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EUTROPHICATION AND WINTER-PERIOD STRUCTURE OF PHYTOPLANKTON IN THREE DEEP LAKES IN THE ŁĘCZNA–WŁODAWA LAKELAND, EASTERN POLAND

ABSTRACT: Studies were done in winter 1996 in three ice-covered dimictic lakes of the Łęczna-Włodawa Lakeland, eastern Poland. They involved physico-chemical conditions (temperature, oxygen concentration, pH, conductivity and Secchi-disc transparency), as well as biological ones (abundance, chlorophyll a concentration and phytoplankton structure). The oxygenation of the near-bottom layers combined with the observed structure of the winter phytoplankton confirm the rate of eutrophication of these bodies of water which had already been observed in the summer.
KEY WORDS: lakes, phytoplankton winter, eutrophication

1. INTRODUCTION

Seasonal changes in the biomass and structure of the phytoplankton of lakes of the northern temperate zone have been studied from many different points of view for many years (i.a. by Spodniewska 1978, Sommer et al. 1986, Talling 1993, Lampert and Sommer 1993). However, the greater part of the work done has been concerned with the growing season, with only more limited data being available in relation to winter phytoplankton.

Under winter ice, the development of phytoplankton is clearly shaped by factors differing from those at work in the growing season. In the temperate zone, the amounts of light reaching a lake are reduced to a minimum in winter by ice and snow. While pure ice may allow through as much as 70–95% of photosynthetically-active radiation, a thin layer of snow is all that is needed to reduce this to 10% (Bolsenga and Vanderploeg 1992). In turn, the layer of water receiving the greatest amount of light is also the coldest, while ice cover also prevents the mixing of water and gaseous exchange with the atmosphere (Wright 1964, Spaulding et al. 1993). The last factor is one of those leading to the phenomenon of the winterkill of fish in shallow lakes (Ellis et al. 1991).

In spite of the seemingly unfavourable conditions for the development of phytoplankton, it is sometimes in this very situation – under ice cover – that mass appearances of algae occur (Wright 1964, Vanderploeg et al. 1992), or quite high values for biomass are recorded (Pennak 1968, Cloern et al. 1992). However, the period is more often associated with a low abundance of phytoplankton (Jones and Ilmavirta 1978, Talling 1993, Agbeti and Smol 1995).

The study presented traced the structure of winter phytoplankton in three deep, dimictic lakes. It took account of abundance, chlorophyll a concentration, and the structure of the phytoplankton as expressed by the percentage occurrence of taxonomic groups and the dominant species present. Also basic physico-chemical conditions were studied as: temperature, oxygen concentration, pH, electrolytic conductivity and Secchi-disc visibility. In order to indicate changes ongoing over time in one of the study lakes – lake Piaseczno, comparisons were made between the years 1971 and 1996 in relation to the physico-chemical parameters like oxygenation and visibility, as well as the structure of winter phytoplankton.

2. THE STUDY AREA

The Łęczna–Włodawa Lakeland is situated in east-central Poland between latitudes 51° 35' and 51° 14' North and longitudes 22° 51' and 23° 38' East. The area has more than 60 lakes, of which the majority are shallow. Lakes: Piaseczno, Rogóźno and Zagłębocze, in which the research described was done, are among the few deeper bodies of water. Their areas, maximum depths and trophic statuses are given in Table 1. Two of the lakes studied (Piaseczno and Rogóźno) are within the Łęczna Lakeland Landscape Park (Fig 1.), while lake Zagłębocze is in the buffer zone of Polesie National Park. Lake Piaseczno is mesotrophic (Radwan et al. 1987). In the 1970s, lakes Rogóźno and Zagłębocze were also classified as mesotrophic (Radwan et al. 1987), based on both physico-chemical

Table 1. Morphometric (Wilgat et al. 1991) and trophic data for studied lakes

Lake	Area (ha)	$Depth_{max.}$ (m)	1970s		1990s	
			trophic status	SD (m) summer	trophic status	SD (m) summer
Piaseczno	84.7	38.8	mesotrophic*	5,2*	mesotrophic**	4,75**
Rogóźno	57.1	25.4	mesotrophic*	3,0*	eutrophic**	2,5**
Zagłębocze	59.0	25.0	mesotrophic*	4,0*	eutrophic***	2,5****

* Acc. to Radwan et al. 1973, ** Acc. to Buszewska-Rydzik et al. 1994, *** Acc. to Radwan et al. 1987, **** Acc. to Wojciechowska (unpubl. data)

