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BUDGET OF NUTRIENTS AND THEIR REAL AND USEFUL LOADS IN THE LAKE SŁAWA WATER BODY

Budget of nutrients for the Lake Sława has been established by determining the loads introduced with surface waters, precipitations and ground waters, as well as those in the outflow from the lake.

From the analysis of nutrient loads contained in the lake water body, it follows that the role of limiting factor of plankton growth in the lake is taken alternately by either phosphorus or nitrogen. Hence, the average annual ,,useful" loads of these elements (i.e. the amount which can be used for phytoplankton production) are smaller than the real ones (i.e. the loads contained in the water body).

It has been stated, that the growth of phytoplankton depends closely on the useful loads of orthophosphate and inorganic nitrogen ($N\text{–}NH_4 + N\text{–}NO_2 + N\text{–}NO_3$) and that the average annual useful concentration of $P\text{–}PO_4$ (calculated from the average annual useful load of $P\text{–}PO_4$), the average concentration of chlorophyll A and the average annual number of phytoplankton organisms are strongly correlated.

1. INTRODUCTION

Eutrophication is a natural process occuring in all kinds of waters, in stagnant ones in particular. Under natural conditions the eutrophication rate, being dependent on local conditions within the given lake or reservoir and its catchment area, is rather slow. The same is true for negative effects of this process which under natural conditions proceeds slowly. As a rule, however, the activity of man and his interference in the natural ecological equilibrium is followed by rapidly intensified eutrophication resulting eventually in deterioration of water quality.

In view of the increasing deficiency of a good quality water, the eutrophication process becomes more and more dangerous and harmful, as it reduces natural water resources stored in lakes and reservoirs which can be utilized for economical purposes.

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The efficient measures against this process would be possible if the most essential factors affecting the course of this process were found and their mutual relations determined.

The purpose of the paper was to establish the budget of nutrients, as the starting point in the considerations concerning the problem of eutrophication (FLORCZYK et al. [3]), to determine the nutrient loads contained in the lake water body and to establish their influence on the production of phytoplankton.

2. DESCRIPTION OF THE TERRAIN AND METHODS

The Lake Sława is situated in the region of Zielona Góra. Its origin dating back to the late Pleistocene period was due to thawing of the dead ice masses in the postglacial trough formed by Scandinavian glacier. The Lake Sława has a shape of a shallow, elongated trough, the axis of which shows NW–SE orientation. According to the present data, the area of the Lake Sława equals 827.9 ha (including two islands of 10.6 ha). The maximum depth is 12.3 m, whereas its mean and relative depths are 5.2 m and 0.004 m, respectively. The maximum length of the lake equals 9225 m, the maximum width 1650 m, the mean being 885 m. The langth of the shore line (together with the islands) is 27340 m, while its expansion coefficient is 2.70. The Lake Sława retains 39.6×10^6 m^3 of water.

The catchment area of the Lake Sława is situated in between two regions of different climatic conditions. Weather conditions are characterized by considerable variability. Most of the hot days fall to July (average air temperature is +18.4° C). The mean negative temperature occur from December to February. The ice sheet appears in December and fades in March. The yearly precipitation rate ranges from 500 to 550 mm, the lowest rate being observed in February, and the highest one in July. The snow cover does not last longer than for 40–50 days per year. West and North–West winds prevail in the lake region. Their direction and frequency as well as climatic conditions influence thermal and chemical-biological changes in the lake water, its frequent and intense mixing being favoured by the location of the lake.

The catchment area of the Lake Sława, covering 200.1 km^2, consists of several partial catchment basins which are drained by streams, the tributaries of the lake. Three of these streams are permanent, while the other ones are temporary — the latter are due either to a small catchment area or to an extensive water use for irrigation purposes. The Lake Sława is fed mainly with surface water coming from six partial catchment basins (fig. 1). The Lake Sława is also fed with runoff water from its direct vicinity which covers the area of 37.4 km^2. The excess lake water outflows by the river Obrzyca.

The catchment basin of the lake is managed in the following way: 53% of total acreage is arable land (including ploughland — 41.7%, meadows — 9.8%, pastures — 1.4%, and orchards — 0.1%), forests cover 36.4%, marsh land occupies 0.3%, the waste land represent 0.6%, both rural and urban settlement areas constitute 2.7% of total acreage, whereas the percentage of roads and railroads is 1.7%, and that of stagnant and flowing

