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ECOLOGICAL CHARACTERISTICS OF LAKES IN NORTH-EASTERN POLAND VERSUS THEIR TROPHIC GRADIENT

III. CHEMISTRY OF THE WATER IN 41 LAKES *

ABSTRACT: A characteristics is given of water chemistry in 41 lakes differing in their trophic state and mixis (di- and polymictic). Increasing trophic state of the lakes under study was accompanied by changes in the concentration of the following chemical components of water: an increase in the summer and spring content of total phosphorus and of its mineral and organic form, of total and organic nitrogen, an increase in the concentration of ammonia in spring, a summer increase of content of ammonia near the bottom in dimictic lakes, a growth of the content of calcium, sodium, potassium and bicarbonates, as well as an increase of oxidability and electrolytic conductivity of water in both mictic types and the layers studied, and a growth of the content of magnesium in dimictic lakes.

KEY WORDS: Lakes, trophic state, dimictic lakes, polymictic lakes, chemical composition of water, phosphorus and nitrogen content, stratification, seasonal changes.

Contents

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1. INTRODUCTION

This paper presents the results of studies on water chemistry in several dozen lakes in the north-eastern Poland. The study represents a part of a team research on the so-called "ecological monitoring of lakes" (K a j a k and Z d a n o w s k i 1983). The objective of the study is to describe the chemical composition of water in lakes differing in their trophic state and mixis (di- and polymictic), and to verify the usefulness of particular chemical indices for monitoring the process of lake eutrophication.

2. MATERIAL AND METHODS

A total of 41 lakes in north-eastern Poland were selected for the studies. Descriptions of the trophic state and morphometry of the lakes, as well as of their catchment areas can be found in other papers of this volume (B a j k i e w i c z - G r a b o w s k a 1983, K a j a k and Z d a n o w s k i 1983).

The degree of anthropogenic impact, primarily by direct pollution, varies considerably from lake to lake (K a j a k and

Z d a n o w s k i 1983). The main sources of pollution to lakes are municipal sewage and effluents from food industry (starch plants, scutching plants, distilleries, dairy industry, etc.). The highest degree of pollution is found in the following lakes: Barlewickie, Długie, Ełckie, Hartowiec, Iławskie, Juno Północne, Juno Południowe, Kraksy Duże, Lidzbarskie, Liwieniec, Sasek Mały, Stryjewskie, Szeląg Mały, Sztumskie and Wobel. The following are the lakes for which no data on the amounts of sewage are available at present, while hydrochemical indices indicate their being polluted: Maróz, Rzeckie, Tuchel and Warpuńskie.

Investigations were carried out in 1977 and 1978. Water of each lake was sampled twice: in spring, from the dissappearance of ice until the end of May (13 April-25 May), and during the peak of summer stagnation (12-28 August). Materials obtained for summer period are sufficiently representative, whereas those obtained for spring are (due to a relatively long sampling period) more varied and cause some problems when the lakes are compared. This applies in particular to the dimictic lakes and to a less extent, to the polymictic water bodies. During spring study period the stratification was already establishing itself: in some of the dimictic lakes: Rzeckie, Ołów, Kierzlińskie, Sarż, Piłakno, Ełckie, Sztumskie and Wobel.

Water samples for chemical studies were collected with Bernatowicz's sampler, from the epilimnion layer (0.5 m below the surface) and the hypolimnion layer (0.5 m above the bottom). At the same time water temperature and oxygen content were measured in a vertical profile, from the surface to the bottom.

Chemical analyses of water were made with standard methods described by J u s t and H e r m a n o w i c z (1955), as well as according to the S t a n d a r d M e t h o d s (1955). Colorimetric determinations were made on a "SPECOL" spectrophotometer.

Phosphate phosphorus (PO_4-P) and total phosphorus (Tot-P, after sample digestion in H_2SO_4 with an addition of ammonium persulphate), were determined colorimetrically with ammonium molybdate; ammonia - by direct nesslerization method; nitrites - with α-naphthylamine; nitrates - with phenolbisulphonic acid; total nitrogen (Tot-N) by Kjeldahl's method, after digestion in sulphuric acid and reading the concentrations on an ORION model ion-analyser

407A (total nitrogen represents total content of organic nitrogen and ammonia).

In the epilimnion, content of dissolved and particulate fractions of organic phosphorus and organic nitrogen was determined. Fractionation of organic phosphorus and organic nitrogen was performed filtering water samples through Whatman GF/C blotting paper.

Content of calcium, sodium and potassium was determined on a flame photometer. Total iron was analysed colorimetrically with ammonium rhodanate, silicates - with ammonium molybdate, magnesium - with titanium yellow, manganese - with ammonium persulphate, carbonates and bicarbonates - by titration with 0.1 n HCl in the presence of indicators, sulphates - by the nephelometric method, and chlorides - with silver nitrate.

The electrolytic conductivity of water was measured conductometrically with a DIGI 610 conductometer, and pH - potentiometrically on an ORION Model 407A ion-analyser (pH was measured only in summer period).

3. RESULTS

3.1. Thermal and oxygen conditions

In spring, temperature of the surface water layer in the dimictic lakes varied between 3.8 and 16.0^{o}C, and the content of oxygen - between 9.3 and 14.2 mg $\cdot$ dm^{-3}. Temperature of the near-bottom water layer ranged in that period from 3.6 to 8.4^{o}C, and oxygen content - from 0.0 to 14.2 mg $\cdot$ dm^{-3}. Near the bottom, concentration of oxygen dropped below 1 mg $\cdot$ dm^{-3} in the following lakes: Lidzbarskie, Szeląg Mały and Wobel.

In summer, temperature of the surface water layer in the dimictic lakes varied between 16.6 and 24.6^{o}C, and oxygen content - between 8.6 and 16.8 mg $\cdot$ dm^{-3}. Near the bottom, temperature of water ranged from 4.5 to 9.0^{o}C, and oxygen content - from 0.0 to 5.0 mg $\cdot$ dm^{-3}. In the majority of the lakes under study a decrease of oxygen in the vertical profile agreed with a decrease of water temperature. Oxygen curve of the shape corresponding to a negative heterograde was recorded only for Leleskie Lake; in case of all other lakes - it was a typical clinograde.

In the polymictic lakes, temperature of the surface and near-bottom water layers in spring ranged from 6.8 to 16.2°C and from 5.0 to 14.5°C, respectively, whereas the content of oxygen ranged from 7.0 to 15.7 mg $\cdot$ dm^{-3}, and from 3.9 to 13.5 mg $\cdot$ dm^{-3}, respectively. In Lake Kraksy Duże the concentration of oxygen in spring was over 20 mg $\cdot$ dm^{-3}. In spring period, stratification of temperature and oxygen-concentration was recorded for the following lakes: Tuchel, Warpuńskie, Kołowin, Rańskie, Sędańskie, Sasek Mały and Brajnickie.

In the polymictic lakes differences in summer water temperatures between the surface and the near-bottom layer were small (18.1-19.6°C and 15.1-19.5°C, respectively). Stratification of water temperatures was recorded only in lakes Tuchel, Warpuńskie and Sędańskie.

Content of oxygen in water of the polymictic lakes in summer varied between 7.3 and 18.7 mg $\cdot$ dm^{-3} in the surface layer, and between 6.0 and 14.0 mg $\cdot$ dm^{-3} near the bottom. Lakes Kraksy Duże and Tuchel have been excluded from the comparisons, as in these lakes the oxygen content near the surface and near the bottom was much lower, and amounted in Lake Kraksy Duże to 2.0 and 1.4 mg $\cdot$ dm^{-3}, and in Lake Tuchel to 4.8 and 0.3 mg $\cdot$ dm^{-3}, respectively.