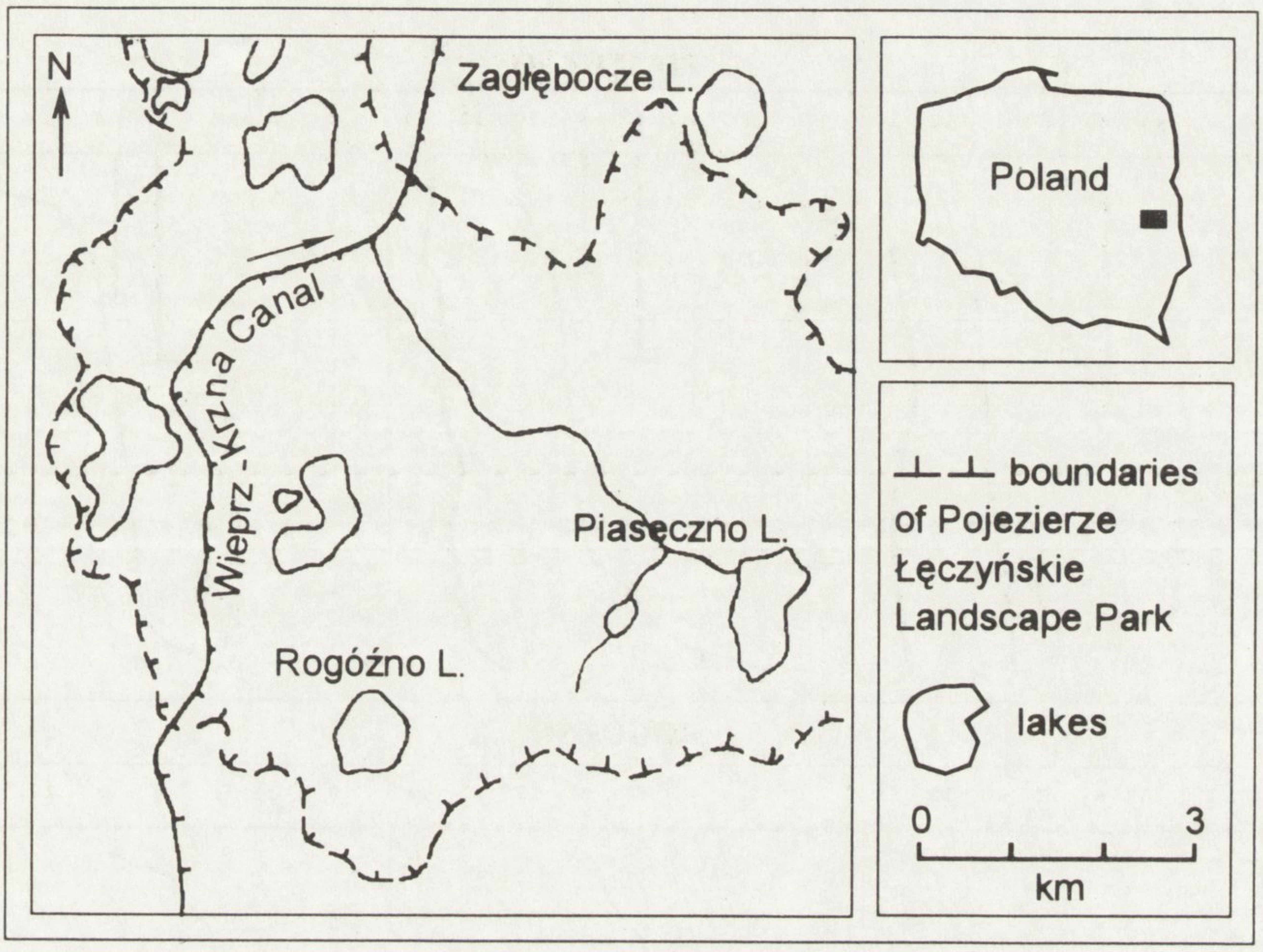

Fig. 1. The locations of the lakes studied

features (visibility, conductivity and oxygenation), and biological ones (the composition of zooplankton). However, these bodies of water are now classified as eutrophic (Buszewska-Rydzik et al. 1994).

3. MATERIALS AND METHODS

The physico-chemical and biological factors were studied in winter 1996. In the period January-March, the lakes were covered with a thick, 50–60 cm layer of ice overlain with a layer of snow of 5 cm. All the physico-chemical and biological variables were measured throughout the water column. Water sampling was done and measurements of physico-chemical variables made in stations where depth is up to 20 m (Fig. 2, Table 2). Measurements of temperature and oxygenation were made at depth intervals of one metre with the aid of an WTW OXI 96 oxymeter. Water for biological analyses was taken using a Ruttner-type water-sampler of 2 dm^3 capacity – at depth intervals of 2 m in the euphotic zone, and at intervals of 3 m below that. The pH and electrolytic conductivity of each sample were measured and mean values calculated for the euphotic and aphotic zones. Water for biological analyses consisted of combined samples for the two zones separately.

Measurement of the concentration of chlorophyll involved the filtering of water through Whatman GF/C filter papers, followed by homogenization of the papers and extraction in boiling 90% ethanol (Nusch 1980). Measurements of absorption were made following 12-hour extraction with the aid of an EMCO spectrophotometer at wavelengths of 665 and 750 nm.

