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The journal publishes original works reporting experimental results, descriptive works and theoretical investigations in every sphere of hydrobiology. The article must contain original research not already published and which is not being considered for publication elsewhere. Papers will be published in the official Congress languages of *Societas Internationalis Limnologiae* (at present: English, French, Italian and German).

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A. SZCZEPAŃSKI

## LIMNOLOGY OF THE KRUTYNIA DRAINAGE AREA

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### ABSTRACT

In the Krutynia drainage area of 638 km<sup>2</sup> of surface, the number of 93 lakes are situated. This drainage area was shaped by several stadials of the last glaciation. Basing upon the chemical analysis of water of larger lakes the author established the dependence of water chemical character on the peculiarities of the drainage area. The correlation between total solids and electrolytic conductivity and the situation of lakes within the compass of the drainage area. Lakes situated on the esker area outwash deposits showed the conductivity lower than 215  $\mu$ S, whereas lakes situated on morainic deposits — over 230  $\mu$ S. The chief ions are Ca<sup>++</sup> and HCO<sub>3</sub><sup>-</sup> and these both ions exhibit the same connections. The discussed correlations are more distinct in epilimnetic waters. In the water of hypolimnion these correlations are modified by typological properties of lakes.

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2. Methods	Total solids
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Maximum depth	Sodium and potassium
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Transparency	6. Summary
pH	7. References

### 1. INTRODUCTION

The present investigation was undertaken under stimulating influence of a monograph of KONDRACKI and MIKULSKI "Hydrography of Krutynia drainage area" edited in 1958. The authors presented a detailed hydrological study of this area and characterized its geomorphological conditions.

The aforesaid study enabled an attempt to refer the limnological characteristics of the examined area to its geomorphological peculiarities. This attempt seemed particularly interesting for on a relatively small surface (637.7 km<sup>2</sup>) several stadials of baltic glaciation were distinguished.

The number of 93 lakes of various size and of various stages of maturity situated within the drainage area of Krutynia river encourage comparative typological investigations. The fact that the lakes under discussion are almost unknown is also important. In the review of OLSZEWSKI (1951) notes about the surface or depth of only 5 lakes are encountered, with the exception of lake Babięty Wielkie

treated in more detail on account of the paper of BRANDT (1944). Data from 10 lakes concerning temperature oxygen, pH, alkalinity, and transparency were collected by OLSZEWSKI and PASCHALSKI (1959). Some further data on lakes Babięty Wielkie and Lisunie are included in an earlier paper (SZCZEPAŃSKI 1968).

The geomorphology of Mrągowo district and thus the Krutynia drainage area occupies several pages of the paper of KRAUSE (1926). A list of 36 lakes of the same district is found here as well, with informations on their surface, depth, altitude above sea level, transparency and water colour, but without the data of measurement.

More detailed data on the chemical composition of Krutynia river water below the lake Zyzdrój were furnished by STANGENBERG (1958)\*.

As it follows from the quoted papers, limnological data concerning the discussed area are rather scanty.

## 2. METHODS

The present consideration are based on the results of measurements of physical and chemical properties of water of the lakes under investigation.

Samples from eight lakes (Table I, Nos 2, 5, 18, 20, 22, 24, 35, 38) were taken at 1 month intervals from spring to autumn. A single sampling from 30 remaining lakes was carried out in August, 1959. In all lakes the sampling site was localized in the deepest part. From lakes examined every month samples were taken from the following levels, counting down from the surface: 0.0; 2.5; 5.0; 7.5; 10.0; 12.5; 15; 20; 30; 40; 50; 60 m. Where single sampling was performed, samples from the surface and from the level 1 m above the bottom were analyzed (STANGENBERG 1936).

The measurements comprised temperature, electrolytic conductivity, pH,  $O_2$ ,  $Ca^{++}$ ,  $K^+$ ,  $Na^+$ ,  $PO^{---}$ , ammonia nitrogen, Fe, alkalinity and total solids. Analyses were performed following the methods used in State Institute of Hygiene (JUST, HERMANOWICZ 1955). Sodium, calcium and potassium were determined with a flame photometer after turning carbonates into chlorides. The total of 2820 water analyses of the investigated lakes were performed.

## 3. CHARACTERISTICS OF THE REGION

Krutynia river drains 63.770 ha. The drainage area comprises 93 lakes of a total area of 5 559.5 ha. The analyses covered 38 lakes of a total area of 5 083.2 ha, which accounted for 91.4% of the total lake surface. The remaining lakes were disregarded as they were very small, in many cases turning into swamps surrounded by peat bogs, totalling up to 476.3 ha, that is 8.6% of the joint lake surface.

Table I presents morphometric data of the examined lakes. These data originate from the monograph of KONDRACKI and MIKULSKI (1958). In cases where our measurements of maximum depth were higher, than those given

\*) Basing upon the given data the sampling site remains not clear. The text reads "stream Syzdrojanka below lake Syzdrój" while in the enclosed "catalogue of chemical composition of river waters in Poland" the site is denoted as "Syzdrój—outflow from the lake near the village Pupy". Between the lake Zyzdrój Mały and the village Spychowo (former Pupy) is situated the lake Spychowskie. Hence probably the matter is of the outflow from the lake Spychowskie and not from lake Zyzdrój.

by the above authors, it was marked in the Table using heavy types. The disposition of the examined lakes is shown on the map (Fig. 1). Numbers of lakes on the map accord with those in Table I.

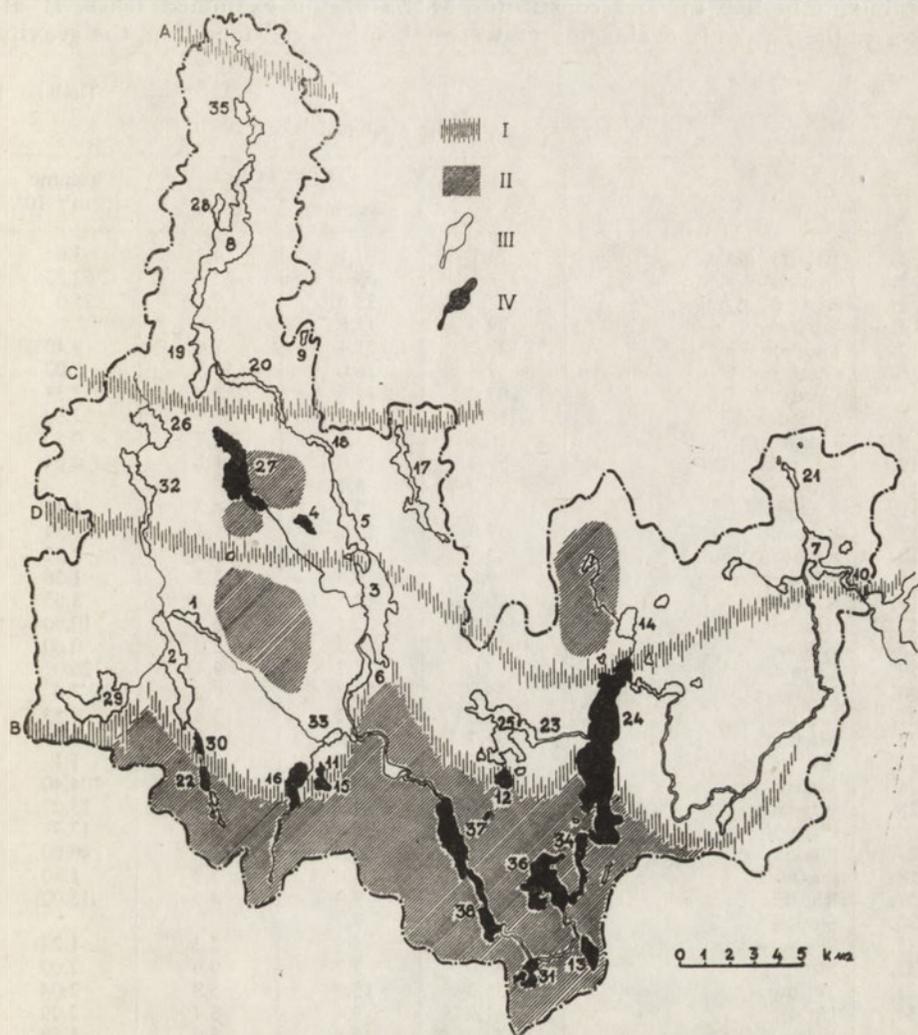


Fig. 1. Krutynia drainage area

Numbers of lakes correspond to those in Table I. I Morainic ridges; A-C Pomeranian stadial; C-D Frankfurt stadial II; B-D Frankfurt stadial I; II Outwash deposits; III Lakes with electrolytic conductivity of surface water  $> 225 \mu\text{S}$ ; IV Lakes with electrolytic conductivity of surface water  $< 225 \mu\text{S}$

#### 4. RESULTS

##### MAXIMUM DEPTH

The examined lakes show maximum depths from 2.2 to 53 m, the deepest being the lake Babięty Wielkie. However only 4 lakes exceed the depth of

30 m, that is Babięty Wielkie (63 m), Piłakno (55.3 m), Mokre (45.7 m) and Lampackie (33.7 m). The frequency of occurrence of particular classes of depth is presented on Fig. 2A. The most numerous group of lakes is that of maximum depth of 5.1–10.0 m and constitutes 34.2% of the examined lakes. If all lakes of the Krutynia drainage area were taken into consideration, the gravity

Table I

## Morphometric data of the examined lakes

No.	Name of lake	Surface in ha	Depth in m		Volume in m <sup>3</sup> · 10 <sup>6</sup>
			maximum	average	
1.	Babięty Małe	73.1	7.1	4.2	3.01
2.	Babięty Wielkie	271.1	<b>63.0</b>	22.9	62.23
3.	Białe Krutyńskie	374.0	28.0	9.4	35.0
4.	Borówko	29.0	<b>11.5</b>		
5.	Dłużec	127.0	21.4	7.4	9.40
6.	Gant	37.8	26.0	10.3	2.00
7.	Gardyńskie	107.0	<b>10.6</b>	2.2	2.34
8.	Gieładzkie	416.0	23.2	7.9	32.80
9.	Janowskie	18.6	3.7	2.7	0.50
10.	Jerzewko	59.0	3.0	1.1	0.64
11.	Kały	7.0	<b>5.0</b>		
12.	Kielbonki	37.0	7.9	4.2	1.42
13.	Kierwik	59.0	<b>14.9</b>	5.7	3.34
14.	Kołowin Wielki	82.5	6.5	3.6	2.87
15.	Krawienko	39.8	8.6	3.2	1.28
16.	Krawno	80.2	10.5	4.4	3.53
17.	Krzywe	140.0	22.4	5.1	10.80
18.	Kujno	30.0	5.5	2.0	0.60
19.	Lampackie	278.0	33.7	9.4	26.0
20.	Lampasz	76.0	22.2	9.2	7.0
21.	Lisunie	13.0	<b>8.2</b>	3.8	0.53
22.	Miętkie	31.7	4.0	2.3	0.76
23.	Mojtyńskie	32.6	<b>6.4</b>	3.2	1.1
24.	Mokre	797.8	<b>45.7</b>	13.1	104.40
25.	Nawiady	272.5	24.9	8.5	23.27
26.	Pierwój	152.0	20.0	9.0	13.7
27.	Piłakno	278.7	<b>55.3</b>	14.6	40.60
28.	Pustniki	33.2	8.6	3.9	1.30
29.	Rańskie	282.0	9.0	4.5	13.02
30.	Słupek	23.0	<b>5.7</b>		
31.	Spychowskie	54.1	5.9	2.3	1.24
32.	Stromek	140.0	2.2	0.6	2.00
33.	Tejsowo	35.2	<b>15.0</b>	5.8	2.04
34.	Uplik	61.9	9.4	3.4	2.09
35.	Warpuńskie	49.5	6.8	3.0	1.50
36.	Zdróżno	246.8	<b>12.4</b>	4.7	11.62
37.	Zyzdrój Mały	42.4	10.6	3.8	1.62
38.	Zyzdrój Wielki	200.1	<b>13.5</b>	5.0	9.92

centre would move proable to the class of shallowest and at the same time smallest lakes. The largest class of lakes accounts for 15.9% of surface of the examined lakes and 14,5% of the total surface of lakes of this drainage area. The above mentioned 4 deepest lakes cover 32% of surface of the examined lakes and 29.2% of surface of all lakes of the area under investigation. These relations are summarized in Table II.

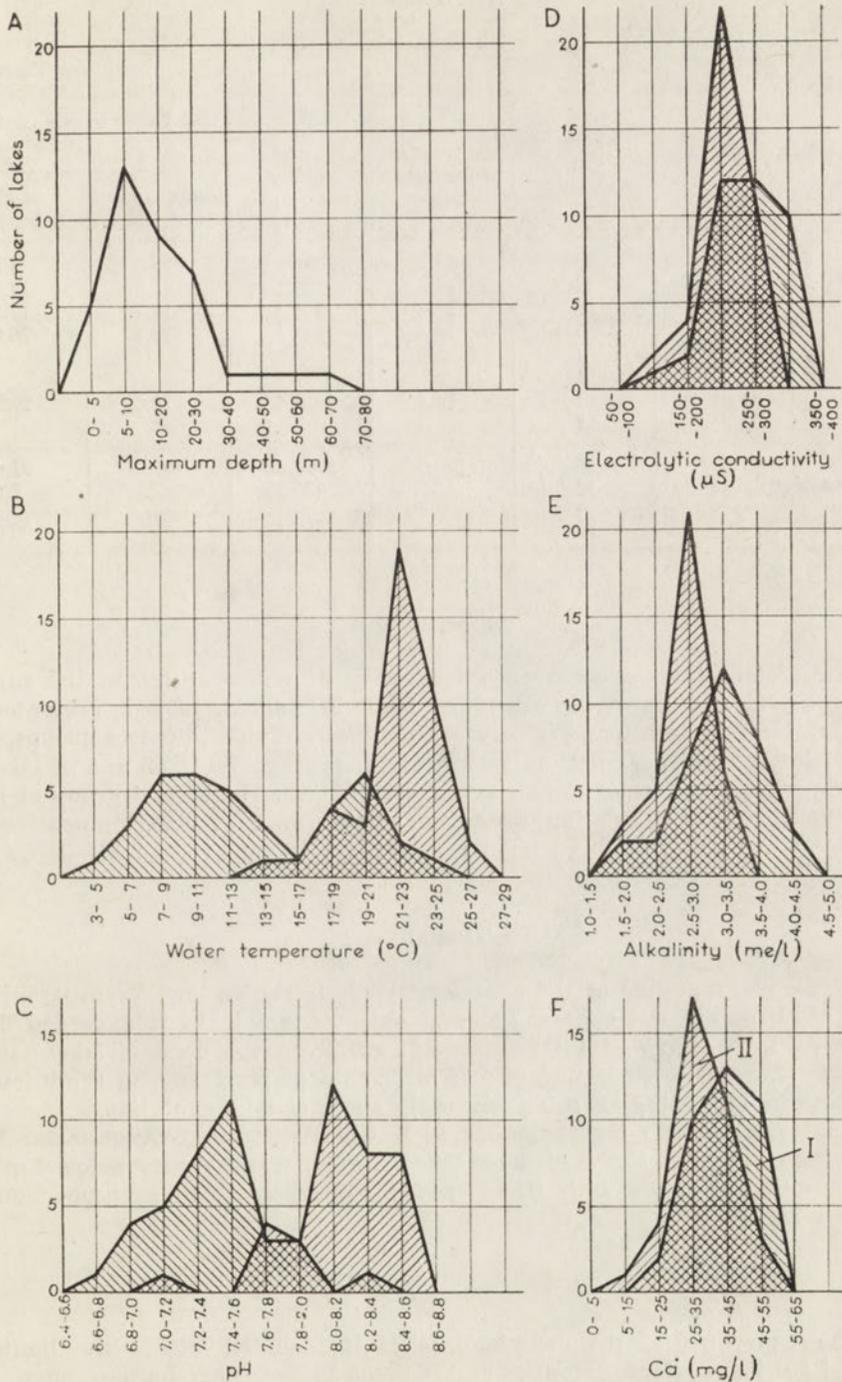


Fig. 2. Frequency of occurrence of particular values of parameters  
 A. maximum depth m; B. water temperature °C; C. pH; D. Electrolytic conductivity µS;  
 E. Alkalinity me/l; F. Calcium concentration mg/l; I at the surface; II near the bottom

Table II

Classes of depth	Number of examined lakes	Per cent of the number of examined lakes	Total surface in ha	Lakes in per cent of surface	
				of examined lakes	of all lakes
0.0—5 m	5	13.3	256.3	5.0	4.6
5.1—10 m	13	34.2	807.1	15.9	14.5
10.1—20 m	9	23.6	951.7	18.7	17.1
20.1—30 m	7	18.4	1443.3	28.4	26.0
30.1—40 m	1				
40.1—50 m	1				
50.1—60 m	1	10.5	1624.8	32.0	29.2
60.1—70 m	1				
Total	38	100.0	5083.2	100.0	91.4
Remaining lakes	55		476.3		8.6
Total	93		5559.4		100.0

## TEMPERATURE

The distribution of occurrence frequency of temperatures at the surface and near the bottom of the examined lakes in August, 1959, is presented on Fig. 2B. Near-bottom temperatures are distinctly divide into two groups, that is of lakes of cold near-bottom water (on an average 7—11°C) and of lakes of warm near-bottom water (on an average 19—21°C). The second group of lakes belongs to those circulating over the whole summer. The temperature of surface waters was in this period rather high, on an average 21—23°C.

## TRANSPARENCY

Water transparency of the examined lakes is rather low. Transparency of 60% of them did not exceed 2 m and only in two lakes it exceeded 3.5 m (Mojtyńskie — 4 m and Piłakno — 5.35 m). Even the deepest lake Babięty Wielkie showed transparency of 1.75 m despite of good oxygen conditions at the bottom, indicating an relatively early stage of lake evolution.

Analogical values for the lakes of Suwałki district (STANGENBERG 1936) were higher, as but 15.5% of these lakes showed transparency below 2 m and the number of lakes with transparency exceeding 3.5 m is proportionally 4 times higher.

## pH

The water pH of the examined lakes is included within the limits of 7.15—8.60 for surface samples and 6.80—8.35 for near-bottom ones. The frequency of occurrence of particular values is presented on Fig. 2C. The near-bottom waters exhibit in general lower pH values than surface waters. The most frequently occurring pH values in near-bottom waters are 7.41—7.60 and in only 7 lakes these values are higher. On the contrary the surface

waters are more alkaline. The most frequently occurring pH values were 8.01—8.20 and these values were lower in surface waters of only 8 lakes.

In the Krutynia drainage area larger lakes of the Suchar-type (small dystrophic) do not occur, hence also water pH is higher than average pH of lakes of the Suwałki district. The near-bottom waters of lakes of Krutynia drainage area exhibit higher pH values than those of the Suwałki district even disregarding the Suchar-type lakes.

#### ELECTROLYTIC CONDUCTIVITY

The conductivity of water ( $\kappa_{20}$ ) of the examined lakes ranges from 139  $\mu\text{S}$  to 330  $\mu\text{S}$ . The diagram (Fig. 2D) illustrates the frequency in particular classes of values. A lower conductivity of surface waters than that of near-bottom ones is connected with a lower content of electrolytes. Among the examined lakes 22 of them show surface water conductivity within the range of 201—250  $\mu\text{S}$ . The near-bottom waters are in general characterized by higher values, as in 22 lakes the conductivity exceeds 250  $\mu\text{S}$ . This situation may indicate an accumulation of electrolytes in the hypolimnion or an impoverishment of epilimnion as regards the soluble salts.

#### TOTAL SOLIDS

The character of distribution of occurrence frequency of the amount of dry residue in water samples from the examined lakes is very similar to that of electrolytic conductivity, as discussed above, that is the near-bottom waters leave a heavier residue than the surface ones. Average value for surface samples amounts to 180.6 mg/l and for near-bottom samples — to 199.9 mg/l, that is more by almost 20 mg/l.

#### ALKALINITY

The quantity of particular alkalinity classes is analogical to that of conductivity and total solids, as follows from Fig. 2E. The values for surface samples and their amplitude are low (1.51—3.50 meq/l). For the near-bottom waters the amplitude is higher (1.51—4.50 meq/l) and the distribution-curve top is flattened. The most numerous is the class of 3.01—3.50 meq/l, whereas for surface waters the values are concentrated in the class of 2.51—3.00 meq/l.

The comparison of mean value of alkalinity for the lakes of Suwałki district (apart from Suchar-type), calculated as 3.20 meq/l basing on the data of STANGENBERG (1936) with the same for the lakes of Krutynia drainage area, averaging 3.19 meq/l, proves a distinct analogy between waters of both regions.

#### CALCIUM

The course of frequency distribution of calcium content is similar to the former ones, as shown on Fig. 2F. Surface water contained in general less calcium than the near-bottom water. Concentrations of calcium range from 17 to 59.5 mg/l. Mean value for near-bottom waters equals 43.3 mg/l.

## SODIUM AND POTASSIUM

The curves of frequency distribution of concentration classes of sodium and potassium remind a binomial curve. There are no significant differences between surface and near-bottom waters. Values occurring most frequently are 3.75 mg/l sodium and 2.5 mg/l potassium.

## 5. DISCUSSION

The mere knowledge of variability range of numerous environmental factors of water is insufficient to deduce the interrelations between particular factors and to establish the general character of the investigated lakes.

Two parameters supply evidence of the total content of lake water constituents, that is dry residue and electrolytic conductivity. The conductivity indicates the concentration of dissociated salts in solution and the dry residue on evaporation is proportional to both, the amount of dissolved substances and seston.

The occurrence of a positive correlation between the conductivity and total solids enables to infer that the lake water contains chiefly dissociated salts which constitute the residue on evaporation, or that these salts influence in some way positively the content of seston, which consequently raises the amount of residue.

A negative correlation would prove that the drop of seston content is connected with an increase of concentration of electrolytes. The correlation coefficient equal to nought reflects the lack of interdependence between both factors. The relationship between total solids and electrolytic conductivity for the lake waters of the Krutynia drainage area is presented on Fig. 3A.

The existence of a positive correlation between the discussed factors follows distinctly from the diagram. It may then be assumed that either the electrolytes account for the bulk of dry residue, or they condition the amount of seston. This relationship would be direct in first case and indirect in the second. The next diagram of correlation (Fig. 3B) presenting the dependence of dry residue on the calcium content, explains which case is dealt with in the examined lakes. The correlation is again positive, as the increase of dry residue corresponds to that of calcium. On this diagram (Fig. 3B) the calculated amounts of  $\text{CaCO}_3$  are given together with the concentrations found of  $\text{Ca}^{++}$ . These amounts constitute on an average 52.7% of total solids. Taking into consideration the presence of remaining ions it should be admitted that mineral salts account for at least 80% of total solids.

The correlation of calcium concentration and electrolytic conductivity is demonstrated on Fig. 3C. As it was to be foreseen the positive correlation is in this case considerably more distinct, since  $\text{Ca}^{++}$  is the chief ion responsible for the electrolytic conductivity of water. The relationship between electrolytic conductivity and alkalinity is analogical (Fig. 3D).

The last of the discussed correlations, i.e. that of alkalinity and calcium content of the examined waters is shown on Fig. 3E. The relationship between  $\text{HCO}_3^-$  and  $\text{Ca}^{++}$  in the examined lakes are of the same character as the remaining ones.

Basing upon the quoted data the following conclusion may be accepted:

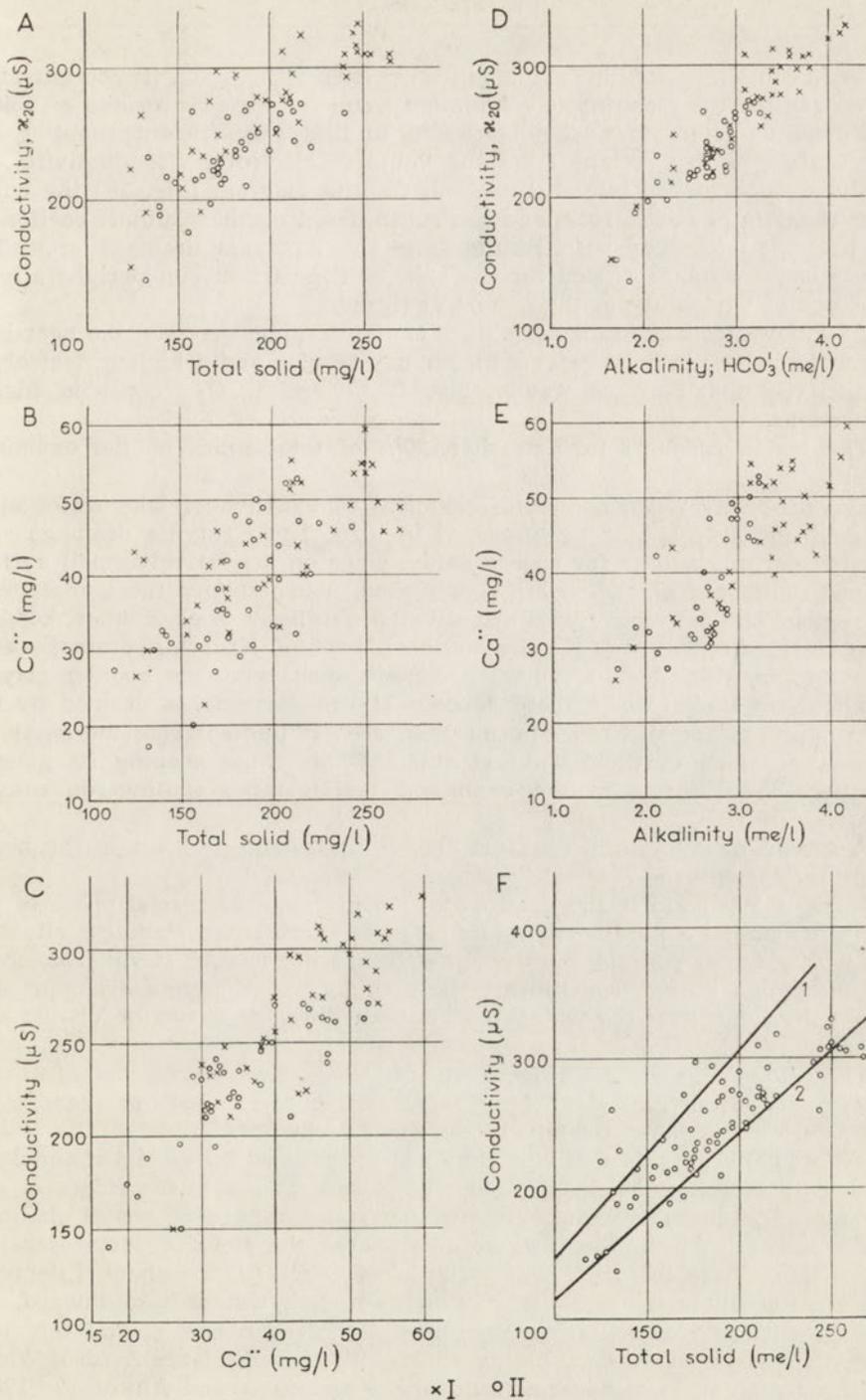


Fig. 3. Correlations

A. Total solids mg/l and conductivity  $\mu$ S. B. Total solids mg/l and Ca<sup>2+</sup> mg/l. C. Ca<sup>2+</sup> mg/l and conductivity  $\mu$ S. D. Alkalinity me/l and Ca<sup>2+</sup> mg/l. E. Alkalinity me/l and Ca<sup>2+</sup> mg/l. F. Total solids mg/l and conductivity  $\mu$ S dots results from Krutynia drainage area. I Calculated after Kolthoff, 2. Results from Ohle (1959). I near the bottom. II at the surface

the main constituent of the examined waters is  $\text{Ca}(\text{HCO}_3)_2$  and its concentration is decisive for the electrolytic conductivity and for the dry residue of water.

Numerous attempts were undertaken to find a coefficient enabling the computation of dry residue from the value of electrolytic conductivity, the results were however rather divergent. On the diagram (Fig. 3F) the curve from the data of OHLE (1959) and the curve based on the Kolthoff coefficient are presented together with results from the Krutynia drainage area. The curves based on data quoted for the sake of comparison run peripherally to the scope of variability of the factors analyzed.

As follows from the range of values of the examined factors, the near-bottom waters show in most cases a higher dry residue and a higher electrolytic conductivity than surface waters, also  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$  occur in higher proportions.

The seston accounts for less than 20% of total solids of the examined waters.

The problem of dependence of chemical composition of lake water upon the drainage area should be discussed in turn. The Krutynia drainage area is particularly adequate for such a study, since on a relatively small surface various stadials of glaciation are represented, which shaped the landscape of the region. The morainic ridges are situated parallelly to each other, keeping the general direction W—E. The southern part of Krutynia drainage area is covered by thick beds of outwash deposits overlaying the boulder clay of Brandenburg stadial\*). On these deposits several large lakes drained by the river Krutynia are situated. The outwash area is limited from the north by a morainic ridge of the Frankfurt stadial. This ridge keeping its general direction W—E forms in the examined region three southwards convex arches.

A second ridge of the Frankfurt stadial is situated 3—9 km to the north from the first one.

More or less 5 km to the north from the moraines of second phase of the Frankfurt stadial a parallel morainic ridge of Pomeranian stadial is situated. The next ridge of end moraines is situated at a distance of 15 km from those of Pomeranian stadial, constituting the boundary of Krutynia drainage area and at the same time the watershed between drainage basins of Vistula and Pregel.

The course of morainic ridges, outlined after KONDRACKI and MIKULSKI (1958) differs from that given by KRAUSE (1926), particularly as regards the neighbourhood of lakes Babięty Wielkie and Mokre.

Spaces between ridges of end moraines are crossed by glacial channels of a meridian direction. These channels cut in several places the ridges of end moraines. The majority of lakes of the Krutynia drainage area is of channel-lake character. Within the intermoraine spaces the flow of surface waters occurs along these channels, connecting lakes which fill the channel depressions. On the whole the direction of flow of surface waters is southward.

After forcing trough the end moraines of the Frankfurt stadial the river Krutynia crosses the outwash plaine utilizing the basis of lakes Zyzdrój Wielki and Zyzdrój Mały which seem, following KONDRACKI and MIKULSKI (1958), together with other lakes of the same outwash plaine, to be of kettle origin.

\*) The geomorphological conditions are discussed basing on the monograph of KONDRACKI and MIKULSKI (1958).

Joining the lake Spychowskie Krutynia river turns northwards, through lake Mokre reaches again the area comprised by the Frankfurt stadial and confined to this area discharges into lake Bełdany.

The surface of the Krutynia drainage area totals 637.4 km<sup>2</sup> where about 90 km<sup>2</sup> belong under Pomeranian stadial about 270 km<sup>2</sup> under Frankfurt stadial another 100 km<sup>2</sup> are covered by outwash deposits. The terminal part of Krutynia drains about 175 km<sup>2</sup> of the area of Frankfurt stadial. The geomorphological situation is presented on Fig. 1.

Particular parts of the river Krutynia and of its tributaries bear various names which introduced by the text would embroil the picture; for the sake of simplicity these names disregarded and it was admitted after KONDRACKI and MIKULSKI (1958) that Krutynia springs are situated at 144 m above sea level, near the village Burszewo upwards of the lake Warpuny and crosses 18 lakes. The longitudinal profile of Krutynia is presented on Fig. 4. A number of tributaries join the main river the largest being the system of Babięty stream which drains 16 000 ha.

A considerable geomorphological differentiation is followed on the examined area by lithological one. Boulder clays and gravels prevail in the region of Pomeranian stadial whereas the region classed to Frankfurt stadial is built of sands and clays and in its eastern part of gravels occurring in larger amounts. The outwash plaine is formed from sands, according to its origin. In its lower course Krutynia crosses alluvial depressions filled with peat.

The lakes of the Krutynia drainage area influenced by feeding waters originating from regions lithologically different, should display dependence upon these regions. This dependence resulting from chemical erosion will be apparent in changes of total amount of dissolved salts and in changes of their composition in water originating from various parts of the drainage area. This is still more complex owing to a variable character of agricultural exploitation of the discussed area.

As it is known the electrolytic conductivity of water supplies evidence on the total content of dissolved salts. From Fig. 4 it is visible that the value of electrolytic conductivity for surface waters is more levelled and as a rule, lower than of near-bottom waters. However a more important conclusion can be drawn from this diagram, that is a distinct and sharp decrease of conductivity that may be observed at the transition from morainic regions to outwash plaine. So long as Krutynia flows through the area of morainic deposits, the values of conductivity exceed 250  $\mu$ S and for surface waters average 262  $\mu$ S. On transition to outwash plaine, that is the area of fluvioglacial deposits the conductivity falls to about 213  $\mu$ S and remains at a low level throughout all lakes of the outwash plaine. When the river reaches again the morainic region, the value of conductivity rises to 230  $\mu$ S showing a tendency of a further increase, as in lake Bełdany, to which Krutynia discharges, this value attains 245  $\mu$ S.

The diagram for near-bottom waters is of a similar character, although in this case considerably higher oscillations are observed.

The distribution of concentration of main ions including Ca<sup>++</sup> and HCO<sub>3</sub><sup>-</sup>, along the discussed series of lakes is analogical. This distribution for hydrogen carbonate ion is presented on Fig. 4. Also in this case the near-bottom waters display a larger range of oscillations of alkalinity value than surface samples, which are more levelled.

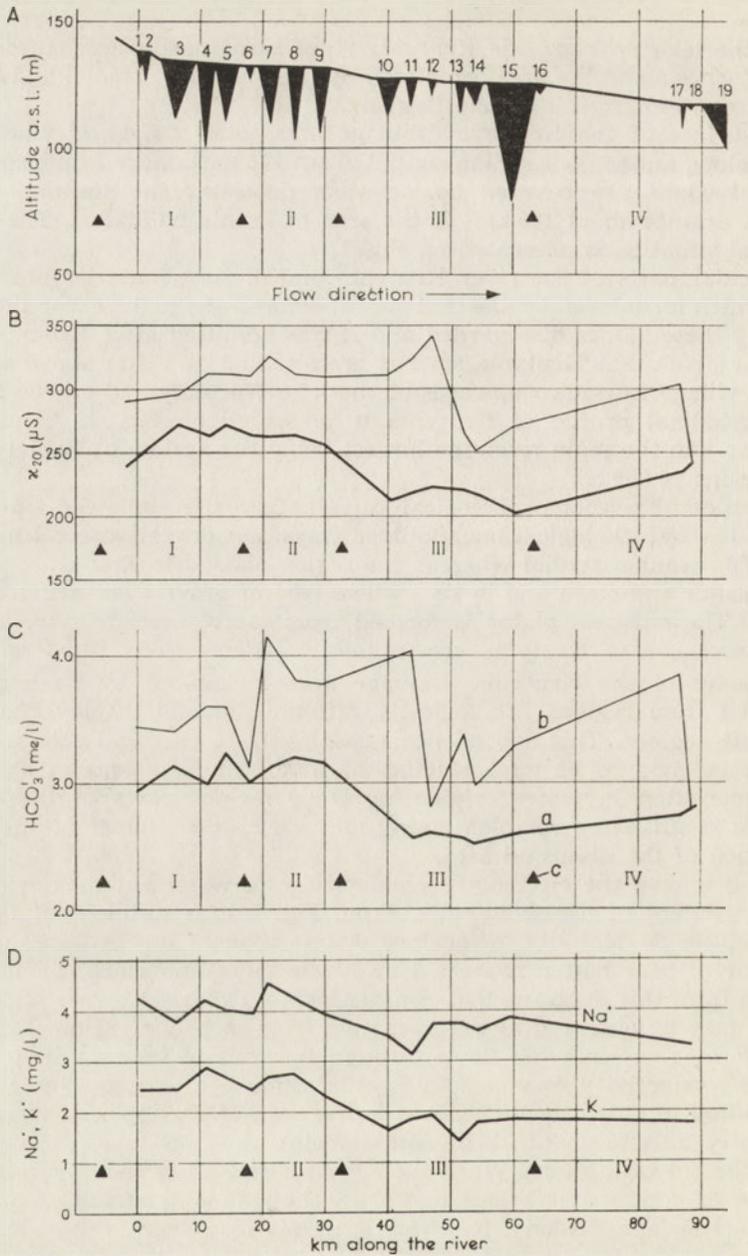


Fig. 4. Changes of particular parameters of lake waters along the Krutynia river  
 Names of lakes. 1. Warpuńskie. 2. Zyndackie. 3. Gieładzkie. 4. Lampackie. 5. Lampasz. 6. Kujno.  
 7. Dłużec. 8. Białe. 9. Gant. 10. Zyzdrój Wielki. 11. Zyzdrój Mały. 12. Spychowskie. 13. Zdróżno.  
 14. Uplik. 15. Mokre. 16: Krutyńskie. 17. Garty. 18. Jerzewko. 19. Beldany. A. longitudinal  
 profile. B. electrolytic conductivity. C. alkalinity. D. K and Na in the surface water. I. Mora-  
 inic deposits Pomeranian stadial. II. Morainic deposits Frankfurt stadial. III. Outwash deposits.  
 IV. Morainic deposits Frankfurt stadial, a. at the surface. b. near the bottom. c. watershed

The variability of occurrence of sodium and potassium in the examined lakes is not so clear as it was with the above discussed factors, however a fall of concentration on the line, delimitating morainic and outwash area, is distinct. On the other hand there is no increase of concentration of these cations in lakes of the lowermost part of the river, situated again in morainic region (Fig. 4).

Up from times when MINDER (1923) found a biological water decalcification, numerous investigations of this problem have been performed. These investigations concerned mostly the processes occurring in a water body itself, although THIENEMANN (1925) stated, that stream waters underwent decalcification by crossing a lake. In Poland this problem was elaborated by STANGENBERG (1935, 1936, 1937).

The processes of biological decalcification in a lake are overlain by a dominating over these processes dependence of calcium content upon the lithological conditions of the drainage area hence the resulting picture is more complicated than it was hitherto claimed.

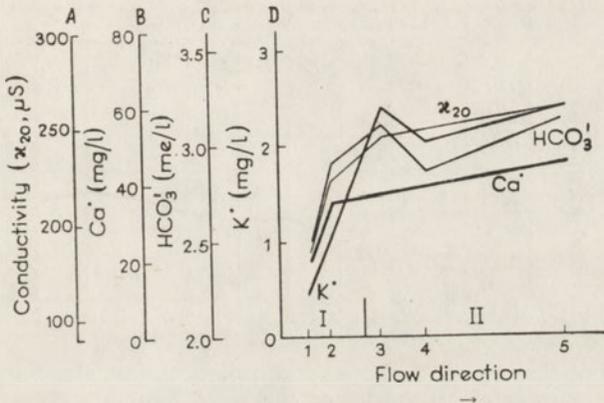


Fig. 5. Changes of particular parameters of lake surface water along Bobrek — tributary of Krutynia river

Names of lakes (on the abscissa). 1. Miętkie. 2. Słupiek. 3. Babięty Wielkie. 4. Babięty Małe. 5. Gant. A. Conductivity in  $\mu\text{S}$ . B. Potassium mg/l. C. Calcium mg/l. D. Alkalinity meq/l. I. Morainic deposits. II. Outwash deposits

The following arguments would prove the domination of influence of drainage area over biological decalcification.

1. Beside calcium an analogical course of variability is found for sodium and potassium.

2. After reaching again the morainic region by the river no further depletion of alkalinity is observed but its increase. Sodium and potassium remain nearly at the same level.

The comparison of the discussed series of lakes with that connected by a stream originating in lake Bobrek indicates as well that geomorphological conditions are decisive. The aforesaid stream begins in the outwash region and joins Krutynia in the morainic region of Frankfurt stadial. Analogically to the previous case the transition from outwash deposits to moraines is bound with the change of main water constituents, the content of these constituents increasing in morainic area. This regards as well Ca, K, Na, as hydrogen carbonate ions. The electrolytic conductivity increases also as related to the mentio-

ned ions. The variability of these constituents in lakes connected by the discussed stream is presented on Fig. 5.

The increase of calcium content associated with transition from outwash plaine to morainic area indicates clearly that changes in calcium content should not be explained only by processes of biological decalcification or that it should be admitted, the intensity of processes of biological decalcification to be ruled by the geomorphological character of drainage area. PATALAS (1960) analyzing analogical data from Węgorzewskie lakes arrived to somewhat different conclusions. This author stated, that in surface waters of lakes connected with a river "a depletion of calcium content is observed downstream. A longer part of the river enriched in calcium the lower situated lake". Basing upon the chemical analyses of water of lake Wigry, STANGENBERG (1935) established that calcium content in Czarna Hańcza river rises as the distance from the outflow from Wigry lake increases. This increment amounted to about 10% per 3 km distance. As results from the analysis of data collected on streams of Krutynia drainage area, such an enrichment may occur when

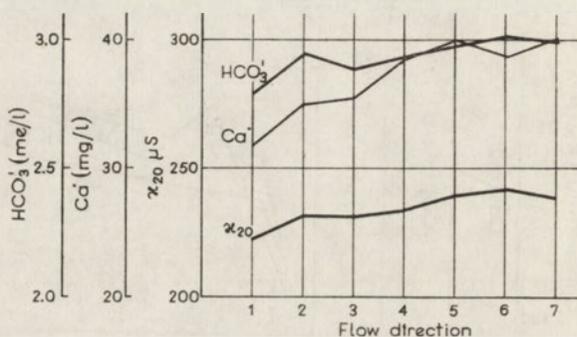


Fig. 6. Changes of  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$  concentration and of electrolytic conductivity of river along the lower course of Krutynia river 1,2,3... sampling stations. Station 1. Outflow from lake Krutyńskie. Station 7. Discharge to lake Garty

the stream crosses a morainic region. This situation is illustrated by Fig. 6. A distinct rise of electrolytic conductivity and of  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$  content is observed in the river segment downstream from the issue of the lake Krutyńskie where Krutynia crosses a morainic plateau. When the river attains alluvial depressions no further increase of the discussed parameters is observed.

As regards Na, PATALAS (1960) found that its lowermost concentrations are encountered in lakes situated in proximity to water sheds. The present data show rather the reverse. Lakes situated near the water shed of Krutynia show a mean content of 4.5 mg Na/l in comparison to average 3.6 mg Na/l for all examined lakes of Krutynia drainage area. In the present discussion the lake Mokre was ranged among lakes influenced by outwash deposits, but this might create doubts. Such a ranging has following reasons. The lake situated in a glacial gate between two arches of end moraines of Frankfurt stadial. This gate opens southwards towards the outwash plaine. The immediate drainage area of the lake amounts to about 25 km<sup>2</sup>, 2/3 of which is covered by the lake open surface. From north and west flow waters from deposits of Frankfurt stadial, draining 54.7 km<sup>2</sup>, that account for 10% of drainage area of lake

Mokre, totalling 516.9 km<sup>2</sup>. Waters from the remaining 90% of drainage area cross 100 km<sup>2</sup> of outwash deposits including 5 lakes and consequently 90% of water of lake Mokre is of outwash origin, as it is confirmed by chemical analyses. Realizing that the situation had to be considerably simplified, the lake under discussion was ranged among outwash plain lakes. The series of lakes connected by Krutynia river exemplifies the dependence of lake water chemical regime upon the geomorphological character of surroundings. The analysis of complete data emphasizes this dependence still more distinctly.

The enclosed map (Fig. 1) presents the dependence of electrolytic conductivity of lake surface waters on the geomorphology of surroundings. As follows from the map lakes of a conductivity higher than 225  $\mu\text{S}$  are all situated to the north from end moraines of Frankfurt stadial. Lakes situated southwards from these moraines that is on outwash deposits, exhibit a conductivity lower than 225  $\mu\text{S}$ . The exception of lakes Piłakno and Borówko, showing conductivity below 225  $\mu\text{S}$  although situated on deposits of Frankfurt stadial, is due to a local spot of outwashsands.

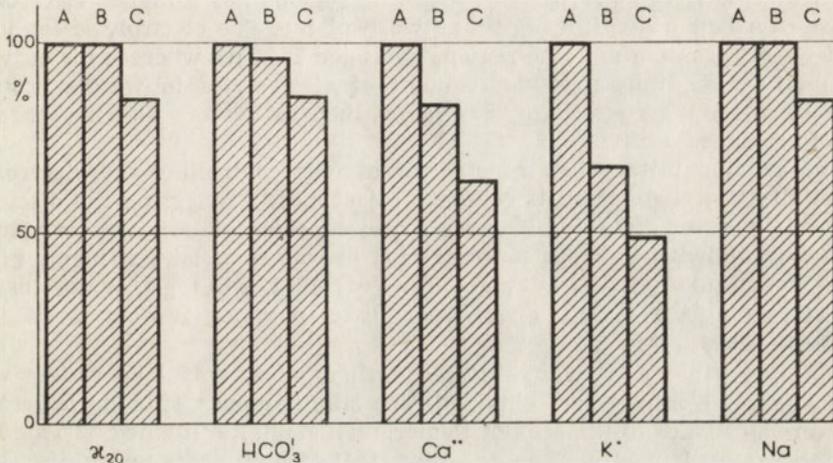


Fig. 7. Comparison of contents of main mineral constituents in surface waters of lakes situated on various glacial deposits

A. Morainic deposits of Pomeranian stadial, B. Morainic deposits of Frankfurt stadial, C. Outwash deposits. Values for region of Pomeranian stadial are taken for 100%

The occurrence of constituents which condition the already discussed conductivity, is analogical as it is demonstrated on Fig. 7. For the sake of better comparability the ratios of values for particular constituents are presented in per cent taking for 100% the average values for lakes situated within the region of Pomeranian stadial. Values presenting a sum of various, like electrolytic conductivity and total solids, as well as main constituents, like  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$  or quantitatively secondary constituents like sodium and potassium exhibit the same type of distribution. Lakes situated on the area of Pomeranian stadial show the highest values. Somewhat lower values are observed in the region of Frankfurt stadial. Outwash deposit plaines are characterized by the lowest values in all discussed cases.

The same values for near-bottom waters, although displaying larger differentiations connected with the limnological type of water body, show on

analogical relation to the geomorphological character of surroundings. Beyond this scheme only alkalinity is found, higher in outwash plains than in morainic ones (only for near-bottom waters).

An analysis of similar materials from the area of Schleswig-Holstein by OHLE (1959) indicates, that waters from lakes situated on outwash plains exhibit lower conductivity than those from moraine regions.

The electrolytic conductivity of water of lakes of Krutynia drainage area, situated on outwash deposits averages 84.6‰ of that of morainic lakes. The same value for the lakes of Schleswig-Holstein, computed from the data of OHLE, was 87‰, that is close to that for Krutynia lakes.

