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Changes in the concentration of main cations in the lakes of Northeast Poland

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Abstract: This study compares the concentration of calcium, magnesium, sodium and potassium in 251 lakes located in the northeast part of Poland in the 1960s and 1990s. It has been proved that the pace of increase in cation concentration was diversified, both in the case of particular lakes and physico-geographical regions. The fastest rise in cation concentration occurred in the lakes located in intensively agricultural regions. Specific attention has been drawn to wider ranges of cation occurrence and changes in the ratio of calcium to magnesium. The main causes leading to the change in cation concentration include lake pollution with sewage and washing chemical compounds out of artificial manures.

Key words: cations (calcium, magnesium, sodium, potassium), pace and causes of changes.

Introduction

Cations are a part of ions that occur in the biggest amount in various types of waters. The main cations combine calcium, magnesium, sodium and potassium ions. Depending on concentration and reciprocal proportions of cations and anions, it is possible to classify surface and underground waters. These proportions alter together with changes in environmental conditions and increase in anthropopressure. With respect to toxicity, cations of calcium, magnesium, sodium and potassium have been classified as harmless (Wood, 1974). Their presence in waters, however, affects living organisms in a considerable way. Nevertheless, it is accepted that too big a concentration of cations in waters is generally harmful for these organisms. The importance of calcium in the ion economy of water organisms was presented by W. Lampert and U. Sommer (1993), among others.

The concentration of ions in lake waters (chemical contents of lake waters included) undergoes changes with respect to the evolution of natural environment conditions. This concentration largely depends on the chemical composition of rocks and soils in a lake catchment.

Natural numbers of concentration and proportions between ions have been considerably altered as a result of impurities discharged into lakes. In the case of the northeast part of Poland, changes of that type intensified in the second half of the twentieth century, and were related to industrial development and agricultural chemicalisation, as well as considerable neglect in the field of municipal and sewage management. The growth of anthropopressure differed in various parts of Northeast Poland, and was the biggest in agricultural areas and in the vicinity of towns and cities.

Changes in cation concentration have not been thoroughly analysed in limnological literature so far. Due to obvious reasons, detailed studies have concerned biogenic and toxic substances which decide upon lake trophy and pollution to a bigger extent. Remarks on cation concentration in 41 lakes of Northeast Poland in the years 1977–1978 were included in the work by B. Zdanowski (1983). It seems, however, that while analysing processes connected to natural and anthropogenic transformations in lakes, such problems as changes in cation concentration must not be neglected. This statement can be proven by the fact that cations (beside anions) belong to the basic elements in the chemical composition of waters, not only lake waters.

Area of investigations

The northeast part of Poland is located in a young glacial area. Young glacial plateaux dominate among physico-geographical regions. They occur particularly in the central part. The southern fragments of the analysed area are covered by sandurs. The most characteristic features of morainic plateaux and sandurs combine various types of postglacial lakes (mainly channel lakes, but also moraine and sandur lakes). Those lakes cannot be found only in the north part of the area, where depressions and water accumulation plains are predominant.

In the northeast part of Poland there are 2061 lakes of over 1-hectare area (Choiński, 1991). Among them small lakes (from 1 do 10 ha) prevail. They constitute as much as 50.7% of all the lakes. There are 236 lakes of an area exceeding 100 ha. They make up 11.4% of all the lakes. This area contains both the biggest and the deepest lakes in Poland (Śniardwy of 114.9 km^2 and Hańcza of maximum depth of 108 meters).

Agricultural and forest areas dominate in this region. In the western part of the analysed area there is a distinct dominance of farmlands, where intensive and highly commercial farming is conducted. The biggest forest complexes are located in the central and southern part. In the eastern part, there are both forest complexes and agricultural areas. However, there is a big proportion of meadows and pastures in those agricultural areas. Due to the above-mentioned reasons, there is a considerable variety in the management of the studied lakes' catchments. The lake catchments in the western part of the area, are predominantly of an agricultural character (among many of them, farmlands cover 80% of the area), while forest-agricultural and forest catchments dominate in the eastern part.

Methods of investigations

In the years 1996–2000 field investigations of over 150 lakes were conducted in the northeast part of Poland. The investigation encompassed the lakes where it was possible to obtain unpublished results of the measurements conducted in the first half of the 1960s, that is 35 years ago (on average). Field investigations included all basic measurements in the field of physical and chemical limnology. Chemical analyses of lake waters were carried out using photometers PhotoLab S6 and MPM 3000 on the day of their sampling. The present work includes only a part of investigation results of water chemical composition obtained during the research project concerning the lakes in this part of Poland. They comprise the concentration of the main cations (calcium Ca^{2+}, magnesium Mg^{2+}, sodium Na^{+}, and potassium K^{+}) in surface and bottom layers of lake waters during summer stagnations, and in the lake surface during spring homothermy periods.