The abundance of phytoplankton was determined by way of the method described by Vollenweider (1969), us-

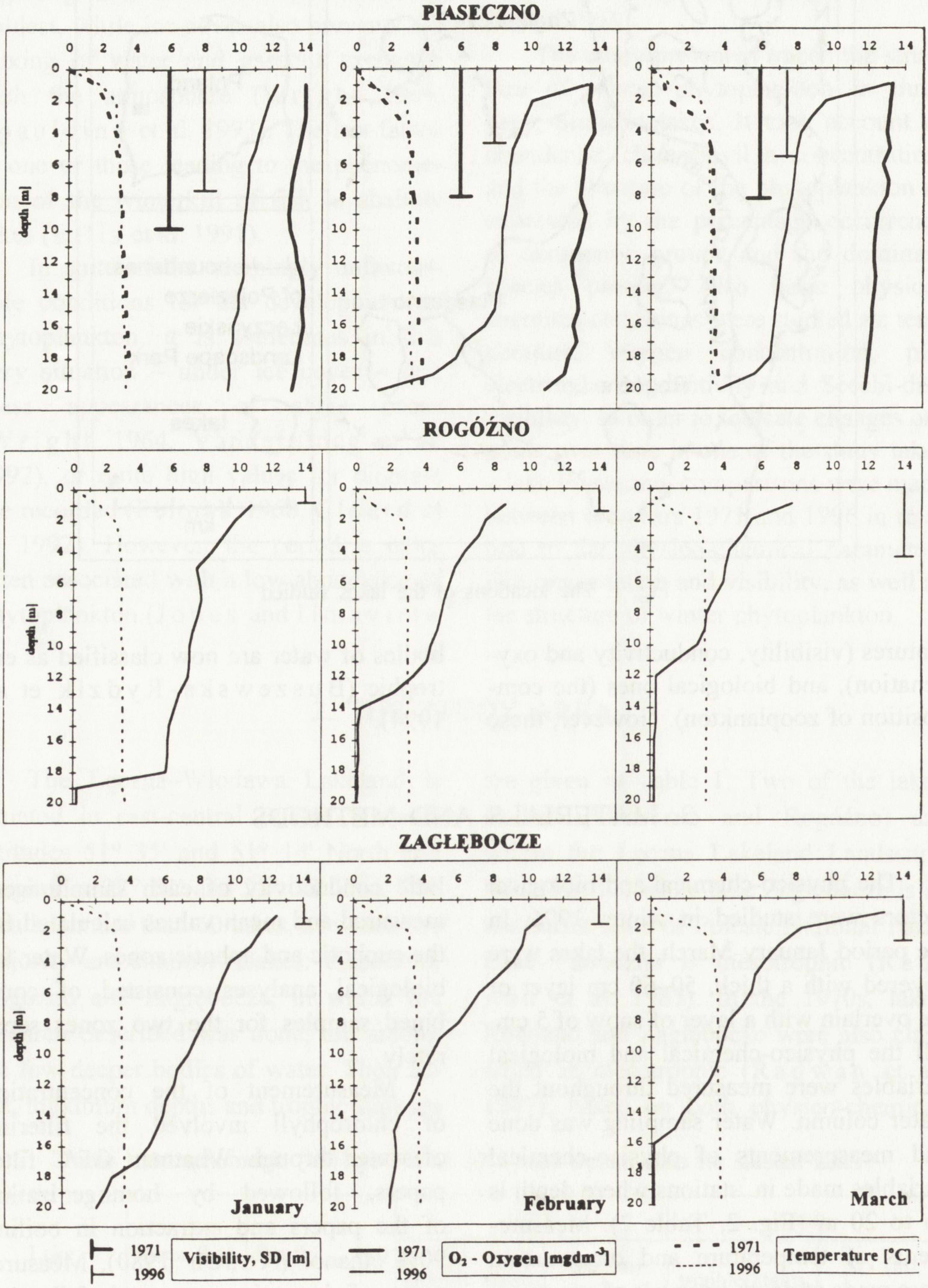

Fig. 2. Differences in temperature (°C) and oxygen contents (mg O_2 · dm^{-3}), as well as Secchi-disc visibility (m), in lake Piaseczno in the winters of 1971 and 1996, and in lakes Rogóźno and Zagłębocze in the later year

ing an inverted microscope and expressing the result per dm^3. The abundance and structure of phytoplankton in lake Piaseczno in 1971 was presented on the basis of the study by L e c e w i c z et al. (1973).

Table 2. Electrolytic conductivity (EC, μS cm^{-1}) and pH in studied lakes in winter 1996

Lake	Zone	January		February		March	
		pH	EC	pH	EC	pH	EC
Piaseczno	euphotic	7.0	75.3	6.6	73.5	6.6	61.0
	aphotic	7.4	74.0	6.5	74.0	6.8	63.0
Rogóźno	euphotic	7.9	171.0	7.6	220.0	7.4	182.5
	aphotic	8.1	169.0	7.3	234.0	7.2	188.0
Zagłębocze	euphotic	8.0	146.5	7.4	159.0	7.3	131.5
	aphotic	7.8	149.0	7.1	164.0	7.2	138.0

4. RESULTS

Two of the three lakes studied (Rogóźno and Zagłębocze) showed similarities in terms of pH and electrolytic conductivity (Table 2). Throughout the winter period, mean values for pH for both the euphotic and aphotic layers varied within the range 7.2–8.0, while conductivity measured from 135 to 224 μS · cm^{-1}. Lake Piaseczno was shown to be different in character, with pH values between 6.5 and 7.2, and conductivites in the range 62–75 μS · cm^{-1}. Secchi-disc transparency varied in Lakes Rogóźno and Zagłębocze from 2 to 4 m, with an upward trend in late winter (March). In contrast, lake Piaseczno was characterized by the greatest transparency (8 m) in January, with values around 5 m in February and March (Fig. 2).

