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EXTENT OF MARINE WATER INFLUENCE ON CHEMICAL FEATURES OF LAKE BUKOWO BOTTOM SEDIMENTS

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Abstract

The 15 - cm layer of bottom sediments of the Lake Bukowo was examined. Organic sediments make up to 32% of the Lake Bukowo bottom surface, the mixed sediments - 52% and the sandy ones - 16%. Bottom sediments of this lake displayed a high content of organic matter ca. 28%, nitrogen ca. l. 2%, silica 65% and phosphorus 0.9%. Nitrogen and phosphorus were deposit into sediments in the main form of organic compounds. These sediments were characterized by low content of metals (average: Ca 1%, Mg 0.8 %, Fe 1.3% and Al 1.1%). The pollution of Lake Bukowo increased comparison to 1987.

Key words: bottom sediments, lake, granulometric, chemical compositions

INTRODUCTION

Bottom sediments very well reflect the mechanical and chemical changes occurring in lakes as their component substances participate in the cycle of particular elements thus influencing the aquatic environment and being able to change its properties (Januszkiewicz 1978a). The sediment accumulation rate, their physical structure and chemical composition depend on many factors. However, it is the property of drainage basin, the lake's physico-chemical and biological conditions and its water supply pattern that are most important (Trojanowski *et al*. 1982). Chemical composition of sediments changes in the vertical profile. The most active layer that participates in chemical change in the water-sediment area is 10-15 cm thick surface layer (Wiśniewski 1989); some estimate it several millimetres thick (Gawrońska 1987, 1989). Bottom sediments are not only the centre for chemical changes, but also a place where various substances accumulate as well as many toxic compounds entering the water body deactivate and decompose (Kostecki *et al*. 1998). They make a trap for nutrients when their concentration in water is high; but, on the other hand, they become their source when their concentration in water is low (Trojanowska *et al*. 1993a, Trojanowska *et al*. 1993b).

In this way, lakes make a kind of natural „settling tanks" for rivers which flow through them. They leave much of their pollution in coastal lakes before entering the sea. The lake's heavy contamination and high extent of eutrophication make them become half-dead estuaries which will be getting more and more shallow in the near future as the lake's basin gets filled with the dropping down substances. One of the primary reasons why the coastal lakes have not yet become completely degraded is the frequent marine water gate. The marine water enters the lakes when the Baltic waters dam up, or when the lake water table lowers significantly. Marine water dilutes lake waters in terms of nutrient and organic matter contents, but on the other hand, it shakes their balance by introducing too much of chloride ions (Majewski 1972, Trojanowska 1993a).

Bottom sediment properties make quite a representative indicator of long-term changes to water reservoirs pollution, and may also be used as indicators of biological and chemical changes to water environments.

The objective of the present study was:

- to specify the chemical composition of 15 cm thick bottom sediments of Lake Bukowo, which well reflect the impact of introduced pollution and which make the source of inner supply,
- to show the changes pattern of the sediments in comparison with previous data,
- to specify the marine water impact on the character of the examined lake sediments.

MATERIAL AND METHODS

Lake Bukowo neighbours on Lake Jamno and in earlier times those two lakes must have formed a coastal flood as there is a lowered strip of marsh between those lakes, close to the village of Łazy. It must have been flooded during the small maximum of Litorina transgression (Majewski 1972). Table 1 presents the limnometric characteristics of the lake. Lake Bukowo covers an area of 1 747.7 ha; its mean depth is 1.8 m, maximum depth is 2.8 m.

Table 1

Morphometric characteristics of Lake Bukowo

Property of lake	Value
Surface area (km^2)	17.47
Shore line (km)	23.2
Volume (km^3)	0.032
Maximum depth (m)	2.8
Mean depth (m)	1.8
Maximum length (km)	8.80
Maximum width (km)	3.36

The lake is linked with the Baltic Sea by a 500 m long channel, which usually is covered in the coastal rubble sand (Fig. 1). All the lake's coastline is overgrown by bulrush vegetation. Submersed vegetation occurs not only off the coasts but it can also be found in different parts of the lake where it is shallow.