The main methodical objective of the investigations in the 1990s was to conduct them in the same places and in the similar period as in the 1960s. The investigations were conducted in the deepest places of the lakes in mid-August and during spring homothermy. The basis of measurement results was expanded with the results of other investigations that had been carried out in similar periods. Thanks to that, it was possible to collect data for 251 lakes, though due to various reasons, they were not complete in some cases. With respect to its location, every lake was classified into one of 13 physico-geographical regions. It was also possible to indicate the diversified pace of changes in cation concentration in this part of Poland.

The analysed lakes are considerably diversified with respect to morphometric parameters and the catchment area and its management. Moreover, they constitute approximately 25% of the number of all the lakes that are bigger than 10 ha, and over 50% of their total area and volume. Due to those reasons, they can be considered as representative of the entire area of Northeast Poland.

Results

In the period of the last 35–40 years the chemical composition of lake waters in the field of main cation concentration – and similarly in the case of other properties (Marszelewski, 1999) – underwent considerable modifications. These changes depend upon increase in cation concentration in the entire area. The biggest upsurge (by 63.8% on average) occurred in the case of calcium cation and sodium cation (by 38.8% on average). The increase in the concentration of magnesium and potassium was noticeable (by 12.9% and 13.3% on average). Changes in cation concentration occurred with various intensity in different regions (lakelands) of the discussed area. In some regions of Northeast Poland there was a decline in magnesium concentration as well as (though considerably more seldom) in the concentration of potassium and sodium. In all the regions calcium concentration increased largely.

Calcium concentration increased by 63.8% on average in all the 251 analysed lakes. The biggest rise was noted in the western part of the area: the Chełmno Lakeland (by 130% on average) and the Iława Lakeland (by 81 % on average). At the same time in 22 of the Great Mazurian Lakes the increase in calcium concentration was several times smaller, and it amounted to 33% on average. It is worthwhile noting that at the end of the 1990s calcium concentration was the smallest in the lakes of the same regions as in the 1960s, that is in the lakes of the Mazurian Plain and the Augustów Plain.

In the analysed lakes the range of calcium concentration expanded considerably. At the end of the 1990s it was almost three times bigger and oscillated between 19 and 160 mg $Ca^{2+}L^{-1}$ (Tab.1). The pace of calcium concentration increase was very diversified in particular lakes. In some lakes it only amounted to 0.2–0.3 mg $Ca^{2+}year^{-1}$ and was nearly ten times slower in comparison to Lake Łasin, where the pace of calcium concentration increase was fastest, 2.7 mg $Ca^{2+}year^{-1}$ on average (Fig. 1). Due to the pace of calcium concentration changes, the lakes in Northeast Poland can be divided into three groups. The first group comprises lakes of a constant, yet very slow, calcium concentration increase (Lake Jegocin and Hańcza among others). The second group consists of lakes where calcium concentration increase was rather small in the 1960s and 1970s, but it accelerated in the successive years (Lakes Lampackie, Chalińskie and Piłakno among others). The lakes classified in the third group were characterised by a fast and almost equal calcium concentration growth during all those years (Lakes Łasin, Mełno, Sztum, and Wieczno among others). The diversified pace of changes in calcium concentration is presented in Fig. 1.

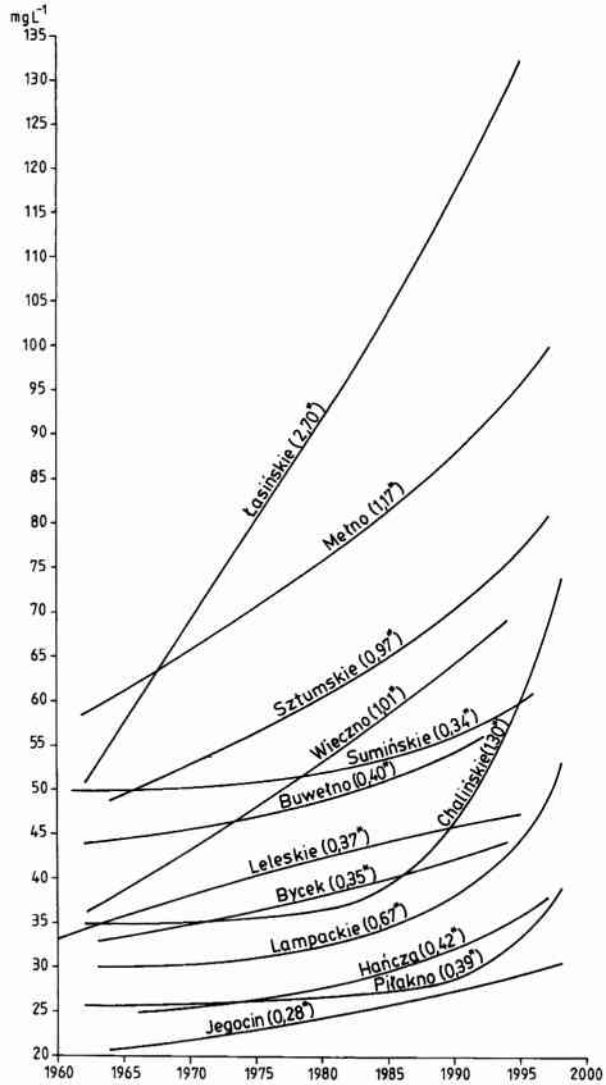

Fig. 1. Increase in calcium concentration in selected lakes of Northeast Poland (in surface water layers, in August). Symbols: * – mean annual increase of calcium concentration (mg Ca^{2+} $year^{-1}$)