3.2. Characteristics of the chemical composition of water

3.2.1. Introduction

Characteristics of water chemism in spring and summer periods are presented separately for the dimictic and the polymictic lakes. In each of these two types, three lake groups were distinguished which differed as regards summer content of total phosphorus in the surface water layer. Dimictic lakes: group 1 - 0.020-0.044 mg $\cdot$ dm^{-3} (lakes Gim, Kierzlińskie, Kuc, Leleskie, Maróz, Ołów, Piłakno, Probarskie, Sarż, Skanda), group 2 - 0.059-0.147 mg $\cdot$ dm^{-3} (lakes Czos, Kalwa Duża, Kokowo, Lampackie, Małszewo, Rzeckie, Sasek Duży)[1], group 3 - 0.175-0.506 mg $\cdot$ dm^{-3}

[1] Higher concentrations of total phosphorus were found only in two lakes: Małszewo and Kokowo (0.137 and 0.147 mg$\cdot$dm^{-3}), whereas in the remaining lakes content of total phosphorus never exceeded 0.087 mg$\cdot$dm^{-3}.

(lakes Ełckie, Juno Północne, Juno Południowe, Sztumskie and Wobel); polymictic lakes: group 1 - 0.054-0.092 mg $\cdot$ dm^{-3} (lakes Burgale, Kołowin, Mój, Rańskie, Sędańskie, Siercze), group 2 - 0.134--0.285 mg $\cdot$ dm^{-3} (lakes Bądze, Brajnickie, Długie, Hartowiec, Sambród, Sasek Mały, Stryjewskie, Warpuńskie), group 3 - 0.321--0.940 mg tot-P $\cdot$ dm^{-3} (lakes Barlewickie, Iławskie, Kraksy Duże, Liwieniec, Tuchel).

The range and the mean concentrations of particular chemical components of water in the trophic groups of di- and polymictic lakes in spring and summer are presented in Table I.

3.2.2. The trophic state and the content of phosphorus in water of the lakes under study

In spring average contents of total, organic and phosphate phosphorus in the surface and near-bottom water layers of the dimictic and polymictic lakes increased along with increasing lake trophic state (according to the summer content of tot-P in the epilimnion). Average concentrations of total, organic and phosphate phosphorus were, at this time, usually slightly higher in the near-bottom water layer (Table I). In spring, the differences between minimal and maximal content of the analysed phosphorus fractions in the epilimnion and near the bottom also increased along with increasing trophic state. Most significant differences were noted in poly- and dimictic lakes of the highest trophic state (Table I).

In spring, the percentage of phosphates in total phosphorus in the surface water layer of the dimictic lakes ranged from to 87 and in the polymictic lakes - from 5 to 83%. The highest mean percentage of phosphates was recorded for dimictic lakes of a high trophic state (60%), whereas in the remaining trophic and mictic groups the respective values were half lower. They amounted to 38 and 35% in the dimictic lakes of the first and the second group, and to 23, 28 and 30%, respectively, in the three trophic groups of the polymictic lakes.

In summer, average content of phosphate and organic phosphorus in the surface water layer, and of total, organic and phosphate phosphorus in the near-bottom water layer increased in the di- and polymictic lakes as the concentration of total phosphorus rose in the epilimnion (Table I). Similarly to changes in the content of

Table I. Spring and summer range of variation and the mean content of mineral salts, pH, oxidability and electrolytic conductivity of water of the surface (s) and near-bottom (b) layers in dimictic and polymictic lakes and in their trophic groups, differing in the summer content of total phosphorus in the epilimnion

Period	Lakes	Trophic group of lakes	TOT-P s	TOT-P b	TOTorg-P s	TOTorg-P b	PO_4-P s	PO_4-P b	TOT-N s	TOT-N b
			mg · dm^{-3}							
Spring	dimictic	1	0.038 0.020-0.085	0.063 0.036-0.099	0.021 0.007-0.064	0.037 0.016-0.063	0.017 0.006-0.035	0.026 0.001-0.071	1.05 0.56-2.06	1.12 0.56-2.80
		2	0.079 0.057-0.104	0.099 0.055-0.183	0.050 0.023-0.093	0.045 0.004-0.103	0.029 0.003-0.077	0.053 0.011-0.100	1.08 0.59-1.48	1.31 0.98-1.78
		3	0.481 0.140-0.864	0.547 0.140-0.935	0.168 0.085-0.354	0.140 0.118-0.445	0.313 0.050-0.554	0.407 0.050-0.695	1.81 1.29-2.36	2.08 1.61-3.16
	polymictic	1	0.044 0.022-0.058	0.054 0.033-0.080	0.033 0.018-0.047	0.036 0.000-0.063	0.011 0.004-0.026	0.012 0.000-0.026	1.52 0.83-2.36	2.08 1.06-4.96
		2	0.109 0.056-0.181	0.123 0.060-0.243	0.075 0.045-0.121	0.086 0.025-0.169	0.035 0.004-0.102	0.037 0.006-0.102	2.00 0.76-3.96	1.49 0.72-1.91
		3	0.309 0.082-0.806	0.317 0.067-0.840	0.152 0.068-0.236	0.130 0.032-0.275	0.157 0.014-0.275	0.187 0.011-0.808	2.01 1.16-2.66	1.96 1.06-2.66
Summer	dimictic	1	0.036 0.020-0.044	0.093 0.037-0.176	0.025 0.015-0.038	0.027 0.000-0.060	0.011 0.004-0.025	0.066 0.024-0.134	1.24 0.95-1.70	1.12 0.47-2.10
		2	0.091 0.059-0.147	0.178 0.071-0.265	0.065 0.010-0.129	0.049 0.000-0.140	0.025 0.002-0.058	0.129 0.024-0.207	1.49 1.00-1.95	1.50 0.82-2.01
		3	0.326 0.175-0.506	0.884 0.277-1.197	0.180 0.043-0.359	0.118 0.000-0.233	0.146 0.095-0.185	0.766 0.062-1.197	2.18 1.86-2.66	4.00 1.56-8.56
	polymictic	1	0.079 0.054-0.092	0.076 0.058-0.141	0.052 0.029-0.078	0.031 0.002-0.059	0.027 0.012-0.053	0.045 0.022-0.082	1.36 0.62-1.66	1.09 0.64-1.56
		2	0.169 0.134-0.285	0.206 0.126-0.337	0.106 0.036-0.191	0.127 0.086-0.198	0.062 0.031-0.106	0.079 0.037-0.145	1.96 1.46-3.26	2.03 1.11-3.76
		3	0.526 0.321-0.940	0.539 0.321-0.980	0.173 0.102-0.281	0.166 0.096-0.215	0.353 0.076-0.838	0.373 0.106-0.817	3.00 1.76-4.46	3.14 1.41-4.46