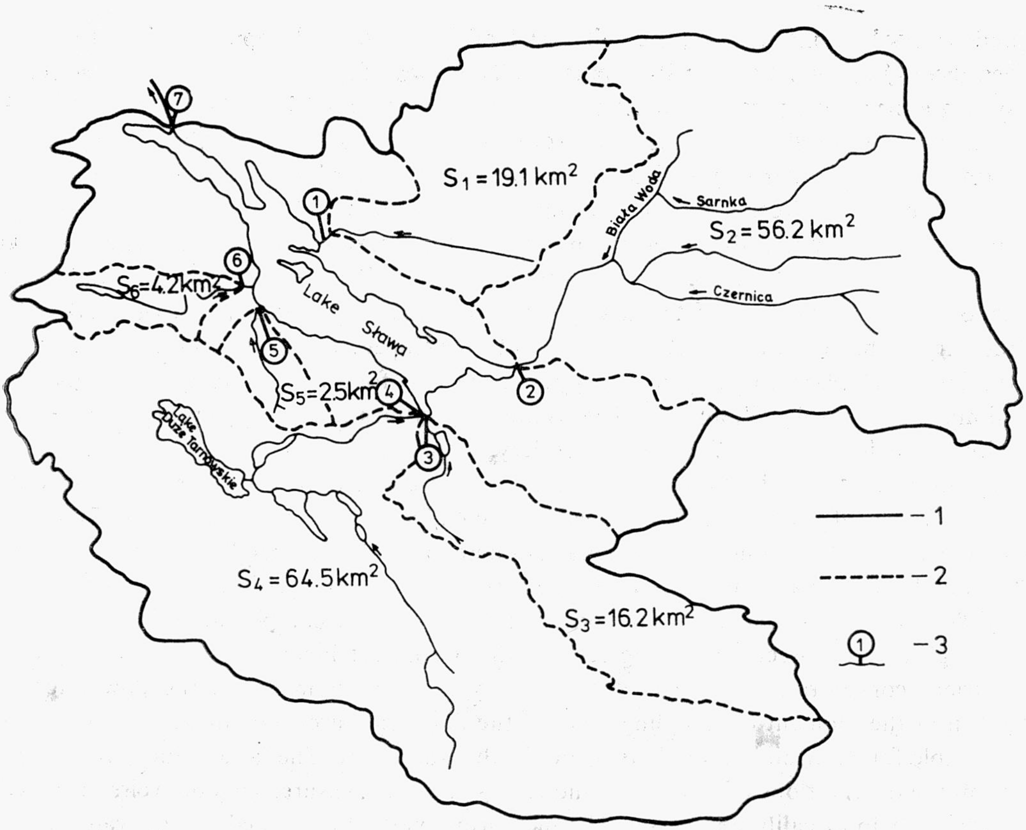

Fig. 1. Catchment area of the Lake Sława

1 — area of watershed, *2* — partial catchment basins, *3* — investigated cross-sections

Rys. 1. Zlewnia jeziora Sława

1 — powierzchnia wododziału, *2* — poszczególne zlewnie, *3* — badane przekroje

waters are 4.7% and 0.6%, respectively. The average application rate of NPK (nitrogen–phosphate–potash) fertilizers used for arable land equaled 1920 t (contributions of the nitrogen, phosphorus and potash fertilizers being 30%, 22% and 48%, respectively) and that of soil lime amounted to 1463 t, at its average application rate of 156 kg/ha. The commercial fertilizers are supplemented with manure produced in the catchment area. Forests cover mainly the higher terraces and moraine uplands of the catchment area. Most of the soils being sandy soils, pine woods covering 95.5% of the afforested area, the remaining 4.5% is overgrown with the admixture of the deciduous trees such as alder, birch and oak.

Within the catchement basin of the Lake Sława, there are fifteen villages and one town of Sława Śląska. The number of inhabitants in every village is over 1,000 persons, whereas the population of the town of Sława equals 2,600. The number of permanent residents totals 7,740 persons reaching 12,740 persons on average during the holiday season. As the villages within the basin are not sewered, people are using ind vidual septic tanks and cesspools. Consequently, the pollution load from the rural population is not discharged directly to the lake or to its tributaries. The town of Sława has no sanitary sewerage system either. Domestic wastewaters are partially discharged into the local septic tanks without outlet, partially into the storm sewerage system via Imhoff settling tanks, and the remaining wastewaters flow directly to Czernica Creek with no treatment. There are several recreational centres located around the lake, in which up to 6,600 persons can stay at the same time. Moreover, the number of the weekend guests is estimated as 5,000 persons. Although the recreational centres are not well equipped with the systems for collection and treatment of the sewage, it is not discharged directly into the lake. The industry within the catchment basin is poorly developed. Except for the town of Sława, the industrial plants, mainly of the agricultural and food-processing type, are loacated within the basins S_1, S_2 and S_4. The tributaries within the basin S_2 are heavily polluted with the effluents from the diary, distillery, slaughterhouse, and the laundry. Animal husbandry in the Lake Sława catchment basin is characterized by the following data: total number of cattle is 5,472 animals of which 2,783 are cows. There are 14,871 swines, 1,620 sheep and 1,419 horses. Poultry is estimated as 572 birds per 100 ha of arable land.

Loads of nutrients introduced into the lake with surface water inflows were established by determinig systematically the concentrations of these compounds in water flowing through the cross-sections closing each of the partial catchment basins. The analyses of nutrient concentrations were accompanied by the measurements of the flow intensity, taken at the moment of sampling, and by the daily measurements of water levels, indispensable for determining the daily values of the water flow. The latter data were obtained from the observations of water-level indicators and the measurements on weirs or directly with the help of calibrated vessel. The measuring method depended on the water flow in a water-course. Water samples taken 2–4 times a month were analysed in order to determine phosphorus and nitrogen compounds. The loading of surface water with nutrients were examined for each of six partial catchment basins of the Lake Sława and for outlet from the lake. The loads of nutrients discharged from the partial catchment basins were determined from the relationship between the temporary loads (in the days of measurements) and the flow volumes. The daily values of load were reconstructed from the equations describing the relation between the transient load of the examined nutrients and the flow volume. The final value of the annual loads of the analysed substances was given by the sum of daily loads for the annual investigation cycle.

The nutrients loads introduced by precipitation were established from average concentrations of nitrogen and phosphorus determined in rain water and from the ammount of water coming in with the precipitation. The loads of nutrients introduced with ground water were established by the analyses of ground water samples taken five times from the piezometric pipes or from wells built around the lake. The magnitude of ground water seepage was calculated from the formula into which the value of the real retention was introduced:

$$Q_g = \sum_{0}^{n} (R_r - R)$$

Fig. 2. Bathymetric data of the Lake Sława
and location of the sampling points

Rys. 2. Dane batymetryczne jeziora Sława
i położenie punktów pomiarowych

where:

Q_g — the ground water inflow (seepage) into the lake during the hydrological year,

R_r — the real retention determined from the relationship between water table height in the lake (read out from water-gauge) and water volume,

R — the water retention calculated from the formula

$$R = D+P-Q-E$$

in which:

D — the surface water inflow into the lake,

P — precipitation,

Q — water outflow from the lake,

E — evaporation from the lake surface.