Changes in magnesium concentration occurred in a different way. While the contents of magnesium enlarged by nearly 13% on average, magnesium concentration increase occurred only in seven out of 13 regions of Northeast Poland. The fastest magnesium concentration growth, though hard to explain at the present stage of investigations, took place on the Augustów Plain and in the neighbouring Suwałki Lakeland (by 98% and 55%). On the other hand, in the Great Mazurian Lakes and the Mazurian Plain magnesium concentration decreased by approximately 30%. Changes in magnesium concentration in the lakes located in particular regions occurred in various directions, which can be proven by the data presented in Tab. 1.

Table 1. Comparison of the quantity of calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) in the 1960s and 1990s (in August) in the surface layers in the lakes of Northeast Poland

No	Lakeland (Region)	Calcium (Ca^{2+})						Magnesium (Mg^{2+})					
		Number of lakes	Mean values			Range		Number of lakes	Mean values			Range	
			1960s	1990s	Change in %	1960s	1990s		1960s	1990s	Change in %	1960s	1990s
1	Dobrzyń	23	36.4	61.3	68.4	23-50	38-88	23	9.6	11.8	22.9	4.0-22.0	2.4-21.7
2	Chełmno	20	33.1	76.2	130.2	24-59	36-160	20	13.6	18.8	38.2	7.5-20.0	8.2-26.2
3	Brodnica	20	35.8	53.9	50.5	26-49	44-80	16	13.8	13.2	-4.4	7.0-24.0	5.2-33.0
4	Iława	25	32.5	58.7	80.6	12-52	19-132	25	10.2	11.9	16.7	2.1-16.5	1.9-33.7
5	Garb Lubawski	9	35.4	55.0	55.4	32-37	50-70	9	7.6	10.5	38.1	5.5-10.0	6.2-19.8
6	Olsztyn	27	31.6	49.9	57.9	9-46	34-69	24	9.7	7.8	-19.6	2.5-18.0	3.4-12.6
7	Mrągowo	22	30.5	47.7	56.4	21-41	29-60	20	10.1	9.2	-8.9	5.5-16.5	6.5-14.1
8	Great Mazurian Lakes	22	36.5	48.5	32.9	26-47	36-64	16	12.4	8.8	-29.1	4.0-18.0	2.4-12.2
9	Ełk	28	35.6	55.7	56.5	21-48	37-70	27	11.3	13.7	21.2	4.0-19.0	4.5-25.4
10	Suwałki	22	31.1	49.3	58.5	22-43	25-93	20	8.7	13.5	55.2	4.0-19.0	7.2-29.2
11	Augustów Plain	8	25.8	44.1	70.9	18-33	35-50	8	8.0	15.6	95.0	5.0-12.5	9.3-23.3
12	Mazurian Plain	14	28.9	41.6	43.9	19-43	30-59	14	8.3	5.6	-32.5	3.0-15.0	2.8-8.8
13	Urszulewo Plain	11	31.0	52.1	68.1	27-39	46-61	11	8.2	7.5	-8.6	3.5-12.0	4.0-12.6
	Northeast Poland	251	32.6	53.4	63.8	9-59	19-160	233	10.1	11.4	12.9	2.1-24.0	1.9-33.7

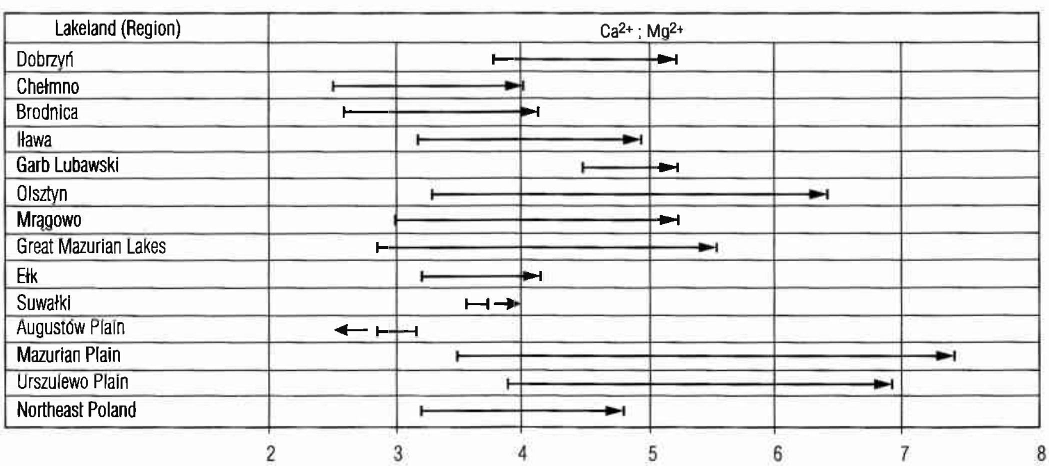

Fig. 2. Changes in the ratio of calcium to magnesium (on the grounds of the investigation results obtained in mid-August in the 1960s and 1990s.

