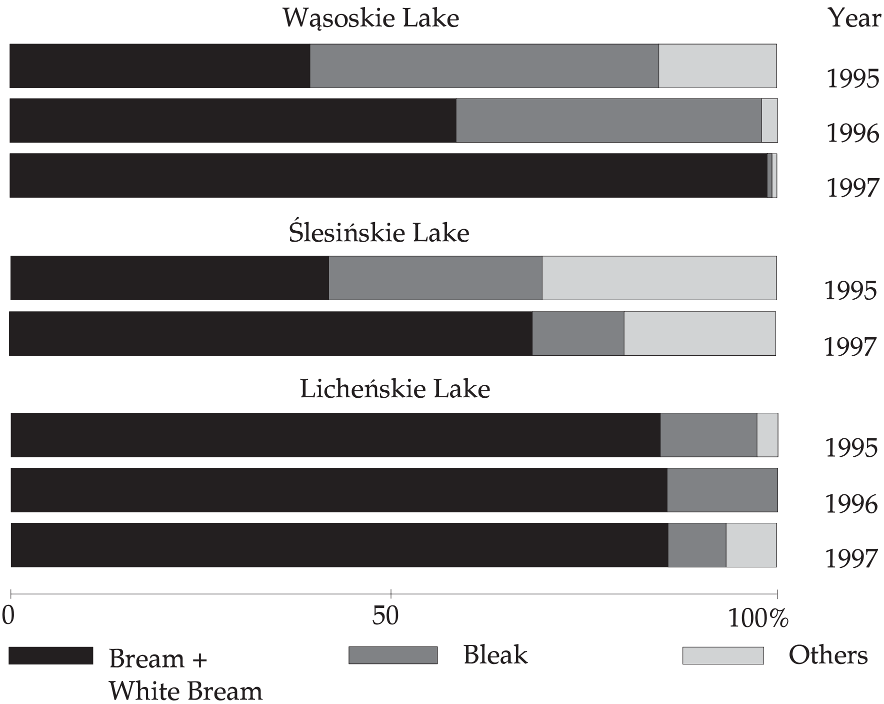

Fig. 12. Species composition of pelagic fish in 1995-1997 in three Konin lakes.

TABLE 3

Numbers and density of pelagic fish in three Konin lakes during heating (A) and without heating (B)

Water layers	Study period	Licheńskie Lake		Ślesińskie Lake		Wąsoskie Lake	
		N (thousand)	Fish ha^{-1}	N (thousand)	Fish ha^{-1}	N (thousand)	Fish ha^{-1}
Epilimnion	A (June)	-	-	395.1	2.4	548.8	2.1
	B (October)	-	-	157.3	1.0	291.7	1.1
Hypolimnion	A (June)	-	-	84.9	0.7	44.8	0.2
	B (October)	-	-	38.8	0.4	13.1	0.1
All layers	A (June)	921.4	5.2	505.5	3.0	590.5	2.2
	B (October)	252.2	1.5	195.8	1.2	303.7	1.2

ity (natural or fishing) should rather be excluded. Thermal water pollution and progressing eutrophication induced a change in the species composition of the ichthyofauna. The share of bream and white bream increased rapidly (Fig. 12), while the percentage of predatory fish decreased. No perch was found, and the pike-perch share was only 3.5%. This was also confirmed by Ciepielewski (1994). The methods of acousto-fishing monitoring made it possible to reveal seasonal changes of fish distribution and fish resources caused by thermal pollution. Acoustic surveys were used to prepare maps of fish distribution and densities in the epilimnion and hypolimnion waters. These maps can aid in designating areas which are threatened from an ecological point of view.

CONCLUSIONS

The three examples of water reservoirs presented here show that the effect of power plant activities on fish population, abundance and distribution is evident. It may be considered as positive or negative from the viewpoint of water quality. In this sense, we would say that it is positive in the Solina Reservoir, where low fish densities are associated with high zooplankton densities and low phytoplankton concentrations (because it is effectively grazed by large filtrators). In Żarnowieckie Lake, this influence is also positive as the intensive mixing of the water column leads to better oxygenation, the lowering of the trophy state and higher transparency. In the Konin lakes, the increase of water temperature increases the speed of eutrophication processes, and, as such, must be considered negative. From the fishery point of view, all three examples must be considered as negative, leading to unfavorable changes in fish population structure, and, in the case of Solina Reservoir, lowering the fish yield.

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STRESZCZENIE

WPŁYW SYSTEMÓW HYDROENERGETYCZNYCH NA ZASOBY RYB I ICH ROZMIESZCZENIE

Przedstawiono wyniki monitoringu hydroakustycznego i połowów kontrolnych ryb w trzech ekosystemach wodnych poddawanych presji antropogennej. Dotyczy to typowego solińskiego zbiornika zaporowego w rekreacyjnym górskim krajobrazie (rys. 1) oraz Jeziora Żarnowieckiego, gdzie działa elektrownia

szczytowo-pompowa (rys. 2) oraz trzech jezior okresowo wykorzystywanych w systemie chłodzącym zespołu energetycznego Konin-Pątnów (rys. 3).

Monitoring akustyczny realizowano przy wykorzystaniu echosondy Simrad EY-M (70 kHz). Zastosowano metodę zliczania echa ryb przy zakresowej regulacji wzmocnienia TVG 40 log R. Do analizy danych wykorzystano program HADAS, a do obliczania liczebności ryb i mapowania danych program SURFER. Identyfikację gatunkową i rozkład wielkości ryb otrzymywano z połowów kontrolnych włokiem pelagicznym i 13 panelowymi zestawami nieselektywnych wontonów.

W badanych ekosystemach rozmieszczenie, biomasa i migracje ryb były zależne od zmienności warunków środowiska wynikających z działalności człowieka. W solińskim zbiorniku zaporowym zasoby ryb były niekiedy ponad 20 razy mniejsze niż w pozostałych dwóch badanych ekosystemach (tab. 1). W Jez. Żarnowieckim liczebność ryb wzrastała w okresie lata czterokrotnie (tab. 2), prawdopodobnie w wyniku migracji ryb z litoralu do pelagialu, podczas gdy w jeziorach konińskich zmniejszała się 2,7 razy (tab. 3) w wyniku migracji ryb do pozostałych dwóch jezior aktualnie podgrzewanych. Prawdopodobnie jest to wynik bardzo dużych wahań poziomu wody i braku litoralu, czyli miejsc do rozrodu i rozwoju ryb. Wydaje się więc, że monitoring hydroakustyczny zasobów ryb może być wartościowym elementem oceny zmian i jakości środowiska wodnego.

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