In order to obtain the data necessary to establish the water balance, the following parameters were measured: water table and flow in the cross-sections closing the partial catchment basins and at the water outlet from the lake, evaporation from the water table and ground surface, precipitation, and ground water table.

The samples of lake water were taken once a month from five profiles (fig. 2) and at the following depths: 0.0 m, 0.2 m, 1.0 m, 3.0 m, 5.0 m, 7.0 m, 10.0 m, the last sample being taken 0.5 m above the bettom. The parameters determined included among other: temperature, transparency (Secchi disc), dissolved oxygen (Winkler method), nitrogen compounds ($N\text{–}NH_4$, $N\text{–}NO_2$, $N\text{–}NO_3$, N–organic) and phosphorus compounds (P–total and $P\text{–}PO_4$), chlorophyll A, as well as quantitative and qualitative composition of net plankton. The nutrient compounds were determined as follows: total phosphorus — orthophosphate analysis by persulphate method after preliminary digestion (mineralization), $P\text{–}PO_4$ — in the samples filtred trough the bacterial filtres applying colorimetric molybdate method, $N\text{–}NH_3$ — using direct Nessler's method after the sample pretreating as above, $N\text{–}NO_2$ — using sulphanilic acid–alfanaphtylamine colorimetric method (TECHNICON autoanalyser), $N\text{–}NO_3$ — applying the method as above after preliminary reduction of nitrates with hydroxylamine, and N–organic — by Kjeldahl's method. Inorganic and total nitrogen were calculated by summing $N\text{–}NH_3 + N\text{–}NO_3 + N\text{–}NO_4$, and N–inorganic + N–organic, respectively. Concentration of chlorophyll A was determined after STRICKLAND and PARSONS [8]. For calculation of transient loads of the considered substances present in the lake water body, the algorithm BILX was used (KRASNODĘBSKI et al. [4]).

The investigations were carried out during two-year cycle, i.e. from June 1973 to June 1975.

3. RESULTS AND DISCUSSION

The load of the nitrogen, introduced into the lake during the first year of the research (fig. 3), was equal to 56.8 t. About 47% of the load (26.6 t) was attributed to the surface water inflows, about 20% (11.7 t) to the ground water seepage and the remaining of 33%

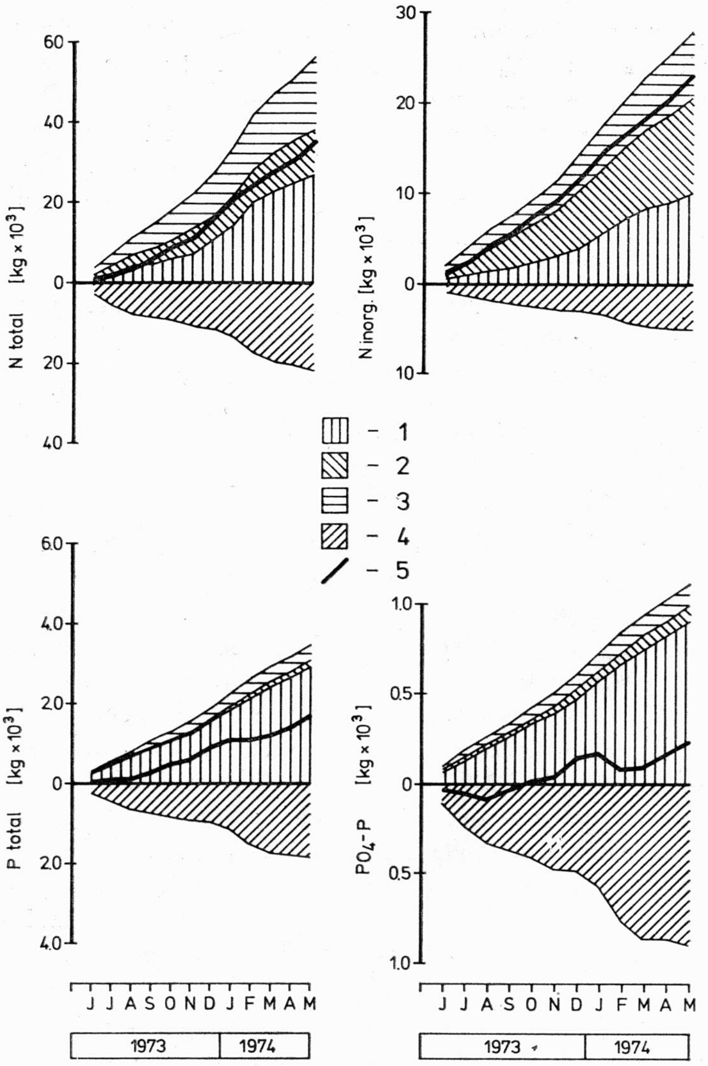

Fig. 3. Nitrogen and phosphorus budget of the Lake Sława for the first year of investigations

1 — tributary stream inflow, *2* — ground water seepage, *3* — atmospheric precipitation, *4* — outflow from the lake, *5* — nutrient balance curve

Rys. 3. Budżet azotu i fosforu w jeziorze Sława w pierwszym roku badań

1 — dopływy, *2* — gruntowa woda przeciekowa, *3* — opad atmosferyczny, *4* — odpływ z jeziora, *5* — krzywa bilansu substancji biogennych

(18.5 t) to the atmospheric precipitation. In the next year of the investigations the load of total nitrogen increased by about 41% and was equal to 81.6 t, of which 63% (51.5 t) was introduced with the surface water inflows, 14% with ground water, and 23% with the rain water. Considering the area of lake water table equal to 817 ha lake surface loading with total nitrogen was 6.9 g $N/m^2/y$ in the first year of investigations and 9.9 g $N/m^2/y$ in the second year.