Considering the variability of chemical properties of lake series connected by upper course of Schwentine river, OHLE (1959) noticed a decline in alkalinity and electrolytic conductivity progressing downstream. This author takes it for a result of biological decalcification.

Data collected in 1961 concerning running waters of the Krutynia drainage area exhibit analogical variability in space as the discussed earlier data from lakes. Water of streams flowing in morainic regions has a higher electrolytic conductivity than water flowing on outwash plain. The electrolytic conductivity of waters crossing moraine regions averaged 284.5  $\mu\text{S}$  whereas for outwash areas — 246.1  $\mu\text{S}$ , thus the total content of electrolytes in waters crossing outwash deposits accounts for 86.6‰ of that in waters flowing through morainic regions.

Since calcium is the chief constituent of ions controlling the electrolytic conductivity, the changes of its content project most strongly on the discussed situation. Processes occurring in lakes retain considerable amounts of calcium in bottom sediments. Calcium concentration in waters of lake affluents in the area of Pomeranian stadial averages (for year 1961) 84.1 mg/l. Water leaving this area contains 54.4 mg/l. From every litre of water 29.7 mg Ca is then retained in lakes.

In the year 1959 as it was discussed earlier, when only lake waters were analyzed, similar values were obtained. The lake Lampasz, situated lowermost in the series of lakes of the area of Pomeranian stadial, contained 52.5 mg/Ca/l in surface water. It may be then admitted, that in both years under discussion the calcium content was similar.

Admitting, that the annual discharge from the discussed region totals 10 million  $\text{m}^3$  (outflow from Gieładzkie lake), as computed from data of KONDRACKI and MIKULSKI (1958), this region supplies about 550 tons Ca yearly, and the lakes retain 300 t Ca.

The comparison of surface and near-bottom waters in the examined lakes leads to very interesting results. The dependence of water composition on lake situation is distinct as well. The results are summarized on Table III.

Values for surface waters are given in ‰ of values for near-bottom waters. Except sodium, which occurs at the surface in somewhat higher concentration than near the bottom and this is true only in morainic lakes, all remaining values are lower at the surface. The lowest differences are observed in lakes of the area of Frankfurt stadial, somewhat higher — in lakes of Pomeranian stadial. On the contrary the lakes situated on the outwash plain show highest differences between concentrations at the surface and near the bottom.

Sodium exhibits the lowest differences, thus proving to be involved to a smallest degree in processes of circulation of matter.

Table III

Relation between constituents of and near-bottom waters, presented in % of concentration in near-bottom waters

Analysis	Pomeranian stadial morainic deposits	Frankfurt stadial morainic deposits	Outwash deposits	Total Krutynia drainage area
Total solids	89.2	94.5	87.7	93.0
Conductivity	85.7	89.6	75.8	85.7
HCO <sub>3</sub> <sup>-</sup>	85.5	88.3	73.0	84.4
Ca <sup>++</sup>	91.2	91.2	74.2	85.5
K <sup>+</sup>	96.6	92.6	83.3	91.8
Na <sup>+</sup>	101.0	102.2	96.0	100.5

The highest differences between the surface and near-bottom layers regard the observed content of hydrogen carbonates, these differences averaging 15.6% for all lakes.

In previous analysis all the data were treated as a whole. Doubts may then arise that the results are influenced by disregarding the mictic type of lake in the analysis and the picture obtained results from differences in the mictic type in particular parts of the drainage area. However as it appears, an analogical analysis of data, excluding lakes which circulate over the whole summer, supplies a still more distinct picture of connections of the lake with the drainage area and its geomorphological and lithological character. As example the results of measurement of electrolytic conductivity may be quoted. So far, as for all lakes, mean differences between surface and near-bottom water were: in the morainic region of Pomeranian stadial 14.3%, in the morainic region of Frankfurt stadial 10.4% and on the outwash plain 24.2% — in relation to near-bottom waters, on excluding the circulating lakes the average differences in electrolytic conductivity amounted in the region of Pomeranian stadial to 13.2%, in the region of Frankfurt stadial — to 14.4% and on the outwash plain to 27.8% in relation to near-bottom waters. The difference in electrolytic conductivity between surface and near-bottom water for all the examined lakes of the Krutynia drainage area averaged 14.3%. On excluding lakes it rose to 18.1% in relation to near-bottom waters. This difference became therefore still more distinct.

## 6. SUMMARY

The drainage area of Krutynia river was shaped by several stadials of the last glaciation, its surface totals 638 km<sup>2</sup>. Ridges of end moraines are situated parallelly at a distance of 5—10 km from each other. Southern part of the drainage area is formed by outwash deposits. In the limits of the drainage area 93 lakes are found of a total surface of 5560 ha, drained by Krutynia river.

In 38 larger lakes accounting together for 91% of water surface chemical analyses were carried out during summer stagnation. The analysis concerned electrolytic conductivity, pH, O<sub>2</sub>, Ca<sup>++</sup>, K<sup>+</sup>, Na<sup>+</sup>, PO<sub>4</sub><sup>---</sup> ammonia N, Fe, alkalinity and dry residue. On the basis of these results the scope of variability of the examined factors was discussed and correlations between particular parameters were analyzed. It was found that the main constituents of the examined waters were Ca<sup>++</sup> and HCO<sub>3</sub><sup>-</sup>.

In this context a positive correlation exists between conductivity, dry residue, alkalinity and calcium content.

The relations of lake water chemical regime and the drainage area were analyzed. As it was found, the lakes situated on outwash plains show lower conductivity ( $< 215 \mu\text{S}$ ), than lakes situated in moraine region ( $> 230 \mu\text{S}$ ). The connections between chemical composition of water and lithological peculiarities of the drainage area are more distinct for epilimnetic waters. The waters of hypolimnion reflect the typological dependences, which in some way modify these relations to drainage area. The largest differences in chemical composition between epilimnetic and hypolimnetic waters are observed for  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$ , the smallest—for  $\text{Na}^+$ , the largest differences being found in lakes situated on outwash plains. This would indicate a dominant effect of lithological conditions, in some way modifying the processes of biological decalcification.

## 7. STRESZCZENIE

Dorzecze Krutyni o powierzchni  $638 \text{ km}^2$  ukształtowane zostało przez kilka stadiów ostatniego zlodowacenia. Ciągi moren czołowych przebiegają równoleżnikowo w odległości 5–10 km od siebie. Południowa część tego dorzecza utworzona została przez sandry. W obrębie dorzecza Krutyni znajdują się 93 jeziora o łącznej powierzchni  $5560 \text{ ha}$  odwadniane przez Krutynię.

Na 38 większych jeziorach, tworzących łącznie  $91\%$  lustra wody przeprowadzone zostały badania chemizmu wody w okresie letniej stagnacji. Analiza dotyczyła przewodnictwa, pH,  $\text{O}_2$ ,  $\text{Ca}^{++}$ , K,  $\text{Na}_2\text{PO}_4^{---}$ ,  $\text{NNH}_4$ , Fe, węglanowości i suchej pozostałości. Omówiono na tej podstawie zakres zmienności badanych składników oraz analizowano powiązania między poszczególnymi parametrami. Stwierdzono, że głównym składnikiem badanych wód są  $\text{Ca}^{++}$  i  $\text{HCO}_3^-$ . W związku z czym istnieje dodatnia korelacja między przewodnictwem, suchą pozostałością, węglanowością i ilością Ca.

Analizowano powiązania między chemizmem wody jeziornej a zlewnią. Stwierdzono, że jeziora leżące na sandrach mają niższe przewodnictwo ( $< 215 \mu\text{S}$ ) niż jeziora leżące na morenach ( $> 230 \mu\text{S}$ ).

Powiązania między składem chemicznym wód a litologicznymi właściwościami zlewni są znacznie wyraźniejsze dla wód epilimnetycznych. Wody hypolimnionu odzwierciedlają zależności typologiczne, które w pewien sposób modyfikują te powiązania ze zlewnią. Największe różnice składu chemicznego między wodami epilimnetycznymi i hypolimnetycznymi stwierdza się dla  $\text{Ca}^{++}$  i  $\text{HCO}_3^-$ , najmniejsze dla  $\text{Na}^+$ . Przy czym największe różnice obserwuje się w jeziorach leżących na sandrach. Wskazywałoby to na dominujące oddziaływanie warunków litologicznych, w jakiś sposób modyfikujących procesy biologicznego odwapnienia.

## REFERENCES

- BRANDT, A. 1944. Über den Zelluloseabbau in Seen. *Arch. Hydrobiol.*, 40, 778–821.
- KONDRACKI, J., MIKULSKI, Z. 1958. Hydrografia dorzecza Krutyni. [Hydrography of Krutynia basin]. *Pr. geogr., Inst. Geogr. PAN*, 1958, 1–87. (Polish).
- KRAUSE, P. G. 1926. Eiszeiterinnerungen aus dem Kreise Sensburg. In *Unsere Masurische Heimat*.
- MINDER, L. 1923. Über biogene Entkalkung im Zürichsee. *Verh. int. Ver. Limnol.*, 1, 20–32.
- OHLE, W. 1959. Die Seen Schleswig-Holsteins, ein Überblick nach regionalen, zivilisatorischen und produktionsbiologischen Gesichtspunkten. *Vom Wasser*, 26, 16–41.
- OLSZEWSKI, P. 1951. Dotychczasowe wiadomości z zakresu chemizmu jezior na Mazurach. (The present state of investigations in lake chemistry of the Mazure lake). *Kosmos, Warsz.*, 66, 411–459. (Engl. summ.)
- OLSZEWSKI, P., PASCHALSKI, J. 1959. Wstępna charakterystyka limnologiczna niektórych jezior Pojezierza Mazurskiego. (Preliminary limnological characterization of some lakes in the Mazurian Lake district). *Zesz. nauk. WSR Olsztyn*, 4, 1–109. (Engl. summ.)

- PATALAS, K. 1960. Charakterystyka składu chemicznego wody 48 jezior okolic Węgorzewa. (Characteristics of chemical composition of water in forty eight lakes of Węgorzewo district). *Rocz-i Nauk roln., Ser. B*, 77, 243—297. (Engl. summ.)
- STANGENBERG, M. 1935. Chemische Untersuchungen am Wigrysee. *Arch. Hydrobiol.*, 9, 183—221.
- STANGENBERG, M. 1936. Szkic limnologiczny na tle stosunków hydrochemicznych Pojezierza Suwalskiego. „Suchar” i „Jeziorko” jako stadium przejściowe zanikania jezior. (Limnologische Charakteristik der Seen des Suwałki-Gebiets auf Grund der hydrochemischen Untersuchungen. „Suchar”- und „Jeziorko”-Seen als Stadien fortschreitender Seenverlandung). *Rozpr. Spraw. Inst. badaw. Las. państw., Ser. A*, No. 19, 85pp. (Polish and German summ.)
- STANGENBERG, M. 1937. Charakterystyka limnologiczna jezior grupy Kleszczowieckiej i Hańczańskiej na pojezierzu Suwalszczyzny. (Limnologische charakteristik der Seen der Kleszczówek- und Hańczagruppe im Suwałki Gebiete). *Rozpr. Spraw. Inst. badaw. Las. państw., Ser. A*, Nr. 23. (German summ.)
- STANGENBERG, M. 1958. Ogólny pogląd na skład chemiczny wód rzecznych Polski. (A general outlook on the chemical composition of river waters in Poland). *Pol. Arch. Hydrobiol.*, 4, 289—359. (Engl. summ.)
- SZCZEPAŃSKI, A. 1968. Scattering of lakes and visibility in water different types of lakes. *Pol. Arch. Hydrobiol.*, 15, 51—77
- THIENEMMAN, A. 1925. Die Binnengewässer Mitteleuropas. Eine limnologische Einführung. *Die Binnengewässer*, 1, 225 pp.



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## SEASONAL CHANGES OF THE HETEROTROPHIC MICROFLORA OF THE ILAWA LAKES BOTTOM DEPOSITS

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### ABSTRACT

The distribution of the heterotrophic microflora in the bottom sediments of the Ilawa lakes depends mainly on the bottom type. The total number of heterotrophic bacteria, aerobic sporeforming bacteria, proteolytic bacteria, as well as those liberating ammonifying is higher in bottom deposits of the muddy type, lower in sandy bottom deposits. Seasonal fluctuations in the development of heterotrophic bacteria display a regularity, that is maximum numbers of bacteria occur in the vegetative period, minimum numbers in winter. The bottom deposits of the lake Jeziorak Mały which is polluted with industrial effluents and farm sewage contain a heterotrophic flora greater in number, the maximum of bacteria occurring at different seasons, sometimes also in winter.

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### 1. INTRODUCTION

In order to characterise a basin from the microbiological point of view data concerning the microflora of bottom deposit are very important. This is the place where the most intense processes of mineralisation of organic substances occur leading to accumulation of nutrient elements which play an important role in the life of the waters (ROSENBERG and MIEFIEDOWA 1958). This action of bacteria is also characterized by the increase of biomass which serves as food for numerous invertebrate animals living at the bottom of the basin (Cвиц 1960, FOX and COE 1943, KALINIENKO 1951, RODINA 1949 a, b, ROZENBERG and MIEFIEDOWA 1956, 1958, ZOBELL and FELTHAM 1938, ZOBELL and LANDON 1937).

The spread of bacteria in bottom deposits as well as their qualitative content were subject of numerous studies in sea waters (DUGGELI 1936, HUTTON and ZOBELL 1949, KRISS 1959, LLOYD 1931, OSNICKAJA 1953, SISLER and ZOBELL 1950, STONE 1946, WAKSMAN 1933, ZOBELL 1946, 1962, ZOBELL and MORITA 1957 and others), as well as in inland waters (FISCHER 1961, GAMBARJAN 1958, IWANOW and TIERIEBKOWA 1959 a, b, JEGOROWA 1951, KUZNIECOW 1947, 1951, 1952, ROMANOWA 1963 and others). It has been found that the deposit microflora displayed a greater biochemical activity in comparison to the water microflora, as well as a more numerous occurrence of the anaerobic microflora together with a marked dependence of bacteria distribution on the

deposit type (WAKSMANN 1933, ZOBELL 1946) and a clear decrease in bacteria number with increasing depth due to carbon exhaustion with a concomitant accumulation of noxious metabolic products (KUŹNIECOW 1951, 1952, ROMANOWA 1963, ZOBELL 1946, ZOBELL and ANDERSON 1936).

As there were no data concerning the microflora of bottom deposits in climatic conditions of the lakes in the North of Poland attempts were made in the years 1960—1963 to characterize the dynamics of development of the heterotrophic microflora in bottom deposits of the lake Jeziorak Mały as a sewage reservoir (NIEWOLAK, 1966 a) together with the eutrophic lake Jeziorak in the Masurian Lake District. The studies were conducted in three consecutive year cycles.

## 2. DESCRIPTION OF THE INVESTIGATED LAKES AND THE METHODS USED

The lake Jeziorak Mały the surface of which is 26 ha (Fig. 1) and mean depth 4—5 m is situated in the area of the town Hawa. Its maximal depth in its middle part is 6.4 m. The N lake shore is covered with trees and shrubs, the E shore is

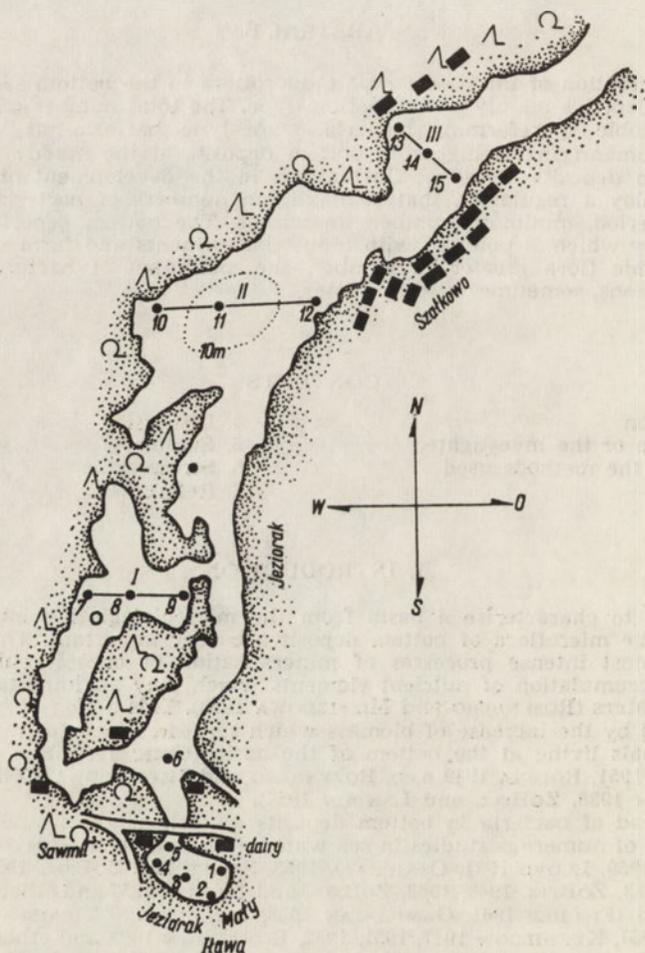


Fig. 1. Localisation of the investigated Hawa lakes (Jeziorak Mały and Jeziorak)  
I, II, III — sections; 1, 2, 3... — sampling sites

partly used as a sailing harbour. Close by there is the outlet of the sewage from a dairy plant. A significant amount of sewage comes also into the lake from the nearby situated farms and a part of the town sewage. To the S the shore passes into a meadow. The W part is shut by the sawmill terrain the wood waste of which can be found on a significant area of the bottom. This basin is connected with the larger Jeziorak lake by a narrow pass under a bridge. The littoral flora is as a rule poor, it appears in a belt about 3 m wide. The bottom at the shore is sandy, further on muddy.

The Jeziorak lake is a relatively young lake, formed during the last glaciation. Situated to the N of the town Ilawa it covers the surface of 3230 ha, its average depth is 5 m, maximum depth occurs in the S part reaching 11.1 m. The W shores of the lake are covered with forest, the E ones about 13 km border on fields and the village Szalkowo, then on coniferous and mixed forest. In the S segment of the lake, there is a big isle of a surface 2 km<sup>2</sup> covered with mixed wood. There is also a big farm on the isle. In the W part, before the reed belt there is a belt of natatorial plants. In view of large surface and small depth Jeziorak is an eutrophic lake. The shore areas, especially the fields and meadows grazed by cattle, have a great influence on the degree of eutrophication as well as the town Ilawa, in the S part. From the fishery point of view the lake is considered as one of the perch pike type.

The choice of sites for microbiological studies was done taking into account their disposition in the vicinity or far from the pollution sources, but the criterion of the greatest interest was the bottom character (sandy, muddy or some other type). A brief characteristics of the sites chosen is given in Table I.

Table I

Some hydrographic data of the investigated stands and bottom deposit type of the Ilawa lakes

Lake	Site	Distance to the shore	Depth	Bottom deposit type
Jeziorak Maty	1	15 m	4.5 m	muddy
	2	20 m	4.5 m	muddy
	3	in the middle of the lake	6.4 m	muddy
	4	20 m	2.0 m	muddy with a thick sawdust layer
	5	20 m	5.0 m	muddy
Jeziorak	6	150 m	5.0 m	muddy
	7	15 m	2.0 m	muddy
	8	300 m	2.5—3.0 m	sapropel
	9	15 m	2.0 m	muddy
	10	15 m	5.0 m	sandy
	11	650 m	11.1 m	muddy
	12	15 m	5.0 m	sandy
	13	15 m	6.0 m	sandy
	14	450 m	6.0 m	muddy
	15	15 m	5.0 m	sandy

Samples of the bottom deposits were taken more or less once a month during the period from April 29-th 1960 till April 29-th 1963 by means of the Ekman sampler into sterile petri dishes. 10 g of wet weight of the deposit were transferred into flasks containing 90 ml of 0.85 per cent NaCl solution, then they were shaken for 15 min on a shaker and plated directly or after dilution on suitable media.

The following determinations were performed in the samples of bottom deposits under investigation.

1) the total number of heterotrophic bacteria in broth agar medium at pH 7.2 and 20°C during 7 days (RHEINHEIMER, 1960).

2) the total number of anaerobic heterotrophic bacteria in broth agar medium at pH 7.2 after 48 hours incubation at 25°C, according to SZTURM (RODINA 1956).

3) aerobic sporeformers in broth agar medium at 30°C during 3 days (MISUS-TIN 1948).

4) proteolytic bacteria in a gelatin medium at 22°C during 4 days (SEELEMAN et al. 1956).

5) the titre of ammonifying bacteria in a broth medium containing 3 per cent peptone after 3 days incubation at 25°C. The course of ammonification could be followed by observing the increasing turbidity of the culture and color change of the red lacmus indicator paper from red into blue. The indicator paper was inserted with the stopper above the medium. In order to determine the decomposition of proteins accompanied by the liberation of hydrogen sulphide strips of paper impregnated with lead acetate and moistened with sterile water were inserted together with the indicator paper. All the determinations were accomplished in three parallel platings and the results obtained calculated per 1 gram of dry or wet weight of the deposits.

### 3. RESULTS

Among the bottom deposits of Ilawa lakes three main types can be recognized: 1) sandy type containing negligible amounts of organic substances (1—2 per cent) and a high dry weight content (98 per cent) as well as a high silica content (95—97 per cent) 2) muddy deposits containing up to 42 per cent of organic substances, lesser dry weight (57 per cent) and silica (15 per cent), 3) bottom deposits not mineralized to a great extent, rich in organic remnants, becoming lighter in color on drying, of the sapropel type. In the group of muddy deposits there are deposits contaminated by organic sewage as well as those that are not.

In view of the minimal differences in the quantitative occurrence of heterotrophic microflora, which have been found during the period of investigations, are negligible for the given type of bottom deposits, the following sampling sites shall be discussed: 3 (muddy deposits highly polluted by sewage), 8 (weakly mineralized deposits of the sapropel type), 13 (sandy type of deposits) and 14 (muddy deposits not polluted by sewage).

The distribution of the heterotrophic microflora is not even in particular types of bottom sediments of the Ilawa lakes (Fig. 2). In the muddy type of deposits where the organic substance content is higher than in the sandy ones, a considerably higher number of bacteria has been found. The influence of the bottom type on the number of heterotrophic microorganisms is especially clear in the bottom deposits in particular sampling sites of the Jeziorak Lake, section II and III. The sandy bottom of the shore (station 13) contains a relatively poor microflora (ranging from several hundred to about ten thousand cells per gram dry weight, depending on the seasons). Exceptionally in October and November 1960 the heterotrophic bacteria content in sandy type of deposits exceeded 100 thousand cells per gram dry weight, which could result from a longer vegetative period than usual and the accumulation of a greater amount of easily assimilable organic matter. A considerably greater number of heterotrophic bacteria was found in muddy bottom deposits (e.g. in station 14) and in deposits in the region of Moty, mineralized to a smaller extent (station 8). But even in these places heterotrophic bacteria occurred in much greater numbers in the year 1960 than in the subsequent years. The numbers of bacteria ranged from about ten thousand to millions of cells per gram dry weight. Great numbers of heterotrophic bacteria occurred also in the bottom deposits of the lake Jeziorak Mały polluted by sewage. With a few exceptions their number exceeded 100 thousand cells per gram dry weight and often 1 or more millions of cells per gram were found (station 3).

As to seasonal changes in the number of heterotrophic bacteria in the bottom deposits of Jeziorak on the sandy type of bottom together with the muddy ones and the deposits in the region of Moty that are not mineralized to a great extent, these bacteria occur in maximal numbers in summer (in August) and in autumn (in October or November). Fairly large numbers of heterotrophic bacteria occurred also in spring (in May). In winter (especially February) the

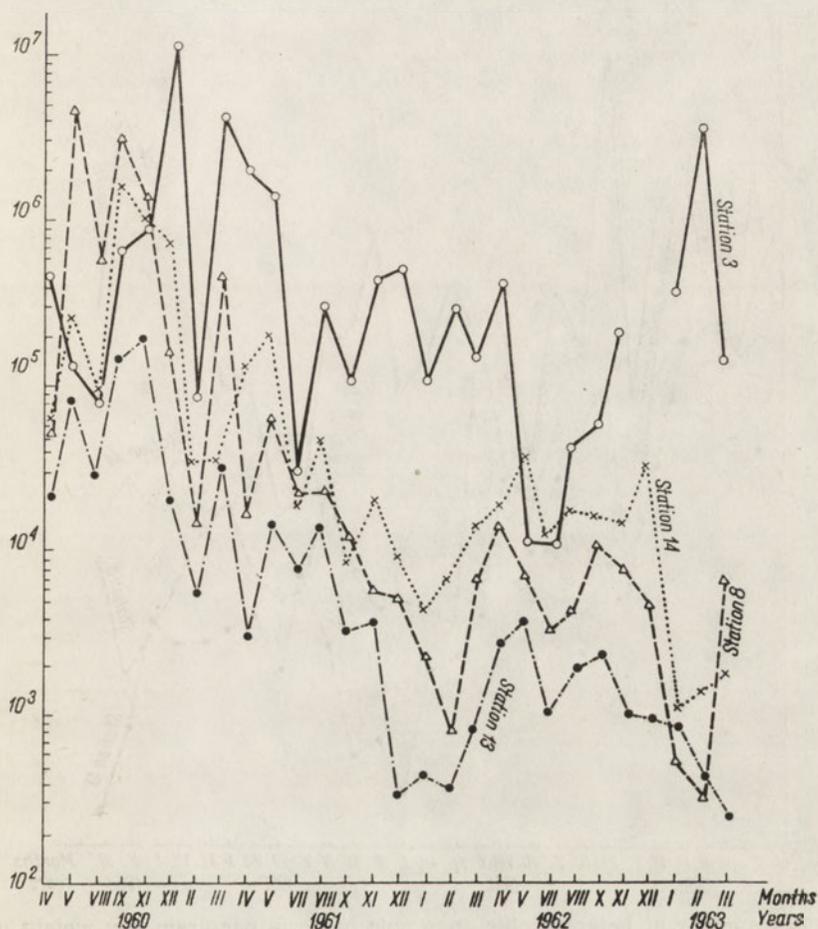


Fig. 2. The number of heterotrophic aerobic bacteria per gram dry weight of the bottom deposits of Iława lakes in the years 1960—1963 in the logarithmic scale (mean values from 3 parallel counts)

number of heterotrophic bacteria in the above mentioned deposit types reached a minimum and generally did not exceed 10 thousand per gram dry weight. The samples taken in 1961 are the only exception, as in the station 8 and 14 16.1 and 37.8 thousand cells were found per gram of the bottom deposits respectively. The decrease in the cell number in the bottom deposits of this basin in winter is probably related to the decrease of temperature of the surface layer of the deposits or is the result of the exhaustion of organic matter that

can easily be assimilated. The deficit of oxygen has also probably some influence on this fact (NIEWOLAK 1966 b).

In the more polluted bottom deposits of the lake Jeziorak Mały maximum numbers of heterotrophic bacteria have been found to occur in different periods, sometimes even in winter. This is caused by the irregular pollution of this basin by sewage in different seasons and in particular years.

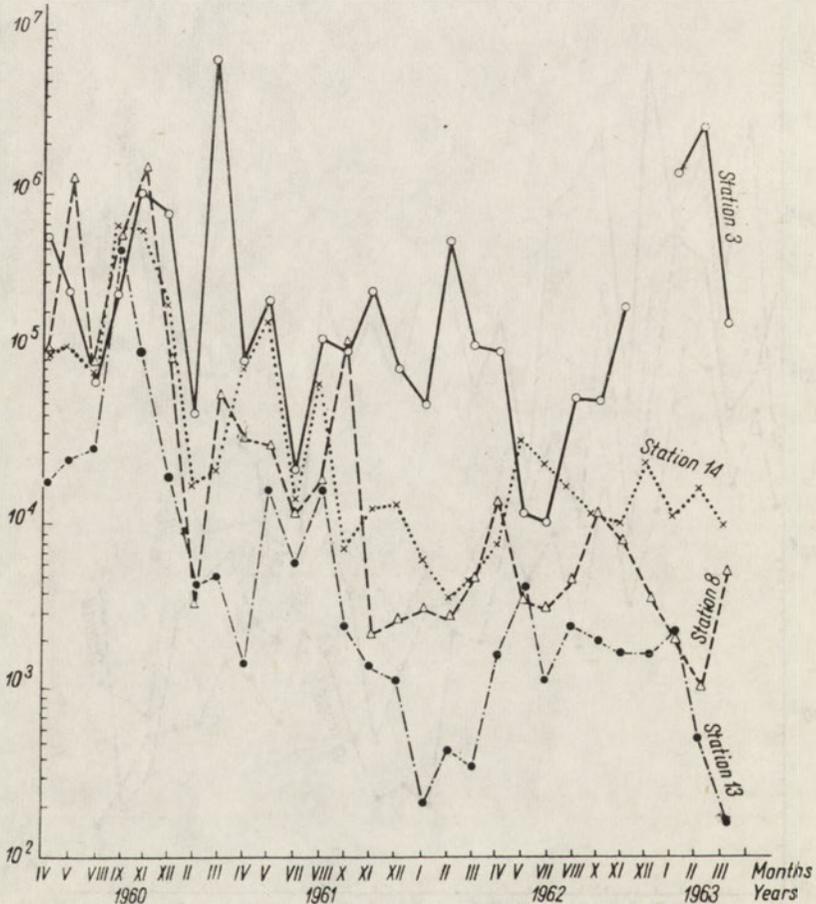


Fig. 3. The number of heterotrophic anaerobic bacteria per gram dry weight of the bottom deposits of Iława lakes in the years 1960—1963 in the logarithmic scale (mean values from 3 parallel counts)

Also anaerobic bacteria occur among the microflora of the Iława lakes bottom deposits (Fig. 3). They were found in all examined stations of the lakes in question, in numbers slightly smaller or close to the general number of the heterotrophic aerobic microorganisms. Similarly to aerobic bacteria, the anaerobic ones are more numerous in muddy type of bottom deposits (station 14) or in less mineralized bottom sediments in site 8. Great numbers of anaerobic bacteria were found in the bottom sediments of Jeziorak Mały (station 3), where often an oxygen deficit occurred (NIEWOLAK 1966 b). The num-

ber of bacteria ranged from about 20 thousand to several millions cells per gram dry weight. The maximum numbers of anaerobic bacteria in the bottom deposits of Jeziorak occurred as a rule in May and August. Sometimes greater numbers or anaerobic heterotrophic bacteria were also found in July and in winter (under the ice). The course of the seasonal change in the development of anaerobic bacteria in the polluted bottom deposits of Jeziorak May displayed maximum numbers in various periods, sometimes even in winter, which is probably related to irregular pollution of this basin by sewage.

Table II

The number of aerobic sporeforming bacteria and their percentage in relation to the general number of heterotrophic bacteria per gram dry weight of bottom deposits from station 3, 8, 13 and 14 of the Iława lakes (mean values from 3 parallel counts)

Date	Station		3		8		13		14	
	number	per cent	number	per cent	number	per cent	number	per cent	number	per cent
IV 1960 r.	2 050	0.40	3 590	7.36	680	3.17	1 450	2.25		
V	820	0.50	2 210	0.04	2 970	3.05	1 360	0.50		
VII	280	0.36	300	0.06	930	3.08	960	1.04		
IX	9 230	1.32	355	0.01	3 280	2.70	3 500	0.20		
XI	4 580	0.42	135	0.01	450	0.23	900	0.08		
XII	2 300	0.02	65	0.04	220	0.98	1 220	0.16		
II 1961 r.	600	0.75	10	0.05	115	2.53	755	1.98		
III	2 400	0.05	1 410	0.28	50	0.13	300	0.80		
IV	1 160	0.05	475	2.44	170	5.65	550	0.38		
V	6 230	0.40	1 850	2.74	580	3.00	1 315	0.57		
VII	330	0.98	510	2.31	210	2.75	620	3.20		
VIII	11 600	3.38	290	1.20	345	2.30	660	1.18		
X	6 800	5.38	535	0.40	235	6.25	165	1.83		
XI	14 500	2.88	400	6.50	445	11.50	530	2.38		
XII	5 060	0.82	—	—	8	2.32	680	6.90		
I 1962 r.	4 220	3.20	15	0.67	15	3.05	210	4.13		
II	1 050	0.30	42	5.20	55	14.68	360	5.05		
III	1 665	1.00	200	2.83	15	1.70	180	1.08		
IV	39 025	8.60	30	0.18	228	8.00	600	2.93		
V	370	2.84	145	2.00	75	1.82	1 030	2.22		
VII	240	1.80	15	0.40	125	9.60	185	1.40		
VIII	440	0.90	35	0.72	5	0.22	300	1.57		
X	310	0.50	95	0.85	55	2.18	10	0.05		
XI	905	0.44	30	0.38	10	1.06	25	0.15		
XII	—	—	260	5.30	120	12.50	410	1.05		
I 1963 r.	3 820	0.86	35	6.00	80	9.63	50	4.13		
II	130	0.002	25	10.2	—	—	60	3.90		
III	4 100	2.75	230	3.10	30	12.55	70	3.60		

Also aerobic sporeforming bacteria occur in the bottom sediments of Iława lakes (Table II). In the majority of samples, however, their number was negligible in relation to the total number of heterotrophic bacteria. The relatively greatest numbers were found in the sandy bottom deposits of Jeziorak. As an example, it can be said, that in station 13 (of the sandy type) sporeforming aerobic bacteria represented 1.06 to 14.68 per cent of the total number of the heterotrophic microorganisms with only two exceptions. In the sapropel type bottom deposits which are less mineralized, in the region of Moty (station 8) the per cent content of sporeformers among heterotrophic microflora was smaller and amounted from 0.01 to 10.2 per cent. In the muddy deposits of

this basin, though sporeformers occurred in greater amounts, the per cent content of these organisms among the general number of heterotrophic bacteria was negligible and ranged from 0.05 to 6.9 per cent (station 14). An equally small percentage of sporeformers has been found in the muddy deposits of the lake Jeziorak Mały polluted by sewages (in station 3 sporeforming bacteria represented 0.02 to 8.6 per cent of the whole heterotrophic flora).

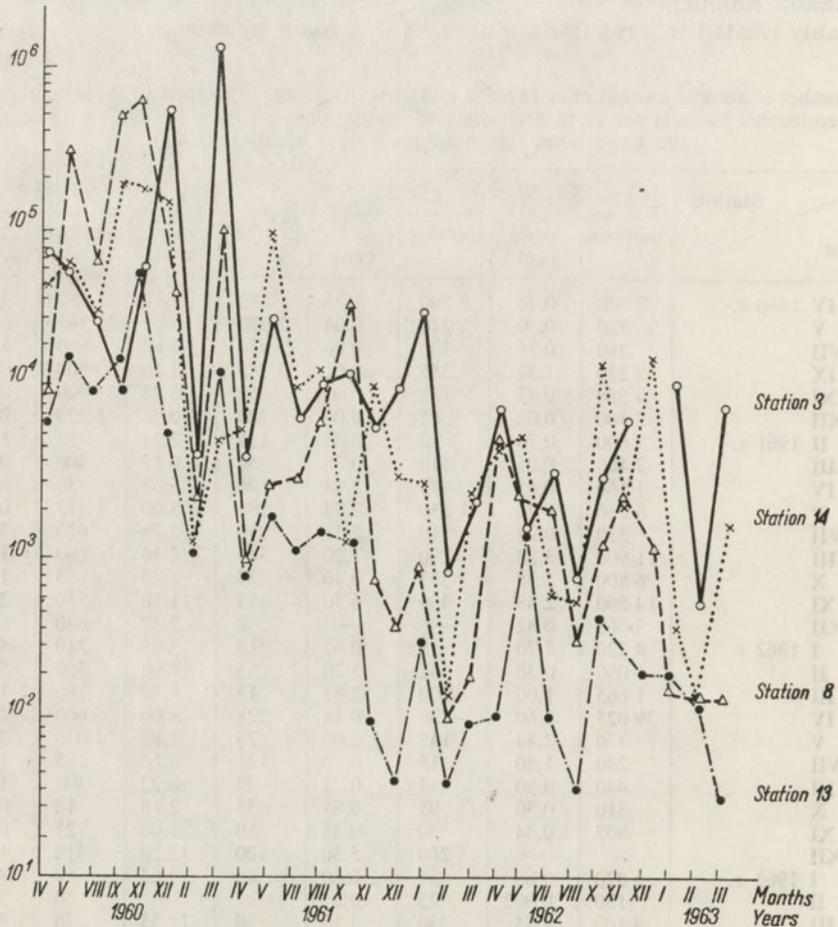


Fig. 4. The number of proteolytic bacteria per gram dry weight of the bottom deposits of Ilawa lakes in the years 1960—1963 in the logarithmic scale (mean values from 3 parallel counts)

Proteolytic bacteria represent a considerable part within the heterotrophic microflora of the bottom deposits of the lakes under study (Fig. 4). It seems, that the bottom type plays an important role in the development of these bacteria in the bottom deposits of Ilawa lakes. In muddy parts of the bottom or in its less mineralized parts in the region of Moty where there are great amounts of organic substances the proteolytic bacteria, similarly to the heterotrophic bacteria in general, occur in greater numbers than in the sandy bottom deposits in the littoral. This is especially clearly seen in the stations of the

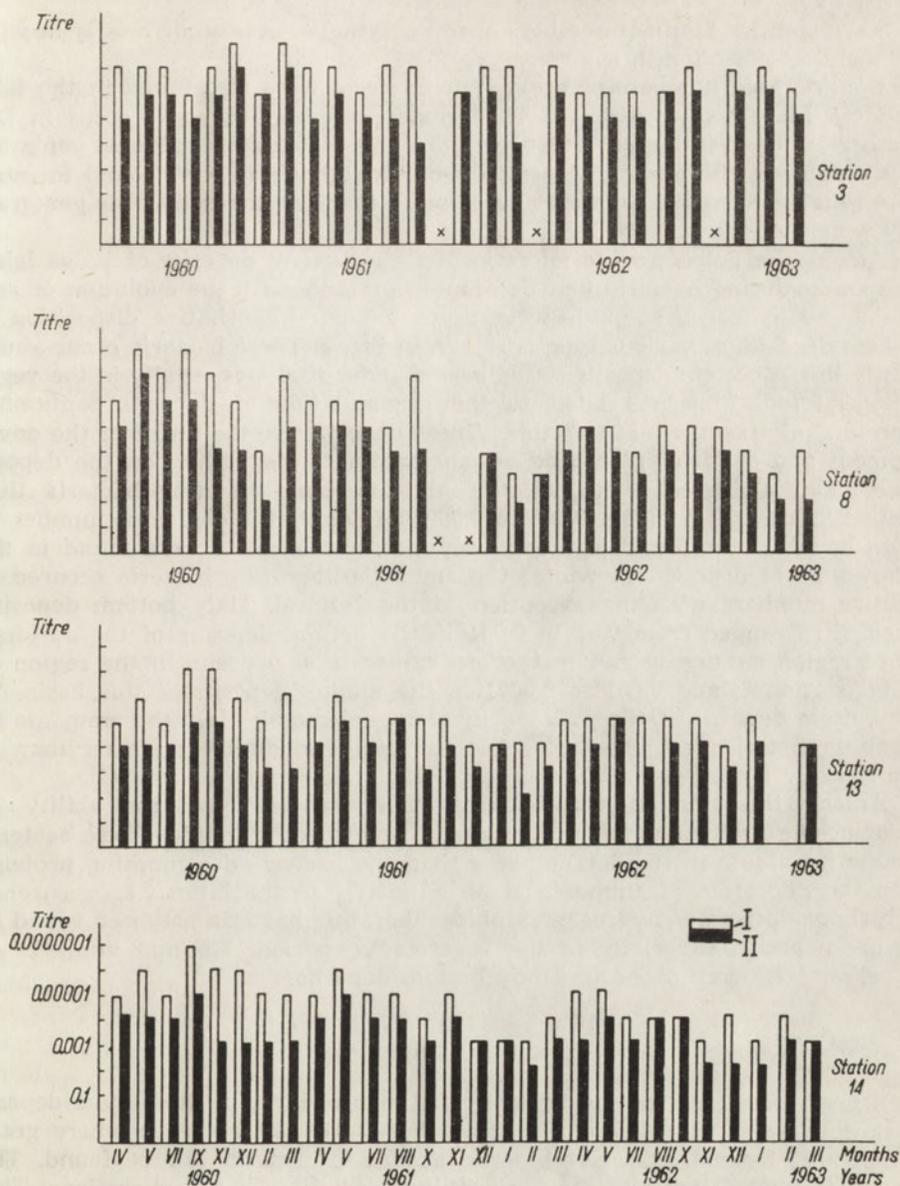


Fig. 5. The titre of the ammonifying bacteria in the bottom deposits of Iława lakes in the years 1960—1963

I the titre of the bacteria decomposing proteins with the liberation of ammonia. II the titre of bacteria decomposing proteins with the liberation of hydrogen sulphide

lake Jeziorak section II and III. In the muddy bottom deposits of these sections, in their middle stations, the proteolytic bacteria content is as a rule considerably higher (station 14) than in the sandy bottom at the shore (station 13). The course of seasonal changes of this microflora, similar to the changes in the total number of bacteria, show maxima in May and November, rarely

in other months. Minimal numbers of proteolytic bacteria occur mostly in winter months, less often in summer.

Considerable numbers of proteolytic bacteria were also found in the lake Jeziorak Mały bottom deposits. The greatest numbers found to occur in December 1960 and in March 1961 were 575.3 and 1486.4 thousand cells per gram dry weight. In the remaining period proteolytic bacteria were found in numbers ranging from several thousand to more than ten thousand cells per gram dry weight of the deposits.

Among the heterotrophic microflora of the bottom deposits of Ilawa lakes also ammonifying bacteria that decompose proteins with the evolution of ammonia and hydrogen sulphide were present. Their quantitative disposition in bottom deposits of various type is shown in Fig. 5. These bacteria occur abundantly in the bottom deposits of the basins under study, especially in the vegetation period. This is related to the accumulation of deposits containing more organic substances at this time. These deposits are the result of the development and death of plant and animal organisms depending on the deposit type and the degree of its pollution the ammonia-liberating bacteria titre ranged at this period from 0.001 to 0.0000001. As a rule a greater number of these bacteria was found in muddy deposits, less bacteria were found in the sandy type of deposits. In winter the ammonia-liberating bacteria occurred in smaller numbers with the exception of the Jeziorak Mały bottom deposits. Their titre ranged from 0.01 to 0.001 in the bottom deposits of the Jeziorak shore region (station 3) and in the less mineralized deposits in the region of Moty (station 8) and 0.001 to 0.0001 in the muddy deposits of this basin. In the bottom deposits of the polluted by sewage Jeziorak Mały the ammonia-liberating bacteria developed sometimes in winter in numbers greater than in summer.

Among the ammonifying bacteria many species have the ability of decomposing proteins with the liberation of hydrogen sulphide. These bacteria occurred as a rule in smaller numbers than the bacteria decomposing proteins with the liberation of ammonia alone. Similarly to the latter, the occurrence of higher numbers of hydrogen sulphide-liberating bacteria has been found in muddy deposits, especially in the vegetative period. Minimal numbers of these bacteria were found in sandy bottom deposits.

#### 4. DISCUSSION

A very important role is played by the surface layer of the bottom deposit in the biological processes of the Ilawa lakes. This is the place where great numbers of heterotrophic aerobic and anaerobic bacteria can be found. The bottom type is decisive in the horizontal distribution of the microflora. This can be seen especially clearly when comparing the numbers of microorganisms from muddy and sandy deposits. Sandy types of bottom deposits containing small amounts of organic substances have a relatively poor microflora, which is comprehensible because of the scarcity of food. Muddy deposits as well as less mineralized bottom deposits of lakes containing great amounts of organic substances (ŻUKOWSKA 1960) have numbers of bacteria that are equal to those of the bottom deposits of some eutrophic lakes of the USSR (the lakes Briszerowo, Kołomno, Pjawoczne) in which the total heterotrophic bacteria number reached from about 40 thousand to 200 thousand cells per gram dry weight

(EKZERCEW 1948, ZAWARZINA 1955). Heterotrophic anaerobic bacteria occurred in bottom sediments of Ilawa lakes the of this type in numbers higher than in the above mentioned USSR lakes, where they were found in numbers ranging 2 to 16 thousand per gram dry weight. It is possible, that the redox conditions of the Ilawa lakes bottom deposits are more favourable for this physiological group of bacteria. Maximum numbers of heterotrophic bacteria in the Jeziorak bottom deposits occurred in the second half of the vegetative period (the end of August and in October and December) similarly the lake Czernoje in Kosino (KUZNIECOW 1952) and in the bottom deposits of the Barents sea (NIKITINA 1955). This pattern of seasonal changes in the development of the heterotrophic microflora of Jeziorak bottom deposits can be explained by the accumulation of great amounts of organic substances on the bottom at this period, which in turn is related to the mass dying of the phyto- and zooplankton as result of the decrease of temperature. However, the decrease in the heterotrophic bacteria number in the bottom deposits of this basin in winter is probably related to the temperature decrease of the deposit surface layer or is the result of the exhaustion of organic substances that can easily be assimilated. In the lake Jeziorak Mały there is no such regularity in the seasonal occurrence of the bottom deposit microflora and this is caused by their irregular pollution by the farm and industrial (mainly dairy ones) effluents. The latter were let into the basin in their natural state which, of course, influenced the disposition of the microflora and its quantitative content.

Among the heterotrophic microflora of the bottom deposits of Ilawa lakes the sporeforming bacteria represent a relatively small portion. In the majority of samples examined they were found in small numbers and they exceeded rarely 10 per cent of the general number of the heterotrophic microorganisms. The same percentages of sporeformers were found by SALAMANOW (1959) in the bottom deposits of the Kujbyszew basin in the USSR. The small percentage of sporeformers is probably related to the fact, that there are considerable amounts of easy assimilable organic matter, especially in muddy deposits.

The numbers of proteolytic bacteria were the same in the Ilawa lakes bottom deposits as in other deposits of this type. More or less similar numbers of these bacteria (11 to 220 thousand per gram) were found by ROMANOWA (1963) in the bottom deposits of the lake Bajkał. The same numbers of proteolytic bacteria were found by ZOBELL (1938) for sea bottom deposits. Sandy types of bottom deposits were an exception, proteolytic bacteria occurred there in smaller numbers. Smaller numbers of proteolytic bacteria in sandy types of bottom deposits are related to the small amount of organic matter in this part of basins. The comparison of the number of the gelatin-liquefying bacteria with the total number of bacteria on broth agar shows that this faculty occurs fairly often among the heterotrophic bacteria of the bottom deposits of the lakes under investigation.

