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THE ICHTHYOFAUNA OF THE DYSTROPHIC LAKE SMOLAK (NORTHERN POLAND) IN LIGHT OF SELECTED PHYSICAL AND CHEMICAL WATER CONDITIONS THIRTY YEARS AFTER THE CONCLUSION OF LIMING AND FERTILIZATION

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ABSTRACT. The aim of ichthyofauna studies conducted in Lake Smolak (northern Poland) in the 2002-2004 period was to evaluate species richness, growth rate, and fish assemblage structure in light of environmental conditions. This initially dystrophic lake, which, in the 1950s, was inhabited by only two fish species – perch, *Perca fluviatilis* L., and pike, *Esox lucius* L., was subjected to experimental liming and fertilization (to stimulate eutrophication) and stocking in the 1971-1974 period. Currently, the ichthyofauna of the lake is comprised of ten species belonging to four families. The density of the fish in this lake is not high; the most numerous are roach, *Rutilus rutilus* (L.) and bream, *Abramis brama* (L.). Roach was characterized by a rapid growth rate, but that of bream was very slow. The environmental parameters of the lake undoubtedly have a negative impact on the ichthyofauna, especially the gradients of and seasonal variation in the physical and chemical parameters of the water as well as the absence of submerged hydrophytes and the limited occurrence of helophytes.

Key words: DYSTROPHIC LAKE, PHYSICAL AND CHEMICAL CONDITIONS, LIMING, MINERAL FERTILIZATION, ICHTHYOFAUNA, GROWTH RATE

INTRODUCTION

The specific prevailing environmental conditions in dystrophic lakes do not provide ample opportunity for fish development. This results in the paucity of their natural ichthyofauna, which is usually comprised of only a few species (crucian carp, *Carassius carassius* (L.), tench, *Tinca tinca* (L.), roach, *Rutilus rutilus* (L.), European perch, *Perca fluviatilis* L., and northern pike, *Esox lucius* L.). These lakes are inhabited frequently by just two, and, in extreme cases, only one species (Zawisza 1961, Zdanowski et al. 1978, Białokoz and Krzywosz 1992, Robak et al. 2004). The factors that have a decisive impact on ichthyofauna composition include, foremost, water acidity, low oxygen

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concentrations (especially in winter), and limited possibilities for spawning (Białokoz and Krzywosz 1992, Robak et al. 2004).

The pH of the water in dystrophic lakes can be steered naturally or with anthropogenic acidification. Due to the low buffering capacity, lakes of this type are especially vulnerable to acid rain. A distinct decrease in the pH of the water in these types of lakes was observed in North America and Central Europe, including Poland, in the second half of the twentieth century (Wright and Snekvik 1978, Kelso et al. 1990, Hillbricht-Ilkowska et al. 1998).

The first symptom of lake acidification observed was change in the ichthyofauna composition. The negative impact of low water pH on the fish was noted at pH < 6.5. Increasing water acidity resulted in the decline of species diversity and richness and an increase in populations of species that were less vulnerable to low water pH values. The number of more vulnerable species declined, with some finally disappearing from the lake (Appelberg 1998). In very acidic waters (pH < 5.5), most fish populations died out (Rask et al. 1995), and the biomass of fish in very acidic lakes was not high. Of the small number of fish caught, most were large, old specimens. Low water pH levels caused reproductive disturbances and limited growth, high mortality among juveniles, and limited fish growth. In moderately acidic waters, an increase in growth rate was noted, which could stem from a drop in food competition (Rask 1992, Appelberg 1998).

Liming has been applied in an effort to prevent the acidification of surface waters (Henrikson et al. 1995). In Poland, experimental liming has been conducted in two lakes (Smolak and Flosek) and in mountainous areas (Hillbricht-Ilkowska et al. 1998, Zdanowski and Hutorowicz 1998). Lakes in which liming has been conducted have been resettled by species sensitive to low levels of water pH. Changes in the chemical composition effected by liming have resulted in accelerated growth rates, improved reproduction, and increased density of species sensitive to high acidity (Degerman et al. 1992, Rask 1992, Appelberg 1998). A consequence of liming has usually been increased species richness and density of fish aggregations. However, there have also been simultaneous increases in intraspecies and interspecies competition, which has resulted in the reduced density of species resistant to high acidity.

Two fish species occurred in Lake Smolak in the 1950s, namely European perch and northern pike (Zawisza 1961). The lake was stocked during the liming and fertilizing period as well as in the 1990s. Following the conclusion of liming and fertilizing, environmental conditions stabilized, and in many aspects (excluding water acidity) they were close to those prevailing in dystrophic lakes (Zdanowski and Hutorowicz 1998, Hutorowicz 2001, Hutorowicz and Hutorowicz 2002), which could have, however, had a significant impact on the ichthyofauna.

The aim of the study was to determine the species richness, size distribution, and growth rate of the fish as well as to evaluate the impact of water acidity and concentrations of oxygen, ammonia nitrogen, and iron on the ichthyofauna of the lake. According to quality criteria in fish rearing (Karpiński 1994), these parameters can have a significant impact on the development and growth of fish.

MATERIAL AND METHODS

STUDY AREA

Lake Smolak (Great Mazurian Lakeland) is a small (5.3 ha), relatively shallow (maximum depth – 5.3 m) lake with no outlet surrounded by pine forests; it is subjected to natural dystrophication processes (Zdanowski and Hutorowicz 1998). Prior to liming and fertilization, the water of this lake was characterized by low content of humic substances, high acidity (pH values at the surface ranged from 4.4 to 5.8), low contents of dissolved minerals (conductivity of 15-49 $\mu S\ cm^{-1}$), and low lime contents (less than 5.0 $mg\ dm^{-3}$) (Hutorowicz 2001).