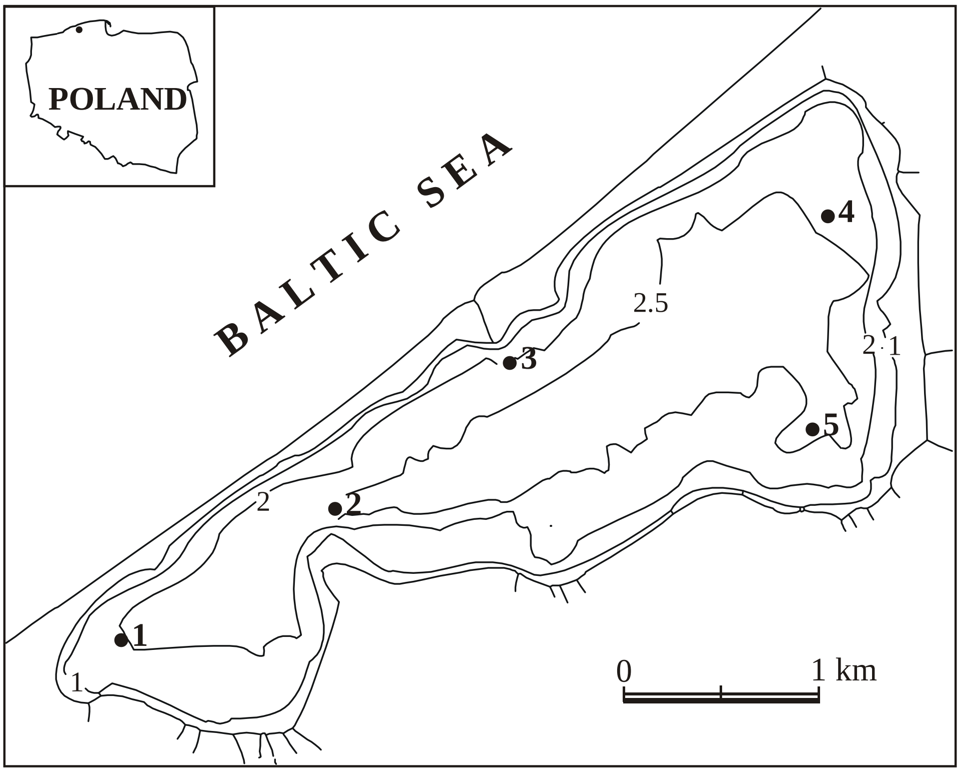

Fig. 1. Location of sampling stations in the Lake Bukowo

Lake Bukowo has very few affluents, which results in a ninefold annual water exchange. The lake's largest affluent is the River Bagiennica, which brings in some waters of the River Grabowa - a tributary of the Wieprz. Other affluents are melioration ditches catching run-off from the neighbouring fields and meadows (Choiński 1995).

Bottom sediments at five research stations were studied. The location of the stations are presented in Fig. 1:

- Station 1 was located in the western part of the lake, at the outlet into the melioration ditch joining that lake with Lake Jamno,
- Station 2 was located in the deepest part of the lake,
- Station 3 was fixed at the canal joining the lake to the sea,
- Station 4 was fixed in the eastern part of the lake, close to Dąbki village,
- Station 5 was placed at the River Bagiennica mouth into the lake.

A single summer sampling (1987 and 1997) was done by means of an Ekman sampler. Three sediment samples were collected from each station, and the results were averaged out. The over sediment water was collected carefully; the interstitial water was separated by means of filtering fresh sediment through a stilon bolting-cloth. The samples were then kept in tightly insulated vessels, at about 4°C for later phosphorus and nitrogen compounds determination. Granulometric composition was determined in the collected samples, which were carried out with the use of the aerometric method modified by Prószyński, and by sieve method (Mirowski and Rytelewski 1981). Analyses the bottom sediment were done following the method by Januszkiewicz (1978b).

Silica and undissolved components were determined by means of fusing the sediments with unhydrous sodium carbonate and unhydrous potassium carbonate at 1:1 ratio. Having determined silica in that solution, manganese, calcium, magnesium and iron were then determined with the use of a complexometric method. In the samples, iron was determined prior to defining aluminium.