Period	Lakes	Trophic group of lakes	TOTorg-N s	TOTorg-N b	NH_4-N s	NH_4-N b	NO_2-N s	NO_2-N b	NO_3-N s	NO_3-N b	Ca^{++} s	Ca^{++} b
			mg · dm^{-3}									
Spring	dimictic	1	1.04 0.56-2.05	1.12 0.56-2.80	0.01 0.00-0.08	0.01 0.00-0.06	0.003 0.001-0.011	0.006 0.000-0.017	0.06 0.01-0.25	0.09 0.01-0.25	39 26-49	41 27-53
		2	1.04 0.59-1.48	1.24 0.95-1.75	0.04 0.00-0.11	0.07 0.00-0.23	0.003 0.000-0.011	0.007 0.000-0.019	0.15 0.01-0.63	0.13 0.01-0.54	55 48-71	56 48-75
		3	1.65 0.87-2.23	1.78 1.38-2.43	0.16 0.01-0.42	0.29 0.01-0.73	0.009 0.000-0.022	0.017 0.000-0.052	0.47 0.26-0.66	0.45 0.13-0.71	63 54-75	64 56-75
	polymictic	1	1.42 0.81-2.33	1.98 1.04-4.67	0.09 0.03-0.23	0.09 0.02-0.29	0.006 0.000-0.014	0.007 0.000-0.014	0.12 0.01-0.51	0.[illegible]6 0.03-[illegible].53	58 49-82	57 46-80
		2	1.82 0.64-3.78	1.30 0.59-1.69	0.17 0.11-0.36	0.18 0.06-0.35	0.005 0.000-0.017	0.002 0.000-0.007	0.14 0.03-0.45	0.[illegible]9 0.01-[illegible].48	52 36-68	53 36-68
		3	1.82 1.02-2.50	1.78 0.95-2.41	0.19 0.14-0.27	0.17 0.11-0.25	0.005 0.000-0.019	0.005 0.000-0.019	0.11 0.03-0.27	0.[illegible] 0.06-[illegible]33	73 51-98	73 50-98
Summer	dimictic	1	1.23 0.95-1.61	1.07 0.47-1.36	0.06 0.00-0.20	0.14 0.01-0.52	0.002 0.000-0.011	0.006 0.000-0.034	0.03 0.00-0.06	0.[illegible] 0.02-[illegible]	40 26-44	41 27-52
		2	1.42 0.96-1.88	1.23 0.71-1.69	0.08 0.00-0.16	0.31 0.11-0.58	0.000 0.000-0.004	0.017 0.000-0.078	0.04 0.02-0.07	0.[illegible] 0.01-[illegible]8	45 37-56	54 46-69
		3	2.09 1.77-2.48	3.00 1.55-4.69	0.08 0.07-0.14	1.01 0.01-3.87	0.007 0.000-0.011	0.005 0.000-0.010	0.04 0.03-0.05	0[illegible] 0.03-[illegible]	54 48-68	61 53-75
	polymictic	1	1.35 0.65-1.71	1.05 0.64-1.59	0.05 0.00-0.11	0.05 0.00-0.12	0.003 0.000-0.011	0.002 0.000-0.007	0.04 0.01-0.07	0.[illegible] 0.01-[illegible]8	50 37-71	50 38-71
		2	1.90 1.16-3.06	1.89 0.92-3.63	0.13 0.04-0.30	0.15 0.08-0.22	0.000 0.000-0.007	0.000 0.000-0.005	0.05 0.01-0.14	0.[illegible] 0.01-[illegible]5	41 30-53	42 29-54
		3	2.87 1.59-3.55	2.74 1.33-4.36	0.23 0.00-0.62	0.20 0.00-0.62	0.019 0.000-0.095	0.021 0.000-0.095	0.07 0.04-0.14	0.[illegible] 0.01-[illegible]14	64 45-84	65 51-84

Period	Lakes	Trophic group of lakes	K^+ s	K^+ b	Na^+ s	Na^+ b	Mg^{++} s	Mg^{++} b	Mn^{++} s	Mn^{++} b	TOT-Fe s	TOT-Fe b
			mg · dm^{-3}									
Spring	dimictic	1	1.9 0.6-4.4	2.0 0.6-4.5	3.4 1.7-6.5	3.5 1.6-6.4	9.1 4.0-12.0	9.6 5.2-12.8	0.01 0.00-0.09	0.01 0.00-0.11	0.05 0.00-0.10	0.07 0.00-0.16
		2	3.0 1.6-4.2	3.3 1.6-4.4	5.8 4.2-9.5	5.9 4.3-9.5	12.4 7.7-17.6	11.4 7.1-13.6	0.03 0.00-0.07	0.02 0.00-0.07	0.12 0.00-0.40	0.18 0.00-0.64
		3	8.6 3.1-16.9	8.7 3.3-16.9	15.0 8.1-26.7	15.1 8.1-26.7	12.0 8.8-16.6	12.8 10.4-17.5	0.04 0.00-0.7	0.24 0.00-0.85	0.03 0.00-0.09	0.04 0.00-0.10
	polymictic	1	1.4 0.4-3.3	1.4 0.6-3.2	3.8 1.0-7.6	4.7 2.7-7.4	6.2 3.9-8.8	5.2 3.5-7.0	0.02 0.00-0.07	0.02 0.00-0,05	0.04 0.00-0.14	0.06 0.00-0.13
		2	4.0 0.4-13.0	3.9 0.2-13.0	7.0 1.9-23.2	6.9 2.0-23.2	6.4 1.8-10.4	7.0 2.5-11.2	0.04 0.00-0.12	0.03 0.00-0.12	0.07 0.00-0.19	0.08 0.00-0.23
		3	6.7 2.7-19.3	6.6 2.4-19.3	13.3 6.3-28.4	13.1 6.0-28.4	8.6 6.4-11.2	8.8 5.8-12.2	0.05 0.00-0.15	0.08 0.00-0.15	0.18 0.01-0.59	0.16 0.02-0.52
Summer	dimictic	1	2.1 0.1-5.0	2.1 0.2-4.5	3.6 1.6-6.3	3.5 1.8-6.3	8.1 5.6-11.6	8.6 6.1-12.5	0.01 0.00-0.10	0.14 0.00-0.60	0.02 0.00-0.08	0.13 0.00-1.08
		2	3.1 1.6-4.6	3.3 2.2-4.5	5.5 3.9-8.1	5.9 4.9-8.4	12.4 7.4-21.4	12.4 7.1-21.4	0.03 0.00-0.10	-	0.03 0.00-0.09	0.19 0.00-0.91
		3	8.2 4.0-15.5	8.3 3.1-15.6	14.4 8.2-25.2	13.7 7.4-24.2	13.0 9.5-15.3	21.0 14.0-28.0	0.00 0.00-0.10	0.54 0.00-1.65	0.02 0.00-0.07	0.09 0.00-0.18
	polymictic	1	1.1 0.1-3.9	0.5 0.0-1.0	4.6 2.4-7.1	4.3 2.4-7.1	6.6 4.0-8.0	5.7 4.0-7.1	0.04 0.00-0.12	0.05 0.00-0.15	0.01 0.00-0.06	0.04 0.00-0.18
		2	3.2 0.4-10.1	2.3 0.2-10.6	4.6 3.1-22.0	4.6 2.7-20.8	6.5 3.5-10.4	6.1 2.5-8.8	0.03 0.00-0.07	0.04 0.00-0.12	0.05 0.00-0.32	0.10 0.00-0.47
		3	6.5 2.6-17.9	6.7 3.1-18.5	13.2 4.5-26.2	13.7 5.0-27.8	10.7 9.5-14.2	8.4 4.5-16.0	0.02 0.00-0.05	0.09 0.00-0.30	0.08 0.00-0.22	0.07 0.00-0.22