The Ilawa lakes deposits contain also a fairly great number of protein decomposing bacteria with the liberation of hydrogen sulphide. The number of these bacteria changed in the course of the year depending on the temperature and the supply of hydrolysable organic nitrogen compounds and probably on the protein content of the falling detritus. That is the reason for the fact that maximal numbers of bacteria occurred more often in the vegetative period. These numbers were close to those given by SZTURM et al. (1945) for the sapropel deposits of the lake Pjawoczne and Szitowskie in the USSR.

As the ammonifying bacteria occur in great numbers in the bottom deposits of Iława lakes it can be presumed that they represent an important factor in the accumulation of hydrogen sulphide in the layers of water close to the bottom.

#### 5. SUMMARY

In the years 1960—1963 microbiological investigations of the Iława lakes (lake Jeziorak Mały and lake Jeziorak) have been accomplished. They included the quantitative determination of the heterotrophic microflora that takes part in the matter cycle in water basins. It has been found that the bottom type together with the organic substance content has the greatest influence on the microflora disposition. In muddy type of deposits the heterotrophic bacteria content ranges from several hundred thousand to several million cells per gram dry weight, in sandy type of deposits it is several times lower and ranges from about 200 to about 200 thousand cells per gram dry weight. The differences in number between heterotrophic aerobic and anaerobic bacteria were negligible in most cases with some exceptions. Among the bottom deposit microflora of Iława lakes there are also some spore-forming as well as proteolytic and ammonifying bacteria which decompose plant and animal proteins with the liberation of ammonia and hydrogen sulphide. Sporeforming bacteria occurred in greatest numbers in muddy deposits but represented a considerably smaller percentage of the general number of heterotrophic bacteria than in the sandy type of bottom deposits. Proteolytic bacteria and those liberating ammonia occurred in greater numbers in the muddy type of bottom deposits. Seasonal changes in the heterotrophic microflora content showed maximal numbers during the vegetative period in Jeziorak and minimal in winter. In Jeziorak Mały, as a result of irregular pollution of the basin with organic sewage maximal content of the heterotrophic microflora could be observed in different periods, also in winter.

#### 6. STRESZCZENIE

W latach 1960—1963 przeprowadzono badania mikrobiologiczne osadów dennych jezior iławskich (Jeziorak Mały i Jeziorak). Obejmowały one oznaczenie ilościowe mikroflory heterotroficznej biorącej udział w obiegu materii w zbiornikach wodnych. Stwierdzono, że w rozmieszczeniu mikroflory największe znaczenie ma charakter dna i zawartość substancji organicznej. W osadach mulistych zawartość bakterii heterotroficznych waha się od kilkuset tysięcy do kilku milionów komórek w 1 g suchej masy, na podłożu piaszczystym jest wielokrotnie mniejsza i wynosi od kilkuset komórek do kilkudziesięciu tysięcy w 1 g suchej masy. Różnice między liczebnością bakterii heterotroficznych tlenowych i beztlenowych poza nielicznymi wyjątkami były nieznaczne. Wśród mikroflory osadów dennych jezior iławskich występują także bakterie przetrwalnikujące oraz bakterie proteolityczne i amonifikacyjne rozkładające białka roślinne i zwierzęce m.in. z wydzieleniem amoniaku i siarkowodoru. Bakterie przetrwalnikujące występowały najliczniej w osadach mulistych, ale stanowiły one tam znacznie mniejszy procent bakterii heterotroficznych, aniżeli w osadach dennych o podłożu piaszczystym. Bakterie proteolityczne i amonifikacyjne występowały liczniej w osadach dennych typu mulistego. Sezonowe wahania mikroflory heterotroficznej wykazywały w jeziorze Jeziorak maksymalne ilości w okresie wegetacyjnym, minimalne zimą. W Jezioraku Małym wskutek nierównomiernego zanieczyszczania zbiornika ściekami pochodzenia organicznego mikroflora heterotroficzna występowała w ilościach maksymalnych w różnych okresach, niejednokrotnie także zimą.

#### 7. REFERENCES

- CVINC, V. 1960. Contribution à la connaissance du rôle des bactéries dans l'alimentation des larves de langouste (*Palinurus vulgaris* Latr.). *Rapp. P.-V. Réun. Comm. int. Explor. scient. Mer Méditerran.*, 25, 45—47.

- DUGGELI, M. 1936. Die Bakterienflora in Schlamm des Rotsees. *Z. Hydrol. Hydrogr. Hydrobiol.*, 7, 205—363.
- [ЕКЗЕРСЕВ, В. А.] ЭКЗЕРЦЕВ, В. А. 1948. Определение мощности микробиологически активного слоя иловых отложений некоторых озер. [Delimitation of microbiologically active layer of silt deposits of some lakes]. *Mikrobiologija*, 17, 476—483. (Russian).
- FISCHER, E. 1961. Próba charakterystyki mikrobiologicznej jednego z drobnych zbiorników okolic Warszawy w okresie zimowym. (Attempt of the microbiological characteristic of a small pond in Warsaw environs in winter season). *Pol. Arch. Hydrobiol.* 9, 319—347. (Engl. summ.).
- FOX, D. L., СОЕ, W. R. 1943. Biology of the California sea mussel (*Mytilus californianus*). II. — Nutrition metabolism, growth and calcium deposition. *J. exp. Zool.*, 93, 205—249.
- (ГАМВАРИАН, М. Е.) ГАМБАРЯН, М. Е. 1958. Ассимиляция молекулярного азота в воде и грунтах озера Севан. (Assimilation of molecular nitrogen in the water and grounds of the Sevan lake). *Mikrobiologija*, 27, 366—370. (Engl. summ.).
- HUTTON, W., ZOBELL, C. E. 1949. The occurrence and characteristics of methane-oxidizing bacteria in marine sediments. *J. Bact.*, 58, 467—473.
- (ІВАНОВ, М. В., ТЕРЕВКОВА, Л. С.) ІВАНОВ, М. В., ТЕРЕВКОВА, Л. С. 1959 а. Изучение микробиологических процессов образования сероводорода в Соленом озере. I. (A study of microbiological processes of hydrogen sulphide formation in the Solenoe lake. II.). *Mikrobiologija*, 28, 413—418. (Engl. summ.).
- (ІВАНОВ, М. В., ТЕРЕВКОВА, Л. С.) ІВАНОВ, М. В., ТЕРЕВКОВА, Л. С. 1959 б. Изучение микробиологических процессов образования сероводорода в Соленом озере. II. (A study of microbiological processes of hydrogen sulphide formation in the Solenoe lake. II.). *Mikrobiologija*, 28, 413—418. (Engl. summ.).
- (ЕГОРОВА, А. А.) ЕГОРОВА, А. А. 1951. Микробиологические исследования озера Беловодь. [Microbiological investigations of Belovod lake]. *Mikrobiologija*, 20, 103—112. (Russian).
- [КАЛИНЕНКО, В. О.] КАЛИНЕНКО, В. О. 1951. Бактерии и морские беспозвоночные животные. [Bacteria and marine invertebrates]. *Mikrobiologija*, 20, 320—323. (Russian).
- [КРИСС, А. Е.] КРИСС, А. Е. 1959. Морская микробиология (глубоководная). [Marine microbiology (deep-sea)]. Moskva, Izd. AN SSSR. (Russian).
- [КУЗНЕЦОВ, С. І.] КУЗНЕЦОВ, С. І. 1947. Распространение в озерах бактерий, окисляющих газообразные и жидкие углеводороды. [Expansion in lakes of bacteria oxidizing gaseous and liquid hydrocarbons]. *Mikrobiologija*, 16, 429—436. (Russian).
- [КУЗНЕЦОВ, С. І.] КУЗНЕЦОВ, С. І. 1951. Роль микроорганизмов в образовании сапроплевых отложений. [Role of microorganisms in formation of sapropel deposits]. *Mikrobiologija*, 20, 245—255. (Russian).
- [КУЗНЕЦОВ, С. І.] КУЗНЕЦОВ, С. І., 1952. Роль микроорганизмов в круговороте вещества в озерах. [Role of microorganisms in turnover of matter in lakes]. Moskva, Izd. AN SSSR. (Russian).
- LLOYD, B. 1931. Muds of the Clyde Sea area. II. — *J. Mar. biol. Ass. U. K.*, 17, 751—756.
- [МИШУСТИН, Е. Н.] МИШУСТИН, Е. Н. 1948. О роли спороносных бактерий в почвенных процессах. [Role of sporeforming bacteria in soil processes]. *Mikrobiologija*, 17, 201—207. (Russian).
- NIWOLAK, S. 1966 а. Ocena sanitarna wód powierzchniowych jezior ławskich w latach 1960—1963. (The sanitary evaluation of surface waters in Ława lakes in 1960—1963). *Zesz. nauk. WSR Olszt.*, 21, 99—110. (Engl. summ.).
- NIWOLAK, S. 1966 б. The microbiological character of Ława lakes in the years 1960—1963. I. — Some physico-chemical properties of water in Ława lakes. *Zesz. nauk. UMK., Nauki mat.-przyr.* 16. *Pr. St. Limnol. w Hawie*, No. 2, 33—54.
- [НИКИТИНА, Н. С.] НИКИТИНА, Н. С. 1955. Сезонные изменения бактериального состава грунтов литорали восточного Мурмана. [Seasonal variations of bacterial composition of litoral grounds of east Murman]. *Mikrobiologija*, 24, 580—588. (Russian).
- [ОСНИЦКАЯ, Л. К.] ОСНИЦКАЯ, Л. К. 1953. Распространение гнилостных, тионовокислых, метанооксиляющих и водородоксиляющих бактерий в грунтах северного Каспия. [Distribution of putrefactive, tionic, methane-oxidizing and

- hydrogen-oxidizing bacteria in grounds of north Caspian Sea]. *Mikrobiologija*, 22, 399—407. (Russian).
- REINHEIMER, G. 1960. Der Jahresrhythmus der Bakterienkeimzahl in der Elbe zwischen Schackenburg und Hamburg. *Arch. Mikrobiol.*, 35, 34—43.
- [RODINA, A. G.] РОДИНА, А. Г. 1949 а. Роль бактерий в питании личинок тендипедид. [Role of bacteria in feeding of Tendipedidae larvae]. *Dokl. Akad. Nauk SSSR.*, 67, 1121—1123. (Russian).
- [RODINA, A. G.] РОДИНА, А. Г. 1949 б. Бактерии как пища для пресноводных моллюсков. [Bacteria as food for freshwater mollusc]. *Mikrobiologija*, 17, 232—239. (Russian).
- [RODINA, A. G.] РОДИНА, А. Г. 1956. Методы микробиологического исследования водоемов. [Methods of microbiological investigations of water bodies]. In: V. N. Zadin (ed.) *Zizn presnych vod SSSR*, 4 (1), 7—121. Moskva, Izd. AN SSSR. (Russian).
- [ROMANOVA, A. P.] РОМАНОВА, А. П. 1963. Микробиологическая характеристика глубоководных грунтов южной части озера Байкал. [Microbiological characteristics of deep underwater grounds of south part of Baykal lake]. *Trudy limnol. Inst. Sibir. Otd.*, 2(22), čs. 2, 3—16. (Russian).
- [ROSENBERG, L. A., MEFEĐOVA, N. A.] РОЗЕНБЕРГ, Л. А., МЕФЕДОВА, Н. А. 1956. Взаимосвязь бактерий с химическим режимом и зоо-организмами в грунтах северо-западной части Тихого океана. [Interrelation of bacteria to chemical regime and zoo-organisms in grounds of north-west Pacific Ocean]. *Mikrobiologija*, 25, 61—65. (Russian).
- [ROSENBERG, L. A., MEFEĐOVA, N. A.] РОЗЕНБЕРГ, Л. А., МЕФЕДОВА, Н. А. 1958. Комплексное исследование грунтов северо-западной части Тихого океана. [A complex study of grounds of the north-western part of the Pacific Ocean]. *Mikrobiologija*, 27, 214—220. (Engl. summ.).
- [SALMANOV, M. A.] САЛМАНОВ, М. А. 1959. Микробиологическая характеристика Куйбышевского водохранилища. (Microbiological characteristics of the Kuybyshev reservoir). *Mikrobiologija*, 28, 557—564. (Engl. summ.).
- SEELEMAN, M., PAPAVALIOU, J., WEGENER, K. H. 1956. Die bakteriologische Beschaffenheit des Gebrauchswassers auf dem Bauernhof und ihre Bedeutung für die Reinigung und Desinfektion der Milchgeräte. *Kieler milchw. ForschBer.*, 3, 263—285.
- SISLER, D., ZOBELL, C. E. 1950. Hydrogen utilizing sulfate reducing bacteria in marine sediments. *J. Bact.*, 60, 747—756.
- STONE, R. W. 1946. Fermentation of organic acids by marine mud cultures. *J. Bact.*, 51, 600. (An abstract).
- [STURM, L. D., KANUNNIKOVA, Z. A.] ШТУРМ, Л. Д., КАНУНИКОВА, З. А. 1945. Распределение микроорганизмов в пресноводных иловых отложениях. [Distribution of microorganisms in freshwater silt deposits]. *Mikrobiologija*, 14, No. 4. (Russian).
- WAKSMAN, S. A. 1933. On the distribution of organic matter in the sea bottom and the chemical nature and origin of marine humus. *Soil Sci.*, 36, 125—147.
- [ZAVARZINA, N. B.] ЗАВАРЗИНА, Н. Б. 1955. Изучение причин, задерживающих развитие микроорганизмов в толще иловых отложений в оз. Бисерово. [Analysis of factors suppressing growth of microorganisms in silt deposits in Biserovo lake]. *Mikrobiologija*, 24, 573—579. (Russian).
- ZOBELL, C. E., ANDERSON, D. Q. 1936. Vertical distribution of bacteria in marine sediments. *Bull. Amer. Soc. Pet. Geol.*, 20, 258—268.
- ZOBELL, C. E., LANDON, W. A. 1937. Bacterial nutrition of the Californian mussel. *Proc. Soc. exp. Biol. med.*, 36, 607—609.
- ZOBELL, C. E., FELTHAM, C. B. 1938. Bacteria as food for certain marine invertebrates. *J. Mar. Res.*, 2, 312—327.
- ZOBELL, C. E. 1946. *Marine microbiology*. Waltham, Mass. Chronica Botanica Comp.
- ZOBELL, C. E., MORITA, R. Y. 1957. Barophilie bacteria in some deep sea sediments. *J. Bact.*, 73, 563—568.
- ZOBELL, C. E. 1962. Bacterial life at the bottom of the Philippine trench. *Science*, 115, 517—512.
- ZUKOWSKA, I. 1960. *Obserwacje nad fauną denną jeziora Jeziorak*. [Observations on bottom fauna of Jeziorak lake]. B. S. Thesis — Univ. M. Kopernik, Toruń. (Polish).

H. KLIMOWICZ

## OCCURRENCE OF ROTIFERS (ROTATORIA) IN SEWAGE PONDS

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## ABSTRACT

Fauna of rotifers occurring in sewage ponds has been examined. It has been ascertained that the amount of the rotifers and the number of their species depend upon the degree of cleaning of the sewages supplied to the ponds, and upon the annual seasons. The influence of the rotifers upon the oxygen balance in sewage ponds is thought to be the result of the swallowing of phytoplankton by the rotifers, and a consequence of the oxygen consumption necessary for their own physiological processes. A different number of rotifers found at the near-surface and bottom layers has been considered as well.

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## 1. INTRODUCTION

The method of sewage treatment in ponds was introduced in 1880 near Berlin, but only in the early twenties of this century several papers appeared, describing the results of studies on the sewage ponds. In a discussible article concerning the sewage treatment in ponds, KLIMOWICZ (1966) presented the results of studies gathered from 58 publications. First of all, the studies aimed at explaining the processes of the sewage treatment in ponds, whereas the organisms that participate in these processes have so far only scarcely been recognized from the systematic point of view.

It results from the publication by PASZEK and PASZEK (1966) that PRZYŁĘCKI was the first to propagate the idea of sewage treatment in Poland. He initiated a project of sewage treatment in the ponds situated in Cracow and in the south-western quarters of Warsaw. In Poland, the very researches made to explain the sewage treatment processes in ponds were initiated by BOŻKO, BITOWT, KALISZ, KRÓLIKOWSKI, LATOSZEK, RZECHOWSKA, SIDOR and SUCHECKA (1962), BITOWT-DRAPAŁA and KALISZOWA (1962), BOŻKO, KALISZ and SUCHECKA (1966). The authors mentioned above suggest that under climatic conditions of Poland, the sewage ponds can be considerable importance. These problems were elaborated also by AKSAMIT (1959), SZULICKA and GRENDEYSZ (1960), as well as by SUCHECKA (1961), CHOJNACKI (1962), GODZIK, KOTULSKI and SZCZYGIEL (1963).

In the world's literature we find only few publications, in which the individual species of rotifers and their total amount were taken into account when discussing the organisms dwelling in sewage ponds. The papers by ZAHAROV and KONSTANTINOVA (1929), or by UHLMANN (1958—1959) present some data on the occurrence of several species of rotifers in annual cycle. Information on the participation of rotifers in the sewage treatment processes in ponds are given in the paper by GALKOVSKAJA (1961) only.

## 2. OBJECT OF STUDY AND METHODS

The present study was made in three experimental ponds situated in an old channel of the river Warta, within a quarter of Częstochowa. The total area of the ponds was 1,2 ha, the maximum depth amounting to 120—140 cm, the breadth of the ponds from sewage supply pipes to the sewage draining pipes — as much as 25—40 m. Prior to the study, in the mid of October, water was completely removed from the ponds. The bottoms of the ponds were cleaned up,

Table I  
Species of rotifers ascertained at the time when sewage were brought down to ponds No. I and No. II (18.12.1965—8.7.1966); control pond No. III without sewages

Ordinal number	Name of species	No. of pond		
		I	II	III
1.	<i>Brachionus calyciflorus pala</i> (Ehrb.)	+++++	+++++	++++
2.	<i>Brachionus calyciflorus anuraeiformis</i> (Brehm)	+++++	+++++	+++
3.	<i>Brachionus rubens</i> Ehrb.	+++++	++++	+++
4.	<i>Brachionus angularis</i> Gosse	++++	++++	++++
5.	<i>Epiphanes senta</i> (Müller)	++++	++++	+++
6.	<i>Brachionus calyciflorus dorcas</i> Gosse	+++	+++	+++
7.	<i>Brachionus quadridentatus</i> Hermann	+++	+++	
8.	<i>Brachionus urceolaris</i> Müller	+++	+	
9.	<i>Filinia longiseta</i> Ehrb.	+++	+	+++
10.	<i>Rotaria rotatoria</i> (Pallas)	++	++	++
11.	<i>Philodina roseola</i> Ehrb.	++	+++	
12.	<i>Asplanchna priodonta</i> Gosse	+	+	+++
13.	<i>Cephalodella catellina</i> (Müller)	+	+	+
14.	<i>Euchlanis dilatata</i> Ehrb.	+	+	+
15.	<i>Rotaria neptunia</i> Ehrb.		+	+
16.	<i>Filinia passa</i> (Müller)		+	
17.	<i>Philodina megalotrocha</i>	+		
18.	<i>Encentrum mustela</i> (Milne)		+	
19.	<i>Polyarthra vulgaris</i> Carlin			++++
20.	<i>Filinia limnetica</i> (Zacharias)			++++
21.	<i>Brachionus calyciflorus dorcas spinosa</i> (Wierzejski)			++++
22.	<i>Synchaeta pectinata</i> Ehrb.			+
23.	<i>Lepadella patella</i> (Müller)			+
24.	<i>Keratella cochlearis</i> (Gosse)			+
25.	<i>Testudinella patina</i> (Hermann)			+
26.	<i>Cephalodella ventripes</i> (Dix.-Nut)			+
27.	<i>Filinia brachiata</i> (Rousselet)			+
28.	<i>Cephaladella gibba</i> (Ehrb.)			+
29.	<i>Notholca squamula</i> (Müller)			+

+ — sporadic occurrence, ++ — 5 to 10 individuals in 1 l., +++ — 10 to 100 individuals in 1 l., ++++ — 100 to 1000 individuals in 1 l., +++++ — 1000 to 43000 individuals in 1 l.

and two of them (No. I and II) were limed according to the fishery recommendations. The bottom of the control pond (No. III) was not limed, however, and no sewages were supplied during the research works. To pond No. I municipal sewages were brought down with a small amount (about 15%) of the industrial wastes which had previously been cleaned up mechanically on grating, sand trap and Imhoff's settling tank. To pond No. II were supplied sewages of the same collecting pipe. The sewages were previously cleaned mechanically and biologically by means of activated sludge in an installation of Inka and Kessener type.

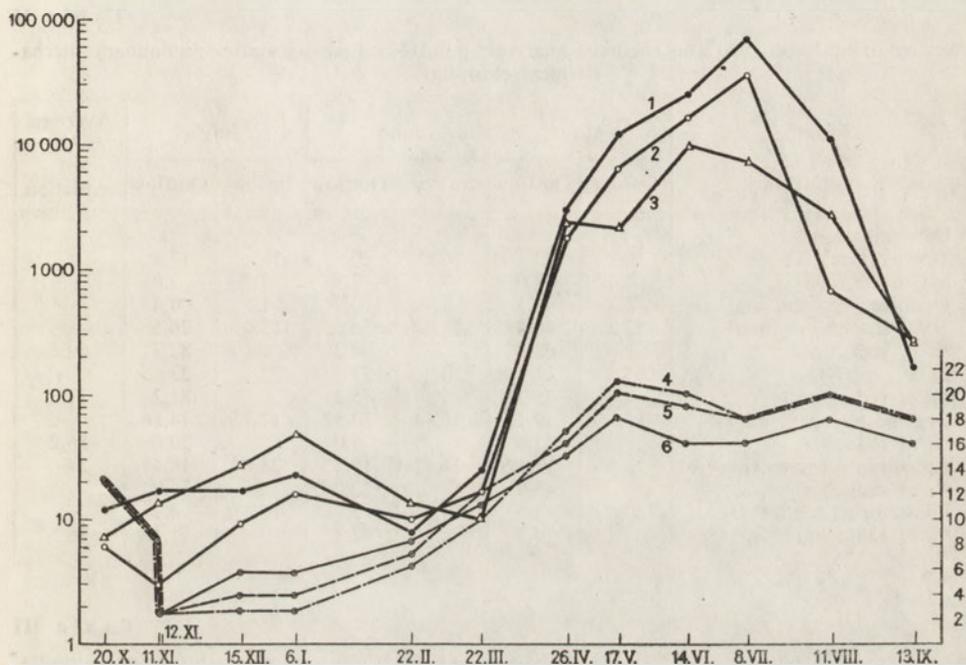


Fig. 1. Average amount of rotifers in annual cycle. The average amount of rotifers in the individual ponds is presented using logarithmic scale (number of individuals in 1 l). The average temperatures of water concern control pond No. III without sewages. The average temperatures of sewage were measured in ponds No. I and II close to the sewage supply and sewage draining pipes

1 — pond No. 1, number of Rotifers; 2 — pond No. 2, number of Rotifers; 3 — pond No. 3, number of Rotifers; 4 — temperature in the vicinity of effluent inflow pipes; 5 — temperature in the vicinity of effluent outflow pipes; 6 — temperature in the control pond

Samples were being taken, from September 1965 to October 1966, once a month at least. The following are points at which 4 samples were taken in the ponds filled in with sewages: 1 — neighbourhood of the sewage supply pipe; 2 — opposite shore near the draining pipe; 3 and 4 — central parts of the ponds — one at the surface layer and one at the bottom layer. Two samples were taken from the control pond — one at the surface layer and one at the bottom layer. The sampling was performed by means of a bailer of Patalas type, characterized by its 1 l capacity. The samples were then filtered through a mill gauze No. 25. The organisms found in each of the samples were computed separately (number of individuals in 1 l of water) in a 1 ml chamber equipped

with a scale for quantitative calculations. The average monthly frequency of rotifers for each pond is given in Figure 1. The materials collected were elaborated in the Laboratory of the Experimental Centre of the Institute of Communal Economy at the Municipal Enterprise for Water Supply and Sewage System in Częstochowa.

Tables II and III give the results of physical and chemical examinations of a water-sewage mixture from ponds No. I and II. The data are from a period of the proper exploitation of the ponds, begun after the starting period,

Table II

Average monthly physical and chemical analyses; pond No. I (sewages after preliminary mechanical cleaning)

Month	May		June		July		Average % of reduction
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	
Determination							
Temperature, °C	16	20	16	20	16	17.3	—
pH reaction	7.7	8.0	7.5	7.7	7.7	7.6	—
Dissolved oxygen, mg/l O <sub>2</sub>	1.7	1.5	2.8	0.0	1.5	0.4	—
Total suspension, mg/l	123.2	46.4	158.0	56.6	153.0	26.5	—
% of reduction		62.3		64.2		82.7	69.7
BOD <sub>5</sub> , mg/l O <sub>2</sub>	193	47	230	57	122	23	—
% of reduction		75.7		75.2		81.2	77.3
Organic nitrogen, mg/l N	11.76	9.1	21.84	20.52	17.75	14.16	—
% of reduction		22.6		6.0		20.0	16.2
Ammonia nitrogen, mg/l N	22.36	12.32	24.92	19.45	28.00	18.45	34
% of reduction		45.0		22.0		34.0	—
Phosphorus, mg/l P <sub>2</sub> O <sub>5</sub>	20.6	5.3	18.6	3.3	16.4	4.7	—
% of reduction		74.3		82.3		71.4	76

Table III

Average monthly physical and chemical analyses; pond No. II (sewages after a preliminary mechanical and biological cleaning in the arrangements of Inka and Kessener type)

Month	May		June		July		Average % of reduction
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	
Determination							
Temperature, °C	18	20	16	19.3	16	18	—
pH reaction	7.3	8.4	7.6	8.4	7.7	7.8	—
Dissolved oxygen, mg/l O <sub>2</sub>	4.5	8.7	4.8	6.2	2.5	5.2	—
Total suspension, mg/l	35.4	18.6	27.5	17.7	19.0	15.4	—
% of reduction		47.5		35.6		19.0	34
BOD <sub>5</sub> , mg/l O <sub>2</sub>	23	19	43	35	23	16	—
% of reduction		17.4		18.6		30	22
Organic nitrogen, mg/l N	9.52	4.5	10.28	5.14	12.64	7.43	—
% of reduction		53		50		41	48
Ammonia nitrogen, mg/l N	27.44	14.91	32.33	23.24	28.27	20.65	34
% of reduction		46		28		27	—
Phosphorus, mg/l P <sub>2</sub> O <sub>5</sub>	8.4	4.2	6.2	4.5	6.5	4.2	—
% of reduction		50		27		36	38

i.e. from May to July. At that time, sewages were regularly brought to the ponds. Samples for chemical analyses were taken 2—3 times a month near the sewage supply and the sewage draining pipes.

### 3. RESULTS

#### A. SEASONAL VARIATIONS OF ENVIRONMENTAL CONDITIONS AND OF ROTIFER FAUNA IN SEWAGE PONDS

Water percolated into the cleaned ponds through sandy bottom and through shores. In the first period, water level spontaneously rose, approximately 5 cm a day, up to the complete infilling of the ponds. The first samples for examinations were taken in the fourth day after the moment of cleaning and of liming the bottom. At that time, the depth of the ponds amounted to 20 cm. From both the quantitative and the qualitative points of view, all the ponds revealed a poor fauna of rotifers. The total amount of the individuals of all the species in the ponds reached approximately 10 in 1 l of water.

Over ten hours before the first snow fall (Oct. 11, 1955), a series of samples was performed. By night, snow covered the shores with a 14 cm mantle, and temperature dropped from 8 to 2,2°C. The day after, additional samples showed the lack of some representatives of the following species, which had occurred the day before: *Keratella quadrata*, *Polyartha vulgaris*, *Trichocerca rattus* and *Rotaria neptunia*. The snow fall could have eliminated only the individuals of the really occurring populations, since the representatives of the above species are found in the natural ponds all the year round.

On January 18, 1965, sewages were for the first time brought down to new-built ponds No. I and II. The first samples of the water-sewage mixture were taken 5 days later. The samples from ponds No. I and II differ from the previous ones mainly in having protozoa that appear in several ten thousands in 1 l. An abundant occurrence of these protozoa was ascertained nearby the sewage supply pipes only. At that time, the ponds were covered with a 4 cm primary ice layer, except for some small areas which amount to approximately 5 m<sup>2</sup>, close to the sewage supply pipes. Water temperature in the ponds nearby the sewage supply pipes ranged from 6.5 to 8.5°C, and that nearby the sewage draining pipes—from 3.5 to 4.5°C. In the control ponds, lacking sewages, water temperature under the ice cover ranged from 2 to 3,5°C.

In December, samples were taken also from under the ice cover. The amount of rotifers in the ponds with the sewages was similar to that in other series, whereas in the control pond it increased twofold. It is worthy to be stressed that the amount of rotifers nearby the sewage supply pipes was threefold greater than that nearby the sewage draining ones.

In January, a further increase was noted in the average amount of rotifers in the control ponds. In the ponds with the sewages, the number of rotifer representatives continuously increased, as well.

A week after the complete ice melting (February 22), the cleaned sewages could not flow out of the ponds due to an exceptionally high water level in the neighbour river. The river water flowed into the control pond through the pipes that connected it with the river. As compared with the previous series, the amount of rotifers decreased. Water temperature was from 6 to 8°C.

In the mid March, the water was a new removed completely from the ponds

and the bottoms were cleaned down and limed. A series of samples was taken in a period when water level in the ponds did not reach the sewage draining pipes. As compared with the previous series, the average amount of rotifers in the sewage ponds increased, whereas in the control pond it slightly decreased.

The samples taken from the sewage ponds in April contained merely few species of rotifers, but these occurred in large quantities. In the control pond, the amount of rotifers augmented more than 200 times, whereas in the sewage ponds — about 100 times only. In the samples of this series abundant algae were observed, which, in the samples of previous series, had appeared sporadically. In the sewage ponds, the amount of algae was considerably greater than that in the control pond. In this series, a quantitative differentiation of rotifers in both top and bottom layers was taken into account. Comparative observations were made at a depth of about 1.4 m. The species predominating in the sewage ponds, e.g. *Brachionus calyciflorus dorcasi*, *B. angularis* and *Rotaria rotatoria* were found to occur at the near-surface layers in a three-fold or fourfold greater amount than at the bottom. This can probably be related to the better insolation of these layers and to the concentration of a greater amount of the algae which serve as the main feed for these rotifers. An exception makes here the form *Epiphanes senta* found to occur rather at the bottom layers. This species is referred to the benthonic rotifers that, for the most part, dwell above the hard substratum, and reluctantly float upwards. The samples, in which the live individuals of *Epiphanes senta* were found in larger amounts, were more transparent and were lacking algae, protozoa and even floating particles of organic detritus. Hence, a conclusion may be drawn that the gluttonous *Epiphanes senta* individuals distinctly provide for the cleaning of the sewage ponds.

During a considerably hot period (May 17, 1965) water temperature on the pond surface was, at 12 o'clock, 21°C; at the bottom, at a depth of 1.4 m — 18°C; air temperature was 25°C. In the sewage ponds, the species *Brachionus angularis* and *B. quadrydentatus* were frequently found. A series of these samples disclosed a slightly larger amount of rotifers at the bottom layer. Pond No. II, filled in with the sewages cleaned up biologically, reveals an almost twofold poorer rotifer fauna than pond No. I filled in with the sewages cleaned up mechanically. In pond No. II, phytoplankton predominated, whereas in pond No. I — rotifer zooplankton.

In June, a considerable increase in the amount of rotifers was noted in all the ponds examined. In pond No. III, a marked development of the representatives of the group Copepoda was observed.

The largest amount of the rotifer representatives in the sewage ponds was ascertained in July, whereas in the control pond, where Copepoda predominated, the number of rotifers proved to be smaller than that in the previous month.

After a heavy rain and after the stopping of sewage supply into the ponds, pond No. I filled in with the sewages cleaned up only mechanically, was covered with a thick layer of duckweed, under which a strong smell of sulphuretted hydrogen could have been felt. Ponds No. II and III were not covered with the duckweed and did not emit any smell of sulphuretted hydrogen. In all the ponds, the amount of rotifers considerably decreased, and numerous Cladocera appeared in the sewage ponds for the first time during the examinations.

The samples taken in September showed a further decrease in the quantity

of rotifers in all the ponds in study. Pond No. I was continuously covered with the duckweed, and emitted smell of sulphuretted hydrogen. The smallest amount of rotifers was, in this case, ascertained in Pond No. I, which during the previous examinations was distinguished by the largest amount of these representatives of fauna.

Table I illustrates the comparison of qualitative and quantitative data concerning the occurrence of rotifers in sewage ponds No. I and II, as well as in the control pond.

Table I does not contain species, which were found only sporadically in the period, when no sewages were brought into the ponds, i.e. in October and November 1965, and in August and September 1966.

The following are species ascertained in pond No. I, but omitted in Table I: *Colurella bicuspidata* (EHRB.), *Keratella quadrata* (MÜLLER), *Eosphora najas* EHRB. and *Trichocerca rattus* (MÜLLER). In pond No. II were found the following species, omitted, however, in Table I: *Keratella quadrata*, *Rotaria tardigrada* (EHRB.), *Eosphora najas*, *Colurella bicuspidata*, *Monostyla closterocerca* (SCHMARDA), *M. hamata* (STOKES), *Lecane signifera ploenensis* (VOIGT) and *Dissotrocha macrostyla* (EHRB.). In pond No. III the following species were ascertained, omitted, however, in Table I: *Keratella quadrata*, *Lophocharis oxysternon* (GOSSE), *Dissotrocha aculeata* (EHRB.), *D. macrostyla* (EHRB.), *Rotaria tardigrada* and *Colurella colurus* (EHRB.).

The ponds foreseen for biological treatment of sewages may be referred to the extremely polytrophic water basins. From the trophic point of view, they make an excellent environment for the development of few species only, whereas most species, common in the natural astatic water basins, are eliminated from the ponds.

In pond No. I (Table II), where rotifers are most abundant, a considerable cleaning of sewages takes place due to the sedimentation of suspended matter, whose reduction reaches more than 70%, and due to the biochemical mineralization. This is proved by a high degree of  $BOD_5$  reduction. The processes are not finished, however, since a marked oxygen deficit is noted to appear in the pond. Consequently, in the ponds there begin nitrification processes, which do not end, as well. This is evidenced by a slight reduction in organic nitrogen, and by a higher one in ammonia. These processes require more oxygen, and the deficiency of this latter impedes their intensity and delays their termination.

The examinations made during this study illustrate that the pond is overloaded with the organic impurities, which cannot be mineralized, mainly due to the deficit in oxygen. To correct the real state, either the intensity of sewage supply should decrease, or the method of additional preliminary oxidizing of sewages should be applied.

In pond No. II (Table III), a slight reduction of total suspended matter was ascertained. This was caused owing to the presence of a considerable amount of fine, hardly falling suspension matter, as well as by a slight reduction of organic impurities, since the sewages cleaned biologically contain few organic substances, and this weakens the mineralization process of their remains. A marked reduction in organic nitrogen points to the decomposition processes of organic combinations of nitrogen, such as proteins or aminoacids. A large amount of ammonium salts does increase the intensity of the nitrification processes. These latter do not end, however, principally due to the great content of ammonium

salts, and a stable decomposition of nitrogen compounds. Oxidizing conditions in pond No. II are satisfactory and allow us to obtain interesting results in the treatment of the sewages previously cleaned up in the arrangements of Inka and Kessener type.

#### B. INFLUENCE OF ROTIFERS UPON THE PROCESS OF SEWAGE TREATMENT IN PONDS

The research works carried out by UHLMANN (1958—1959) have demonstrated that in the ponds intended for sewage treatment, the amount of rotifers reaches, during the warm seasons, up to several thousands of individuals in 1 l. GALKOVSKAJA (1961), who has investigated rotifers in similar ponds, states that the amount of individuals of only one species *Brachionus calyciflorus* may attain about 66 000 per 1 l of sewages. In pond No. I, i.e. in the pond richest in rotifers, the maximum amount of individuals of all the species of rotifers was 74 260 in 1 l in July; in pond No. II — 22 358 in July, and in control pond No. III — only 9099 in June, in 1 l of water. The amount of rotifers in the sewage ponds, considerably greater than that in the control pond (in the summer period), proves that the municipal sewages probably stimulate the development of the rotifers that belong here, however, to few species only. At the time, when ponds No. I and II were filled in with sewages (Table I), only 18 species were found to occur in them. In more considerable amounts were encountered only *Brachionus calyciflorus*, *B. calyciflorus anuraeiformis*, *B. urceolaris*, *B. rubens*, *B. angularis* and *Epiphanes senta*. These may here greatly affect the processes of sewage treatment. Such an abundance of rotifers was reported to appear only in warm period — from April to October. During the remaining, colder month, the rotifers occurred sporadically. Their occurrence in ponds No. I and II may have been conditioned by an excess of clear water in the mixture with sewages. UHLMANN (1958—1959) and GALKOVSKAJA (1961) did never find rotifers in winter, in the ponds filled in with the municipal sewages.

The sewages in the aerobic ponds are cleaned mainly owing to an abundant development of phytoplankton. Due to photosynthesis, the phytoplankton supplies water with oxygen, which enables a bacterial decomposition of organic substance found in the sewages. Rotifers that strongly develop in the sewage ponds belong to the species which feed on fine phytoplankton. A strong development of zooplankton, mainly of rotifers, in the ponds here examined, affected the amounts of phytoplankton. In pond No. I, where, during the warm season, the strongest development of rotifers was noted, water was always characterized by a colour lighter than that in pond No. II, where the fauna of rotifers was poorer. In the sewage ponds UHLMANN (1958—1959) observed a marked development of both phytoplankton and zooplankton that appeared in various periods. In the case of a notable occurrence of rotifers in the ponds, GALKOVSKAJA (1961) observed a simultaneous presence of phytoplankton. This latter was characterized, however, by greater sizes (*Pandorina*, *Eudorina*, *Euglena*). Thus, they could not have been swallowed by rotifers. This was a basis for her to draw a conclusion that in a sewage pond the rotifers decide upon the composition of phytoplankton species, too. She also informs that one individual of *Brachionus calyciflorus* swallows approximately 10 000 cells of *Chlorella pyrenoidosa* from a pure culture in one day. PENNINGTON (1941) has

proved in his experimental studies that one individual of *Brachionus calyciflorus* swallows about 48 200 representatives of the group Diogenes, in one day. Taking into account a fact that in pond No. I the maximum amount of rotifers was up to 74 260 individuals in 1 l, and that one individual swallows from 10 000 to 40 200 phytoplankton cells, we may calculate that the rotifers which occur in 1 l may consume from 742 600 000 to 3 579 332 000 green cells of phytoplankton in one day.

The experiments carried out by UHLMANN (1958—1959) showed that the oxygen curve continuously changed. The most considerable decrease of oxygen in ponds, from 0,2 to 0,1 mg/l, was noted at the time of the maximum growing of zooplankton. BELJACKAJA (1959) states that one representative of *Brachionus calyciflorus* does consume  $0,320 \cdot 10^{-5}$  mg oxygen in one hour, at a temperature of 20°C. Considering the fact that individuals of the other species of rotifers also consume approximately the same amounts of oxygen, we may calculate that the rotifers, which occur in 1 l, use during their maximum growth, about 5,7 mg oxygen in one day.

The maximum data, concerning the consumption of algae and of oxygen by rotifers, presented in this paper, illustrate a significant role in the process of sewage treatment, played by the rotifers during the summer seasons in the aerobic ponds. The previous literature, dealing with the theme here considered, was concentrated mainly on the oxygen consumption by the decomposing organic substances in the sewages. The results of the experiments presented in this paper, summed up with those of previous experiments, suggest that, during the determination of oxygen balance in sewage ponds, the consumption of oxygen by zooplankton should also be taken into account.

#### 4. CONCLUSIONS

The largest number of individuals, but the smallest amount of species have been found to occur in pond No. I with the sewages cleaned only mechanically (Table I). In pond No. II, filled in with the sewages previously cleaned up by mechanical and biological methods using activated sludge, besides the rich rotifer fauna, a high development of phytoplankton was ascertained. At the time, when the sewages were brought into the ponds, the greatest number of rotifer species was found in control pond No. III (Table III). The sewages flowing out of the pond No. II were well cleaned up mainly due to the previous cleaning with the aid of activated sludge. The sewages from pond No. I (cleaned previously only mechanically) flowed off, revealing the deficit of oxygen, in spite of the fact that in this pond they were markedly cleaned up. A considerable development of duckweed (*Lemna*) is responsible for the deficit of oxygen in ponds, and for the decrease in the amount of rotifers. In the spring time, a greater occurrence of rotifers, except for the species *Epiphanes senta*, could have been ascertained at the surface layer of water.

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## 5. SUMMARY

Studies on rotifer fauna were conducted in an annual cycle in ponds filled in with municipal sewages. The largest amount of individuals and the lowest quantity of species have been found to occur in the pond filled in with the sewages cleaned up only mechanically, i.e. with the aid of grating, sand trap and Imhoff's settling tank. In the pond previously cleaned up by both mechanical and biological methods using activated sludge in the arrangements of Inka and Kessener type, the rich rotifer fauna was accompanied by a considerably developed phytoplankton. From spring to the summer end, a gradual increase in the amount of rotifers can be observed. In winter they occur here sporadically. In warm seasons, in turn, the development of rotifers greatly affects the oxygen balance, mainly due to the swallowing of phytoplankton by the rotifers and due to the oxygen consumption, necessary to hold up their physiological processes. At a depth of 140 cm, a distinct differentiation in the amounts of rotifers can be observed between the near-surface and bottom layers.

## 6. STRESZCZENIE

Wprowadzono w cyklu rocznym badania fauny wrotków w stawach dopełnianych ściekami komunalnymi. Największą liczbę osobników a najmniej gatunków stwierdzono w stawie napełnianym ściekami oczyszczonymi jedynie mechanicznie — kratą, piaskownik i osadnik Imhoffa. W stawie ze ściekami oczyszczonymi poprzednio mechanicznie i biologicznie za pomocą osadu czynnego w urządzeniach Inka i Kessenera obok bogatej fauny wrotków stwierdzono najbogatszy rozwój fitoplanktonu. Od wiosny do końca lata dostrzega się stopniowy wzrost liczebności wrotków, które w zimie występują tu sporadycznie. Rozwój wrotków wywiera poważny wpływ w cieplej porze roku na bilans tlenowy poprzez wyjadanie fitoplanktonu i zużywanie tlenu na własne procesy fizjologiczne. Przy głębokości 140 cm dostrzega się wyraźne zróżnicowanie liczebności wrotków pomiędzy warstwami powierzchniowymi i przydennymi.

## REFERENCES

- AKSAMIT, I. 1959. Stawy ściekowe. [Sewage ponds]. *Gaz Woda Tech. sanit.*, 1959, No. 7, 426—429. (Polish).
- [BELJASKAJA, JU. S.] БЕЛЯЦКАЯ, Ю. С. 1959. Применение поплавкового микро-респирометра к измерению газообмена у планктонных животных. [Application of flowing microrespirometer in measurements of respiration in planktonic animals]. *Dokl. Akad. Nauk. Beloruss. SSR*, 7, 315—317. (Russian).
- BOZKO, L., BITOWT, J., KALISZ, L., KRÓLIKOWSKI, W., LATOSZEK, A., RZECHOWSKA, E., SIDOR, C., SUCHECKA, T. 1962. Stawy ściekowe na terenie oczyszczalni ścieków w Kielcach. [Sewage ponds in sewage treatment plant in Kielce]. *Mat. V Konf. naukowo-techn.* Katowice. (Polish).
- BOZKO, L., KALISZ, L., SUCHECKA, T. 1966. Stawy biologiczne jako trzeci stopień oczyszczania ścieków. [Ponds as third degree of sewage purification]. *Gaz Woda Tech. sanit.*, 1966, No. 6, 201—202. (Polish).
- СНОЖНАСКИ, А. 1962. Очyszczanie ścieków w stawach stabilizacyjnych. [Sewage purification in stabilization ponds]. *Gospod. wodna*, 22, 437—439. (Polish).
- [ГАЛКОВСКАЯ, Г. А.] ГАЛКОВСКАЯ, Г. А. 1961. Видовой состав, количественное развитие и участие коловраток в самоочищении воды в биологических прудах. [Species composition, quantitative development, and role of rotifers in self-purification of water in biological running waters]. In: *Očistka stočnyh vod v biologičeskich prudah*, p. 113—118. Minsk. (Russian).
- GODZIK, S., KOTULSKI, B., SZCZYGIEL, P. 1963. Badania nad oczyszczaniem ścieków Zakładów Chemicznych „Oświęcim” metodą stawów ściekowych. [Investigations on purification on chemical plant sewage „Oświęcim” using plant sewage]. *Gaz Woda Tech. sanit.*, 1963, No. 1, 19—24. (Polish).

- KLIMOWICZ, H. 1966. Przegląd piśmiennictwa o oczyszczaniu ścieków w stawach biologicznych. [Review of literature on sewage purification in biological ponds]. *Prz. inform. Inst. Gosp. Komun., Wodociągi i kanalizacja*, 1966, No. 2, 5—17. (Polish).
- PASZEK, B., PASZEK, F. 1966. Oczyszczanie i unieszkodliwianie ścieków w stawach. [Purification and neutralization of sewage in ponds]. *Biul. techn. MGK*, 1966, 45—64. (Polish).
- PENNINGTON, W. 1941. The control of the numbers of fresh-water phytoplankton by small invertebrate animals. *J. Ecol.*, 29, 204—211.
- SUCHECKA, T. 1961. Oczyszczanie ścieków bytowych z małych osiedli przy zastosowaniu stawów utleniających. [Purification of communal sewage from small localities using oxidizing ponds]. *Gaz Woda Tech. sanit.*, 1961, No. 12, 446—447. (Polish).
- SUCHECKA T. 1965. Wpływ glonów na oznaczanie biochemicznego zapotrzebowania tlenu. [The influence of algae on measurement of biochemical oxygen demand]. *Gaz Woda Tech. sanit.*, 1965, No. 9, 305—307. (Polish).
- SUCHECKA, T., BITOWT-DRAPAŁA, J., KALISZ, J. 1962. Oczyszczanie ścieków w stawach biologicznych. [Sewage purification in biological ponds]. *Prz. inform. Inst. Gosp. Komun., Wodociągi i kanalizacja*, 1962, No. 3, 5—33. (Polish).
- SZULICKA, J., GRENDYSZ, J. 1960. Wpływ przetrzymywania ścieków z fabryki suchej destylacji drewna w stawach na unieszkodliwianie ścieków. [The effect of keeping wood distillation plant sewage in ponds on its neutralization]. *Gaz Woda Tech. sanit.*, 1960, No. 9, 346. (Polish).
- UHLMANN, D. 1958/59. Untersuchungen über die biologische Selbstreinigung häslichen Abwasser in Teichen. *Wiss. Z. Karl-Marx-Univ. Lpz*, 8, 17—66.
- [ЗАХАРОВ, N. G., КОНСТАНТИНОВА, E. F.] ЗАХАРОВ, Н. Г., КОНСТАНТИНОВА, Е. Ф. 1929. Очистительные пруды Люблинских полей фильтрации в 1919—1920 гг. [Purification waters in filtrating grounds at Lublinsk in the years 1919—1920]. *Trudy sovešč. po očistke stočnyh vod*, 11, 1—124. (Russian).