The investigation results allow a comparison of the ratio of calcium to magnesium in the lake waters. It is known that natural and unpolluted waters contain between three and four times more calcium than magnesium. In all the analysed lakes this ratio was 3.2 on average in the 1960s, and increased up to 4.8 in the 1990s.

In particular regions changes in the ratio of calcium to magnesium were more diversified. In 12 regions the ratio clearly grew. It was slightly smaller only on the Augustów Plain. It is worth noting that in the 1960s, the ratio of calcium to magnesium remained between 3 and 4 in as many as 10 regions, and only in 5 regions in the second half of the 1990s. Changes in the ratio of calcium to magnesium are presented in Fig. 2.

As in the case of magnesium, changes in potassium concentration occurred in various directions. Decrease in potassium concentration, even by 50–78%, occurred in the lakes located in the regions of the eastern part of the area. On the other hand, in the lakes of the western part of the area, there was a distinct rise in this cation concentration (even up to 50%). Simultaneously, the range of potassium amount expanded considerably (even three times) in the compared lakes (Tab. 2).

Table 2. Comparison of the quantity of sodium ions (Na^+) and potassium ions (K^+) in the 1960s and 1990s (in August) in the surface layers in the lakes of Northeast Poland.

No	Lakeland (Region)	Sodium (Na^+)						Potassium (K^+)					
		Number of lakes	Mean values			Range		Number of lakes	Mean values			Range	
			1960s	1990s	Change in %	1960s	1990s		1960s	1990s	Change in %	1960s	1990s
1	Dobrzyń	23	5.3	13.0	145.3	0.5-11.8	4.8-37.5	23	4.6	6.9	50.0	0.8-10.5	1.6-36.5
2	Chełmno	9	11	15.4	40.0	6.6-14.2	6.4-24.4	9	7.7	10.9	41.5	2.5-12.2	1.5-19.7
3	Brodnica	12	8.5	8.9	4.7	5.4-17.0	5.6-15.7	12	2.7	3.2	18.5	2.0-3.0	1.9-4.5
4	Iława	23	4.7	6.7	42.5	1.1-14.2	1.7-10.1	23	3.0	4.3	43.3	0.7-8.7	0.3-10.6
5	Garb Lubawski	7	3.5	5.6	60.0	1.6-5.5	4.3-9.2	7	2.4	1.9	-20.9	1.5-3.8	1.1-2.7
6	Olsztyn	24	4.5	5.7	26.7	1.6-7.8	2.5-10.1	24	2.5	3.1	24.0	1.0-4.3	0.7-6.7
7	Mrągowo	21	3.9	4.4	12.8	2.7-5.5	3.0-7.1	21	2.1	2.5	19.0	0.7-3.3	0.9-4.4
8	Great Mazurian Lakes	20	6.3	4.3	-31.7	1.6-10.0	0.6-9.5	20	3.0	1.9	-26.7	1.7-5.7	0.2-4.4
9	Ełk	25	5.5	6.5	18.2	1.7-11.2	0.7-12.6	25	2.9	2.5	-13.8	1.5-5.5	0.3-3.9
10	Suwałki	18	2.5	4.6	84.0	0.6-4.1	2.7-6.5	18	2.7	1.3	-51.9	1.0-4.7	0.2-3.3
11	Augustów Plain	7	1.0	2.7	170.0	0.5-2.9	1.3-8.2	7	2.3	0.5	-78.3	1.9-7.0	0.2-1.5
12	Mazurian Plain	13	2.7	4.5	66.7	1.0-5.4	1.8-9.2	13	1.1	1.3	18.2	0.3-2.8	0.4-2.8
13	Urszulewo Plain	10	4.1	5.7	39.0	3.5-6.3	4.4-11.3	10	2.2	3.3	50.0	1.4-4.1	1.6-9.1
	Northeast Poland	212	4.9	6.8	38.8	0.5-17.0	0.6-37.5	212	3.0	3.4	13.3	0.3-12.2	0.2-36.5

Sodium concentration increased noticeably by nearly 39% on average in the lakes of all the regions (apart from the Great Mazurian Lakes). The biggest sodium concentration upsurge occurred in the lakes of the Augustów Plain. Despite this, sodium content in these lakes still remains lowest in comparison to the lakes in other regions (Tab. 2). Spatial diversification in the pace of changes in the concentration of sodium and the remaining cations has been presented in Fig. 3.