Intensive liming and fertilization (3960 kg terrestrial lime ha^{-1} $year^{-1}$; 245 kg ha^{-1} $year^{-1}$ 50% potassium salts; 19.5 kg ha^{-1}, 28% super Thomas slag three times per year; 48.2 kg ha^{-1} 34% ammonium nitrate three times per year) conducted over a four-year period resulted in a six-fold increase in conductivity at the water surface (maximum of 166 $\mu S\ cm^{-1}$), the basification of the water (average pH 7.4 within a range of 6.8-8.8 in 1974), and an increase in lime content to a maximum of 34.0 $mg\ dm^{-3}$ (Niewolak and Korycka 1976, Zdanowski et al. 1978). At the initial stage, water visibility was low (approximately 1 m), but in the final year of liming, when the bottom of the lake became overgrown with Canadian waterweed, *Elodea canadensis* Michx., and Eurasian water-milfoil, *Myriophyllum spicatum* L., water visibility increased to over 4 m (Hutorowicz 2001).

In the thirty years since the end of the experiment, the conductivity of the water has decreased several-fold (in the 1998-2001 period it ranged from 31 to 59 $\mu S\ cm^{-1}$), as has the lime concentration (from 4.0 to 11.7 mg dm^{-3}). The average lime ion concentration remained higher at 5.1 mg Ca dm^{-3} than it had been prior to liming and fertilization (Hutorowicz and Hutorowicz 2002). However, throughout the period since the conclusion of the experiment, the surface waters of the lake in the summer have retained their basicity and low visibility (0.8-2.0 m). The large resources of nutrients in the lake have also remained unchanged (Zdanowski and Hutorowicz 1998, Hutorowicz 2001, Hutorowicz and Hutorowicz 2002). In comparison with the period prior to liming and fertilization, the phytoplankton (Hutorowicz 2001) and zooplankton structures (Ejsmond-Karabin 1998, Węgleńska 1998) have changed completely. The range of occurrence of the floating peatbog has decreased (Hutorowicz 2003), and submerged hydrophytes have also disappeared (Dziedzic 1998, Hutorowicz 2001).

STUDY METHODS

Measurements of the physical and chemical parameters of the waters of Lake Smolak were conducted in the 2002-2003 period. Water samples were collected in April, June, July, September, and November 2002 and in May, June, July, August, September, and November 2003 at a central location in the lake (Fig. 1). Water temperature and dissolved oxygen concentration were measured with a YSI 58 Dissolved Oxygen Meter. Water acidity was measured electrometrically and conductivity with a WTW Digitalmeter Digi 610. Concentrations of ammonium nitrogen (NH_4-N) and total iron were determined with the standard colorimetric method (Rand et al. 1975, Hermanowicz et al. 1976), while those of ammonia (NH_3-N) were calculated based on the equation in Emerson et al. (1975):

$$\%\ \text{un-ionized ammonia} = 1/(10^{pKa-pH} + 1)$$

where: ammonia – measured concentration of NH_4-N; pK_a – mixed acidity constant for the reaction (calculations utilized values reported in Emerson et al. 1975); pH – measured pH of water.

Experimental fish catches were conducted from one to three times annually in the 2002-2004 period. The fish were caught with gill-nets (mesh sizes ranged from 10 to 60 mm) deployed in all regions of the basin. Additionally, fry nets (mesh bar length of 1 mm and a bunt length of 8 m) were used to catch juvenile fish in August 2002 and 2003. The samples were collected during three hauls conducted in daylight.

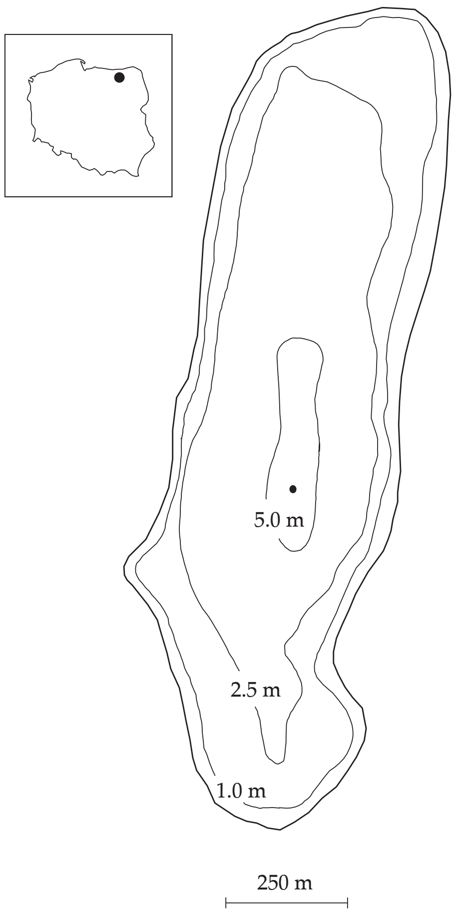

Fig. 1. Bathymetric plan of Lake Smolak.

All of the fish caught were identified to the species, measured (body length – Lc) to the nearest mm, and weighed to the nearest g. The age of the fish was read from scales, and the growth rate was determined with the back-calculation method (Francis 1990).

The growth rates of the most numerous fish species caught were compared with data describing that of the same species from lakes in northern Poland (Nagięć 1961, Żuromska 1961, Wilkońska 1975, Szczerbowski 1981). Data from experimental catches in 1993 conducted with gill-nets, trammel nets, and electric fishing were also used to establish species richness (Zdanowski and Hutorowicz 1998).