Period	Lakes	Trophic group of lakes	SiO_2 s	SiO_2 b	Cl^- s	Cl^- b	SO_4^{--} s	SO_4^{--} b	CO_3^{--} s	CO_3^{--} b	HCO_3^- s	HCO_3^- b	pH s	pH b	Oxidability s	Oxidability b	Electrolytic conductivity s	Electrolytic conductivity b
			mg · dm^{-3}												mg O_2 · dm^{-3}		µS · cm^{-1}	
Spring	dimictic	1	5.2 2.8-12.4	6.0 2.8-12.8	9.0 5.3-13.8	9.8 5.7-14.5	17.4 7.4-29.7	19.4 8.4-30.0	1.5 0.0-6.0	0.6 0.0-3.0	136 91-201	142 104-195			8.6 5.8-10.9	8.9 4.8-11.8	226 166-287	245 166-309
		2	8.7 3.8-16.5	9.4 3.1-17.5	12.3 8.7-21.0	12.2 8.2-20.2	19.0 6.9-28.0	19.6 6.6-30.0	2.3 0.0-6.0	2.1 0.0-6.0	204 167-325	206 158-341			11.1 7.7-17.3	11.2 7.0-17.3	341 228-440	345 288-441
		3	6.0 3.1-11.4	7.0 5.4-10.5	29.0 15.6-54.8	29.6 16.3-55.7	23.1 12.4-49.9	23.5 12.4-46.5	2.4 0.0-6.0	0.0	225 189-257	236 201-274			13.5 8.3-20.8	13.3 8.3-18.0	429 353-594	438 348-614
	polymictic	1	7.1 6.0-11.1	7.3 4.1-11.8	13.4 6.9-28.5	13.6 6.9-28.8	7.4 3.8-11.0	10.4 3.5-29.6	3.8 3.0-4.5	4.0 1.5-7.5	178 171-183	183 177-195			12.8 8.0-19.9	13.0 8.0-21.5	349 302-491	352 306-495
		2	5.2 3.1-11.2	5.2 2.7-11.7	17.1 5.3-40.8	17.0 4.8-41.1	11.4 5.2-18.0	11.6 6.4-18.0	5.2 0.0-9.0	5.8 0.0-15.0	163 102-207	162 102-207			17.2 9.9-28.8	17.4 10.6-28.8	332 157-445	332 156-445
		3	4.6 2.7-7.7	4.4 1.6-9.1	30.0 14.4-62.4	30.0 13.6-62.8	19.6 10.6-23.2	18.7 10.0-23.2	5.1 3.0-7.5	6.0 3.0-12.0	219 153-325	242 159-325			19.7 15.4-28.8	19.5 14.7-28.8	463 359-697	464 360-703
Summer	dimictic	1	5.3 3.9-8.0	6.6 4.4-10.2	8.2 3.7-12.2	7.5 4.1-11.1	12.4 5.2-18.3	13.9 6.6-21.1	2.2 0.0-3.0	0.0	132 100-180	150 112-195	8.2 7.6-8.4	7.2 6.5-7.5	9.6 7.0-12.2	9.4 6.4-12.8	222 149-283	256 173-393
		2	6.8 3.5-14.7	11.6 5.1-28.0	11.2 6.9-19.8	10.9 6.2-18.7	15.0 2.9-29.0	16.0 2.7-27.6	0.0 0.0-1.5	0.0	177 155-281	203 173-303	8.2 8.0-8.8	7.4 7.2-7.8	12.6 9.6-19.8	11.2 9.9-16.0	305 257-430	355 288-502
		3	3.8 1.6-4.9	7.9 6.5-9.9	30.0 16.3-56.7	28.7 14.7-54.6	21.7 14.4-40.0	19.1 14.0-35.0	9.4 0.0-15.0	0.0	178 161-201	247 213-305	8.5 7.9-9.1	7.0 6.3-7.2	15.1 12.8-18.3	13.4 9.9-19.9	364 323-540	471 376-637
	polymictic	1	8.9 5.7-17.7	9.0 6.0-17.2	13.0 6.9-28.6	12.8 5.1-29.1	12.9 5.8-29.6	13.1 4.6-30.4	0.0 0.0-3.0	0.0	171 149-189	175 152-189	8.1 7.8-8.4	8.0 7.8-8.3	13.2 9.0-19.2	12.5 8.0-20.5	324 248-481	331 264-489
		2	6.4 3.6-10.0	6.8 3.1-10.9	12.9 6.7-23.8	16.8 6.7-41.3	9.5 3.5-15.0	8.8 2.7-15.0	2.0 0.0-12.0	1.3 0.0-4.5	135 97-177	142 88-189	8.3 7.6-9.0	8.0 7.4-8.8	18.0 9.6-25.6	17.5 9.9-27.8	298 198-374	262 289-391
		3	8.5 4.6-15.0	8.9 4.6-15.0	30.3 12.1-62.4	30.8 12.4-62.4	13.3 10.2-15.0	14.2 7.4-22.4	0.0 0.0-1.5	0.0 0.0-1.5	231 183-298	256 195-298	8.1 7.3-8.6	7.9 7.2-8.2	19.8 16.3-22.7	18.9 16.3-22.7	473 330-670	476 400-670

total phosphorus in the epilimnion, during the same period, a growth was observed of the concentration of particulate and dissolved organic phosphorus in the epilimnion of the di- and polymictic lakes (Fig. 1).

In summer, average percentage of phosphates in total phosphorus was low (<38%) in lakes of a lower trophic state, and high (>50%) - in di- and polymictic lakes of the highest trophis state (Fig. 3). Average percentage of organic particulate phosphorus in total phosphorus was higher than the percentage of dissolved organic

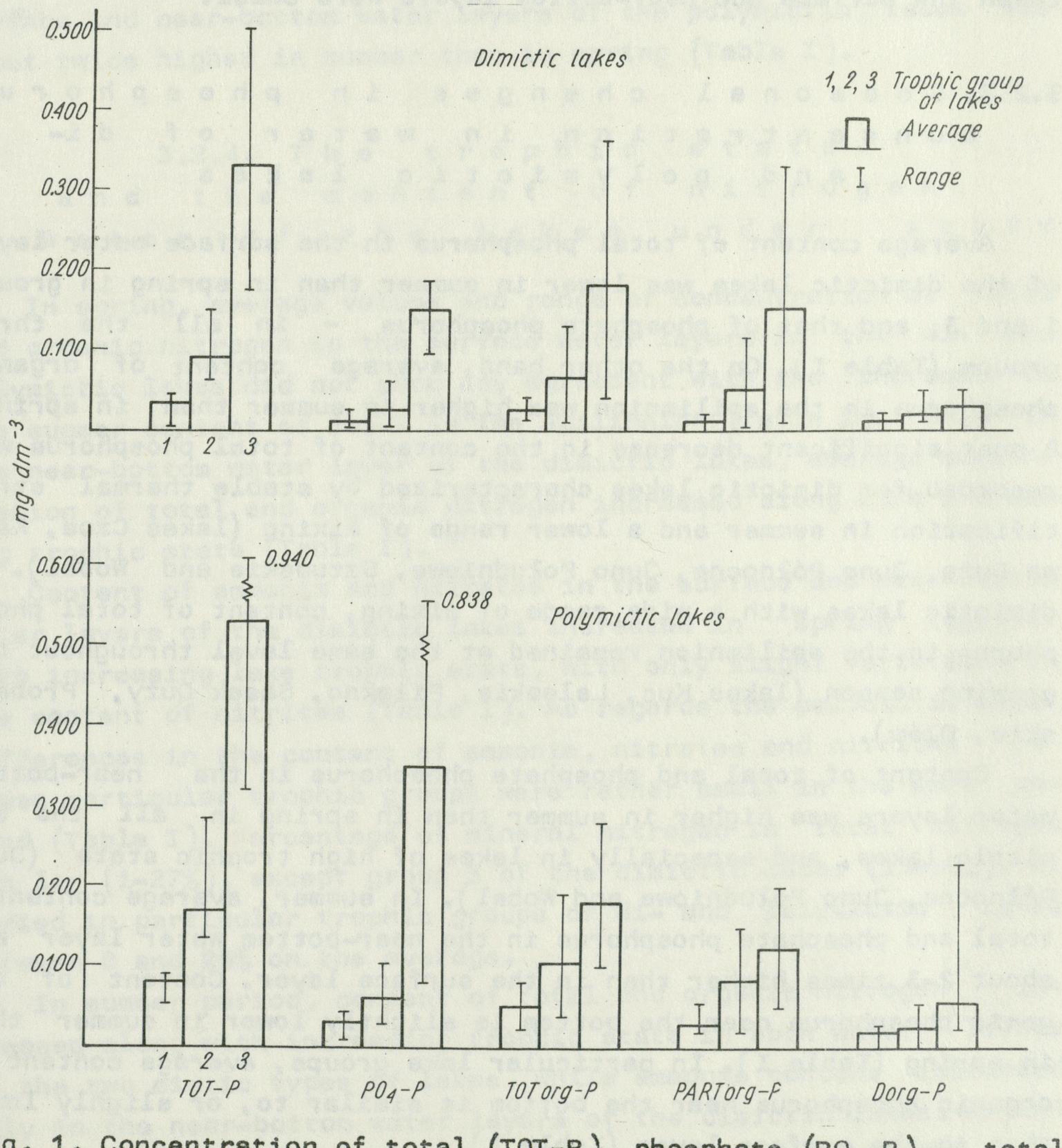

Fig. 1. Concentration of total (TOT-P), phosphate (PO_4-P), total organic (TOTorg-P), particulate organic (PARTorg-P) and dissolved organic (Dorg-P) phosphorus in the epilimnion of trophic groups of dimictic and polymictic lakes in summer

phosphorus in all trophic groups (Fig. 3). Percentage of dissolved organic phosphorus decreased along with increasing lake trophic state.