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## ESPÈCES RARES ET INTÉRESSANTES DE ROTIFÈRES DES LACS SOSNOWICKIE

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### ABSTRACT

Des recherches effectuées en 1961—1963 sur la faune et l'écologie des rotifères des lacs Sosnowickie ont permis de constater la présence de 137 espèces, dont 35 ont été jugées rares pour la faune de Pologne (tab. 1) Le travail présent contient la revue de ces espèces et rapporte quelques données concernant leur écologie et leur répartition en Pologne.

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### 1. INTRODUCTION

Les lacs Sosnowickie sont situés dans la partie nord du complexe de lacs Łęczyńsko-Włodawskie. Les lacs Sosnowickie se composent de trois lacs d'une assez faible étendue: le lac Białe 144,4 ha de superficie et d'une profondeur maximale de 2,7 m, le lac Białskie — 31,7 ha de superficie et 18,2 m de profondeur maximale et le lac Czarne — 34,0 ha de superficie et 15,6 m de profondeur. Des études sur les espèces Rotatoria et leur écologie y ont été effectuées à partir de l'automne 1961 jusqu'à l'hiver 1963. Ces lacs se sont avérés très riches en rotifères car dans les matériaux obtenus on a pu constater la présence de 137 formes appartenant à cette classe. 35 de ces formes furent jugées rares et intéressantes pour la faune des lacs Sosnowickie. Le travail présent contient une description détaillée de ces formes ainsi que des données sur leur écologie et leur répartition en Pologne.

### 2. REVUE SYSTÉMATIQUE DES ROTIFÈRES RARES DES LACS SOSNOWICKIE

La description systématique de ces formes et espèces a été effectuée selon le système de REMANE 1933 tout en tenant compte des remarques de PAWŁOWSKI (1958) sur la valeur taxonomique de certains groupes.

*Familia: Notommatidae*

*Subfamilia: Notommatinae*

1. *Cephalodella delicata* WULFERT, 1937. Espèces rare, trouvée jusqu'à présent en Allemagne dans de la vase de la rivière Saale ainsi que dans des fossés et des tourbières (WULFERT 1939), en Moravie dans des rivières et des flaques d'eau DONNER 1954, en Autriche dans le Danube près de Vienne (DONNER 1954) et en Roumanie dans le delta du Danube (RUDESCU 1960).

En Pologne cette espèce ne fut constatée qu'à Ciechocinek en petites quantités dans une flaque d'eau saumâtre (WULFERT 1943). Un exemplaire de cette espèce fut trouvé en juin 1963 dans un échantillon prélevé parmi des roseaux du littoral du lac Czarne.

2. *Cephalodella obvia* DONNER, 1950. Forme très rare, trouvée uniquement par DONNER (1950, 1954) dans la vase de la rivière Dyja et dans des bras des rivières en Moravie du Sud. Ses exigences écologiques ne sont pas connues. En Pologne elle fut notée par PAWŁOWSKI (1958) dans le vieux lit de la rivière Grabia.

Quelques exemplaires de cette espèce furent trouvés dans la zone pélagique du lac Białe en octobre 1961.

3. *Cephalodella sterea minor* DONNER, 1950. Constatée par DONNER (1950) en Moravie du sud.

Elle fut trouvée en Pologne par PAWŁOWSKI (1958) dans un prélèvement effectué en mai dans la rivière Grabia.

Cette espèce fut constatée en juin 1962 dans la zone littorale du lac Czarne.

4. *Cephalodella sterea mutata* DONNER, 1950. Comme l'espèce précédente elle fut décrite également par Donner qui la trouva dans la rivière Dyja en Moravie du Sud.

Notée en Pologne par PAWŁOWSKI (1958) en octobre dans la rivière Pyszna.

Elle fut constatée en faible quantité en avril, août et novembre uniquement dans le littoral des lacs étudiés.

*Subfamilia: Proalinae*

5. *Proales minima* (MONTET 1915). Espèce bryophyle et rare, trouvée aux USA parmi des sphaignes dans des mares (HARRING et MYERS 1922). D'après WISZNIEWSKI 1954 c'est un psammophyle typique, caractéristique pour l'hydropsammon des rivières et l'hygropsammon des plages pures alcaliques (pH 6,8—7,5).

Sa présence ne fut constatée que dans quelques pays d'Europe ainsi qu'en Amérique du Nord.

Notée par WISZNIEWSKI (1934, 1936) dans la région de Suwałki dans la Vistule et la Bug ainsi que par KLIMOWICZ (1964) dans le littoral du lac Kiszajno en Mazurie.

Le seul exemplaire de cette espèce fut constaté dans un échantillon prélevé en octobre 1962 dans la végétation littorale du lac Czarne.

6. *Proales sordida* (GOSSE 1886). La position systématique de cette espèce fut élucidée par WULFERT (1939) qui démontra que le rotifère mentionné par HARRING et MYERS (1922) sous le nom de *Proales sordida* Gosse appartenait

à l'espèce *Proales fallaciosa* WULFERT. Cet auteur donna une nouvelle diagnose pour *Proales sordida* qu'il appela *Proales sordida vera* (GOSSE). Les dessins et les descriptions compris dans les travaux de VOIGT (1956/1957) et de BARTOS (1959), concernant la même espèce, sont en accord avec ceux de WULFERT.

Cette espèce est fréquente en Europe, elle fut notée également au Java et au Panama. Elle vit parmi la végétation littorale des mares (VOIGT 1956/1957 WULFERT 1939).

Rare en Pologne, constatée jusqu'à présent dans des mares des environs de Cracovie (WIERZEJSKI 1893) ainsi que dans des eaux non précisées des environs de Varsovie (WISZNIEWSKI 1954).

#### *Subfamilia: Tetrastiphoninae*

7. *Tetrastiphon hydrocora* EHRENBERG, 1840. HERRING et MYERS (1922) la considèrent comme une espèce rare qui démontre un penchant pour les eaux légèrement acides. Notée également dans des étangs et dans la vase léculaire (VOIGT 1956/1957). Trouvée aussi en Suède, Angleterre, Allemagne et aux USA.

En Pologne elle ne fut notée que dans des mares de Poméranie (LUCKS 1912).

Un exemplaire de cette espèce fut trouvé en novembre 1962 parmi les plantes des parties littorales du lac Czarne voisines à une tourbière appelée „Marais noir”.

#### *Familia: Lindiidae*

8. *Lindia pallida* HARRING et MYERS, 1922. Forme rare trouvée en Allemagne (VOIGT 1956/1957), Italie et en Amérique du Nord (HARRING et MYERS 1922).

Trouvée jusqu'à présent en Pologne par deux auteurs. WISZNIEWSKI (1954) trouva quelques exemplaires dans une mare tourbeuse des environs de Varsovie, PAWŁOWSKI (1958) constata la présence de cette espèce dans l'hygrosum des rivières Grabia et Oleśnica ainsi que dans des mares situées dans le voisinage de ces rivières.

Un exemplaire de cette espèce fut trouvé dans la zone littorale du lac Czarne en juin 1962.

#### *Familia: Trichocercidae*

9. *Elosa spinifera* WISZNIEWSKI, 1932. Décrite par WISZNIEWSKI (1932) qui constata la présence de cette espèce dans le psammon des lacs Wigry. En dehors de la Pologne cette espèce n'est connue qu'en Union Soviétique, en Suède et en Amérique du Nord (VOIGT 1956/1957) où elle habite des plages pures et alcaliques.

Quelques exemplaires de cette espèce furent trouvés dans des échantillons prélevés dans la zone littorale des lacs Bialskie et Czarne en mai et juin 1963.

*Familia: Asplanchnidae*

10. *Harringia eupeda* (GOSSE 1887). Très rare, en Europe notée en Angleterre, France, URSS et Allemagne (JAKUBSKI 1918/1919, PAWŁOWSKI 1958, VOIGT 1956/1957).

En Pologne sa présence ne fut constatée que dans un petit étang des environs de Cracovie (WIERZEJSKI 1893) et dans la rivière Grabia (PAWŁOWSKI 1958).

Un exemplaire de cette espèce fut noté dans un échantillon prélevé en novembre 1962 dans la zone du lac Czarne.

*Familia: Synchaetidae*

11. *Polyarthra dolichoptera aptera* — (HOOD 1893). Syn. *Anarthra aptera* (HOOD 1895), *Polyarthra aptera* VOIGT 1904, *Polyarthra trigla aptera* Olofsson, 1918.

D'après NIPKOW (1952) c'est une forme appartenant au plancton. Reconnue dans des lacs en Suisse en octobre et durant la période hiverno-printanière.

En Pologne notée par MINKIEWICZ (1914) dans des lacs des montagnes Tatra, par WISZNIEWSKI (1954) dans des eaux non précisées des environs de Varsovie ainsi que par HILLBRICHT (1964) dans des étangs à Żabieniec près de Varsovie.

Quelques exemplaires de cette espèce furent trouvés dans un échantillon prélevé en janvier 1962 dans le pélagial du lac Białe.

*Familia: Brachionidae**Subfamilia: Epiphaniinae*

12. *Epiphanes brachionus* (EHRENBERG 1837). Ce rotifère est connu dans de nombreux pays d'Europe ainsi qu'en Afrique du Sud et en Nouvelle-Zélande. Il se trouve en général dans des eaux marécageuses, des étangs et des mares. KOZAR (1914) le considère comme forme estivale.

En Pologne il fut mentionné par WISZNIEWSKI (1954) qui le trouva dans des eaux non précisées des environs de Wigry et de Varsovie.

Il fut trouvé dans le lac Białskie près de la rive couverte d'une végétation abondante de *Phragmites communis* Trin. Des exemplaires isolés de cette espèce furent notés en avril 1962 durant la floraison d'*Oscillatoria agardhii* Gom.

13. *Cyrtonia tuba* (EHRENBERG 1834). Espèce rare, en dehors de quelques pays d'Europe elle ne fut trouvée qu'aux USA et en Afrique du Sud. D'après WISZNIEWSKI (1954) cette espèce appartient à l'héléoplancton.

En Pologne elle fut notée par PAWŁOWSKI (1958) en juillet et septembre dans les affluents de la rive droite de la rivière Grabia et, en grandes quantités, dans une turbière; CZAPIK (1958) trouva également cette espèce en octobre dans une mare des environs de Cracovie.

Des exemplaires isolés de cette espèce furent constatés dans un échantillon prélevé en septembre 1962 dans le littoral du lac Białskie.

14. *Rhinoglena frontalis* EHRENBERG, 1833. Peu fréquente, connue dans de nombreux pays d'Europe et en Nouvelle-Zélande. Forme printanière, caractéristique pour le plancton des rivières, plus rare dans les étangs (RYŁOW 1935).

En Pologne ce rotifère fut trouvé dans des mares de Poznanie (BLOEDORN 1912) dans des mares environs de Varsovie (WISZNIEWSKI 1954), de Cracovie (CZAPIK 1958), ainsi que dans la rivière Grabia (PAWŁOWSKI 1958). Il fut repéré en exemplaires isolés en avril 1962 dans le pélagial du lac Czarne et en novembre parmi les plantes de la zone littorale des lacs Bialskie et Czarne.

*Subfamilia: Brachioninae*

15. *Platygias quadricornis pentagona* WULFERT, 1956. Espèce distinguée par WULFERT en 1956 dans des échantillons prélevés dans des lacs des environs de Berlin. Comme le remarque PAWŁOWSKI (1958), un dessin de cette espèce avait déjà été publié par AHLSTROM (1940).

La présence de cette espèce en Pologne fut établie par PAWŁOWSKI (1958) dans le bassin de la rivière Grabia entre juin et septembre. Une petite quantité de ce rotifère fut constatée dans le pélagial et le littoral du lac Bialskie.

16. *Keratella hiemalis* CARLIN, 1943. Espèce distinguée par CARLIN (1943) qui la trouva dans la rivière Motala en Suède et la considéra comme appartenant au plancton hivernal. HAUER (1952) affirme que cette espèce est présente dans certains lacs profonds durant toute l'année et qu'elle passe les mois chauds dans l'hypolimnion. Elle est également connue en Tchécoslovaquie, en Autriche et en Roumanie (BARTCS 1959, RUDESCU 1950).

Ce rotifère fut constaté pour la première fois en Pologne par PAWŁOWSKI (1960) dans la rivière Grabia près de la localité Kozuby. Il fut constaté dans les lacs Sosnowickie pendant toute l'année, aussi bien dans le littoral que le pélagial, mais plus fréquemment dans le plancton hiverno-printanier (I—VI). En été et en automne il n'apparaissait qu'en petites quantités. Ce rotifère était rare dans le lac Białe, on n'y trouva que quatre fois des exemplaires isolés dans des échantillons prélevés en février, avril, mai et décembre.

*Subfamilia: Euchlaninae*

17. *Euchlanis calpidia* MYERS, 1930. En Europe cette espèce ne fut notée que dans quelques lieux en Allemagne (HAUER 1936, VOIGT 1956/1957, WULFERT 1939) dans des lacs, des flaques d'eau et des eaux marécageuses. En Amérique du Nord elle est assez fréquente dans les eaux au pH inférieur à 7 (MYERS 1930). Rare en Pologne elle ne fut mentionnée jusqu'à présent que par WISZNIEWSKI (1954) qui la repéra dans des mares des environs de Wigry et par PAWŁOWSKI (1958) dans la rivière Grabia. Dans le terrain étudié cette espèce n'était présente qu'en petit nombre, uniquement dans les parties littorales des lacs. Bialskie et Czarne en mai, juillet et novembre.

18. *Euchlanis lucksiana* HAUER, 1930. Constaté en Allemagne et en Tchécoslovaquie (BARTCS 1959) il est caractéristique pour la zone limnétique des grands lacs (HAUER 1931).

Noté en Pologne seulement par Luck (1931, 1934) dans des lacs de la Poméranie.

Ce rotifère fut trouvé en petit nombre uniquement dans le pélagial des lacs Bialskie et Czarne à partir du mois de mai jusqu'au mois de septembre. Sa présence était accompagnée en général de floraisons d'*Oscillatoria agardhii* Gom. et de *Ceratium hirundinella* (O. F. MULLER).

19. *Euchlanis lyra* HUDSON, 1886. Espèce assez fréquente, notée entre autres aux Etats Unis, en Allemagne, en France (MYERS 1930) et en Suisse (BIRNER 1931). Elle demeure dans les zones littorales abondantes en végétation de différents bassins aquatiques.

Ce rotifère est rare en Pologne. Il ne fut mentionné que par WISZNIEWSKI (1954) qui le trouva dans des eaux non précisées des environs de Wigry et par KLIMOWICZ (1964) qui le détecta dans le littoral du lac Kisajno.

Quant aux lacs Sosnowickie il n'y fut trouvé que dans le littoral. Il apparaissait en général en petit nombre pendant deux périodes de l'année — de mars à juin et de septembre à novembre, démontrant un maximum en mai et un autre en octobre et novembre.

20. *Euchlanis meneta* MYERS, 1930 syn. *Euchlanis oropha* LUCKS, 1912. Mentionné pour l'Europe en Angleterre, Suède, Allemagne, Tchécoslovaquie, il fut également noté en Amérique du Nord, en Nouvelle-Zélande et en Inde. Il vit parmi les plantes aquatiques des lacs (HAUER 1952, MYERS 1931, VOIGT 1956/1957) dans des tourbières, des mares (WULFERT 1940, MYERS 1931) ainsi que dans le psammon et la vase du fond des lacs (KOSTE 1962).

Rare en Pologne, cette espèce y fut repérée par LUCKS (1912) dans des tourbières forestières des environs de Gdańsk, par MICHALSKI, GABAŃSKI et KULMATYCKI (1936) dans la rivière Brda aux environs de Bydgoszcz ainsi que par HILLBRICHT-ILKOWSKA (1964) dans des étangs de Żabieniec près de Varsovie. Des exemplaires isolés de cette espèce furent trouvés dans un échantillon prélevé en juillet 1963 dans le littoral du lac Czarne.

21. *Mytilina mucronata spinigera* (EHRENBERG 1932). Espèce trouvée en Europe, en Inde, au Ceylan et au Panama. Elle habite le littoral couvert de végétation de différents bassins aquatiques (VOIGT 1956/1957) et les rivières (PAWŁOWSKI 1958).

Détectée en Pologne par LUCKS (1912) dans des mares de Poméranie, par BLOEDORN (1912) dans des mares de Poznanie ainsi que par PAWŁOWSKI (1958) dans la rivière Grabia (voïvodie de Łódź).

Dans les lacs étudiés ce rotifère était assez fréquent mais n'apparaissait qu'en petit nombre de mai en juin ainsi que d'août à novembre, uniquement dans la zone littorale couverte abondamment de végétation aquatique.

#### Subfamilia: Colurinae

22. *Lepadella quadricarinata* (STENROOS 1898). Mentionnée en Finlande, Allemagne, Tchécoslovaquie, Norvège, Suède, au Svalbard et aux USA (BARTCS 1959), cette espèce vit parmi la végétation de différentes eaux continentales ou maritimes (DONNER 1964).

En Pologne elle ne fut trouvée que par LUCKS (1912) dans des lacs de Poméranie et dans la Vistule.

Une petite quantité de ce rotifère fut constatée en août 1962 dans le littoral du lac Czarne.

## Subfamilia: Lecaninae

23. *Lecane lauterborni* HAUER, 1924. Cette espèce, trouvée en Allemagne, URSS, Tchécoslovaquie, et aux USA, vit sur de la sphaigne (HAUER 1924, PAWŁOWSKI 1938).

En Pologne elle ne fut notée que par PAWŁOWSKI (1938) dans des échantillons prélevés en avril sur de la sphaigne de mares des environs de Pabianice. Un petit nombre de ces rotifères fut observé en août et en décembre 1963 dans la zone littorale du lac Bialskie.

24. *Lecane ludwigi* (ECKSTEIN 1883). Cette espèce se manifeste dans le monde entier mais toujours en petits nombres (HARRING et MYERS 1926, VOIGT 1956/1957). Elle vit parmi les plantes de la zone littorale de différents bassins aquatiques. Elle fut également trouvée dans des échantillons prélevés du fond des bassins entre avril et janvier.

Ce rotifère, rare en Pologne, fut noté par WIERZEJSKI (1893) et CZAPIK (1958) dans des mares des environs de Cracovie, par KYSEŁOWA (1966) dans des étangs de Haute-Silésie, par BLOEDORN (1912) dans des étangs de Poznań, par KULAMOWICZ (1956) dans les étangs Żeromińskie près de Łódź et enfin par PAWŁOWSKI (1958) dans les rivières Oleśnica et Grabia.

Des exemplaires isolés de cette espèce furent pêchés en janvier et février 1963 dans le littoral des lacs Bialskie et Czarne.

25. *Lecane mira* (MURRAY 1913). Rotifère rare, noté aux USA, en Allemagne, Suède et Tchécoslovaquie (BARTCS 1959, VOIGT 1956/1957). D'après HARRING MYERS (1926) il se trouve dans les étangs aux eaux acides ou neutres, tandis que VOIGT (1955/1957) le considère comme caractéristique pour les tourbières et le littoral couvert de végétation des lacs. Il fut également constaté dans le psammon et le plancton des rivières (WISZNIEWSKI 1936, 1954).

Cette espèce est rare en Pologne, notée en tant que psammoxène dans des lacs des Tatras (WISZNIEWSKI 1936) et dans la rivière Grabia (PAWŁOWSKI 1958).

Des exemplaires isolés de cette espèce furent trouvés de mai en novembre dans le littoral des lacs Białe et Bialskie.

26. *Lecane stichea* HARRING 1913, syn.-*L. methoria* HARRING et MYERS, 1926; *Lecane stichaeoides* HAUER, 1938.

D'après HAUER (1958) ce rotifère est connu en Allemagne, Belgique, Hollande, Suède, URSS, Hongrie, Tchécoslovaquie, Espagne et Amérique du Nord. C'est une forme bryophyle habitant les étangs et les fossés, considérée comme acidophile par GRAAF (1956). On la rencontre aussi dans des thermes et des sources naturelles (VOIGT 1956/1957).

Notée en Pologne par Bryce (WISZNIEWSKI 1954) dans la mousse aux environs de Wigry.

Peu fréquent dans les lacs Sosnowickie, ce rotifère s'y trouvait en faibles quantités dans la végétation de la zone littorale. Dans les lacs Czarne et Bialskie il fut noté en novembre 1963 et dans le lac Białe en mars de la même année.

27. *Lecane subtilis* HARRING et MYERS 1926. Rotifère rare, détecté en Allemagne, Suède et URSS, au Sumatra et au Java, il vit dans la zone littorale des lacs (HARRING et MYERS 1926) ainsi que dans les tourbières (VOIGT 1956/1957).

En Pologne il ne fut trouvé que dans les environs de Pabianice (PAWŁOWSKI 1938) dans une mare couverte de *Sphagnum* sp.

28. *Monostyla pygmaea* DADAY, 1897. Cette espèce typiquement bryophyle est assez fréquente aux USA (HARRING et MYERS 1926). Elle est aussi connue au

Japon, en Nouvelle-Zélande et dans plusieurs pays européens. WULFERT (1942) constata sa présence dans des sources minérales.

Elle fut trouvée en Pologne par PAWŁOWSKI (1938) dans les environs de Wigry, dans la forêt de Białowieża et dans les lacs des Tatras.

Ce rotifère fut constaté en petit nombre en septembre 1962 parmi la végétation immergée du littoral du lac Bialskie.

29. *Monostyla scutata* HARRING et MYERS, 1926. D'après HARRING et MYERS (1926) c'est une espèce extrêmement rare, présente en faible quantité dans des lacs des USA. Elle fut notée également en Allemagne, Suède, Tchécoslovaquie et URSS en général en tant que forme bryophyle (HAUER 1931, VOIGT 1956/1957).

Sa présence en Pologne fut constatée par WISZNIEWSKI (1934) dans le psammon des lacs de Wigry et dans la rivière Bug, par KULAMOWICZ (1956) dans les étangs Żeromińskie près de Łódź ainsi que par PAWŁOWSKI (1958) dans le psammon de la rivière Grabia et dans des mares avoisinantes.

Une petite quantité de ces rotifères fut trouvée dans deux échantillons provenant de la zone littorale du lac Bialskie, l'un d'octobre 1962, l'autre de juin 1963.

30. *Monostyla stenroosi* MEISSNER, 1908. Assez fréquente en Europe elle n'y est néanmoins trouvée qu'en petits nombres (BARTOS 1959, KCSTE 1962). Notée aussi au Japon (SUDZUKI 1964), en Chine et aux USA (HARRING et MYERS 1926), elle vit parmi les plantes aquatiques de différents bassins (BARTOS 1959) dans des flaques d'eau (DONNER 1954) et même dans le psammon (WISZNIEWSKI 1932).

Rare en Pologne elle n'y fut constatée qu'en Basse-Silésie (SACHSE 1914), dans les lacs Wigry (WISZNIEWSKI 1932) et dans le bassin de la rivière Grabia (PAWŁOWSKI 1958).

Cette espèce ne fut notée que dans le pélagial du lac Białe en juin 1963.

31. *Monostyla subulata* HARRING et MYERS, 1926. Cette espèce vit dans la mousse, principalement sur du sphagnum sp. et parmi les plantes des eaux stagnantes HARRING et MYERS 1926, HAUER 1958). Notée dans quelques pays d'Europe et des USA.

Rare en Pologne ce rotifère fut noté par PAWŁOWSKI (1938) à Wigry et dans le bassin de Grabia en tant que forme bryophyle et par Bryce (WISZNIEWSKI 1954) sur du *Sphagnum* sp. également dans les environs de Wigry.

Ce rotifère ne fut trouvé qu'en un seul exemplaire dans le littoral du lac Bialskie en août 1962.

### Subordo: Flosculariacea

#### Familia: Testudinellidae

32. *Testudinella parva bidentata* (TERNETZ 1892). Cette espèce est fréquemment rencontrée dans la région holarctique. Son biotope est formé par la végétation aquatique de différents types d'eaux.

Constatée en Pologne par WIERZEJSKI (1893) dans des mares des environs de Cracovie ainsi que par LUCKS (1912) dans des lacs et des mares de Poméranie.

Elle ne fut notée que deux fois en petit nombre parmi des plantes du littoral du lac Czarne, en septembre.

33. *Testudinella patina intermedia* (ANDERSON 1889). Cette Variété fut reconnue en Allemagne, en Tchécoslovaquie, en Inde, en Australie, en Afrique du

Sud et aux USA (BARTCS 1959). Elle vit surtout parmi les plantes aquatiques de différentes sortes de bassins (BARTCS 1950, CARLIN 1939, GALLIFORD 1946).

Elle ne fut notée en Pologne que dans le bassin de la rivière Grabia (PAWŁOWSKI 1958).

Ce rotifère est rare dans les lacs étudiés. Des exemplaires isolés furent trouvés en août 1962 parmi les plantes du littoral du lac Bialskie.

#### *Familia: Filiniidae*

34. *Filinia maior* (COLDITZ 1924). Espèce caractéristique pour le plancton des lacs et des étangs (BARTCS 1959), plus rare dans les rivières (PAWŁOWSKI 1958); d'après CARLIN (1943) elle est typique pour le plancton d'hiver. Ce rotifère fut mentionné en Allemagne, en Tchécoslovaquie et en Roumanie.

En Pologne il fut noté dans les étangs de pisciculture à Żeromin près de Łódź (KULAMOWICZ 1956) et dans le bassin de la rivière Grabia (PAWŁOWSKI 1958).

Commun dans les trois lacs Sosnowickie il s'y trouve durant toute l'année en grand nombre, surtout entre janvier et mars et entre juin et août. En dehors de la zone pélagiale il fut aussi pêché dans le littoral de ces lacs où il apparaissait en grand nombre, surtout dans celui du lac Biale.

#### *Familia: Conochilidae*

35. *Conochiloides dossuarius* (HUDSON 1885). Noté en Europe, en Amérique du Nord, en Afrique du Sud, en Afrique Orientale, en Australie, au Sumatra et au Java. Il est considéré comme représentant typique du plancton des étangs et des petits lacs (CCLLIN 1912, RYŁOW 1935) mais il est aussi rencontré dans les eaux b-mésosaprobies. Ce rotifère est thermophile et le maximum de son développement correspond à l'été ou à l'automne (RYŁOW 1935).

En Pologne il fut trouvé par WIERZEJSKI (1893) dans un petit étang des environs de Cracovie, par FERĘNSKA (1966) dans des étangs de Silésie et encore par KULAMOWICZ (1956) dans les étangs de pisciculture à Żeromin près de Łódź.

Rare dans les lacs étudiés il n'y fut détecté que dans le pélagial du lac Bialskie en avril et en août.

### 3. CONCLUSIONS

Les espèces rares de rotifères de la faune des lacs Sosnowickie sont celles qui ne sont notées que d'une façon sporadique dans les bassins aquatiques de Pologne ou qui sont peu fréquentes même dans l'holarctique. Ce sont: *Harringia eupoda* GOSSE, *Lindia pallida* HARRING et MYERS, *Proales minima* (MONTET), *Cephalodella delicata* WULFERT, *Cephalodella obvia* DONNER, *Elosa spinifera* WISZNIIEWSKI, *Lecane mira* (MURRAY), *Monostyla scutata* HARRING et MYERS et autres.

Dans les lacs étudiés les formes rares se trouvaient avant tout dans le littoral, parmi les plantes aquatiques (26 espèces). 5 espèces n'ont été trouvées que dans le pélagial: *Cephalodella obvia* DONNER, *Conochiloides dossuarius* (HUD-

son), *Euchlanis lucksiana* HAUER, *Monostyla stenroosi* MEISSNER et *Polyarthra dolichoptera aptera* (HCCD). 4 espèces, par contre, ont été notées dans les deux zones: *Filinia maior* (COLDITZ), *Keratella hiemalis* CARLIN, *Platyas quadricornis pentagona* WULFERT et *Rhinoglena frontalis* EHRENBERG (tab. I).

Table I

Liste alphabétique des rotifères et zone où il furent trouvés

	Nom du rotifère	Lacs		
		Białe	Bialskie	Czarne
1.	<i>Cephalodella delicata</i> Wulfert			L
2.	<i>Cephalodella obvia</i> Donner	P		
3.	<i>Cephalodella sterea minor</i> Donner			L
4.	<i>Cephalodella sterea mutata</i> Donner	L	L	L
5.	<i>Conochiloides dossuarius</i> (Hudson)		P	
6.	<i>Cyrtonia tuba</i> (Ehrenberg)		L	
7.	<i>Elosa spinifera</i> Wiszniewski		L	L
8.	<i>Epiphanes brachionus</i> (Ehrenberg)		L	
9.	<i>Euchlanis calpidia</i> Myers		L	L
10.	<i>Euchlanis lucksiana</i> Hauer		P	P
11.	<i>Euchlanis lyra</i> Hudson	L	L	L
12.	<i>Euchlanis meneta</i> Myers			L
13.	<i>Filinia maior</i> (Colditz)	PL	PL	PL
14.	<i>Harringia eupoda</i> (Gosse)			L
15.	<i>Keratella hiemalis</i> Carlin	PL	PL	PL
16.	<i>Lecane lauterborni</i> Hauer		L	
17.	<i>Lecane ludwigi</i> (Eckstein)		L	L
18.	<i>Lecane mira</i> (Murray)	L	L	
19.	<i>Lecane stichea</i> Harring	L	L	L
20.	<i>Lecane subtilis</i> Harring et Myers			L
21.	<i>Lepadella quadricarinata</i> (Stenroos)			L
22.	<i>Lindia pallida</i> Harring et Myers			L
23.	<i>Monostyla pygmaea</i> Daday		L	
24.	<i>Monostyla scutata</i> Harring et Myers		L	
25.	<i>Monostyla stenroosi</i> Meissner	P		
26.	<i>Monostyla subulata</i> Harring et Myers		L	
27.	<i>Mytilina mucronata spinifera</i> (Ehrenberg)	L	L	L
28.	<i>Platyas quadricornis pentagona</i> Wulfert		PL	
29.	<i>Polyarthra dolichoptera aptera</i> (Hood)	P		
30.	<i>Proales minima</i> (Montet)			L
31.	<i>Proales sordida</i> (Gosse)		L	
32.	<i>Rhinoglena frontalis</i> Ehrenberg		L	PL
33.	<i>Testudinella parva bidentata</i> (Ternetz)			L
34.	<i>Testudinella patina intermedia</i> (Anderson)		L	
35.	<i>Tetrasiphon hydrocora</i> Ehrenberg			L

Signification: P — pélagial, L — littoral

*Keratella hiemalis* CARLIN appartient aussi aux formes rares pour la faune de Pologne, car sa présence y fut constatée en exemplaires isolés seulement dans la rivière Grabia (PAWŁOWSKI 1958). Elle fut trouvée, par contre, très fréquemment dans les deux zones des lacs Sosnowickie pendant toute l'année, mais surtout dans la période hiverno-printanière (I—VI). Ce rotifère est considéré par CARLIN (1943) comme forme sténothermique, aimant le froid et passant l'été dans l'hypolimnion des lacs profonds. De même HAUER (1952) est d'avis que ce rotifère peut être présent dans les lacs profonds pendant toute l'année, se retirant pendant les mois chauds dans l'hypolimnion. Les maté-

rioux obtenus des lacs Sosnowickie, peu profonds et de faible étendue, permettent, par contre, de supposer que *Keratella hiemalis* CARLIN n'est pas trop sensible aux changements de température de l'eau et que, quoique le maximum de son développement correspond à l'hiver et au début du printemps, elle peut vivre pendant toute l'année non seulement dans l'hypolimnion.

#### 4. RESUMÉ

Parmi les 137 espèces et formes de rotifères trouvées dans les lacs Sosnowickie durant des études effectuées en 1961—1963 sur la répartition des rotifères et leur écologie, 35 furent considérées comme rares dans la faune de Pologne (tab. I).

La répartition de ces formes dans les lacs étudiés et quelques données écologiques sont rapportées dans ce travail.

*Keratella hiemalis* CARLIN, espèce considérée comme psychrophile, était notée dans les deux zones des lacs Sosnowickie durant toutes les saisons de l'année.

#### 5. STRESZCZENIE

W toku prowadzonych w latach 1961—1963 badań nad składem gatunkowym i ekologią wrotków jezior Sosnowickich (Białe, Bialskie i Czarne), spośród 137 występujących tam gatunków i form, 35 zaliczono do rzadszych w faunie Polski (tab. I).

Opisano rozmieszczenie tych form zarówno w badanych jeziorach jak i na terenie Polski, uwzględniając ich wymagania ekologiczne.

*Keratella hiemalis* CARLIN, gatunek uważany za formę zimnolubną, w jeziorach Sosnowickich poławiany był w obydwu strefach we wszystkich porach roku.

#### BIBLIOGRAPHIE

- AHLSTROM, E. H. 1940. A revision of the Rotatorien genera *Brachionus* and *Platyas* with descriptions of one new species and two new varieties. *Bull. Am. nat. Hist.*, 77, 143—184.
- BARTOS, E. 1950. Drobnohladna fauna slovenských machov. *Přírodov. Sb.*, 4, 77—92.
- BARTOS, E. 1959. Viřnici — Rotatoria. *Fauna CSR*, 15, pp. 969.
- BIRNER, A. 1931. Die Rotatorienfauna des Vierwaldstättersees und ihre Ökologie. *Mitt. naturf. Ges. Luzern*, 11, 107—243.
- BLOEDORN, J. 1912. Über die Rädertierfauna der Provinz Posen. *Königl. Friedr.-Wilhelm Gymn. Beilage zum Jahresber. Programm* No. 239, 1—37.
- CARLIN, B. 1939. Über die Rotatorien einiger Seen bei Aneboda. *Meddn Lunds Univ. limnol. Instn.*, No. 2, 3—68.
- CARLIN, B. 1943. Die Planktonrotatorien des Motalaström. Zur Taxonomie und Ökologie der Planktonrotatorien. *Meddn Lunds Univ. limnol. Instn.*, No. 5, 1—256.
- COLLIN, A. 1912. Rotatoria und Gastrotricha. *die Süßwasserfauna Deutschlands*, 14, pp. 273.
- CZAPIK, A. 1958. Les rotifères des environs de Cracovie. *Acta zool. cracov.*, 3, 123—134.
- DONNER, J. 1950. Rädertiere der Gattung *Cephalodella* aus Südmähren. *Arch. Hydrobiol.*, 42, 304—328.
- DONNER, J. 1954. Zur Rotatorienfauna Südmährens. *Ost. Zool. Z.*, 5, 30—117.
- DONNER, J. 1964. Die Rotatorien-Synusien submerser Makrophyten der Donau bei Wien und mehrerer Alpenbäche. *Arch. Hydrobiol.*, Suppl. Bd., 27, 227—324.
- FEREŃSKA, M. 1966. Skład zooplanktonu niektórych stawów w Gołysz. (Zooplankton of some ponds at Gołysz). *Acta Hydrobiol. Kraków*, 8, Suppl. 1, 155—166. (Résumé angl.).
- GALLIFORD, A. L. 1946. A contribution to the Rotifer fauna of the Liverpool area. *Proc. Lpool Nat. Fld Club*, 1945, 10—16.
- GRAAF, F., de. 1956. Studies on Rotatoria from the Netherlands. *Biol. Jaarb.*, 23, 145—217.

- HARRING, H. K., MYERS, F. J. 1922. The Rotifer fauna of Wisconsin. *Trans. Wis. Acad. Sci. Arts Lett.*, 20, 553—662.
- HARRING, H. K., MYERS, F. J., 1926. The Rotifer fauna of Wisconsin. III. — A revision of the genera *Lecane* and *Monostyla*. *Trans. Wis. Acad. Sci. Arts Lett.*, 22, 315—423.
- HAUER, J. 1924. Zur Kenntnis des Rotatorien — Genus *Colurella* Bory de St. Vincent. *Zool. Anz.*, 59, 177—189.
- HAUER, J. 1931 a. Zur Rotatorienfauna Deutschlands (II). *Zool. Anz.*, 93, 7—13.
- HAUER, J. 1931 b. Zur Rotatorienfauna Deutschlands (I). *Zool. Anz.*, 92, 219—222.
- HAUER, J. 1936. Rädertiere aus dem Naturschutzgebiet Weingartener Moor. *Beitr. naturk. Forsch. SüdwDtl.*, 1, 129—152.
- HAUER, J. 1952. Pelagische Rotatorien aus dem Windgfällweiher, Schluchsee und Titisee in südlichen Schwarzwald. *Arch. Hydrobiol.*, Suppl. Bd. 20, 212—237.
- HAUER, J. 1958. Rädertiere aus dem Sumpfe „Grosse Seewiese“ bei Kist. *Nachr. naturw. Mus. Aschaffenburg*, 60, 1—52.
- HILLBRICHT-ILKOWSKA, A. The influence of the fish population on the biocenosis of a pond, using Rotifera fauna as an illustration. *Ekol. pol.*, Ser. A., 12, 453—503.
- JAKUBSKI, A. W. 1918/1919. Fauna wrotków (Rotatoria) i brzuchorzęsków (Gastrotricha) stawu Gródeckiego i okolicy. (Ueber die Rotatorien- und Gastrotrichenfauna des Gródek-Teiches und der Umgebung). *Kosmos, Warsz.*, 43/44, 20—42. (Rés. allem.).
- KLIMOWICZ, H. 1964. Rotifer of "astatic waters". Part I. — The littoral of lake Kisajno. *Pol. Arch. Hydrobiol.*, 12, 279—305.
- KOSTE, W. 1962. Über die Rotatorienfauna des Darnsees in Epe bei Bramsche, Kreis Bersenbrück. *Veröff. naturw. Ver. Osnabr.*, 30, 73—137.
- KOZAR, L. 1914. Zur Rotatorienfauna der Torfmoorgewässer, zugleich I. Ergänzung zur Kenntnis dieser Fauna Galiziens. *Zool. Anz.*, 44, 413—425.
- KULAMOWICZ, A. 1956. Badania nad wrotkami planktonowymi stawów rybnych w Żerominie pod Łodzią. (Recherches sur les rotifères planctoniques des étangs poissonneaux de Zeromin, près de Łódź). *Pr. Łódz. Tow. Nauk.*, No. 42 pp. 47. (Rés. franc.).
- KYSEŁOWA, K. 1966. Plankton niektórych stawów dorzecza górnej Wisły. (Plankton of some ponds in the basin of the upper Vistula river). *Acta Hydrobiol., Kraków*, 8, 247—273. (Rés. angl.).
- LUCKS, R. 1912. Zur Rotatorienfauna Westpreussens. Danzig, Westpreus. bot.-zool. Ver. pp. 207.
- LUCKS, R. 1931. Die Cladoceren, Copepoden und Rotatorien des Mariensees. *Ber. westpreuss. bot.-zool. Ver.*, 53, 1—8.
- LUCKS, R. 1934. Das Zooplankton des Glamkesees. *Ber. westpreuss. bot.-zool. Ver.*, 56, 1—4.
- MICHALSKI, K., GABAŃSKI, J., KULMATYCKI Wł. 1936. Fragment fizjograficzny rzeki Brdy w obrębie Bydgoszczy w świetle ścieków niektórych miejscowych zakładów przemysłowych. [Étude physiographique de la rivière Brda en la ville de Bydgoszcz, en rapport avec la présence d'égouts industriels]. *Prz. bydg.*, 4, 21—55. (En polonais).
- MINKIEWICZ, St. 1914. Przegląd fauny jezior tatrzańskich. (Übersicht de Fauna der Tatra-Seen). *Spraw. Kom. fizyogr. Kraków*, 48, 114—137. (Rés. allem.).
- MYERS, F. J. 1930. The Rotifer fauna of Wisconsin. V. — The genera *Euchlanis* and *Monommata*. *Trans. Wis. Acad. Sci. Arts Lett.*, 25, 353—413.
- MYERS, F. J. 1931. The distribution of Rotifera on Mount Desert Island. *Amer. Mus. Novit.*, No. 494, 1—12.
- NIPKOV, F. 1952. Die Gattung *Polyarthra* Ehrenberg im Plankton des Zürichsees und einiger anderer Schweizer Seen. *Schweiz. Z. Hydrol.*, 14, 135—181.
- PAWŁOWSKI, L. K. 1938. Materialen zur Kenntnis der moosbewohnenden Rotatorien Polens. I. *Annls Mus. Zool. Pol.*, 13, 115—159.
- PAWŁOWSKI, L. K. 1958. Wrotki (Rotatoria) rzeki Grabi. Część I — faunistyczna. (Les rotifères de la rivière Grabia. I. — Partie faunistique). *Pr. Łódz. Tow. Nauk.*, No. 50, p. 439. (Rés. franc.).
- PAWŁOWSKI, L. K. 1960. Rotifères nouveaux et rares parmi la faune de la Pologne. *Bull. Soc. Sci. Lett. Łódź*, No. 11.
- REMANE, A. 1933. Rotatoria. *Bronn's Klassen und Ordnungen des Tierreichs*. 4, Abt. 2, Teil 1, p. 576.
- RUDESCU, L. 1960. Rotatoria. *Fauna Republici Populare Române*, 2, fasc. 2, pp. 1192.

- RYLOV, V. M. 1935. Das Zooplankton der Binnengewässer. *Die Binnengewässer.*, 15, 36—96.
- SACHSE, R. 1914. Zur Rotatorienfauna Deutschlands. I. *Arch. Hydrobiol.*, 9, 495—502.
- SUDZUKI, M. 1964. New systematical approach to the Japanese planktonic Rotatoria. *Hydrobiologia*, 23, 1—124.
- VOIGT, M., 1956/1957. Rotatoria. *Die Rädertiere Mitteleuropas. Ein Bestimmungswerk.* I.—Textband, II.—Tafelband. Berlin, Borntraeger. pp. 508, Tab. 115.
- WIERZEJSKI, A. 1893. Rotatoria (Wrotki) Galicji. [Rotifères du sud de la Pologne]. *Rozpr. Wydz. mat.-przyr. Pol. Akad. Umiejętn.*, 26, 160—265. (En polonais).
- WISZNIEWSKI, J. 1932. Les Rotifères des rives sablonneuses du lac Wigry. Note préliminaire. *Arch. Hydrobiol. Ryb.*, 6, 86—100.
- WISZNIEWSKI, J. 1934. Badania ekologiczne nad psammonem ze szczególnym uwzględnieniem wrotków. (Recherches écologiques sur le psammon et spécialement sur les rotifères psammiques). *Arch. Hydrobiol. Ryb.*, 8, 149—272. (Rés. franc.).
- WISZNIEWSKI, J. 1936. Notes sur le psammon. IV—V. *Arch. Hydrobiol. Ryb.*, 10, 235—243.
- WISZNIEWSKI, J. 1954. Fauna wrotków i rejonów przyległych. (Les rotifères de la faune polonaise et des régions avoisinants). *Pol. Arch. Hydrobiol.*, 1, 317—490. (Rés. franc.).
- WULFERT, K. 1939. Beiträge zur Kenntnis Rädertierfauna Deutschlands. IV.— Die Rädertiere der Saale-Elster-Niederung bei Meresburg in ökologisch-faunistischer Beziehung. *Arch. Hydrobiol.*, 35, 563—624.
- WULFERT, K. 1940. Rotatorien einiger ostdeutscher Torfmoore. *Arch. Hydrobiol.*, 36, 552—587.
- WULFERT, K. 1942. Neue Rotatorienarten deutschen Mineralquellen. *Zool. Anz.*, 137, 187—200.
- WULFERT, K. 1943. Rädertiere aus dem Salzwasser von Hermannsbad. *Zool. Anz.*, 143, 164—172.
- WULFERT, K. 1956. Die Rädertiere des Teufelssees bei Friedrichshagen. *Arch. Hydrobiol.*, 51, 457—495.



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CALCULATION OF PRODUCTION EFFICIENCY  
IN PLANKTON COPEPODSInstitute of Oceanology, Acad. of Sci. USSR, Institute of Theoretical Physic, Acad.  
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## ABSTRACT

Experimental data of feeding, growth and respiration of *Macrocyclops albidus* JUR. were computed by the integral method, within the individual development from early copepodits to adult forms, as cumulative elements of energy budget. Indices of production efficiency vary in relation to animals growth as follows: Index of feeding efficiency decreases as described by equation:  $U^{-1} = 2,55 \cdot W^{-0,6}$  ( $W$  — wet weight,  $\mu\text{g}$ ); Energy used for growth, as % of energy consumed, decreases:  $K_1 = 1,25 \cdot W^{-0,6}$ ; Energy used for growth, as % energy assimilated, remains constant within the examined period of development:  $K_2 = 50\%$ .

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## Denotations:

- $P$  — Rate of production; biomass growth;  
 $R$  — Rate of consumption; food intake;  
 $T$  — Rate of respiration; cost of maintenance;  
 $\tau$  — Animal age, days;  
 $Rc$  — Cumulative consumption; cumulative food intake;  
 $Tc$  — Cumulative respiration; cumulative cost of maintenance;  
 $W$  — Animals wet weight,  $\mu\text{g}$ ;
- $K_1 = \frac{P}{R}$  — Energy used for growth, as % of energy consumed;  
 $K_2 = \frac{P}{P+T}$  — Energy used for growth, as % of energy assimilated;  
 $U^{-1} = \frac{P+T}{R}$  — Rate of food assimilation, as % of energy consumed; index of feeding efficiency;  
 $QO_2$  — Oxygen consumption.

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## 1. INTRODUCTION

Processes of feeding, growth and respiration in aquatic animals are easily characterized by indices of energy used for growth out as % of the energy consumed —  $K_1$  and as % of energy assimilated —  $K_2$ . Ascertaining these indices for animals belonging to different trophic levels which form any ecosystem enables us to analyse in detail the energy flow and accumulation by this ecosystem. Learning about these indices is especially important for modelling the freshwater ecosystems.