The pace of changes in cation concentration was different in dimictic and polimictic lakes. Polimictic lakes were of a distinctively bigger pace of cation concentration growth (particularly calcium). In the lakes where cation concentration declined, there was a faster fall of cations in dimictic lakes. The above-mentioned dependencies for the lakes located in several regions are presented in Tab. 3.

Table 3. Mean cation values in the lake surface layers in August in the 1960s and 1990s (in mg L^{-1}) depending on mictic types and change in their concentration (in %).

Lakeland (Region)	Type of lake	Ca^{2+}			Mg^{2+}			Na^+			K^+		
		60's	90's	%	60's	90's	%	60's	90's	%	60's	90's	%
Dobrzyń	polimic.	38.9	69.6	78.9	10.1	11.3	11.9	4.8	15.2	216.7	4.6	8.5	84.9
	dimictic	34.0	53.1	56.2	9.1	12.3	35.2	5.7	10.9	91.2	4.6	5.3	15.2
Olsztyn	polimic.	31.4	56.8	80.9	9.9	8.8	-11.2	5.1	5.9	15.7	2.6	3.6	38.5
	dimictic	31.7	46.8	47.6	9.6	7.3	-24.0	4.2	5.6	33.3	2.4	2.7	12.5
Ełk	polimic.	33.2	54.4	63.8	13.3	13.5	1.5	6.5	7.0	7.7	2.4	2.3	-4.2
	dimictic	38.3	57.2	49.3	9.7	13.9	43.3	4.6	6.0	30.4	3.5	2.7	-22.9
Suwałki	polimic.	32.9	59.4	80.5	7.2	12.6	75.0	2.8	4.8	71.4	2.7	1.4	-48.1
	dimictic	30.1	40.2	33.5	9.9	14.3	44.4	2.1	4.3	104.8	2.7	1.2	-55.6