Once the sample has been mineralised, its total phosphorus contents (T-P) were determined by means of colorimetric method of molybdatenic blue. The total nitrogen contents (T-N) were determined with the use of Kiejdahl method; and organic carbon - by the dichromate method.

RESULTS AND DISCUSSION

The bottom sediments of lake Bukowo display certain differentiation in terms of granulometric pattern. They contain about 70% of large-sized particles of 1-0.1 mm. Over 70% of those particles are in the sediments recovered from stations 1, 3 and 4 which are composed mainly of sand. Sediments recovered from lakes Jamno (ca. 45%), Gardno (ca. 50%) and Łebsko (ca. 60%) contained fewer particles of that size (Trojanowska *et al*. 1993a). However, fractions containing 0.1-0.02 mm particles and those smaller than 0.02 mm displayed a similar composition, which was about 15% in each case. It was only at Station 1, which received the run-off from the neighbouring fields and meadows, where second largest fraction was that of less than 0.02 mm particle size and occurred in a silty form (19%; 0.1-0.02 mm - 8%). At Station 3 (at the river mouth into the sea), the bottom sediments contained 10% of particles which were of intermediary sizes, while particles smaller than 0.2 mm made as little as 7%. Lakes Jamno, Gardno and Łebsko contain by 1.5 times more silty forms than bottom sediments of Lake Bukowo.

Chemical analyses done to those samples revealed clear differences between the compositions of the sediments in different lake parts (Fig. 2). Silica were the dominant in those sediments, which made 56-88% (mean 66%) dry mass in 1997. Comparing Lake Bukowo to other eutrophic lakes, its sediments contained an average amount of SiO_2 (Gawrońska 1987, Trojanowski 1987). The greatest amounts of sand were present in the areas where marine water gates occurred (Station 3 - 88%, Fig. 2) and around Station 1 - about 76%. Sand was spotted at its least at the River Bagiennica affluent (Station 5 - 56%) and at the deepest point (Station 2 - ca. 60%, Fig. 3). In terms of particle sizes, organic matter was the second largest component of the sediments in Lake Bukowo (mean 12.8% C_{org}).