The configuration of thermal/oxygenation conditions presented in Fig. 2 shows the low values of oxygen content in the hypolimnion in lakes Rogóźno and Zagłębocze, as well as an increasing oxygen deficit as winter proceeds. In January an absence of, or declines in, the level of oxygenation were observed near the bottom, but by March such conditions characterized depths of more than 10 m. The greatest oxygen deficit was noted in the near-bottom water of lake Rogóźno, where saturation throughout the study period was below 5% (0.2 mg O_2 per dm^3). A similar oxygen deficit occurred in lake Zagłębocze in March.

In lake Piaseczno, oxygenation throughout the water column varied between 7 and 13 mg O_2 · dm^{-3} – corresponding to 60–90% saturation. Only in March at the very bottom the concentration of oxygen was minimal, at about 1 mg per dm^3 (Fig. 2). In March, all lakes had either anoxia (Rogóźno and Zagłębocze) or a decline in oxygenation in relation to previous months (Piaseczno) (Fig. 2). In the case of the latter lake, it was also possible to compare the situation regarding oxygenation with that of winter 1971 (Fig. 2), and it was found that concentration of dissolved oxygen was clearly lower in winter 1996 (at 7.8 mg · dm^{-3} on average, as compared with 12.0 mg · dm^{-3} in 1971).

Analyses of the phytoplankton took account of its abundance and chlorophyll concentration, as well as of its structure expressed in terms of the percentages of taxonomic groups and the dominant species.

Phytoplankton abundance was greatest in lake Zagłębocze, with 500–840 individuals $\cdot 10^3 \cdot dm^{-3}$ in the euphotic zone (Fig. 3). In lake Rogóźno, phytoplankton was much less abundant, at 12–260 individuals $\cdot 10^3 \cdot dm^{-3}$ in the euphotic zone, and there was a clear decline through the winter (Fig. 3). Low values for abundance and a downward trend through the winter were also characteristic