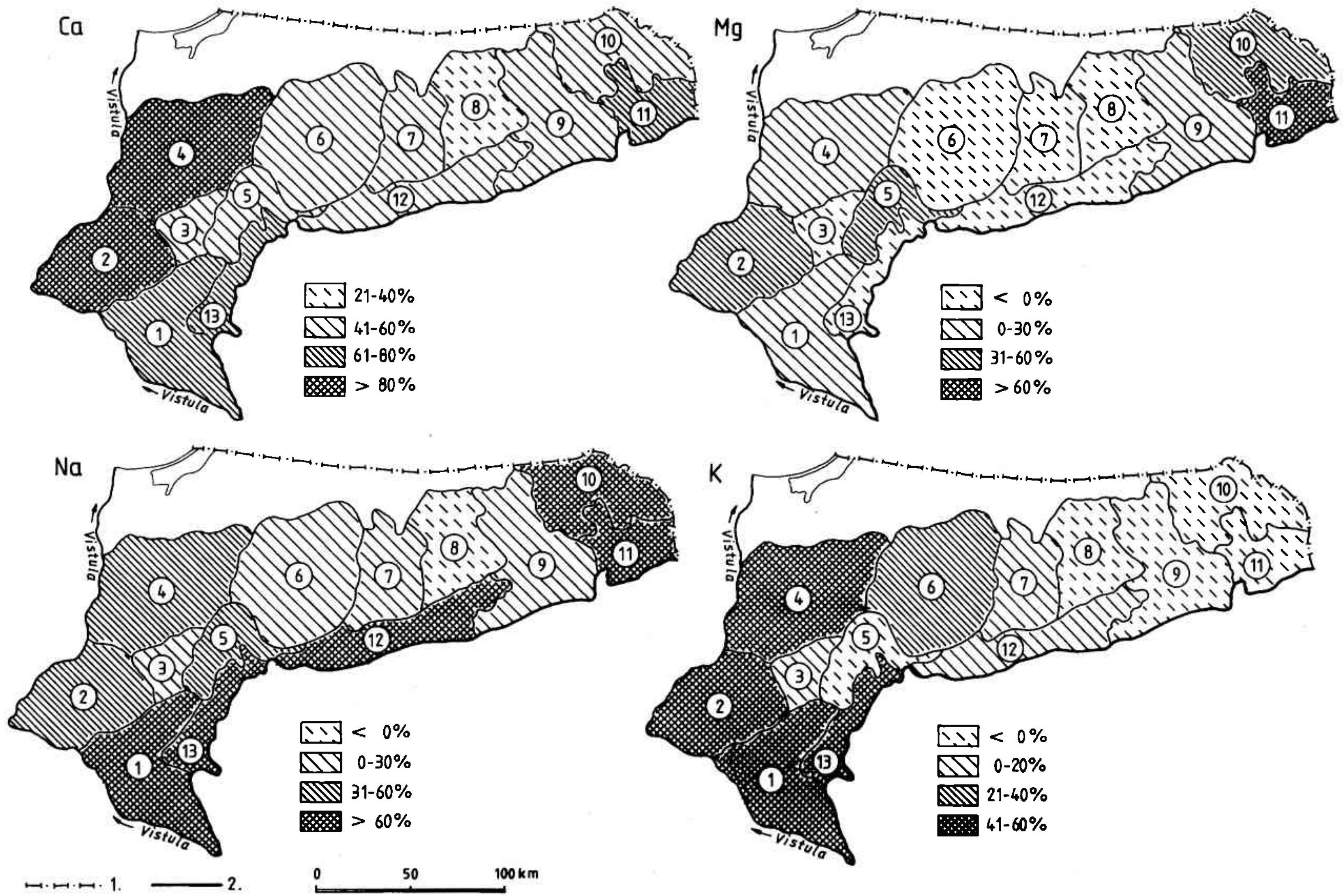

Fig. 3. Changes in the concentration of the main cations in the lake water surface layers in the 1960s and 1990s according to physico-geographical regions.
Symbols: 1 – national borders; 2 – maximum extent of the Weichselian Glaciation. Names of physico-geographical regions: 1 – Dobrzyń Lakeland; 2 – Chełmno Lakeland; 3 – Brodnica Lakeland; 4 – Iława Lakeland; 5 – Garb Lubawski; 6 – Olsztyn Lakeland; 7 – Mrągowo Lakeland; 8 – Great Mazurian Lakes; 9 – Ełk Lakeland; 10 – Suwałki Lakeland; 11 – Augustów Plain; 12 – Mazurian Plain; 13 – Urszulewo Plain.

Changes in cation concentration over summer seasons occurred both in the surface and bottom water layers. The scale and pace of these changes were similar. This can be proven by the fact that both in the 1960s and 1990s the concentration of calcium and magnesium cations above the bottom was larger by approximately 20% than on the surface. Apart from that, for 35 years the increase in the concentration of these cations was bigger by only some percent in the lake bottom layers. As far as the concentration of sodium and potassium cations is concerned, even smaller differences were noted between surface and bottom layers (Fig. 4).

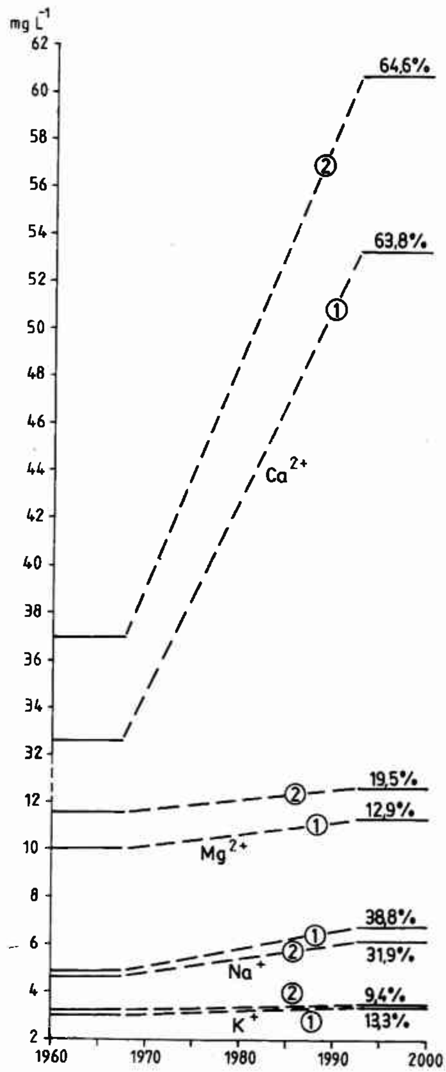

Fig. 4. Tendencies in changes (in %) in the concentration of the main cations in the lake surface and bottom layers (in August). Symbols: 1 – surface layer (0.5 m depth); 2 – bottom layer (approximately 1 m above the bottom)

Changes in cation concentration took place in the periods of spring homothermy, when cation concentration was bigger in comparison to summer seasons. Cation concentration growth was observed in most lakes. The pace of cation increase in springs was similar to the one in summer seasons. Thus, in the springs of the 1990s, as in 1960s, there was slightly bigger cation concentration in comparison to the summer seasons. Sodium concentration remained similar both in the spring and summer periods in the 1990s (Tab. 4).

Table 4. Mean cation values in the lakes of Northeast Poland during spring homothermy and summer stagnation in the 1960s and 1990s

Cation	Season	1960s	1990s
Calcium	Spring	38.0	61.3
	Summer	32.6	53.4
Magnesium	Spring	10.6	11.6
	Summer	10.1	11.4
Sodium	Spring	5.7	6.7
	Summer	4.9	6.8
Potassium	Spring	3.4	3.8
	Summer	3.0	3.4

Discussion

The investigation results presented in this work can be analysed at different angles. The most important issues include: spatial diversification of changes in cation concentration and determination of their causes.