It is interesting therefore to trace general regularities in changes of  $K_1$  and  $K_2$  during the development and growth of animals. Indices  $K_1$  and  $K_2$  can be defined after IVLEV (1939) and WINBERG (1956) as follows:

$$K_1 = \frac{P}{R}, \quad (1)$$

$$K_2 = \frac{P}{P+T}, \quad (2)$$

where  $P$  — the rate of production or biomass growth,  $R$  — the rate of consumption or food intake,  $T$  — the rate of respiration or cost of maintenance, all in identical units (e.g. calories), per unit time.

Thus, to analyse changes in  $K_1$  and  $K_2$  for the period of animal's growth, it is necessary to know the ratios of food consumption, growth, and cost of maintenance of an animal as function of its age,  $\tau$ . However, it is most convenient to determine experimentally the values of food intake, oxygen consumption and body weight for subsequent developmental stages. The rate of production is then expressed by derivative of animal's weight against time,  $\frac{dW}{d\tau}$ .

Estimation of this derivative directly from the experimental data on the growth,  $W(\tau)$  does not ensure an adequate accuracy of thus obtained value  $P$ . Even if we assume that the growth is parabolic, which is true for the animals studied, and then acc. to this approximate  $W(\tau)$ , we will not improve the results, since dependence  $W(\tau)$  can be approximated by several different functions due to real accuracy of the experiment at our disposal. This will lead to a high variation in values  $P$  and consequently to a high variation of indices  $K_1$  and  $K_2$ . There is another way which seems to be more suitable of ascertaining indices  $K_1$  and  $K_2$ . For this, instead of derivatives of food intake —  $R$ , production —  $P$ , and respiration —  $T$ , we will use corresponding integrations as follows:

$$Rc = \int_0^{\tau} R(t) dt,$$

$$Tc = \int_0^{\tau} T(t) dt,$$

$$W = \int_0^{\tau} P(t) dt,$$

where  $Rc$  is cumulative food intake of an animal from its birth to a given moment,  $Tc$  — cumulative oxygen uptake for this period. Similar approach was applied at estimating the cumulative elements of energy budget in the paper by KLEKOWSKI, PRUS, ZYROMSKA-RUDZKA (1967), although the way of calculation was different.

Values  $R$ ,  $T$ , and  $P$  are then time derivatives of  $Rc$ ,  $Tc$ , and  $W$ , respectively:

$$R = \frac{dRc}{d\tau}, \quad (3)$$

$$T = \frac{dTc}{d\tau}, \quad (4)$$

$$P = \frac{dW}{d\tau}. \quad (5)$$

It can be easily seen that  $K_1$  and  $K_2$  in terms of  $Rc$ ,  $Tc$ , and  $W$  can be written as:

$$K_1 = \frac{P}{R} = \frac{dW}{d\tau} : \frac{dRc}{d\tau} = \frac{1}{\frac{dRc}{dW}} = \frac{dW}{dRc}$$

or: 
$$\frac{1}{K_1} = \frac{dRc}{dW} \quad (6)$$

$$K_2 = \frac{P}{P+T} = \frac{dW}{d\tau} : \left( \frac{dW}{d\tau} + \frac{dTc}{d\tau} \right) = \frac{1}{1 + \frac{dTc}{dW}} = \frac{dW}{dW + dTc} \quad (7)$$

or: 
$$\frac{1}{K_2} = 1 + \frac{dTc}{dW}.$$

Ratio  $K_1/K_2$  denotes the rate of assimilation of the food taken,  $U^{-1}$ , and is considered as an index of feeding efficiency of animals:

$$U^{-1} = \frac{K_1}{K_2} = \frac{P+T}{R}. \quad (8)$$

By introducing values  $R$ ,  $T$ ,  $P$  from (3), (4), and (5) to formula (8), one obtains:

$$U^{-1} = \frac{1 + \frac{dTc}{dW}}{\frac{dRc}{dW}}. \quad (9)$$

Therefore, the analysis of indices  $K_1$  and  $K_2$  is reduced to calculating derivatives  $\frac{dRc}{dW}$  and  $\frac{dTc}{dW}$  from the experimental data. These derivatives have their intrinsic meaning. Value  $\frac{dTc}{dW}$  equals to ratio of cost of maintenance to growth (WINBERG 1966): value  $\frac{dRc}{dW}$  equals in fact to ratio  $\frac{R}{P}$  and denotes so-called feeding ratio

$$\frac{dTc}{dW} = \frac{T}{P} = \frac{1-K_2}{K_2} = \frac{1}{v}.$$

Having calculated derivatives  $\frac{dRc}{dW}$  and  $\frac{dTc}{dW}$ , the rest of computation becomes very simple and do not involve manifold meaning, depending on calculation of derivative  $\frac{dW}{d\tau}$ .

## 2. MATERIAL AND METHODS

Functions  $Rc(W)$  and  $Tc(W)$  were calculated from the experimental data on feeding, growth and metabolism of *Macrocyclops albidus* JUR., a predacious species of freshwater Copepoda. The choice of a representative of this group resulted to a greater extent from the fact that copepods form one of the major item of zooplankton biomass both in the freshwater environments and especially in marine zooplankton communities. It can be assumed that some of regularities, probably those of a fundamental importance, found feeding,

growth, and metabolism of this species are of a similar nature in various species of plankton Copepoda (WINBERG 1966). From a relatively numerous observations done by different investigators, on growth and development of some species of marine and freshwater copepods, it can be inferred that the growth curve of many copepod species has a parabolic course for a period preceding sexual maturity (SHUSHKINA 1957). This being the case,  $K_2$ , i.e., % energy assimilated as growth, will maintain a constant value within the whole period of copepods growth (WINBERG 1966). Then dependences  $T(\tau)$ ,  $Rc(\tau)$ , and  $Rc(W)$  can be approximated by exponential functions and  $Tc(W)$  will take form of a straight line.

One can expect that these general regularities in feeding growth and metabolism should be characteristic not only for *Macrocyclus albidus* but also for many species of marine and freshwater copepods.

The experimental part of the work has been carried out in the Department of Experimental Hydrobiology, Nencki Institute (Warsaw). The copepods which had been collected in vicinity of Warsaw were kept for several generations in aquarium under laboratory conditions at ambient temperatures. The experiments were run at a temp. of 21°C at which the complete development from egg to adult lasted for 30 days. The copepods were fed with protozoans, *Paramecium aurelia*. The food concentration in culture vessels was maintained at an approximately constant level. Four different concentrations of food were used. Those experiments whose results were used in the present paper were run at an average food concentration of 10.000 individ./l (food biomass of about 1 g m<sup>-3</sup> of water), which would correspond to feeding conditions similar to those in a mesotrophic lake. For further calculation it was reasonable to accept 500 cal/g wet weight as the calorific value of the food (SLOBODKIN, RICHMAN 1961, COMITA, SCHINDLER 1963, OSTAPENJA, SERGEEV 1963). The amount of food consumed by one copepod of age  $\tau$  and weight  $W$  was measured by means of checking every second day the concentration of the food in the experimental vessels. The rate of oxygen consumption  $QO_2$  by copepods was measured for separate individuals in Cartesian divers as modified by ZEUTHEN (1950); for description of the respirometric method see: KLEKOWSKI 1967, other details on the methods of present experiments can be found in: KLEKOWSKI, SHUSHKINA 1966 a, b.

### 3. RESULTS

The results of simultaneous measurements of the cumulative food consumption —  $Rc$ , oxygen consumption rate —  $QO_2$  per unit weight and individual's weight  $W$  for subsequent age stages, are shown in Figs 1—3.

The points in Fig. 2 represent cumulative food intake by a copepod from the beginning of the experiment  $t = 0$  to a given age  $\tau$ . Thus, function  $Rc$  results from smoothing the step shaped function:  $Rc_1 = R_1$ ;  $Rc_2 = R_1 + R_2$ ;  $Rc_3 = R_1 + R_2 + R_3$ , and so on, where  $R_i$  = food intake within  $i$ 's 24 hrs. The dispersion of points around this curve suggests rather small variation which permits a sufficient precise approximation of function  $Rc(\tau)$ .

Dependence  $QO_2(W)$  Fig. 3 is defined by equation:

$$QO_2 = aW = 1.22 W^{0.84} \quad (10)$$

where  $QO_2$  is expressed in  $\mu\text{l O}_2 \cdot 10^{-3}/\text{hr}$ , weight in  $\mu\text{g}$  of wet weight.

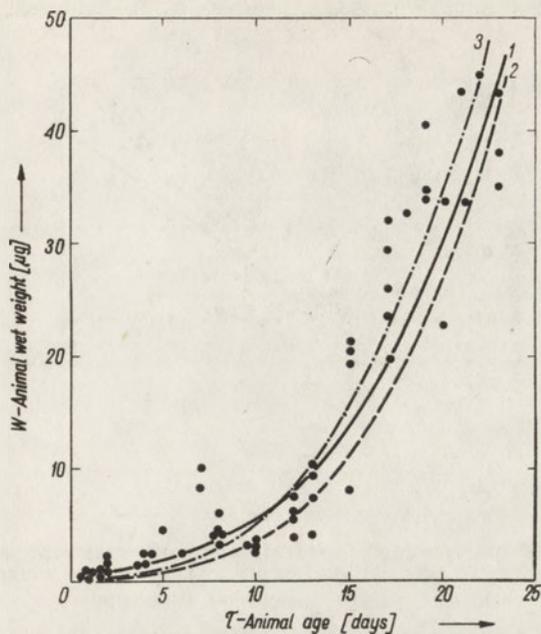


Fig. 1. Growth of *Macrocyclus albidus* JUR.  
1,2,3 = some possible approximations

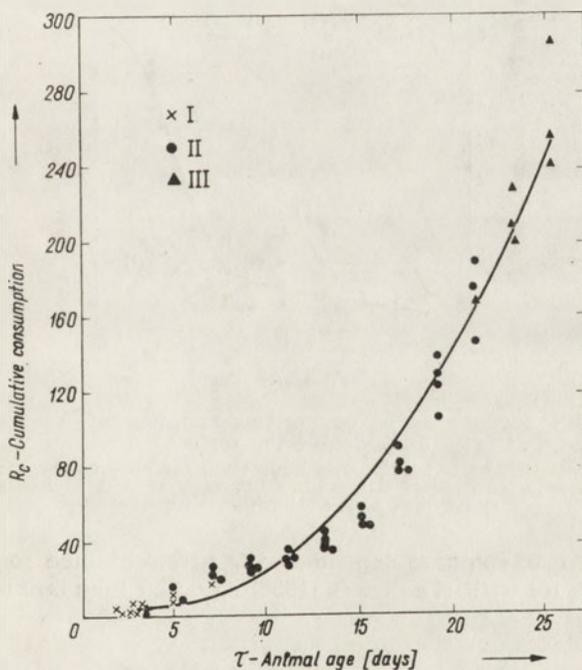


Fig. 2. Cumulative consumption (food intake) of *Macrocyclus albidus* JUR., expressed in  $\mu\text{g}$  wet weight

I — nauplii, II — copepodites, III — adults. Approximation:  $R_c = 0.08 \cdot t^{2.5}$ .

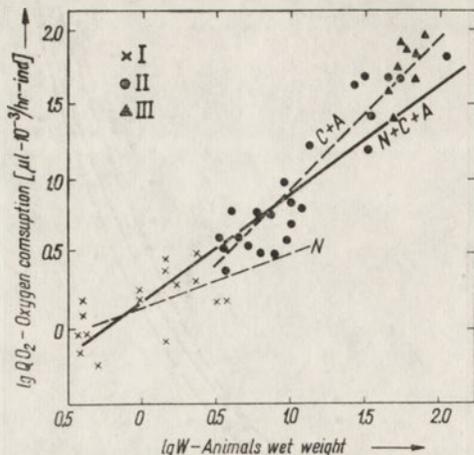


Fig. 4. Daily cost of maintenance (respiration) of *Macrocyclus albidus* JUR., from nauplius to adult animal: expressed in  $\mu\text{g}$  wet weight

I — naupli, II — copepodits, III — adults

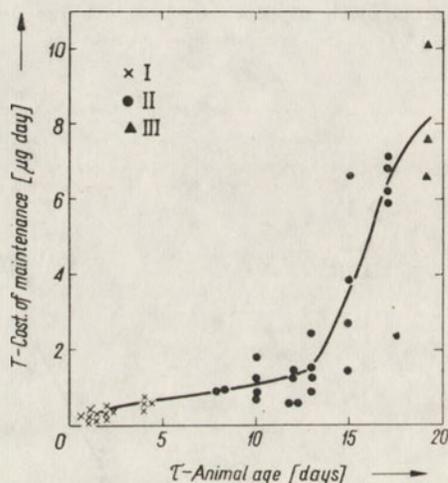


Fig. 3. Size (weight) dependence of oxygen consumption of *Macrocyclus albidus* JUR., double log scale

I — naupli, II — copepodits, III — adults, N — Regression for naupli  $QO_2 = 1.25 \cdot W^{0.34}$ , C + A — Regression for copepodits and adults  $QO_2 = 0.76 \cdot W^{1.02}$ , N + C + A — Regression for naupli, copepodits and adults  $QO_2 = 1.22 \cdot W^{0.84}$

It is interesting to compare dependence  $QO_2(W)$  obtained for *Macrocyclus albidus* (equation 10) with WINBERG'S (1956) equation for plankton crustaceans at temp. of  $20^\circ\text{C}$ :

$$QO_2 = 0.165W^{0.81}, \quad (11)$$

where  $QO_2$  is measured in  $\text{ml } O_2/\text{hr}$  and  $W$  — in grams. In order to do this, it is necessary to use same units for  $QO_2$  and  $W$  in equations (10) and (11), coefficient  $a$  in equation (10) can be calculated as follows:

$$a = \frac{1.22 \cdot 10^{-3} \mu\text{l}}{\mu\text{g}^{0.84}} = \frac{1.22 \cdot 10^{-6} \mu\text{l}}{(\text{g} \cdot 10^{-6})^{0.84}} = 1.22 \frac{10^{-6}}{10^{-5.04}} =$$

$$= 1.22 \cdot 10^{-0.96} = 1.22 \cdot 0.1096 = 0.134 \quad (10a)$$

therefore:  $QO_2 = 0.134W^{0.84}$

This indicates somewhat lower values of respiration than those computed acc. to equation (11).

Further calculations based on equations (6), (7) and (9) must also involve comparable units for all expressions used therein, in this case  $\mu\text{g}$  wet weight/24 hrs. That is why the empirical values of oxygen consumption, expressed in  $\mu\text{l O}_2 \cdot 10^{-3}$  /hr had to be converted into  $\mu\text{g}$  wet weight/ 24 hrs. With oxy-caloric equivalent  $4.86 \text{ cal ml O}_2$  i.e.  $4.86 \cdot 10^{-3} \text{ O}_2 \text{ cal}/\mu\text{l}$  and an average calorific value of wet biomass of copepods equal to  $0.5 \text{ cal}/\text{mg}$ , one  $\mu\text{l O}_2$  corresponds to  $4.86 \cdot 10^{-3} \cdot 2 \cdot 10^{-3} \mu\text{g} = 9.72 \mu\text{g}$  wet weight. Then, for 24 hrs:

$$T = 9.72 \cdot 10^{-3} \cdot 24 \cdot a \cdot W^{0.84} = 0.290 \cdot W^{0.84} \quad (10b)$$

Thus obtained values  $T$ , expressed in  $\mu\text{g}$  wet weight/24 hrs, were plotted (Fig. 4) against corresponding age of copepods yielding function  $T(\tau)$ . The curve in this Figure joins average for each of groups of points corresponding subsequently to  $\tau = 1, 2, 4, 8, 10, 12.5, 15, 17, 19$ . The points in Fig. 1 were obtained by measuring the volume of animals and then calculating dry weight of *Macrocyclus* necessary for estimation of respiration rate  $QO_2$  and daily food consumption  $R$ . On account of high dispersion of points in this graph it is not possible to approximate dependence  $W(\tau)$  with any definite function; e.g. this dependence, can be denoted by exponential functions whose exponents equal to 6.25, 3.0, 2.5. As it has been already mentioned, considerable changes in this exponent bring about considerable deviation of the results when differentiating equation (5). These differences lead, in turn, to unjustifiably large differences in  $K_1, K_2$ , and  $U^{-1}$ . That is why it was absolutely necessary to avoid differentiation  $P = \frac{dW}{d\tau}$  according to the way describe by equations (6), (7) and

(9). In order to do so, it was necessary to estimate derivatives  $\frac{dTc}{dW}$  and  $\frac{dRc}{dW}$ , involved in these equations.

Dependence  $Tc(W)$  was ascertained by the following. Since  $M = \frac{dTc}{dW}$ , values  $Tc$  were obtained with planimeter by measuring the area under curve  $T(\tau)$  (Fig. 4), for age interval from 2 to 19 days, i.e., by measuring the area outlined by curve  $T(\tau)$  in Fig. 4 from  $\tau = 1$  to  $\tau = 2$ , from  $\tau = 1$  to  $\tau = 4$ , etc. Thus obtained values  $Tc$  (ordinate) were plotted against values  $W$  (abscissa), the latter being arithmetic averages of cyclopid body weight within the age classes mentioned. Values  $W$  were taken exclusively from the records made when measuring  $T$ . Dependence  $Tc(W)$  (Fig. 5) takes form:

$$Tc = 1.05W.$$

Hence:

$$\frac{dTc}{dW} = 1.05.$$

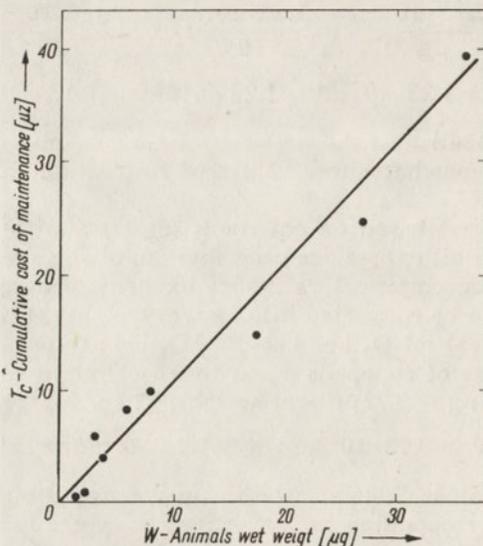


Fig. 5. Size (weight) dependence of cumulative cost of maintenance (respiration) of *Macrocyclus albidus* JUR., expressed in  $\mu\text{g}$  wet weight

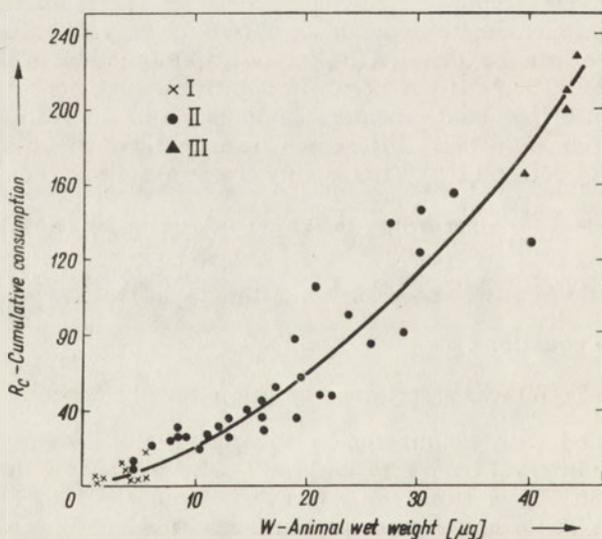


Fig. 6. Size (weight) dependence of cumulative consumption (food intake) expressed in  $\mu\text{g}$  wet weight, of *Macrocyclus albidus* JUR

I — naupli, II — copepodias, III — adults. Approximation:  $R_c = 0.5 \cdot W^{1.6}$

Derivative  $\frac{dT_c}{dW}$  appearing in equations (6), (7), (9), was obtained as follows. Values  $R_c$  from Fig. 2 (ordinate) were plotted against values of weight  $W$  (abs-

cissa) which were taken from Fig. 1 for each age group. Thus obtained dependence  $Rc(W)$ , as presented in Fig. 6, is described by equation:

$$Rc = 0.5 W^{1.6}.$$

$$\text{Hence: } \frac{dRc}{dW} = 0.5 \cdot 1.6 W^{0.6} = 0.8 W^{0.6}.$$

Thus, both derivatives necessary for computation of  $K_1$ ,  $K_2$  and  $U^{-1}$  have been obtained.

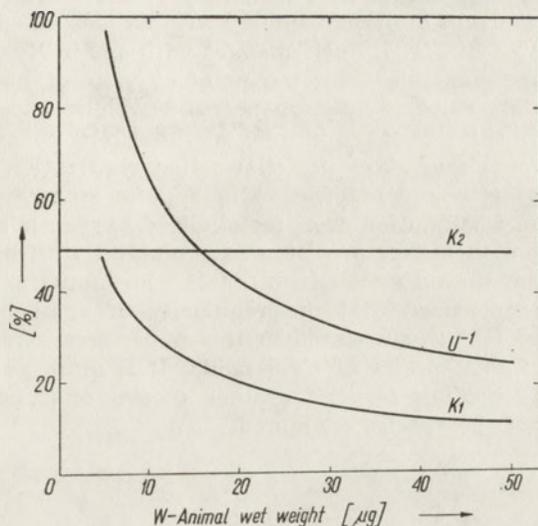


Fig. 7. Size (weight) dependence of indices: 1) Food assimilation, i.e. feeding efficiency ( $U^{-1}$ ); 2) Utilisation for biomass growth, as % of energy consumed ( $K_1$ ); 3) Utilisation for biomass growth, as % of energy assimilated ( $K_2$ ). Indices are computed for *Macrocyclus albidus* Jur. copepodits stages

By including values  $\frac{dRc}{dW}$  and  $\frac{dTc}{dW}$  to equations (6), (7) and (9) one obtains the following

$$K_1 = \frac{1}{\frac{dRc}{dW}} = \frac{1}{0.8 W^{0.6}} = 1.25 W^{-0.6}, \quad (12)$$

$$K_2 = \frac{1}{1 + \frac{dTc}{dW}} = \frac{1}{1 + 1.05} = 0.49, \quad (13)$$

$$U^{-1} = \frac{K_1}{K_2} = \frac{1.25 W^{-0.6}}{0.49} = 2.55 W^{-0.6}. \quad (14)$$

Computed functions  $K_1(W)$ ,  $U^{-1}(W)$ , and  $K_2(W)$  are presented in Fig. 7. Formulae (12), (13), (14) permit to draw preliminary conclusions concerned with changes in index of feeding efficiency  $U^{-1}$  and indices:  $K_1$  and  $K_2$ . According to the

experimental data of this paper, rat of food assimilation,  $U^{-1}$  decreases with animals growth from 97% in young copepodit stage to 25% in adults with the corresponding biomass change from 5 to 50  $\mu\text{g}$  wet weight. Within this range of body weight,  $K_2$  remains constant and equal 50%, whereas the index  $K_1$ , decreases from 50% to 10%.

This would indicate that a young population of the copepod species under study, consisting mostly of growing individuals, utilizes the energy taken from the previous trophic level more efficiently. In terms of productivity, an ecosystem consisting of young populations is more productive when indices  $K_1$  and  $K_2$ , and  $U^{-1}$  for organisms of other trophic levels are described by curves similar to those presented in Fig. 7. Such changes with age in  $K_1$  and  $U^{-1}$  as those shown in Fig. 7 are plausible from the point of view of homeostatic steady state of an ecosystem since production per unit weight (index P/B) tends to increase with diminishing average individuals.

From all what was said above it follows that elaboration of experimental data on feeding, growth and respiration in aquatic animals with the use of integrated forms of consumption or of metabolized oxygen permits to calculate indices  $K_1$  and  $K_2$  with higher precision as compared with direct elaboration of consumption, growth and metabolism for 24 hours units.

It should be emphasized that the regularity of age-specific changes in indices  $K_1$ ,  $K_2$ , and  $U^{-1}$  as presented in this paper was ascertained only for copepodit stages of one species of Cyclopoida. It is quite possible that these regularities will take other forms for other species of Copepoda or for the naupli and adults of the species examined.

#### 4. SUMMARY

Experimental data on the feeding, growth and respiration of *Macrocyclus albidus* Jur. were computed by the integral method, i.e. the sum was calculated of food consumption, oxygen uptake and increase of biomass of the examined animals at any chosen time period within the course of individual development from early copepodits to adult forms. This way of computation and presentation of data enabled to analyze the changes — in relation to the growth of the examined organisms — of indices of use of energy of food consumed  $K_1$  and assimilated  $K_2$ , as well as of the index of feeding efficiency  $U^{-1}$ . The index of feeding efficiency decrease with animals growth: from 97% to 25%; this dependence is of an exponential equation character:  $U^{-1} = 2.55W^{-0.6}$  (where:  $W$  — animal fresh weight,  $\mu\text{g}$ ). The index of use for growth of food consumed decreases from 50% to 10 per cent according to the equation:  $K_1 = 1.25W^{-0.6}$ . The index of use for growth of assimilated food is constant within the examined period of development:  $K_2 = 50\%$ .

#### 5. РЕЗЮМЕ

Экспериментальный материал по питанию, росту и дыханию *Macrocyclus albidus* Jur. обработан интегральным методом, т.е. определены суммарные величины потребления пищи, кислорода и накопления биомасс рачков к концу каждого взятого отрезка времени внутри всего периода развития от младших копеподитов до взрослых форм. Применение этого способа обработки материала позволило описать аналитически изменение коэффициентов использования на рост энергии потребленной  $K_1$  и усвоенной  $K_2$  пищи, а также усвояемость корма  $U^{-1}$ : по мере роста рачков.

По полученным данным усвояемость пищи уменьшается по мере роста рачков с 97% до 25% и описывается уравнением:  $U^{-1} = 2,55W^{-0,6}$ . Уменьшение  $K_1$  с возрастом с 50% до 10% происходит по соотношению:  $K_1 = 1,25W^{-0,6}$ . Коэффициент использования на рост энергии усвоенной пищи  $K_2$  по приведенным данным остается постоянным за время развития роста и равным 50%.

## 6. STRESZCZENIE

Dane doświadczalne o odżywianiu się, wzroście i oddychaniu *Macrocyclus albidus* JUR. opracowano za pomocą metody integracyjnej, tzn. obliczano sumy pobranego pokarmu, zużytego tlenu i przyrostów biomasy badanych zwierząt w każdym dowolnie dobranym okresie czasu w obrębie rozwoju osobniczego od młodszych kopepoditów do postaci dorosłych. Ten sposób opracowania i prezentacji danych umożliwił analizę zmian — w zależności od wieku badanych zwierząt — wskaźników wykorzystania, na przyrost biomasy, energii pokarmu pobranego  $K_1$  i przyswojonego  $K_2$ , jak również wskaźnika przyswajalności pokarmu  $U^{-1}$ . Przyswajalność pokarmu w miarę wzrostu spada: z 97% na 25%; zależność ta ma charakter funkcji wykładniczej:  $U^{-1} = 2,55W^{-0,6}$ , gdzie:  $W$  — żywa waga zwierzęcia,  $\mu\text{g}$ . Wskaźnik wykorzystania na przyrost pobranego pokarmu spada z 50% na 10% zgodnie z funkcją:  $K_1 = 1,25W^{-0,6}$ . Wskaźnik wykorzystania na przyrost przyswojonego pokarmu jest stały w czasie badanego okresu rozwoju:  $K_2 = 50\%$ .

## REFERENCES

- COMITA, G. W., SCHINDLER, D. W. 1963. Calorific values of Microcrustacea. *Science*, 140 (3574), 1394—1396.
- [IVLEV, V. S.] ИВЛЕВ, В. С. 1939. Энергетический баланс карпов. [Energy balance of carp]. *Zool. Zh.* Mosk., 18, 303—318. (Russian).
- [KLEKOWSKI, R. Z., SHUSHKINA, E. A.] КЛЕКОВСКИЙ, Р. З., ШУШКИНА, Э. А. 1966 а. Энергетический баланс *Macrocyclus albidus* (Jur.) в период его развития. [The energetic balance of *Macrocyclus albidus* (Jur.) during the period of its development]. In: *Ekologija vodnyh organismov*. Moskva, Izd. „Nauka”, 125—136. (Russian).
- KLEKOWSKI, R. Z., SHUSHKINA, E. A. 1966 b. Ernährung, Atmung, Wachstum und Energie-Umformung in *Macrocyclus albidus* Jurine. *Verh. int. Ver. Limnol.*, 16, 399—418.
- KLEKOWSKI, R. Z. 1967. Cartesian diver technique for microrespirometry. IBP Meeting on “Methods of assessment of secondary production in freshwaters”. Prague 1967.
- KLEKOWSKI, R. Z., PRUS, T., ZYROMSKA-RUDZKA, H. 1967. Elements of energy budget of *Tribolium castaneum* (Hbst) in its developmental cycle. In: Petruszewicz K. (Ed.) *Secondary productivity of terrestrial ecosystems*. 2, 859—879. Warszawa-Kraków, PWN.
- [OSTAPENJA, A. P., SERGEEV, A. P.] ОСТАПЕНЯ, А. П., СЕРГЕЕВ, А. П. 1963. Калорийность сухого вещества кормовых водных беспозвоночных. [Calory content of dry matter of food water in vertebrates]. *Vopr. Ihtiol.*, 3 (1), 177—183. (Russian).
- SLOBODKIN, L. B., RICHMAN, S. 1961. Calories/gm. in species of animals. *Nature*, Lond., 191, 299.



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S. GOŁOWIN

## DEAD FLOW ZONES EVALUATION OF POLLUTION DEGREE OF RIVERS

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### ABSTRACT

In contrast with the periphyton in the river zones of faster flow, the periphyton at the rocky bottom within microzones of decreased flow, is characterized by its qualitative and quantitative composition, typical of more polluted waters.

The velocity of water masses is not uniform across the entire section of a water course.

It decreases from midstream towards the banks and from the water surface to the bottom (LIEBMAN 1960).

At the bottom zone, even in rapid mountain torrents, which beds are built up of boulders and pebbles, the so-called dead flow zones may appear, characterized by the presence of stagnant water both in the bottom depressions, and between the rock particles covering the river bed, whereas the main water masses flow above these obstacles (AMBÜHL 1959, MAŃCZAK 1964). The formation of the dead flow zones can strongly affect the evaluation of purity of waters, based on the examinations of periphyton.

In 1965, observations were made on periphyton selected at one site in the river Słęża, near Wrocław. The samples for microscope examinations were taken twice, on 20th May and 15th June, and the material was gathered from the river bed boulders, at a depth of about 25 cm, and at a distance of approximately 50 cm from the river bank. At each point, the material for microscope analysis was sampled on a area of 3 cm<sup>2</sup>, according to the scheme presented in Fig. 1. Except for diatoms, the material collected was identified in its alive state. Quantitative analysis was made by means of the evaluation method (STARMACH 1955). The composition of species in the periphyton gathered in May and June was, for the same sampling sites, almost identical. Small quantitative differences were ascertained in the occurrence of the individual species. This, however, did not change considerably the general character of these communities. The results of the analysis made in May 1965 are presented in Table I. The amounts of the encountered organisms were calculated on three preparations. Although the numbers obtained in this way do not reflect an absolute quantity of the individuals per unit surface or volume they depict rather precisely the quantitative relations between the species, and form the

basis to draw a saprobity diagram by means of a vector method (GOŁOWIN 1967) using a system of saprobes, revised by LIEBMAN (1962).

Changes in the saprobic nature of periphyton at the individual points of the site examined, observed in May and June, are presented in Fig. 1B. The curves for both months follow almost identical pattern. Periphyton assemblages at points 1, 2, 3, 9 and 10 show  $\beta$ —mesosaprobic character resembling that of slightly polluted waters. The saprobity determined for the periphyton assemblages found at points 5, 6 and 7 situated in the depressions between boulders, is within  $\alpha$ —mesosaprobic zone. At these points numerous species appear and develop which are characteristic of strongly polluted waters and of putrefied

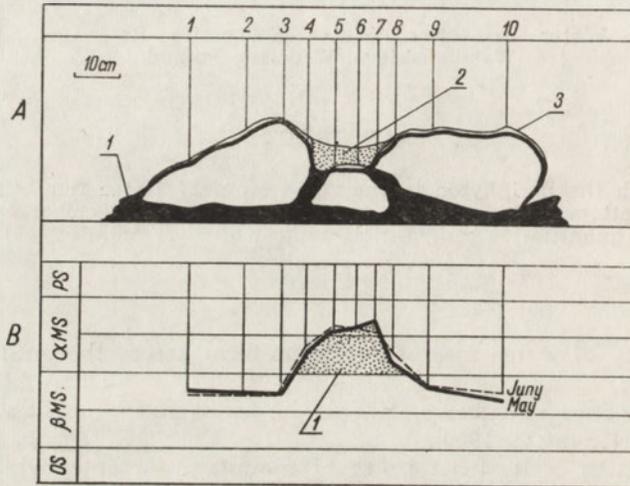


Fig. 1. A. Scheme of sampling sites; numbers 1—10—sampling points

1—bottom sediment; 2—dead flow zone; 3—periphyton

B. Degree of saprobity at sampling points

1—Increase in saprobity of dead flow zone

deposits (LIEBMAN 1962). To these species belong mainly: *Oscillatoria putrida*, *O. chlorina*, *O. farmosa*, *Euglena viridis*, *Bodo saltans*, *Astasia klebsii*, *Chilodonna cucullus*, *Paramaecium caudatum*, *Colpoda cucullus*, *Metopus ex Vorticella microstoma*, *V. convallaria*. Simultaneously, at these points, a decrease can be observed in the amount of representatives of  $\beta$ —mesosaprobionts and of oligosaprobionts, characteristic of slightly or feebly polluted waters. The periphyton communities found at points 4 and 8 also show the  $\alpha$ —mesosaprobic character, but the occurring there organisms are of intermediate nature between the two groups mentioned before.

These main changes in saprobic nature of the periphyton assemblages at the points situated close to each other, as well as the composition of species of these assemblages pointing to various ecological conditions at points 5, 6 and 7 on the one hand, and at points 1, 2, 3, 9 and 10, on the other, can be explained by the presence of the dead flow zone stretching between points 4 and 8 (Fig. 1A).

The material brought by the current to the dead flow zones is deposited there and, if it contains easily putrescible organic matter, it decomposes. Such situation leads to strong change in ecological conditions of the dead flow zones, mainly because of their low capacity, with a simultaneous consid-

Table I

Organisms found in May 1965 in the periphyton of the river Słęża

+ — very small amount, 1 — single specimens, 2 — average amount, 3 — large amount; OS = oligosaprobiont,  $\beta$ MS =  $\beta$ mesosaprobiont,  $\alpha$ MS =  $\alpha$ mesosaprobiont, PS = polisaprobiont.

	Species	Index	Sampling point									
			1	2	3	4	5	6	7	8	9	10
Cyanophyta												
1	<i>Microcystis aeruginosa</i> Kütz.	$\beta$ MS	+	+	+	+					+	+
2	<i>Oscillatoria tenuis</i> Agardh.	$\alpha$ MS	+		+	+	+	1	+	1	+	+
3	<i>O. putrida</i> Schmidle	PS				1	2	2	1	+		
4	<i>O. chlorina</i> Kütz	$\alpha$ MS	+			+	1	+	1	+		+
5	<i>O. formosa</i> Bory	PS				1	1	2	1	+		
Bacillariophyceae												
6	<i>Melosira varians</i> Ag.	$\beta$ MS	1	+	1						+	1
7	<i>M. italica</i> v. <i>tenuissima</i> (Grun.) O. Müll.				+	+						+
8	<i>Meridion circulare</i> Ag.	OS	1	+	1	+		+		+		+
9	<i>Diatoma vulgare</i> Bory	$\beta$ MS	1	2	+	+	+	+		1		1
10	<i>Fragilaria capucina</i> Desm.		1	+	1	1	+	+	1	1	+	+
11	<i>F. construens</i> (Ehr.) Grun.		+			+	1			+	1	
12	<i>Synedra ulna</i> (Nitzsch.) Ehr.	$\beta$ MS	2	1	1	+	+		+	+	+	1
13	<i>S. acus</i> Kütz.	OS	2	1	+			+			+	+
14	<i>Cocconeis placentula</i> Ehr.		+	+	+	+	+		+		+	+
15	<i>Stauroneis anceps</i> Ehr.		+	+	+	+		+		+		
16	<i>Navicula cuspidata</i> Kütz.		+	1	+	+	+		+	+	1	
17	<i>N. cuspidata</i> v. <i>ambigua</i> (Ehr.) Cl.			+						+	+	
18	<i>N. pupula</i> Kütz.			+		+		+		+	+	
19	<i>N. atomus</i> (Näg.) Grun.	$\beta$ MS	1	1	1	+		+	+	1		1
20	<i>N. cryptocephala</i> Kütz.	$\alpha$ MS		+		1	1	1	2	1	+	1
21	<i>N. rhynchocephala</i> Kütz.	$\beta$ MS	1	1	+	+		+	+	1	+	1
22	<i>N. viridula</i> Kütz.	$\alpha$ MS	+		+	1	3	2	2	1	+	1
23	<i>N. hungarica</i> v. <i>capitata</i> (Ehr.) Cl.		2	1	+	+	2	1		+	1	
24	<i>N. radiosa</i> Kütz.		1	+	+	1	+	+	1	1	+	1
25	<i>N. gracilis</i> Ehr.			+				+				
26	<i>N. exigua</i> (Greg.) Müll.		+				+			+	+	
27	<i>N. oblonga</i> Kütz.		+	+	+	+		+	+	+		+
28	<i>Pinnularia microstauron</i> v. <i>Brebissonii</i> (Kütz.) Hust.			+				+		+		+
29	<i>P. maior</i> (Kütz.) Cl.	$\beta$ MS	2	1	1	+	+			+	+	1
30	<i>P. viridis</i> Ehr.			+			+			+		+
31	<i>Neidium dubium</i> (Ehr.) Cl.		+	1	+	1	1	+		+	1	+
32	<i>Caloneis amphibaena</i> (Bory) Cl.			+	+				+	+	+	+
33	<i>Gyrosigma acuminatum</i> (Kütz.) Rabh.		1	1	+	+	1	+	1	+	+	+
34	<i>Amphora ovalis</i> Kütz.		+	+		+	+				+	
35	<i>Cymbella naviculiformis</i> Auersw.		+			+	+		+		+	+
36	<i>C. ventricosa</i> Kütz.	$\beta$ MS	1	+	1	+	+		+	1	+	+
37	<i>C. aspera</i> (Ehr.) Cl.			+	+			+		+		+
38	<i>Gomphonema acuminatum</i> v. <i>coronatum</i> (Ehr.) W. Sm.		1			+		+		+	1	
39	<i>G. parvulum</i> (Kütz.) Grun.			1	+		+	+			+	
40	<i>G. angustatum</i> (Kütz.) Rabh.		+				+	+			+	
41	<i>G. angustatum</i> v. <i>productum</i> Grun.		1		1				+	1		+
42	<i>G. constrictum</i> Ehr.		+	1			+	+		1		
43	<i>G. olivaceum</i> (Lyngb.) Kütz.	$\beta$ MS	3	2	2	+	+	+		2	+	1
44	<i>G. olivaceum</i> v. <i>calcareum</i> Cl.		+	+		+	+	+		+	+	+
45	<i>Hantzschia amphioxys</i> (Ehr.) Grun.	$\alpha$ MS	+	1		1	2	1	1	+	+	+
46	<i>Nitzschia tribionella</i> Hantzsch.		1		1		+	1			1	+
47	<i>N. stagnorum</i> Rabh.	$\beta$ MS	1	1	1		+		+	+	+	1
48	<i>N. recta</i> Hantzsch.		+			+		+			+	+
49	<i>N. nirocephala</i> Grun		+	2				1		1		+

cont. Table I

	Species	Index	Sampling point									
			1	2	3	4	5	6	7	8	9	10
50	<i>N. palea</i> (Kütz.) W. Sm.	$\alpha$ MS	+	+		2	3	2	3	2	1	
51	<i>N. sigmoidea</i> (Ehr.) W. Sm.		1	1	+	1	+	1		1	+	+
52	<i>N. vermicularis</i> (Kütz.) Grun.		+	+	+		+		+	+		+
53	<i>N. acicularis</i> W. Sm.	$\beta$ MS	4	3	3	+	+	+		1	2	3
54	<i>Cymatopleura solea</i> (Bréb.) W. Sm.	$\beta$ MS	1	+	+						+	
55	<i>C. elliptica</i> (Bréb.) W. Sm.	$\beta$ MS	+	1	1			+	+	1	+	1
56	<i>Surirella linearis</i> W. Sm.			+				+				+
57	<i>S. angustata</i> Kütz.		2	+		1		1	+		+	2
58	<i>S. robusta</i> v. <i>splendida</i> (Ehr.) V. H.			+			+					+
59	<i>S. tenera</i> Greg.		+			+					+	
60	<i>S. ovata</i> Kütz.		2	+				+		1		
	Chlorophyta											
61	<i>Scenedesmus acuminatus</i> Bréb.	$\beta$ MS	+	+	+		+			+	+	+
62	<i>S. quadricauda</i> Bréb.	$\beta$ MS	+	1	1	+	+	+				+
63	<i>Closterium moniliferum</i> (Bory) Ehr.	$\beta$ MS	+	+	+	+	+	+		+	+	+
64	<i>C. acerosum</i> (Schrank) Ehr.	$\alpha$ MS	+		+	+	+	1	+	1	+	
65	<i>C. Ehrenbergii</i> Menegh.	$\beta$ MS	+	+	+					+	+	+
	Euglenophyta											
66	<i>Euglena viridis</i> Ehr.	PS	+	1	+	+	2	2	1	+	+	
67	<i>Trachelomonas</i> sp.			+			+			+		+
	Rhizopoda											
68	<i>Amoeba proteus</i> L.	$\beta$ MS	1	1	1			+		1	+	+
69	<i>Arcella vulgaris</i> Ehr.		+			+				+		
	Flagellata apochromatica											
70	<i>Bodo saltans</i> Ehr.	$\alpha$ MS		1		+	1	2	1	+	+	
71	<i>Astasia klebsii</i> Lemm.	$\alpha$ MS	+			+	+	1	+	1	+	
	Ciliata											
72	<i>Chilodonella cucullulus</i> O. F. Müll.	$\alpha$ MS	+	+		+	1	1	+	1	+	
73	<i>Paramaecium bursaria</i> Focke	$\beta$ MS	1	+	+	+					+	+
74	<i>P. caudatum</i> Ehr.	$\alpha$ MS		+	+	1	1	1	+	1	+	
75	<i>Colpoda cucullus</i> O. F. Müll.	$\alpha$ MS			+	1	1	1	+	+		
76	<i>Metopus</i> es Clap. et Lachm.	PS		+		1	2	2	1	2		+
77	<i>Vorticella campanula</i> Ehr.	$\beta$ MS	+		+					+	+	+
78	<i>V. microstoma</i> Ehr.	PS			+	+	2	2	1	1		
79	<i>V. convallaria</i> Noland	$\alpha$ MS				+	2	1	+	+	+	
	Oligochaeta											
80	<i>Stylaria lacustris</i> L.	$\beta$ MS	+		+	+						+
	Rotatoria											
81	<i>Brachionus urceus</i> (L.) Pestal.	$\beta$ MS	+	+		+				1		+

rably reduced speed with which decomposition products are being carried away. Consequently, this brings about the occupation of the dead flow zones by the assemblages of organisms which are adapted to the conditions predominating only within these low-capacity sites, in this case — to the conditions of considerably higher pollution of water, than in the zone of normal flow.

This phenomenon, which can appear in each water course, is of a considerable importance, particularly as concerns saprobiology, dealing with studies of water pollution, is based inter alia the sedentary periphyton assemblages of living organisms. The periphyton assemblages are, among other communities, also of some assistance in the general evaluation of a mean degree of water pollution (GOŁWIN 1967). However, the interpretation of the results of analyses

of samples taken from the periphyton assemblages occupying dead flow zones, can lead to completely erroneous generalizations as to the state of water pollution in the stream examined.

#### SUMMARY

Quantitative and qualitative evaluations have been made of the composition of periphyton communities found on the rocky bottom of their river Słęża, near Wrocław. It has been ascertained that in the dead flow zones, at a very low rate of water current, the periphyton communities are, characterized by the composition of species typical of more polluted waters, as compared with the periphyton found in the zones of a faster flow. Thus, when applying the analysis of periphyton for evaluation of degree of water purity in rivers, we should also take into account the conditions of water flow in the neighbourhood of sampling sites.

#### STRESZCZENIE

Wykonano jakościowe i ilościowe oceny składu zespołów peryfitonu kamienistego dna rzeki Słęzy w okół Wrocławia. Stwierdzono, że w martwych strefach przepływu, przy bardzo niskich szybkościach prądu wody, zespoły peryfitonu mają skład charakterystyczny dla wód silniej zanieczyszczonych — w porównaniu do peryfitonu miejsc o szybszym przepływie. Należy więc, posługując się analizą peryfitonu do oceny stopnia czystości wody w rzekach, brać pod uwagę warunki przepływu wody w najbliższym otoczeniu miejsca poboru prób.

#### REFERENCES

- AMBÜHL, H. 1959. Die Bedeutung der Strömung als ökologischer Faktor. *Schweiz. Z. Hydrol.*, 21, 133—264.
- GOŁOWIN, S. 1967. Bioseston rzeki Odry na odcinku Chalupki — Brzeg Dolny. (Bioseston of the Odra river within the sector of Chalupki). *Pr. Inst. Gosp. Wod.*, 4 (3), 87—98. (Engl. summ.).
- GOŁOWIN, S. 1967. Wektorowa metoda określania saprobowości jako sposób interpretacji wyników badań hydrobiologicznych przy ocenie stopnia zanieczyszczenia wód. (A vector method for saprobity determination as a way of interpretation of hydrobiological investigations at evaluating water pollution degree). *Pr. Inst. Gosp. Wod.*, 4 (4), 5—23. (Engl. summ.).
- LIEBMANN, H. 1960. *Handbuch der Frischwasser- und Abwassers-Biologie II*, München, R. Oldenburg.
- LIEBMANN, H. 1962. *Handbuch der Frischwasser- und Abwasser-Biologie 1*, Aufl. 2., Jena, G. Fischer Verlag.
- MAŃCZAK, H. 1964. Poprawa warunków tlenowych potoków górskich za pomocą zabiegów hydrotechnicznych na przykładzie rzeki Czerniawki. (The improvement of the oxygen conditions of mountain torrents by hydraulic constructions). *Pr. Inst. Gosp. Wod.*, 2 (3), 11—150. (Engl. summ.).
- STARMACH, K. 1955. *Metody badania planktonu*. [Methods of plankton investigation]. Warszawa, PWRL. (Polish).