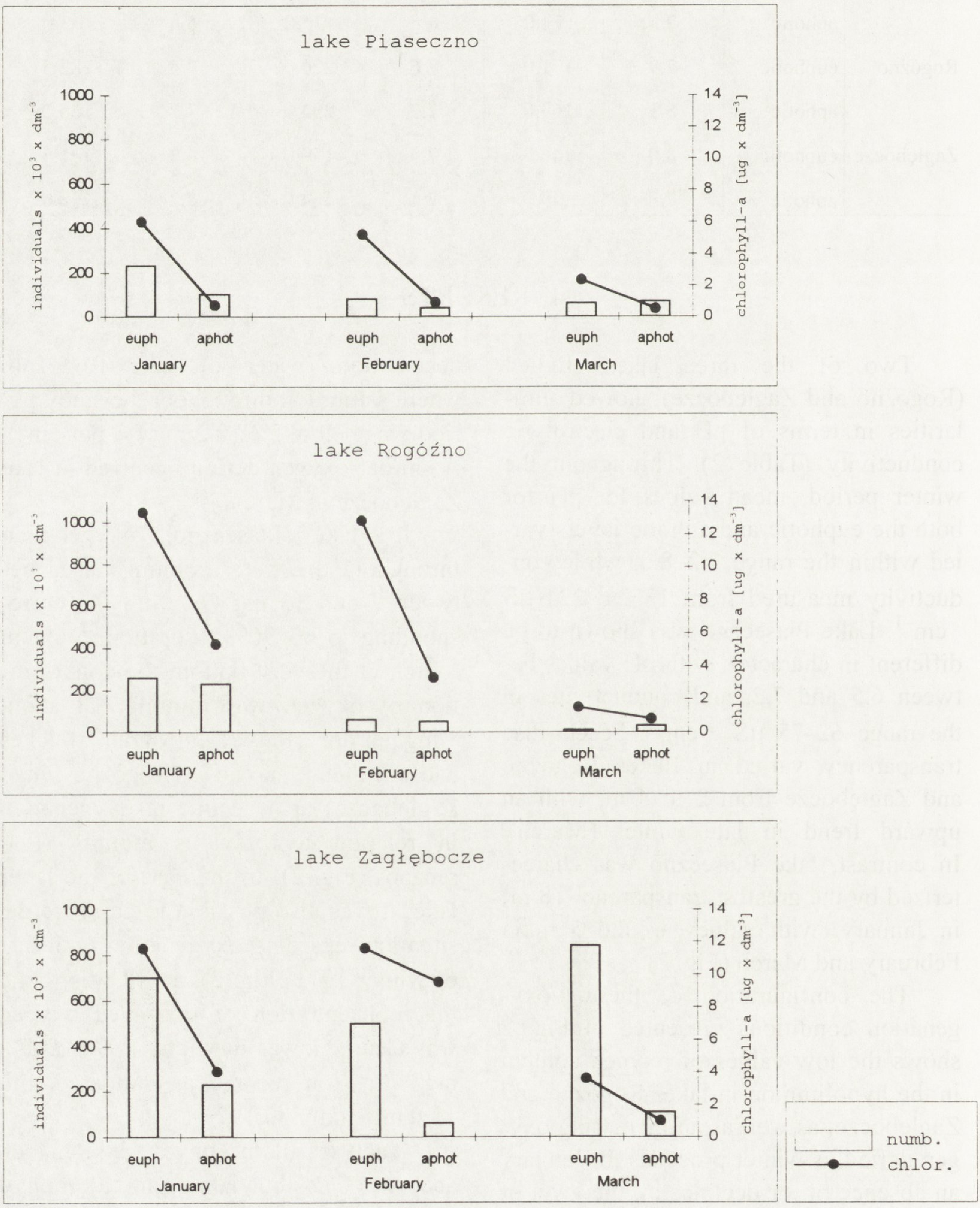

Fig. 3. Abundance of phytoplankton (10^3 individuals $\cdot dm^{-3}$) and concentrations of chlorophyll *a* and phaeopigments ($\mu g \cdot dm^{-3}$) in the euphotic and aphotic zones of lakes Piaseczno, Rogóźno and Zagłębocze in winter 1996

of the phytoplankton of lake Piaseczno (60–230 individuals $\cdot 10^3 \cdot dm^{-3}$).

The concentrations of chlorophyll *a* calculated for the euphotic and aphotic zones of lakes Rogóźno and Zagłębocze were similar, being higher in the euphotic zones (11.6–13.3 μg $\cdot dm^{-3}$ in January and February, 1.5–3.6 μg $\cdot dm^{-3}$ in March; Fig. 3). The amounts of chlorophyll a were lowest in lake Piaseczno (at 2.3–6.0 μg $\cdot dm^{-3}$), with a clear downward trend being noted through the winter (Fig. 3).

The studied lakes manifested a certain similarity of phytoplankton structure. Blue-greens and diatoms were clearly dominant, with the remaining taxonomic groups usually not accounting for more than 15% of the total abundance. An exception here was the cryptophyte group, of which the contribution to the phytoplankton in lake Piaseczno in January was above 20% (Fig. 4).