Spatial diversification of changes in cation concentration was only possible to present in two ways: according to hydro-geographical classification (after categorising every lake to a particular basin) or according to the division into physico-geographical regions. Due to several reasons, the analysis of the lakes based on hydro-geographical classification proved to be more complicated. Considerable diversification in basin sizes (from dozens of km^2 to over two thousand km^2) as well as basin series, and their big number seemed the most important causes. Moreover, there were entirely different ways of management and utilisation of their individual parts, particularly in the case of the biggest basins. This diversification is significantly smaller in the case of the physico-geographical regions which have been distinguished due to quite similar geological, geomorphological, hydrographical and floral properties (Kondracki, Richling, 1998). Thanks to this, it was possible to examine the lakes in the regions of a typically agricultural character (for instance the Chełmno and Dobrzyń Lakeland), forest-agricultural character (for example the Olsztyn and Mrągowo Lakelands, Great Mazurian Lakes), and of a typically forest character (the Augustów and Mazurian Plains for example).

Taking into account the entire area of Northeast Poland it should be stated that the biggest growth of cation concentration occurred in the lakes located in the western part (Fig. 3), where farming lands are predominant. This increase took place in the lakes which were classified as the most polluted in Poland as early as in the 1960s. (Korycka, 1991). The lakes situated in the rather small Brodnica Lakeland provide an exception. This lakeland is covered with a thick forest complex, which makes it more distinct from the neighbouring regions. Moreover, since the formation of the Natural Scenic Area in 1985, the Brodnica Lakeland has been under more thorough protection. However, it is hard to estimate whether a small increase (or even a decline, as in the case of magnesium) in cation concentration in the lakes of this region results from the forest character of the lake catchments or protective activities. Both those factors have an obvious influence upon the small degree of hydro-chemical transformations of the lakes in this Lakeland.

A noticeably smaller increase (and even decrease) in cation concentration occurred in the lakes located in the central and eastern part of the analysed area. Particularly, it refers to the Great Mazurian Lakes where cation concentration (except for calcium) diminished. The lakes in the Suwałki Lakeland and Augustów Plain had various tendencies in the changes of cation concentration. In these lakes there was a big rise in magnesium and sodium concentration. The quantity of potassium fell (Fig. 3). Although magnesium and sodium concentration increased (even up to 170%) in the lakes of the Suwałki Lakeland and Augustów Plain, the mean quantity of sodium is still one of the smallest in the entire area of Northeast Poland and amounts to between 2.7 and 4.6 mg Na L^{-1}. This illustrates that the lakes in these regions are not heavily polluted (or are unpolluted) with industrial waste that would lead to a fast increase in sodium concentration. This problem is completely different in the western part of the analysed area (the Dobrzyń and Chełmno Lakelands), where the mean quantity of sodium rose up to 13.0–15.4 mg Na L^{-1} at the end of the 1990s. This growth resulted from the discharge of various types of sewage into the lakes. In some cases, the contents of sodium exceeded 37 mg Na L^{-1}.

As much as sodium concentration is related to the increase in lake pollution with sewage, the changes in calcium and potassium concentration were influenced by other factors. Artificial manures, which are washed out of soil, seem to be one of the most important factors. Washing chemical compounds out of artificial manures took place in the 1970s and 1980s, mainly in rural areas utilised by the State Farms.

Artificial manures were widely applied in those days (Fig. 5). The State Farms fertilised in an irrational way regardless of atmospheric conditions and often with a view to carrying out a predetermined plan. Calcium compounds' wash-out exceeded even 200 kg Ca from ha $year^{-1}$. Flowing waters in the drainage networks in the Chełmno Lakeland were found to have a large concentration of calcium, which exceeded seasonally 280 mg Ca L^{-1}. Surely, extensive utilisation of calcium manures in 1960–1990 caused its higher concentration in all the analysed lakes, on average from 32.6 to 53.4 mg Ca L^{-1}, that is 63.8% higher. At the beginning of the 1960s, 35 out of 251 lakes could be classified as lakes with an average (from 10 to 26 mg Ca L^{-1}) or low (from 1 to 10 mg Ca L^{-1}) content of calcium. After 35 years there were only two lakes like that. Water hardness increased in consequence of calcium concentration rise. It has caused the diminishment of water reaction.

The results of the analyses of potassium concentration indicate a different course and range of their changes in comparison to calcium for instance. In the lakes located in five regions, mainly in the eastern part of the studied area, potassium concentration diminished, contrary to the lakes in the western regions. It is known that the biggest amounts of potassium flow into waters from both soils fertilised with potassium salts and animal and vegetable wastes. The utilisation of potassium manures was highest in the western part of the studied area, and was very diverse (Fig. 5).