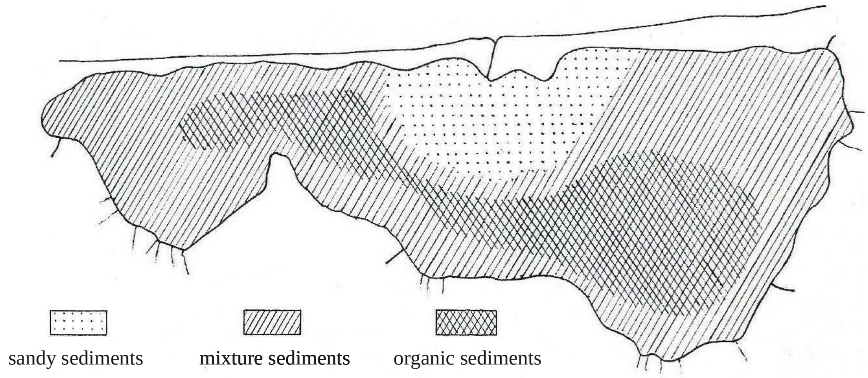

Fig. 2. Distribution of organic, mixed and sandy sediments in the Lake Bukowo

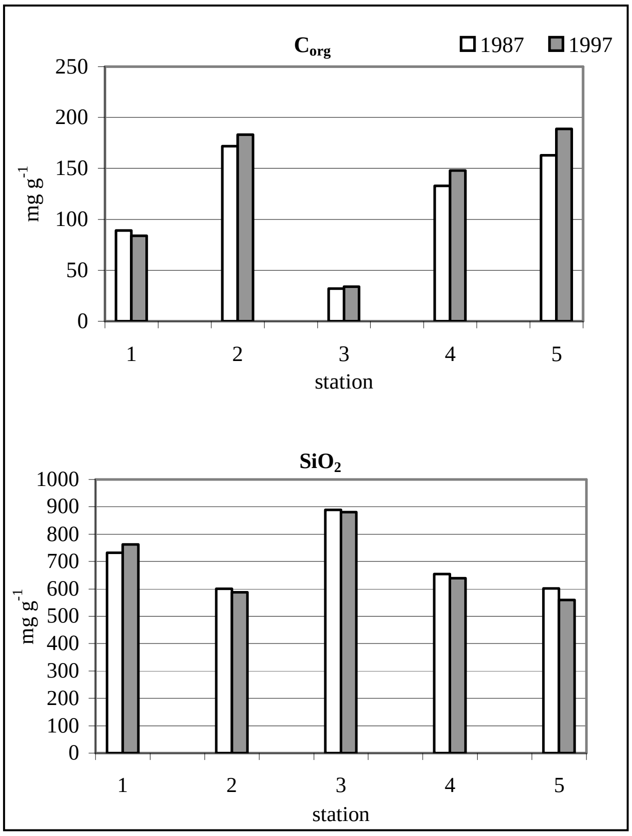

Fig. 3. Mean contents of organic carbon (C_{org}) and of silica (SiO_2) in bottom sediments of the Lake Bukowo in years 1987 and 1997 (stations 1-5)

The organic matter contents in the lake's sediments changed within the 6.5-26% range and it could be defined as high (Fig. 3), in other eutrophic water bodies alike (Trojanowski 1987, Martinova 1998, Gawrońska 1989). It was only at stations 1 and 3 that it was significantly lower. This composition pattern at Station 3 very much depends on marine water, which flows in at certain periods of time, bringing sand behind. Large amounts of organic matter occurring at Station 5 (18.9% $C_{org.}$ converted into dry mass) originate from the River Bagiennica, which brings in a lot of pollution (Żmudziński *et al*. 1993). At its mouth into the lake, the river water purity extent was beyond any classification scale. That could be due to a salmon fish farm, which is located on the river.

Organic carbon accumulation in the deepest parts (Station 2 - 17.3% C_{org}) is a well-known phenomenon and has widely been commented on in literature (Bjork 1972, Januszkiewicz 1970, Korzeniewski *et al*. 1978). Studying bottom sediments of various lakes, Januszkiewicz (1980) found out that chemical changes occurring to them cause organic carbon disappear from sediments sooner than organic nitrogen. The shallower the lake parts, the better sediment oxygenation and their warming up, which in turn drives at a faster and higher extent of organic substances decomposition. This is confirmed by a low carbon-nitrogen ratio - about 12. According to Lityński *et al*. (1976), during an organic substance decomposition at C:N ratio less than 17, mineral nitrogen compounds (including ammonia) are released into the water. Despite a great mineralisation rate, the lake is not able to catch up with a full organic substances decomposition, which was confirmed by lower value data in 1987. In comparison to 1987 (Trojanowska *et al*. 1993a), the mean organic carbon contents increased by 8.5 %, with a greatest rise, about 14.5% recorded at stations 4 and 5 (Fig. 3). An increase in the organic matter concentration in Lake Bukowo bottom sediments provides evidence on an ongoing eutrophication process in that water body.

Due to the role nitrogen and phosphorus play in an eutrophication process, much attention was paid to the contents and cross-connections of those nutrients with other sediment components. The Lake Bukowo bottom sediments are fairly rich in nitrogen compounds and are characterised by 0.23-1.52% (mean 1.05%) total nitrogen contents (T-N). The data are well matched with other eutrophic lakes (Trojanowska *et al.* 1993b, Gawrońska 1985, Austin and Lee 1973, Dean 1976). Yet, there is a distinct quantity differentiation within the lake itself (Fig. 4). There occur three distinct zones: the eastern part of the lake deepest (stations 4 and 5) and the deepest area (Station 2) where the nitrogen contents in the sediments is about 1.4%; the western part (Station 1) which contains about 0.8% of nitrogen and the area of the lake water outflow with 0.2% of nitrogen.