Throughout the winter, the phytoplankton of lake Zagłębocze was charac-

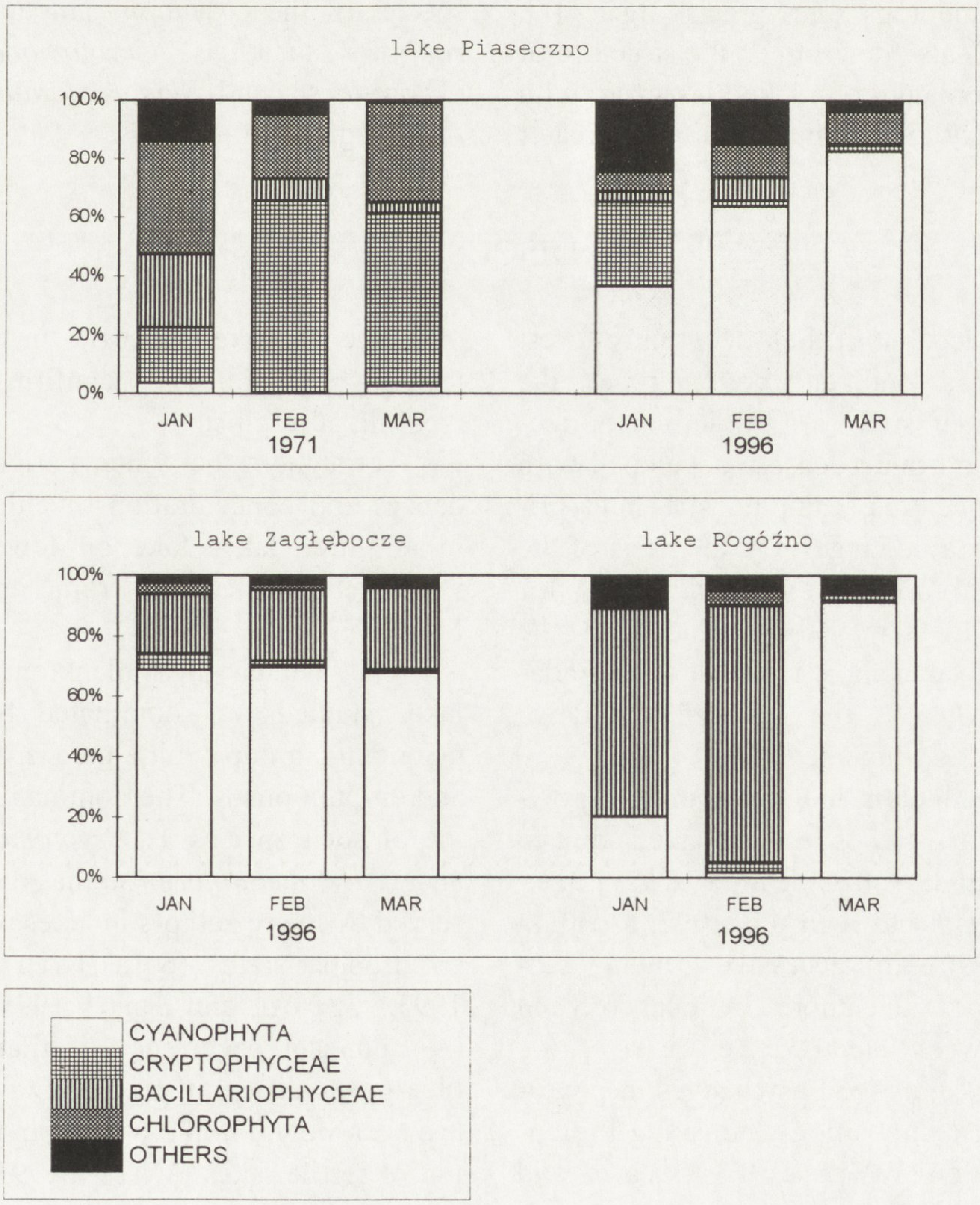

Fig. 4. Percentage shares of taxonomic groups in the overall abundance of phytoplankton in lake Piaseczno in the winters of 1971 and 1996, and in lakes Rogóźno and Zagłębocze in winter 1996 (means for the whole water column)

terized by abundance of blue-green algae of over 60%. The dominants were *Oscillatoria agardhii* Gom. and *O. redekei* Van Goor. Among the diatoms (accounting for about 20% of total abundance), the dominant species were *Asterionella formosa* Hass. In lake Rogóźno, diatoms were dominant in the first two months (55–98%), with abundance determined by *Asterionella formosa*. Blue-green algae were predominant in March, with the most abundant species being *Oscillatoria agardhii* (Fig. 4).

Filamentous blue-green algae (*O. agardhii*) also determined the structure of the phytoplankton in lake Piaseczno, with a tendency to account for an ever greater percentage of abundance as the months passed (Fig. 4). Within this grouping, a high proportion of the total numbers present in January was taken by small nanoplanktonic species of cryptomonad, most notably *Cryptomonas* sp., as well as by euglenids, predominantly *Trachelomonas volvocina* Ehr.

The winter periods of 1971 and 1996 were compared in terms of the structure of the phytoplankton in lake Piaseczno (Fig. 4). In the earlier periods, the main determinants were small nanoplanktonic species of the *Cryptophyceae* and *Chlorophyta*, such as *Cryptomonas* sp., *Chlorella* sp. and *Monoraphidium minutum* (Nag.) Kom.–Legn.

5. DISCUSSION

On account of their dry, sandy-forest shorelines, depth and bottom types, the lakes under study are attractive for recreation and quite densely-developed with summer centres, camping sites and private holiday cottages. On the basis of the method from Bajkiewicz-Grabowska (1987), they may be included in the group of lakes most resistant to degradation where the Łęczna-Włodawa Lakeland is concerned.

Nevertheless, long-term (mainly growing-season) studies in these lakes point to their rapid eutrophication (Wojciechowska and Krupa 1992, Kornijów 1996). In successive growing seasons more and more frequent oxygen deficits were noted (Wojciechowski et al 1995), as well as changes in phytoplankton composition indicating the eutrophication (Wojciechowska and Krupa 1992). In winter too, these bodies of water have low saturation, or a complete absence of oxygen in their aphotic layers. Comparisons of amounts of oxygen in lake Piaseczno in the winters of 1971 and 1996 confirm the increasing of trophism.

Throughout the winter period, abundances and concentration of chlorophyll in all three lakes take on low values, which tend to decrease from January to March.

The winter phytoplankton of the lakes studied was dominated by three taxonomic groups: blue-greens, diatoms and cryptomonads. The dominance under ice of such species as *Cryptomonas* sp. and *Asterionella formosa* has been observed by many authors in lakes of different trophic status (Spaulding et al. 1993, Agbeti and Smol 1995), while the abundant occurrence of filamentous blue-green algae of the genus *Oscillatoria* has been found in the winter phytoplankton of fertile lakes (Varis 1993, Seip and Reynolds 1995). In the lakes studied, *O. agardhii* and *O. redekei* occurred either throughout the winter period (Zagłębocze and Piaseczno), or in shorter period (Rogóźno in March). However, filamentous blue-greens were not noted in the phytoplankton of lake Piaseczno at the beginning of the 1970s. The dominance of such species in 1996 thus attests to an increase in the fertility of this body of water.

Also the differences in the population dynamics of the winter phytoplankton were observed in lake Piaseczno: increase of abundance in winter 1971 and a decrease in winter 1996. However, this mainly resulted from good light conditions under the ice in the early 1970s as a result of the lack of overlying snow cover (Lecewicz et al. 1973), as opposed to light attenuation through the overlying snow present in 1996. Light-related differences in the abundance and structure of winter phytoplankton have also been observed by other authors (Spaulding et al. 1993).