In the first year total phosphorus load introduced into the lake (fig. 3) amounted to 3499.5 kg, of which almost 84% (2931.5 kg) was attributed to the surface water inflows, over 4% (156.0 kg) to the ground water seepage and about 12% (412.2 kg) was introduced with atmospheric precipitation In the second year the total phosphorus load was higher by 36% and amounted to 4750.1 kg. The percentages of the three above mentioned sources of nutrient were equal to 88% (4181.9 kg), over 3% and about 9%, respectively. The lake loadings with total phosphorus in the successive years were 0.43 and 0.58 g $P/m^2/y$.

Considering the loads outflowing from the lake, the total nitrogen and total phosphorus loads remaining in the lake in the first year amounted to 35.6 t and 1.680 kg, respectively, the corresponding data for the next year being 45.8 t and 1.6176 kg (fig. 3).

The inorganic nitrogen and phosphorus inflows into the lake in the first year of investigation are illustrated in fig. 3. Of the total (28.0 t) of inorganic nitrogen, 35.7% (10.0 t) was introduced by the surface inflows, 37.9% by ground water seepage and 26.4% by atmospheric precipitation. In the second year, the total inorganic nitrogen load amounted to 39.9 t, the respective percentages of the mentioned above factors being 54.8%, 26.6% and 18.6%.

The $P\text{–}PO_4$ load that entered the lake during the first year was equal to 1125.5 kg, of which 80.7% (909.2 kg) was introduced with the surface water inflows, 8.3% with the ground water and 11% with the rain water (fig. 3). During the second year, the respective percentages to the total phosphorus load (1411.3 kg) were 84.7%, 6.6% and 8.7%.

Considering the nutrient loads leaving the lake, its water body was enriched with 23.1 t of inorganic nitrogen and 229.8 kg of $P\text{–}PO_4$ during the first year of investigation; during the second year the respective value for nitrogen was equal to 31.4 t, and the negative input-output balance of $P\text{–}PO_4$ was equal to 131.4 kg.

The annual nitrogen and phosphorus loads resulted in high surface loadings of the lake studied. No correlation, however, has been stated between the input loads and those contained in the water body, compare also the observations of Sonzogni, Uttormark and Lee (1976).

The content of inorganic forms of nitrogen ($N\text{–}NH_4 + N\text{–}NO_2 + N\text{–}NO_3$) and phosphorus ($P\text{–}PO_4$) were subject to annual variations in the lake water body (fig. 4). During the first year of studies, i. e. from June 1973 to May 1974, the monthly loads of inorganic nitrogen ranged within 5056.6–17164.4 kg, and averaged 11045.7 kg. The corresponding data for $P\text{–}PO_4$ amounted to 57.8–3722.6 kg and 1489.8 kg, respectively, varying in the next year from 122.3 kg to 3397.1 kg, at the average amounting to 1867.4 kg.

Within the whole period studied the inorganic nitrogen to $P\text{–}PO_4$ weight ratio in the lake body varied from 2.7:1–185.8:1. It is assumed (Stumm [9]) that algae utilize nitrogen and phosphorus in 16:1 ratio (Landner [5]). This quantitative ratio of both the elements is used to establish — according to Liebig's law — the limiting factor. It has been also assumed that the amounts of these elements which may be used for phytoplankton production in lake water body must result from the ratio of inorganic nitrogen to $P\text{–}PO_4$ = 16:1. From June to December 1973 and from May 1974 to February 1975 this ratio

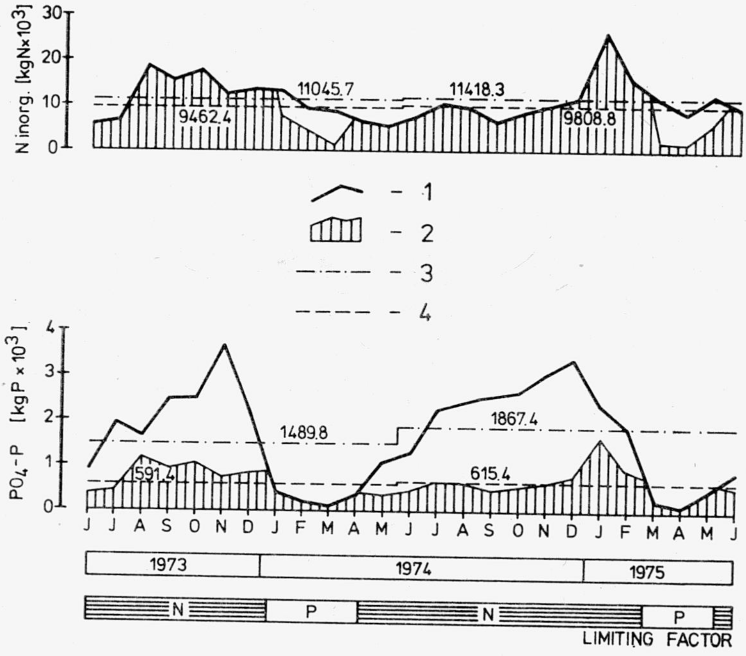

Fig. 4. Real and useful loads of inorganic nitrogen and orthophosphates

1 — real load, *2* — useful load, *3* — average annual real load, *4* — average annual useful load

Rys. 4. Rzeczywiste i użyteczne ładunki azotu nieorganicznego i ortofosforanów

1 — ładunek rzeczywisty, *2* — ładunek użyteczny, *3* — średni roczny ładunek rzeczywisty, *4* — średni roczny ładunek użyteczny

ranged within 2.7:1–11.3:1, nitrogen being the limiting factor. The P–PO_4 amounts stated in this period of time would allow to include into phytoplankton production the amount of nitrogen exceeding its content in the lake water body. In this period the real loads of inorganic nitrogen reduced the usability of P–PO_4 load present in the lake water to the level resulting from the ratio N:P = 16:1, i. e. to the amounts much lower than its real loads. From January to April 1974 and from March to May 1975 the inorganic nitrogen to P–PO_4 ratio ranged within 18.5:1–148:1, thus the role of limiting factor was performed by phosphorus. Its loads allowed to use only a part of the real inorganic nitrogen load in the lake water.