RESULTS

PHYSICAL AND CHEMICAL CONDITIONS

Two layers formed in the lake in summer – the epilimnion and the near-bottom metalimnion. The surface water temperature ranged from about 9.0°C in April to 24.8°C in July, and 2.5°C in November 2002 and from 14.5°C in May, 26.8°C in early August, and 4°C in mid November 2003. In the layer cut off by the 4 m isobath (to the bottom), variation was substantially less pronounced – from 4.5°C in April to 13.4°C in September 2002, and from 6.3°C to 13.8°C in September 2003. The thermocline had already formed by April. In spring and early summer, the largest temperature gradient in the vertical profile (6.5°C m^{-1} in June 2002, 5.5°C m^{-1} in May 2003, 6.9°C m^{-1} June 2003) was observed between depths of 2 and 3 m, while in the summer it was between 3 and 4 m (5.6°C m^{-1} in July 2002, 4.3°C m^{-1} in July 2003, and 5.9°C m^{-1} in August 2003); however, the largest temperature drop occurred between the depths of 2 and 3 m (Fig. 2).

In the vegetative season, the oxygen contents of the surface waters ranged from 7.2 to 13.3 mg O_2 dm^{-3}; however, thermal stratification limited mixing and led to oxygen deficits in the deeper water layers. In 2002, a clear oxygen deficit appeared at depths over 4 m in early June. The water layer without oxygen spread to depths of 3 m in July, and in early September – to depths of 4 m. In 2003, oxygen deficits occurred in the layer deeper than 4 m, and there was a total lack of oxygen near the lake bottom as early as in mid June. In August, the layer of water with very low oxygen contents (0.7 mg O_2 dm^{-3}) reached a depth of 3 m. In the first decade of September, there were clear indications that the water was mixing (deepening of the epilimnion), which led to good oxygen conditions to a depth of 4 m. The near-bottom water remained totally devoid of oxygen.

The pH of the surface waters ranged very widely in 2002 (Fig. 3); in April pH was 9.8, from June to September – pH 7.4-8.9, and in November it was barely pH 6.7. During thermal and oxygen stratification, the near-bottom layer was always acidic (pH 5.9-6.6). A very substantial pH gradient (pH 2.8 m^{-1}) was observed in June between the depths of 3 and 4 m (Fig. 3). A similar gradient (pH 2.7 m^{-1}) also occurred in July between depths of 2 and 3 m; however, in September a drop in pH of 0.6-0.9 units m^{-1}

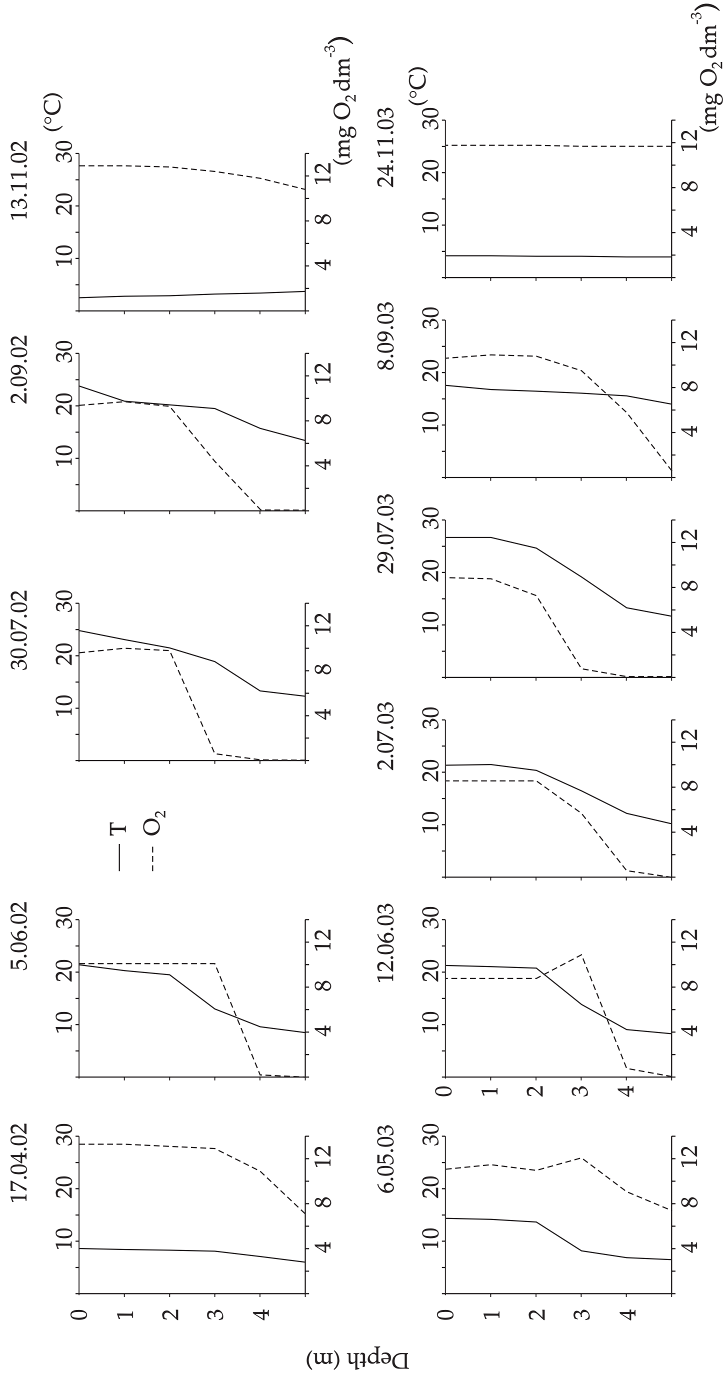

Fig. 2. Thermal and oxygen stratification and water visibility in Lake Smolak in 2002 and 2003 (T – water temperature, O_2 – oxygen concentration).