The winter studies in lake Piaseczno do nevertheless confirm the increasing fertility of this body of water as suggested previously by other authors (Wojciechowski et al. 1995, Radwan and Sender 1996). The trophic differences between the lakes are shown on the basis of indicators for the summer period (Table 1), with lakes Rogóźno and Zagłębocze have been shown as eutrophic and lake Piaseczno as mesotrophic. This is also maintained in winter, as it is documented by the chlorophyll concentration and the oxygenation of the layers over lying the bottom.

6. SUMMARY

Three dimictic lakes (Piaseczno, Rogóźno and Zagłębocze) located in the Łęczna-Włodawa Lakeland of east-central Poland (Fig. 1) were studied during three winter months at the beginning of 1996. These lakes are among the deepest in the area (Table 1), and were described as mesotrophic in the 1970s. However, all have been proved to be attractive to tourists and have thus come under anthropopressure.

Studies were concerned with physicochemical features (oxygenation, pH, conductivity and Secchi-disc visibility), as well as biological ones (the abundance and structure of phytoplankton and the concentration of chlorophyll *a*).

Lakes Zagłębocze and Rogóźno were found to have similar values for pH, electrolytic conductivity (Table 2) and oxygenation (Fig. 2). Both had oxygen deficits in winter (below 10 m depth in March), while transparency as measured by Secchi disc was in the range 2–3 m.

Lake Piaseczno was found to be somewhat distinct in character, having lower pH and conductivity (Table 2), as well as oxygen saturation throughout the water column at 60–80%. Nevertheless, oxygen conditions were clearly worse than in 1971 (Fig. 2).

The greatest abundances of phytoplankton were noted in L. Zagłębocze (500–840 individuals $\cdot 10^3 \cdot dm^{-3}$). The other two lakes had values in the range 12–260 individuals $\cdot 10^3 \cdot dm^{-3}$ (Fig. 3). Concentrations of chlorophyll a were always higher in the euphotic zone, with the highest being the 11.6–13.3 μg $\cdot dm^{-3}$ noted in January and February in lakes Zagłębocze and Rogóźno.

Filamentous blue-green algae (especially *Oscillatoria agardhii*) predominated in the structure of the phytoplankton of all the lakes, along with diatoms (with the dominant being *Asterionella formosa*). The remaining taxonomic groups did not usually account for more than 15% of overall abundance, although one exception concerned cryptophytes, for which the value in January in lake Piaseczno was higher than 20% (Fig. 4). The latter lake had manifested clear differences in phytoplankton structure in comparison with 1971.

The results presented (especially those relating to oxygen deficits and phytoplankton structure) point to the eutrophic nature of the lake studied. In the case of the lake Pi-

aseczno, the studies in the winter period further confirm the increase in productivity of this lake indicated previously by other authors.