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## HATCHABILITY OF THE EGGS OF *TRIOPS CANCRIFORMIS* BOSC IN DILUTED SEA-WATER

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### ABSTRACT

The eggs of *Triops cancriformis* showed the highest percentage hatchability at salinity of 5‰. At salinity higher than 20‰, the eggs did not hatch. A temporary stay in saline water brought about an acceleration of hatching. Similar, stimulating effect was that of later desiccation.

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### 1. INTRODUCTION

Among Branchiopoda, only *Artemia salina* has a rich literature dealing with its development and occurrence in waters of different salinities. The mature animals can live in water even completely saturated with salts (ca 222‰ after WATERMAN 1960). The experimental data on hatchability of eggs in this species are rare (e.g. DUTRIEU 1960). Many other Anostraca were reported to occur in waters of a considerable salinity. In the literature available to us, we failed to find any information on occurrence of Notostraca in saline waters. In general (e.g. MATHIAS 1937), it is thought that this group is typical for fresh waters and does not occur in brackish waters.

Few data can be found in literature on the effect of salinity and osmotic pressure on development and hatchability of eggs in aquatic invertebrates. DAVIS (1966) ascribed a significant role to changes in permeability of egg membranes and to changes in osmotic pressure in the process of hatching and development of *Diaptomus*. STYCZYŃSKA-JUREWICZ (in lit.), studying the effect of different concentrations of sea water on development of *Physa* eggs (Gastropoda), has reported on osmoregulatory role of capsular fluid. MATHIAS and BOUAT (1934) advanced a hypothesis on analogy between the action of desiccation and that of considerable hypertonic conditions of aquatic environment. These two factors act in a similar way, i.e., they both stimulated diapausing eggs of *Branchipus stagnalis*, to develop and hatch after they had been transferred to fresh water. Similar was found when measuring osmotic

pressure of hemolymph in a mollusc, *Coretus corneus* (KLEKOWSKI 1963). Both desiccation and the stay in diluted sea water had similar effect. The increase in freezing-point depression of hemolymph endurable for animals, was similar both after desiccation and after sea-water treatment. However, the physiological mechanisms of these phenomenon were different. At desiccation, the hydration of hemolymph was diminishing, whereas in sea-water the increase of freezing-point depression resulted from penetration of ions from the external environment.

In previous paper (HEMPEL-ZAWITKOWSKA, KLEKOWSKI 1968), the effect of desiccation on development and hatchability of the eggs of *Triops cancriformis* Bosc was studied. The aim of the present study is to perform analogous experiments, using sea-water as treatment factor.

## 2. MATERIAL AND METHODS

The eggs used in the experiments were collected in the same manner as for the previous study (HEMPEL-ZAWITKOWSKA, KLEKOWSKI 1968). They were removed from the egg pouches (for method see: HEMPEL 1963) of parthenogenetic females. The animals were caught in a fish pond (fry pond I) of the fish farm Łąki Jaktorowskie near Warsaw, in June 1966. This pond contains water for 6—8 weeks of each season (May—July). *Triops cancriformis* was found to be an abundant and permanent inhabitant in this pond (HEMPEL-ZAWITKOWSKA 1967). The main treatments of the experiments are presented in Table I, with subsequent stages marked by numbers (e.g. [4]), to which we will refer in the further text on methods. Before the start of the experiment, the eggs were kept in the pond water for 24 hrs at a temperature of 20°C [1]. All of the experiments were carried out at a room temperature (about 20°C). Two types of experiments were designed. A. The eggs were kept in sea-water throughout the whole experiment [2]; B. The eggs stayed in saline water for an appropriate, planned period of exposure and later on they were transferred to fresh water where their hatchability was checked [3]. The artificial sea-water was used (acc. to HALE 1958).

A group of around 500 eggs was placed into each of 50 ml containers filled with sea-water or its different dilutions (5, 10, 15, 20, 25, 30, 34‰) [4]. After

Table I

Design of experiments

Removal of eggs from egg pouches	
One day in pond water [1]	
Type A Hatching in saline water [2]	Type B Hatching in fresh water after stay in saline water [3]
Sea-water: 5, 10, 15, 20, 25, 30, 34.33‰, stay for 40 days; hatchability recorded every 1—2 days. [4]	Sea-water: 5, 10, 15, 20, 25, 30, 33, 34‰, stay for 2, 7, 11 days. [5]
Washing with fresh water, drying in air for 3 weeks [7]	Tap water, stay up to 30 days, hatching checked every 1—2 days. [6]
Tap water, stay up to 2 weeks, hatching records. [9]	Drying in air for 3 weeks [8]
	Tap water, stay up to 2 weeks, hatching records. [10]

2,7 and 11 days, portions of 100 eggs were taken from each container and transferred to new containers with conditioned tap water. The remaining eggs, over 100 in each container, were left in sea-water for 40 days [4]. During this time the number of hatched eggs was recorded, at the beginning — daily, later on — every second day.

The egg after a stay in sea water (type B) were transferred to fresh water [6] and stayed there for 30 days, during which their hatchability was recorded.

Both the eggs which had stayed in sea-water (type A) and those transferred to fresh water (type B), were later removed from water and air dried for about 3 weeks [7, 8]. Next, the eggs were placed again into conditioned tapwater, their hatchability being checked during further 2 weeks [9, 10]. The desiccation was applied in order to break a possible diapause in unhatched eggs and to cause their development and hatching. Those eggs which did not hatch after this stimulus were considered as dead.

The control series consisted of a part of eggs taken from the eggs stocked for experiments and placed in tap water. There were two such series: in aerated and in non-aerated water.

### 3. RESULTS

#### A. CONTINUOUS STAY IN SEA-WATER AND IN ITS DILUTIONS

The highest per cent of hatched eggs was observed (Fig. 1) in sea-water with salinity of 5‰. In this medium 95% of eggs were hatched after 22 days. Thus, the hatchability in this treatment was even higher than in both the

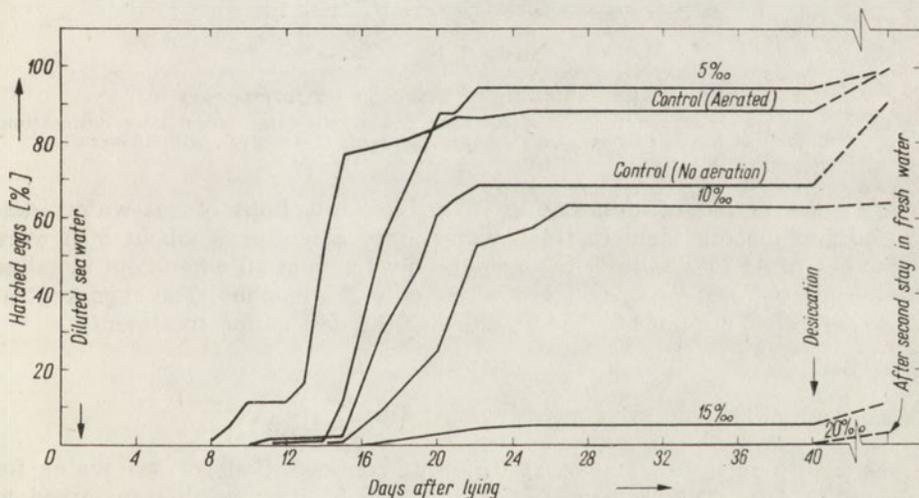


Fig. 1. Hatching of *Triops cancriformis* eggs in diluted sea water of different salinity as percentage of initial number

control series, aerated (ca. 83%) and non-aerated (ca. 69%). At 10‰ concentration, the hatchability was much lower (about 63%), and in 15‰, only 6% of eggs was hatched. With further increase in salinity (i.e., 20, 25, 30, and 34.33‰) no hatches were observed.

The differences in percentage of hatching between control series were conspicuous. In aerated fresh water the hatching began earlier, followed faster, and was higher by about 20% than in non-aerated water.

Cumulative results of the second period of hatching after the desiccation treatment (Tab. I [9, 10]), are presented in Fig. 2. Of the eggs which did not hatch during the first period of submerging in water, the highest percentage of eggs hatched of these which were kept in non-aerated fresh water. It can be supposed that these conditions caused death of about 10% of eggs, since in aerated water all the eggs which had failed to hatch in the first period were able to hatch in the second period following the desiccation.

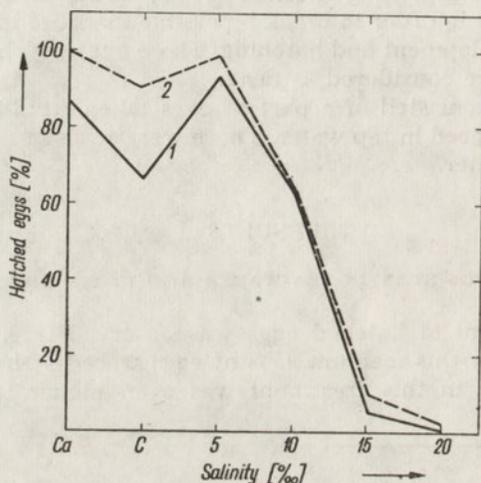


Fig. 2. Cumulative hatching of *Triops cancriformis* eggs in:

- 1 — diluted sea-water of different salinities and, 2 — fresh water (after later desiccation) as percentage of initial number. CA — control, aerated, C — control, without aeration

After the period of submerging in all concentrations of sea-water, desiccation and placing them in fresh water, only a few eggs (about 5%) were able to hatch. At 20‰ salinity the eggs did not hatch at all when kept in saline water, and on transferring to fresh water only 2% hatched. The eggs kept at higher salinities, did not hatch at all after the desiccation treatment.

#### B. LIMITED STAY IN SEA-WATER AND IN ITS DILUTIONS

The eggs which had stayed at different concentrations of sea water for 2, 7 and 11 days (Tab. I. Type B [5]; Fig. 3, 4, 5) after being transferred to fresh water, hatched the better (in higher percentage), the lower was the concentration of sea-water. The only exception were these eggs which stayed for 2 days at 5‰ salinity (Fig. 3a), they hatched in lower percentage than those kept previously in 10‰ concentration. After the stay in sea-water at concentrations higher than 20‰ (25‰ and more), no hatching was observed.

At salinities 5, 10, 15‰, the eggs hatched earlier than in control series. This regularity was clearly expressed, in all the exposure times: 2 (Fig. 3a), 7

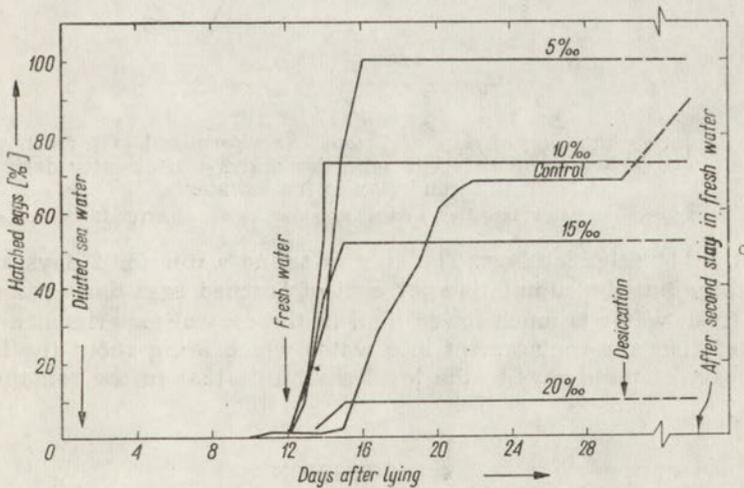
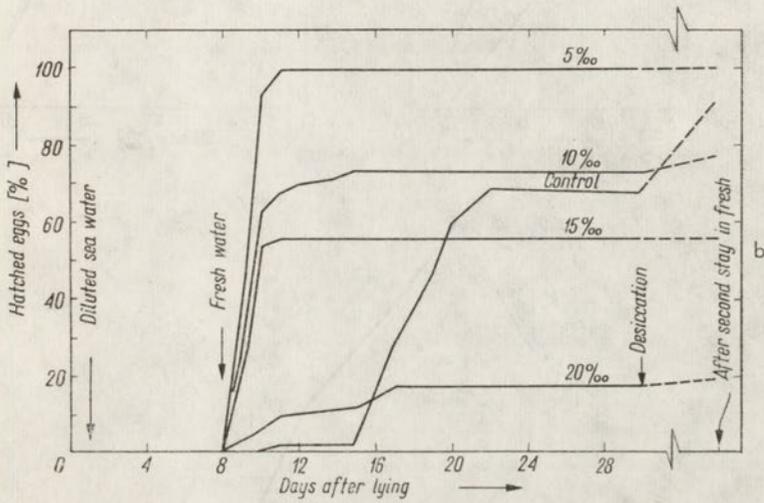
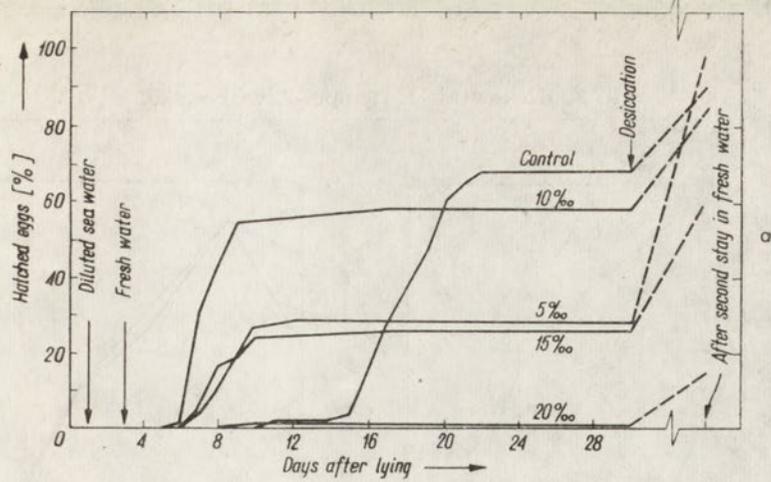


Fig. 3. Hatching of eggs of *Triops cancriformis* in fresh water after stay in diluted sea-water of different salinities  
 a. After 2 days in saline water, b. After 7 days in saline water, c. After 11 days in saline water

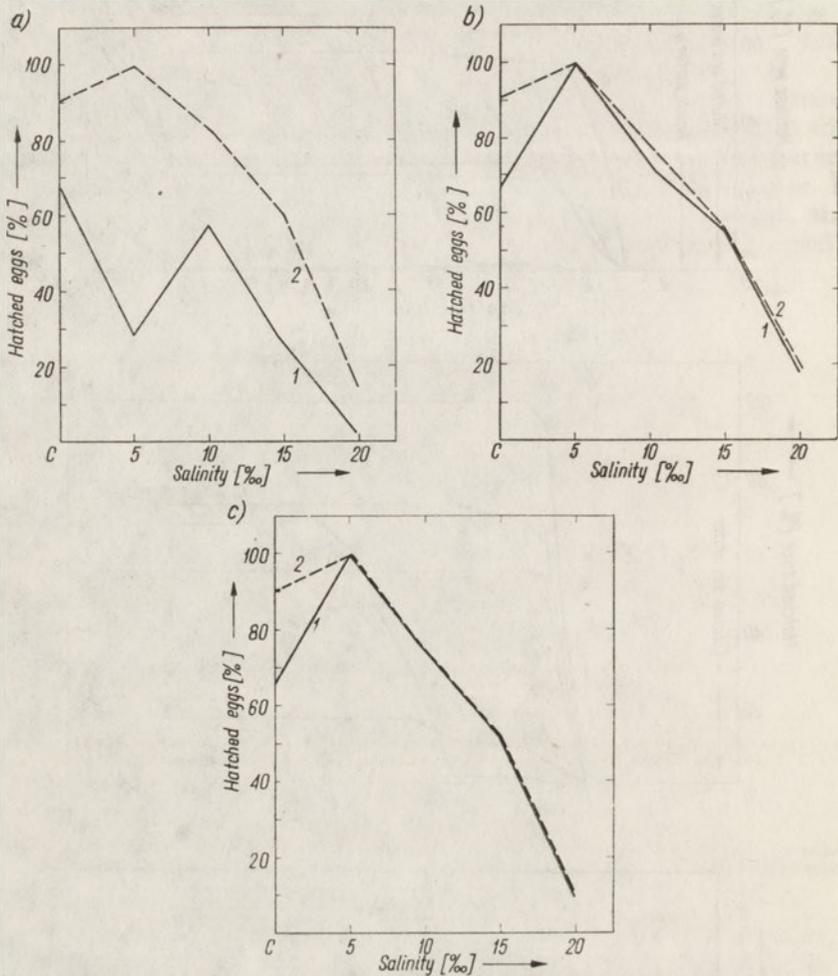


Fig. 4. Cumulative hatching of eggs of *Triops cancriformis*: 1 — in fresh water after stay in diluted sea-water of different salinities and 2 — after later desiccation, during second stay in fresh water

a. After 2 days in saline water, b. After 7 days in saline water, c. After 11 days in saline water

(Fig. 3b), or 11 (Fig. 3c) days. The stay in saline water for 2 days accelerated the hatching but the cumulative per cent of hatched eggs during their further stay in fresh water is much lower than in the control experiments. These are the desiccation and replacement into water which bring about the increase in hatchability of these eggs to the level similar to that in the remaining series (Fig. 4).

#### 4. DISCUSSION

The observed acceleration of hatching due to the effect of sea-water allows to suppose that the effect of sea-water is directly proportional to the time of exposure and to the concentration of salts. Similarly as in the case of

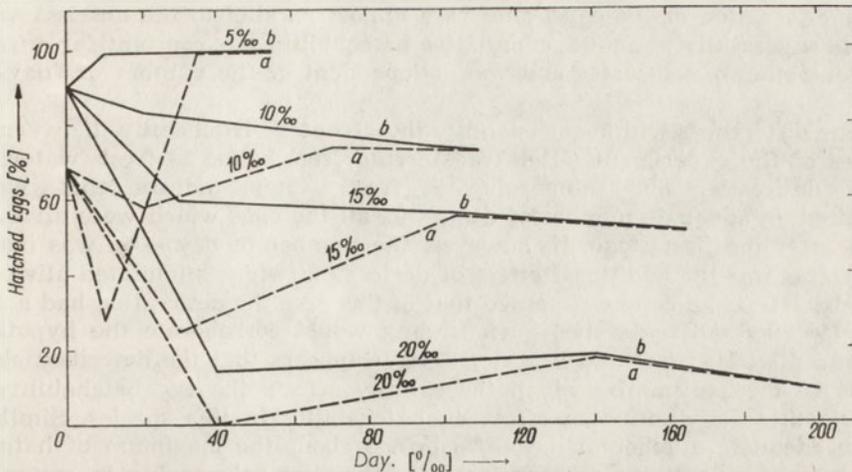


Fig. 5. Intensity of hatching (‰) as a function of day — ‰ for different concentrations as sea-water

a — cumulative % of hatching after transferring from saline water to fresh water, b — cumulative hatchability after desiccation and second submerging in water

the effect of temperature on the embryonic development e.g. in fish, the number of days multiplied by concentration of saline water (in ‰) for each duration and concentration, and these products will result in so-called “day-per-mill” (day — ‰) per analogiam to “day-degrees” (Tab. II). Figure 5 shows the intensity of hatching (‰) as a function of day — ‰ for each concentration of sea-water. The control series were considered as day — ‰ equal 0. Different curves represent two stages of the experiments i.e., 1) cumulative percentage of hatchings after the eggs were transferred from saline water to fresh water (Tab. IIb) and 2) total, cumulative hatchability after desiccation and second submerging in water (Tab. IIc).

Table II

Exposure to sea-water (days)	Concentration of sea-water (‰).											
	5			10			15			20		
	a	b	c	a	b	c	a	b	c	a	b	c
2	10	28.4	99.9	20	58	84	30	25.4	59.9	40	0.9	14.9
7	35	99.9	99.9	70	73.0	77.0	105	55.6	55.6	140	17.7	19.2
11	55	100	100	110	72.7	72.7	165	51.4	51.4	220	9.6	9.6

a. Number of “day-permille”, b. Per cent of eggs hatched in fresh water, after prior exposure to sea-water of a given salinity (Tab. I, [5]), c. Per cent of eggs hatched additionally after desiccation and submerging in fresh water (Tab. I [10]).

All the curves pertaining to the first stage of experiments (Tab. IIb) showed the lowest per cent of hatches for the lowest (for each series) number of day ‰. Later on, the per cent of hatches for the lowest (for each series) number of day ‰. Later on, the per cent of hatches rose and stayed at more or less constant level, different for each of concentrations. The curves representing the results of the 2nd stage of experiments (Tab. IIc), did not show any decline

after desiccation of the eggs, and were almost parallel to the abscissa which would suggest that the total, cumulative hatchability was constant for different concentration of sea-water and was independent of the number of "day-per-mille".

The differences within each salinity in percentage hatchability between two stages of the experiment (after transferring from saline to fresh water, and after desiccation and submerging in fresh water) indicate that, having acquired an adequate number of day — ‰, all the eggs which were alive hatched after the first stage. If, however, the number of day — ‰ was insufficient, this was the additional effect of desiccation which stimulated alive eggs to hatch. Hence, it can be supposed that in this case the desiccation had a similar effect as had sea water. Such finding would corroborate the hypothesis advanced by MATHIAS and BCUAT (1934). It appears that the described above, tentative mechanisms by which the salinity affects the egg hatchability resemble those of desiccation effect on hatchability in this species. Similarly, as an adequate number of day — ‰ brings about the maximum of hatching within a given salinity as early as after the first submerging in water, the desiccation which is long enough or recurring, triggers the hatchability of eggs shortly after their desiccation (HEMPEL-ZAWITKOWSKA 1967).

## 5. CONCLUSIONS

Sea-water affects the developing eggs of *Triops cancriformis* in two ways:

1) it accelerates their development, making the eggs ready for hatching in a much shorter time than is needed for development of the eggs in fresh water. From the comparison of hatchability values in fresh water and at 5‰ salinity, it can be assumed that the latter concentration can stimulate the development and hatching even of those eggs (about 10% of initial number) which would have not hatched after a single stay in fresh water, thus it promotes hatching of all the eggs used in the experiments.

With increasing number of day — ‰, the difference in percentage hatchability between the two stages of the experiments was found to diminish, as indicated by converging lines in Fig. 5.

2) At concentrations higher than 5—10‰, the sea-water has a harmful effect depending on killing rather a high percentage of eggs, this percentage being directly proportional to the increase in salt concentration. The toxic reaction can be already seen after the shortest in these experiments exposure to sea-water (2 days) and this effect does not increase with prolonged time of exposure up to 11 days, within a given salinity. From this, it can be inferred that the toxic agent present in sea-water (perhaps increased osmotic pressure) affects only these eggs which differ from the rest of them in some respect, and become vulnerable to this factor.

## 6. SUMMARY

Records were made of percentage hatchability of *Triops cancriformis* eggs developing and hatching at different concentrations of sea-water, or hatching in fresh water after a prior stay in sea-water, at the same concentrations. The eggs which did not hatch for the first time were dried and placed again in fresh water in order to find out additional hatches (see: design of experiment — Tab. I).

The highest per cent of hatches was that at 5‰ salinity (higher than in fresh water); this percentage was decreasing with increasing salinity. At salinity higher than 20‰, no hatching was observed (Fig. 1). A limited stay in saline water (at all concentrations used) brought about a considerable acceleration of hatching in fresh water (Fig. 3a, b, c). At each salinity, the maximum of hatching followed after an adequately long exposure to saline water. Too short exposure to saline water can be compensated later by desiccation (Fig. 4a, b, c).

The toxic effect of sea-water, observed already at concentrations of about 10‰ (or somewhat less) became stronger with increasing salinity and was independent from the time the eggs staged in saline water, within the range of 2—11 days.

## 7. STRESZCZENIE

Rejestrowano % wylęgu jaj *Triops cancriformis* rozwijających się i legnących w różnych stężeniach wody morskiej lub też w wodzie słodkiej, po uprzednim pobycie w takich samych stężeniach wody morskiej. Jaja niewylęgte suszono i umieszczano powtórnie w wodzie słodkiej dla rejestrowania dodatkowych wylęgów (schemat doświadczeń: tab. I).

Najwyższy % wylęgów miał miejsce w zasoleniu 5‰ (wyższy niż w wodzie słodkiej), malał wraz ze wzrostem zasolenia; w zasoleniu większym niż 20‰ wylęgów nie obserwowano (rys. 1).

Okresowy pobyt w wodzie zasolonej, we wszystkich użytych stężeniach powoduje znaczne przyspieszenie wylęgów w wodzie słodkiej (rys. 3a, b, c). Dla każdego zasolenia maksimum wylęgów następuje dopiero po odpowiednio długim pobycie w wodzie słonej. Zbyt krótkie działanie stymulujące zasolenia może być skompensowane późniejszym przesuszeniem (Fig. 4a, b, c).

Toksyczne działanie wody morskiej występuje już w stężeniach od ok. 10‰ (lub nieco niższych), wzrasta proporcjonalnie do wzrostu zasolenia i nie zależy od czasu pobytu jaj w wodzie zasolonej, w granicach 2—11 dni.

## REFERENCES

- DAVIS, C. 1966. Hatching processes in the eggs of aquatic invertebrates. *Verh. int. Ver. Limnol.*, 16, 1685—1689.
- DUTRIEU, J. 1960. Observations biochimiques et physiologiques sur le développement d'*Artemia salina* Leach. *Archs. Zool. exp. gen.*, 99, 1—133.
- HALE, L. I. 1958. *Biological laboratory data*. London, Methuen.
- HEMPEL, J. 1963. Obserwacje biologiczne nad przepoknicą *Triops cancriformis* (Bosc) w warunkach naturalnych i w hodowli. (Biological observations dealing with *Triops cancriformis* (Bosc) under natural and laboratory breeding conditions). *Annls zool.*, Warsz., 20, (No. 18) 343—352. (Engl. summ.).
- HEMPEL-ZAWITKOWSKA, J. 1967. Natural history of *Triops cancriformis* (Bosc). *Zoologica Pol.*, 17, 173—239.
- HEMPEL-ZAWITKOWSKA, J., KLEKOWSKI, R. Z. 1968. The influence at different air humidities on hatchability of *Triops cancriformis* (Bosc) eggs. *Pol. Arch. Hydrobiol.*, 15, 183—189.
- KLEKOWSKI, R. Z. 1963. Water balance and osmoregulation in the snail *Coretus cornutus* (L.) under conditions of desiccation and in diluted sea-water. *Pol. Arch. Hydrobiol.*, 11, 219—239.
- MATHIAS, P. 1937. Biologie des Crustacés Phyllopoies. *Actual. scient. ind.*, 447, 1—106.
- MATHIAS, P., BOUAT, M. 1934. Sur le développement de l'oeuf de *Branchipus stagnalis* L. (Crustacé, Phyllopoie). *C. R. hebd. Séanc. Acad. Sci., Paris*, 199, 320—322.
- STYCZYŃSKA-JUREWICZ, E. (in lit.) Osmotic properties of egg-capsule fluid of *Physa acuta* Drap. (Gastropoda) at different salinities.
- WATERMAN, T. H. 1960. *The physiology of Crustacea*. Vol. 1. New York. Academic Press.



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A. CHODOROWSKI

## PREDATOR-PREY RELATION BETWEEN *MOCHLONYX CULICIFORMIS* AND *Aedes COMMUNIS*

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### ABSTRACT

Three types of predator-prey relation between *Mochlonyx culiciformis* and *Aedes communis* i.e. the parallel, the retarded and the self-regulating, were observed under differing climatic spring conditions. In the self-regulating type of predation cannibalism appears. The preying-degree of *Mochlonyx culiciformis* on the larvae of *Aedes communis* increases with the raising of water level and with the overcrowding of populations.

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### 1. INTRODUCTION

Since the larvae of mosquitoes occur in great numbers in ephemeral pools, they form excellent preying conditions for the species of predators feeding on them. The chief enemies of *Aedes communis* larvae in sylvatic ephemeral pools of the Kampinos Forest are the larvae of *Mochlonyx culiciformis* (Culicidae, Chaoborinae). Another representative of this subfamily — *Chaoborus crystalinus* — also a predator, occurs in deeper and more permanent sylvatic pools (most frequently in depressions of canals). In the water bodies such as flooded meadows and depressions in reedgrass, the most frequent enemies of mosquitoes are, beside the amphibians, are *Mesostoma lingua* (Turbellaria) and the larvae of dragonflies and beetles.

The relation predator-prey, one of many kinds of nutritional interrelations in CLEMENTS and SHELFORD (1939) coactions system, takes place (ODUM 1954) between two species, when one of them is actively destroyed by the other and the abundance of predator depends on the abundance of its prey. GAUSE (1934a, 1934b) investigated under experimental conditions the types of predator-prey relation between two species of protozoa: *Didinium nasutum* (a predator) and *Paramecium caudatum* (its prey). In the case when the prey cannot protect itself from the predator, first the former and, then — the latter perish. If the prey can find shelter, usually the predator becomes extinct after a series of varied abundance fluctuations. A perma-

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nent occurrence of both the species, if their abundance varies periodically, may be retained when both the component species regularly immigrate. When the prey abundance lowers below minimum, the population of the predator defends itself against extinction by beginning to feed on other species (buffer species) or by cannibalism (rule of "scarcity-escape" — WOODBURY 1954).

A straight predator-prey relation between *Mechlonyx culiciformis* and *Aedes communis* (CHODOROWSKI 1958a), which may nearly serve as a model for predator-prey relation, occurs in the sylvatic ephemeral pools of Kampinos Forest during the phase of mosquito larvae dominance (CHODOROWSKI 1958b, 1961). The characteristic feature of this system is the impossibility of any increase of either of the investigated populations because no reproduction occurs at these stages of development. Occasionally there are periodic hatchings of mosquito larvae (MONCADSKY, BERZINA 1959) which increase the abundance of predator or that of the prey, and they could cause the identical ecological effect as reproduction itself they have not, however, been observed in the investigated reservoirs.

The larvae of *Mochlonyx culiciformis* possess a distinct manner of feeding. Suspended motionless in water, they wait for a prey to approach and then suddenly catch it in the middle, with a suitable organized oral apparatus, and devour it. According to MONCADSKY and BERZINA (1959) the larvae of *Mochlonyx culiciformis* preying from the beginning of their development on the uniform food (e.g. the larvae of *Aedes*) for conditioned reflex helpful in arising some difficulties in attacking other species. A suitable hydrostatic apparatus (air bubbles) and respiration of the air dissolved in water enable the larvae to hang motionless in one spot for a very long time. Contrary to the larvae of *Mochlonyx*, the larvae of *Aedes* are compelled to move constantly between the bottom (feeding area) and the water surface (area of respiration). During this trajectory, they might be subject to attacks of predators. Usually the *Mochlonyx* larvae do not attack any larvae feeding on the bottom nor those near the water surface. These areas are the refuge of the *Aedes* larvae from predators. It has not been observed that the *Mochlonyx* larvae attacked the pupae of mosquitoes, gathering usually near water surface. Similar observations were made by MONCADSKY (1959). He explained them by stating that in the case of *Mochlonyx* larvae there is a lack of formed reflex for catching the pupae, which move in a quite different way than the larvae.

The methods of investigation were described in the other paper (CHODOROWSKI 1968), a detailed description of reservoirs and of climatic and hydrographic conditions in the Kampinos Forest was given formerly by CHODOROWSKA, CHODOROWSKI (1958).

## 2. RESULTS

### A. PARALLEL TYPE OF PREDATION

The larvae of *Mochlonyx culiciformis* appear in the reservoir immediately after hatching of the *Aedes* larvae. The relative abundance of the two species varies and near the end of their larval period it favours the predator. In most of the cases predator abundance does not exceed 20% that of its prey.

To understand the influence of drying processes on the development of *Aedes communis* — *Mochlonyx culiciformis* relation, some series of experiments concerning the influence of water quantity and density of population have been carried out.

#### a. Influence of water-quantity

##### Experiment No. 1AB

On June 12, 1955 the material was sampled from pool M<sub>17</sub> and it was arranged in 2 series (4 aquaria in each). A — 2.5 l of water in each aquarium B — about 3 times more i.e. 8 l. During the initial phase in series A there were

about 50—70 larvae of *Aedes communis* in a aquarium (average 24 ind./1); in series B about 130—175 larvae in an aquarium (average 20 ind./1). At the same time there were about 4—7 larvae of *Mochlonyx culiciformis* (average 2.3 ind./1) in series A and about 13—18 larvae in series B average: 2 ind./1. The decrease

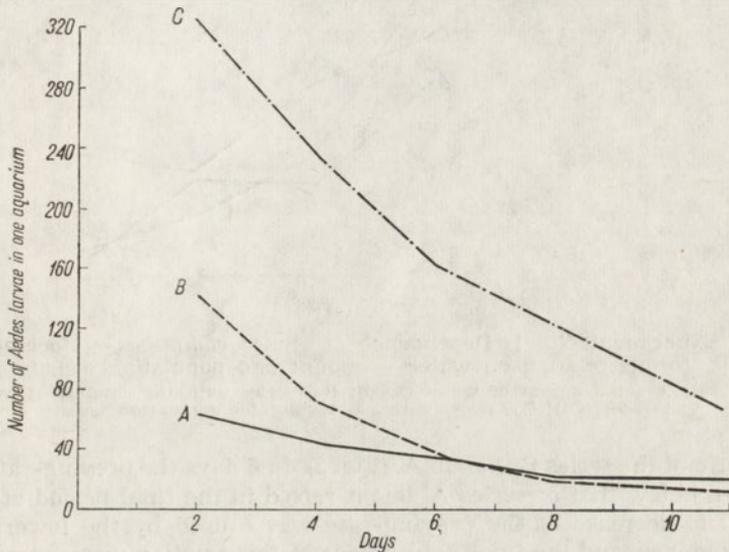


Fig. 1 — A decrease of *Aedes communis* number because of preying on the of *Mochlonyx culiciformis*

A — series with a small amount of water (2.5 l); B — series with the amount of water 3 times greater (8 l); C — series with 5 times greater population density

of the number of larvae, due to predation was faster in aquaria of series A than in those of series B (Fig. 1A, B). After 5 days the abundance in both of the series became nearly equal, and in series B the abundance even settled below that of series A. The density of the larvae (i.e. ind./1) in the final days of the experiment was several times lower in series B only 2 ind./1 than in

Table I

The influence of water — quantity on average number of *Aedes communis* larvae consumed by larva of *Mochlonyx culiciformis* in 24 hours

No. of experiment	Amount of water		Increase of preying rate
	2—3 ls	4—9 ls	
1 AB	0.81	1.05	29%
2	0.2	0.51	155%
3	0.64	0.97	48%
4	1.8	4.1	128%

series A 10 ind./1. Rate of preying i.e. the number of *Aedes communis* larvae which were eaten by a larva of *Mochlonyx culiciformis* in 24 hours, was higher (mean value c. 29%) in the aquaria with more water (Table I) then in the others. At the beginning of the experiment the preyin-rate was much higher in

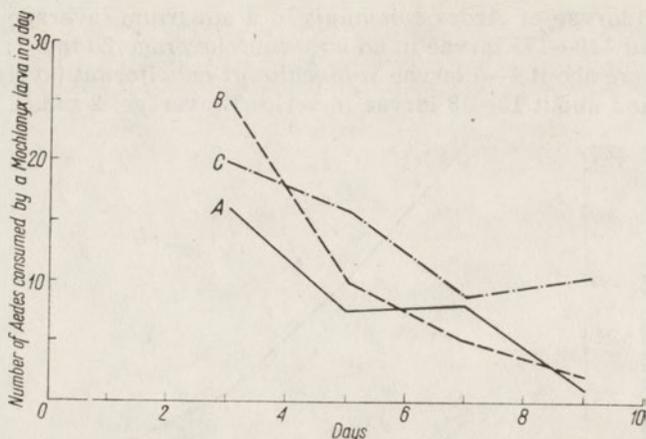


Fig. 2. — Experiment No. 1. Dependence of *Aedes communis* — *Mochlonyx culiciformis* relation on water — amount and population density  
 A — series with a small amount of water (2.5 l); B — series with the amount of water 3 times greater (8 l); C — series with 5 times greater population density

the aquaria of the series B than in A. (Fig. 2). In 6 days the preying-rate in series B lowered below that of series A, but it raised in the final period of the experiment. The decrease of the preying-rate was caused by the lowering of the prey-abundance, and the final fluctuations of this relation were connected with the pupation — period of both species.

#### Experiment No. 2

On May 3, 1956, the material was taken from pool No. M<sub>17</sub> (water and mosquitos) and it was distributed into 2 series, 4 aquaria each. 1) 9 l of water each, 2) 3 l of water each. In the aquaria of series (1) were 166 *Aedes communis* larvae at the beginning and 42 larvae in the last phase of their development just before pupation. Rate of preying in the aquaria with more water higher (155%) that in aquaria with less water (Table I).

#### Experiment No. 3

On February 19, 1957, the material was taken from pool No. C<sub>6</sub> and it was distributed into 2 series, 8 aquaria in each. There was twice as much water from the pool in one series (4 l) than there was in other (2 l). The average density of *Aedes communis* population was 11 individuals in 1 l. Rate of preying was higher (about 48%) in the series with more water, than in that with less water (Table I).

#### Experiment No. 4

On April 14, 1957, the material was taken from the pool No. D<sub>10</sub> and it was distributed into 2 series, 2 aquaria in each. The quantity of water from the pool, together with the larvae (average — 12 ind./l) was identical in both series (2 l) but to one of them 2 l of distilled water had been added. Rate of preying was very high in the both cases, but in the aquaria with more water it was higher

about 128% (Table I). Here, when *Mochlonyx* larvae destroyed the whole population of *Aedes* larvae, the former began to practice cannibalism.

It follows from the above, that the volume of the vessels of the same shape influence the increase of preying-rate of the *Mochlonyx culiciformis* larvae on the larvae of *Aedes communis* (Mean value: 29—155%). This may be explained by the fact that *Mochlonyx culiciformis* encounters its prey more often when the larvae of *Aedes communis* are compelled to pass the longer distance from the bottom to the surface.

### b. Influence of population overcrowding

#### Experiment No. 1C

At the same time as the experiment No. 1AB, series C was prepared. It consisted of 4 aquaria, 2.5 l of water in each and the population of both the species has been condensed (5 times). Initially there were 300—500 individuals of *Aedes communis* larvae in 1 aquarium (average density 130 ind./l) and 16—25 individuals per aquarium (average density: 8.8 ind./l of *Mochlonyx culiciformis*. The decrease in number of *Aedes communis* larvae (Fig. 1C) is more distinct as compared than in series A (experiment No. 1AB), but the density of population in the final phase of the experiment was about 3 times higher than in series A reaching 31 ind./l. The rate of preying of *Mochlonyx* larvae on *Aedes* larvae was about 38% higher in the aquaria in which the population was 5 times denser (Table II), than in others.

Table II

The influence of overcrowding of organism on the average number of *Aedes communis* larvae devoured by a larva of *Mochlonyx culiciformis* in a day 24 hours

Experiment No.	Density of organisms		Increase of preying-rate
	Normal	5 times higher	
1C	0.81	1.12	38%

The increase of density (about 5 times) of the investigated populations influences the preying-rate of *Mochlonyx culiciformis* larvae because the individuals of both species can meet more often. A comparison of the above results with those of the experiment No. 1AB shows that a fivefold increase of density influences the preying on *Aedes communis* larvae only slightly more than therrefold enlargement of water volume.

### B. RETARDED TYPE OF PREDATION

#### Experiment No. 5

On April 17, 1956 the material was taken from reservoir C<sub>6</sub> and 2 series, 4 aquaria in each, have been started. In the first series there were 3 l of water, in the second 9 l. The density of *Mochlonyx* larvae was in both series equal to about 2 ind./l. The larvae of *Mochlonyx* did not prey on the *Aedes* larvae and their growth was hindered. At the end of April all the individuals

of *Aedes communis* reached imago stage but those of *Mochlonyx* remained for some weeks at the larval stage I or II. At the end of the experiment there was a distinct layer of bacteria in the aquaria (in the form of a foggy cloud), above which there were *Spirostomum ambiguum* and *Mochlonyx* larvae in succession. It is possible that the latter fed on the former because of lack of any other food, but it was not proved, neither was cannibalism observed.

The *Mochlonyx* larvae, when deprived of the basic food, do not develop and they die out due to starvation if they cannot find suitable "bufer species". The fact that these predators do not shift to cannibalism in the early developmental stages might be explained, according to MONCADSKY and BERZINA (1959), by the lack of adaptations to prey on large animals resembling the predators themselves, or by the lack of cannibalism in the early development stages of the larvae, especially in the population with the density of 2 ind./l.

### C. SELF-REGULATING TYPE OF PREDATION

#### Experiment No. 6

The experiment was organized as the designed one in the parallel type. During one day the *Mochlonyx culiciformis* larvae destroyed the rest of *Aedes communis* population and they began feeding upon themselves (Fig. 3). In the normal series (water undiluted) the number of larvae decreased by about

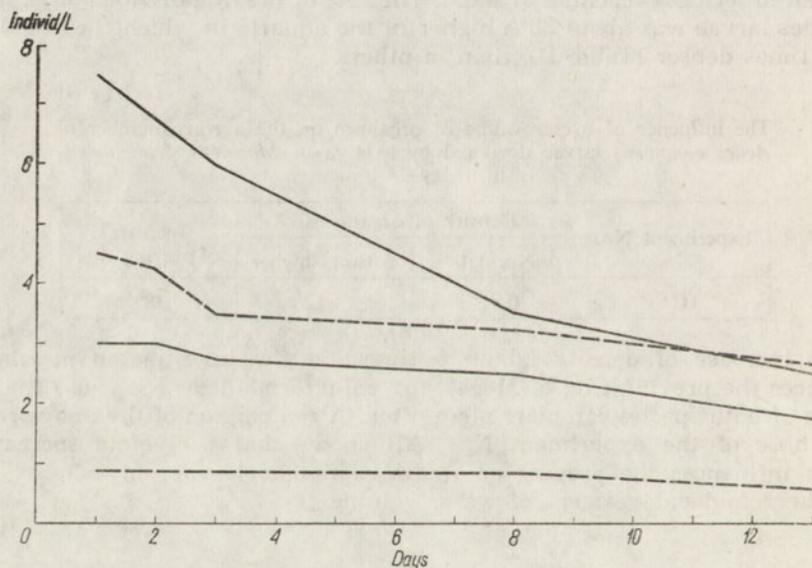


Fig. 3.— Experiments No. 6 and 7. Dependence of cannibalism of *Mochlonyx culiciformis* larvae on water—amount and population density—5 times; unbroken lines—series with small amount of water (2 l); broken lines—series with greater quantity of water (4 l)

50% in one aquarium and about 25% in the other, during 5 days. In the aquaria with diluted water (2 times) the cannibalism was less established. The decrease in population density (number of ind./l.) due to the cannibalism is presented in diagrams (Fig. 3)

## Experiment No. 7

The sample was taken on April 14, 1957 from the pool No. D<sub>10</sub>, it was condensed to 0.2 of the initial volume and placed in 2 series, 2 aquaria in each. One series contained 2 l of water, to the other one the distilled water was added so that together there were 4 l of water in the aquaria of this series. In the initial hours of the experiment the *Mochlonyx* larvae began devouring each other and the cannibalism was more distinct here then in the previous experiment (Fig. 3), especially in the aquaria with undiluted water. Finally, the density of *Mochlonyx* population, disregarding the initial phase, lowered to 2—3 ind./l.

## Experiment No. 8

The material sampled on April 2, 1959 from the pool No. C<sub>6</sub> was divided into 2 series, 6 aquaria in each. From one series all the *Aedes communis* larvae were removed, in the second series all the *Mochlonyx* larvae were preying on the *Aedes* larvae as they usually did. There was no cannibalism in the series devoid of the *Aedes* larvae, probably due to the fact that the crowding of predator population was too small (average number: 2 individuals in 1 l). The pupation of the *Mochlonyx* larvae appeared earlier in the aquaria with larvae of *Aedes* than in those devoid of them; the top point was about 48 hours earlier (Table III).

Table III

The influence of *Aedes* larvae removal on the pupation-rate of *Mochlonyx culiciformis*: Experiment No. 8

Series	% pupating <i>Mochlonyx</i> larvae in days		
	8	9	10
With <i>Aedes</i> larvae	77	77	88
Without <i>Aedes</i> larvae	22	27	55

It follows from the above, that when the density of the *Mochlonyx culiciformis* larvae is higher than 3 ind./l. The typical reaction on "scarcity-escape" (WOCDBURY 1954) is cannibalism in the case of a sudden extinction of prey species. According to MONČADSKY and BERZINA (1959), the turn to cannibalism of the larvae of *Mochlonyx culiciformis*, which usually prey on larvae of her mosquitoes, is a normal phenomenon, because of a rather mechanical preying habits of the species. When the density of *Mochlonyx culiciformis* population is lower than 2—3 ind./l, usually no cannibalism occurs, as the possibility of meeting of two predators is too small. The population of predator either dies out, or ends its development in starving conditions or begins to prey on other substituting species.

## 3. DISCUSSION

The biocoenotic system *Mochlonyx culiciformis* — *Aedes communis* is a predator-prey relation in which the species being preyed on may escape from its predator; but there is no abundance increase of either of the component spe-

cies because the larvae do not reproduce themselves. The shelter of *Aedes communis* larvae from those of *Mochlonyx* is the feeding area of *Aedes* and a water layer immediately below the water surface, where the larvae gather to breathe the atmospheric air. When the samples of biocoenosis are transferred from the natural station into the laboratory, the "shelter" area in aquaria seemed to diminish, because after the beginning of the experiment the *Aedes communis* population becomes scarce. In some cases (experiments Nos 6 and 7) the larvae of *Aedes* were exterminated in the initial hours of the experiment though in natural conditions they survived for a longer period in spite of a considerable *Mochlonyx culiciformis* abundance.

The larvae of *Mochlonyx culiciformis* prey when those of *Aedes communis* wander between the bottom and the water-surface in the reservoir. When this route is longer (in the series where more water is used) the possibly of meeting the predator increases and thus the rate of preying of *Mochlonyx* on *Aedes communis* larvae rises too. The increase of population density gives similar results, for it also leads to a greater number of contacts between the predator and its prey<sup>1</sup>.