Average percentage of phosphates in total phosphorus in summer was about twice as high in the near-bottom water layers as in the surface layer in three groups of the dimictic lakes (69-91%), and in the first group of the polymictic lakes (on the average 60%). In the remaining trophic groups of the polymictic lakes the differences in the percentage of phosphates in total phosphorus between the surface and near-bottom layers were small.

3.2.3. Seasonal changes in phosphorus concentration in water of di- and polymictic lakes

Average content of total phosphorus in the surface water layer of the dimictic lakes was lower in summer than in spring in groups 1 and 3, and that of phosphate phosphorus - in all the three groups (Table I). On the other hand, average content of organic phosphorus in the epilimnion was higher in summer than in spring. A most significant decrease in the content of total phosphorus was recorded for dimictic lakes characterized by stable thermal stratification in summer and a lower range of mixing (lakes Czos, Kalwa Duża, Juno Północne, Juno Południowe, Sztumskie and Wobel). In dimictic lakes with a wide range of mixing, content of total phosphorus in the epilimnion remained at the same level throughout the growing season (lakes Kuc, Leleskie, Piłakno, Sasek Duży, Probarskie, Ołów).

Content of total and phosphate phosphorus in the near-bottom water layers was higher in summer than in spring in all the dimictic lakes, and especially in lakes of high trophic state (Juno Północne, Juno Południowe and Wobel). In summer, average content of total and phosphate phosphorus in the near-bottom water layer was about 2-3 times higher than in the surface layer. Content of organic phosphorus near the bottom is slightly lower in summer than in spring (Table I). In particular lake groups, average content of organic phosphorus near the bottom is similar to, or slighly lower than in the surface layer (Table I).

In the polymictic lakes, direction of changes in the content of total, organic and phosphate phosphorus in the surface and near--bottom water layers during the growing season is different from that in the dimictic lakes. Except for lakes Barlewickie, Długie and Sasek Mały, for which a lower summer content of total phosphorus in the epilimnion was recorded, the content of total phosphorus was higher in summer than in spring.

The highest increase in phosphorus content was recorded for the following lakes: Liwieniec, Iławskie, Stryjewskie and Tuchel. Average content of total, organic and phosphate phosphorus in the surface and near-bottom water layers of the polymictic lakes was about twice higher in summer than in spring (Table I).

3.2.4. The trophic state and the content of nitrogen in water of the lakes under study

In spring, average values and range of concentration of total and organic nitrogen in the surface water layers in the di- and polymictic lakes did not show any agreement with the increase in the summer content of tot-P in the epilimnion (Table I). Only in the near-bottom water layer of the dimictic lakes, average concentration of total and organic nitrogen increased along with increasing trophic state (Table I).

Content of ammonia and nitrates in the surface and near-bottom water layers of the dimictic lakes increased in spring together with increasing lake trophic state, with only slight variations in the content of nitrites (Table I). As regards the polymictic lakes, differences in the content of ammonia, nitrates and nitrites between particular trophic groups were rather small in the same period (Table I). Percentage of mineral nitrogen in total nitrogen was low (1-27%), except group 3 of the dimictic lakes (15-39%). It varied in particular trophic groups of di- and polymictic lakes between 8 and 25% on the average.

In summer period, content of total and organic nitrogen increased along with increasing trophic state in both water layers of the two mictic types of lakes, while ammonia content increased only in the near-bottom water layers of the dimictic lakes. No such regularities were found for concentrations of ammonia in the surface water layers in the dimictic lakes, or for concentrations of nitrates and nitrites in both mictic groups (Table I). Organic nitrogen is the basic form of total nitrogen. In particular trophic groups, it represented on an average about 90% of the average content of total nitrogen in the surface water layer (Fig. 3). Lower percentages of organic nitrogen in total nitrogen were found only at the bottom in the dimictic lakes (3.78%, on the average 22%).

Average content of particulate and dissolved organic nitrogen increased in accordance with increasing trophic state, with similar average percentages of these forms in total nitrogen in particular groups (Figs. 2, 3). High average concentrations of dissolved organic nitrogen compared to particulate organic nitrogen were recorded only for the dimictic and polymictic lakes of the highest trophic state (Fig. 2).

In relation to spring, summer concentration of total and organic nitrogen in the surface water layer increased mainly in the

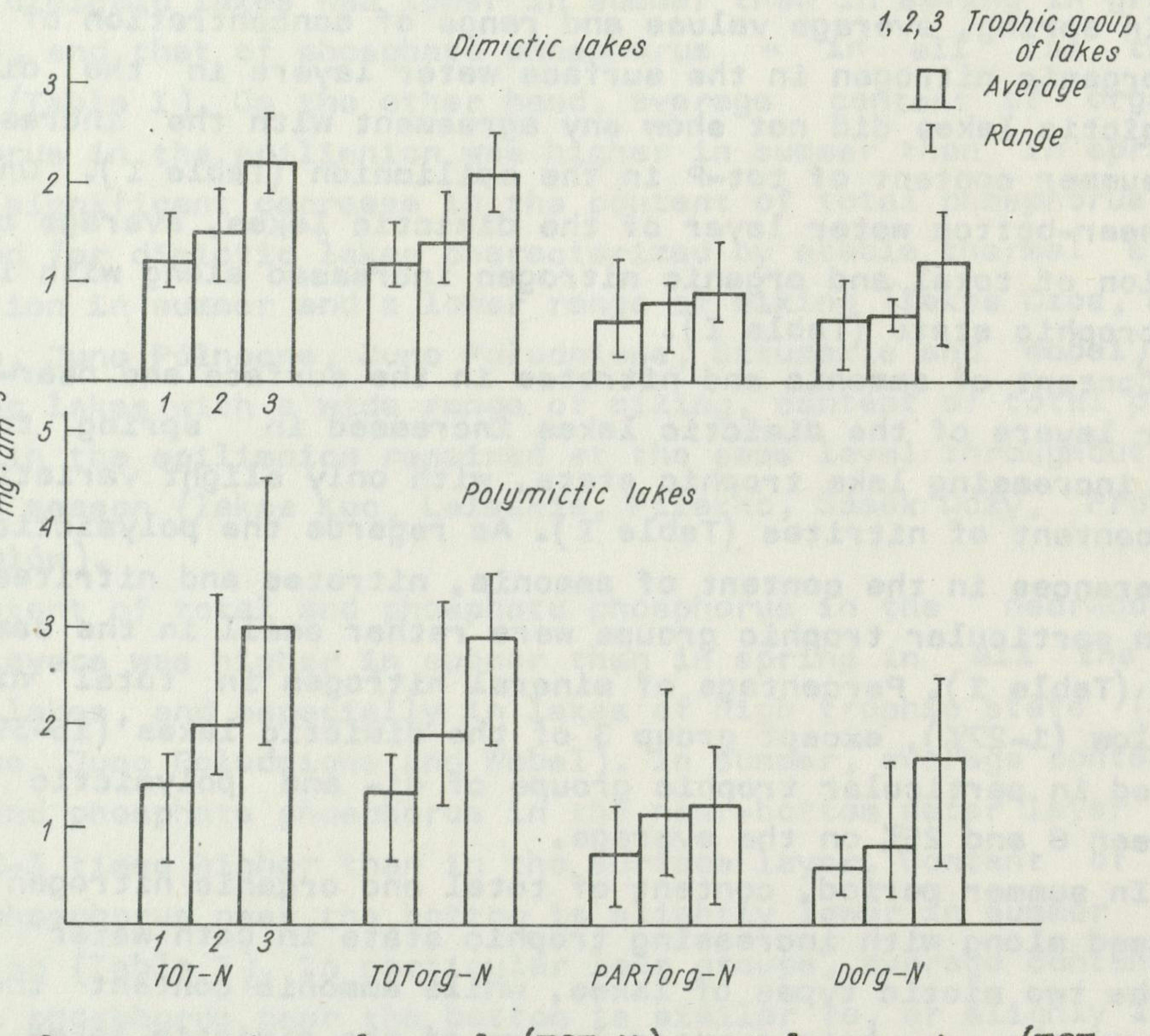

Fig. 2. Concentration of total (TOT-N), total organic (TOTorg-N), particulate organic (PARTorg-N) and dissolved organic (Dorg-N) nitrogen in the epilimnion of trophic groups of dimictic and polymictic lakes in summer