The nitrogen accumulated in the lake's bottom sediments occurs mainly as organic matter component of autochtonic and allochtonic origin. It is additionally supported by a positive fundamental correlation between organic matter contents and nitrogen, on the significance level of 0.001 ($r = 0.81$, $n = 28$, $y = 2.08x + 0.68$). In sediments, nitrogen undergoes a number of biochemical changes, turning mainly into ammonia (Górniak and Jekaterynczuk-Rudczyk 1985). When released from the sediment, nitrogen very much depends on oxygen conditions. Under anaerobic conditions, ammonia may be accumulated, whereas when in aerobic environment it may be oxidised. Under anaerobic conditions, part of nitrogen undergoes denitrification processes and may be released out of the lake. When compared to 1987, the mean nitrogen contents (0.97%) in Lake Bukowo bottom sediments has increased by 8.2%, whereas the total phosphorus contents has increased by about 7%. A greatest increase was recorded at Station 5 and was about 19%.

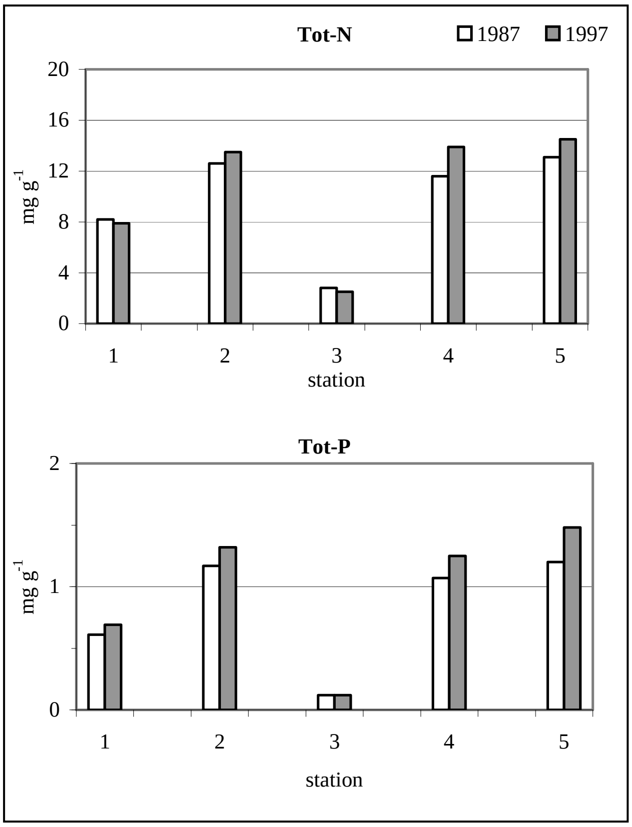

Fig. 4. Mean contents of total nitrogen (TN) and total phosphorus (TP) in bottom sediments of the Lake Bukowo in years 1987 and 1997 (stations 1-5)

Phosphorus compounds are those components in a lake that decide on the water body trophy. They enter the sediments in form of organic compounds with organic matter or sediment along with several metals compounds (Williams *et al*. 1976, Nöges and Jürvet 1998). Phosphorus content is strictly associated with the eutrophication extent of a lake and with bottom sediment's sorption abilities (Golachowska 1971, Trojanowski 1991). Mean phosphorus concentration in Lake Bukowo bottom sediments was 0.91% (Fig. 4). This value is characteristic of eutrophic lakes (Trojanowska *et al*. 1993a). Other components alike, phosphorus distribution in particular lake strata was uneven. The greatest contents of phosphorus compounds were recorded at the River Bagiennica mouth (Station 5 ca. 0.15%); the lowest - at Station 3 - 0.025%. It is definitely the marine water inflowing in the lake at regular intervals, that caused such low phosphorus (Trojanowska *et al*. 1993b) and nitrogen concentration values. Marine water normally contains less nitrogen and phosphorus and thus it rinses those components out of sediments and brings in marine sand leaving it on top.

Substantial correlation has been found between organic carbon and phosphorus ($r = 0.78$, $y = 21.93x + 2.83$, $n = 28$), as well as between nitrogen and phosphorus ($r = 0.88$, $y = 0.104x - 0.15$, $n = 28$). This makes evidence of phosphorus occurrence, mainly in organic forms.