As opposite to the normal (parallel) type of predator-prey relation, in the case when the predator cannot prey on the *Aedes communis* larvae, the *Mochlonyx* larvae follow the rule of "scarcity-escape" and either engage in cannibalism, or try to prey on other species. If the larvae of *Mochlonyx* cannot prey on *Aedes* larvae from the beginning, as it happens in the retarded type, and the density is small (less than 2—3 ind./l.), no cannibalism occurs. If the density of population were higher, the cannibalism would probably develop too, in spite of the lack of conditioned reflexes, which according to MONCADSKY, enable the animal to prey on "mosquito-like" organism. In the retarded type, because of lack "buffer" species in the ephemeral pools of the Kampinos Forest, the development of the predator is so poor, that *Mochlonyx* larvae cannot pupate before the drying up of the pool.

Self-regulating type of the predator-prey relation was observed when the predator in its final stages of larval development (III or IV stage) was devoid of its basic food and when at the same time, the density was rather high. In natural conditions such an event occurs when at the end of the first domination phase, the water body freezes for several days. This exterminates the *Aedes* larvae since they breathe with atmospheric air, but the larvae of *Mochlonyx* survive because of their respiratory exchange through the skin. In such a case the cannibalism develops, immediately the larvae pupate and some of them leave reservoir. This cannibalism takes place as a rule among the dragonfly larvae *Lestes nympha* in spite of abundant food (FISCHER 1961, 1964).

<sup>1</sup> The chance of *Aedes communis* larvae to be caught by a predator when the larvae migrates between the bottom and the surface doubles when there is three times more water and it nearly triples, when the population density increases 5 times but the same quantity of water is retained. The preying chance (P) can be calculated, provided that the predator is randomly distributed in the water, from the Poisson formula

$$p = 1 - e^{-\lambda \pi r^2 h}$$

(where: e—the base of the Natural logarithmus;  $\lambda$  the mean number of predators per volume unit; r—the distance between the predator and its prey in which the prey might be captured; h—the distance between the bottom and the water surface).

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#### 4. SUMMARY

In sylvatic ephemeral pools of the Kampinos Forest, the system predator-prey: *Mochlonyx culiciformis* — *Aedes communis*, occurs. The latter species can escape from its predator. Because the larvae do not reproduce, the abundance of both the component species in the pool does not increase. This system, depending on the climatic spring conditions may occur in 3 types: 1) parallel type — *Mochlonyx* larvae develop parallelly to *Aedes* larvae and pupate immediately after them; 2) retarded type — *Mochlonyx* larvae develop with some retardation and they do not keep place in development with *Aedes* larvae and therefore the former cannot prey on the latter; 3) self-regulating type — the *Aedes* larvae are exterminated by heavy frost (ice — cover on water bodies) and the *Mochlonyx* larvae have no food.

The raising of the water level causes the increase of the preying of *Mochlonyx culiciformis* on the larvae of *Aedes communis*, because it increases the possibility of contact between the prey and the predator (Table I, Fig. 1—2). The similar result is achieved when the possibilities of encounters are increased by overcrowding of the population (Table II, Fig. 1—2).

When the development of *Mochlonyx culiciformis* is retarded in comparison with that of *Aedes communis*, the predator usually perishes because of lack of suitable food.

When the population of *Aedes communis* is destroyed before end of larval development of both the species, and crowding of a preying species is greater than 3 ind./l. the cannibalism and quantitative self-regulation of *Mochlonyx culiciformis* (Fig. 3) appears. When the density of predator population is smaller, the *Mochlonyx culiciformis* larvae of the III-rd and IV-th development stages pupate under in the conditions of the lack of basic food, and they are retarded in their growth for several days (Table III).

#### 5. STRESZCZENIE

W leśnych zbiornikach efemerycznych Puszczy Kampinoskiej występuje układ drapieżnik-ofiara; *Mochlonyx culiciformis* — *Aedes communis*, w którym gatunek niszczonej ma możliwość ucieczki przed drapieżnikiem, a ponieważ larwy nie rozmnażają się — nie dochodzi do zwiększenia liczebności obu komponentów. Układ ten w zależności od przebiegu wiosny może wystąpić w trzech głównych typach: 1° — równoległym, 2° — opóźnionym, 3° — samoregulacyjnym.

Podwyższenie poziomu wody wpływa na zwiększenie stopnia wyżerania larw *Aedes communis* przez *Mochlonyx culiciformis* ze względu na większą możliwość spotkań ofiary z drapieżnikiem (Table I, Fig. 1—2). Podobny rezultat osiąga się przez zwiększenie możliwości spotkań na skutek przegęszczenia obu populacji (Table II, Fig. 1—2).

Opóźnianie rozwoju *Mochlonyx culiciformis* w stosunku do *Aedes communis* powoduje na ogół wyginiecie drapieżnika na skutek braku odpowiedniego pokarmu.

Wyniszczenie populacji *Aedes communis* w okresie przed końcem rozwoju larwalnego obu gatunków, przy zagęszczeniu drapieżnika ponad 3 osobniki/l, wywołuje kanibalizm i samoregulację ilościową u *Mochlonyx culiciformis* (Fig. 3). Przy mniejszym zagęszczeniu drapieżnika, larwy III-go i IV-go stadium rozwojowego *Mochlonyx culiciformis* przepoczwarzają się w warunkach braku podstawowego pokarmu z kilkudniowym opóźnieniem (Table III).

#### REFERENCES

- CHODOROWSKA, W., CHODOROWSKI, A. 1958. Drobne zbiorniki Puszczy Kampinoskiej. — Szkic limnologiczny. (Small pools in the Kampinos Forest. — Limnological sketch). *Ekol. pol.*, Ser. B, 4, 203—223. (Engl. summ.).

- CHODOROWSKI, A. 1958 a. Wpływ wysychania zbiorników okresowych na stosunek drapieżnik-ofiara. (The influence of the drying-up of temporarily-formed pools on the relation between the predaceous insect and its victim). *Ekol. pol., Ser. B*, 4, 41—44. (Engl. summ.).
- CHODOROWSKI, A. 1958 b. Badania nad zmiennością układów biocenotycznych w okresowych zbiornikach Puszczy Kampinoskiej. (Examination of the mutability of biocenotic systems in the periodical pools of the Kampinos Forest). *Ekol. pol., Ser. B*, 4, 237—241. (Engl. summ.).
- CHODOROWSKI, A. 1961. Recherches sur la dynamique des espèces dominantes dans les eaux périodiques. *Verh. Internat. Verein. Limnol.*, 14, 1029—1034.
- CHODOROWSKI, A. 1969. The influence of desiccation of sylvatic ephemeral pools on the development rate of *Aedes communis* larvae. *Pol. Arch. Hydrobiol.*, (in press).
- CLEMENTS, F. E., SHELFORD, V. E. 1939. *Bio-ecology*. New York, Hapman & Hall.
- FISCHER, Z. 1961. Cannibalism among the larvae of the dragonfly *Lestes nympha* Selys. *Ekol. pol., Ser. B*, 7, 33—39.
- FISCHER, Z. 1964. Cycle vital de certaines espèces de libellules du genre *Lestes* dans les petits bassins astatiques. *Pol. Arch. Hydrobiol.*, 12, 349—382.
- GAUSE, G. F. 1934 a. *The struggle for existence*. Baltimore, Williams & Wilkins.
- [GAUSE, G. F.] ГАУСЕ, Г. Ф. 1934. О процессах уничтожения одного вида другим в популяциях инфузории. (Destruction of one species by another in populations of protozoa). *Zool. Zh., Mosk.* 13, 18—26. (Engl. summ.).
- [MONCADSKIJ, A. S.] МОНЧАДСКИЙ, А. С. 1959. Внутривидовые отношения у хищных личинок комаров подсемейства Chaoborinae (Diptera, Culicidae). (Intraspecific relations of predaceous larvae of the subfamily Chaoborinae (Diptera, Culicidae)). *Ent. Obozr.*, 38, 505—516. (Engl. summ.).
- [MONCADSKIJ, A. S., BERZINA, A. N.] МОНЧАДСКИЙ, А. С., БЕРЗИНА, А. Н. 1959. Внутривидовые отношения у хищных личинок комаров подсемейства Chaoborinae (Diptera, Culicidae). II. Intraspecific relations of predaceous larvae of the subfamily Chaoborinae (Diptera, Culicidae). — II). *Zool. Zh. Mosk.*, 38, 1554—1558. (Engl. summ.).
- ODUM, E. P. 1954. *Fundamentals of ecology*. Philadelphia, W. B. Saundres.
- WOODBURY, A. M. 1954. *Principles of general ecology*. New York, Blakiston Co.

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CRUSTACEAN PLANKTON OF SOME MAZURIAN LAKES  
CHARACTERIZED BY DIFFERENT FISH YIELD

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## ABSTRACT

Annual studies have been carried out on the plankton composition and seasonal changes occurring in it in six lakes of different morphology, chemism, and fish yield. Attempts were made to establish relationships, if there are any, between those properties and the crustacean plankton. There have been found pronounced differences and some similarities in the composition, dominants, and seasonal changes in particular species of the lake plankton under study. The number of species was the greater the deeper the lake but in the latter case the plankton density in the epilimnion was lower than in the shallower lakes. The plankton abundance grew with the electrolyte contents of the water. There was also found a quite distinct relationship between the average number and the character of the seasonal changes of the plankton and the fish yield of the lakes under study.

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## 1. INTRODUCTION

The present work is one of a series dealing with an analysis of environmental conditions found in lakes of different fish yield. To that purpose six lakes have been chosen; their annual yield ranges from as little as 2.0 to as much as 110 kg/ha. Those lakes are situated near Węgorzewo in a country which from the geological point of view is quite homogeneous. Their limnological characteristics can be found in the works by PATALAS (1960a, b, c, d), KONDRACKI and SZOSTAK (1960) and more detailed data concerning seasonal changes in their thermal conditions and chemism are provided by KORYCKA (1969). As limnological types they represent dystrophy (lake Smolak), a pondlike lake type (lake Arklickie), and different degrees of eutrophy (lakes Lemięt and Zywy). Lake Upinek is halfway between a pondlike lake type and eutrophy, while lake Piecek is between dystrophy and eutrophy. Table I presents principal morphometrical data as well as those concerning the fish yield.

The present work has tried to answer the question whether there are any differences in the species composition, crustacean plankton abundance, and the character of seasonal changes, which could explain varying fish yields of the lakes under study.

To this purpose studies were carried out from March 1961 to April 1962. Samples were taken at monthly intervals from spring to autumn and every two or three

Table I

## Characteristics of studied lakes

Lake	Area in ha	Maximum depth in m	Average depth in m	Limnol. type	Fish yield kg/ha/year (Average for 1959—1961)
Lemięt	70.5	18.0	5.5	eutrophy	11.0
Żywy	115.0	24.5	4.7	eutrophy	12.2
Upinek	10.0	5.0	2.0	pondlike/eutrophy	26.8
Piecek	23.3	8.4	3.4	dystrophy/eutrophy	7.6
Arklickie	62.0	2.0	1.3	pondlike	110.0
Smolak	5.3	5.1	2.4	dystrophy	2.0

months in winter. Since there are inconsiderable differences in the shapes of the mentioned lake basins, samples were taken from one point, not far from the maximum depth. A five-litre self-acting water sampler devised by the author (PATALAS 1954) was used. Each series consisted, depending on the lake depth, of one to three samples secured from the water layers of similar thermal conditions (epi-, meta- and hypolimnion). Each sample consisted of 6—10 samplers filtered through bolting silk No. 17. Biomass has been calculated from the number of individuals multiplied by the weight of an individual according to MORDUKHAY-BOLTOVSKAYA (1954).

## 2. RESULTS

## A. SPECIES COMPOSITION

In the six lakes under study 28 species (31 taxa) have been found, among them 11 Copepoda and 17 Cladocera. Of 28 species 11 were eulittoral in their character and their presence in the middle part of a lake should be looked upon as something more or less accidental, particularly so as only single individuals were found there. Lake Żywy (15 taxa) had the most numerous pelagic forms of the plankton then was lake Lemięt (12), lake Piecek (11), lake Upinek (10), lake Arklickie (8), and lake Smolak (5). Thus, deeper lakes of more differentiated environmental conditions were richer in the species (Table I). On the whole, it confirms the BOWKIEWICZ's theory of Entomostraca complexes (1938). Taking into account indicator species, distinguished by him, 3—4 species (*Eudiaptomus graciloides*, *Daphnia cucullata*, *Diaphanosoma brachyurum*, and *Leptodora kindtii*) have been found in the lakes: Żywy, Lemięt, Piecek, and Upinek, while only 2 species (*Eudiaptomus graciloides* and *Diaphanosoma brachyurum*) occurred in lake Arklickie and Smolak (Table II).

## B. SEASONAL CHANGES IN ABUNDANCE OF PARTICULAR SPECIES

Figs 1 show changes in the number of crustaceans in the course of a year.

*Eudiaptomus graciloides* was a permanent component of the plankton through the whole year, found in deeper lakes, as Żywy and Lemięt and in a moderately deep lake, Piecek. It showed two distinct numerical maxima

Table II

Composition of crustacean plankton found in pelagial

Species	Lakes					
	Żywy	Lemięt	Piecek	Upinek	Arklickie	Smolak
<i>Eudiaptomus graciloides</i> (Lilljeb.)	XXX	XXX	XXX	XXX	XX	X
<i>Mesocyclops leuckarti</i> (Claus)	XXX	XXX	XXX	XXX	XXX	
<i>Mesocyclops oithonoides</i> (G. O. Sars)	XXX	XXX		XXX		
<i>Cyclops kolensis</i> (Lilljeborg)	XXX		XXX			
<i>Cyclops bohater</i> Koźmiński	.					
<i>Cyclops vicinus</i> vic. Uljanin		XXX				
<i>Cyclops strenuus landei</i> Koźmiński						XXX
<i>Acanthocyclops bicuspidatus</i> (Claus)	.					
<i>Acanthocyclops viridis</i> (Jurine)	.					
<i>Eucyclops serrulatus</i> (Fischer)						
<i>Macrocyclus albidus</i> Jurine						
<i>Daphnia cucullata</i> Sars	XXX	XXX	XXX	XXX		
<i>Daphnia longisp. hyal. v. pell.</i> P. E. Müller	X	X	.			
<i>Daphnia longispina longisp.</i> O. F. Müller					XX	
<i>Daphnia cristata crist.</i> G. O. Sars	.					
<i>Ceriodaphnia quadrangula</i> O. F. Müller			.			XXX
<i>Bosmina coregoni thersites</i> Poppe				XX		
<i>Bosmina coregoni crassic.</i> Lilljeb.	X	.				
<i>Bosmina coregoni berolin.</i> Imhof	X					
<i>Bosmina longirostris</i> (O. F. Müller)	.		XXX	XXX	XXX	XX
<i>Chydorus sphaericus</i> O. F. Müller		XX	X	XX	.	
<i>Alona quadrangularis</i> O. F. Müller						
<i>Rhynchotalona rostrata</i> Koch						
<i>Leydigia leydigii</i> Fischer						
<i>Acroperus harpae</i> Baird						
<i>Pleuroxus trigonellus</i> O. F. Müller		.				
<i>Pleuroxus uncinatus</i> Baird		.				
<i>Peracantha truncata</i> O. F. Müller						
<i>Diaphanosoma brachyurum</i> (Lievin)	XX	.	.	X	.	X
<i>Sida crystallina</i> O. F. Müller		.	.	.	.	
<i>Leptodora kindtii</i> (Focke)		.	.	.	.	
Total number of species or subspecies (eulittoral ones excluded)	15	12	11	10	8	5

Explanations: XXX — forms usually representing more than 10% of the total number (dominants); XX — forms which only in one month were dominants; X — forms which usually represent 1–10% of crustaceans (non-dominants); . — forms representing less than 1% of the total number of crustaceans (adominants).

in those lakes in spring and autumn, divided by a rather pronounced drop in number in August. In lake Arklickie and lake Smolak it was quite numerous only in spring. A spring development and the absence of the second maximum in autumn seems to be a rule in shallow lakes (PATALAS 1963). An intermediate situation occurred in lake Upinek where although no maximum was observed in autumn nevertheless the population was pretty numerous.

*Mesocyclops leuckarti* — the second most important component of the plankton from spring o autumn showed in all the lakes a tendency towards two maxima: in spring and summer. A sharp decrease in its abundance in summer was generally much more pronounced in deeper lakes with thermal stratification than in the shallower polymictic ones.

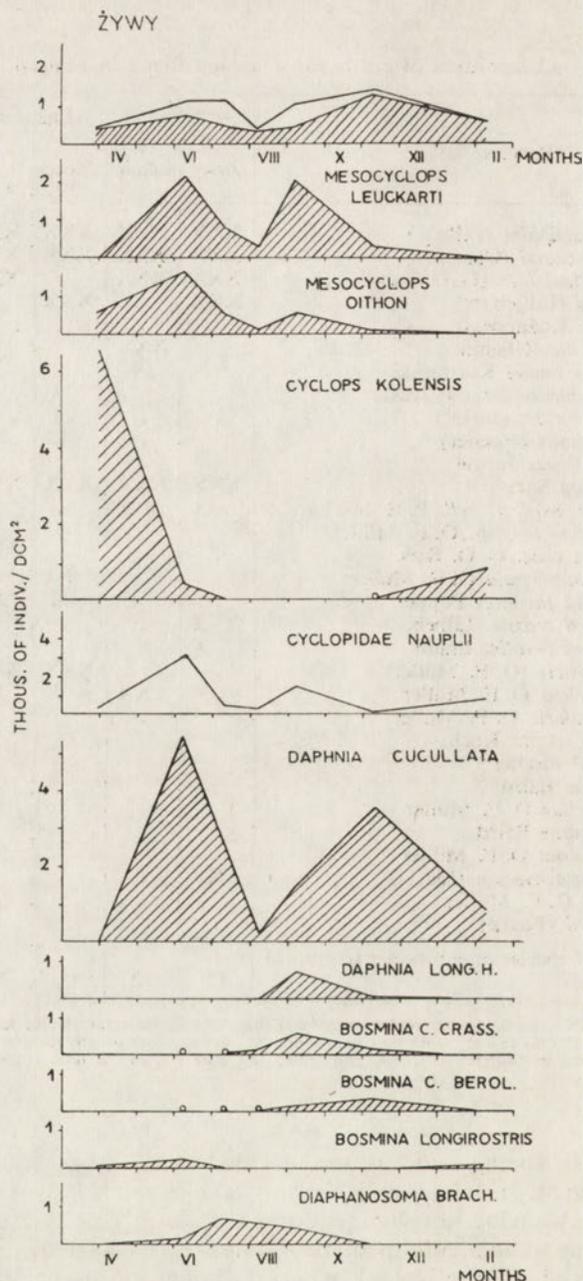


Fig. 1.1. Seasonal changes in the quantity of crustaceans in lake Żywy

Similarly, *Daphnia cucullata* of lakes Żywy, Lemieł, Piecek and Upinek showed two periods of its maximum development.

*Bosmina longirostris* was more abundant only in the shallower and moderately deep lakes: Arklickie, Upinek, Smolak and Piecek. It was of no great

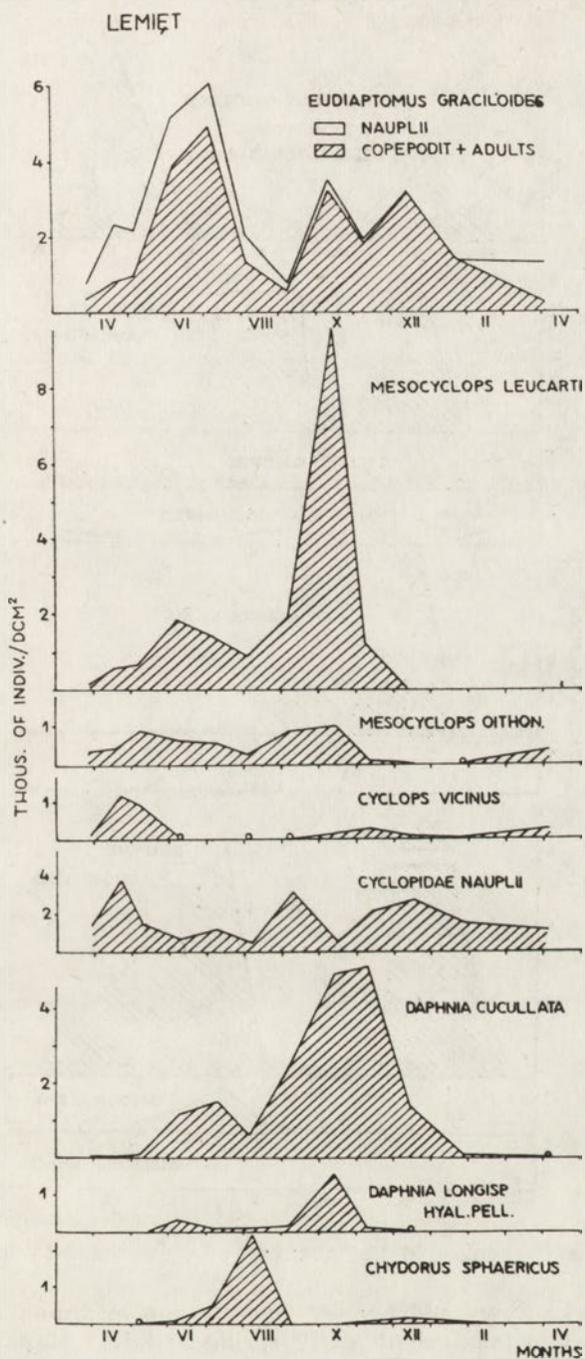


Fig. 1.2. Seasonal changes in the quantity of crustaceans in lake Lemieć

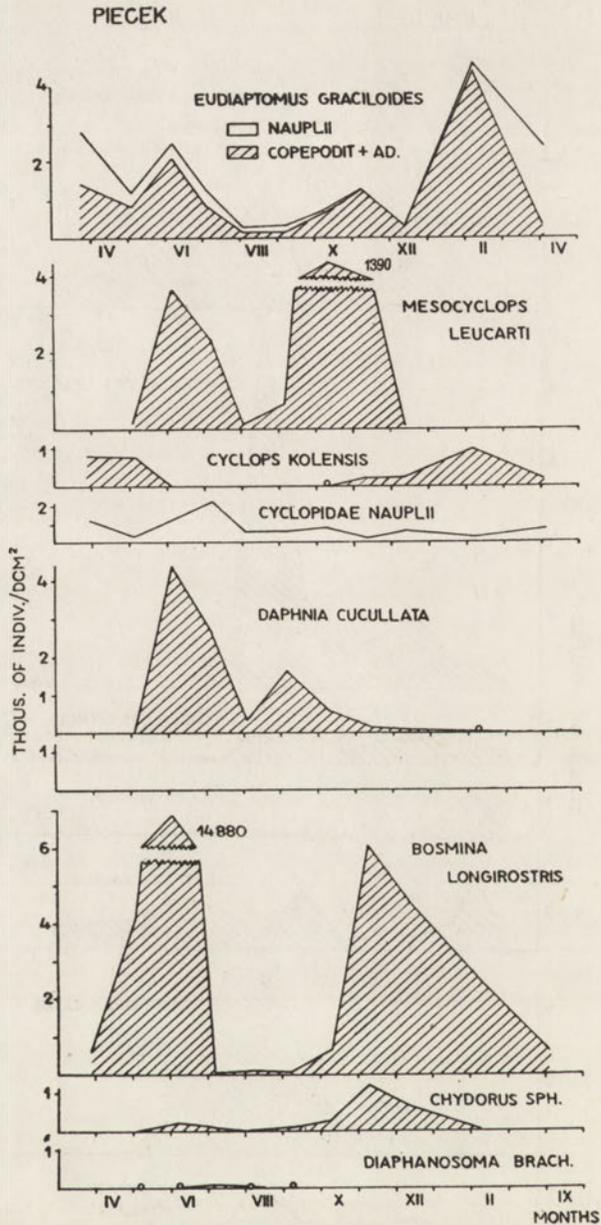


Fig. 1.3. Seasonal changes in the quantity of crustaceans in lake Piecek

significance in lake Żywy and Lemieł. One autumn maximum was observed in lake Smolak, two maxima (in early spring and late autumn) in Upinek and Piecek, and three maxima, in spring, summer, and autumn, in lake Arklickie.

*Daphnia longispina longispina* was abundant in lake Arklickie only in May.

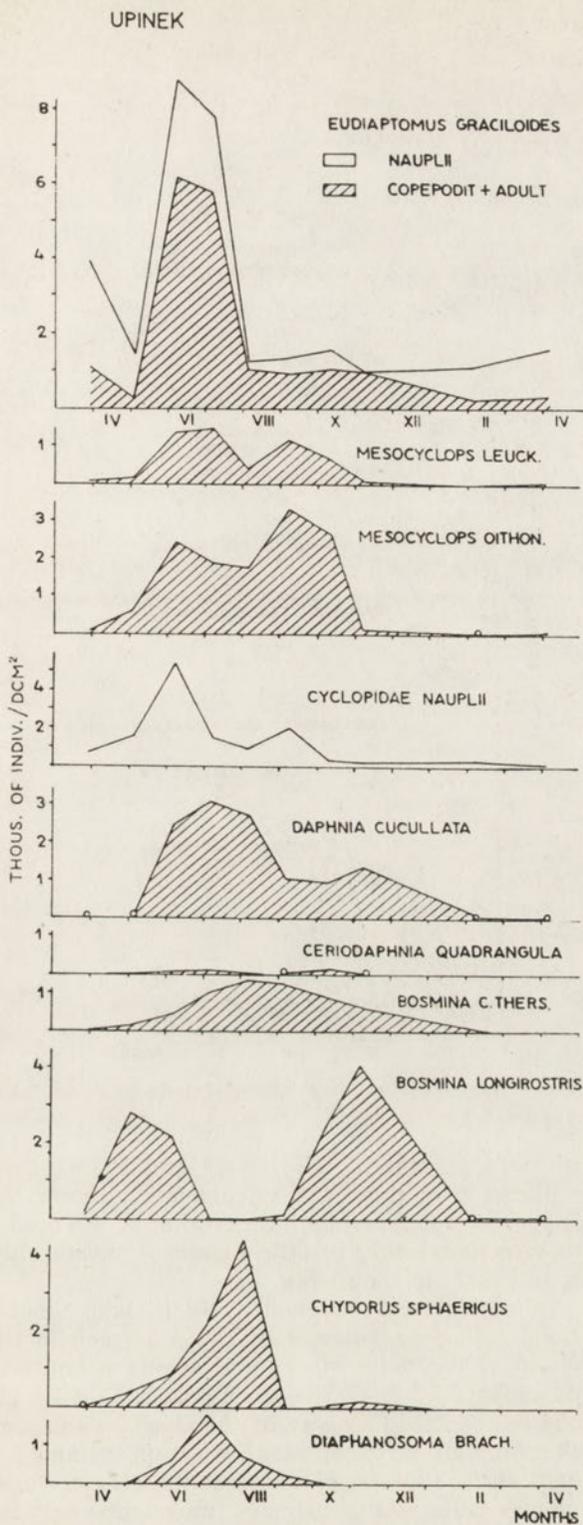


Fig. 1.4. Seasonal changes in the quantity of crustaceans in lake Upinek

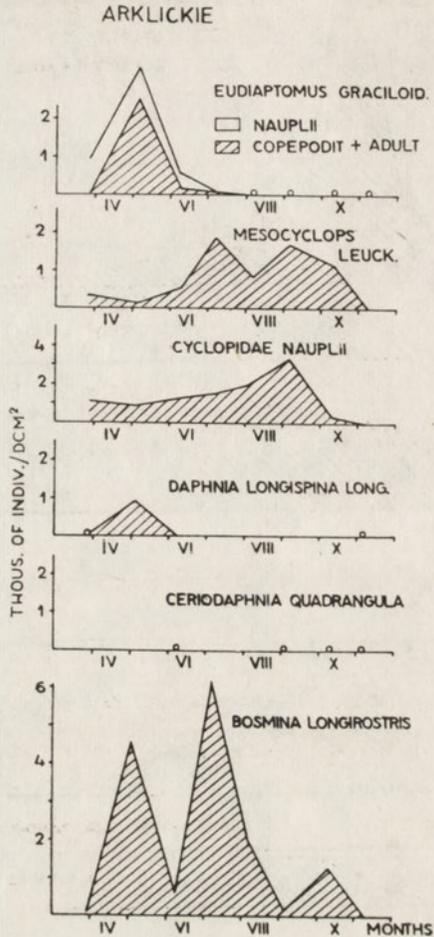


Fig. 1.5. Seasonal changes in the quantity of crustaceans in lake Arklickie

*Cyclops kolensis* was present in lake Żywy and Piecek and affected the abundance of the plankton in those lakes from late autumn to early spring. In summer it disappeared from the plankton resting in the mud.

*Cyclops vicinus* was found only in lake Lemieł. It was quite numerous at the end of autumn and early in the spring.

*Cyclops strenuus landei* occurred exclusively in lake Smolak. Its annual cycle resembled that of *Cyclops kolensis*. It could be seen in the plankton in late autumn, was almost the only winter and spring component of the lake plankton and it disappeared late in the spring. It should be pointed that in summer it had not been replaced by any of the Cyclopidae species. From this point of view lake Smolak is exceptional since in summer it lacks such a common component of the summer plankton as the *Mesocyclops* genus.

*Ceriodaphnia quadrangula* was of primary importance only in the plankton of lake Smolak where it distinctly dominated from spring to autumn.

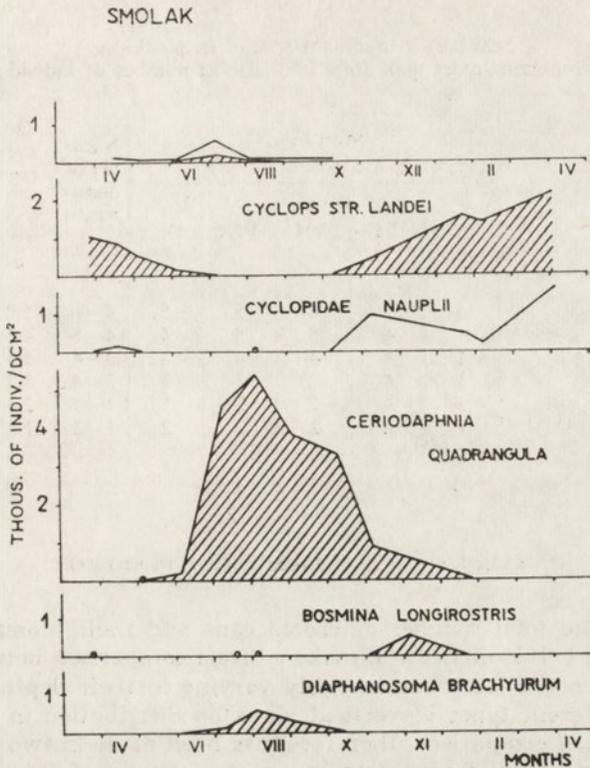


Fig. 1.6. Seasonal changes in the quantity of crustaceans in lake Smolak

It follows from Table II and Fig. 1 that four lakes: Żywy, Lemieł, Upinek and Pieciek had, on the whole, a similar species composition of the plankton. Lake Arklickie and lake Upinek in particular, were clearly different from them. A number of very common species did not occur in them, while there were present species comparatively rare in lakes such as *Daphnia longispina longispina* in lake Arklickie and *Cyclops strenuus landei* in lake Smolak.

There are also distinct differences in the crustacean Community structure of those lakes. Table III shows the number of species which represented at least 10 per cent of the total number of crustaceans in particular months (dominant species).

The simplest plankton structure had lakes Smolak and Arklickie where in spring and summer the plankton usually consisted of two dominant species. lake Pieciek and lake Lemieł presented a more complex picture since there were usually found 3 or 4 dominant species at the same time and finally the most complex situation was in lake Żywy and lake Upinek where 4—6 dominant species occurred. The number of dominants, as a rule, was generally the higher the more species were present in a lake (since a relatively constant  $\frac{b}{a}$  ratio in Table III). The only exception was lake Upinek where despite of a relatively small number of species (10) the highest number of dominants (5) could be observed.

Table III

Number of dominant species in plankton  
(They represent more than 10% of the total number of individuals)

Lake	Months					Number of dominants	On average	Total number of pelagic species	$\frac{b}{a}$
	V	VI	VII	VIII	IX				
							a	b	
Upinek	4	5	6	5	5	4-6	5.0	10	2.0
Żywy		4	5	5	4	4-5	4.5	15	3.3
Lemięt	4	4	4	4	3	3-4	3.8	12	3.2
Piećek	3	4	3	3	3	3-4	3.2	11	3.4
Arklickie	3	4	2	2	1	1-4	2.4	8	3.3
Smolak	1	2	2	2	2	1-2	1.8	5	2.8

#### C. ABUNDANCE AND BIOMASS OF PLANKTON

Changes in the total number of crustaceans and their biomass have been presented in Fig. 1. It is difficult to make a direct comparison between plankton numbers found in the lakes considerably varying in their depths if one takes into account different types of vertical plankton distribution in stratified and polymictic lakes. A comparison, therefore, has been made in two ways, one has established the number of plankters in a water column of 1 dcm<sup>2</sup> (Fig. 1) the other in 1 litre of water of a five-metre layer showing a maximum density of crustaceans (Fig. 2). Usually it was a surface water layers from 0-5 m. Table IV gives average values for different periods as calculated in two ways.

Lake Upinek turned out to be the richest in crustaceans both from the point of view of the number of individuals and biomass as well. It contained about five times more of plankters per one unit of surface than the poorest lake, Smolak, and about twice as much as lake Żywy which occupies an intermediate position.

Lake Arklickie showed the highest density of crustaceans per one volume unit of water. The average number was 332 individuals in the period from May to September, rising up to 500 indiv./l in maximum periods. The figures of the same order have been found also in lake Upinek. The biomass of lake Upinek, however, was almost twice as great as in lake Arklickie which abounded in small forms such as *Bosmina longirostris*.

The lowest crustaceans density has been found in lake Smolak. Lake Żywy contained hardly more plankton. It concerns both the number and biomass of crustaceans.

On the whole, the curve of seasonal changes in the biomass (Fig. 2) was more or less parallel to the curve of numbers in the lakes: Żywy, Lemięt, Piećek and Upinek. It is not true of lake Arklickie where a divergence was observed between high numbers of plankters occurring in summer and autumn and the biomass which was not high. As has been mentioned, small *Bosmina longirostris* dominated in its plankton.

Table IV

Average numbers of individuals and biomasses of plankton crustaceans

Lake	Average values in months		
	III—XI	V—IX	VII—VIII
Individuals/dcm <sup>2</sup>			
Upinek	12.350	15.320	17.220
Piecek	9.900	9.360	5.064
Lemięt	9.434	8.680	8.860
Żywy	8.120	7.860	4.365
Arklickie	4.850	6.640	7.260
Smolak	2.700	3.265	5.654
Individuals/litre			
Arklickie	242	332	363
Upinek	246	305	344
Piecek	198	187	101
Lemięt	106	114	131
Żywy	72	87	47
Smolak	45	68	120
Biomass in mg/dcm <sup>2</sup>			
Upinek	174.200	223.200	277.000
Lemięt	171.694	153.800	159.275
Żywy	144.000	129.200	76.150
Piecek	138.200	123.500	80.856
Smolak	44.200	41.400	61.000
Arklickie	33.200	48.100	35.330
Biomass in mg/litre			
Upinek	3.485	4.470	5.542
Piecek	2.760	2.455	1.587
Arklickie	1.656	2.400	1.767
Lemięt	1.898	2.050	2.371
Żywy	1.260	1.368	0.811
Smolak	0.915	0.857	1.294

### 3. DISCUSSION

It has been proved in the paper that there is a more or less distinct difference in the quantity and species composition of the crustacean plankton found in the lakes under study. Those lakes differ in a number of features, such e.g. as their depth and mineral matter content. They may serve as an example when considering the effects of those features on the species composition and the abundance of crustaceans.

As it follows from Fig. 3 the total number of pelagic species found during a year, clearly correlated with the depth of the studied lakes. Lake Żywy and Lemięt, the deepest, were the richest in species, while the shallow lakes, Arklickie and Smolak, were the poorest. As lakes become shallower and shallower the degree of the environment differentiation decreases and this in turn

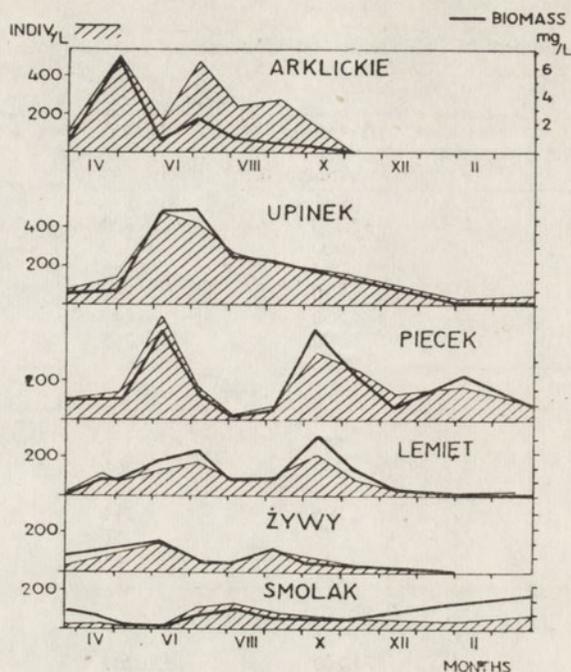


Fig. 2. Seasonal changes in the quantity and biomass of crustaceans in the six lakes

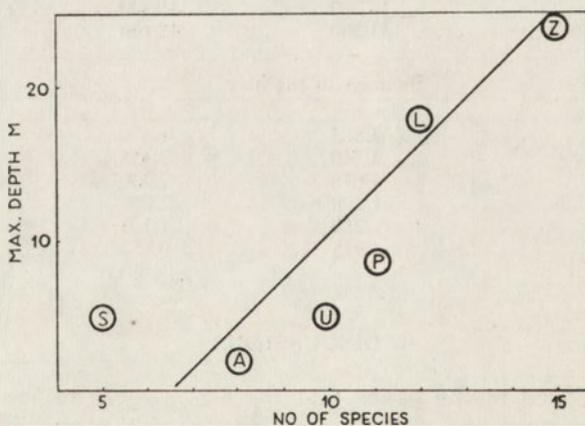


Fig. 3. Relations between the lake depths and the number of species in crustacean plankton

leads to the elimination of some species which do not find any longer suitable conditions (BOWKIEWICZ 1938, PATALAS 1954). But as the elimination process goes on, new species appear, particularly in extreme lakes (*Daphnia longispina longispina* in lake Arklickie and *Cyclops strenuus landei* in lake Smolak).

There was also a correlation between the depth of a lake and the density of crustaceans in the epilimnion or an appropriate surface water layer of the

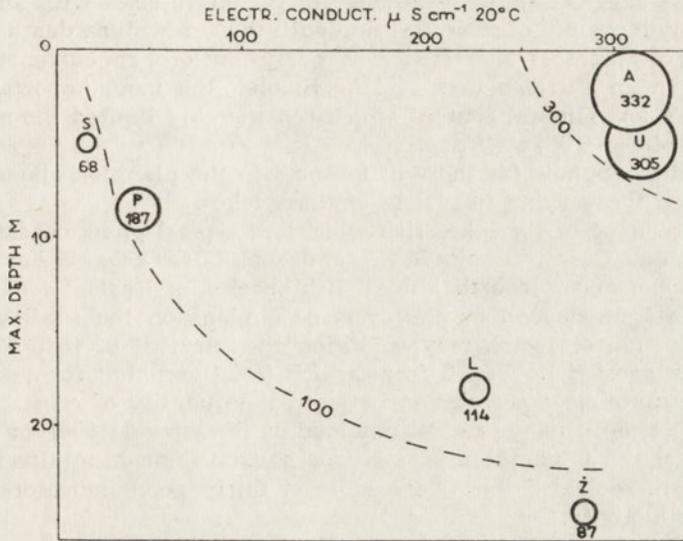


Fig. 4. Relations between the lake depth and electrolyte content and the average number of crustaceans in the plankton. (Radius of the circle is proportional to number of plankters in 1 litre of water. Points representing different classes of plankton abundance have been separated with a dotted line)

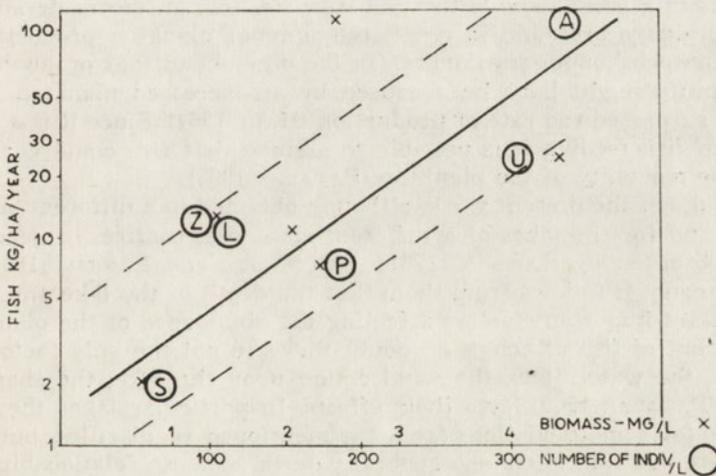


Fig. 5. Relations between the number of plankters and the yield of fish

shallower lakes. The deeper lakes, as a rule, had a lower density of crustaceans. Only in a certain degree it can be explained by a more spacious habitable zone found in those lakes or a rarefication of the plankton. The deep lakes had at the same time low plankton numbers when calculated per one unit of their surface (Table IV).

The effects of the depth of a lake upon the abundance of the plankton cannot be separated from the influence of other factors, such e.g. as the mineral

content, Fig. 4 suggests that the number of plankters rises with an increase in the electrolyte content of the water and with the diminishing depth of a lake. The quantity of plankters, therefore, was a resultant of a concurrence of those two factors. In an extreme case of lake Smolak the most important factor proved to be a low mineral content which considerably limited the number of plankters despite of its small depth.

A question arises how far these differences in the plankton abundance are connected with the varying fish yield of those lakes.

Although in none of the lakes fish which are typical plankton eaters, such as small whitefish (*Coregonus albula* L.?) and smelt? (*Osmerus eperlanus* L.) are of primary importance, nevertheless all fish species, at least at some of their development stages, depend on the crustacean plankton the availability and proper composition of which may condition the survival of fish. The above seems to be suggested by Fig. 5 from which it follows that the lakes under study show a quite clear correlation between the quantity of crustaceans and the fish yield. It confirms the results obtained by PETROVICH (1954) for the lakes of Belorussia. Even if plankton crustaceans had no immediate effects on the fish yield of those lakes, they were at least fairly good indicators of their biological productivity.

It is worth-while mentioning that although the plankton of almost all the lakes showed a quantitative decrease in the middle of the summer (Fig. 2), that drop, however, was most pronounced in the lakes of the lowest fish yield (Piecek, Żywy and Lemięt). On one hand it might have been conditioned by morpho- and hydrological factors which prevented an intensive circulation of nutrients in a lake (a stable thermal stratification, an inconsiderable inflow from the drainage area and in result the summer plankton production based mainly on autochthonous substances. On the other hand that pronounced drop in the quantity might have been caused by an increased plankton mortality which had surpassed the rate of production (HALL 1964). Since it is a period of a maximum fish feeding it is possible to assume that fish could considerably increase the mortality of the plankton (PATALAS 1963).

The results of the present work, although obtained in a different geographical region and for the lakes of a different class size, confirm in general relationships observed by RAWSON (1961), NORTHCOPE and LARKIN (1956) in the lakes of Canada. It follows from them that the depth of the lake and its mineral content are important factors affecting the abundance of the plankton and indirectly that of fish although no doubt they are not the only factors. Apart from them, the water flow, the wind action upon the lake, the shape of the basin etc. (PATALAS 1960) have their effects. In particular lakes they may be responsible for some deviations from the mentioned regularities, but it seems that they are not able to change general patterns of those relationships.

#### 4. SUMMARY

In the course of a year the crustacean plankton was studied in 6 lakes of different surface area (from 5.3—115 ha), maximum depth (2.0—24.5 m), chemical water composition (electrolytic conductance from 17—315  $\mu\text{S}^{20}\text{cm}^{-1}$ ) and fish yield (2—110 kg/ha).

The present work tried to find out what relations there are between these features and the crustacean plankton of those lakes. Seasonal changes in the number

of plankters belonging to particular species have been analysed (Fig. 1). *Eudiaptomus graciloides*, *Mesocyclops leuckartii*, and *Daphnia cucullata* were principal species dominating in the plankton of the deeper and moderately deep lakes (Żywy, Lemieł, Piecek and Upinek). An uncommon plankton composition was found in the dystrophic lake Smolak (*Cyclops strenuus strenuus*) and in the shallow and very fertile lake Arklickie (*Daphnia longispina longispina*). Considerable differences have been observed in the structure of the crustacean complex, which in the lakes Arklickie and Smolak was based on two dominant species and in the lakes Upinek and Żywy on 4–6 species (Table III). The average number of individuals in the summer plankton was from 68 plankters/l in lake Smolak to 332 plankters/l in lake Arklickie. The average biomass was from 0.85 mg/l in lake Smolak to 4.47 mg/l in lake Upinek.

It has been found that the number of the plankton species increased with the depth from 5 to 15 species (Fig. 3). The deeper lakes under study showed usually a lower density of plankters in the epilimnion than the shallower ones. The number of plankters rose with an increase in the water electrolyte content and with the diminishing lake depth (Fig. 9). There was also observed a fairly distinct dependence of the fish yield on the average plankton quantities in the lakes under study (Fig. 5). The most pronounced drops in the number of plankters in the middle of the summer occurred in the lakes of low fish yields (Fig. 2). On the whole it is possible to state that the depth of lakes and their mineral contents are important although certainly not the only factors affecting the number of plankters and indirectly that of fish as well.

## 5. STRESZCZENIE

Badano w ciągu roku plankton skorupiakowy w 6 jeziorach różniących się pod względem powierzchni (od 5,3–115 ha), głębokości maksymalnej (2,0–24,5 m), składu chemicznego wody (przewodnictwo elektrolityczne od 17–315  $\mu\text{S}^2\text{cm}^{-1}$ ) jak również i wydajności rybackiej (2–110 kg/ha).