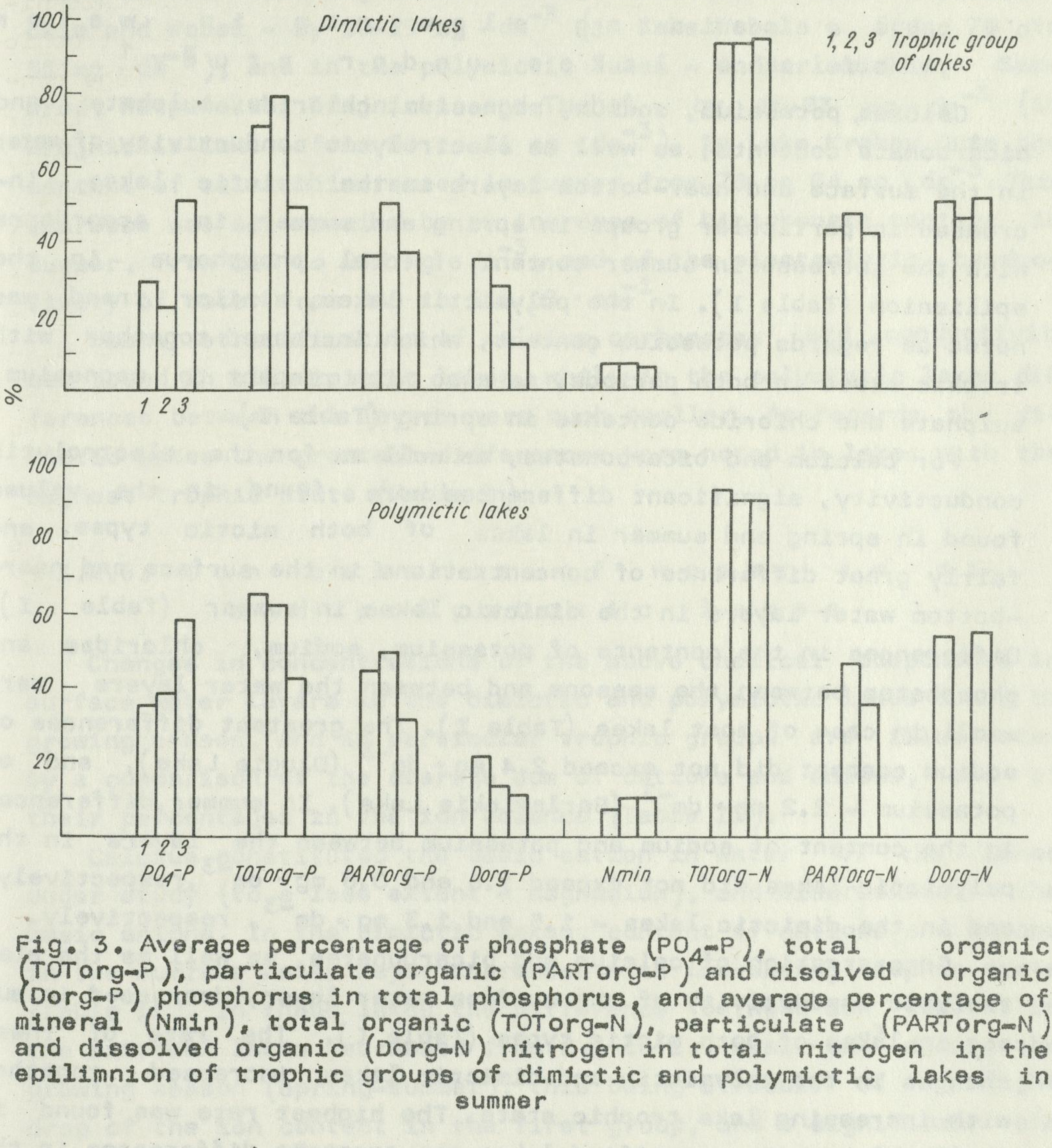

Fig. 3. Average percentage of phosphate (PO_4-P), total organic (TOTorg-P), particulate organic (PARTorg-P) and disolved organic (Dorg-P) phosphorus in total phosphorus, and average percentage of mineral (Nmin), total organic (TOTorg-N), particulate (PARTorg-N) and dissolved organic (Dorg-N) nitrogen in total nitrogen in the epilimnion of trophic groups of dimictic and polymictic lakes in summer

dimictic lakes (Table I). Also ammonia content in the near-bottom water layers increased in particular trophic groups of these lakes (Table I). Ammonia content increased most significantly at the bottom of lakes in the group 3, for which also seasonal differences in the total and organic nitrogen were most pronounced (Table I). Average percentage of mineral nitrogen in total nitrogen at the bottom of the dimictic lakes was high, ranging in particular groups from 10 to 20%, with a maximum of 45% of total nitrogen, in Lake Wobel.

3.2.5. The trophis state and the content of the remaining elements in water of the lakes under study[1]

Calcium, potassium, sodium, magnesium, chloride, sulphate and bicarbonate contents, as well as electrolytic conductivity of water in the surface and near-bottom layers in the dimictic lakes increased in particular groups in spring and summer, in accordance with the increase in summer content of total phosphorus in the epilimnion (Table I). In the polymictic lakes, similar trend was noted as regards potassium content, which increased together with trophic state in both periods, as also with respect to magnesium, sulphate and chloride contents in spring (Table I).

For calcium and bicarbonates, as well as for the electrolytic conductivity, significant differences were found in the values found in spring and summer in lakes of both mictic types, and fairly great difference of concentrations in the surface and near-bottom water layers in the dimictic lakes in summer (Table I). Differences in the contents of potassium, sodium, chlorides and phosphates between the seasons and between the water layers were small in case of most lakes (Table I). The greatest differences of sodium content did not exceed 2.4 $mg \cdot dm^{-3}$ (Długie Lake), and of potassium - 2.2 $mg \cdot dm^{-3}$ (Barlewickie Lake). In summer, differences in the content of sodium and potassium between the layers in the polymictic lakes did not exceed 1.6 and 0.6 $mg \cdot dm^{-3}$, respectively, and in the dimictic lakes - 1.5 and 1.3 $mg \cdot dm^{-3}$, respectively.

Concentration of calcium and bicarbonates, as well as the electrolytic conductivity of the surface water layer, decreased in summer in lakes of both mictic types (Table I). The rate of these changes in the polymictic and dimictic lakes increased together with increasing lake trophic state. The highest rate was found in shallow lakes. In stratified lakes the greatest differences in the concentration of calcium between spring and autumn periods were

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[2]Average pH values of water in the surface and near-bottom layers were similar in the distinguished trophic groups (Table I). No significant differences were found in the content of manganese and total iron in the surface layer in spring and summer (Table I). In summer, the highest content of manganese at the bottom was found in Rzeckie Lake (0.97) and Lake Wobel (1.65 $mg \cdot dm^{-3}$), and of total iron - in Rzeckie Lake (1.20), Lake Sarż (1.08) and Lake Kokowo (0.91 $mg \cdot dm^{-3}$). In the polymictic lakes, high content of total iron was found in lakes Kraksy Duże and Sasek Mały.

found in the following lakes: Maróz, Czos, Kalwa Duża, Kokowo, Ełckie and Wobel - by 10-19 mg · dm^{-3} (in Lake Wobel - from 70 to 51 mg · dm^{-3}), and in the polymictic lakes - in Barlewickie, Sambród, Warpuńskie, Brajnickie and Tuchel - by 15-23 mg · dm^{-3} (in Brajnickie Lake - from 64 to 41 mg · dm^{-3}). In Lake Kraksy Duże the content of calcium increased in summer from 78 to 84 mg · dm^{-3}. This increase was accompanied by an increase of bicarbonate content in summer, from 210 to 298 mg · dm^{-3}, and of the electrolytic conductivity of water from 449 to 562 µS · cm^{-1}.