Lake Bukowo bottom sediments, lakes Gardno and Mutek alike, contain little iron, manganese and aluminium alike (Fig. 5 and 6) as well as in Lake Mutek (Gawrońska 1987) and Lake Gardno (Trojanowski *et al.* 1991).

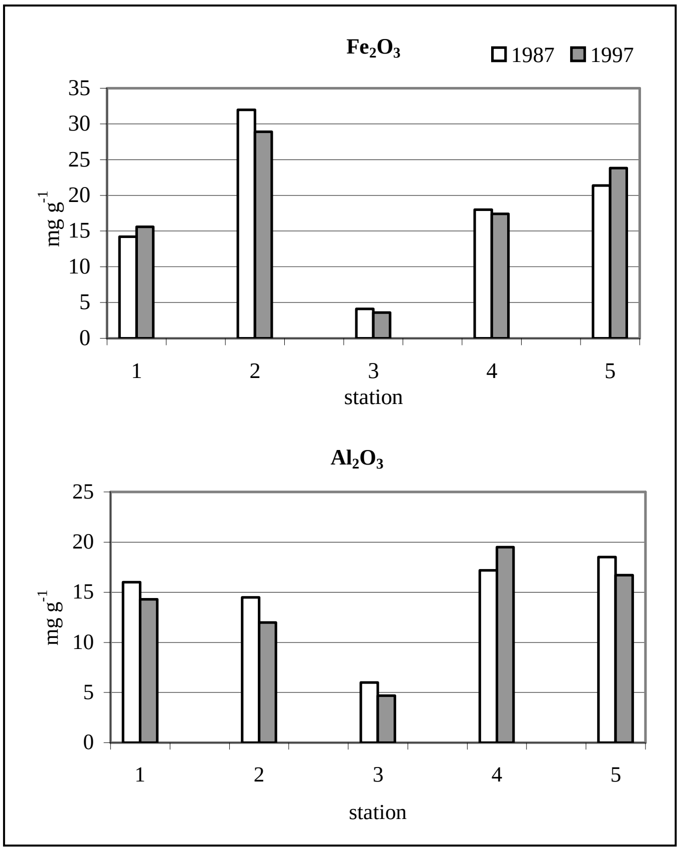

Fig. 5. Mean contents of iron and aluminium in bottom sediments of the Lake Bukowo in years 1987 and 1997 (stations 1-5)

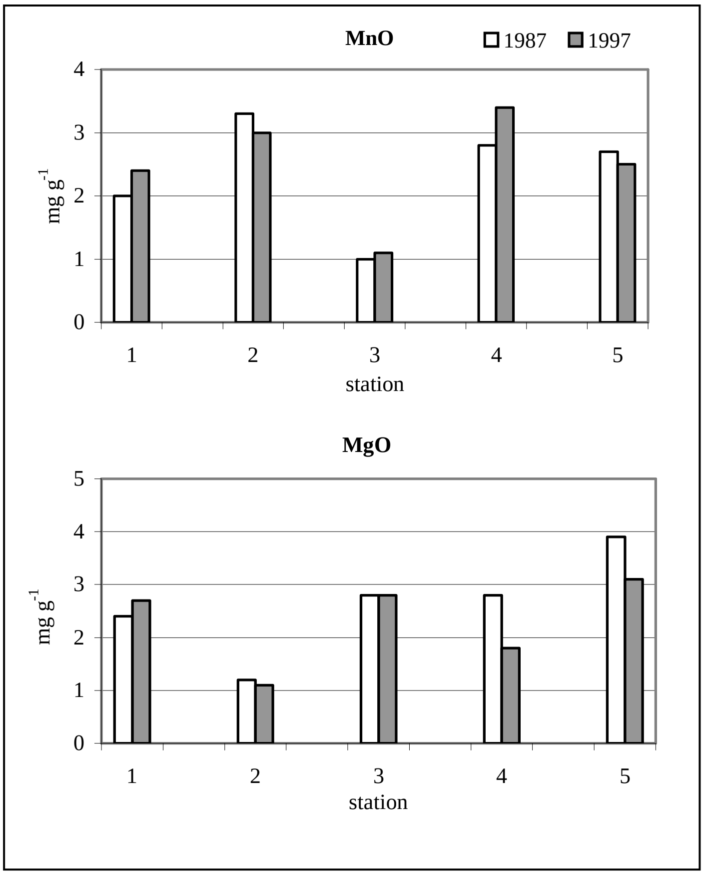

Fig. 6. Mean contents of magnesium and manganese in bottom sediments of the Lake Bukowo in years 1987 and 1997 (stations 1-5)