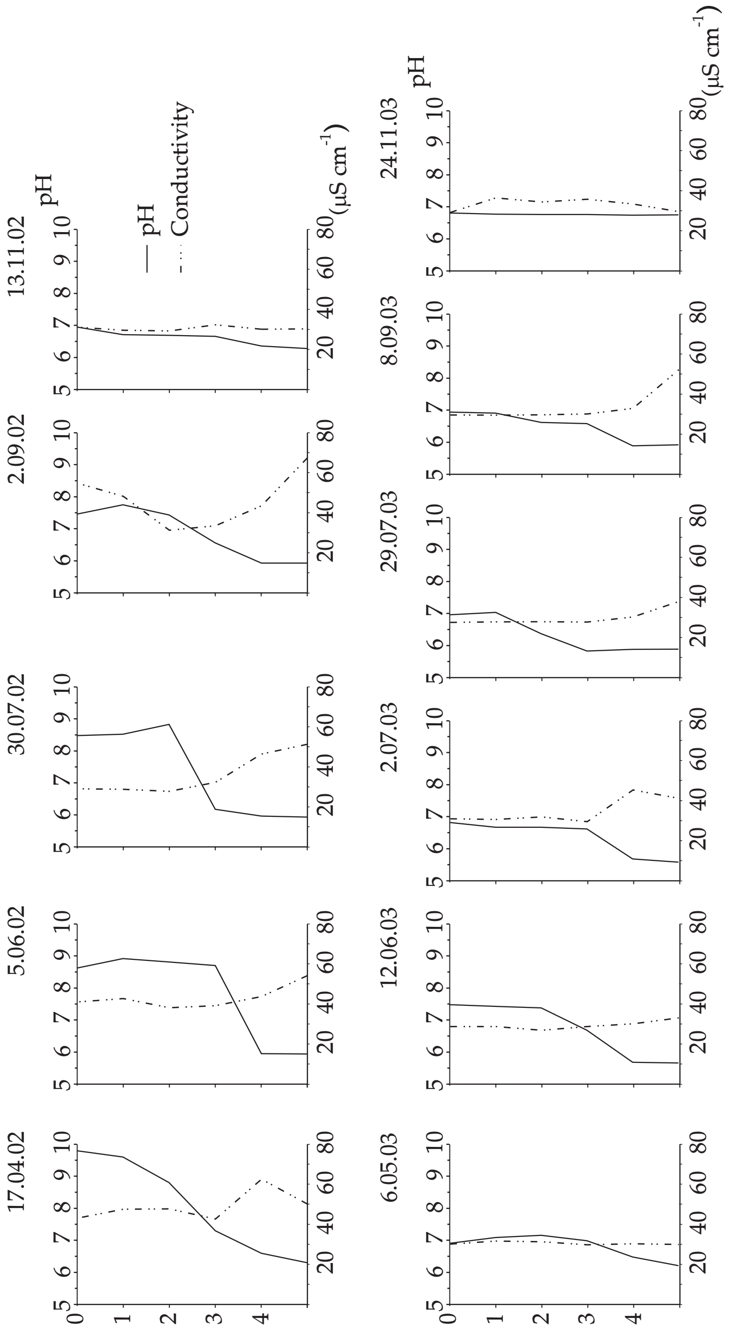

Fig. 3. The acidity and conductivity of Lake Smolak waters in 2002 and 2003.

was recorded between depths of 2 and 4 m. In 2003, the pH range of the water in the epilimnion was decidedly smaller than in the preceding year (pH 6.4-7.5); however, it was similar in the near-bottom layer (pH 5.6-5.9). The pH gradient observed was also smaller than that in 2002, and the pH decreased by 0.5-1.0 units between the depths of 3 and 5 m from July to September (Fig. 3).

In 2002, conductivity in the epilimnion ranged from 28 to 55 $\mu S\ cm^{-1}$, while in the near-bottom layer it was from 30 to 68 $\mu S\ cm^{-1}$; this range was smaller, however, in 2003 (27-36 $\mu S\ cm^{-1}$ in the epilimnion and 30-52 $\mu S\ cm^{-1}$ above the bottom). A clear conductivity gradient was only observed during periods of thermal stratification. The largest increase in conductivity (of 20 $\mu S\ cm^{-1}$) was noted between depths of 3 and 4 m in April and between 4 and 5 m in September 2002, while in 2004 this was noted only in September below depths of 4 m.

Concentrations of iron and ammonia nitrogen varied as depth increased (Fig. 4). In the epilimnion, the concentration range of total iron in both years was similar (0.02-0.06 mg dm^{-3}), but in the near-bottom layer clear increases of iron concentration were observed during thermal stratification from 0.08 in April to 0.30 mg dm^{-3} in September 2002 and from 0.08 in May to as high as 0.46 mg dm^{-3} in September 2003.