Summer stratification of calcium, carbonates and conductivity was found in all dimictic lakes, while in the polymictic lakes differences between the layers were much smaller. As regards the dimictic lakes the greatest differences were noted in lakes with the highest trophic state (Table I).

3.2.6. Ion balance of water in di- and polymictic lakes

Changes in concentrations of the above chemical components in surface water layers in the dimictic and polymictic lakes during the growing season, and in particular trophic groups are illustrated by a comparison of the average sum of cations and anions, and of their percentages in the ion balance (Table II).

Calcium constituted the basic cation in water of the lakes under study (to a less extent - magnesium), and bicarbonates - the basic anions. In the dimictic lakes, content of cations and anions in the surface water layer increased with increasing trophic state (Table II). In these lakes the difference between ion content in the extremal lakes decreased from 2.1 to 1.7 mval · dm^{-3} during the growing season (spring-summer), this being a result of a slight drop of the ion content in the first group, and a significant one (by 0.5 mval · dm^{-3}) in trophic groups 2 and 3 (Table II). In the polymictic lakes the highest sum of ions was recorded in spring for the third group, and the lowest - for the second group. The average difference between these groups is about 1.6 mval · dm^{-3}. In summer, the trend of ion content is similar in all groups. In this period the difference in ion content increased to 1.9 mval·dm^{-3} (between group 2 and group 3). The greatest reduction in the content of ions was found for the lakes of the second trophic group, by 0.7 mval · dm^{-3} (Table II).

Table II. Average total cations and anions ($mval \cdot dm^{-3}$) and their percentage in the surface water layers in dimictic and polymictic lakes, and in particular trophic groups of these in spring and summer (values in brackets - summer)

Lakes	Trophic group of lakes	Cations ($mval \cdot dm^{-3}$)	Per cent				Anions ($mval \cdot dm^{-3}$)	Per cent		
			Ca^{++}	Mg^{++}	K^{+}	Na^{+}		Cl^{-}	SO_4^{--}	HCO_3^{-} CO_3^{--}
Dimictic	1	2.89 (2.87)	67 (69)	26 (24)	2 (2)	5 (5)	2.90 (2.73)	9 (8)	12 (9)	79 (83)
	2	4.09 (3.58)	67 (62)	25 (29)	2 (2)	6 (7)	4.16 (3.54)	8 (9)	9 (9)	83 (82)
	3	5.00 (4.59)	63 (58)	20 (23)	4 (5)	13 (14)	5.07 (4.53)	16 (18)	9 (10)	75 (72)
Polymictic	1	3.60 (3.27)	80 (77)	14 (16)	1 (1)	5 (6)	3.58 (3.44)	10 (11)	4 (8)	86 (81)
	2	3.53 (2.86)	74 (71)	15 (19)	3 (3)	8 (7)	3,57 (2.84)	14 (13)	7 (7)	79 (80)
	3	5.10 (4.81)	71 (67)	14 (18)	3 (3)	12 (12)	5.01 (4.92)	17 (18)	8 (6)	75 (76)

An increase of trophic state in the di- and polymictic lakes was accompanied by a decrease of the percentage of calcium and carbonates in the ion balance in the last trophic group, with an about 2-fold increase in the percentage of sodium and chlorides. Percentage of potassium and sodium increased as the trophic state of the dimictic lakes increased. The same applies to the polymictic lakes, in which an increase of the average percentage of chlorides was also observed (Table II).

3.2.7. Water oxidability

An increase in water oxidability was observed together with an increase in trophic state of di- and polymictic lakes (Table I). Polymictic lakes were characterized by higher water oxidability than dimictic lakes both in spring and summer. The highest average water oxidability, noted in the dimictic lakes of the third group was only slightly higher in comparison with average oxidability stated in polymictic lakes of the first trophic group.

4. DISCUSSION

Trophic state of lakes is most often described in terms of: type of oxygen stratification, oxygen concentration and per cent saturation of water with oxygen in the epi- and hypolimnion, average summer or annual content of total phosphorus and total nitrogen, and alkalinity or content of phosphates in the near-bottom water layers in summer (Stangenberg 1936, Olszewski and Paschalski 1959, Patalas 1960a, 1960b, Sakamoto 1966, Vollenweider 1968, Forsberg and Ryding 1980, Olszewski et al. 1980).

Comparison made in this study of changes taking place in concentration of basic chemical components of water in spring and summer in the particular mictic types and their trophic groups, analysed in a trophic gradient indicates that an increase of trophic state in the lakes under study is characterized by: an increase in spring and summer concentrations of phosphate phosphorus, total organic phosphorus, particulate and dissolved organic phosphorus, total nitrogen, total organic nitrogen, and particulate and dissolved organic nitrogen; a growth of the content of ammonia in the surface and near-bottom water layers in lakes of both mictic types in spring, and a growth of the concentration of ammonia in the surface and near-bottom water layers in polymictic lakes in summer; an increace in the concentration of nitrates in both layers in dimictic lakes in spring; an increase in the concentration of calcium, sodium, potassium and bicarbonates, and an increase of water oxidability and electrolytic conductivity in the surface and near-bottom water layers in lakes of both mictic types and in the seasons analysed, as well as an increase in the concentration of magnesium in dimictic lakes.

An increase of trophic state in the lakes under study is also indicated by: a decrease of total phosphorus content in summer in relation to spring, in the epilimnion of dimictic lakes, and an increase in the concentration of total phosphorus and total nitrogen in polymictic lakes at the same time; an increase of differences in the concentration of total phosphorus, phosphate phosphorus, total nitrogen, ammonia, calcium, bicarbonates and water conductivity in summer between the surface and near-bottom layers in dimictic lakes.

High lake trophic state (lakes under a stronger impact of anthropogenic factors, especially of direct pollution) is indicated by higher than in the other lakes contents of: total phosphorus (>0.100 mg $\cdot$ dm^{-3}) and total nitrogen (>1.5 mg $\cdot$ dm^{-3}); summer concentration of ammonia and nitrites in the surface water layers of polymictic lakes, and summer concentration of ammonia near the bottom of dimictic lakes; high content of calcium, potassium, sodium and chlorides, as well as a high water oxidability and electrolytic conductivity in particular seasons and layers; lower percentage of calcium and bicarbonates at increased percentages of sodium, potassium and chlorides in the ion balance; higher summer and spring concentrations of phosphates, and their high percentage ($>50\%$) in total phosphorus in the epilimnion.

As regards the chemical indices, the greatest variations were noted with respect to total phosphorus and its different forms in the surface and near-bottom water layers during the growing season, as also for total and organic nitrogen, ammonia, calcium, bicarbonates, and electrolytic conductivity.

It was found that changes in the concentration of phosphorus and nitrogen in the epilimnion and in the near-bottom water layers of dimictic lakes were determined by lake statics. In dimictic lakes, characterized by high stability of thermal stratification, the amount of total phosphorus in the epilimnion was lower in summer than in spring. The rate of the decrease depended on the trophic state of the lakes, being the higher the higher the trophic state. Average content of total phosphorus in dimictic lakes dropped by about 10% in relation to the spring content of this element. In this case, sedimentation of organic matter may be the decisive factor, determining changes in phosphorus content (G o l a c h o w s k a 1971, K a j a k and Ł a w a c z 1977, K a j a k 1979).