Correlation and regression analyses have not revealed any dependence on iron or phosphorus contents. There was, however, a very weak relation between aluminium and phosphorus, the correlation coefficient of which was r = 0.58 at 0.005 significance level. This also points to aluminium playing a certain role in phosphorus assimilating in the lake's bottom sediments. Those sediments contained on average 1.14% aluminium and 1.27% iron in the sediment dry mass. Iron was most abundant, about 2.9%, in the sediment's deepest part (Station 2). Aluminium, on the other hand, occurred in greatest amounts in the eastern part of the lake (stations 4 and 5). A substantial correlation found between iron and aluminium indicates that those metals compound sediment in a similar way.

When compared to 1987, those metals contents have slightly diminished. An only rise was recorded at stations 1 and 5 (Fig. 5) and referred to iron, which suggested that their main source were the affluents.

Calcium is an important component of Lake Bukowo bottom sediments in terms of amount. It occurs in the sediments when discharged from the river basin and as a result of the processes going on inside the lake. Its contents (1% on average) in the lake's sediments were lower than in other lakes (Januszkiewicz 1978a, Trojanowski *et al*. 1982) and oscillated between 0.46 and 1.41% (Fig. 7). The western part of the lake (Station 1) was the richest in calcium - about 1.4%, while the deepest areas had the least calcium contents - about 5%. The great amount of calcium found at Station 1 could have resulted from the accumulation of crustacean shells in that area.

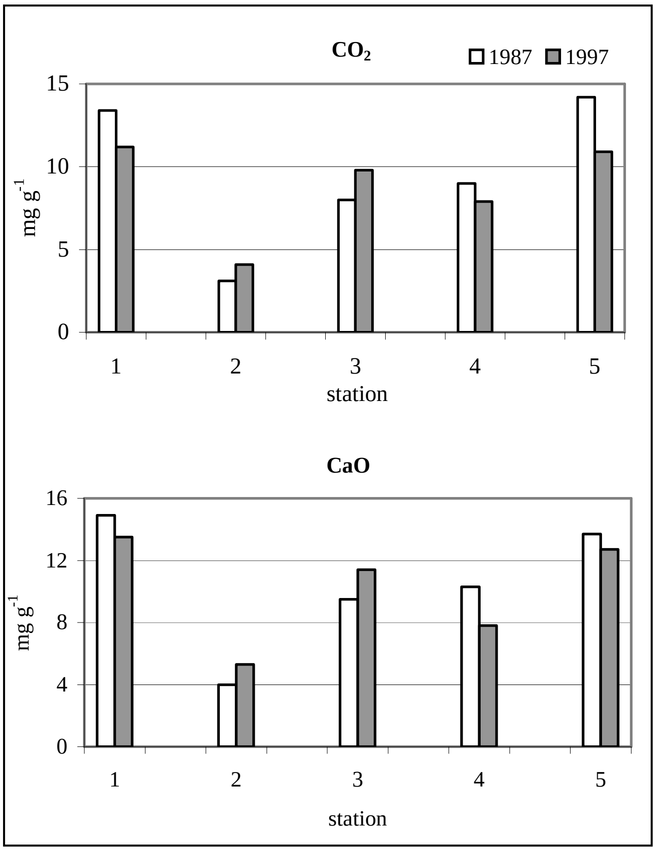

Fig. 7. Mean contents of carbonates (CO_2) and calcium (CaO) in bottom sediments of the Lake Bukowo in years 1987 and 1997 (stations 1-5)