As a potential utilization of P–PO_4, resulting from the ratio N:P = 16:1, was much lower than the real P–PO_4 load in the lake water, the "useful" load of P–PO_4 (which could be used for phytoplankton production) was also lower. During the first year of study the average useful P–PO_4 load was 591.4 kg, i.e. 39.7% of the average real load (1489.8 kg). In the next year it amounted to 615.4 kg, i.e. 32.9% of the average phosphorus load (1867.1 kg) stated in the lake water. The average useful P–PO_4 load in the second year increased by 24.0 kg, although the real average P–PO_4 load in the water increased by 377.3 kg.

The average useful inorganic nitrogen load amounted to 9462.4 kg (86% of the average real load) and 9808.8 kg (86.2% of the average real load) in the first and in the second years of study, respectively. In the second year, an average useful inorganic nitrogen load was higher by 346.4 kg and its increase corresponded approximately to the increase of the average real load amounting to 372.6 kg (fig. 4).

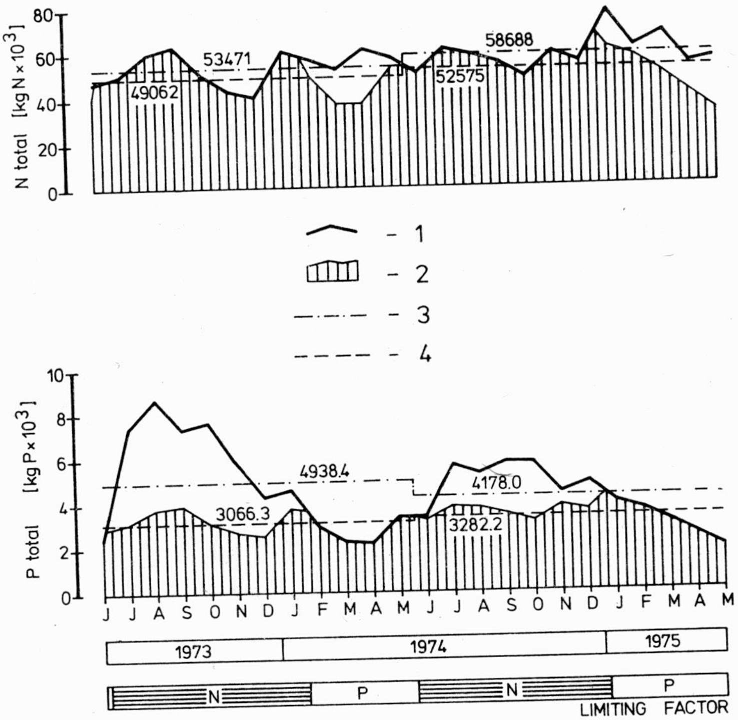

Fig. 5. Real and useful loads of total nitrogen and total phosphorus

1 — real load, *2* — useful load, *3* — average annual real load, *4* — average annual useful load

Rys. 5. Rzeczywiste i użyteczne ładunki całkowitego azotu i fosforu

1 — ładunek rzeczywisty, *2* — ładunek użyteczny, 3 — średni roczny ładunek rzeczywisty, *4* — średni roczny ładunek użyteczny

The possibilities of utilization of the total nitrogen and total phosphorus were analogical (fig. 5). Useful total nitrogen loads were lower than the real ones by 4.4 t during the first year (92% of the real load) and by about 6.1 t during the second year (about 90% of the total real nitrogen load). The lake loadings with real nitrogen load were equal to 6.5 g $N/m^2/y$ and to 7.2 g $N/m^2/y$ in the first and in the second years, respectively. The corresponding data referred to the useful nitrogen loads were 6.0 g $N/m^2/y$ and 6.4 g $N/m^2/y$, respectively. The average useful load of the total phosphorus was lower than the average real load by 1872.1 kg in the first year and by 895.8 kg in the second year, being equal to 62% and 78.5% of the average real loads, respectively (fig. 5).

From the data obtained during investigations of Japanese lakes, SAKAMOTO [7] stated a distinct relationship between total phosphorus concentration during spring overturn and maximum summer chlorophyll concentration. This relationship was later confirmed by a number of scientists (POWERS et al. [7], DILLON and RIGLER [2] and CARLSON [1]). The concentration of chlorophyll is indicative of the phytoplankton growth. Thus, if there exists a relationship between the concentrations of chlorophyll and phosphorus, then a dependence between the concentration of phosphorus and the number of phytoplankton cells should be also expected.