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Streszczenie

W opracowaniu porównano koncentrację wapnia, magnezu, sodu i potasu w latach 60. i 90. XX wieku w 251 jeziorach położonych w północno-wschodniej części Polski. Głównym założeniem metodycznym badań w latach 90. było przeprowadzenie ich w tych samych miejscach i w zbliżonym czasie jak w latach 60., tj. w najgłębszych miejscach jezior w połowie sierpnia oraz podczas homotermii wiosennych.

W latach 1960–1998 skład chemiczny wód jeziornych uległ istotnym zmianom w zakresie koncentracji głównych kationów. Zmiany te polegają na wzroście koncentracji kationów w skali całego obszaru, który przebiegał jednak z różnym nasileniem w poszczególnych regionach (tab. 1 i tab. 2). We wszystkich regionach znacznie wzrosła koncentracja wapnia oraz rozszerzył się zakres jego występowania. Pod koniec lat 90. był on prawie trzykrotnie większy i mieścił się w granicach od 19 do 160 mg $Ca^{2+}L^{-1}$ (tab. 1). Tempo wzrostu koncentracji wapnia było bardzo zróżnicowane w poszczególnych jeziorach (ryc. 1), które pod tym względem podzielono na 3 grupy. Dużym zmianom uległ także ilościowy stosunek wapnia do magnezu (ryc. 2). Przestrzenne zróżnicowanie tempa zmian koncentracji wapnia i pozostałych kationów przedstawia ryc. 3. Szybszy wzrost koncentracji kationów (zwłaszcza wapnia) nastąpił w jeziorach polimiktycznych. Z kolei w jeziorach, w których koncentracja kationów uległa zmniejszeniu, szybszy spadek kationów nastąpił w jeziorach dimiktycznych (tab. 3). Podobne zmiany (o zbliżonej wielkości i tempie) nastąpiły także w naddennych warstwach jezior (ryc. 4).

Tempo wzrostu kationów w okresach wiosennych było podobne jak w sezonach letnich. Dlatego też wiosną w latach 90., podobnie jak w latach 60., nadal utrzymywała się nieco większa koncentracja kationów w porównaniu do sezonów letnich. Jedynie koncentracja sodu w latach 90. była podobna zarówno wiosną jak i latem (tab. 4).

Największy wzrost koncentracji kationów nastąpił w jeziorach położonych w części zachodniej (ryc. 3), w której wyraźnie dominują grunty orne. Znacznie mniejszy wzrost (a nawet spadek) koncentracji kationów nastąpił w jeziorach położonych w środkowej i wschodniej części analizowanego obszaru. Z kolei jeziora na Pojezierzu Suwalskim i na Równinie Augustowskiej charakteryzowały się dużym zróżnicowaniem tendencji zmian koncentracji kationów. Pomimo znacznego wzrostu koncentracji magnezu i sodu (nawet do 170%) w jeziorach Pojezierza Suwalskiego i Równiny Augustowskiej, zawartość średnia sodu w tych jeziorach należy nadal do najniższych w skali całego obszaru Polski Północno-Wschodniej i wynosi od 2.7 do 4.6 mg Na L^{-1}. Świadczy to o niewielkim zanieczyszczeniu jezior w tych regionach ściekami przemysłowymi, które są główną przyczyną szybkiego wzrostu koncentracji tego kationu.

O zmianach koncentracji wapnia i potasu zadecydowały inne czynniki. Wśród nich za najważniejszy należy uznać nawozy sztuczne, których zużycie zmieniało się w sposób bardzo wyraźny (ryc. 5). Gwałtowny spadek zużycia nawozów potasowych w połowie lat 90. mógł w dużym stopniu zadecydować o zmniejszeniu się koncentracji potasu w wielu jeziorach. Ujemna tendencja zmian koncentracji potasu może też wynikać ze zużywania jonów potasowych przez rośliny, dla których stanowi on jedną z substancji pokarmowych.

Zmiany koncentracji kationów w jeziorach są związane przede wszystkim z czynnikami antropogenicznymi. Ze względu na znaczne oddziaływanie antropopresji na omawiane jeziora, trudno jest określić wielkość tej części zmian koncentracji kationów, która jest następstwem wyłącznie oddziaływania czynników naturalnych. Jedynie w przypadku wapnia i jezior położonych w zlewniach leśnych można zaryzykować stwierdzenie, że wzrost jego koncentracji w warunkach zbliżonych do naturalnych nie powinien przekraczać 0.1 mg Ca $L^{-1}year^{-1}$. Wyniki badań wskazują na duże zmiany składu chemicznego wody w jeziorach Polski Północno-Wschodniej. Powoduje to konieczność wprowadzenia korekt w ogólnych charakterystykach hydrochemicznych jezior w tej części Polski i prawdopodobnie także w innych częściach. Zmiany te ulegają jednak zahamowaniu i wydaje się, że w najbliższej przyszłości będą przebiegały znacznie wolniej. Jest to efekt zdecydowanego zmniejszenia się zanieczyszczania jezior i rzek różnego rodzaju ściekami.