Carbonates showed a firm correlation with calcium (r = 0.92, y = 0.93x - 0.65, n = 28) and occurred in 0.40-1.21%. Their distribution was similar to that of calcium because both components are linked genetically and occur in form of calcium carbonates. There occurred weaker connections between magnesium and carbonates (r = 0.70) which, however, are of pretty much importance because they indicate that some of the magnesium is combined with carbonate ions in the sediments. The same phenomenon was recorded in lakes Wadąg (Januszkiewicz 1978a), Łętowo and Szczytno Małe (Trojanowski *et al*. 1982). In those lake's sediments, magnesium amount was four times lower than that of calcium and altered within the range of 0.10-0.33% (Fig. 6). The sodium contents (mean 0.6%) in those sediments were over twice that of magnesium. The potassium contents, however, was lower and amounted to 0.15% on average.

Unlike in Lake Bęskie (Gawrońska 1989), the smallest contents of alkaline metals (calcium, magnesium, sodium, potassium) were recorded at the deepest point of the lake (Station 2). As compared to 1987, those metals concentrations have slightly diminished in the sediments.

On the basis of the Lake Bukowo bottom sediments chemical analyses and according to Stangenberg classification, three types of sediments have been specified:

1. organic sediments, stations 2 and 5 - 32% surface of bottom,
2. mixed sediments, stations 1 and 4 - 52% surface of bottom,
3. sandy sediments, Station 2 - 16% surface of bottom, Fig. 2 shows their locations.

CONCLUSIONS

The following conclusions can be drawn on the basis of the collected data:

1. Organic sediments make up to 32% of the Lake Bukowo bottom surface, the mixed sediments - 52% and the sandy ones - 16%.
2. The lake's bottom sediments were characterised by high organic matter and nitrogen contents; there were average amounts of silica and phosphorus and metals occurred in very small amounts.
3. The chemical composition of the water body sediments was very differentiated between the lake parts. It depended mainly on the tributaries (the River Bagiennica in the first place) and the marine water.
4. The seasonal marine water gates affect the composition of the bottom sediments and cause that in the area where lake water flows out into the sea there is the lowest content of organic matter, nitrogen and phosphorus. While diluting the lake water, marine water makes many chemical compounds release out of the bottom sediments, including nutrients.
5. Nitrogen and phosphorus were deposited in the lake sediments mainly in form of organic compounds.
6. Calcium and magnesium were accumulated in those sediments primarily in form of carbonates.
7. Iron and aluminium were deposited in the sediments in similar bonds.
8. The C:N ratio (about 12) indicated a high organic matter mineralisation rate that occurred in the sediments. Moreover, nitrogen organic bonds decomposition was accompanied by nitrogen compounds release (including ammonia) into the deep water.

9. An increase in the contents of organic matter, nitrogen and phosphorus compounds in Lake Bukowo gives evidence of an elevated level of trophy occurring in the lake, when compared to 1987.

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ZASIĘG WPŁYWU WODY MORSKIEJ NA WŁAŚCIWOŚCI CHEMICZNE OSADÓW DENNYCH JEZIORA BUKOWO

Streszczenie

W jeziorze Bukowo badano 15-centymetrową warstwę powierzchniową osadów dennych pod kątem ich właściwości chemicznych. Stwierdzono, że 32% powierzchni dna tego jeziora zajmują osady denne typu organicznego, 52% - typu mineralnego i 16% - typu piaszczystego. Osady denne charakteryzowały się wysoką zawartością materii organicznej - średnio 28%, azotu 1,2%, krzemionki 65% i fosforu 0,9%. Azot i fosfor akumulował się w badanych osadach głównie w formie związków organicznych. Metale występowały w nich w niewielkich ilościach: przeciętnie Ca - 1%, Mg - 0,8%, Fe - 1,3%, Al - 1,1%. Skład chemiczny osadów był zróżnicowany w obszarze jeziora, w zależności od wpływów czynnika lądowego i czynnika morskiego. W rejonie wpływów wody morskiej stężenia materii organicznej, związków azotowych i fosforowych były najmniejsze, a w rejonie dopływów z lądu składniki te wykazywały bardzo wysokie wartości.