These both relationships were used to verify the assumption, that the phytoplankton production depends on the inorganic forms of nitrogen and P–PO_4 rather than on their total amount and that size of this production should not depend on real loads of these forms contained in the water body, but on the useful loads, resulting from inorganic N to P–PO_4 ratio equal to 16:1. To this end the average annual concentrations of chlorophyll in water and average annual number of phytoplankton cells were referred to the average annual concentrations of phosphorus, calculated as follows:

A — average annual „useful" concentration of P–PO_4 is equal to average annual "useful" load of P–PO_4 divided by lake volume,

B — average annual real concentration of P–PO_4 is equal to average annual real load of P–PO_4 divided by lake volume,

C — average annual "useful" concentration of total phosphorus is equal to average annual "useful" load of total phosphorus divided by lake volume,

D — average annual concentration of total phosphorus is equal to average annual real load of total phosphorus divided by lake volume.

The calculations were based on the data recived from investigations of the Lake Sława and 2 other lakes (Lusowo and Góreckie) investigated simultaneously. In the Sława and Góreckie Lakes, the limiting factor is not permanently the same, as its role is alternately taken by either phosphorus or nitrogen. Hence, in the two lakes the average annual useful loads of these elements (i.e. the amount can be used for phytoplankton production) are smaller than the real ones (i.e. the loads contained in the water body). In the Lake Lusowo, phosphorus was the limiting factor during the whole investigation period, therefore the average annual real and useful loads of this element were equal; only average annual useful loads of nitrogen were smaller than the real ones.

The relationship between the concentrations of phosphorus and chlorophyll (fig. 6) is most strictly defined by the points determining the course of curve *A*, which represents the average annual concentration of chlorophyll versus the average annual useful concentration of P–PO_4.

The relationship between the number of phytoplankton cells and phosphorus concentration, established analogically to the foregoing, is presented in fig. 7. The curve *A* passes almost ideally through the points determining this dependence of the separate lakes being examined.

From the both dependences it follows that in the process of eutrophication the decisive role is performed by useful loads of inorganic nitrogen and P–PO_4, i.e. this part

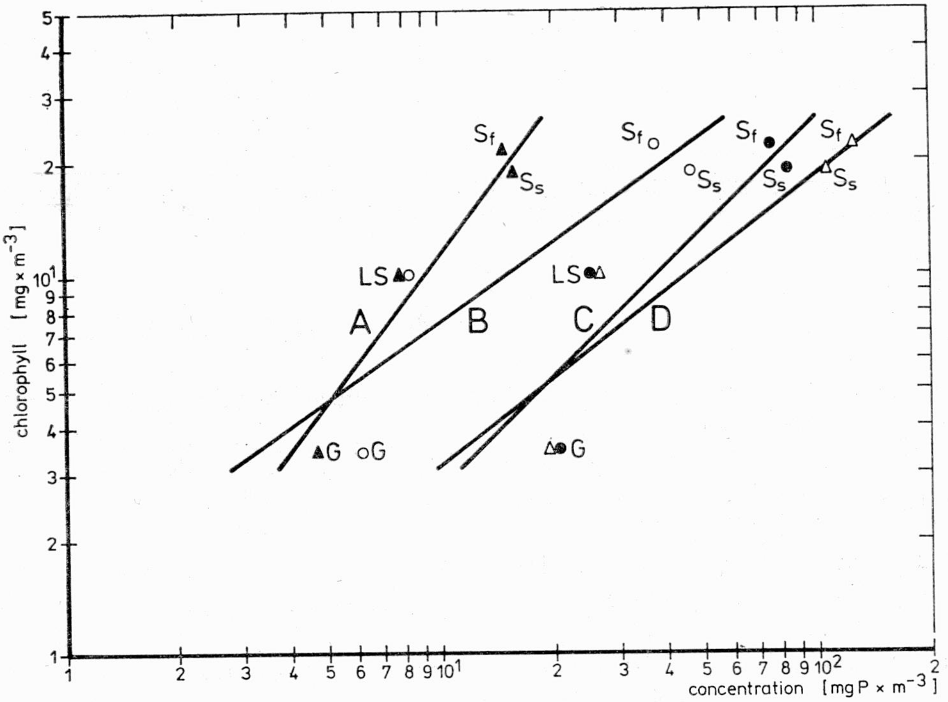

Fig. 6. Annual average chlorophyll concentration versus phosphorus concentration

A – average annual useful concentrations of P–PO_4 (black triangles), *B* – average annual real concentrations of P–PO_4 (white points), *C* – average annual useful concentrations of total phosphorus (black points), *D* – average annual real concentrations of total phosphorus (white triangles), *Sf* and *Ss* – Lake Sława first and second years of investigations, *LS* – Lake Lusowo, *G* – Lake Góreckie

Rys. 6. Średnie roczne stężenie chlorofilu w zależności od stężenia fosforu

A – średnie roczne stężenia użyteczne P–PO_4 (czarne trójkąty), *B* – średnie roczne stężenia rzeczywiste P–PO_4 (puste kółka), *C* – średnie roczne stężenia użyteczne całkowitego fosforu (kółka wypełnione), *D* – średnie roczne stężenia rzeczywiste całkowitego fosforu (puste trójkąty), *Sf* i *Ss* – pierwszy i drugi rok badań jeziora Sława, *LS* – jezioro Lusowo, *G* – jezioro Góreckie

of the real loads which can be utilized for plankton production and which results from the weight ratio of inorganic nitrogen:P–PO_4 = 16:1. In lakes, where P–PO_4 is a limiting factor, the useful loads of inorganic nitrogen will be smaller than the real ones, whereas the real and useful loads of P–PO_4 will be equal. In lakes where inorganic nitrogen is the limiting factor, the opposite situation will be stated. Useful loads of P–PO_4 will be smaller than the real ones, whereas the useful and real loads of inorganic nitrogen will equal each other. In lakes, where the limiting factors are altering within the year, the useful loads of both inorganic nitrogen and P–PO_4 will be smaller than the real loads.