Average content of total nitrogen in the epilimnion of dimictic lakes increased in summer by about 25% in relation to the spring concentration. This might have been the result of binding of atmospheric nitrogen by some species of blue-green algae.

In the near-bottom water layers of dimictic lakes an increase was observed in summer content of total phosphorus, phosphate phosphorus and ammonia. The higher the trophic state of the lakes, the greater the changes in the concentration of these components. A summer accumulation of total phosphorus, phosphate phosphorus and ammonia at the bottom occurred mainly as a result of their release from bottom sediments (Z d a n o w s k i 1983a).

In polymictic lakes, intensive water mixing, high summer temperatures and oxygen content at the bottom, determine high rate of mineralization of organic matter and exchange of phosphorus and nitrogen between water and bottom sediments. In most of the polymictic lakes under study these processes lead to intensive, increasing with trophic state, inner enrichment of these lakes with phosphorus and nitrogen. This process was reflected by a drop of the content of organic phosphorus in bottom sediments in summer in relation to spring (by about 26%) and, except some lakes, a decrease of the concentration of organic nitrogen by about 15% in relation to spring (Z d a n o w s k i 1983a). As a result, average summer concentration of total phosphorus in polymictic lakes was higher by about 70% than the spring content. Average summer content of total nitrogen was higher by about 12% than its spring concentration. This applies primarily to very fertile lakes.

The above changes in summer content of phosphorus and nitrogen in dimictic and polymictic lakes increased differences between lakes of these two mictic types as regards their phosphorus and nitrogen resources and, consequently, also with respect to their primary productivity. Due to intensified process of inner enrichment, in polymictic lakes primary productivity in summer was higher than in dimictic lakes, and also higher than in spring (Spodniewska 1983, Zdanowski 1983b).

It was found that variations in the concentration of calcium and bicarbonates, as well as in the electrolytic conductivity of water, were strictly correlated. This agrees with studies carried out by other authors (Szczepański 1968, Korycka 1969, Korycka and Zdanowski 1976, A. Korycka - unpublished data). Summer values of these indices for all lakes were, as a rule, lower than their spring levels. The changes depended on trophic state of the lakes, the higher the trophic state the higher the rate of changes. They resulted from the process of biological decalcification. In lakes with a high trophic state, percentage of calcium and carbonates in the ion balance decreased, while concentration of chlorides, sodium and potassium increased.

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5. SUMMARY

Water chemistry was studied in 41 lakes in the north-eastern Poland. Morphometry and trophic state, as well as the degree of anthropogenic impact upon the lakes have been described by Kajak and Zdanowski (1983).

Water samples for chemical analyses from the surface layer (0.5 m) and from the near-bottom layer (0.5 m above the bottom) were collected twice on each lake: during the spring circulation (April-May) and in the period of summer stagnation (August). Investigations were carried out in 1977-1978.

Chemical composition of water in spring and summer has been described separately for dimictic and polymictic lakes (a list of the lakes under study is contained in the paper by Kajak and

Z d a n o w s k i 1983). In each of the two types three lake groups were distinguished, differing in the content of phosphorus in the epilimnion (Table I).

A comparison of variations in the content of chemical components in water during the growing season in the mictic types and their trophic groups indicates that an increase of trophic state of the lakes studied is characterized by: an increase in spring and summer concentration of phosphates, total organic, and dissolved and particulate organic phosphorus; a growth of total, total organic, dissolved organic and particulate organic nitrogen (Table I, Figs. 1, 2); an increase in the content of ammonia in the surface and near-bottom water layers in both mictic types in spring, and an increase in the content of ammonia in the surface and near-bottom water layers in polymictic lakes in summer (Table I); a growth of the concentration of nitrates in both layers of dimictic lakes in spring; an increase in the content of calcium, potassium, bicarbonates, water oxidability and electrolytical conductivity in both layers and mictic types in spring and summer; a growth of the content of magnesium in dimictic lakes (Table I).

A high trophic state of lakes under the influence of, among other, pollution, is indicated by high levels (higher than in the other trophic groups) of the following: content of total phosphorus (>0.100 mg $\cdot$ dm^{-3}) and total nitrogen (>1.5 mg $\cdot$ dm^{-3}); summer concentration of ammonia and nitrites in the surface water layers of polymictic lakes; high summer content of ammonia at the bottom of dimictic lakes; high content of calcium, potassium, sodium, chlorides, sulphates, carbonates, high level of oxidability and electrolytic conductivity of water (Table I); but lower percentage of calcium and bicarbonates, at higher percentage of sodium, potassium and chlorides in the ion balance (Table II); high summer and spring concentration of phosphates, as well as their percentage ($>50\%$) in total phosphorus in the epilimnion (Figs. 1, 3).

6. POLISH SUMMARY

Przeprowadzono badania składu chemicznego wody w 41 jeziorach północno-wschodniej Polski. Charakterystykę morfometrii i trofii oraz stopnia antropogennego zagrożenia jezior podaje K a j a k i Z d a n o w s k i (1983).

Próby wody do analiz chemicznych pobierano z warstwy powierzchniowej (0,5 m) i przydennej (0,5 m nad dnem) na każdym jeziorze 2-krotnie: w okresie cyrkulacji wiosennej (kwiecień-maj) i stagnacji letniej (sierpień). Badania wykonano w latach 1977-1978.

Charakterystykę składu chemicznego wody w okresie wiosennym i letnim przeprowadzono oddzielnie dla jezior dymiktycznych i polimiktycznych (wykaz badanych jezior podano w pracy K a j a k a i Z d a n o w s k i e g o 1983). W każdym z tych typów wydzielono po 3 grupy jezior, różniące się letnią zawartością fosforu ogólnego w epilimnionie (tab. I).

Z porównania zmian zawartości składników chemicznych wody w sezonie, w poszczególnych typach miktycznych i ich grupach troficznych, wynika, że wzrost trofii badanych jezior charakteryzuje: wzrost wiosennego i letniego stężenia fosforu fosforanowego, organicznego ogólnego, organicznego rozpuszczonego i upostaciowanego; wzrost azotu ogólnego, organicznego ogólnego, organicznego rozpuszczonego i upostaciowanego (tab. I, rys. 1, 2); wzrost zawartości amoniaku w powierzchniowych i przydennych warstwach wody w obu typach miktycznych w okresie wiosennym oraz wzrost zawartości amoniaku w powierzchniowych i przydennych warstwach wody w jeziorach polimiktycznych w okresie letnim (tab. I); wzrost stężeń azotanów w obu warstwach w jeziorach dymiktycznych w w okresie wiosennym; wzrost stężeń wapnia, sodu, potasu, dwuwęglanów, utlenialności i przewodnictwa elektrolitycznego w obu warstwach i typach miktycznych w okresie wiosennym i letnim; wzrost stężeń magnezu w jeziorach dymiktycznych (tab. I).

Na zbiorniki o wysokiej trofii, znajdujące się m.in. pod wpływem zanieczyszczeń, wskazuje wyższa niż w pozostałych grupach troficznych: zawartość fosforu ogólnego ($>0,100$ mg $\cdot$ dm^{-3}), azotu ogólnego ($>1,5$ mg $\cdot$ dm^{-3}); letnia koncentracja amoniaku i azotynów w powierzchniowych warstwach wody w jeziorach polimiktycznych; wyższe letnie stężenia amoniaku przy dnie w jeziorach dymiktycznych; wysoka zawartość wapnia, potasu, sodu, chlorków, siarczanów, węglanów, utlenialność i przewodnictwo elektrolityczne wody (tab. I); niższy procentowy udział wapnia i dwuwęglanów, przy wzroście udziału sodu, potasu i chlorków w bilansie jonowym (tab. II); wyższe letnie i wiosenne stężenia fosforanów oraz wysoki ich udział (>50%) w fosforze ogólnym w epilimnionie (rys. 1, 3).

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