The concentration of ammonia nitrogen (NH_4-N) in the epilimnion in 2002 ranged from 0.178 to 0.362 mg NH_4-N dm^{-3}, and in 2003 from 0.193 to 0.407 mg NH_4-N dm^{-3}. During the period of thermal and oxygen stratification, increases in the concentrations of ammonia nitrogen from 0.448 mg dm^{-3} in April to 2.384 mg dm^{-3} in September 2002 and from 0.352 mg dm^{-3} in May to 1.634 mg dm^{-3} in September 2003 were observed in the near-bottom layer. When the water in the epilimnion was less acidic in April 2002, the concentration of the undissociated form of ammonia (NH_3-N) ranged from 0.045 at depths of 2 m to 0.108 at 1 m, and 0.164 mg dm^{-3} at the surface. Values exceeding 0.05 mg NH_3-N dm^{-3} were noted in June (0.051 mg NH_3-N dm^{-3}) at 1 m and in July (0.080 mg NH_3-N dm^{-3}) at 2 m. In 2003, due to the basicity or slight acidity of the water, the contents of ammonia nitrogen in the epilimnion did not exceed 0.004 mg NH_3-N dm^{-3}.

SPECIES RICHNESS AND DOMINANT SPECIES

In the 2002-2004 period, a total of 122 specimens belonging to eight fish species were caught. Interspecies hybrids were also confirmed. Based on catches made in 1993

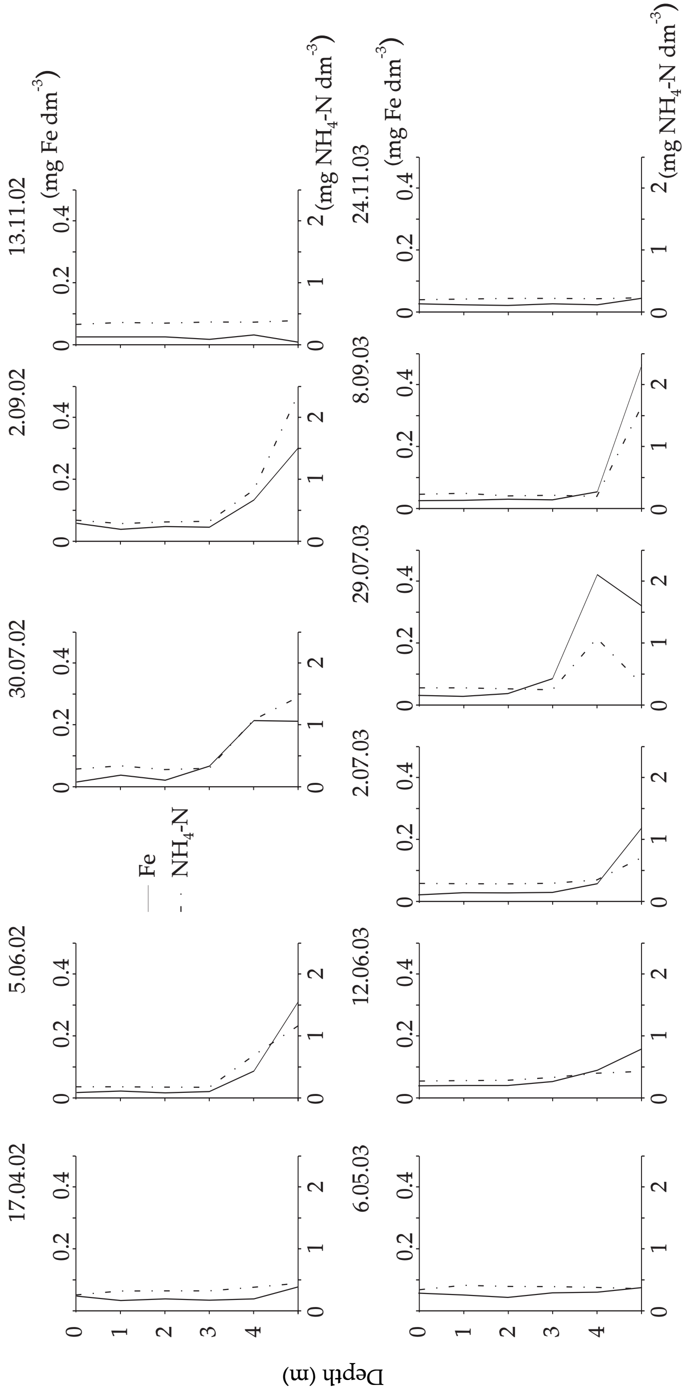

Fig. 4. Concentrations of total iron (Fe) and ammonia nitrogen (NH_4-N) in the water of Lake Smolak in 2002 and 2003.

and information from anglers, it was established that an additional two species occur in the lake (Table 1).

TABLE 1

Species composition of fish aggregations occurring in Lake Smolak according to spawning groups (Balon 1990)

Specification			Years 50-th	2002-2004
Non-guarding and open substratum egg scattering				
Pelagophil	Eel	*Anguilla anguilla* (L.)	-	+
Phytolithophils	Roach	*Rutilus rutilus* (L.)	-	+
	Silver bream	*Abramis bjoerkna* (L.)	-	+
	Bream	*Abramis brama* (L.)	-	+
	Perch	*Perca fluniatilis* L.	+	+
Phytophils	Rudd	*Scardinius erythrophthalmus* (L.)	-	+
	Silver crucian carp	*Carassius auratus gibelio* (Bloch)	-	+
	Carp	*Cyprinus carpio* L.	-	+
	Pike	*Esox lucius* L.	+	+
Guarding and nesting				
Phytophil	Pikeperch	*Sander lucioperca* (L.)	-	+

Six of the species noted belong to the family Cyprynidae, two to Percidae, and one each to Esocidae and Anguillidae. Roach comprised the largest share of the ichthyofauna of the lake, followed by bream, *Abramis brama* (L.) (Fig. 5A). The permanence of occurrence of these species in the catches was the highest at approximately 60%. The remaining species were caught irregularly and in very small numbers. In comparison with the period preceding liming and fertilization, species richness was several-fold higher.