4. SUMMARY

Eutrophication of lakes is stimulated by nutrients introduced with surface water inflows, ground water seepage, and with atmospheric precipitation. The correct estimation

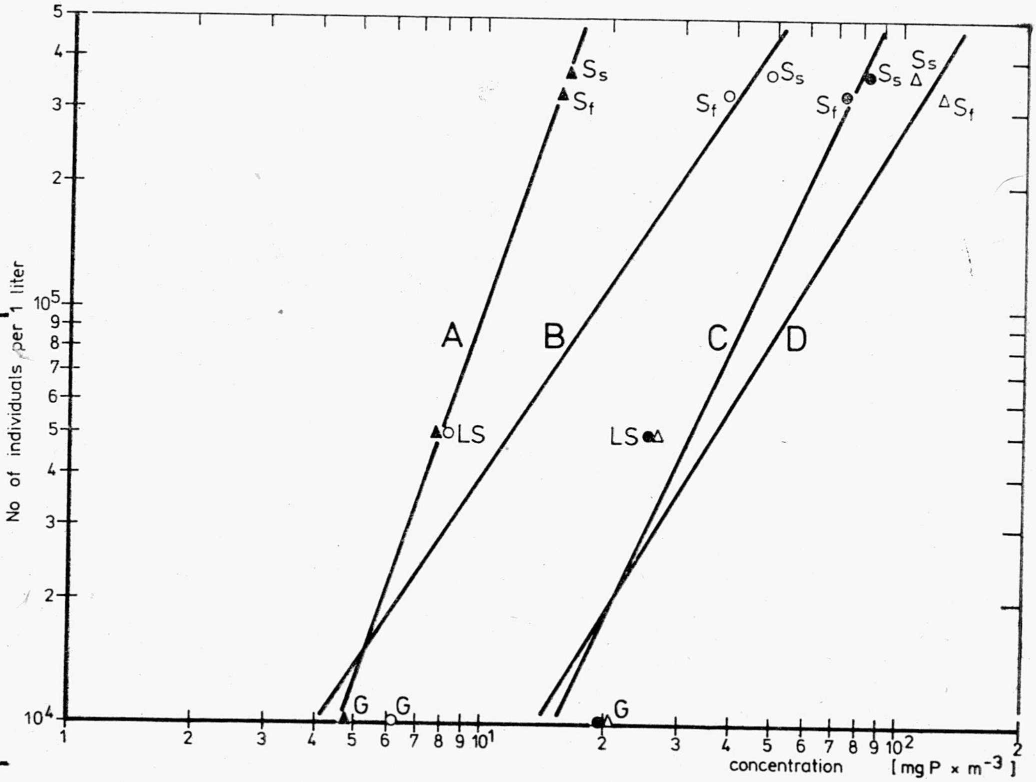

Fig. 7. Annual average number of phytoplankton cells versus phosphorus concentration

A — average annual useful concentrations of P–PO_4 (black triangles), *B* — average annual real concentrations of P–PO_4 (white points), *C* — average annual useful concentrations of total phosphorus (black points), *D* — average annual real concentrations of total phosphorus (white triangles), *Sf* and S_S — Lake Sława first and second years of investigations, *LS* — Lake Lusowo, *G* — Lake Góreckie

Rys. 7. Średnia roczna liczba komórek fitoplanktonu w zależności od stężenia fosforu

A — średnie roczne stężenia użyteczne P–PO_4 (czarne trójkąty), *B* — średnie roczne stężenia rzeczywiste P–PO_4 (puste kółka), *C* — średnie roczne stężenia użyteczne całkowitego fosforu (kółka wypełnione), *D* — średnie roczne stężenia rzeczywiste całkowitego fosforu (puste trójkąty), *Sf* i S_S — pierwszy i drugi rok badań jeziora Sława, *LS* — jezioro Lusowo, *G* — jezioro Góreckie

of the budget of nutrients is the starting point whenever the problem of eutrophication, its causes and consequences are considered.

The investigations of the Lake Sława carried out during two-year period have shown that 47–63% of the total nitrogen load introduced yearly into the lake was attributed to surface water inflows, 14–20% to the ground water seepage, and 23–30% to the atmospheric precipitation. The respective data for inorganic nitrogen were about 36–55%, 27–38% and 19–26%. For total phosphorus the percentages of the three above mentioned sources of nutrients were: 84–88%, 3–4%, 9–12%, and the corresponding data for P–PO_4 being: 81–85%, 7–8% and 9–11%.

The contents of nutrients were subject to annual variations in the lake water body. To establish the limiting factor it has been assumed that algae utilize nitrogen and phosphorus in 16:1 ratio. In the Lake Sława the limiting factor is not permanently the same as its role is alternately taken by either phosphorus or nitrogen. Hence, in the lake the average annual useful loads of these elements (i.e. the amounts which can be used for plankton production) are smaller than the real ones (i.e. the loads contained in the water body).

From the dependences stated between the average annual chlorophyll concentration and that of phosphorus and the number of phytoplankton cells versus phosphorus concentration it follows that in the process of eutrophication the decisive role is performed by useful loads of inorganic nitrogen and $P\text{–}PO_4$, i.e. this part of the real loads which can be utilized for plankton production and which results from their weight ratio, i.e. inorganic nitrogen: $P\text{–}PO_4 = 16:1$.

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BUDŻET SUBSTANCJI BIOGENNYCH ORAZ ICH RZECZYWISTE I UŻYTECZNE ŁADUNKI W WODZIE JEZIORA SŁAWA

Proces eutrofizacji jest stymulowany przez substancje biogenne, wprowadzane z dopływami wód powierzchniowych i podziemnych oraz z opadami atmosferycznymi. Dokładny ich bilans dla każdego rozpatrywanego obiektu jest punktem wyjścia we wszelkich rozważaniach dotyczących przyczyn i skutków procesu eutrofizacji.