7. REFERENCES

1. Agbeti M. D., Smol J. P. 1995 – Winter limnology: a comparison of physical, chemical and biological characteristics in two temperate lakes during ice cover – Hydrobiologia 304: 221–234.
2. Bajkiewicz-Grabowska E. 1987 – Ocena naturalnej podatności jezior na degradację roli zlewni w tym procesie [the valuation of lakes natural compliance for degradation, and the rola of thh drainage basins in this process] · wiad. Ekol. 33: 279–289.
3. Bolsenga S. J., Vanderploeg H. A. 1992 – Estimating photosynthetically available radiation into open and ice-covered freshwater lakes from surface characteristics; high transmittance case study – Hydrobiologia 243/244: 95–104.
4. Buszewska-Rydzik E., Girsztowtt K., Lachowska G., Matysiewicz E. 1994 – Stan czystości jezior województwa lubelskiego za rok 1993 [Environmental state of Lublin voivodship lakes in the year 1993] – Biblioteka Monitoringu Środowiska, Lublin, 176 pp.
5. Cloern J. E., Alpine A. E., Cole B. E., Heller T. 1992 – Seasonal changes in the spatial distribution of phytoplankton in small, temperate-zone lakes – J. Plank. Res. 14: 1017–1024.
6. Ellis C. R., Stefan H. G., Gu R. 1991 – Water temperature dynamics and heat transfer beneath the ice cover of a lake – Limnol. Oceanogr. 36: 324–335.
7. Jones R. I., Ilmavirta V. 1978 – Vertical and seasonal variation of phytoplankton photosynthesis in a brown-water lake with winter ice cover – Freshwat. Biol. 8: 561–572.
8. Kornijów R. 1996 – Krajobrazowe i morfometryczne uwarunkowania podatności dimiktycznych jezior Polesia na degradację oraz wskazania dotyczące ich racjonalnego użytkowania i ochrony [Degradation ability of the dimictic Polesie lakes resulting from their landscape and morphometric conditions, and suggestions for the management and protection measures] (W: Funkcjonowanie ekosystemów wodno-błotnych w obszarach chronionych Polesia [In: The functioning of wetland ecosystems in the protected areas of Polesie] Ed. S. Radwan) – Wydawnictwo UMCS, Lublin, 73–78.
9. Lampert W., Sommer U. 1993 Limnoökologie – Georg Thieme Verlag Stuttgart, New York, 374 pp.
10. Lecewicz W., Sokołowska W., Wojciechowski I. 1973 – The changes of winter phytoplankton in relation to the light climate in the lakes with various trophy – Ekol. pol. 13: 193–208.
11. Nusch E. A. 1980 – Comparison of different methods for chlorophyll and pheopigment determination – Arch. Hydrobiol. Beih. Ergebn. Limnol. 14: 14–36.
12. Pennak R. W. 1968 – Field and experimental winter limnology of three Colorado mountain lakes – Ecology 49: 505–520.
13. Radwan S., Kowalczyk Cz., Podgórski W., Fall J. 1973 – Materiały do hydrochemii Pojezierza Włodawskiego. Część III. Właściwości fizyczne i chemiczne [A contribution to the hydrochemistry of the Łęczna and Włodawa Lake District. Part III. Physical and chemical properties] – Ann. UMCS, Sec. C, 28: 97–116.
14. Radwan S., Kornijów R., Kowalik W., Jarzynowa B., Zwolski W., Kowalczyk C., Popiołek B. 1987 Ecological and fishery characteristics of lakes situated in the Future Western Polesie National Park – Ann. UMCS, Sec. C, 42: 163–183.
15. Radwan S., Sender J. 1996 – Kształtowanie się różnorodności biologicznej w obszarach wodno-błotnych Pojezierza Łęczyńsko-Włodawskiego [Biological diversity in the wetland araes of Włodawa-Łęczna Lakeland] (W: Funkcjonowanie ekosystemów wodno-błotnych w obszarach chronionych Polesia [In: The functioning of wetland ecosystems in the protected areas of Polesie] Ed. S. Radwan) – Wydawnictwo UMCS, Lublin, 45–55.
16. Seip K. L., Reynolds C. S. 1995 – Phytoplankton functional attributes along trophic gradient and season – Limnol. Oceanogr. 40: 589–597.

17. Sommer U., Gliwicz Z. M., Lampert M., Duncan A. 1986 – The PEG-model of seasonal succession of planktonic events in freshwaters – Arch. Hydrobiol. 106: 432–471.

18. Spaulding S. A., Ward J. V., Baron J. 1993 – Winter phytoplankton dynamics in a subalpine lake, Colorado, U.S.A. – Arch. Hydrobiol. 129: 179–198.

19. Spodniewska I. 1978 – Phytoplankton as the indicator of lake eutrophication. I. Summer situation in 34 Masurian Lakes in 1973 – Ekol. Pol. 26: 53–70.

20. Talling J. F. 1993 – Comparative seasonal changes, and interannual variability and stability, in a 26-year record of total phytoplankton biomass in four English lake basins – Hydrobiologia 286: 65–98.

21. Vanderploeg H. A., Bolsenga S. J., Fahnenstiel G. L., Liebig J. R., Gardner W. S. 1992 – Plankton ecology in an ice-covered bay of Lake Michigan: utilization of a winter phytoplankton bloom by reproducing copepods – Hydrobiologia 243/244: 175–183.

22. Varis O. 1993 – Cyanobacteria dynamics in a restored Finnish lake: a long term simulation study – Hydrobiologia 268: 129–145.

23. Vollenweider R. A. 1969 – A manual on methods for measuring primary production in aquatic environments – Blackwell, Oxford-Edinburgh, 213 pp.

24. Wilgat T., Michalczyk Z., Turczyński M., Wojciechowski K. H. 1991 – Jeziora Łęczyńsko-Włodawskie [The Łęczna-Włodawa Lakes] (W: Wybrane zagadnienia wartości i zagrożeń środowiska przyrodniczego jezior Piaseczno i Głębokie na Pojezierzu Łęczyńsko-Włodawskim [In: Selected problems of values and threats to the natural environment of Piaseczno and Głębokie lakes in the Łęczna-Włodawa Lakeland]) – Stud. Ośr. Dok. Fizjogr. 19: 23–140.

25. Wojciechowska W., Krupa D. 1992 – Many-years and seasonal changes in phytoplankton of lakes of Polesie National Park and its protection zone – Ekol. pol. 40: 317–332.

26. Wojciechowski I., Czernaś K., Krupa D. 1995 – Biotyczne walory jezior Poleskiego Parku Narodowego i jego otuliny i ich uwarunkowania [The biotic values and conditions of lakes in The Polesie National Park and its protection zone] (W: Ochrona ekosystemów wodnych w Poleskim Parku Narodowym i jego otulinie [In: Protection of freshwater ecosystems in The Polesie National Park and its protection zone] Ed. S. Radwan) TWWP Lublin, 38–45.

27. Wright T. R. 1964 – Dynamics of a phytoplankton community in an ice-covered lake – Limnol. Oceanog. 9: 163–179.

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