Celem pracy było stwierdzenie, czy istnieją zależności między tymi cechami a planktonem skorupiakowym tych jezior. Przeanalizowano sezonowe zmiany w liczebności osobników poszczególnych gatunków (rys. 1). Podstawowymi gatunkami dominującymi w planktonie jezior głębszych i średnio głębokich (Żywy, Lemieł, Piecek i Upinek) były *Eudiaptomus graciloides*, *Mesocyclops leuckarti* i *Daphnia cucullata*. Najbardziej wyróżniały się składem planktonu dystroficzne jezioro Smolak (*Cyclops strenuus strenuus*) oraz płytkie i bardzo żyzne jezioro Arklickie (*Daphnia longispina longispina*). Stwierdzono duże różnice w strukturze zespołu skorupiaków, który w jeziorach Arklickie i Smolak opierał się na dwóch gatunkach dominujących a w jeziorze Upinek i Żywy na 4–6 gatunkach (tab. III). Średnie liczby osobników w planktonie letnim wynosiły od 68 osobn./l w jez. Smolak do 332 osobn./l w jeziorze Arklickim. Średnia biomasa odpowiednio od 0,85 mg/l w jez. Smolak do 4,47 mg/l w jez. Upinek.

Stwierdzono, że liczba gatunków w planktonie wzrastała w miarę wzrostu głębokości od 5 do 15 gatunków (rys. 3). Głębsze spośród badanych jezior wykazały na ogół niższe zagęszczenie planktonu w warstwach epilimnionu niż jeziora płytsze. Liczebność planktonu wzrastała w miarę wzrostu zawartości elektrolitów w wodzie oraz w miarę spadku głębokości jezior (rys. 4).

Stwierdzono również dość wyraźną zależność między średnią liczebnością planktonu a wydajnością rybacką badanych jezior (rys. 5). Najsilniejsze załamania liczebności planktonu w środku lata wystąpiły w jeziorach o niskiej wydajności rybackiej (rys. 2). Ogólnie można stwierdzić, że głębokość jezior i ich zasobność w sole mineralne są ważnymi, choć z pewnością nie jedynymi, czynnikami warunkującymi liczebność planktonu a pośrednio i ryb.

## 8. REFERENCES

- BOWKIEWICZ, J. 1938. Über einige Regelmässigkeiten in der Zusammensetzung des Seenplanktons. *Fragm. Faun. Mus. Zool. Pol.*, 3, 18, 345–413.  
 HALL, D. J. 1964. The dynamics of a natural population of *Daphnia*. *Verh. int. Ver. Limnol.*, 15, 660–664.

- KONDRACKI, J., SZOSTAK, M. 1960. Zarys geomorfologiczny i hydrograficzny jezior okolic Węgorzewa. (The outline of geomorphology and hydrography of lakes in Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 77, 7—59. (Engl. summ.).
- KORYCKA, A. 1969. Seasonal changes in water chemical composition of some lakes near Węgorzewo. *Pol. Arch. Hydrobiol.*, 16,
- [MORDUKHAY-BOLTOVSKAYA, D. F.] МОРДУХАЙ-БОЛТОВСКАЯ, Д. Ф. 1954. Материалы по среднему весу беспозвоночных бассейна Дона. (Materials concerning the average weight of invertebrates of the Don Basin.) *Trudy probl. temat. sovešč. Problemy gidrobiologii vnutrennyh vod*. Vyp. 2, 223—241. (Russian).
- NORTHCOTE, T. G., LARKIN, P. A. 1956. Indices of productivity in British Columbia lakes. *J. Fish. Res. Bd. Canada*, 13, 515—540.
- PATALAS, K. 1954. Porównawcze badania nad nowym typem samoczynnego czerpacza planktonowego i hydrochemicznego. (Comparative studies on a new type of self acting water sampler for plankton and hydrochemical investigations). *Ekol. Pol.*, 2 (2), 231—242. (Engl. summ.).
- PATALAS, K. 1954. Zespoły skorupiaków pelagicznych 28 jezior pomorskich. (Pelagic crustacean complexes of 28 Pommeranian Lakes). *Ekol. Pol.*, 2 (1), 61—92.
- PATALAS, K. 1960 a. Stosunki termiczne i tlenowe oraz przezroczystość wody w 44 jeziorach okolic Węgorzewa. (Thermal and oxygen conditions and transparency of water in 44 lakes of Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 77, 105—222. (Engl. summ.).
- PATALAS, K. 1960 b. Mieszanie wody jako czynnik określający intensywność krążenia materii w różnych morfologicznie jeziorach okolic Węgorzewa. (Mixing of water as a factor defining intensity of food materials circulation in morphologically different lakes of Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 77, 223—242. (Engl. summ.).
- PATALAS, K. 1960 c. Charakterystyka składu chemicznego wody 48 jezior okolic Węgorzewa. (Characteristics of chemical composition of water in forty eight lakes of Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 77, 243—297. (Engl. summ.).
- PATALAS, K. 1960 d. Punktowa ocena pierwotnej produktywności jezior okolic Węgorzewa. (The method of classification of primary productivity of lake by point system, applied to the lakes of Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 77, 299—326. (Engl. summ.).
- PATALAS, K. 1963. Sezonowe zmiany w pelagicznym planktonie skorupiakowym sześciu jezior okolic Węgorzewa. (Seasonal changes in pelagic crustacean plankton in six lakes of Węgorzewo District.) *Rocz-i Nauk Roln. Ser. B*, 82, 209—234. (Engl. summ.).
- [PETROWICH, P. G.] ПЕТРОВИЧ П. Г. 1954. Количественное развитие и распределение зоопланктона в озерах западных областей Б.С.С.Р. (Quantitative development and distribution of zooplankton in the lakes of western regions of B.S.S.R.). *Učen. zap. belorussk. gos. Univ. Ser. Biol.* 17, 38—71. (Russian).
- RAWSON, D. S. 1961. A critical analysis of the limnological variables used in assessing the productivity of northern Saskatchewan lakes. *Verh. int. Ver. Limnol.*, 14, 160—166.

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## BOTTOM FAUNA OF A FEW MAZURIAN LAKES OF DIFFERENT FISH YIELDS

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### ABSTRACT

The present work is dealing with the bottom fauna of the littoral and profundal zones of five lakes which are characterized by different fish yields. Attempts were made to find out connections and correlations between composition of the fauna and the fish yield. No correlation has been found between the total biomass of the bottom fauna and the fish yield but some components of that fauna (especially among Tendipedidae larvae) may serve as important indices.

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### 1. INTRODUCTION

The present paper is one of a series which deals with the factors that may affect the fish yield of a lake.

Attempts have been made to establish how far the bottom fauna may be one of those factors.

To study the bottom fauna five lakes (Table I) have been selected near Węgorzewo in the drainage area of the Pregoła river, among the formations connected with the Baltic glaciation, in a countryside pronouncedly morainial in its character (KONDRACKI and SZOSTAK 1960). Those lakes showing great differences in their fish yields and trophy were described by KONDRACKI and SZOSTAK (1960 — geomorphology and hydrography), PATALAS (1960 a,b,c,d — physico-chemical conditions, primary production), J. PATALAS and K. PATALAS (1968 — crustacean plankton), KORYCKA (1969 — physico-chemical conditions), and BERNATOWICZ (1960 — vascular plants).

### 2. METHODS AND MATERIALS

The bottom fauna samples had been collected by means of tubular samplers 25 cm<sup>2</sup> in diameter. The samples had been put through a 0.6 mm mesh sieve and then in most cases picked before their fixation. Formalin of the concentration of

Table I

## Characteristics of the studied lakes

Lake	Area in ha	Maximum depth (m)	Average depth (m)	Limnological type	Fish yield in kg/ha/year (average for 1959—1961)
Arklickie	62.0	2.0	1.3	pond	110.0
Upinek	10.0	5.0	2.0	pond/eutroph.	26.8
Żywy	115.5	24.5	4.7	eutrophy	12.0
Piecek	23.3	8.4	3.4	dystr./eutrophy	7.6
Smolak	5.3	5.1	2.2	dystrophy	~2

about 4 per cent was used to fix selected organisms. Bottom animals have been classified according to generally accepted, usually higher, systematic units (only the Tendipedidae larvae were determined more precisely), they were counted and measured to the nearest 0.5 mm. The total weights of the organisms found in a sample were established according to the accepted taxonomic units.

In most cases the weights were found by weighing to the nearest 0.5 mg, the remaining ones being calculated from the established standard weights.

When analysing the materials, Dreissensia, very numerous in lake Żywy but not significant as food for fish, was usually disregarded.

From lake Arklickie, Piecek, Upinek and Smolak samples were secured at one month's intervals from 20 March to 8 November 1961 and one series was collected between 5 and 7 February 1962. Apart from that samples were taken from lake Piecek 12 December 1961. Samples were taken not so frequently from lake Żywy (6 series instead of 9).

In the lakes: Żywy Piecek, Upinek and Smolak three stations were selected in each, two of them in the littoral (2—3 m deep) and one in or near the maximum depth. In lake Arklickie, apart from littoral stands, two mid-lake stands on the long lake axis have been chosen.

The mid-lake collection stands will be further called profundal irrespective of their depth.

Five samples were taken from each stand at a time. The samples were analyzed separately and afterwards an arithmetical average for every 5 samples coming from the same stand and from the same time was calculated. Basing on these averages, major averages were evaluated.

On the whole, 685 samples were collected and of that 180 from lake Arklickie, 145 from lake Piecek, 135 from lake Upinek, 135 from lake Smolak, and 90 from lake Żywy.

### 3. RESULTS

#### A. QUANTITATIVE DIFFERENCES IN BOTTOM FAUNA OF PARTICULAR LAKES

The lakes (littoral and profundal integrated) showed distinct differences in the average biomass (Fig. 1). The highest biomass has been found in lake Żywy — 314.0 kg/ha (134.4 kg/ha without Dreissensia), then in lake Arklickie — 88.0, Piecek — 56.4, Upinek — 52.8, and Smolak — 19.2 kg/ha.

Considerable differences have been noticed in the biomass at various collection stands of the same lake (Fig. 1). The biomasses of the profundal stands were usually higher than those found in the littoral, when great numbers of Chaoborus (lakes: Żywy, Piecek, Smolak) occurred in the profundal. It is even more obvious when the quantity is taken into account (Fig. 2, cf. Fig. 3).

The smallest organisms occurred in lake Arklickie as it follows from a comparison of the biomasses and quantities (Figs 1 and 2). The average weight of

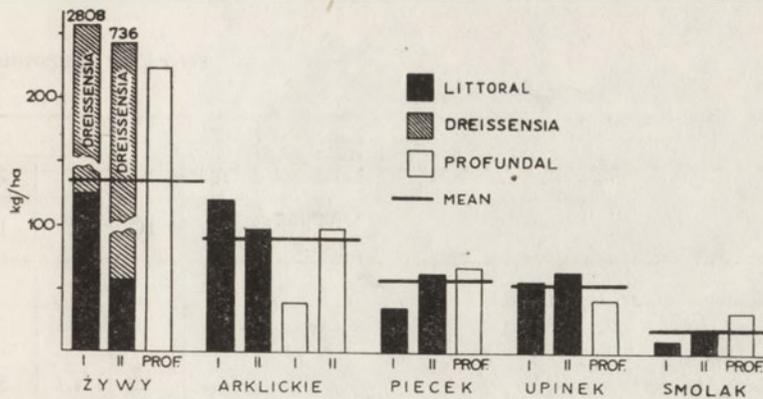


Fig. 1. Average full years biomasses of bottom fauna in different sampling places of the studied lakes

I, II—stations in the littoral and in profundal of each lake

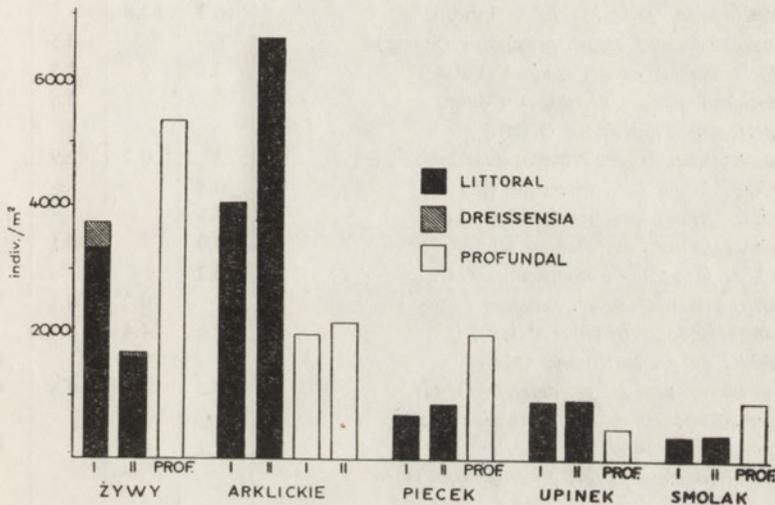


Fig. 2. Average full years quantities of bottom fauna in different sampling places of the studied lakes

I, II—stations in the littoral and profundal of each lake

a bottom fauna individual in milligrams was in lake Arklickie — 2.4, Żywy (without Dreissensia) — 3.9, Smolak — 4.0, Piecek — 4.5 and Upinek — 7.0.

#### B. QUALITATIVE COMPOSITION OF BOTTOM FAUNA

Tendipedidae larvae were the main component of the bottom fauna in some sampling places of the profundal when the weight was considered and in all the littoral stands when the quantity was taken into account (Fig. 3).

Tendipedidae were most numerous in all stations of lake Arklickie (63—80% of the weight and 74—86% of the quantity) and at the littoral collection stands of lake Piecek (84—85% of the weight and 75 and 95% of the number).

Table II

Percentage composition of Tendipedidae  
(weight)

	Zone		Litt-					
	Lake		A	A	Z	Z	P	P
	Sampling place		I	II	I	II	I	II
1. <i>Ablabesmyia ex. gr. monilis</i> (L.)							0.1	
2. <i>Pelopia kraatzii</i> Kieff.	0.6							
3. <i>Pelopia vilipennis</i> Kieff.								
4. <i>Procladius</i> Skuse	13.1	9.2	1.1	5.1	1.4	3.6		
5. <i>Anatopynia plumipes</i> (Fries)	6.8							
6. <i>Anatopynia trifascipennis</i> (Zett.)		0.3						
7. <i>Psectrocladius ex gr. psilopterus</i> Kieff.		0.1						
8. <i>Psectrocladius medius</i> Tshern.			0.1	0.4				
9. <i>Orthocladiinae gen? l. orielica</i> Tshern.	16.2	62.8						
10. <i>Pseudochironomus ex gr. prasinatus</i> (Staeg.)			0.5					
11. <i>Endochironomus ex gr. tendens</i> (Fabr.)	2.1	6.2	2.3				0.1	
12. <i>Endochironomus ex gr. dispar</i> (Meig.)			2.6	5.8				
13. <i>Glyptotendipes polytomus</i> (Kieff.)							9.7	
14. <i>Glyptotendipes ex gr. gripekoveni</i> Kieff.		0.7	2.9		15.6	10.1		
15. <i>Tendipes forma larv. plumosus</i> (L.)	0.3							
16. <i>Tendipes forma larv. semireductus</i> Lenz.	17.1			17.2	72.1	60.0		
17. <i>Tendipes forma larv. thummi</i> Kieff.	5.0		0.1			1.4		
18. <i>Tendipes forma larv. anthracinus</i> Zett.	0.2				2.7			
19. <i>Limnochironomus ex gr. nervosus</i> (Staeg.)		0.2	0.1	0.2				
20. <i>Limnochironomus tritonus</i> (Kieff.)	1.6	4.4	0.4				x	
21. <i>Einfeldia ex gr. carbonaria</i> (Meig.)		3.1		0.5				
22. <i>Cryptochironomus ex gr. defectus</i> (Kieff.)	0.5	1.3	0.8	0.4	3.2	0.5		
23. <i>Cryptochironomus ex gr. vulneratus</i> (Zett.)	x					0.5		
24. <i>Cryptochironomus ex gr. viridulus</i> (Fabr.)	0.1	0.2		0.2		0.4		
25. <i>Cryptochironomus ex gr. pararostratus</i> Harn.								
26. <i>Microtendipes? rezvoi</i> (Tshern.)							0.9	
27. <i>Microtendipes ex gr. chloris</i> (Meig.)	3.7		71.2	41.3		6.6		
28. <i>Polypedilum ex gr. nubeculosum</i> (Meig.)	26.6	0.3	7.6	3.2	0.2	2.7		
29. <i>Polypedilum ex gr. convictum</i> (Walk.)								
30. <i>Polypedilum breviantennatum</i> Tshern.					0.1			
31. <i>Polypedilum ex gr. scalaenum</i> (Schr.)			0.1	0.6	0.3	0.6		
32. <i>Allochironomus crassiforceps</i> Kieff.			6.8	21.7		3.3		
33. <i>Micropsectra ex gr. praecox</i> (Meig.)	0.4	0.5	0.2	0.2	1.5	0.3		
34. <i>Tanytarsus lobatifrons</i> Kieff.	x		0.1	0.2				
35. <i>Tanytarsus ex gr. gregarius</i> Kieff.	1.0	5.1		0.2	0.5	0.1		
36. <i>Tanytarsus ex gr. mancus</i> (Walk.)	0.2	5.0	1.9	2.7	0.3	0.1		
37. <i>Tanytarsus ex gr. lauterborni</i> Kieff.	0.1	0.6						
38. Non det.	0.4		1.1		2.0			

Lakes: A — Arklickie, Z — Żywy, P — Piecek, U — Upinek, S — Smolak.

## fauna of the studied lakes

oral				Profundal						Average				
U	U	S	S	A	A	Z	P	U	S	A	Z	P	U	S
I	II	I	II	I	II									
4.4												x	0.5	
3.2	6.3							0.2		0.2			3.6	
								0.3					0.1	
	2.5	58.9	97.2	5.4	3.3				3.5	8.0	2.0	2.7	1.2	62.2
										2.2				
										0.1				
										x				
	0.1										0.2		0.1	
				34.7	6.3		5.1			25.6		0.1		
											0.2			
10.7	13.4			3.8	7.4					5.0	1.1	0.1	7.8	
											3.0			
													5.9	
	3.7			0.7			2.9			0.2	1.4	12.6	1.8	
	58.4			20.8	22.1	27.7	62.8	34.3	96.5	10.0	6.4	1.4	42.3	19.7
				12.6	38.7	5.8		64.8		19.8	6.5	62.1	25.4	
						18.3	29.0			1.6	4.3	1.5	0.7	
6.4	3.0	1.7	1.9		2.3	46.0				0.8	10.7	1.0	1.5	1.4
				0.2						0.1	0.1		0.1	
				x	1.4					1.9	0.2	x		
				7.9	2.3					2.5	0.1			
6.4	0.1				0.1					0.5	0.5	1.5	0.8	
										x		0.3		
				1.3	0.1			0.1		0.3	0.1	0.2	0.3	
				0.4						0.1			1.0	
			0.9											0.4
27.1	4.7	38.8			0.3	0.5				1.3	46.0	4.0	5.4	16.2
19.2	3.1			9.7	13.5	1.9		0.2		14.4	4.9	1.7	3.8	
	0.3												0.1	
2.1				0.1						x	0.2	0.5	0.2	
											9.7	2.0		
3.4				0.4	0.7					0.5	0.2	0.7	0.4	
		0.4								x	0.1			0.2
15.6				1.7	0.4		0.2			1.8	x	0.3	1.8	
				0.4	0.4					1.4	1.7	0.2		
	0.1									0.1			0.1	
	3.3			0.1	0.9			0.4		1.7	0.5	0.7	1.8	

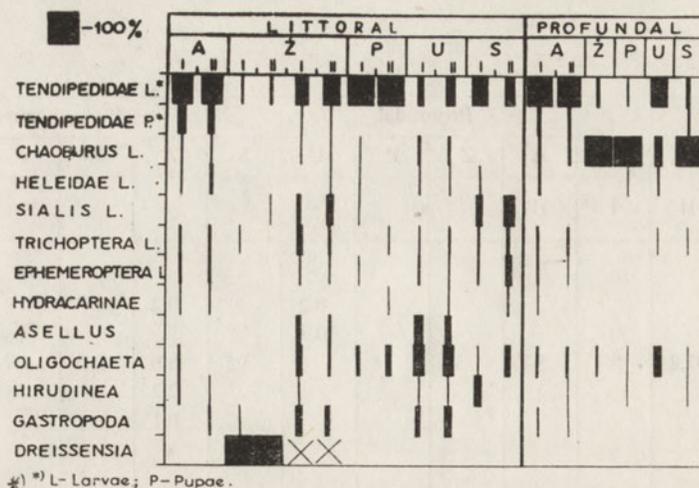


Fig. 3. Percentage composition of bottom fauna in different sampling places of the studied lakes (weight percentage; less important components have been omitted) Lakes: A — Arklickie, Z — Żywy, P — Piecek, U — Upinek, S — Smolak, X — Dreissensia disregarded

Apart from that, Tendipedidae were the most important component of the biomass at the littoral stands of lake Żywy, Dreissensia being disregarded, and at one collection stand in the littoral of lake Smolak. Apart from lake Arklickie they dominated only in the profundal of lake Upinek.

In the whole material there have been found 37 forms of the Tendipedidae larvae (Table II) of which lake Arklickie had 27 (3 not found in other lakes), Żywy — 23 (2 not found in other lakes), Piecek and Upinek 22 each (2 and 1 not found in other lakes respectively), and Smolak — 6 (1 not found in other lakes).

Differences between lakes in the qualitative composition of Tendipedidae have been determined by means of the fauna similarity indices (MARCZEWSKI and STEINHAUS 1959 :

$$P = \frac{w \cdot 100}{a + b - w}$$

where  $a$  = number of forms found in one station,  $b$  = number of forms found at other station and  $w$  = number of common forms. Using those indices, similarities in the composition of Tendipedidae have been presented in the form of a dendrite (according to the Wrocław taxonomic method — FLOREK et al. 1951). In the dendrite most similar stands have been linked directly. The segment lengths which link directly are proportional to the reciprocal of indices (Fig. 4).

When analysing the similarities observed in the fauna of Tendipedidae, the following conclusions seem to be obvious:

— The profundal stations of all lakes, despite of considerable differences, are more alike than the littoral stations (all dendrite points referring to the profundal sampling places are linked directly).

— The smallest differences in the Tendipedidae fauna of the littoral and profundal have been observed in lake Arklickie; inconsiderable differences occurred in lake Smolak, too. It should be mentioned also that the distribution

of the points referring to the stations of lake Arklickie corresponds diagrammatically to the actual distribution of those stations in the lake.

— The lakes, when treated as separate entities, showed a certain correlation between the similarities in the Tendipedidae composition and the total biomass and the numbers in particular (Figs 1 and 2). The lakes, least alike in this respect, Arklickie and Smolak had the lowest similarity index and in the dendrite they are farthest apart; lake Arklickie, characterized by the highest numbers,

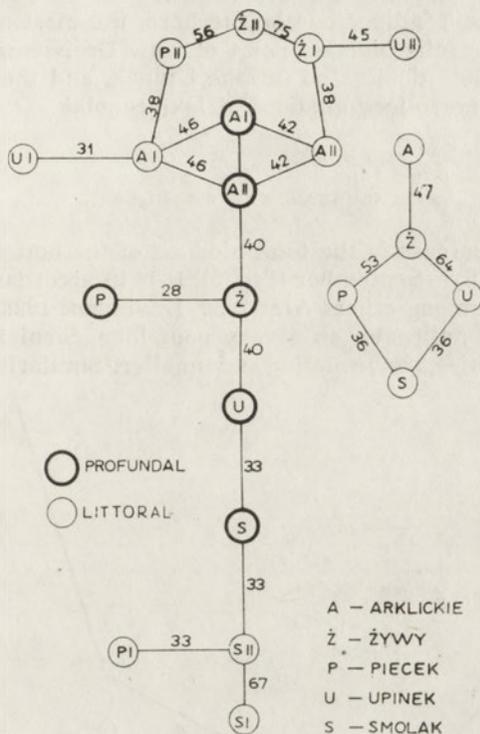


Fig. 4. Dendrites of similarities in the qualitative composition of Tendipedidae larvae of different lakes and various collection stands. Numbers give the highest values of fauna similarity indices, point connecting lines are proportional to the number reciprocals. Only Tendipedidae forms making up more than 1% of the weight have been taken into account

links directly only with lake Żywy which is second when the quantity is considered and first when the biomass is taken into account. The lakes containing average quantities of the fauna, Piecek and Upinek are in the dendrite between Lake Żywy that is rich in fauna and lake Smolak which is poor in it.

The larvae of Chaoborus were the most important among other components apart from Tendipedidae. In the profundal of lake Żywy, Piecek and Smolak they were in preponderance, making up 83—93 per cent of the biomass (Fig. 3). Besides the larvae of Chaoborus and Tendipedidae only Oligochaeta were common for the profundal of the three mentioned lakes; the latter were present, however, in inconsiderable numbers, similarly as the few remaining other components.

A different situation prevailed in lake Upinek which represents a transition type between a eutrophic and a pondlike lake and in lake Arklickie that is a typical pondlike lake the entire bottom of which was covered by plants. Smaller differences have been observed between the littoral and the profundal fauna of these lakes than in the mentioned above. The larvae of Tendipedidae were of greatest importance in the profundal of these lakes (Fig. 3).

The littoral fauna of the lakes under study was characterized as a rule by a higher quantity of components in comparison with the profundal. Of greatest significance were the Tendipedidae larvae here, the most numerous in all the sampling places. From the biomass point of view Dreissensia was dominant in lake Żywy, Oligochaeta dominated in lake Upinek, and the Sialis larvae were most important at one collection stand of lake Smolak.

### C. SEASONAL CHANGES

A considerable decrease in the total biomass of the bottom fauna took place in all the lakes in July—September (Fig. 5). It is in accordance with most data found in literature (among others ALM 1922, LUNDBECK 1926, TYUTENKOV 1959). That drop was least noticeable in a very poor lake, Smolak. From spring the bottom fauna quantities grew smaller and smaller. Similarly, they kept gradu-

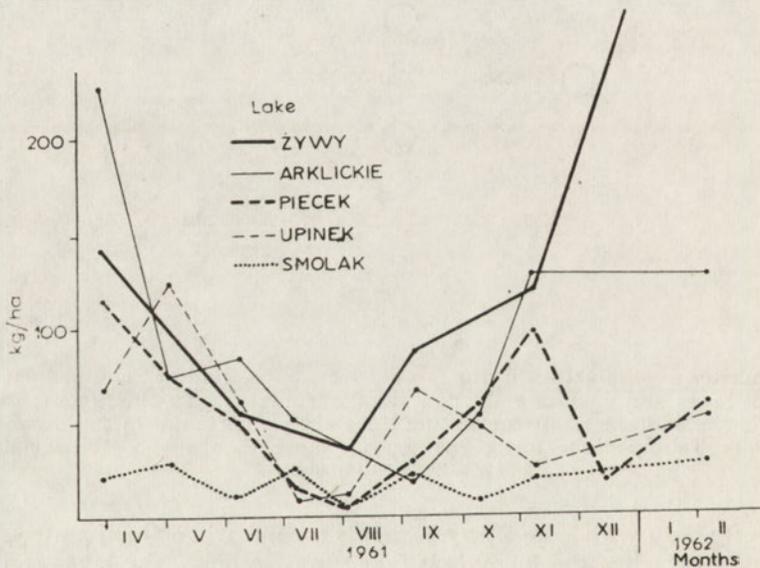


Fig. 5. Seasonal changes in bottom fauna biomass of the studied lakes

ally increasing after the summer minimum. The above tendency could be seen both at the mid-lake and littoral stands from the point of view of the biomass and numbers as well. The spring biomass, however, was higher than that in the autumn, whereas the spring numbers were lower than the autumn ones. Those differences were results of changes in the average size of an organism. Changes in the biomass and number of the Tendipedidae larvae found in a mid-lake sampling place of lake Arklickie may serve as an example here

(Fig. 6). A considerable disproportion between the biomass and the number in the early part of the season was due to the presence of big forms (*Tendipes f.l. plumosus*, *T. f.l. semireductus*), the number of which decreased gradually because either of flying out or mortality. A relative increase in the quantity (in relation to the biomass) during the second part of the season was connected with the appearance of smaller forms (*Polypedilum ex gr. nubeculosum*, *Orthocladiinae gen? l. orielica*) and juvenile individuals of other *Tendipedidae*. During the winter there was only a slight drop in the number, while the biomass grew as a result of individual growth.

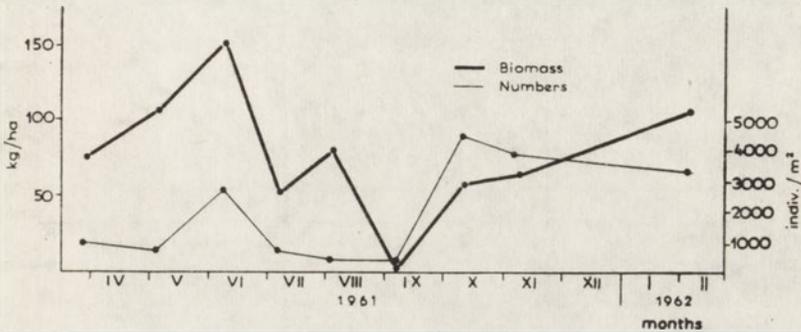


Fig. 6. Seasonal changes in biomass and numbers of *Tendipedidae* larvae in one of the sampling places of lake Arklickie

It has been found that all the components had smaller biomasses in the warmest part of the season. That tendency has been observed not only in the case of the larvae of the insects which leave the aquatic environment but also in the case of other components such as *Oligochaeta* or *Asellus*. It is possible to conclude therefore that either some changes occurred in the environment or the feeding activity of fish increased. It can be also that when some insects had left the aquatic environment the pressure exerted by fish on the remaining components of the bottom fauna became greater.

#### 4. DISCUSSION

The above-presented results suggest a considerable differentiation of the bottom fauna both in its number and biomass in the lakes under study.

Comparing with the data provided by literature (LUNDBECK 1926, KAJAK 1965, WÓJCIK 1955) and taking into account the criteria published in a work by PIECZYŃSKA et al. (1963), it is possible to state that the average biomass was very high in lake Żywy, high in lake Arklickie, moderate in lake Piecek and lake Upinek, and very low in Smolak. Pieczyńska et al. (1963) obtained entirely different results for these lakes, but since they were grounded on single or small series of sampling they might have been accidental, otherwise it would be possible to speak of considerable variability in particular years.

Numerous authors (among others ALM 1922, LUNDBECK 1926, MARKOSJAN 1959 and according to VINBERG and LYAKHNOVICH 1965, among others: LYAKHNOVICH 1961 and 1964, WIRZHUBSKI, SARIG 1954, JOFFE et al. 1955, ILIN,

BACHTINA et al. 1956) tried to find a positive correlation between the bottom fauna biomass and the fish yield of inland water bodies of various types. Their data, however, frequently fail to provide sufficient evidence. The above-mentioned correlations between the total biomass of the bottom fauna and the fish yield have not been observed in the lakes under study either (Fig. 7A). But it has been found that the lakes of a high fish yield usually had considerable biomasses of Tendipedidae in their profundal, whereas the lakes of a low yield contained a small biomass of Tendipedidae (Fig. 7B).

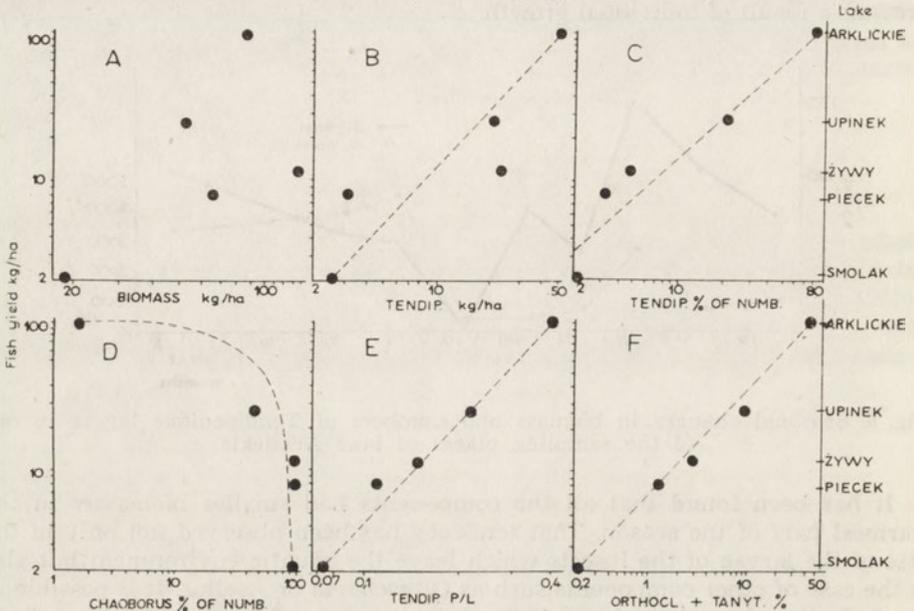


Fig. 7. Correlations between bottom fauna and fish yield of the studied lakes (duble-logscales)

Correlations between fish yield and: A — bottom fauna biomass, B — biomass of Tendipedidae larvae, C — number percentage of Tendipedidae in profundal, D — number percentage of Chaoborus in profundal, E — ratio of Tendipedidae number in profundal to their number in littoral (P/L index), F — weight percentage of Orthoclaadiinae — Tanytarsini within littoral Tendipedidae

Not only quantitative but also qualitative data can be useful when characterizing a lake. The lake typology has been based on the composition of the profundal fauna (THIENEMANN 1922, BRUNDIN 1949), while MACAN (1955) has made attempts to link the *Corixa* species present in the littoral of a lake with the limnological type of the latter. The present work has taken into account the fauna composition in order to characterize the lakes and their fish yields.

It turned out that the higher percentage of the Tendipedidae larvae was in the profundal fauna, the better fish yields were (Fig. 7C). On the contrary, a higher proportion of the Chaoborus larvae in the total number of the profundal fauna was connected with a lower yield (Fig. 7D). The ratio of the number of Tendipedidae in the profundal to their number in the littoral was also of great significance (Fig. 7E). The lakes of a high fish yield showed smaller differences between those two zones (a higher P/L index) than the lakes of poorer yields. The Orthoclaadiinae and Tanytarsini larvae found in the littoral were also clearly important as indicators. When the common percentage

share of these two groups of the littoral Tendipedidae is being considered, then a clear positive correlation between that proportion and the fish yield is obvious (Fig. 7F). It should be explained that both Orthoclaadiinae and Tanytarsini usually are tiny and with that fact BRUNDIN (1958) links considerable oxygen requirements. The representatives of those two groups, if present in the profundal, are forms indicating various degrees of oligotrophy.

It is probable that the above-mentioned correlations do not prove a direct relation between the bottom fauna and the fish yield of the lakes under study. I may be assumed that they are parallel phenomena independent of each other but affected by other factors e.g. chemical (KORYCKA 1969). The direct correlations, however, between the bottom fauna and the fish yield may sometimes exist in certain situations, which is suggested by numerous publications on food of fish which are economically important and here the bottom fauna and Tendipedidae in particular are of considerable significance (WILLER 1924, THIENEMANN 1954). It is possible to think therefore that not by a sheer accident the most pronounced correlations have been observed between the Tendipedidae number and composition and the fish yield.

#### 5. SUMMARY

The present work has tried to find out the effects of the bottom fauna on the fish yield of a lake. The bottom fauna was studied in five lakes near Węgorzewo, which have various fish yields and trophism (Table 1). The samples were taken from the littoral and mid-lake collection stands called profundal.

The lakes differed in their average biomass very clearly (Fig. 1). Generally biomasses found in the profundal were higher than those of the littoral sampling places whenever *Chaoborus* was more numerous in the profundal (Figs 1 and 3).

The Tendipedidae larvae were the most important component of the bottom fauna (Fig. 3, Table II). Taking into account their qualitative composition the fauna similarity indices have been calculated (MARCZEWSKI, STEINHAUS 1959). Then the latter were used to plot dendrites (Fig. 4), from which one can draw the following conclusions: 1. The profundal sampling places of the lakes are more alike than the littoral ones. 2. The smallest differences between the Tendipedidae fauna of the littoral and the profundal have been observed in lake Arklickie and lake Smolak. 3. The lakes which had similar biomasses and numbers of animals showed also similarities in composition of Tendipedidae.

A distinct drop in the number of bottom animals could be seen in all the lakes in summer (Fig. 5). Differences of seasonal changes in the biomass and number (Fig. 6), resulted from changes in the average size of organisms towards the end of the season.

No correlations could have been established between the bottom fauna biomass and the fish yield of a lake (Fig. 7A), although there was a correlation between the Tendipedidae biomass of the profundal and the yield (Fig. 7B) as well as positive correlations between the fish yield and the percentage of the profundal Tendipedidae larvae (Fig. 7C), the ratio of the number of the profundal Tendipedidae to their quantity in the littoral (Fig. 7E), and the total percentage of Orthoclaadiinae and Tanytarsini in the littoral Tendipedidae (Fig. 7F). A negative correlation was between the fish yield and the proportion of the *Chaoborus* larvae occurring in the profundal fauna (Fig. 7D).

Probably, these correlations do not prove a direct relation between the bottom fauna and the fish yield of the lakes under study but may be of value as indicators.

#### 6. STRESZCZENIE

Dla wyjaśnienia w jakim stopniu fauna denna posiada wpływ na produkcję rybacką w jeziorach przeprowadzono badania fauny dennej w litoralu i na stanowi-

skach śródzielnicznych 5 jezior położonych w okolicy Węgorzewa, wyraźnie różniących się między sobą pod względem wydajności rybackiej (tab. I).

Zróżnicowanie jezior pod względem średniej biomasy było wyraźne (rys. 1). Na ogół biomasy na stanowiskach profundalowych były wyższe niż litoralowych w przypadku gdy w profundalu występował w większej ilości *Chaoborus* (rys. 1 i 3).

Najważniejszym składnikiem fauny dennej były larwy Tendipedidae (rys. 3, tab. II). W oparciu o ich skład jakościowy obliczono wskaźniki podobieństwa faunistycznego (MARCZEWSKI, STEINHAUS 1959) i na ich podstawie wykreślono dendryty (rys. 4) z których wynika że: 1. Stanowiska profundalowe wszystkich jezior są do siebie bardziej podobne niż stanowiska litoralowe. 2. Najmniejsze różnice między fauną Tendipedidae litoralą i profundalą stwierdzono w jeziorze Arklickim i Smolak. 3. Podobny skład Tendipedidae wykazywały jeziora o podobnej biomasy i liczbie osobników.

We wszystkich jeziorach nastąpił w lecie wyraźny spadek ilości fauny dennej (rys. 5). Różnice w przebiegu zmian sezonowych biomasy i liczebności (rys. 6) wynikały ze zmian średniej wielkości organizmów w miarę upływu sezonu.

Nie stwierdzono zależności między biomasa fauny dennej a wydajnością rybacką badanych jezior (rys. 7A), zaobserwowano natomiast pewną zależność między biomasa Tendipedidae w profundalu a wydajnością (rys. 7B), oraz dodatnie korelacje między wydajnością rybacką a procentem liczebności larw Tendipedidae w profundalu (rys. 7C), stosunkiem liczebności Tendipedidae w profundalu do ich liczebności w litoralu (rys. 7E) oraz łącznym udziałem procentowym Orthoclaadiinae i Tanytarsini w ramach Tendipedidae litoralą (rys. 7F). Ujemna korelacja wystąpiła między wydajnością a udziałem larw *Chaoborus* w faunie profundalu (rys. 7D).

Korelacje te nie wskazują zapewne na bezpośrednią zależność między fauną denną a produkcją ryb w badanych jeziorach, mogą mieć jednak znaczenie wskaźnikowe.

## 7. REFERENCES

- ALM, G. 1922. Bottenfaunan och fiskens biologi i Yxasjön. *Medd. Kungl. Lantbruksstyrelsen*, No. 236. Stockholm (German Summ.).
- BERNATOWICZ, St. 1960. Charakterystyka jezior na podstawie roślin naczyniowych. (The characteristic of lakes on the base of vascular plants). *Rocz-i Nauk. Roln., Ser. B*, 77 (1), 79—103. (Engl. summ.).
- BRUNDIN, L. 1949. Chironomiden und andere Bodentiere der Südschwedischen Urgebirgseen. *Rep. Inst. of Freshw. (—) Res., Drottningholm*, No. 30.
- BRUNDIN, L. 1958. The bottom faunistic lake system and its application to the southern hemisphere. *Verh. int. Ver. Limnol.*, 13, 288—297.
- FLOREK, K., ŁUKASZEWICZ, J., PERKAL, J., STEINHAUS, H., ZUBRZYSKI, S. 1951. *Taksonomia wrocławska*. [On Wrocław taxonomy]. *Prz. antropol.* 17, 193—211. (Polish).
- KAJAK, Z. 1965. Remarks on the causes of the scarcity of benthos in lake Lisunie. *Ekol. pol., Ser. A*, 13, 23—32.
- KONDRACKI, J., SZOSTAK, M. 1960. Zarys geomorfologiczny i hydrograficzny jezior okolic Węgorzewa. (The outline of geomorphology and hydrography of lakes in Węgorzewo District). *Rocz-i Nauk. Roln., Ser. B*, 77 (1), 7—59. (Engl. summ.).
- KORYCKA, A. 1969. Seasonal changes in water chemical composition of some lakes near Węgorzewo. *Pol. Arch. Hydrobiol.* (in press).
- LUNDBECK, J. 1926. Ergebnisse der quantitativen Untersuchungen der Bodentierwelt norddeutscher Seen. *Z. Fisch.*, 24, 17—67.
- MACAN, T. T. 1955. Littoral fauna and lake types. *Verh. int. Ver. Limnol.*, 12, 608—612.
- MARCZEWSKI, E., STEINHAUS, H. 1959. O odległości systematycznej biotopów. [Systematical distances of biotops]. *Zastosowania matematyki*, 4, 195—212. (Polish).
- [MARKOSJAN, A.] МАРКОСЯН, А. К. 1959. Продуктивность бентоса оз. Севан. (Productivity of benthos in the lake Sevan). *Tr. VI sovešč. po probl. biol. vnutr. vod.* 139—145. (Engl. summ.).
- PATALAS, K. 1960 a. Stosunki termiczne i tlenowe oraz przezroczystość wody w 44 jeziorach okolic Węgorzewa. (Thermal and oxygen conditions and transparency of water in 44 lakes of Węgorzewo District). *Rocz-i Nauk. Roln. Ser. B*, 77 (1), 105—222. (Engl. summ.).

- PATALAS, K. 1960 b. Mieszanie wody jako czynnik określający intensywność krążenia materii w różnych morfologicznie jeziorach okolic Węgorzewa. (Mixing of water as the factor defining intensity of food materials circulation in morphologically different lakes of Węgorzewo District). *Rocz-i Nauk. Roln., Ser. B.*, 77 (1), 223—242. (Engl. summ.).
- PATALAS, K. 1960 c. Charakterystyka składu chemicznego wody 43 jezior okolic Węgorzewa. (Characteristics of chemical composition of water in forty eight lakes of Węgorzewo District). *Rocz-i Nauk. Roln., Ser. B.*, 77 (1), 243—297. (Engl. summ.).
- PATALAS, K. 1960 d. Punktowa ocena pierwotnej produktywności jezior okolic Węgorzewa. (The method of classification of primary productivity of a lake by point system applied to the lakes of Węgorzewo District). *Rocz-i Nauk. Roln., Ser. B.*, 77 (1), 299—326. (Engl. summ.).
- PATALAS, J., PATALAS, K. 1968. Crustacean plankton of some Mazurian lakes characterized by different fish yield. *Pol. Arch. Hydrobiol.* 15, 289—304.
- PIECZYŃSKA, E., PIECZYŃSKI, E., PRUS, K., TARWID, K. 1963. The biomass of the bottom fauna of 42 lakes in the Węgorzewo District. *Ekol. pol., Ser. A*, 11 (19), 495—502.
- THIENEMANN, A. 1922. Biologische Seetypen und die Gründung einer Hydrobiologischen Anstalt am Bodensee. *Arch. Hydrobiol.*, 13, 347—370.
- THIENEMANN, A. 1954. *Chironomus*. Binnengewässer. 20. Stuttgart. E. Schweizerbart.
- [ТЮТЕНКОВ, С. К.] ТЮТЕНЬКОВ, С. К. 1959. Бентос оз. Балхаш и его значение в питании рыб. [Bottom fauna of lake Balkhash and its importance as fish food]. *Sbornik rabot po ihtiologii i gidrobiologii*, 2, 45—79. (Russian).
- [VINBERG, G. G., LYAKHNOVICH, V. P.] ВИНБЕРГ, Г. Г., ЛЯХНОВИЧ, В. П. 1965. Удобрение прудов. [Ponds fertilization]. Moskwa. (Russian).
- WILLER, A. 1924. *Die Nahrungstiere der Fische*. Handb. Binnefisch. Mitteleur. I.
- WOJCIK, S. 1965. Przeżywalność makrobentosu podczas przyduchy. [Survival of macrobenthos during the winterkill]. *Gosp. rybna*, 17 (11), 8—10. (Polish).



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1. REYNOLDS, T. B., YOUNG, J. O., TAYLOR, M. C. 1965. The effect of temperature on the life-cycle of four species of lake-dwelling triclads. *J. anim. Ecol.*, **34**, 23—43.
2. [SHUSHKINA, T. A.] ШУШКИНА, Э. А. 1966. Соотношение продукции и биомассы зоопланктона озер. (Correlation of the production and biomass of the lake zooplankton). *Gidrobiol. Ž.*, **2**, 27—35. (Engl. summ.)
3. [KONSTANTINOV, A. S.] КОНСТАНТИНОВ, А. С. 1959. Питание личинок хирономид и некоторые пути повышения кормности водоемов. [Nutrition of Chironomid larval and some ways of the increase of food animals in water bodies.] *Tr. sovesč. po probl. biol. vnutriennich vod.*, **6**, 260—269. (Russian.)
4. LUCHTEROWA, A. 1961. Z badań nad biocenozą bakteryjną rzeki Wisły. [Untersuchungen der Bakterien-Biozönose der Weichsel.] *Streszcz. ref., V. Zjazd Hydrobiol. Pol. w Gdańsku, 1961.* ss. 77—78. Warszawa, Komitet Hydrobiol. PAN. (Polish.)
5. EKMAN, S. 1953. *Zoogeography of the sea*. London. Sidgwick and Jackson.
6. BEETON, A. M., CHANDLER, D. C. 1963. The St. Lawrence Great Lakes. In: FREY, D. C. (ed.) *Limnology in North America*. pp. 535—558. Madison, The University of Wisconsin Press.

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