TABLE 2

Characteristics of fish caught in Lake Smolak in the 2002-2004 period. N – number, body length (Lc) and body weight ranges provided in parentheses (min-max)

Species	N	Body length (mm)	Body weight (g)	Age group
Roach	66	91.8 (10-148)	14.0 (9-59)	II-IV
Bream	27	159.8 (133-200)	76.1 (40-140)	III-V
Perch	8	137.8 (54-280)	125.7 (6-456)	0, IV-VI
Pike	8	379.7 (321-480)	499.6 (318-805)	III-VI
Rudd	3	115.3 (85-133)	37.0 (13-56)	III-IV
Pikeperch	3	370.0 (340-390)	601.8 (484-674)	III-IV
Silver bream	2	125.0 (116-134)	40.1 (29-51)	III, VI
Silver crucian carp	2	350.0 (340-360)	1723.0 (1594-1852)	X, XI
Hybrids	3	133.3 (131-135)	35.5 (33-39)	V

With the low biomass and small number of fish caught, the ichthyofauna assemblage structure depended primarily on the mean body weight of the specimens from particular species (Table 2). Taking into consideration data on the body weight of carp, *Cyprinus carpio* L., caught by anglers (approximately 9000 g), it was estimated that the largest share of the fish biomass was of carp, silver crucian carp, *Carassius auratus gibelio* (Bloch), and pike, which comprised together nearly 80% of the biomass of fish

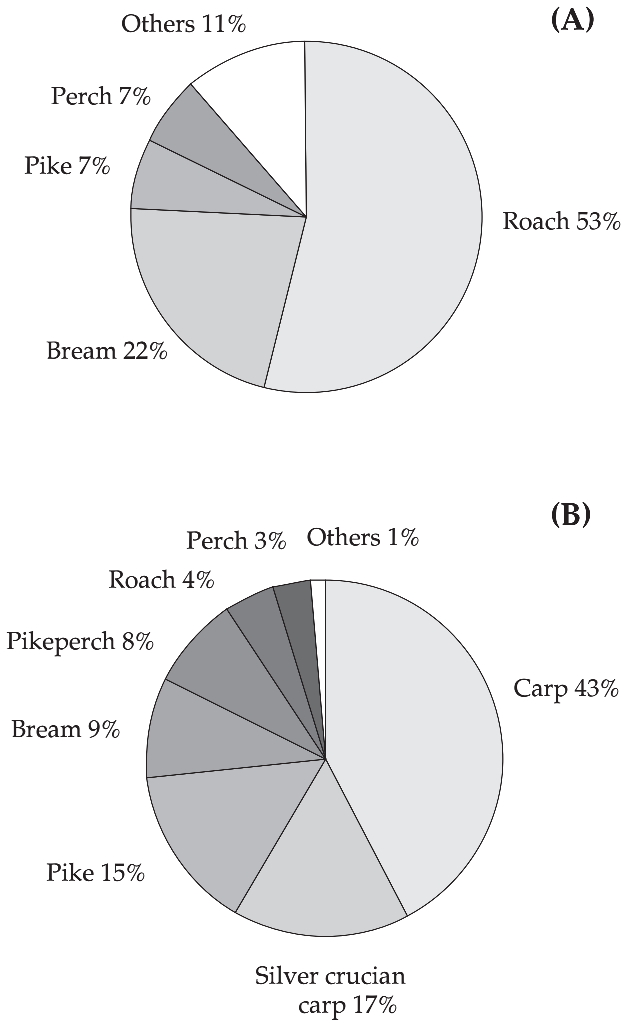

Fig. 5. Domination structure of fish in Lake Smolak in the 2002-2004 period, A – number share, B – weight share.

caught (Fig. 5B). The majority of caught fish were mature specimens, and only in the case of perch was the occurrence of juvenile stages confirmed. Roach was represented almost exclusively by specimens from II age group, while the silver crucian carp specimens caught were large and old.

GROWTH RATE

Sufficient quantities of material that permitted studying the age and body length growth rates were only obtained for roach and bream. These species were represented exclusively by specimens from the II-IV (roach) and III-V (bream) age groups. The roach from Lake Smolak was characterized by a fairly rapid growth rate (Fig. 6A). In the first year of life it attained an average body length of 4.2 cm, and fish from the IV age group were 13.5 cm. The growth rate of bream in Lake Smolak was very low (Fig. 6B). The comparison of the average body length of various age groups with boundary data determined for various types of growth indicated significant differences (Wilcoxon test, P = 0.043). In year I of life bream attained a body length of 4 cm, and year V it was 16.5 cm. A slight increase in body length growth rate was detected between years I and II, while decreases in it were noted until year V of life.

The remaining fish species occurring in Lake Smolak were caught in small quantities. The data obtained from them are not representative and only suggest certain phenomena. The body length growth rate of perch was average. In year I of life, specimens of this species attained a mean body length of 5 cm, and in year V they exceeded slightly a body length of 20 cm (Fig. 6C). Predatory fish (pike and pikeperch, *Sander lucioperca* (L.)) exhibited exceptionally low growth rates with mean body lengths of both species in year III of life of approximately 28 cm.