Badania jeziora Sława, prowadzone przez okres 2 lat, wykazały, że 47–63% ładunku całkowitego azotu przedostającego się w ciągu roku do jeziora doprowadzane jest z dopływami powierzchniowymi, 14–20% – z wodami gruntowymi i 23–30% – z opadami atmosferycznymi. Wprowadzane ilości azotu

nieorganicznego wynoszą odpowiednio około 36–55%, 27–38% i 19–26%. Udział trzech wymienionych źródeł substancji biogennych był następujący: dla fosforu całkowitego — 84–88%, 3–4% i 9–12%, a dla fosforu fosforanowego — 81–85%, 7–8% i 9–11%.

Zawartość substancji biogennych w wodzie jeziora w ciągu roku podlega wahaniom. Zakładając, że glony pobierają azot i fosfor w stosunku 16:1, ustalono, że pierwiastek limitujący w jeziorze Sława zmienia się w ciągu roku: jest nim na zmianę fosfor lub azot. Dlatego średnie roczne ładunki użyteczne substancji biogennych (tj. ilość, która może być zużyta do produkcji pierwotnej) są mniejsze od średnich rocznych ładunków rzeczywistych (tj. ładunków zawartych w masie wodnej jeziora).

Z zależności między stężeniem chlorofilu i fosforu oraz liczebnością fitoplanktonu i stężeniem fosforu wynika, że decydującą rolę w procesie eutrofizacji odgrywają użyteczne ładunki azotu nieorganicznego i fosforu fosforanowego.

HAUSHALT DER BIOGENESUBSTANZEN SOWIE IHRE EFFEKTIVE- UND NUTZLASTEN IM WASSER DES SŁAWASEES

Der Eutrophiezierungsprozeß ist durch Biogenesubstanzen angeregt, die mit den Zuflüssen der Oberflächen — und Grund — sowie mit Niederschlagwässern zugebracht werden. Eine genaue Bilanz aller Faktoren jedes untersuchten Objekts ist der Ausgangspunkt bei der Betrachtung der Ursachen und Folgen des Eutrophiezierungsprozesses.

Die Untersuchungen des Sławasees, die zwei Jahre lang geführt wurden, haben gezeigt, daß 47–63% der Stichstoffgesamtlast die im laufe des Jahres in den See eindrängt, mit den Oberflächenzuflüssen zugeführt wurden, 14–20% mit Grundwässern und 23–30% mit Niederschlagwässern. Die eingeführten Mengen des anorganischen Stichstoffs betragen entsprechend ca 36–55%, 27–38% und 19–26%. Der Anteil der drei genannten Biogenesubstanzenquellen war folgend: für den gesamten Phosphor — 84–88%, 3–4%, und 9–12%, für Phosphatphosphor 81–85%, 7–8% und 9–11%. Der Biogenesubstanzengehalt im Seewasser unterliegt im Verlauf des Jahres Schwankungen. Bei Annahme, daß die Algen den Stickstoff und Phosphor im Verhältniss 16:1 entnehmen, wurde festgestellt, daß das limitierende Element im Sławasee sich im Jahreslauf abwechselnd ändert: es ist Phosphor oder Stickstoff. Deshalb sind die mitteljährlichen Nutzlasten der Biogenesubstanzen (d.h. die Menge, welche zur Primärproduktion verwendet werden kann) kleiner als die mitteljährlichen Effektivelasten (d. h. die Lasten die sich in der Wassermasse befinden).

Aus der Abhängigkeit zwischen Chlorophyll- und Phosphorkonzentration sowie dem Umfang des Phytoplanktons ergibt sich, daß im Eutrophiezierungprozeß die Nutzlast des anorganischen Stickstoffs und des Phosphatphosphors eine entscheidende Rolle spielen.

БЮДЖЕТ БИОГЕННЫХ ВЕЩЕСТВ И ИХ РЕАЛЬНЫЕ И ПОЛЕЗНЫЕ ЗАПАСЫ В ВОДЕ ОЗЕРА СЛАВА

Процесс эвтрофизики стимулируется биогенными веществами, вводимыми с притоками поверхностных и подземных вод, а также с атмосферными осадками. Тщательный их баланс для каждого рассматриваемого объекта является исходной точкой во всяких рассуждениях, касающихся причин и следствий процесса эвтрофизации.

Исследования озера Слава, проводимые в течение 2 лет, показали, что 47–63% полного запаса азота, проникающего в течение года в озеро, проводится с притоками поверхностных вод, 14–20% с грунтовыми водами и 23–30% — с атмосферными осадками. Вводимые количества неорганического азота составляют соответственно около 36–55%, 27–38% и 19–26%. Доля трёх отмеченных источников биогенных веществ была следующая: для полного фосфора — 84–88%, 3–4% и 9–12%, а для фосфатного фосфора — 81–85%, 7–8% и 9–11%.

Содержание биогенных веществ в воде озера в течение года подвергается колебаниям. Принимая, что водоросли поглощают азот и фосфор в отношении 16:1, было установлено, что лимитирующий химический элемент в озере Слава изменяется в течение года: им является фосфор или азот. Поэтому средние годовые полезные запасы биогенных веществ (т. е. количество, которое может быть использовано для первичного производства) меньше средних годовых реальных запасов (т. е. запасов, содержащихся в водяной массе озера).

Из зависимости между концентрацией хлорофилла и фосфора, а также численностью фитоплантона и концентрацией фосфора следует, что решающую роль в процессе эвтрофизации выполняют полезные запасы неорганического азота и фосфатного фосфора.