DISCUSSION

Studies of the species composition and richness of fish assemblages are an important source of information regarding lakes subjected to liming treatments (Degerman et al. 1992, Vuorinen and Vuorinen 1992, Rask et al. 1995). The water pH in limed lakes is the decisive factor regarding species composition and fish assemblage structure. Decreases in the density of the dominant perch and increases in that of cyprinids, especially roach, in lakes prior to liming has been observed numerous times (Appelberg et al. 1992). This type of change has also been observed in Lake Smolak, in

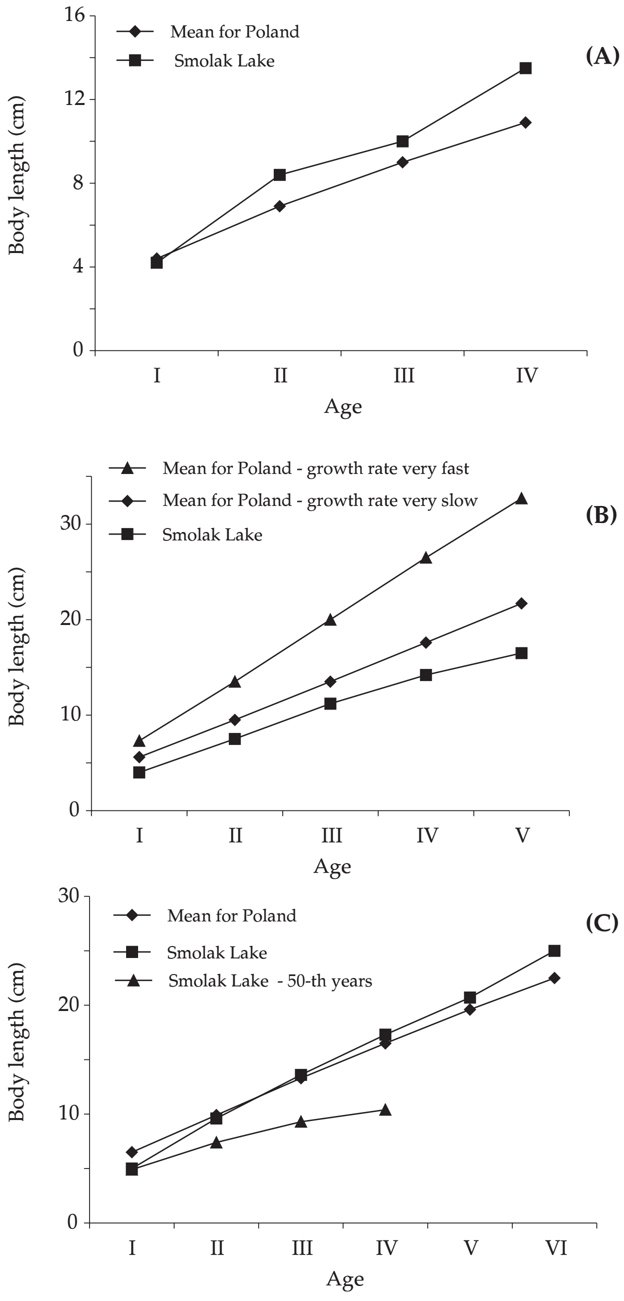

Fig. 6. Growth of roach (A), bream (B), perch (C) in Lake Smolak in comparison with the mean growth of fish in lakes in northern Poland.

which, prior to liming, the most numerous species was perch (Zawisza 1961). The current fish assemblage structure is dominated by roach. Changes in the assemblage structure are confirmed by increases in the resources of mineral nutrients in the lake (Hutorowicz 2001, Hutorowicz and Hutorowicz 2002).

The growth rates of fish in limed lakes generally increased (Appelberg et al. 1992, Rask 1992). The growth rates of predatory fish (pike, perch) increased in response to the increased density of prey. However, further increases in the number of fish in the assemblage meant that there was more intraspecies and interspecies competition; this lowered the growth rates of the most numerous species. In comparison with fish from the same age groups from other lakes in northern Poland, the predatory fish (pike, pikeperch) in Lake Smolak attained the smallest sizes; this was the result of low fish density. Food resources also had a decisive impact on the body length sizes attained by planktivorous (roach, perch) and benthic feeders (bream). The benthic fauna in dystrophic lakes is not abundant (Clarke et al. 1997); this may explain the very slow growth rate of bream in comparison with that of populations of this species inhabiting other Polish lakes (Szczerbowski 1981). Liming lakes causes a substantial increase in the density of zooplankton (Ejsmont-Karabin 1998, Węgleńska 1998), which is why a fairly high growth rate was determined for planktivorous fish that did not occur at high densities. The body length growth rate of perch in Lake Smolak was similar to the mean values determined in the lakes of northern Poland and simultaneously much higher than in the period prior to liming (Żuromska 1961), when this species attained much smaller sizes than currently.

One of the most significant abiotic environmental factors impacting the stability of fish assemblages is variation of water pH levels. The periodic decreases of water acidity observed following liming had the most significant impact on the ichthyofauna of these lakes. It was observed that in these lakes the species composition underwent greater variation than in lakes that had not been acidified (Appelberg 1998). Increases in the water pH levels of Lake Smolak permitted species to inhabit it that had not previously done so. Since the lake is not connected with other lakes, the only source of new species is stocking, which was done during same period as the liming treatment (Zdanowski and Hutorowicz 1998). Additionally, the owner of the lake stocked it at varying frequencies in the 1990s.

The small number of juvenile specimens and the occurrence of interspecies hybrids suggest fish reproduction is disturbed in Lake Smolak. Sensitivity to low pH is species specific. Disturbances in the embryonic development of roach and bream was observed at pH 6, while in perch and pike a decrease in egg survival and an increase in larva mortality were observed at pH 5 (Rask 1992, Vuorinen and Vuorinen 1992). Although fairly large fluctuations in water pH have been registered in Lake Smolak in recent years, they have remained within the tolerance limits of fish. This suggests that water pH was probably not the parameter directly responsible for fish occurrence, but it could have impacted substantially the reproduction of species that are most sensitive to low pH. The low success rate of fish in the lake could also have been caused by the lack of appropriate spawning grounds. Most of the species confirmed in the lake are either from phytophilous or phyto-lithophilous spawning groups, and there are not enough appropriate spawning sites for these species. Currently, there are no submerged hydrophytes. In the shore zone, with the exception of the floating peatbog that occupies approximately 50% of the length of the shoreline (Hutorowicz 2003), there are only small phytocenoses of vascular vegetation (Dziedzic 1998). The bottom sediments also pose a problem for developing eggs. As is the case in typically dystrophic basins, the bottom is covered in organic sediments (Hutorowicz et al. 1998), which always have a thick, loose structure and a low pH (Stangenberg 1938, Górniak 1996, Hutorowicz et al. 1998).

The periodic occurrence of undissociated ammonia nitrogen in the water surface layer could also have a negative impact on reproduction. This phenomenon was observed on days when there was intense photosynthesis by phytoplankton, which led to a substantial increase in the pH value. The high basicity of the water (pH 9.8) meant that half of the total ammonia that occurred was undissociated, and in extreme cases exceeded three-fold values of 0.05 mg NH_3-N dm^{-3}, which is considered to be safe in cyprinid fish cultivation (Karpiński 1994). The iron in the epilimnion did not have any adverse effects on the fish since concentrations of it were several-fold lower than critical levels (Karpiński 1994, Szczerbowski and Zdanowski 1995).

Furthermore, conditions for the fish are not advantageous from the end of spring until metalimnion circulation in the fall. The deciding factors in this included the total lack of oxygen in the near-bottom water layer as well as critically low concentrations of it at depths greater than 2 m (< 4 mg O_2 dm^{-3}). According to Szczerbowski and Zdanowski (1995) as well as Karpiński (1994), this can lead to inhibited embryonic development, retarded hatching, as well as to slowed growth in cyprinid species, the most commonly occurring species in Lake Smolak. The large acidity gradient between the epilimnion and the deeper water layers and the high concentrations of ammonia nitrogen and iron in the these layers might have had a disadvantageous impact on the fish. Due to these factors and the fact that the basin is shaped like a trough with steeply inclined shores, as much as 70% of the lake bottom in spring and summer is not available for spawning or feeding.

CONCLUSIONS

1. Only two species of fish occurred in Lake Smolak in the period prior to liming and mineral fertilization, while the current ichthyofauna is represented by ten species, most of which are from the cyprinid family.
2. The fish assemblage confirms the increased productivity of the lake that is suggested in the literature.
3. The growth rate of planktivorous fish (roach) was faster, while that of predatory fish was slower than in many other Polish lakes. Fish growth was probably slowed by long-term critically low oxygen concentration levels at depths of more than 2 m and its total lack in the near-bottom water layers. The slow growth rate of predatory fish was a consequence of their low density.
4. The breeding success of most of the species was poor; this was likely due to the periodic occurrence of the undissociated form of ammonia nitrogen in the epilimnion of the lake as well as the lack of appropriate spawning grounds for phytophilous and phyto-lithophilous species.
5. The liming and natural fertilization of this dystrophic lake increased nutrient resources permanently and also caused a total shift in the structure of the phyto- and zooplankton, limited the range of occurrence of the floating peatbog, and altered permanently the structure of the fish assemblage. The anticipated increase in fisheries yield was not noted. For these reasons, it is evident that these types of treatments, with the exception of sort-term liming to prevent the anthropogenic acidification of dystrophic lakes, failed in terms of nature preservation and fisheries.

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STRESZCZENIE

ICHTIOFAUNA DYSTROFICZNEGO JEZIORA SMOLAK TRZYDZIEŚCI LAT PO ZAPRZESTANIU WAPNOWANIA I NAWOŻENIA

W latach 50-tych XX w. w niewielkim i płytkim jeziorze Smolak (rys. 1) występowały tylko okoń *Perca fluniatilis* L. i szczupak, *Esox lucius* L. Przeprowadzone w latach 1971-1974 eksperymentalne wapnowanie i nawożenie mineralne jeziora upodobniło ten zbiornik do jezior harmonicznych o obojętnym odczynie wody. Na podstawie badań prowadzonych w latach 2002-2004 określono bogactwo gatunkowe, tempo wzrostu oraz strukturę zespołu ryb na tle aktualnych warunków fizyczno-chemicznych wody. W jeziorze wyróżniono dwie strefy, epi- i metalimnionu, wyraźnie zróżnicowane pod względem termicznym, tlenowym (rys. 2), odczynu i przewodności elektrolitycznej wody (rys. 3) oraz zawartości żelaza i azotu amonowego (rys. 4). Ichtiofauna jeziora reprezentowana była przez 10 gatunków należących do 4 rodzin (tab. 1-2). Ryby w jeziorze występowały w niewielkim zagęszczeniu. Najbardziej liczne były płoć, *Rutilus rutilus* (L.) i leszcz, *Abramis brama* (L.) (rys. 5). Płoć charakteryzowała się szybkim tempem wzrostu, natomiast leszcz bardzo wolnym (rys. 6). Ograniczone występowanie hydrofitów oraz znaczne wahania i gradient właściwości fizyczno-chemicznych wody wpływały negatywnie na ichtiofaunę jeziora.